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ACOUSTICAL ASPECTS OF REPLACING TRADITIONAL MATERIALS IN BUILDING ELEMENTS WITH RENEWABLE AND RECYCLED ONES

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Abstract. Building elements, especially partitions, floors and external walls significantly affect indoor acoustic comfort. Their ability to reduce noise transmission from neighbouring rooms or from outdoors depends on the element composition and the building materials used. In Central Europe, the heavyweight masonry or concrete walls and slabs are typical elements both for family and residential buildings. However, increasing popularity of lightweight multi-layered structures is noticeable. This creates new opportunities for the gradual replacement of traditional materials with renewable and recycled ones, both for load-bearing components and for fillings and other layers of building elements. This paper introduces such design changes in relation to acoustics, particularly airborne sound insulation. The greatest attention is paid to the replacement of masonry and mineral wool insulation with timber and wood fibres. The overview is supplemented by examples of low-energy house external wall and timber wall with recycled infill whose sound insulation has been determined by measurements in the acoustic laboratory.

Keywords: Building acoustics, sound insulation, sound reduction index, building elements.

1. Introduction

In building acoustics, as in other fields of building design, there has been an effort in recent years to gradually replace traditional materials with more environmentally friendly ones. Regarding this, multi-layered lightweight building elements provide more opportunities. Due to their complex character, material substitution can be made either in the load-bearing construction, sheathing or filler layers. Since the requirements for sound insulation are constantly increasing, such changes should not impair the acoustic properties. This can be verified by comparative laboratory tests of original and new solutions.

This paper focuses on airborne sound insulation of interior and exterior walls. For interior wall, the aim was to improve poor sound insulation at low frequencies which is typical for lightweight structures and to increase the overall weighted sound reduction index with regard to new acoustical requirements described in Section 2.1. The composition of exterior wall is usually driven by reaching the target value of the heat transfer coefficient. The sound insulation is often not so determining because the weakest parts of building envelopes are windows. Therefore, only the overall effect of material substitution on R_w value is of interest in this paper.

2. Sound insulation requirements for dwellings

Different descriptors are used to express requirements for sound insulation in buildings in various EU countries. Therefore, great efforts have been made to harmonize them in the form of a new classification scheme in recent years, see Section 2.2. However, for laboratory measurements determining the airborne sound insulation of building elements, it is common to use the same quantities throughout Europe, the weighted sound reduction index R_w and relevant spectrum adaptation terms C, C_tr, $C_{50-3150}$, etc.

2.1. National requirements according to new ČSN 73 0532

In December 2020, after ten years of using the older version, the new Czech standard specifying requirements for sound insulation in buildings was issued. The new requirements, listed in Table 1, are 0–2 dB higher for walls and floors between apartments, but 2 dB lower for walls between habitable rooms within the same flat. However, this second requirement, which is not typical for other EU countries, has been extended to all habitable rooms in the apartment (not just one as it was before).

The requirements for sound insulation of building envelopes depend on external noise levels and range between 30 dB and 48 dB in extreme cases. The quantity R'_w is used for individual parts (e.g. windows or

Type of space	Floors		Walls
	R'_w, $D_{\mathrm{n}T,\mathrm{w}}$	$L'_{\mathrm{n,w}}$, $L'_{\mathrm{n}T,\mathrm{w}}$	R'_w, $D_{\mathrm{n}T,\mathrm{w}}$
Between all habitable rooms within the same flat	≥ 47	≤ 58	≥ 40
Between habitable room and all rooms of other apartments	≥ 54	≤ 53	≥ 53

Table 1. Required sound insulation between habitable rooms in family houses and residential buildings [1].

Type of space	Class A	Class B	Class C	Class D	Class E	Class F
Between habitable rooms in dwellings and other dwellings	$D_{\mathrm{n}T,50} \geq 58$	$D_{\mathrm{n}T,50} \geq 54$	$D_{\mathrm{n}T,\mathrm{A}} \geq 52$	$D_{\mathrm{n}T,\mathrm{A}} \geq 48$	$D_{\mathrm{n}T,\mathrm{A}} \geq 44$	$D_{\mathrm{n}T,\mathrm{A}} \geq 40$

Table 2. Classes for airborne sound insulation [2].

walls) and $D_{\mathrm{n}T,\mathrm{w}}$ for building envelope as a whole.

2.2. Classification scheme according to ISO/TS 19488:2021

In 2021, ISO/TS 19488:2021 introducing new acoustic classification scheme for dwellings was issued. This new technical specification is based on the work of COST Action TU0901 "Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions" between 2009 and 2013, summarized in [3]. This new document uses six quality classes A to F (the best acoustic comfort ensures class A) based on the evaluation of various acoustic aspects (the airborne sound insulation is one of them), for details see Table 2.

