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ARTICLE

# Sand Combined Used as an Analytical Technique to Make Sound Characterization in an Acoustic Room

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## ABSTRACT

Decorative construction typically accounts for 20–50% of total project costs. China introduces energy-saving panels, primarily composed of sand particles, to reduce its energy consumption. Most importantly, it has the ability to efficiently resolve intricate acoustic issues with remarkable speed and convenience. This study focuses on sand-based energy-saving panels, which efficiently address complex acoustic issues while reducing energy consumption. Using Delany-Bazley empirical models and acoustic simulation software (Zorba, INSUL), four surface treatments (Plain-P, SA1, PF, SA2) were compared to optimize room acoustics. Results show that plain sand spray (Plain-P) exhibits the highest sound absorption capacity, with a noise reduction coefficient (NRC) of 0.85 and a sound absorption coefficient exceeding 0.9 in high frequencies. Simulation of rooms with sand-based wall coatings confirms its environmental friendliness and adaptability to curved surfaces, arched ceilings, and special-shaped walls. The results demonstrate that empirical models and simulation together improve the approach to studying acoustic parameters like sound absorption through sound impedance and propagation coefficient. Additionally, the material expresses excellent sound insulation, with an average transmission loss (TL) of approximately 70.71 dB. This research highlights the overlooked potential of sand-based materials, providing a practical solution for energy-efficient and acoustically optimized interior design, specifically emphasising a method that has not been paid much attention to.

***Keywords:*** Empirical Model; Sound Absorption; Acoustic Simulation; Specials-shaped Ornament; Composed Acoustic Material

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ARTICLE INFO
Received: 17 July 2025 | Revised: 5 August 2025 | Accepted: 18 August 2025 | Published Online: 29 September 2025
DOI: https://doi.org/10.30564/jbms.v7i3.11102

CITATION
Tang, Z., 2025. Sand Combined Used as an Analytical Technique to Make Sound Characterization in an Acoustic Room. Journal of Building Material Science. 7(3): 233–242. DOI: https://doi.org/10.30564/jbms.v7i3.11102

# 1. Introduction

## 1.1. Research Background

Even with recent attempts to lower building carbon dioxide emissions and increase the use of natural or recycled materials, buildings continue to consume a sizable portion of the world's energy resources [1,2]. Typically, the cost of the decorating construction project constitutes 20–50% of the total project expenditure, underscoring its significant value in light of the desired efforts in this field. This study introduces a sand-based ornamental material that aims to reduce China's energy consumption, particularly for acoustic building decoration. The indoor noise problem has been recognised as a kind of pollution impacting the environment under increasing attention, and the concern about acoustic comfort in offices, homes, schools, hospitals, and other spaces is increasingly emphasized and being taken care of in an emphasised trend. The study employs model analysis and simulation to evaluate the acoustic potential of various acoustic materials, particularly the assembly sand panel, for ecological preservation in interior rooms. It is also important to investigate whether this phenomenon is dual in nature: on the one hand, it represents a rapidly evolving acoustic settlement, and on the other, it serves as an innovative strategy to reduce building energy consumption [3].

Compared to other porous materials, sand panels have substantially better flow resistance and significantly lower porosity. Certain types of particles or granular materials, including polyurethane particles, clay granules, and rubber particles, have had their acoustic absorption properties disclosed. However, existing studies focusing on this new application have not even mentioned the sand particles, which are the primary constituents of the assembled seamless sound-absorbing substance, advantageous for base treatment.

The coefficient of diffuse-field absorption is more feasible for the majority of architectural and environmental applications [4], particularly in genuine construction. The Delany-Bazley and Voronina models imply a particular propagation coefficient (c) and impedance (Z0). Then it could be possible to change these numbers to the absorption coefficient in the diffuse-field and compare them with data from measurements taken in the reverberation chamber [4]. Delany and Bazley [5] introduced an empirical approach for determining the properties of porous materials, although their non-physical nature causes inaccuracy at low frequencies and they function well only with a restricted range of materials [6]. Based on the real situation, Voronina's model [7] used four physical parameters of the four types of granular materials to predict their properties. However, this semi-phenomenological model doesn't work very well [8] and can't explain the acoustic properties of polyurethane particles [9], which are also granular materials. Numerous studies [10–15] have pushed forward their models with acoustic absorption coefficients and other parameters (for example, using the mathematical model's accuracy in Allard's work). However, it is still necessary to determine if these models are applicable to other materials, such as sand panels, which share the same granular element, to ensure the coherence of the sand-porous panel structure. The majority of these accomplishments [16–23] relate to both typical and atypical porous materials (clay granulates, rubber particles, granulates, fluid-saturated porous, fibre [24,25] granulates, sintering ceramic material, and so on), investigating their influential factors and relations on sound absorption property. Some of these results also assessed the acoustical characteristics of specifically formulated granular materials using experimental methods or empirical deduction.

