IMPROVED SOUND INSULATION IN MODULE BASED TIMBER FRAMED BUILDINGS

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ABSTRACT

This paper describes an ongoing research project at Luleå University of Technology. The project deals with lightweight building systems based upon industrial prefabricated building volumes. The size of each module can be approximately 8x4 m^2. Although the technique has the same typical drawbacks as other similar lightweight building constructions, i.e. poor sound and vibration performance at low frequencies, the concept invites to some unique solutions which could benefit the sound properties. The overall objective of the project is to find new/modified economical constructions which enable module based wooden buildings to fulfill stated building codes with reasonable margin. Various constructions, and thereby various sound properties, should be offered according to the customers demand. The project contains a number of sub studies which are presented.

1. INTRODUCTION

In the timber building trade of today, a clear trend towards industrial manufacturing - prefabrication - is observed. Not only does the proportion compared to on-site manufacturing increase but so does the degree of prefabrication. The great advantage is that a major part of the prospective building is manufactured indoors at a factory with optimized production technique. This in turn leads to benefits in terms of minimized risk of moisture problem during building, better working environment for the workmen, excellent accuracy to size and shorten production time at the building yard. Prefabrication brings also potential to a better production economy leading to less expensive tenements.

For a volume system, the idea is to construct and manufacture modules which contain floors, walls and ceiling together with electrical, heating, water, sanitation and ventilation installations. The system is often used for tenements where each volume typically constitutes a small apartment, one room or a part of a larger living room.

Although different levels of completeness can be chosen it is common that as much of the work as ever possible is performed at the factory. The modules then arrive to the building yard with completed surface layer as well as kitchen- and bathroom fixtures.

To form an entire building, the modules are stacked upon each other, usually with a strip of vibration insulation (often made of polyurethane) in between, see Figure 1. This vibration insulation is an important factor in order to obtain good vibro-acoustic properties. With a proper design the insulation can greatly reduce sound- and vibration transmission from one floor to another.

A great advantage, indicating condition for good sound insulation is that the separating floor can be constructed as two separated parts. The upper module contains the upper part of the floor and the lower module contains the ceiling. An example of such a floor-ceiling construction is presented in Figure 2.

