

A short review of the impact of wooden panels on room acoustics

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ABSTRACT

The article provides an overview of information on the impact of wood panels and wood-based composites on room acoustics. It focuses on key parameters such as reverberation time (RT), sound absorption, and speech and music clarity (Clarity, STI). Wood-based panels and composites show strong potential as sustainable acoustic solutions, reducing reverberation time and improving clarity, while requiring careful optimization of porosity, thickness, and perforation to balance performance across frequencies.

Keyword: Acoustic, Sound Absorption, Wood-based Composites



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1. Introduction

Acoustic comfort is a fundamental component of the built environment, influencing learning processes, work performance, and overall well-being. Growing urbanization and noise pollution drive the search for effective methods to improve indoor acoustics [1]-[3].

Conventional sound-absorbing materials, such as mineral wool and polymer foams, offer high acoustic efficiency but are largely derived from non-renewable resources, require energy-intensive manufacturing processes, and entail significant environmental burdens and potential health risks for users and installers. Moreover, their low biodegradability and end-of-life management issues hinder alignment with circular economy principles. In the context of increasing requirements for building decarbonization and the implementation of sustainable development strategies, there is a growing demand for alternative, bio-based, and recycled sound-absorbing materials that combine good acoustic performance with a reduced environmental footprint and lower health risks. Wood-based panels represent a promising, sustainable alternative to conventional sound-absorbing materials [2,3]. Table 1 summarizes the key differences between conventional and sustainable sound-absorbing materials, including raw material origin, energy required for production, impacts on user health, and end-of-life scenarios [4].

Research focuses on wood-based composites such as medium-density fiberboard (MDF), oriented strand board (OSB), and wood-wool cement boards (WWCB), which can be used as porous sound absorbers [2]. Moreover, the development of natural-fiber composites, such as polylactic acid (PLA) reinforced with wood fibers (WFCMPP), offers significant potential for health and environmental protection while providing impressive acoustic performance [3]. Many of these materials combine sustainability with other desirable properties of building materials, including resistance to fire, water, and biological growth [2].

Table 1. Comparison between conventional and sustainable sound-absorbing materials.

Aspect	Conventional (mineral wool, foams)	Sustainable alternatives
Raw material source	Petrochemicals, non-renewable mineral resources	Plant-, animal-, and textile-based waste, biomass
Emissions and energy	High (high-temperature processes, high Global Warming Potential)	Lower emissions and energy demand
User health	Dust generation, skin/respiratory irritation, fiber inhalation	Non-toxic, low irritation risk
End of life	Poor biodegradability, waste generation, and microplastics	Biodegradable, recyclable, compostable options
Acoustic properties	Very good, but weaker at low frequencies unless thick	Often comparable; performance tunable through design

The purpose of this review is to systematize current knowledge on the mechanisms through which wooden panels and composites influence room acoustics. The focus is placed on objective acoustic parameters, panel design methods, and optimal placement strategies to enhance conditions for speech and music.

This review is organized into sections covering reverberation time reduction, sound absorption mechanisms, clarity indices, frequency control, and future perspectives.

2. Reduction of Reverberation Time (RT)

Reverberation time (RT) is a key parameter used to assess a room's acoustic quality, and high RT values are detrimental to speech clarity. Excessive RT, background noise, or both can reduce the Signal-to-Noise Ratio (SNR). Standards such as DIN 18041 and UNI 11532-2 define optimal RT values for occupied and unoccupied rooms as a function of the room volume (V). For example, in a classroom with a volume of approximately $V \approx 226.13 \text{ m}^3$, the optimal RT for unoccupied conditions ($T_{\text{opt,unocc}}$) was calculated to be 1.00 s. In contrast, for occupied conditions ($T_{\text{opt,occ}}$), it was 0.58 s.

2.1. Influence of Panel Area and Placement on RT

Effective RT reduction can be achieved by increasing the area covered with sound-absorbing panels. Studies indicate that RT decreases linearly with increasing proportion of decorative wooden surfaces (DR). However, diminishing marginal utility is observed, meaning that the impact of additional DR on RT decreases, which should be taken into account when designing cost-effective acoustic treatments [5].