It should be noted that it is significant to investigate acoustic features of granular materials, even if they are porous, because their microstructures are more like those of sand panels, which determine a number of the panels' physical and chemical properties. Previous research helps us understand this acoustic structure more directly and deeply. This study quantitatively evaluates the acoustic insulation and absorption of this material structure by the Delany and Bazley models, combined with an acoustic software whose calculation procedure is definitively presented on the basis of these empirical models, which will be presented in detail in the subsequent sections. Conversely, it is not intended to obtain another new granular porous panel but to process a comparative study on the four possible common settlements for upgrading acoustic characteristics in a room to propose a more advisable selection, which is the novelty of this research. Multi-functional building materials often possess a combination of properties that can effectively contribute to energy conservation; moreover, they are in great demand to simultaneously enhance the quality of the interior environment for inhabitants [26].

Besides, it is more critical to point out that the sand is simply available, no matter its existing amount in the surroundings or its acquirable convenience, as the dominating ingredient for this assembly of sand material, making the sustainable value of the structure jump out.

### 1.2. The Purpose of This Study

This study employs simulations and empirical models to examine the sound-absorbing properties of the sand coating and panel when they are put together [27]. Sand panels are mechanically robust, environmentally friendly, fire-resistant, and have good durability in harsh environments, according to test results [28]. In this paper, a test was designed to compare four representatives for surface treatments, with three primary objectives in mind: First, (1) to find out how well an assembled sand system can absorb sound and insulate for decorative projects at different material parameter values; (2) to see if this material can produce a reliable effect by simulating a room with its wall covered in an assembled sand painting; and (3) to make important discoveries by focusing on the assembly of sand materials in the software Zorba, which sets up its calculation prowess.

## 2. Insulation and Acoustic Absorption

### 2.1. Acoustic Absorption in the Delany and Bazley Models

Flow resistivity is a significant non-acoustic factor affecting the sound absorption characteristics of a porous absorber. The absorber's ability to absorb sound energy is directly linked to it. This relationship is determined through empirical estimation using regression analysis, specifically for the features of fibre porous materials [29]. The equations (1)–(4) can predict both the property impedance  and the propagation coefficient .

$$Z_0 = \rho_0 c_0 * \left[1 + 9.08 * \left(\frac{f}{\sigma}\right)^{-0.75}\right] \tag{1}$$

$$X = \rho_0 c_0 * \left[(-11.9) * \left(\frac{f}{\sigma}\right)^{-0.73}\right] \tag{2}$$

$$\alpha = 10.3 * \left(\frac{\omega}{c_0}\right) * \left(\frac{f}{\sigma}\right)^{-0.59} \tag{3}$$

$$\beta = \frac{\omega}{c_0} * \left[1 + 10.8 * \left(\frac{f}{\sigma}\right)^{-0.70}\right] \tag{4}$$

where $\rho_0$ is the air density in kg/m$^3$, $c_0$ is sound velocity in air in m/s, σ is the flow resistivity in g/(s·cm$^{-3}$) (i.e., 1000 N·s/m$^4$),  is the frequency in Hz and is related to ω by ω = 2πf, while j is the imaginary unit, $\rho_0$ is the porous material's primary density. Besides, and  directly influence and decide the sound absorption feature of the granular material, which also applies to sand assembly. Several researchers have suggested empirical formulas that only rely on a single, simply measurable parameter, such as the airflow resistivity (r). Empirical models, like the ones proposed by Johnson et al., necessitated a greater quantity of non-acoustic indices, such as porosity (/) and tortuosity (a1), which cannot be easily measured using experimental techniques. So it is beneficial to combine the two together to improve the approach to studying acoustic parameters like sound absorption through sound impedance $Z_0$ and propagation coefficient γ [30].

Obviously, the 4 equations clearly explain the relationship between these essential figures constituting the indicators and constants. A regression equation displays a possible tendency of the behaviour of the interaction of the involved figures, where physical properties are the acting elements. The models were developed through the multi-approach simulation software Zorba 3.0, which can graphically and simply provide an interface for model establishment and simulation in an efficient operating medium.

