Improvement of airborne sound insulation of lightweight timber framed walls through prefabricated multilayer wood studs

V. Desarnaulds and R. Fecelier
EcoAcoustique SA, 24 av. Université, 1005 Lausanne, Switzerland, desarnaulds@ecoacoustique.ch.

Summary

Coupling properties of structures are one of the most important parameters for sound insulation of wooden buildings. Independent double structures or interposition of resilient elements are usually used to reduce coupling between lightweight walls panels. To decrease costs and assembly time, a multi-layer stud was developed, using an ultrasonic process to thermo-glue different types of resilient layers (composite foam, recycled tires rubber) between two thin wood studs. The evaluation of the decoupling properties of these various multilayers studs was performed by acceleration measurements on small size samples. Based on the average acceleration attenuation between the panels, improvements of the various multilayers studs compared to a single plain wood stud have been characterized, according to the resilient type and thickness. Third octave bands results were used to predict airborne sound insulation.

PACS no. 43.55.Rg, 43.55.Ti

1. Introduction

During the last two decades, there has been an increasing interest in timber based lightweight components and buildings because of their low cost, short assembly time and low environmental impact. However, acoustic performances of lightweight buildings are challenging due to their natural frequencies of resonance and the low mass of building material used in these elements. Coupling properties of structures are one of the most important parameters for sound insulation of timber frame buildings [1]. Thus, independent double structures or interposition of resilient fixing elements are usually used to reduce coupling between lightweight walls panels. But all this solutions are cost and time consuming.

According to Muellner [2], there is an urgent need to develop an economically competitive one-stud-system which can provide sufficient uncoupling properties without being sensitive to the workmanship's influence.

Innovative low-cost multi-layer stud system was recently developed in Switzerland as sound protection profiles. Different types of resilient but structurally stable layers are thermo-glued by an ultrasonic process between two thin wood studs. To contribute to sustainable development, only ecological material were used as resilient layer (recycle composite foam, recycled tires rubber). Lightweight single frame double walls with high sound insulation can be prefabricated with low production cost and assembly time.

This paper presents the evaluation and optimization of the uncoupling properties of various multilayers studs using vibration measurements on small size samples. Based on measurement results, two analytical methods were used to predict airborne sound insulation of bearing and non-bearing walls.

2. Methodology

2.1 Experimental setup

Coupling property of various studs were determined through acceleration measurement on small size (1.3 x 1.0 m) double walls structures submitted to point excitation. Reproducible excitation conditions were obtained with a Swiss pendulous hammer, developed for equipment noise evaluation [3]. This hammer is very useful for decoupling measurement, especially in lightweight construction [4]. Preliminary experiments have been conducted to minimize flanking transmissions and measurement uncertainty (about 1 dB in each 1/3 octave band for 10 successive measurements). Finally, the sample

---

was suspended through 4 isolated hangers in the two separated cross-beams (figure 1).

Figure 1. Experimental setup, sample suspended with isolated hangers).

Accelerometers and impact locations were fixed on and between (1/3, 1/2 and 2/3 distance) stud positions. Impact average vibration level difference between the two panels ($\overline{D_{v,ij}}$) were measured with a dual channel analyzer in both directions in 12 different configurations according to (1).

$$\overline{D_{v,ij}} = \frac{D_{v,ij}+D_{v,ji}}{2} \qquad (1)$$

2.2 Samples

Two widths of 60 mm thick studs were considered for non-bearing (100 mm) and bearing (200 mm) walls.
High-density (1'150 kg/m3) gypsum boards of 15 mm thickness have been screwed on two 600 mm spaced studs. The gaps between the gypsum boards have been filled with 1 or two 75 mm thick layer of rock-wool (60 kg/m3). Some experiments have been conducted with two 15 mm panels in each side.

Figure 2. Sample NBW2 for non-bearing wall (100 mm including 20 mm rubber).

In a first step, 3 types of studs were tested for non-bearing walls (NB, cf. Figure 2):

- NB0: 100 mm wood (rigid)
- NB1: 40 mm wood + 20 mm composite foam (recycled 170 kg/m3) + 40 mm wood.
- NB2: 40 mm wood + 20 mm rubber (recycled tires 780 kg/m3) + 40 mm wood.