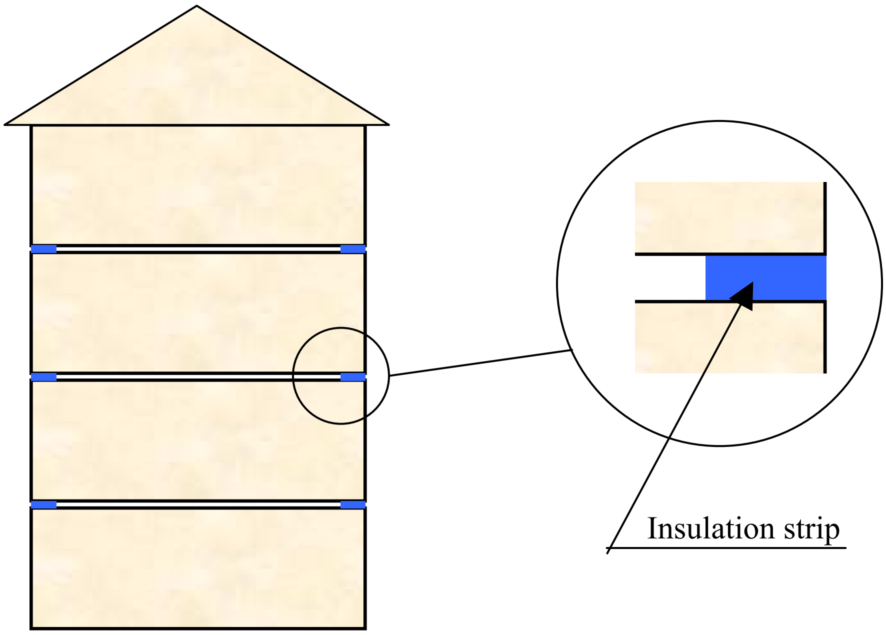

Figure 1. *Volume based building system with intermediate vibration insulation.*

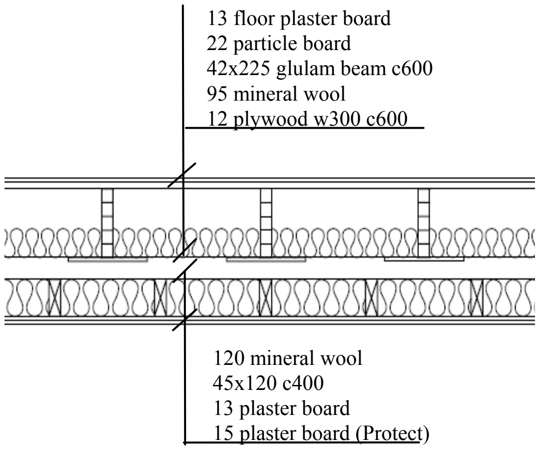

Figure 2. *Separated floor (upper) and ceiling (lower) sections.*

Although the technique has existed for some years and has been developed continuously ever since, but still it is not as well-tried and trusted as other more traditional ways of building. The technique share several classical drawbacks with other forms of lightweight building e.g. the poor sound and vibration properties at low frequencies.

Luleå University of Technology is running a research and development project which aims to improve the sound properties for volume based systems where the impact noise, which often is the most significant problem for the actual kind of building technique, is in focus. The objectives should be achieved by a series of sound measurements on different constructions, both in laboratory as in fields, all combined with appropriate calculations and acquiring of existing knowledge. A selection from a number of sub studies within the project is presented below where all measurements were performed in accordance to appropriate ISO-standards 140-4, 140-6, 140-7, 717-1 and 717-2.

2. IMPACT SOUND MEASUREMENTS

The impact sound pressure level was measured for a temporary set-up that consisted of two volumes, one upon the other, construction according to Figure 2. This introductory study aimed to figure out how a specific construction responds to certain modifications;

a) Parquet was used as floor covering with a thin layer of gray rag board underneath, which is the manufacture's standard. As an alternative, underlayer foam replaced the grey rag board.

b) As standard, the volumes are equipped with two metal centering studs, diagonally positioned, in between every two separating floor plan. A test was performed with the centering studs omitted to see whether these contributed to sound and vibration transmission in any significant way.

c) An extra layer of floor plaster board was added to the construction.

d) The upper volume was raised by two trucks in an attempt to avoid preloading of the insulation strip.

The results are summarized in Table 1 where it can be seen that using gray rag board or underlayer foam underneath the parquet does not affect the impact sound level. The same is true for the centering studs whereas the addition of an extra layer of floor plaster board improved the impact sound insulation with 3-4 dB, Figure 3. To raise the upper volume serves as a rough estimation of the flanking transmission's contribution. The impact sound was here reduced by 2-3 dB indicating important flanking transmission. A more thorough description of the tests and the results are given in [1].

Table 1. *Test results, impact sound pressure level.*

Setup	Description	$L'_{n,w} + C_{I,50\text{-}2500}$
Ref	Reference. The manufacture's standard	54
A	Underlayer foam in stead of grey rag board	54
B	An extra layer of floor gypsum board (Two in total) and underlayer foam	50
C	An extra layer of floor gypsum board (Two in total) with grey rag board	50
D	As reference, repetition	53
E	Centering studs removed	53
G	As ref. but upper module raised to avoid preloading of the insulation strip	51

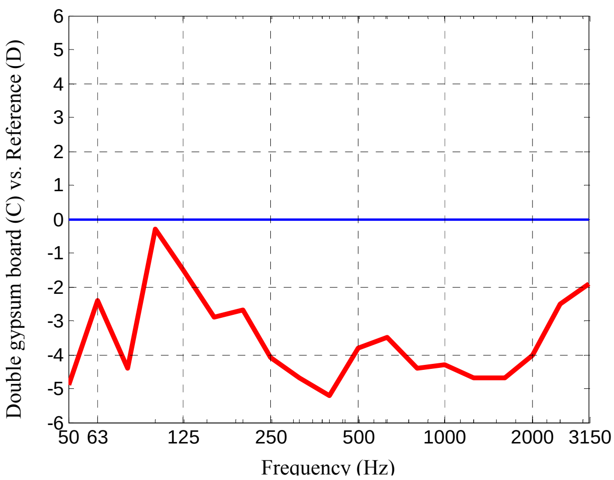

Figure 3. The effect of using double layer floor plaster board in stead of single (dB).