**Figure 1** reveals the configuration of one typical room interior corner with the design of acoustic decoration that is intended to be introduced and studied in this research, in a composed sand sound absorption material. As it shows, on the wall, there are 5 layers from the bottom to the top surface. Except for the regular construction that serves as a partition frame for the mechanical base, it also uses the sound-absorbing base panel on the frame, covered with a levelling layer (2–3 mm thick) composed of sand aggregates with the grid cloth as the base layer. The outermost layer that can be seen and comes into contact with is the aggregation seamless sound absorption surface (1–2 mm thick).

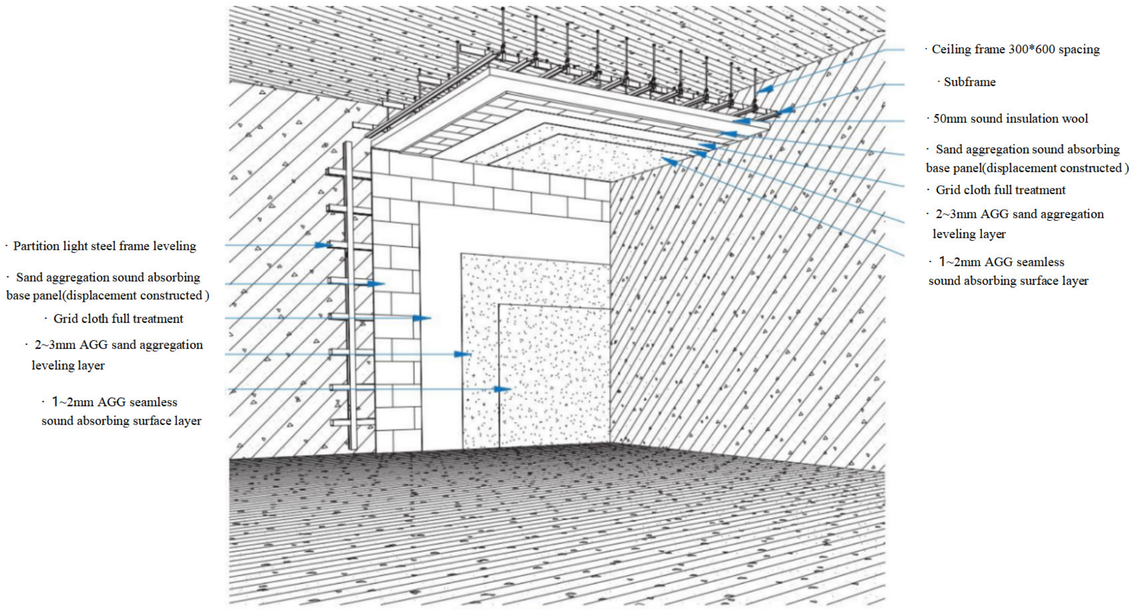


**Figure 1.** Sound absorbing construction sectional details of ceiling and walls.

In the ceiling's acoustic configuration, the sub-frame and frame constitute the skeleton layers, functioning as the mechanism's enduring structure. Because the acoustic standard regarding a ceiling is higher than that regarding a wall, it adds one sound insulation wool layer on the skeleton (50 mm thick), and the upper part is the aggregation sound-absorbing construction, which is the same placement and installation as those in the wall.

## 2.2. Simulation Design

In order to understand how this composed sand material plays its acoustic characteristic role in the ornament of a room, it is essential to design and carry out an experiment, making use of effective technical tactics. Given the specialised nature of the software (Zorba, INSUL) used in this study, a detailed explanation would be helpful to articulate the principle that these programmes exhibit unique features of accurately testing the NRC and TL of any combination as designed in a short time, making them greatly superior to other acoustic simulation tools. Subsequently, by setting up the comparative simulation in Zorba, taking advantage of its economy and time-saving, it will be confirmed whether this porous absorber could actually absorb sound energy using the above-mentioned models and equations.

As the 4 representatives for the surface settlements, this test was put through based on the sound absorption coefficients($\alpha_{\omega}$), NRC, same frame's and sand granular spray's thickness T(mm) value-75 and 5 mm, for the following 4 configurations: plain panel with sand spray (Plain-P), slat absorber (SA1), perforated facing (PF), and slot absorber (SA2). Here the reinforced glass fibre base panel was selected for the 4 configurations, so in this comparative study, the only varying parameter among them is thickness, which refers to the thickness of the reinforced glass fibre base panel T (mm) and the thickness of absorber T (mm) separately. The $\sigma_1$ (53,100 Rayls/m) and $\sigma_2$ (91,150 Rayls/m) denote the dual layers of two materials within the structures of the 4 panels, each characterised by $\sigma_1$ and $\sigma_2$, respectively. The σ value is only determined by the chemical constituent of the material itself, not connected with its thickness, unlike some parameters [31]. Therefore, $\sigma_1$ and $\sigma_2$ maintain identical values across samples with varying layers. Besides, the pore diameter (mm), together with the spacing between pores (mm), is also listed in **Table 1**.