In a second step, 5 types of studs were tested for bearing walls (B) with the various thickness of composite foam, best resilient layer according to non-bearing results:

- B0: 200 mm wood (rigid)
- B1: 100 mm wood + 20 mm composite foam + 80 mm wood.
- B2: 80 mm wood + 40 mm composite foam + 80 mm wood.
- B3: 80 mm wood + 60 mm composite foam + 60 mm wood.
- B4: 40 mm wood + 20 mm composite foam + 80 mm wood + 20 mm composite foam + 40 mm wood.

Figure 3. Sample BW4 for bearing wall (200 mm including 2x20 mm composite foam).

3. Measurement Results

3.1 Non bearing walls

1/3 octave band vibration level differences for non-bearing walls (100 mm stud) are presented in figure 4. As expected, softer studs give better results, with steeper increase according to frequency. Good decoupling properties are obtained for stud with foam as resilient layer (NB2), especially in high frequency range (22 dB to 34 dB level difference when f>800 Hz). In low frequency (<250 Hz) the level difference drop to 8 dB with foam and about 3 dB with rubber (NB1) or without resilient layer (plain wood, NB0). Rubber seems to be too stiff to provide good decoupling conditions.
Considering plain wood stud (NB0) as reference, the improvement of studs with resilient layers are presented in figure 5. The composite foam is clearly the most efficient layer with an improvement, compared to plain wood, of 5 dB in low frequency, 13 dB in mid frequency and 20 dB in high frequency range. The rubber has no effect in low frequency. The improvement is only 3 dB in mid frequency and 8 in high frequency range. For both layers, maximum improvement is obtained at 2500 Hz.

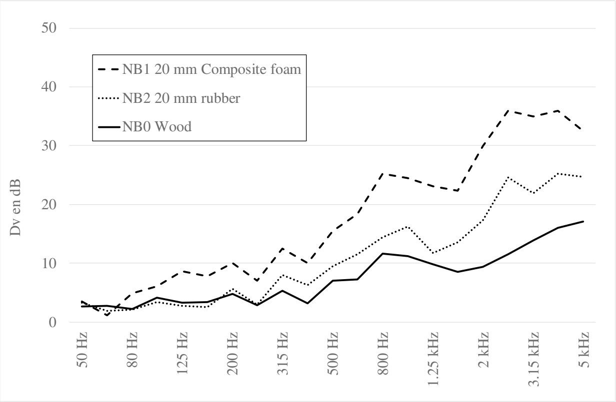

Figure 4. Vibration level differences for non-bearing walls (100 mm studs).

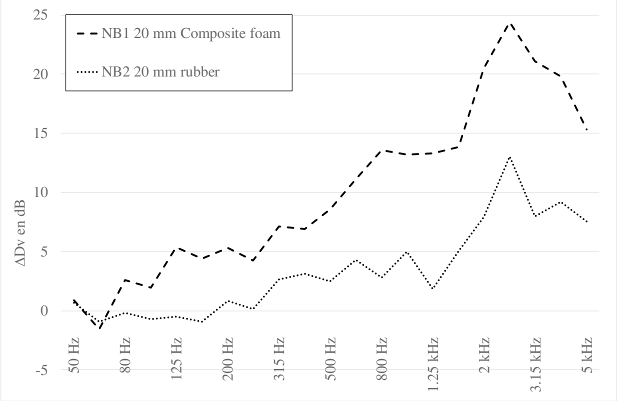

Figure 5. Decoupling improvement for stud with resilient layer compared to non-bearing plain wood studs (NB0).

3.2 Bearing walls

For bearing wall, 200 mm stud with various thickness of composite foam were measured. 1/3 octave band vibration level differences between are presented in figure 6 and improvement compared to plain wood (B0) in figure 7.

Increasing of stud thickness (100 to 200 mm) brings a 10 dB improvement of the vibration level difference of a plain wood stud (difference between non-bearing NB0 and bearing B0 stud).

The interposition of resilient layer is efficient only above 250 Hz. Studs with 20 mm (B1) and 40 mm (B2) thickness foam layers give equivalent results. Compared to plain wood stud (B0) the improvements are 8 dB in mid frequency and about 13 dB in high frequency range.