Classification scheme for airborne sound insulation uses weighted standardized level differences $D_{\mathrm{n}T,\mathrm{A}}$ and $D_{\mathrm{n}T,50}$ ($D_{\mathrm{n}T,\mathrm{A}} = D_{\mathrm{n}T,\mathrm{w}} + C$ and $D_{\mathrm{n}T,50} = D_{\mathrm{n}T,\mathrm{w}} + C_{50-3150}$). Since this paper is focused on acoustical behavior of building elements (in laboratory conditions), corresponding quantities $R_\mathrm{w} + C$ and $R_\mathrm{w} + C_{50-3150}$ are used instead. Acoustic classification of façades is based on descriptor $D_{\mathrm{n}T,\mathrm{A,tr}}$ ($D_{\mathrm{n}T,\mathrm{A,tr}} = D_{\mathrm{n}T,\mathrm{w}} + C_\mathrm{tr}$). From the same reasons as for internal walls and floors, $R_\mathrm{w} + C_\mathrm{tr}$ is used instead in this paper.

3. Timber wall with crushed brick rubble infill

The original idea was to use the recycled loose-fill in a timber frame interior wall and to compare the acoustical properties of such structure with the same wall with mineral wool infill and with a traditional hollow brick partition of approximately the same thickness and weight. The goal was to achieve equal or better weighted sound reduction index and to improve poor sound insulation at low frequencies, which is typical for lightweight building elements. Schemes of all three walls are shown in Figure 1.

The tested timber wall with crushed brick rubble infill had following composition (thickness 140 mm, mass per unit area ca. 134 kg/m^2):

- structural plasterboard 12.5 mm (11.5 kg/m^2),

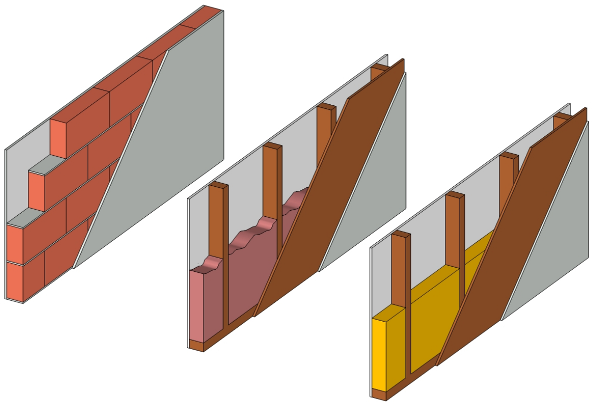

Figure 1. Schemes of tested walls: masonry (left), timber with recycled infill (center), timber with mineral wool (right).

- timber frame from KVH profiles (spruce wood) 60 × 100 mm, axial distance of studs 625 mm, filled with recycled brick rubble 4–8 mm,
- oriented strand board 15 mm (9 kg/m^2),
- structural plasterboard 12.5 mm (11.5 kg/m^2).

The process of filling the wall with crushed brick rubble is shown in Figures 2 and 3. For the lightweight variant, mineral wool boards, 100 mm thickness ($\geq$ 15 kg/m^3 and $\geq$ 5 kPa · s/m^2) were used instead of rubble infill. The approximate total weight for this wall was 43.5 kg/m^2. The hollow block masonry partition was 145 mm thick and weighted ca. 137 kg/m^2.

The measured laboratory sound reduction index vs. frequency is shown in Figures 4 and 5.

There are several interesting observations coming from the frequency response:

- the sound reduction index of timber wall with rubble infill is higher compared to the other variants almost in all frequency bands below 1 600 Hz,
- sound insulation is well improved especially in low frequency region (in some 1/3-octave bands by more than 10 dB),
- the acoustical behaviour of the wall is rather com-

Figure 2. Crushed brick rubble in the cavity between sheathing and studs (photo by K. Staněk).

Figure 3. Filling the wall with crushed brick rubble (photo by K. Staněk).

plex and the wall has probably two critical frequencies; the first around 315 Hz is possibly caused by bending stiffness of the wall as a whole (it is higher than the critical frequency of single hollow brick wall approx. 160 Hz); the second around 2 500 Hz, associated with plasterboard sheathing, is the same for both dry wall variants, it comes from the fact that plasterboards are not rigidly fixed with the core (recycled infill).