**Table 1.** Sound coefficients, NRC, layer sizes and other parameters in 4 different configurations.

| Outer Layer | Plain-P | | Slat Absorber -SA1 | | Perforated Facing-PF | | Slot Absorber-SA2 | |
|---|---|---|---|---|---|---|---|---|
| NRC | 0.85 | 0.30 | 0.20 | 0.45 | 0.55 | 0.45 | 0.85 | 0.40 |
| $\alpha_\omega$ | 0.90 | 0.20 (*H*) | 0.25 | 0.35 (*MH*) | 0.55 | 0.40 (*H*) | 0.85 | 0.30 (*H*) |
| $\sigma_1$ (Rayls/m) | 53,100 | 53,100 | 53,100 | 53,100 | 53,100 | 53,100 | 53,100 | 53,100 |
| $\sigma_2$ (Rayls/m) | 91,150 | 91,150 | 91,150 | 91,150 | 91,150 | 91,150 | 91,150 | 91,150 |
| Frame T (density 45kg/m$^3$) | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 |
| Reinforced glass fibre base panel T (mm) | 50 | 5 | 50 | 5 | 50 | 5 | 50 | 5 |
| Sand granular spray T (mm) | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Absorber T (mm) | – | 6 | – | 6 | – | 6 | – | 6 |
| Pore's diameter (mm) | – | 6 | – | 6 | – | 6 | – | 6 |
| Spacing between pores m (mm) | – | 13.5 | – | 13.5 | – | 13.5 | – | 13.5 |

Note: T - thickness; Spacing - between pores, parallel with the surface.

## 3. Results Analysis

**Figure 2** shows the trends of the aggregation sand panel system's four sound absorption coefficients (α) when the reinforced glass fibre panel base has the same thickness (75 + 50 mm), but the external layers have different designs. All the values of α, the imaginary and real parts of acoustic impedance, and NRC in this study were calculated under the random incidence condition, conforming to the real scene. The P curve is similar to the SA2 curve. A turning point occurs at 340 Hz, and, prior to this frequency, the SA2's α is marginally higher than the plain's, but following it, it reverses. The α values of both exhibit a horizontal moving track, especially in the frequency range higher than 400 Hz. The highest α values present a notable capacity to absorb sound, which is higher than 0.9 (almost reaching 0.94) in each configuration. PF and SA1 both have 75 mm thick base panels, but they disappoint us by trailing the front. The first two performed poorly due to slats and perforated settlements, which allow sound waves to penetrate the entire surface microstructures, particularly in SA1's construction, with α values only 0.22 for SA1 and 0.55 for PF.

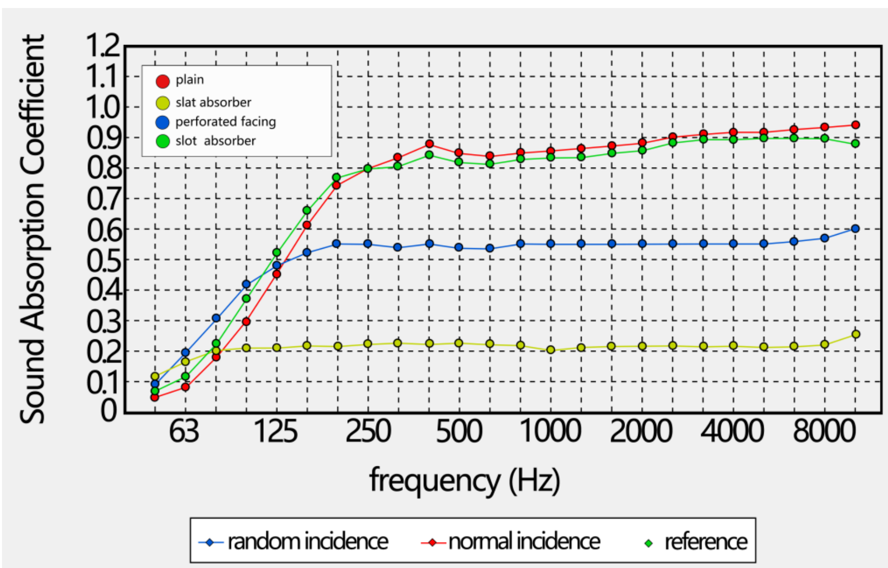


**Figure 2.** Sound absorption coefficients with outer base layer 50mm in 4 different configurations.

In terms of the outer layer, NRC provides a mildly higher value (=0.85) for both the simply assembled sand spray and the slot absorber in the four constructions that have a thicker base panel (75 + 50 mm) than the others (75 + 5mm). This result indicates that the base panel's adequate thickness is conducive to fully displaying the sound absorption capacity. In contrast to PF and SA1, P and SA2 offer more effective achievement of the wall's acoustic decoration.