Better results are obtained with the thickest 60 mm single layer (B3), with improvements from 14 to 16 dB in mid respectively high frequency range.

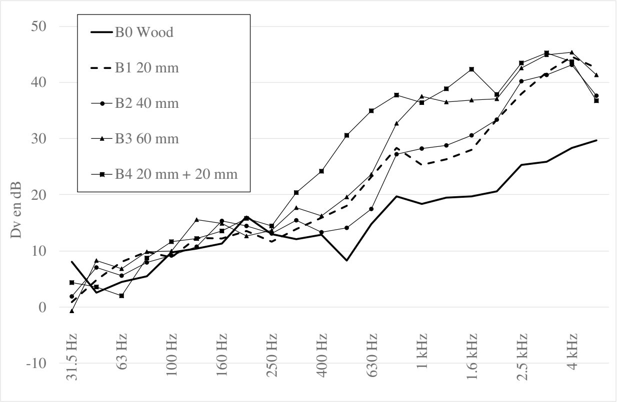

Figure 6. Vibration level differences for bearing walls (200 mm studs).

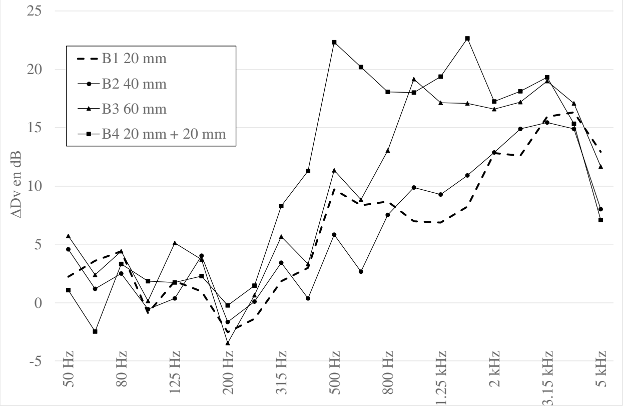

Figure 7. Decoupling improvement for studs with resilient layer compared to bearing wood studs (B0)

The “sandwich” stud with two thin layers of 20 mm (B4) gives the best results.

The performances are especially good in mid frequency, where the average improvement reaches 20 dB. In these two later cases (B3 and B4), the maximum improvement is obtained in a broad band frequency range (1000 resp. 500 to 3150 Hz).

4. Airborne insulation calculation

As already mentioned, sound insulation of wooden buildings is mostly influenced by coupling properties of structures. Concerning lightweight single frame double wall, airborne sound transmission is mainly determined by the (semi-) rigid connection between panels though studs. With his predicting model of air borne sound transmission of double leaf cavity walls, Davy [5,6] has shown, that, above the mass-spring-mass resonance frequency (about 57 Hz for non-bearing and 40 Hz for bearing wall), the structure borne transmission via point and line connection are highly predominant.

4.1 Sound transmission prediction model

Assuming the dominance of vibrational path, the sound transmission loss (R_{calc1}) can be derived directly from the measured average vibration level difference between the two panels ($\overline{\boldsymbol{D_{v,ij}}}$), through the equation (2)

$$\boldsymbol{R_{cal1} = \overline{D_{v,ij}} + 10log_{10}\left[\frac{\omega^3}{4\rho_0^2c_0^2}\frac{\eta_{p1}m_{sp1}^2}{\sigma_{p1}\sigma_{p2}f_{cp1}}\frac{S_{p1}}{S_{p2}}\right]} \quad \textbf{(2)}$$

With air density (ρ_0), speed of sound in air (c_0), area (S_p), mass per unit area (m_{sp}), damping factor (η_p), radiation efficiency (σ_p) and critical frequency (f_{cp}), thickness (t) and longitudinal speed of sound (c_L) of the panels, parameters defined in [7]:

$$\boldsymbol{f_{cp} = \frac{c_0^2}{(1.8c_Lt)}} \quad \textbf{(3)}$$

Experimental data from Guigou-Carter [8] have been used for damping factor of gypsum board panels:

- 7% for f ≤125 Hz
- linear decrease to 5.5% at f = 200 Hz,
- 5.5% for 200 Hz ≤ f ≤ 630 Hz;
- linear decrease to 3.5% at f = 3150 Hz,
- 3.5% for f ≥ 3150 Hz)

