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The influence of different material properties of straw on the building acoustic performance of lightweight wall constructions

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ABSTRACT

In the presented research, straw as building material, is used as absorptive material in metal stud walls and timber frame constructions. The results of building acoustic measurements are used to quantify the acoustic potential of straw in those wall constructions. The influence of parameters like density, dynamic stiffness and air flow resistivity of straw on the measured sound reduction index is discussed. Especially the density and the dynamic stiffness, are important material parameters to achieve a high sound reduction index of the wall constructions. An increase of the dynamic stiffness of the straw, results in a higher mass-spring-mass resonance frequency and a better mechanical coupling of the wall sheets. This can lead to a reduction of the sound reduction index up to 19 dB of the investigated double wall. For the timber frame wall, the sound reduction index including the spectrum-weighting value (R_w+C_{tr}) varied between 42dB and 46dB in dependence of the dynamic stiffness of the blow in straw. The results show that the building acoustic performance of wall constructions with straw is comparable to the performance of already on the market established wall constructions, if the material properties of straw are optimized.

Keywords: *Straw, Sound insulation, Lightweight wall constructions, sustainability*

INTRODUCTION

The need for energy-efficient and sustainable construction practices has led to the exploration of new building materials. One such material is straw, a renewable and widely available by-product of grain production that has shown promise as a blow-in insulation material. While blow-in insulation using materials like cellulose has gained popularity for its eco-friendly nature and thermal and acoustic properties, an innovative Austrian company has developed a quality-assured alternative by processing straw. The unique manufacturing process enables the straw to be introduced into the building components at a higher density, which promises a thermal advantage due to increased storage mass and improved performance during summer overheating. While previous research has focused on the environmental and thermal properties of this product, little is known about its acoustic properties. This paper presents a comprehensive measurement approach to quantify the influence of different straw properties on the sound reduction index of various wall

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structures. Previous studies showed that the material properties of the cavity material can influence the sound insulation performance of the wall construction [1,2]. Especially [3] shows that the dynamic stiffness of the cavity material is an important parameter for the low frequency performance of the wall construction, if the cavity of the wall construction is completely filled with the absorbing material. The results of this research will assist manufacturers and planners in making informed decisions regarding the overall sound insulation performance of buildings using straw insulation.

1. METHODOLOGY

1.1 Measurement

The airborne sound reduction index *R* of the wall structures was measured according to EN ISO 10140-2:2021 with a calibrated measuring equipment. All measurements were carried out with third-octave band filters in the frequency range from 50 Hz to 5000 Hz. The frequency depended sound reduction index is calculated by equation 1 with L_1 energy average sound pressure level in the source room in dB, L_2 energy average sound pressure level in the receiving room in dB, *S* the area of the free test opening in which the test element is installed in m² and A the equivalent sound absorption area in the receiving room in m².

$$R = L_1 - L_2 + 10\lg\frac{S}{A} \tag{1}$$

The mass-spring-mass resonance frequency f_R of a double wall is calculated according to formula 2, based on the surface weight of the wall cladding layers *m*' and the dynamic stiffness *s*' of the insulation material in the wall cavity. The effect of the metal studs was neglected.

$$f_R = \frac{1}{2\pi}\sqrt{s'\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)} \tag{2}$$

1.2 Constructions

1.2.1 Metal stud wall

To minimize the influence of other factors on the sound transmission of different materials within the cavity of lightweight constructions, a construction was selected that provides reduced sound transmission through the studs. The objective was the measurement of the sound reduction index of a 20.5 cm thick double stud wall (Figure 1,) with different materials for cavity damping (Table 1.). The metal stud wall, approx. 10.4 m², was installed between two reverberation rooms according to EN ISO 10140-5.