The use of 50.0 mm WWCB panels in an existing classroom reduced the average RT ($T_{20; 125-4000\text{Hz}}$) from 1.32 s (without panels) to 1.11 s, exceeding the improvement observed for the other tested wood-based composites. Although this reduction did not reach the ideal $T_{\text{opt,unocc}}$ (1.00 s), it significantly improved speech intelligibility [2].

Strategic placement of absorptive materials is essential. It is recommended that absorption be concentrated toward the rear of a room, while areas close to the sound source remain more reflective to direct beneficial reflections toward the audience [6]. Other guidelines suggest applying absorptive materials to 20-30% of the ceiling and 15% of the rear wall for rooms of approximately 300 m^3 . Installing absorption on the central zone of the wall has also been proposed [2]. It has been shown that concentrating absorptive materials solely on the ceiling or walls may result in longer RT than a more homogeneous distribution. Configurations that used absorption only on the ceiling were less effective at reducing RT than those that combined ceiling and rear-wall absorption [6].

2.2. Role of Porosity

Porosity is one of the most important factors influencing the acoustic properties of materials, such as fiber-based panels [7]. Their fibrous or porous structure allows airflow, enabling sound waves to enter the pores and dissipate acoustic energy as heat. This phenomenon occurs because air molecules are forced to vibrate within the pores, generating thermal and frictional losses that reduce their initial energy [1].

Panels manufactured at lower pressing pressure (2.5 MPa) exhibited higher porosity (55.7%) and better acoustic performance, with a sound absorption coefficient close to 0.8 at 3.2 kHz [1]. Increasing porosity in fibrous composites results in higher absorption coefficients and reduced noise [7]. Microscopic analysis confirmed that irregular pore structures and complex, convoluted material morphology enhance sound absorption by forcing sound waves to undergo rapid, random internal reflections, thereby dissipating energy [3].

3. Enhanced Sound Absorption (Perforations and Microperforations)

Wooden panels and composites exhibit strong sound-absorptive properties, which are crucial for reducing RT [5]. Porous materials, such as wood fiber, exhibit high absorption coefficients, particularly at higher frequencies [2,8].

3.1. Absorption Mechanism and Composite Materials

The mechanism of sound absorption is based on converting acoustic energy into thermal energy due to friction caused by the vibration of air molecules within porous or perforated structures [3]. Among composites, WWCB materials absorb more acoustic energy than other composites (e.g., MDF, OSB) due to superior sound-absorbing characteristics [2].

Wood-based recycled materials, such as panels made from oak waste, exhibit high acoustic potential, with maximum absorption coefficients α reaching 0.9 [8,9]. Natural fibers – for example, rubberwood shavings in WFCMPP (wood fiber/PLA) composites – achieved a maximum absorption coefficient of 0.989. Increasing wood-fiber content in this composite showed a strong positive linear correlation with higher absorption and porosity [3].

3.2. Perforations and Microperforated Panels (MPP)

Microperforated panels (MPPs) are considered among the most promising next-generation sound absorbers [4]. The MPP concept, introduced by Maa, relies on ultra-thin panels (typically ≤ 1 mm) with micro-holes (typically 0.5-2 mm in diameter) and a perforation ratio of 1-2% [3,10]. Each microperforation behaves like an individual Helmholtz resonator [3,11]. Absorption results from resonance and viscous losses occurring in the perforation neck.

Sound absorption in MPP depends on optimizing hole size. If holes are too small, acoustic waves cannot penetrate; if they are too large, acoustic resistance and reactance decrease, reducing absorption. In WFCMPP panels, increasing the perforation volume (both diameter and panel thickness) caused the first absorption peaks to become smaller and narrower, and to shift toward lower frequencies. The highest absorption (0.93) occurred at a perforation thickness of 2 mm and a hole diameter of 0.2 mm [11].