According to Craik [9], the radiation efficiency of a panel is given by equations **(4)**:

$$\sigma_p = \frac{P_p}{4\pi^2\sqrt{ff_{cp}\left(\frac{f_{cp}}{f}-1\right)S_p}}\left\{ln\left[\frac{\left(\frac{f_{cp}}{f}\right)^{\frac{1}{2}}+1}{\left(\frac{f_{cp}}{f}\right)^{\frac{1}{2}}-1}\right]+\frac{2\left(\frac{f_{cp}}{f}\right)^{\frac{1}{2}}}{\left(\frac{f_{cp}}{f}-1\right)}\right\} \; for\; f < f_{cp}$$

$$\sigma_p = \sqrt{\frac{2\pi f}{c_0}}L_{xp}^{1/2}[0.5 - 0.15L_{xp}/L_{yp}] \; for\; f = f_{cp}$$

$$\sigma_p = \frac{1}{\sqrt{1-(\frac{f_{cp}}{f})}} \; for\; f > f_{cp}$$

Sound transmission losses have been calculated according to equation (2) for a standard non-bearing wall (100 mm plain wood stud). As shown in figure 8, there is a reasonable agreement between prediction and laboratory measurement results except in low frequency (80 Hz) near the mass-spring-mass resonant frequency.

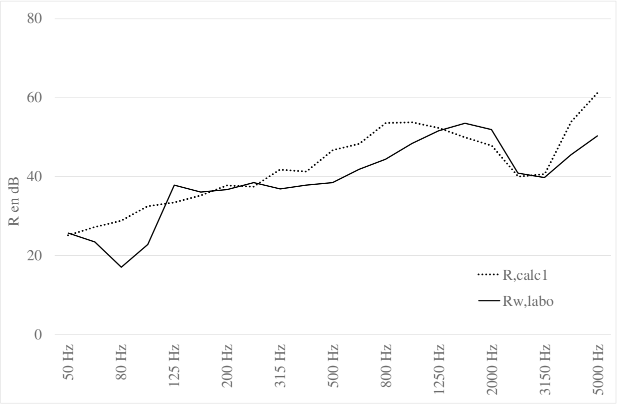

Figure 8. Calculated and measured transmission loss for standard non-bearing wall (100 mm plain wood studs).

4.2 Indirect evaluation from laboratory data

Still based on hypothesis of dominance of vibrational path, the sound transmission loss of a wall with improved studs (R_{calc2}) can also be indirectly derived from the sound transmission loss of a standard construction measured in laboratory measurement ($R_{labo(wood)}$) and the vibration level difference of the walls with standard ($\overline{\boldsymbol{D_{v,wood}}}$) and improved studs ($\overline{\boldsymbol{D_{v,ij}}}$) :

$$\boldsymbol{R_{calc2} = R_{labo\,(wood)} + (D_{v,ij} - D_{v,wood})} \quad \textbf{(5)}$$

Sound transmission loss have been calculated according to direct (equation 2) and indirect (equation 5) evaluation for anon-bearing wall with 20 mm foam resilient layer (NB1). As shown in figure 9, there is a very good agreement between the two prediction methods except near the resonant frequency.

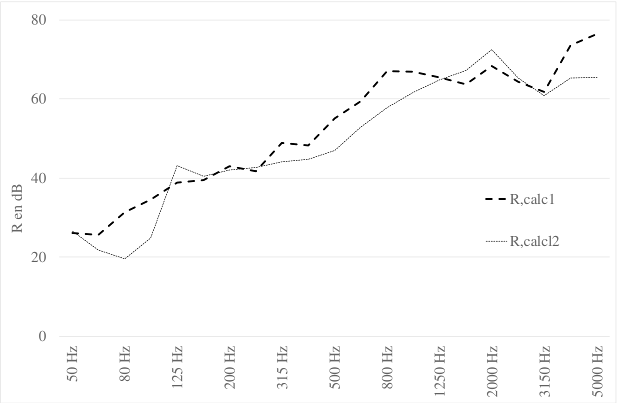

Figure 9. Direct (R_{calc1}) and indirect (R_{calc2}) evaluation of sound transmission loss for non-bearing wall with 20 mm foam (NB1).