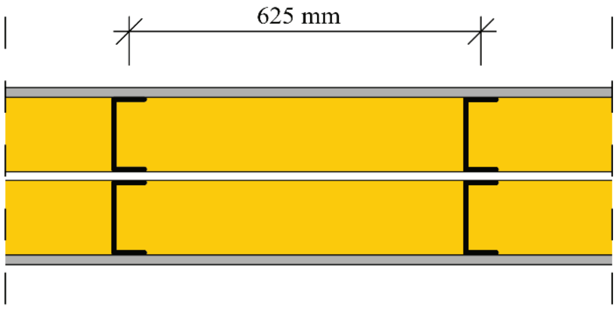

Figure 1. Cross section of the examined double metal stud wall construction (2 x 12.5 mm gypsum plasterboard, 75 mm insulation material, 5 mm air, 75 mm insulation material, 2 x 12.5 mm gypsum plasterboard)

The double metal stud wall construction described in Figure 1 was used to test different insulation materials with varying densities (as specified in Table 1) for their sound reduction capabilities. The measurement setup, as illustrated in Figure 2, involved creating a removable opening of approximately 30 cm width in the upper area of the wall, where the insulation material was inserted before closing it again with plasterboard. To ensure airtightness, the joints were taped with adhesive tape.

Table 1. Comparison of the dynamic stiffness *s*' of the materials used for cavity damping

Material	*s*' in MN/m³
Mineral wool [4]	1
Cellulose [5]	3-7
Straw (128 kg/m³, measured)	32
Wood fiber [6]	10-15

Figure 2. Measurement setup according to EN ISO 10140-2 for measuring the airborne sound insulation of the wall construction.

1.2.2 Timber frame wall

The objective was the measurement of the airborne sound insulation of a 20.5 cm thick wooden frame wall (Figure 3.) with different materials for cavity damping. The wooden frame wall, approx. 1.8 m², was installed between two reverberation rooms according to EN ISO 10140-5.

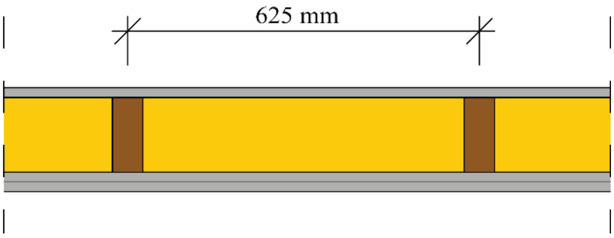

Figure 3. Cross section of the examined wooden frame wall (2 x 12.5 mm gypsum fiber board, 160 mm insulation material (Mineralwool, Straw with different densities), 2 x 10 mm gypsum fiber board)

In the cavity of the in figure 3 described timber frame wall, different insulation materials (Mineralwool, Straw) were introduced, without changing the frame, and the airborne sound insulation was measured. The measurements were carried out in the window opening of the test facility (see Figure 4).

Table 2. Measured relationship between the dynamic stiffness s' and the density of blow in straw

Density ρ in kg/m³	Dynamic stiffness s' in MN/m³
63	4
108	15
120	32

Figure 4. Measurement setup according to EN ISO 10140-2 for measuring the airborne sound insulation of the wall construction in the window opening.

2. RESULTS

2.1 Metal stud wall

The results presented in this section compare the performance of different materials that can be introduced by blowing in, namely mineral wool, cellulose, wood fiber, and straw. The discussion covers the acoustic performance of the wall construction as well as an environmental comparison between the different materials.

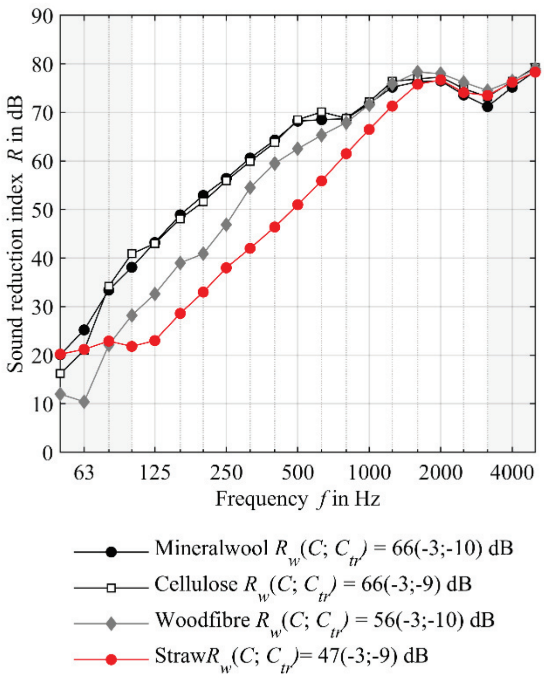

Figure 5. Frequency-dependent trend of the sound reduction index of a double metal stud wall under the influence of different insulation materials in the cavity [7]