For the overall rating of walls the single number quantities presented in Table 3 are the most important. Based on the R_w values, wall with recycled infill is by 2 dB better than the other walls. Compared to the national requirement $R'_w \geq 40$ dB on walls between all habitable rooms within the same flat, the laboratory value $R_w = 44$ dB is high enough even with regard to correction for flanking sound transmission. The parameter $R_w + C_{50-3150}$ is by 3 dB better compared to dry wall with mineral wool.

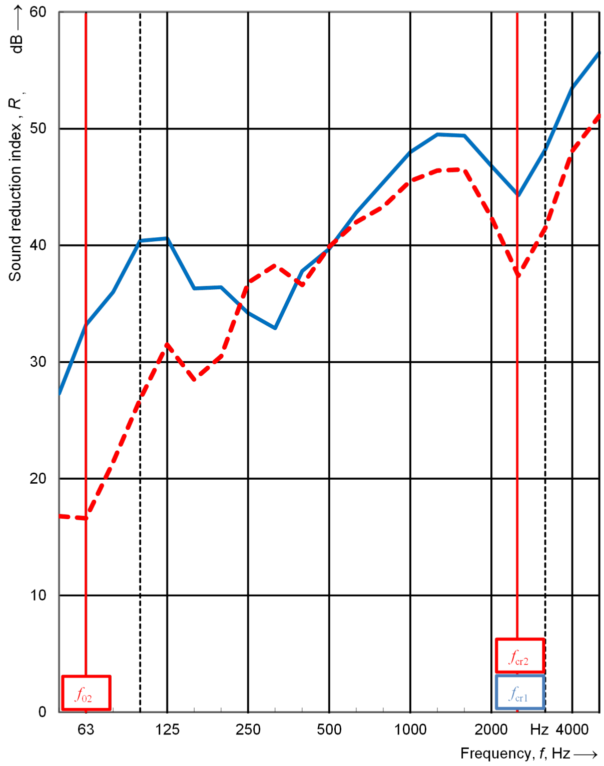

Figure 4. Sound reduction index of walls: timber with recycled infill – the solid blue curve, timber with mineral wool – the dashed red curve.

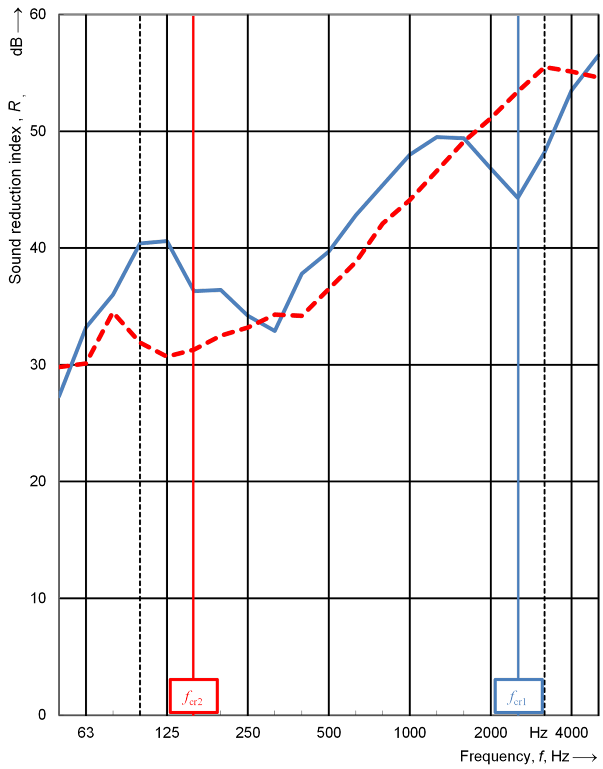

Figure 5. Sound reduction index of walls: timber with recycled infill – the solid blue curve, masonry – the dashed red curve.

Type of wall	R_w [dB]	C [dB]	C_{tr} [dB]	$C_{50-3150}$ [dB]	$C_{tr,50-3150}$ [dB]
Recycled infill	44	-1	-3	-1	-3
Mineral wool	42	-2	-3	-2	-8
Solid	42	-1	-3	-1	-4

Table 3. Single number results for internal walls.

Type of wall	R_w [dB]	C [dB]	C_{tr} [dB]	$C_{50-3150}$ [dB]	$C_{tr,50-3150}$ [dB]
Wood fibre – basic element	40	-2	-6	-2	-10
Mineral wool – basic element	44	-1	-2	-3	-13
Wood fibre – with ETICS	42	-1	-5	-1	-7
Mineral wool – with ETICS	51	-1	-6	-5	-17

Table 4. Single number results for external walls.