3. STATISTIC EVALUATION

The impact sound pressure level was measured for a number of four-storey tenement houses within the same building project. In total 24 measurements were performed in apartments with nominally identical construction. The averaged sound pressure for all the measurements was $L'_{n,w}$=53 dB and $L'_{n,w}+C_{I,50\text{-}2500}$=55 dB. In Figure 4 the variety of the measurements in 1/3 octave bands is presented. The deviation from average is about +/-5 dB for frequencies ≤500 Hz and about +/-10dB above 500 Hz.

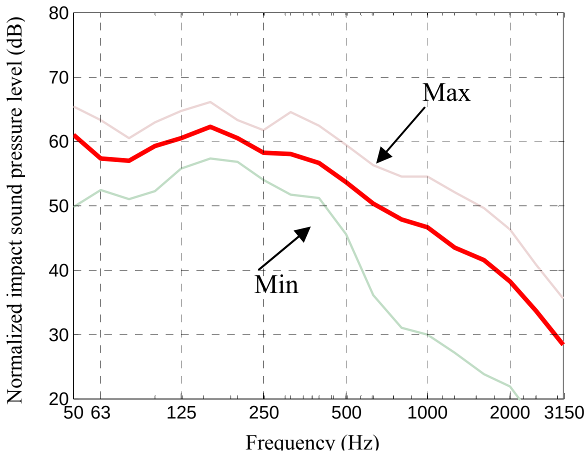

Figure 4. *The variety of normalized impact sound pressure level for 24 apartments.*

The results were analyzed statistically with ANOVA (Analysis of Variance) and multiple regression analysis. Three main parameters were tested: 1) Room size (m^3), floor plan and type of floor covering (parquet or ceramic tiles). The analysis shows whether any of the tested parameters are of significant importance with respect to impact sound insulation. It was found that neither the size of the room nor the floor covering affected the sound pressure level (95% confidence, LSD). However, the floor plan was of significant importance. The sound pressure level was 2 dB lower at floor plan 3 compared to plan 1 and 2 (no relative difference between plan 1 and 2). According to Figure 5, the difference between floor plan 3 and the remaining plans is evident from 100 Hz while almost no difference is noticed for the lowest frequencies, 50-80 Hz.

The reason for better impact sound insulation higher up in the building is probably to be found in the insulation strip. As the load to the insulation strip is higher in the lower part of the building the insulation must be made stiffer which in turn makes it harder to prevent vibration energy transmission.

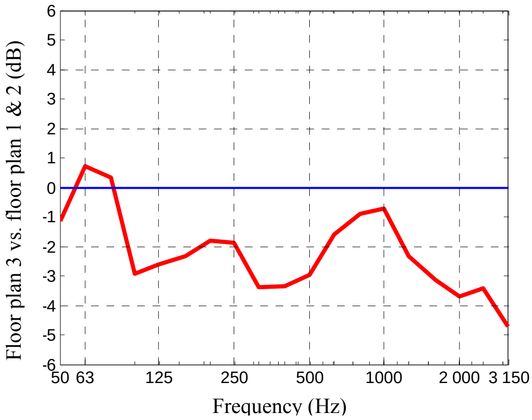

Figure 5. *Difference in impact sound pressure level between floor plan 3 vs. plan 1 and 2.*

4. INSULATION STRIP

With the same condition given in "2 Impact sound measurements" above, a test was performed where the insulation strip were completely omitted meaning that the upper and lower volume had direct contact with each other, wood against wood. Surprisingly, the measurement indicated 1 dB lower impact sound pressure level in the absence of insulation strip!