The results of multiple measurement series are averaged to obtain the sound insulation dimension values shown in figure 5, which represent the influence of different wall constructions on the sound insulation performance at different frequencies. The classic curves depict the variations in mass-spring-mass resonances of the different materials tested, with the straw and wood fiber variations showing the respective resonances in the range of 63 Hz to 125 Hz. The different dynamic stiffness of the insulation materials explains the different position of the mass-spring resonance. The wall construction with straw in the cavity shows better performance than walls with lighter cavity fillings below the mass-spring-mass resonance frequency due to its higher overall mass and stiffness (f_r is higher). Plateaus observed in the sound reduction index for mineral wool and cellulose variations at around 500 Hz can be attributed to the dominated transmission path over the metal studs, which are decoupled by a 5 mm thick foamed polyethylene connection seal. The pressure of the "blow in" procedure for wood fiber and straw variations introduced an air gap, due to the deformation of the gypsum boards, between the metal studs, which explains the absence of the plateau region in their sound reduction index. All wall construction variations show an increase in sound reduction index of around 12 dB/octave above 800 Hz, and the dip at 3150 Hz represents the coincidence region of the plasterboard planking. The density of straw in the cavity does not significantly improve the sound insulation dimension in comparison to other materials tested.

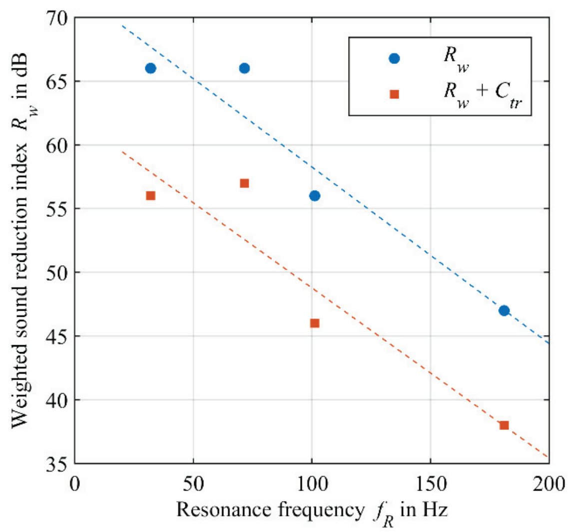

Figure 6. Relationship between the single number rating of the sound insulation of the double wall and the mass-spring-mass resonance frequency

Figure 6 shows the relationship between the measured single-number rating of sound insulation R_w (measurement setup Figure 2) for the double-wall, according to figure 1, construction and the mass-spring-mass resonance frequency resulting from the wall construction. The resonance frequency is calculated (formula 2) based on the surface weight of the wall cladding layers m_i' and the dynamic stiffness s' (table 2) of the insulation material in the wall cavity.

A linear relationship between Rw / R_w+C_{tr} and f_R can be observed. As the resonance frequency f_R increases, the sound insulation rating decreases by approximately 1 dB/10 Hz. For the investigated double wall construction with blow in straw a low mass-spring-mass resonance frequency f_R, and therefore a low density of the straw (see table 2), is beneficial for the sound insulation rating.

2.2 Timber frame wall

The sound insulation measurements for different wall constructions were obtained by averaging several measurement series, each using different loudspeaker and microphone positions, resulting in values of the sound insulation dimension as a function of frequency. Various insulation materials were used for cavity damping. The course of the sound reduction index for all variants followed a typical pattern for multi-shell constructions, with a dip in the index caused by mass-spring-mass resonance. The frequency at which this dip occurs shifts according to the stiffness of the spring, which is significantly affected by the insulation material's stiffness and density. The highest values for single-number-weighted parameters were observed for the variant with the cavity filled with mineral wool, as the mass-spring-mass resonance was outside the frequency range considered. For wooden frame walls filled with straw, an increasing resonance frequency was observed with increasing density, and a broad dip with higher densities may be caused by uneven density distribution. Above the mass-spring-mass resonance frequency, there is an increase of 10 dB/octave in the sound reduction index, influenced by the overall mass of the construction. The overall level of the slope is higher for constructions with higher densities of straw in the frequency range between the mass-spring-mass resonance frequency and the critical frequency of the wall panels. The weighted sound reduction index is mainly affected by the mass-spring-mass resonance dip and shows an increasing airborne sound insulation measure with decreasing bulk density and lower dynamic stiffness. The introduction of straw with low bulk density can lead to an improvement of up to 2 dB in the single-rated airborne sound insulation dimension, enabling the wall structure to achieve comparable building acoustic levels as with conventional ones.