It can be explained in terms of the acoustic impedance in two parts: a real part and an imaginary part. Both the real and imaginary parts in our test were negative. It is believed that the closer the points are to the circle boundaries, the easier it is for them to form a larger sound impedance. As a result, there is no contradiction between the investigated regulations that affect both the sound absorption coefficient (α) and impedance. Surprisingly, **Figure 3** depicts a sharp corner that resembles a triangle stretching upward and bending all four to the right. The shift is more noticeable; the α curves' turning points (in terms of their frequency spans) appear to have occurred earlier and are associated with the figure.

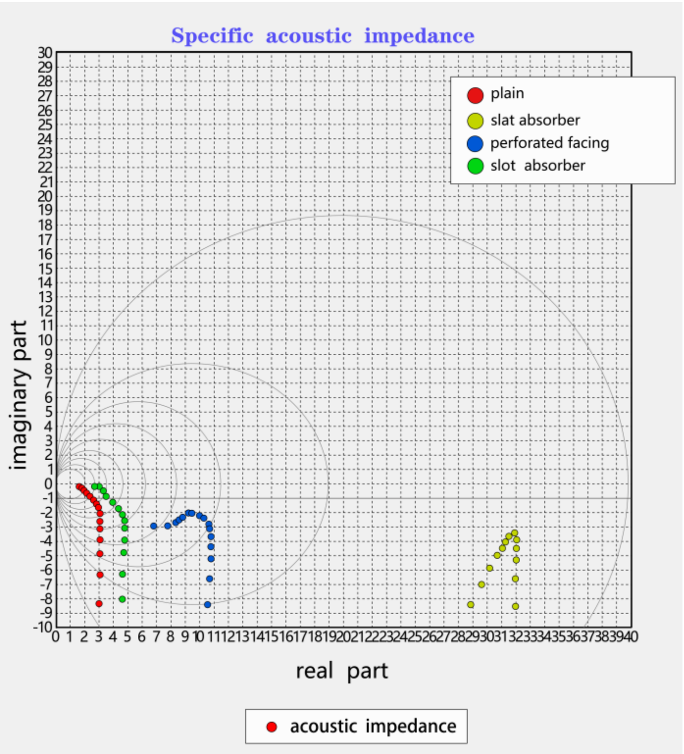


**Figure 3.** NRC with outer base layer 50mm T in 4 different constructions.

A strong correlation was achieved between the theoretical and experimental findings. The study demonstrated the effective utilisation of expanded granulate clay layers, with a thickness ranging from 50 to 100 mm, for noise mitigation across a wide spectrum of frequencies. Additionally, semi-phenomenological models were formulated, including the one proposed by Johnson et al. [32].

This result appears to be distinct from the α changing trend in **Figure 1**, where the reinforced glass fibre base panel's thickness T of only 5mm replaces a type of extremely thin and lightweighted component. PF exhibits the lowest α value (approximately 0.6) among the four acoustical absorption experiments. While this curve appears to be the most relaxing as it climbs, it also produces the frequency span's earliest turning signal. SA1, SA2, and P get promoted higher on longer slopes, orderly from the small to the large frequencies, then they start to descend. However, none of the three reaches the maximum α value in the fairly high-frequency range, whereas the medium frequency (1300 Hz) is where the PF's maximum value points exist (**Figure 4**).

