BNAM 2018
Baltic-Nordic Acoustics Meeting
15-18 April 2018
Harpa, Reykjavík, Iceland

# Practical considerations for good low frequency sound insulation in refurbished houses

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In recent years, studies have shown that there is a much better correlation between impact sound levels and perceived disturbance in lightweight apartment buildings when you include frequencies down to at least 50 Hz, preferably even down to 20–25 Hz. Good airborne and impact sound insulation, at frequencies down to 50 Hz, can be achieved in refurbishment of lightweight buildings through careful acoustic design. Impact sound insulation below 50 Hz is a much harder task and require special considerations. This article describes results and considerations based on experiences from acoustic refurbishment design. Key design elements include a sufficiently heavy and stiff floor plate to withhold the input of impact energy from footsteps, and a vibration isolation system that is stiff enough to fulfil a sufficiently low floor deflection from walking (dynamic) and furniture (static) load, and still soft enough to achieve a resonance frequency that, including the air spring, is well below 50 Hz. A central consideration in the design process in many cases is to keep the floor height low, especially in attics, since with a slanted ceiling a higher floor will decrease the floor area and hence reduce the selling price. Finally, it is important that the proposed design is reasonably easy to build, handles building cost effectively and takes care of building physics like fire protection, acceptable mass load, and humidity problems. Otherwise it is likely that other disciplines will alter the design in unwanted ways. Further, several examples of good sound insulation at low frequencies are explained.

## 1 Introduction

### 1.1 Scope

It is possible to reach good sound insulation down to 50 Hz in old houses with rather lightweight wooden joists, with only a small increase in construction height, and a good stability of the floor. The scope of this article is to show practical considerations and experiences in several cases of refurbishment of old houses, where very good results are reached, in order to show that demands of impact- and airborne sound insulations should go down to at least 50 Hz.
The examples and principles shown have a special focus on houses with wooden framework and heavy loadbearing walls, but the considerations are also applicable for old houses with steel frame–work and thin concrete slabs. In Sweden, these kinds of houses were primarily built between 1880–

1940. The flanking transmission from the joists through the walls can normally be considered as unimportant, except for complementary loadbearing in wooden inner walls within apartments. These limitations put the focus on the separation of the lower and upper side of the separating partition.

## 1.2 A historical background

The acoustical properties of higher class multi-family houses, often in the city centres, with heavy load bearing brick walls, 3 cm thick plaster in the ceiling and parquet floors are normally quite similar. It does not differ much between sound insulation with 7–10 cm thin concrete slabs with a wooden upper side or wooden joists with approximately 10–15 cm wide wooden beams, semi heavy filling between the beams and an approximately 30 mm wooden upper side, covered with parquet. It is approximately 50 dB of airborne sound insulation and an impact sound insulation of $L'_{n,w}$ = 63–68 dB. The sound insulation is normally quite poor in the frequency range of 125–200 Hz, primarily due to resonances in the wooden subfloor. The difference in the measured sound insulation values between different separating partitions mainly come from difference in the weight of the construction, but there is a difference in the perceived very low frequency sound insulation that mainly seems to come from difference in stiffness – very low frequency impact sounds due to long spans, or effective energy input of footfall due to weak floors.

In these houses there is an opportunity to make new dwellings in the attic or in the basement, or sometimes to remake the whole building if it hasn't been maintained properly. In the city centres the prices for the apartments are high, and the demands are high, and for those who have had an empty attic as the neighbour above it is certainly a strong demand for a good sound insulation – hence, it is important for a successful project to do what is possible to get good sound insulation, and it is almost always possible.

## 1.3 Government regulations

The Swedish government regulations for refurbishing buildings or changed use of the space within buildings (e.g., an earlier attic storage, shop or office is changed into a dwelling), is to strive to fulfil the requirements for new dwellings, or if that is not within reach, at least not reduce the sound insulation compared to before the change, unless it still is better than the requirements for new buildings. Is this enough – no, it is just the lowest permitted level. And a big problem is that this really not sets any lowest permitted level of sound insulation for new dwellings in old houses – if it was a disaster before, like $D_{nT,w}$ = 35 dB, a builder can change that to $D_{nT,w}$ = 40 dB and simply say that he has strived to fulfil the regulation for new buildings but didn't come any closer, and it is not worse than before … Below sound class D the space ought to not be used for dwellings.

Some building acousticians accept sound insulations below regulations for new houses, but as is shown in this paper, it is only on rare occasions that you can't fulfil the regulations, or even sound class B, with just reasonable strikes on costs, construction height, etc. Landlords can be convinced to take the cost by saying that the maintenance cost will be lower as the tenants will feel more pleased and hence will not move as often.