4.3 Sound transmission for non-bearing walls

Sound transmission losses and have been calculated for non-bearing walls according to indirect evaluation (equation 5) because of its simplicity. Results are presented in figure 10, and calculated weighted sound reduction index (Rw) in table I.

Even if the use of studs with 20 mm rubber has little impact in low and mid frequencies compared to standard wood studs, this layer could induce 4 dB increase of the weighted sound reduction index. This can be explained by the improvement provided in high frequency by the rubber layer, which reduces the weakness around critical frequency of gypsum board panels.

When the studs include 20 mm layer of composite foam, the sound transmission increased significantly not only in high frequencies around critical frequency, but also in mid frequency. According to our evaluation method, introduction of 20 mm foam in studs leads to about 9 dB improvement of the weighted sound reduction index.

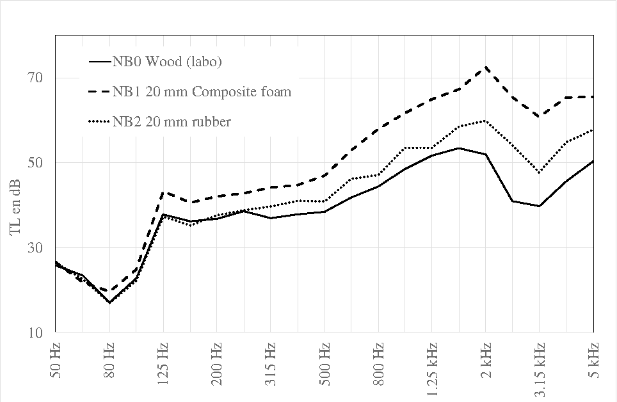

Figure 10. Indirect calculation (R_{calc2}) and laboratory measurement (NB0) of sound transmission loss for non-bearing walls.

Table I. Weighted sound reduction index (Rw) and improvement compared to plain wood for non-bearing walls

Configuration Layer	NB0 wood	NB2 Rubber	NB1 foam
R_w (dB)	43	47	52
ΔR_w (dB)	-	4	9

4.4 Sound transmission for bearing walls

Calculations with the same methodology were also made for various configuration of bearing walls.

First of all, we can notice that the laboratory measurement show a deep dip in 80 Hz range which is higher than the theoretical mass-spring-mass resonance frequency (40 Hz for 200 mm bearing wall). This can be explained by the fact, pointed out by Bradley [12], that a rigid connection between the wall leaves moves the mass-air-mass resonance to the frequency of the structural resonance.

As shown in Figure 11 and table II, interposition of a single layer of rubber could increase the sound reduction index from 5 dB for 20 or 40 mm thick layers (B1, B2) to 7 dB for 60 mm layer (B3). The thickness of the layer is not very relevant.

Better results are obtained with the sandwich stud comprising two layer of 20mm foam (B4). As already seen (cf. §3.2) this composition has a greater effect also in mid frequency. According to indirect evaluation, the sound reduction index of bearing wall should be increased by about 10 dB using sandwich studs instead of plain wood stud.

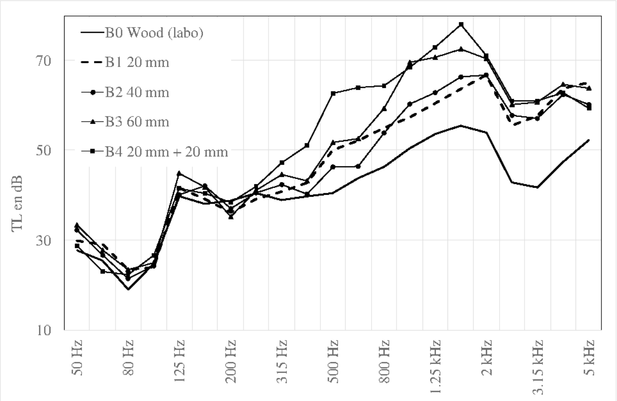

Figure 11. Indirect calculation (R_{calc2}) of sound transmission loss for various bearing walls.