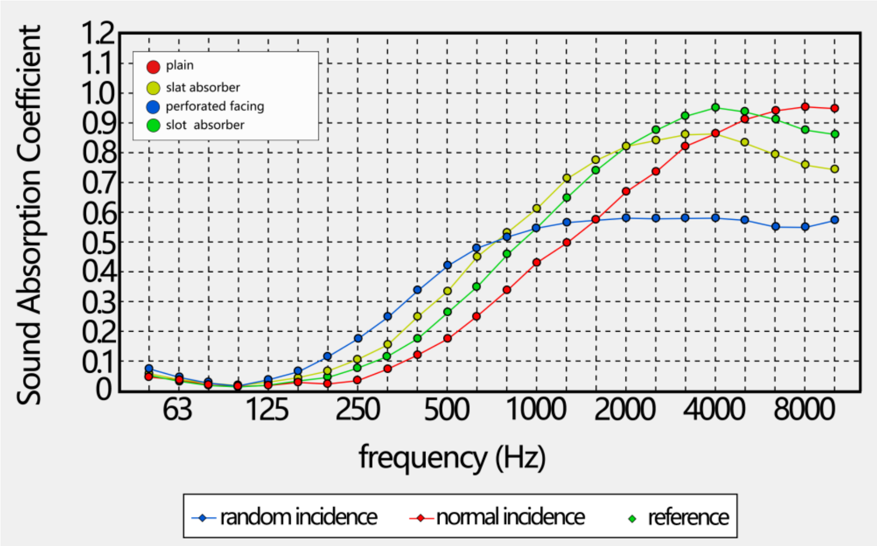


**Figure 4.** Sound coefficients with outer base layer 5mm T in 4 different constructions.

The α curves begin to rise more slowly when they are farther to the left, where the distributing points are positioned. When the points are closer to the circle boundaries, they more easily form a larger sound impedance, a phenomenon reminiscent of the figure. Remarkably, in contrast to the scenario described in **Figure 5**, the point array bends to the left side (**Figure 5**). In terms of both NRC and the sound absorbent coefficient α, the outer layer of plain assembled sand emerged as the most notable choice. Regarding ceiling acoustic treatment, is it true that the aggregation sand system demonstrates the ability to absorb sound in an identical or analogous way? It was decided to test its ability to adjust sound in a large room setting (**Table 2**).

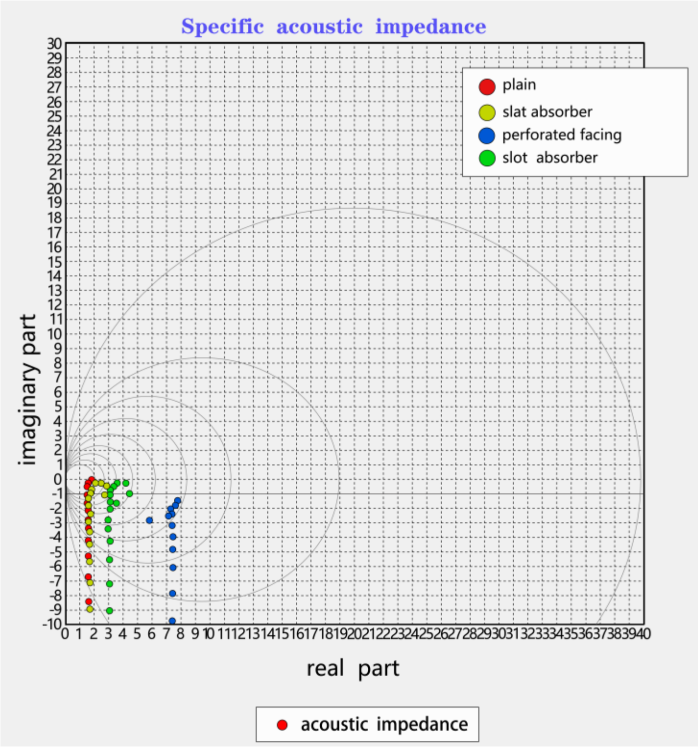


**Figure 5.** NRC with outer base layer 5mm T in 4 different constructions.

**Table 2.** Sound absorption performance of whole sound absorption structure(S) and each base (R-root layer and s-spray layer).

| **Frequency/Hz** | | **100** | **125** | **160** | **200** | **250** | **315** | **400** | **500** | **630** |
|---|---|---|---|---|---|---|---|---|---|---|
| | S- | 0.61 | 0.65 | 0.74 | 0.80 | 0.77 | 0.84 | 0.93 | 0.95 | 0.99 |
| **Sound absorption coefficient $\alpha_S$** | R- | 0.12 | 0.10 | 0.19 | 0.22 | 0.42 | 0.50 | 0.92 | 0.95 | 1.00 |
| | s- | 0.15 | 0.31 | 0.38 | 0.56 | 0.60 | 0.65 | 0.72 | 0.78 | 0.72 |
| **Frequency /Hz** | | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 |
| | S- | 0.96 | 1.00 | 1.01 | 1.02 | 1.05 | 1.02 | 1.02 | 0.99 | 0.99 |
| **Sound absorption coefficient $\alpha_S$** | R- | 1.07 | 1.10 | 1.12 | 1.15 | 1.13 | 1.07 | 1.05 | 1.01 | 0.95 |
| | s- | 0.70 | 0.72 | 0.71 | 0.70 | 0.74 | 0.76 | 0.74 | 0.73 | 0.75 |

Note: S—assembled sand sound absorbing system; R—Reinforced glass fibre sound absorbing panel; s—assembled sand sound absorbing spray.