In order to follow up this subject, a similar field test was performed; a) with standardized insulation strip and b) without any vibration insulation at all (just a soft rubber moulding to prevent air leakage). The field test showed improvement in impact sound insulation $L'_{n,w}+C_{I,50-2500}$ by 3 dB and in sound reduction $R'_{w}+C_{50-3150}$ by 6 dB when the insulation strip was used indicating that the insulation strip indeed affect the building's sound and vibration properties. Obtained impact sound pressure level in Figure 6.

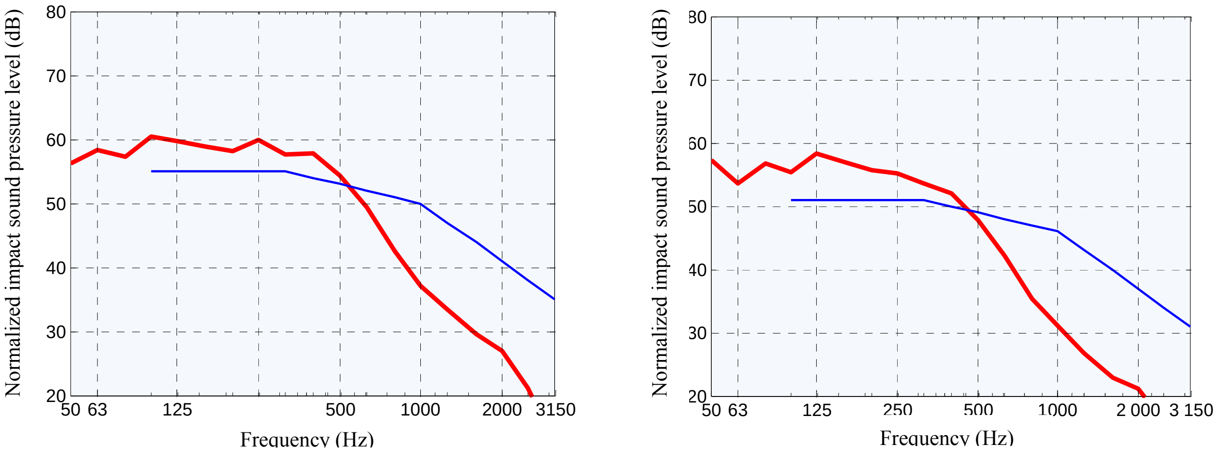

Figure 6. *Normalized impact sound pressure level with (right) and without (left) insulation strip.*

5. FIELD MEASUREMENTS

Sound measurements were performed inside a two-storey office building. The construction, which differs from the previous one mentioned previously, is presented in Figure 7. This floor is, comparatively, not that well designed to obtain good sound properties. The number of gypsum board layers is less, both for the upper floor and for the ceiling, effective vibration insulation is absent and the floor cavity is partitioned by boards.

A series of construction modification took place in order to see to what extent the sound properties were affected. Several volumes where modified in the manufacture stage; Boards in floor- and ceiling section were removed or altered and additional layers of gypsum board were added in various ways. Test setup and results are presented in Table 2.

A closer look at the sound measurements reveals that the sound insulation is especially poor from 200 to 800 Hz in comparison with the (ISO) reference curve. Besides, the standard cases (A,B) shows substantial transmission of impact sound at 50 Hz.