## 1.4 Prerequisites

The first step of acoustical design at changes in old houses should always be to analyze the prerequisites, for example:

1. Are there any building preservation limitations? How strict – e.g., can a special flooring be disassembled and then reassembled?

2. Are there any necessary changes in the piping or other technical installations, that set the necessary spaces?
3. Are there any construction limitations, like if the present filling in the joists is to be removed, any necessary reinforcements, or is the building leaning?
4. Is construction height very important or is building cost the main objective?
5. Are both the lower and upper side of the joists available for measures, or is just one side possible?
6. Is the aim very high-class sound insulation, good but cost effective, or just cheapest possible within current regulations?
7. The sound insulation of the current construction – doing measurements, analyzing the different frequency regions, and then relating the measurement results to current regulations or special demands.

All the prerequisites above need to be gone through before starting to design the measures to increase the sound insulation. In many cases quite a few possibilities are ruled out based on non-acoustic reasons, so you should always have the underlying physics in mind. This paper will show the physical principles to achieve good impact sound insulation at low frequencies and give a few examples from actual buildings.

# 2 Principles

## 2.1 General

Achieving good sound insulation for frequencies below 100 Hz in lightweight partitions is usually more challenging for impact sound than for airborne sound. Therefore, dimensioning for a good impact sound insulation will often also result in a good enough airborne sound insulation, and hence this article focusses on measures for good impact sound insulation.

We will show means for improvement on the upper side, on the lower side, and the inside of the partition. The choice of measures depends on factors that differ for each case. Actions on the lower side of the partition are usually simpler to perform – no need to break up the floor covering and no change in floor levels. But, flanking transmission via lightweight load-bearing walls is not handled. Actions on the upper side is a good way reduce the input of impact energy from footsteps to the floor, by choosing a top layer that mismatches the impedance to the human foot, i.e. by being relatively heavy and stiff. Actions on the upper side of the partition are of course preferred in attic developments.

## 2.2 Sound insulating measures, floating floors

The design goals for floating floors are to design the acoustical measures so the various demands on sound insulation are fulfilled as well as criteria for dynamic and static deflection. The resonance frequency of the unloaded floating floor should be well below 50 Hz. At the same time, according to the Eurocodes, a floor should not feel unpleasant to walk on and there is an approximate limit of 1,5 mm movement, including both the movement of the floating floor and the joists, and in our experience a maximum of 1 mm deflection of the resilient layer, from 100 kg point load, should not be exceeded. We need a high effective mass on the floor and a soft effective spring, including both the resilient material and the air spring under the subfloor.

Close to walls where it is reasonably relevant to put a bookshelf it is necessary to account for a locally heavier load, especially to prevent the resilient layers from creeping due to overload, otherwise the subfloor will be damaged.

You need to take into account the local deflection of the floating floor, and with 22 mm flooring chipboard and two layers of flooring plasterboard glued to it, the point load of a person walking on the floor should be spread over approximately 0.5–1 m², which will give you input for the lower limit of spring stiffness of the resilient material – please note that the deflection of elastomers is not linear to the load, so use well documented elastomers. At the same time, the spring stiffness must be sufficiently soft to achieve a resonance frequency well below 50 Hz, including the air spring under the chipboard, in the unloaded case.
In the case of a stiff and heavy upper layer, like with a floating floor consisting of 30 mm reinforced screed cast on a supporting 22 mm flooring chipboard, the point load of a walking person is distributed over a much larger area and the relative change in load on the springs is much lower, allowing for a softer resilient material to be used and thus an even lower resonance frequency can be achieved.
Whenever boards are used instead of screed, the stiffness should be increased by gluing the sheets together in addition to screwing so that they constructively act more as one layer. With an increase in the mass and stiffness of the floating construction, you also gain in impedance mismatch between foot and floor, and hence reducing the input of impact energy to the structure [1]. The lowered critical frequency due to the increased stiffness is normally of much less importance than the advantages in this case.
When changing the upper side of the partition, the construction height is often a high priority, of several reasons: there may be existing door openings, stairwells, and other heights to relate to, and in attics with sloped ceilings the floor level is directly related to the accountable floor area which largely determines the selling price. To lower the construction height, perforate or remove, in part or fully, the earlier floorboards on the upper side of the joists, to gain access to the air gap between the beams. A way to gain even more height is to put the resilient pads on supports between the wooden beams.
Another way to make a good floating floor is to put soft, acoustic mats on top of the existing floorboards and cast screed upon the mats. In this case, as in the other cases above, it is of absolute importance to keep from getting structure-bridges between the floating floor and the rest of the building.