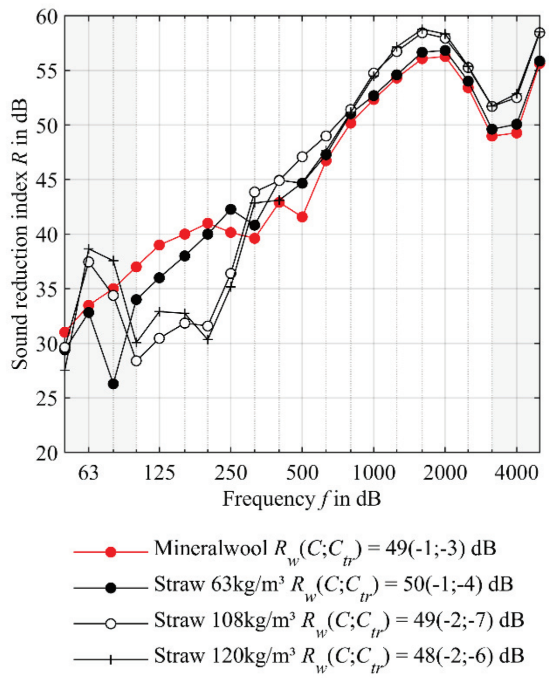

Figure 7. Frequency-dependent trend of the sound reduction index of timber frame wall under the influence of different insulation/ absorptive materials in the cavity with increasing density [7]

Figure 8 illustrates the correlation between the single-number rating of sound insulation R_w for the double-wall construction, as depicted in Figure 2, and the mass-spring-mass resonance frequency arising from the wall construction. The resonance frequency is determined by considering the surface weight of the wall cladding layers m_i' and the dynamic stiffness s' of the insulation material in the wall cavity. A linear relationship between the two variables is evident, regardless of whether the spectrum adaptation value for traffic noise C_{tr} is taken into consideration or not. As the resonance frequency increases, the sound insulation rating diminishes by an approximate 1 dB per 10 Hz.

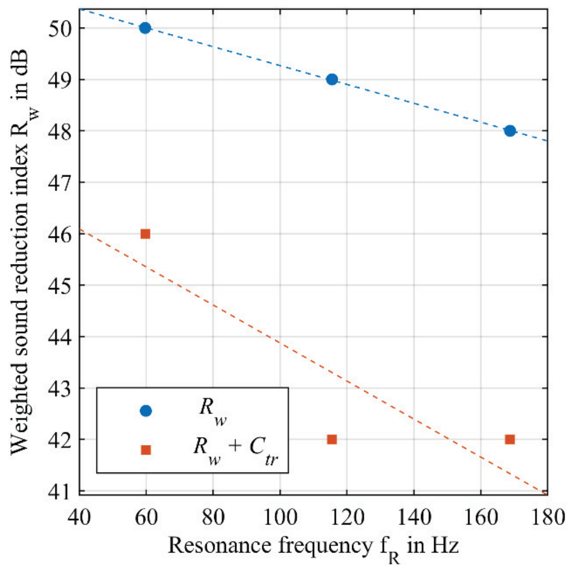

Figure 8. Relationship between the single number rating of the sound insulation of the timber frame wall and the mass-spring-mass resonance frequency

3. SUMMARY

In conclusion, the study demonstrates that the use of straw as a sound-absorbing material in the cavity of double-walls and timber frame constructions can provide comparable sound insulation performance to other common absorbing materials. The impact on the sound reduction index is closely linked to the density and dynamic stiffness of the blown-in straw. The research also revealed a linear correlation between the sound reduction index and the mass-spring-mass resonance frequency, which is determined by the dynamic stiffness of the cavity material and the area mass of the planking boards. An increase in resonance frequency leads to a decrease in the sound reduction index of the analyzed constructions by approximately 1 dB/10 Hz.

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