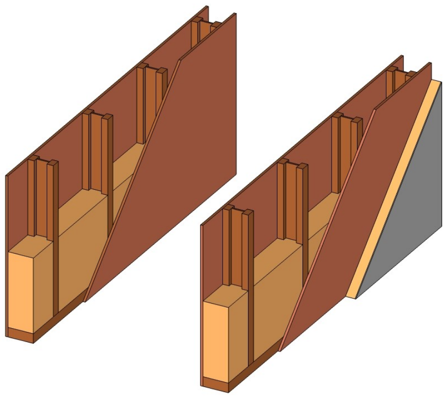

Figure 6. Schemes of tested external walls: basic part of the wall (left), basic part with ETICS (right).

Figure 7. Wood fibre boards between I-joists STEICO wall.

4. External wall for low energy houses

The external wall with pre-insulated I-joists is an environmentally friendly building system for low energy and passive houses. The heat transfer coefficient varies between ca. 0.15 and 0.18 W/(m$^2\cdot$K), depending on the thickness of thermal insulation. The external wall shown in Figure 6 was tested with two types of thermal insulation: wood fibre boards and mineral wool of the same thickness.

The composition of wall with wood fibre insulation was as follows (thickness 255 mm, mass per unit area ca. 55.8 kg/m^2), the layers of the basic element (thickness 190 mm, mass per unit area ca. 32.4 kg/m^2) are in italics:

- 5 mm base coat with reinforcing fibre mesh (7.5 kg/m^2),
- 60 mm thermal insulation wood fibre boards 265 kg/m^3 fastened with anchors (15.9 kg/m^2),
- *vapour-permeable wood fibre board 15 mm (9 kg/m^2),*
- *pre-insulated I-joists STEICO wall 60/160 mm, stud centres 625 mm, with 2 × 80 mm wood fibre boards 60 kg/m^3 and ≥ 5 kPa · s/m^2 (14.4 kg/m^2),*
- *oriented strand board 15 mm (9 kg/m^2).*

The composition of wall with mineral wool was following (thickness 252.5 mm, mass per unit area ca. 46.5 kg/m^2), the layers of the basic element (thickness 187.5 mm, mass per unit area ca. 30 kg/m^2) are in italics:

- 5 mm base coat with reinforcing fibre mesh (7.5 kg/m^2),
- 60 mm thermal insulation mineral wool boards 150 kg/m^3 fastened with anchors (9 kg/m^2),
- *vapour-permeable wood fibre board 15 mm (9 kg/m^2),*
- *pre-insulated I-joists STEICO wall 60/160 mm, stud centres 625 mm, with 160 mm mineral wool 20 kg/m^3 and ≥ 8 kPa · s/m^2 (8 kg/m^2),*
- *plasterboard 12.5 mm (13 kg/m^2).*

The measurement results are listed in Table 4. The test elements are shown in Figures 7 and 8.

Figure 8. Mineral wool boards of ETICS fastened with anchors.

Figure 9 shows that the sound reduction index of the basic element with mineral wool is higher across the frequency spectrum compared to the element with wood fibres. Since the structural parts of the wall were not changed (except OSB replaced with plasterboard), it can be assumed that sound transmission via studs is almost the same in both cases and the difference in the sound reduction index is therefore caused by increased sound transmission through the cavity for wall with wood fibres. This is also indicated by different slope of R between 100 Hz and 1 000 Hz (for wood fibres 8 dB/octave and for mineral wool 4 dB/octave). Smaller slope is typical for the effect of sound bridges (wooden studs) while steeper slope is common for cavity effect (usually due to weakly attenuated cavity).

The difference between walls is also significant if we look at the weighted sound reduction index R_w which differs by 4 dB. The difference for $R_w + C_{tr}$ (recommended descriptor for traffic noise spectrum) is even 8 dB. In contrast, when the low frequencies below 100 Hz are taken into account, the difference for $R_w + C_{tr,50-3150}$ is only 1 dB. This is due to the absence of a drop in *SRI* curve for the wall with wood fibres. For walls with ETICS the observations are almost the same with even greater differences, see Figure 10 and Table 4.

For masonry external walls, typical values of R_w are between 45 dB and 50 dB. This is similar to the wall with mineral wool. Taking into account the spectrum adaptation term C_{tr}, quantity $R_w + C_{tr}$ for masonry wall will be approximately 5 dB higher. This can be compensated with independent interior plasterboard lining in case of timber wall, which is often used for fire protection and for electrical installations.