Even wooden panels with larger perforations (1-3 mm) may exhibit MPP-like absorption behavior and can be modeled with the Maa-Flex model, which accounts for sound-induced panel vibrations. Absorption is enhanced by the combination of Helmholtz resonance and panel vibration, which may amplify absorption peaks and broaden absorption bandwidths. The inherent porosity of wood, compared to intentional perforation, has minimal influence on the acoustic performance of perforated wooden panels [12].

4. Improved Speech/Music Clarity (Hybrid Absorption–Diffusion)

For voice-oriented spaces such as classrooms and conference rooms, achieving high speech intelligibility is as essential as controlling RT. Objective parameters such as the Speech Transmission Index (STI) and Clarity (C_{50}) are critical in this context [2,6].

4.1. Speech Intelligibility (STI and C_{50})

The STI index, measuring speech intelligibility on a scale from 0 to 1, requires values above 0.64 in conference rooms [6]. In a classroom study, the use of 50.0-mm WWCB panels increased STI at all measurement points, with the largest improvement from 0.57 to 0.62 (point D). An STI value close to 1.00 represents optimal speech transmission conditions [2].

The C_{50} index, expressed in decibels, quantifies perceived speech clarity, with optimal values ($C_{50;0.5-2}$ kHz) ≥ 2 dB in small rooms [6]. In one simulation study, the best absorber configurations achieved $C_{50;0.5-2}$ kHz values of around 7 dB in a larger room and approximately 5.5 dB in a smaller room – well above the optimal threshold [6]. In another experiment, hybrid panels with a higher perforated surface area showed increased C_{80} values, thereby enhancing music clarity [13].

4.2. Hybrid Absorption and Diffusion

Combining diffusive and absorptive surfaces is recommended to simultaneously reduce RT and maintain desirable c_{50} values [2,6]. Diffusers evenly distribute sound energy within the room, preventing unwanted effects such as flutter echo.

Recent studies introduced hybrid absorptive-diffusive panels with tunable acoustic properties, consisting of wooden overlays shaped using third-degree Bézier curves [13]. Due to their three-dimensional geometry (depth variation 0-30 mm), these panels provide diffusion, while perforations enable absorption. Acoustic tuning is achieved by rapidly replacing perforated overlays with solid ones. This modification allows the absorption class to shift among standard classes A, C, or D, adapting the acoustic environment to different room functions [13,14].

In situ studies showed that replacing perforated overlays with solid ones significantly altered the sound field: fewer perforated overlays led to lower RT. In contrast, panels with a higher perforated surface increased C80 [13].

5. Optimal Panel Placement

Studies by Labia et al. [6] in medium-sized conference rooms (300–500 m³) showed that optimal configurations rely on combining absorptive surfaces. It is recommended to apply absorption on the ceiling (or its perimeter) and the upper part of one side wall (including the rear wall). In the examined regularly shaped room, the best configuration involved absorption on the ceiling and rear wall.

In general, for larger rooms (~500 m³), 50-70% of the ceiling and 30-50% of the walls should be covered with absorptive materials, whereas for smaller rooms (~300 m³), recommended values are 20-30% of the ceiling and up to 15% of the rear wall. The use of diffusers alone did not provide significant objective improvements over absorption alone, although perceptual studies indicate that diffusers are subjectively preferred, especially in small rooms, where they help control flutter echo [6].

6. Frequency Control (Thickness, Density, Perforation)

The acoustic properties of wooden panels are strongly linked to their physical characteristics [7]. Frequency-selective absorption is achieved by precisely adjusting thickness, material density, and perforation geometry to set the system's acoustic resonance.

6.1. Influence of Density and Thickness

Density is a key determinant of acoustic performance. Generally, low-density fiberboards (e.g., 220 kg/m³) exhibit higher sound absorption coefficients than high-density boards because acoustic waves penetrate more easily. In contrast, higher-density structures achieve better absorption at frequencies above 2000 Hz [7]. WWCB panels (50 mm) with lower density (0.36 g/cm³) showed the best absorption among the tested composites [2].