Table II. Weighted sound reduction index (Rw) for various bearing walls without and with composite foam layer of various thickness

Config. Layer	B0 Wood	B1 20mm	B2 40mm	B3 60mm	B4 20+20
R_w (dB)	45	50	50	52	55
ΔR_w (dB)	-	5	5	7	10

5. Discussion

Decoupling properties of the studs can be improved by furthermore optimization of layer types and number, for example asymmetric sandwich bearing stud comprising 20 mm + 40 mm thick composite foam layers. Configuration with one or two layers with lower dynamic stiffness (for example composite foam with lower density) should be tested.

To validate the direct and indirect evaluation methods, laboratory tests of various bearing and non-bearing walls are currently in progress. In laboratory as in situ, measurements include vibrational flanking transmission due to (semi) rigid contact all around the wall. This rigid contact between parts of the isolated stud can reduce the performance regarding to our experimental setup (suspended sample without any contact) [8].

Better evaluation of some parameters, such as radiation factor [10] and damping factor of the panels [7] could improve the direct method. Better knowledge of the physical properties (such as dynamic stiffness) of the material used as resilient layer should be established to perform better calculation model using Statistical Energy Analysis (SEA) [9] or Finite Element Modeling (FEM) [11]. Utilization of recycled materials often results to higher variability of their physical properties.

Low frequency range should be investigated more in detail considering airborne path and mass-spring-mass resonance frequency. This could be done with a wave approach with translational line springs at stud position [11].

Finally, sound insulation performances will be measured in situ to evaluate flanking transmissions due to assembly problems or bad workmanship.

6. Conclusions

To decrease costs and assembly time, a multilayer stud was developed, including different types and thickness of resilient layers. Decoupling properties of various sound insulating studs was performed by vibration measurements on small size samples.

20 mm composite foam was clearly the most efficient layer material with an improvement, compared plain wood, of 5 dB (low frequency) to 20 dB (high frequency) for 100 mm non-bearing walls studs. For 200 mm bearing walls, “sandwich” stud with two layer of 20 mm gives the best results, especially in mid and high frequency ranges.

Assuming the dominance of vibrational path, the sound transmission loss can be derived directly or indirectly from the measured average vibration level difference. According to both evaluation methods, introduction of one or two (for bearing studs) 20 mm foam resilient layers leads up to 9 dB improvement of the weighted sound reduction index compared to standard plain wood studs.

Acknowledgement

This project has been partially funded by Samvaz SA.

References

[1] COST Action FP0702: Net-Acoustics for Timber based Lightweight Buildings and Elements.

[2] H. Muellner, I. Plotizin: The influence of the screw position on the airborne sound insulation of plasterboard walls. Proc. Forum Acusticum 08, Sevillia 2008.

[3] M. Walk, F. Emrich, L. Leuthardt : Entwincklung von Simulationsmethoden für haustechnische Benutzergeräusche, DAGA 2003, Aachen, p.168-169.

[4] V. Desarnaulds, H. Lissek, D. Bard and R. Beffa, Swiss pendulous hammer for decoupling measurement of service equipment in wooden multi-storey building, Proc. Euronoise 2012, Prague.

[5] J. L. Davy The improvement of a simple theoretical model for the prediction of the sound insulation of double leaf walls. J. Acoust. Soc.Am. 127 (2010), 841–849.

[6] J. L. Davy. Sound transmission of cavity walls due to structure borne transmission via point and line connections. J. Acoust. Soc.Am. 132 (2012), 814–821.

[7] EN 12354-1 (2000): Estimation of acoustic performance of buildings from the performance of elements — Part 1: Airborne sound insulation between rooms

[8] C. Guigou-Carter, M. Villot. Modelling of Sound Transmission Through Lightweight Elements with Stiffeners. Building Acoustics Vol 10 Nr 3 (2003) Pages 193 – 209.

[9] R.J.M. Craik (1996) Sound transmission through buildings using statistical energy analysis, Gower Publishing Ltd., 1996.

[10] J. Nurzyński . Radiation factor for frame plasterboard walls airborne and structural excitation, Porc. Forum Acusticum 2014, Krakow.

[11] C. Guigou-Carter et al. Characterization of metallic studs used in gypsum board single frame walls. Proc. Acoustics 2012, Apr 2012, Nantes, France.

[12] J. S Bradley, J. A Birta,. “A simple model of the sound insulation of gypsum board on resilient supports,” Noise Control Eng. J. 49, 216–223. (2001).