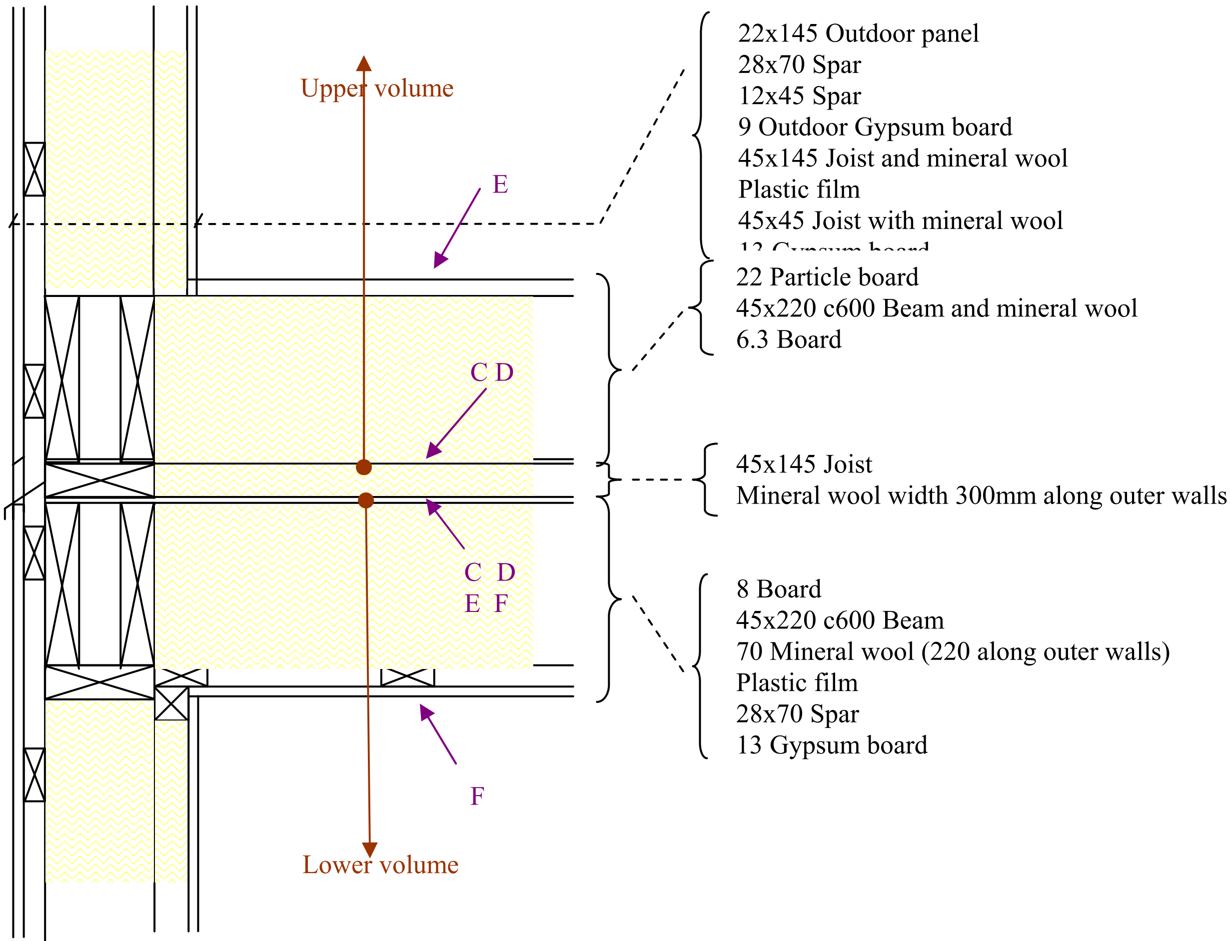

Figure 7. *Construction. Letters C-F refers to test cases described in Table 2.*

Table 2. *Test setup and results.*

Test	**Description**	$L'_{n,w}+C_{I,50\text{-}2500}$	$R'_w+C_{50\text{-}3150}$
A	Standard	59	54
B	Standard	61	55
C	Board stripes of 300mm in stead of fully covered board, upper volume Board in lower volume omitted	58	53
D	Board in upper volume replaced by wind protecting film Board in lower volume omitted	55	57
E	Additional floor gypsum board, upper volume Board in lower volume omitted	61	54
F	Additional ceiling gypsum board, lower volume Board in lower volume omitted	54	59

The obtained results are sometimes in accordance with what should be expected while for some cases the results surprise, which is perplexing. When both floor- and ceiling board are omitted (D) the impact sound improves by 5 dB and the airborne sound insulation by 2 dB related to standard. This should be expected since a dividing board normally worsens the sound properties. In accordance, the similar case (C) in which the upper volume's board is replaced with stripes should have shown improvement – but that was not the case here. However, a fully covered board in the center of the floor construction should not be recommended.

No improvement as a result of adding gypsum board to the floor could be seen, surprisingly. On the other hand, the improvement of adding extra gypsum board to the ceiling was more than expected, 6 and 4 dB for impact- and airborne sound insulation respectively.