5. Conclusions

The use of renewable and recycled materials in building elements can significantly change their acoustical properties. It was shown in two examples that this

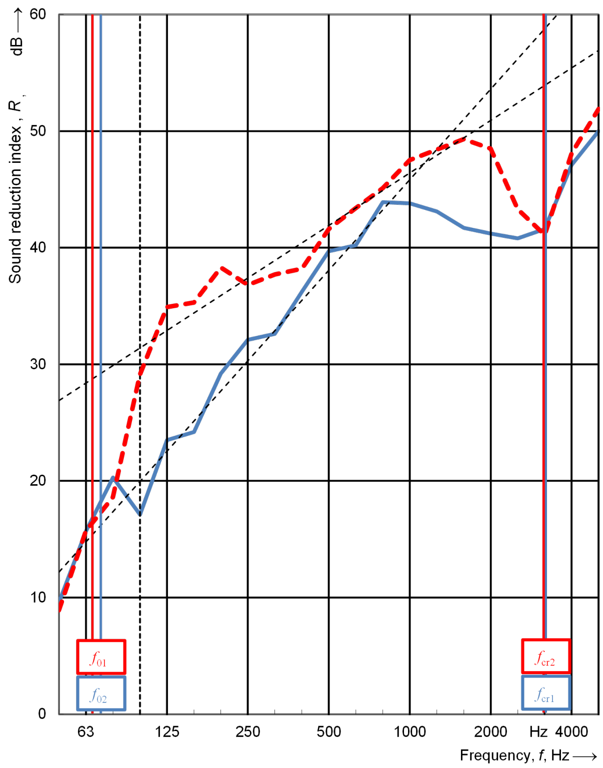

Figure 9. Sound reduction index of basic element: wood fibre – the solid blue curve, mineral wool – the dashed red curve.

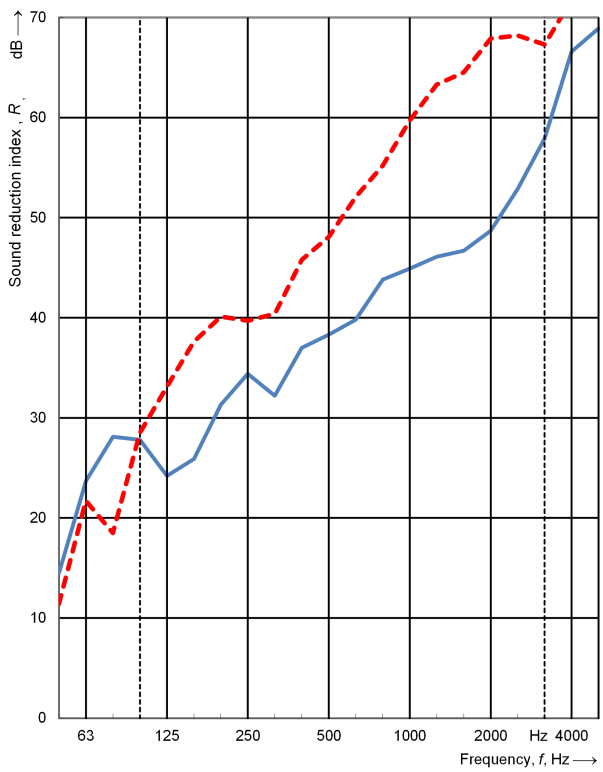

Figure 10. Sound reduction index of walls with ETICS: wood fibre – the solid blue curve, mineral wool – the dashed red curve.

change can mean either improvement or deterioration of airborne sound insulation.

The idea of using recycled crushed brick rubble infill for increasing the sound reduction index of walls, especially at low frequencies, was found correct. Although the application to a vertical structure is probably not so acoustically efficient as in the case of floors (since the rubble infill increases bending stiffness of the wall), the measured weighted sound reduction index $R_w = 44\,\mathrm{dB}$ was nevertheless higher than for the double wall with mineral wool or for the hollow brick partition. This value is fully sufficient also with regard to the Czech requirement for sound insulation between the habitable rooms of the same apartment. Outstanding sound reduction index at low frequencies predetermines the use of such a wall between bedrooms and livings rooms where sources with strong low frequency components are common (e.g. home cinema, reproduced music) [4]. It can be also successfully used as a part of a wall between different dwellings if supplemented by independent acoustic lining.

Interpretation of achieved results for tested external wall is more complicated. In general, the wood fibre infill was found less acoustically efficient than mineral wool in studied case, probably because it provides less sound attenuation in the cavity. However, the observed differences in sound reduction index can be also affected by different type of structural boards used at one side of the wall, since the wood based boards are lighter than plasterboards or gypsum fibre boards. The total weight must be considered in acoustic design and if necessary, the wall should be provided with independent lining on interior side.

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