**Figure 6** depicts the structure's sound absorption characteristic curve and NRC, with α values ranging from 0.6 to 1.05 in the overt frequency spans, rising quickly from very low to 400 Hz and then to very high. It is even more remarkable when combined with cavities. The sound absorption spraying of gathering sand causes an increase in α values from 0.15 to 0.7 (at 400 Hz frequency), with the majority of values fluctuating within this range. The use of Acoustic NRC ≥ 0.9 in conference centres, lecture halls, sports facilities, gyms, theatres, and other public spaces is entirely appropriate. It is also necessary to run a simulation in INSUL to further investigate the sound insulation property. The results are shown in **Figure 7**, which establishes a model based on the actual AGG wall's construction and material circumstances as demonstrated.

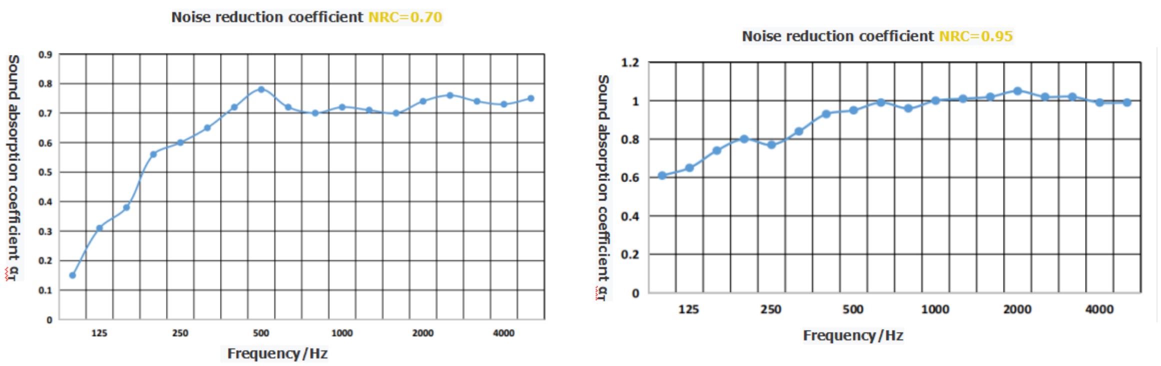


**Figure 6.** Sound absorption characteristic curve and NRC of assembled sand sound absorption spraying (left) and structure (right).

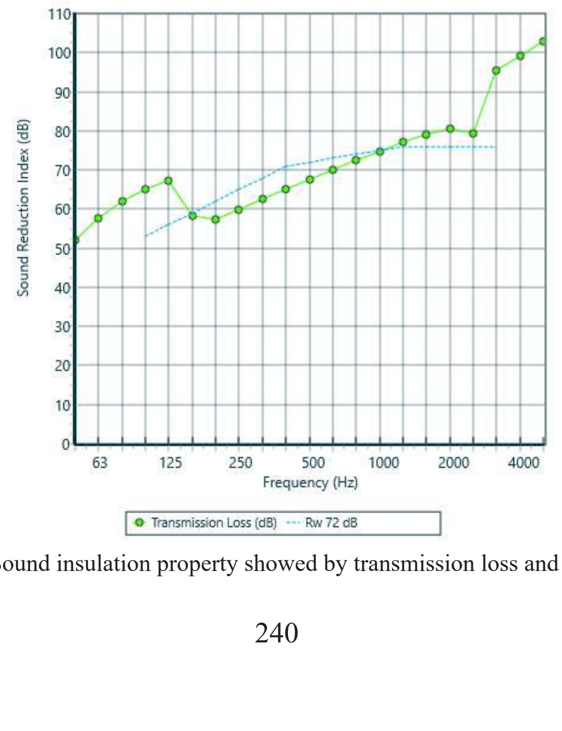


**Figure 7.** Sound insulation property showed by transmission loss and Rw 72dB.

A sound insulation indicator is used to predict how well a material will insulate against sound by calculating the air sound insulation of supporting walls, ceilings, floors, roofs, windows, and porous materials. In particular, impact calculations on the floor and roof are used to account for the sound of rain. For sound insulation calculations or acoustic design, the TL, Ln, and Rw (or STC) or LnTw (or IIC) can be predicted at the 1/3 octave band under the random incident condition. This is advantageous in the interface, global and custom material databases, and materials' comparative data calculation. According to the right vertical 7 average values of TL, each in a frequency span of 1/3 octave band, the overall average TL value of these 7 sums is approximately 70.71 dB, indicating that typical walls are sound-insulated (**Table 3**).