In fact, it is very hard to draw significant conclusions from an experimental measurement series like this since the variation among nominally identical rooms and building volumes seems to be of major importance.

6. LABORATORY MEASUREMENTS

The floor construction described in Figure 2 was investigated in a series of impact sound pressure level in laboratory environment. Again the focus was to find out how minor construction changes could affect the sound properties. Three nominal identical floor sections in combination with two nominally identical ceiling sections formed the complete floor. Gypsum boards from different manufactures, different mounting techniques of floor gypsum boards, density of mineral wool, free distance between floor and ceiling and floating floor were tested. Test setup and results are presented in Table 3.

Table 3. *Test setup and results.*

Test	**Description (deviation from standard)**	**Relative $L_{n,w}+C_{I,50-2500}$**
A	Increased free distance between floor and ceiling (75mm in stead of 60)	-1
B	Alternative manufacturer of floor gypsum board, only screwed floor gypsum board	-1
C	Only screwed floor gypsum board	-1
D	Standard (glued and screwed floor gypsum board, stripes of plywood underneath beams)	0
E	Fully covering plywood underneath beams	+3
F	Perforated plywood (20%, ∅190)	+1
G	Perforated plywood (40%, ∅190)	0
H	Harder gypsum board in ceiling	+1
J	Mineral wool of higher density	+1
K	Standard, repetition	0
L	Double layer of floor gypsum board	-1
M	Elastic glue for mounting of floor gypsum boards, no screws used	-2
N	Floating floor	-4

6.1. Floor gypsum board

No effect could be seen when the floor gypsum board used as standard was replaced with one from another manufacturer (B,C). When the glue was omitted (B,C), the impact sound pressure level decreased 1 dB, the improvement was found in the region above 300 Hz. Elastic glue was quite effective to reduce energy transmission and thereby the impact sound insulation increased 2 dB (M). When measured, the glue was allowed to harden sufficiently long time although nothing could be said about any long-time effects. An additional layer of gypsum boards (M) decreased the impact sound level 1 dB which is far less compared to previous test (2 "Impact sound measurements"). Any obvious explanation has not been found.

6.2. Mineral wool

When the standard light mineral wool was replaced with a heavier stone wool (450 kg/m^3) (J), the impact sound pressure level increased 1 dB as a result of worse performance if the region 200-250 Hz.

6.3. Ceiling gypsum board

Harder and denser ceiling gypsum boards (12 kg/m^2 vs. 9 kg/m^2) did not improve the sound properties, in fact the impact sound insulation dropped 1dB (H).

6.4. Plywood

Plywood was tested in three configurations; fully covered (E), 20% opening area (F) and 40% opening area (G), the latter corresponds to the same opening area as in the standard case (D). The impact sound level successively improved as the opening increased. Fully covered plates resulted in 4 dB increased level and for the case of 20% area: 1 dB. The reason is likely to be found in the floor's resonance. In the standard case the resonance frequency is about 30 Hz but as the cavity is restricted the resonance frequency(-ies) goes up to about 50-60 Hz. The difference in sound characteristic was indeed found in the low frequency area, below 100Hz.

6.5. Increased distance between floor and ceiling

To increase the free distance between ceiling- and floor section from 60 to 75mm (A) did not affected the sound level, $L_{n,w}$.

6.6. Floating floor

A layer of 18mm stone wool was placed upon the main beams, underneath the particle board. The floating floor (N) resulted in significantly reduced impact sound level, 4 dB. Despite the improvements, a number of drawbacks come with the modification; increased building cost and risk to obtain permanent deformations due to e.g. heavy furniture which in turn might leads to reduce affect over a long-time period.

7. CONCLUSIONS

It has been shown so far in the project that module based lightweight building technique has potential to obtain good sound insulation. The system makes it natural to mechanically separate an upper volume's floor from a lower volume's ceiling (apart from the boundaries). With careful design of specific details, including vibration insulation, it is possible to construct lightweight buildings with satisfactory sound insulation.

8. REFERENCES

[1] Ljunggren, F., and Ågren, A. "How to improve impact sound insulation in a lightweight module based system," 19th *International Congress on Acoustics, Madrid 2-7 September 2007*.