## 2.3 Sound insulating measures, suspended ceilings

The acoustic design of a suspended ceiling has fewer parameters to consider than measures done on the upper side, since there is no moving mass load to handle, but in cases with load bearing wooden wall structures you will get flanking transmission, unless you cover these walls with plasterboards on free standing studs. If the subfloor is weak you will get very high low frequency impact noise, below 50 Hz, which will lead to disturbances.
Normally, spring elements, like acoustic hangers or acoustic profiles (sheet metal profiles designed to offer vibration isolation) should be used – acoustic profiles for small airgaps, and spring hangers for high demands with larger airgaps and hence lower resonance frequencies.
Heavy crystal chandeliers are normally the only point load to consider in dwellings, but in other types of rooms it is not unusual with semi-heavy or heavy loads to consider – use special reinforced hangers or fasten the load to the beams. Sprinkler installations must be considered separately as each fastening shall be designed to withstand 500 kg load.

## 2.4 Sound insulating measures, within the construction

The need for good impact sound insulation at high frequencies in bathrooms, and similar wet rooms, is limited – the few steps you take are seldom taken with shoes with hard heels. Instead it is more important to handle low frequency structure-borne sound from washing machines and to keep water out of the construction. For wooden joists the risk of low frequency noise from a household

washing machine is large. One solution is to fill the space between the wooden beams with cement stabilized grains of Leca and a top of 20 mm layer of screed. Below the washing machine a thick concrete mass is cast.
If the load bearings can handle it, complementing the structure with weight, like sand, gravel or cast concrete between joists, either all the way between the joists or just close to each joist, is a good way to increase the sound insulation. If reinforced concrete is used, the weight increase can be done without increasing the stress on the joists. It is important that the mass connects to the joist system, so that the joists moves as one mass as high in frequency as possible. In the case of sand or gravel, push it close to the beams, and in addition to the increase in mass there is an increase in structural damping.

# 3 Examples

In the following examples we show three cases with different solutions, but all with good results down to 50 Hz or lower. These cases show the practical implementation of several good ways to get good results at low frequencies at the refurbishment of old buildings, and hence good reasons to not exclude old buildings from demands down to 50 Hz.
The cases are illustrated with exploded views, results before and after refurbishment or rebuildings, and a brief description of the solution used. The impact sound insulation is shown down to 20 Hz to show the results relative to the findings of very low frequency impact sound according to the AkuLite project [2].

## 3.1 High class dwellings, built approx. 1900 – turning attic into new dwellings

A housing cooperative (the residents own the right to their apartment and own the building together) sold the attic to be built with new apartments, and the residents below the attic were part of the board for the cooperative, and hence very eager not to risk any sound disturbances from the attic apartments. The demand on impact noise was hence chosen to fulfil sound class A, $D_{nT,w,50}$ = 60 dB and $L_{nT,w,50}$ = 48 dB. Before rebuilding the attic, the sound insulation was $D_{nT,w,50}$ = 56 dB, $L_{nT,w,50}$ = 60 dB and $L_{nT,w,20}$ = 63 dB. After rebuilding: $D_{nT,w,50}$ = 69 dB, $L_{nT,w,50}$ = 43 dB and $L_{nT,w,20}$ = 50 dB.
The existing joists was too weak to fulfil the deflection regulations if any modifications were made. The solution was to build separate joists for the new apartments, in between the old joists. A test specimen was made on site, which allowed us to make an impact sound measurement in an early stage. Because the results were not good enough to match the high demands some modifications were made – we used damping glue between the layers of the subfloor and made the fastening of the beams to the supporting structures with elastic interlayers. An advanced solution with a very good result.


*Figure 1. Exploded view of the rebuilt joists separating the attic from the apartment below. To the right is the impact sound insulation, before (dashed) and after (solid) the refurbishment. The dotted line is the reference curve after the change. The vertical solid line marks the 50 Hz limit of evaluation, the vertical dashed line marks the 100 Hz limit of evaluation.*

## 3.2 Refurbishment of a single-family house built approx. 1940 into new apartments

An old single-family house from approximately 1940 is totally refurbished and turned into a two-family house, with new layout in both apartments. The aim was to fulfil the regulations for new built houses, $D_{nT,w,50}$ = 52 dB and $L_{nT,w,50}$ = 56 dB. Before rebuilding the house, the sound insulation was $D_{nT,w,50}$ = 44 dB and $L_{nT,w,50}$ = 73 dB, $L_{nT,w,20}$ = 77 dB. After rebuilding: $D_{nT,w,50}$ = 60 dB, $L_{nT,w,50}$ = 55 dB and $L_{nT,w,20}$ = 65 dB.