**Table 3.** TL min at each frequency and average TL at each 1/3 octave band frequency.

| **Frequency /Hz** | | **50** | **63** | **80** | **100** | **125** | **160** | **200** | **250** | **315** | **400** | **500** | **630** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transmission Loss TL(dB) | Minimum values | 44 | 45 | 45 | 46 | 45 | 43 | 45 | 47 | 50 | 52 | 55 | 57 |
| | Average values | | 55 | | | 62 | | | 59 | | | 67 | |
| **Frequency /Hz** | | **800** | **1000** | **1250** | **1600** | **2000** | **2500** | **3150** | **4000** | **5000** | | | |
| Transmission Loss TL(dB) | Minimum values | 60 | 62 | 64 | 65 | 67 | 68 | 70 | 72 | 73 | | | |
| | Average values | | 74 | | | 80 | | | 98 | | | | |

By using the simultaneous measurements of the noise level on both sides of the wall in conjunction with the sound insulation measurements of the relevant decorative layers, as in the four examples discussed above, it is possible to develop such an objective and straightforward approach.

# 4. Conclusions

This study is the first to take sand-based materials (energy-saving boards composed of sand particles) as the core research object. By combining the Delany-Bazley empirical model with Zorba and INSUL acoustic simulation software, it systematically compares the acoustic performance of four surface treatment schemes (Plain-P, SA1, PF, and SA2), filling the research gap in the field of indoor acoustic optimization for sand-based porous materials. Moreover, the research is not aimed at developing new types of granular porous boards, but rather at providing better choices for improving indoor acoustic characteristics through comparative analysis. This research perspective has been previously overlooked.

In the presence of inter-advancement in the modal and simulation of the structure, the adaptive methodology has been shown to enhance understanding of the sound-absorbing features of the specific spray and panel structures made of sand. The Johnson-Champoux-Allard (JCA) model accurately predicted the sound absorption of porous materials in both low and high frequency ranges. This model served as the basis for the development of several other semi-phenomenological models, including the Stinson model, the Wilson model, and the JCAL model [33].

New findings:

(1) It is clearly demonstrated that Plain-P (ordinary sand spray) has the best sound absorption performance among the four schemes, with a noise reduction coefficient (NRC) reaching 0.85 and a high-frequency sound absorption coefficient approaching 0.94.

(2) The dual advantages of sand-based materials are verified: they are both environmentally friendly and acoustically functional, and can be adapted to complex shapes such as curved and arched ceilings, achieving a combination of decoration and acoustic optimization.

(3) Through INSUL simulation, it is confirmed that the material has excellent sound insulation performance, with an average sound transmission loss (TL) of approximately 70.71 dB, making it suitable for places with high acoustic requirements, such as meeting rooms and theaters.

# Funding

This work was supported by China Scholarship

Counsil (CSC) (grant number: 202206935003) and Shanxi Province Nature and Science (grant number: 202203021222098).

## Institutional Review Board Statement

Not applicable.

## Informed Consent Statement

Not applicable.

## Data Availability Statement

The readers can access the data used in the study when requested.

## Acknowledgement

The author is greatly thankful to China Scholarship Council (grant number: 202206935003) and Natural and Science foundation of Shanxi Province (grant number:202203021222098) have supported the work with the sources of funding, including specific grant numbers, Ziqing T received the grant.

## Conflicts of Interest

The author declares that there is no conflict of interest to report regarding the present study.

## Abbreviations

| **Plain panel with sand spray** | **Plain-P** |
|---|---|
| Slat absorber | SA1 |
| Perforated facing | PF |
| Slot absorber | SA2 |
| Noise reduction coefficient | NRC |
| Flow resistivity 1 | σ1 |
| Flow resistivity 2 | σ2 |
| Air density | $\rho_0$ |
| Velocity in air | $c_0$ |
| Flow resistivity | σ |
| Frequency | f |
| 2 | ω |
| Imaginary unit | j |
| Porous material's primary density | $\rho_0$ |
| Property impedance | $Z_0$ |
| Propagation coefficient | γ |

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