Increasing the thickness of a porous material improves absorption by reducing surface impedance, especially at low frequencies [2,7]. Studies show that doubling sample thickness (from 25 mm to 50 mm) shifted the first absorption peak toward lower frequencies [9]. For MPP, increasing panel thickness shifts the absorption peak downward, though excessive thickness may significantly reduce absorption due to increased reactance [11].

6.2. Perforation and Helmholtz Resonance

Perforated panels operate as Helmholtz resonators, where hole parameters (diameter, thickness, spacing) and air-gap depth determine acoustic impedance and resonance frequency [3,12]

Studies on finely perforated panels (hole diameter 1-3 mm) show that:

- Increasing panel thickness or hole spacing increases absorption peak value, shifts resonance to lower frequencies, and narrows the absorption bandwidth [12].
- Increasing the hole diameter decreases the peak absorption, shifts the resonance to higher frequencies, and broadens the absorption bandwidth [12].

For MPP, maximum absorption occurs at the resonance frequency and depends on acoustic mass. Increasing the air-gap depth reduces the stiffness of the acoustic “spring,” allowing the panel to resonate at lower

frequencies and thereby shifting the absorption peak. In the WFCMPP composite, despite differences in air-gap depth (10-30 mm), peak absorption remained almost unchanged, indicating robustness of the samples [3].

Simultaneous changes in perforation volume (panel thickness and hole diameter) increase acoustic mass, lowering resonance frequency. Optimal perforation design requires achieving a relative acoustic impedance close to unity [11].

Certain panel properties, such as dynamic Young's modulus and damping coefficient, also affect panel-vibration frequencies that coexist with Helmholtz resonance and may enhance absorption. Increasing dynamic Young's modulus shifts vibration-induced absorption peaks to higher frequencies [11].

7. Conclusions

Wooden panels and wood-based composites represent advanced and sustainable solutions in acoustic engineering, offering performance comparable to – and in many cases exceeding – that of traditional materials [2,8,9]. Table 2 compares the acoustic properties of sample panels [7]-[9,12].

Table 2. Comparison of acoustic performance across wooden panel types.

Panel Type	Max Absorption Coefficient (α)	Sound Transmission Loss (dB)	Notes
Oak wood panel	0.9 – 0.98	Up to 11	High absorption, good insulation
Wood composite (WPC)	0.9	Up to 28 (advanced designs)	Enhanced with natural fibers/additives
Micro-perforated panel	0.93 – 0.99	Up to 79 (3D-printed)	Tunable by perforation volume/design
Low-density fiberboard	0.5 – 0.6	-	Best at low/mid frequencies

The key conclusions are as follows:

- Reduction of RT – Reverberation time is effectively reduced, particularly through porous, low-density materials with appropriately selected thickness [1,7]. The use of 50.0 mm WWCB panels significantly decreases RT and improves STI [2].
- Sound Absorption – the absorption mechanism relies on viscous losses within perforations and pores. Microperforated panels (MPP) based on wood–PLA composites achieve near-optimal absorption coefficients ($\alpha \approx 0.99$) at resonance. Absorptive performance is strongly dependent on fiber content and the resulting porosity [3].
- Acoustic clarity – high STI and C50 values can be achieved through strategic combinations of absorption and diffusion [2,6]. Newly developed hybrid absorptive–diffusive panels, designed with third-degree Bézier curves, allow rapid changes in acoustic class (from D to A) by replacing overlays – an ideal feature for multifunctional spaces [13].
- Frequency Control – precise tuning of resonance and absorption bandwidth is achieved by optimizing physical parameters (thickness, density) and perforation geometry (hole diameter, spacing, air-gap depth) in accordance with the Helmholtz resonator model [12].

Future research should focus on further optimizing hybrid materials with tunable acoustic properties and integrating them with room acoustic simulation models (e.g., ray tracing) to enhance design accuracy and reduce installation costs, while accounting for diminishing marginal utility [5,10,13]. Wood-based panels hold strong potential to become a leading sustainable solution in modern architecture, enhancing the quality of indoor acoustic environments [9].

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