The original construction was wooden joists with wood shavings filling, a flooring of approx. 30 mm wood panel and parquet floor, and below wood panel and wood fibre board panels. Load bearing wood walls in inner walls and façade.

The solution was to put a new ceiling on 95 mm wood studs and mineral wool filling, 25 mm acoustic profile and 2 layers of 13 mm plasterboard, and to put coverings on the load bearing inner walls and façade walls with 70 mm free standing studs with mineral wool filling, and 2 layers of 13 mm plasterboard. Simple solutions with good results down to 50 Hz.

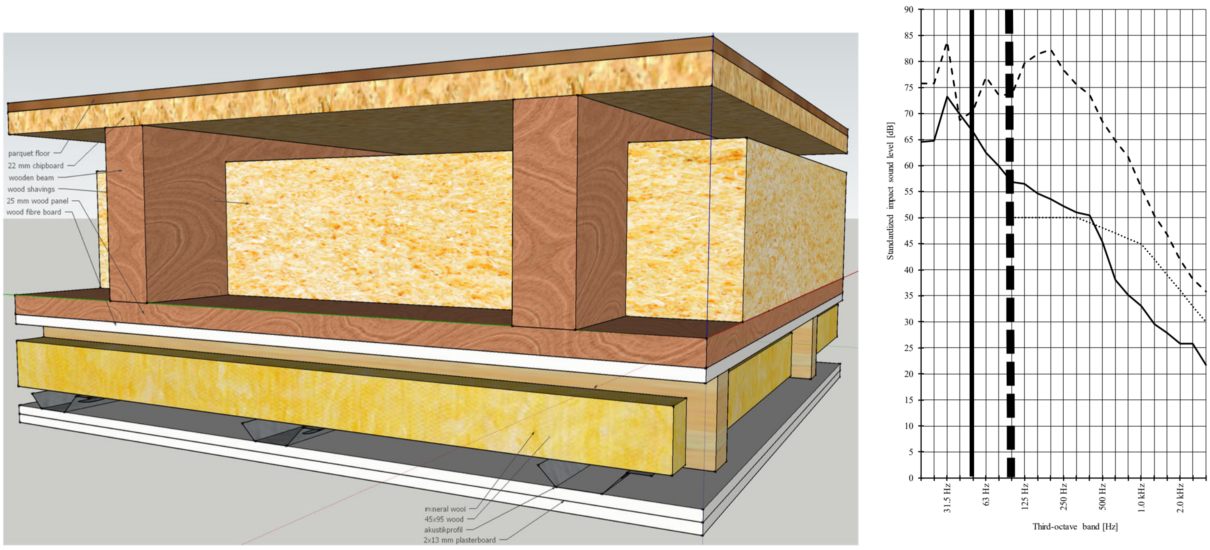


*Figure 2. Exploded view of the joists separating the apartments. To the right is the impact sound insulation, before (dashed) and after (solid) the refurbishment. The dotted line is the reference curve after the change. The vertical solid line marks the 50 Hz limit of evaluation, the vertical dashed line marks the 100 Hz limit of evaluation.*

### 3.3 Night club in old building

An old house built 1854, for a long time used as a restaurant and night club with a lot of disturbances to neighbouring hotel and offices, is totally refurbished and turned into a show stage and night club with the aim to not disturb the offices above or the neighbours. When we entered the project, the construction was already on its way, with structural reinforcements to the joists and an upper chipboard that was essential to the construction. The building height needed to be as low as possible, both on the upper and lower side of the construction.
The boards on the upper and lower side were perforated to access the air gap in between, soft springs were put above and below, and as heavy weight as accepted from a construction point of view. After rebuilding: $D_{nT,w,50}$ = 67 dB, $L_{nT,w,50}$ = 37 dB and $L_{nT,w,20}$ = 54 dB. An example of good results with difficult prerequisites, but with quite high cost, that in this case was accepted.


*Figure 3. Exploded view of the separating construction. To the right is the impact sound insulation after the refurbishment. Dotted line is the reference curve. Vertical solid line marks 50 Hz limit of evaluation, the vertical dashed line marks 100 Hz limit of evaluation.*

## 4 Conclusions and discussion

For light weight wooden constructions that fulfil the government regulation values, there is low, or very low, correlation between the weighted impact sound insulation $L_{nT,w}$ and subjective rating. The correlation is much better including the spectral correction term $C_{I,50–2500}$ [3]. This article shows some good practice on how to design separating constructions with good results at low frequencies. Even better correlation is achieved if lower frequencies are included. In the AkuLite project a new spectral correction term, $C_{I,20–2500}$, is presented – the results here are compared to this. In [4] the results are adjusted to a flat frequency dependency down to 25 Hz.

## References

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