Low frequency sound transmission in multifamily wooden houses

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ABSTRACT

In the recently finished research projects, AkuLite and AcuWood, it is clearly stated that low frequencies should be considered far more, prior to design new wooden structural building system. Lower than 50 Hz is preferable, and the most annoying frequencies appear between 20 and 50 Hz. However, it is still a long way to go in order to convince acousticians, the entire global industry and authorities that these frequencies have to be considered in order to build wooden structures which are experienced by the habitants as equally good as heavy structures. To "save" the industry, a lower limit of at least 50 Hz at least for impact sound should be mandatory in the near future globally, in spite of the fact that the new standard ISO 16717 will not be reality. This paper describes the main reasons why it is needed to include these low frequencies in residential buildings. It describes different constructions and their appearance due to low frequency impact sound transmission. The paper comprises some examples designed to fulfill the Swedish requirements, which equals $L'_{n,Tw}$ and $L'_{n,Tw}+C_{I,50\text{-}2500} \leq 56$ dB between dwellings. It comprises also a discussion regarding optimizing constructions for various uses, e.g. different types of housing.

Keywords: Sound, Insulation, requirements I-INCE Classification of Subjects Number(s): 51.4; 51.5

1. INTRODUCTION

Within building acoustics, frequencies below 100 Hz is still not considered to a very large extent globally, even though much more advanced building technique regarding structural components is developed, more and more noise sources are present in our daily life, more time is generally spent indoors. Nevertheless, acousticians are still using the arguments that there is to high uncertainty to include frequencies below 100 Hz in single number ratings, perhaps since they are used to use statistical methods. The uncertainty might be higher in some cases, but it is even higher if these frequencies are completely omitted, since they cause annoyance in many building structures. No one is served, not the habitants for the future houses, neither the industry if the right frequency range for target values is provided when new building technique is developed. Different types of housing units have also various "needs". Student dwellings, normal family dwellings and dwellings for elderly have to be considered different due to their different using and due to different probability to "produce noise". But when new target values are developed it is very rare that future expected living habits and need for various housing types are considered. A residential house is considered as a residential house, no matter who will use it. We need more investigations, or rather use current available demographic research to develop better target values. Nevertheless, evaluation methods in this paper consider "normal" residential units for families. The rest is more a general discussion.

New building technique has to be developed in order to fulfill requirements regarding sustainability and industrialization. And it is needed in order to produce cost efficient dwellings to a large extent for many categories of people in our society. But the standards and the building requirement target values certainly need to include frequencies that cause the actual annoyance. And by slowly introducing new target values, research can run in parallel and continuously provide necessary input in order to refine

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the target values. We should use current knowledge and take it as an opportunity to help and guide the industry to produce nice sustainable residential houses adapted to the experienced sound insulation for the future. They could be produced by using structural material of concrete, steel or wood, and the acoustic society has to make sure that the acoustic requirements cover all these potential structural material. The acoustical requirements and the need for low frequency consideration are in particular evident for impact sound in light structures, e.g. wooden and steel structures. The very low frequencies (below 50 Hz or sometimes below 100 Hz) do not seem to be of high importance when it comes to airborne sound insulation, however for impact sound it is very important (1). The rest of the content in this paper focuses on evaluation of impact sound level.

2. STRUCTURES

Different structures have different “needs”. For many traditional building materials as homogeneous concrete, the frequency range between 100-3150 Hz is by far enough to cover, in order to secure an acceptable sound insulation between dwellings. However, for other materials and for some more slender hollow concrete structures it might be needed to add other frequencies, below 100 Hz or sometimes even below 50 Hz.

2.1 Concrete structures

Concrete structures are not affected at all of low frequency phenomena caused by normal household activities. Of course slender concrete structures might be affected, however limiting to massive concrete structures, they are not affected as long as only normal household activities are considered. What is needed is normally only a simple impact sound layer to secure that the high frequencies are reduced sufficiently.

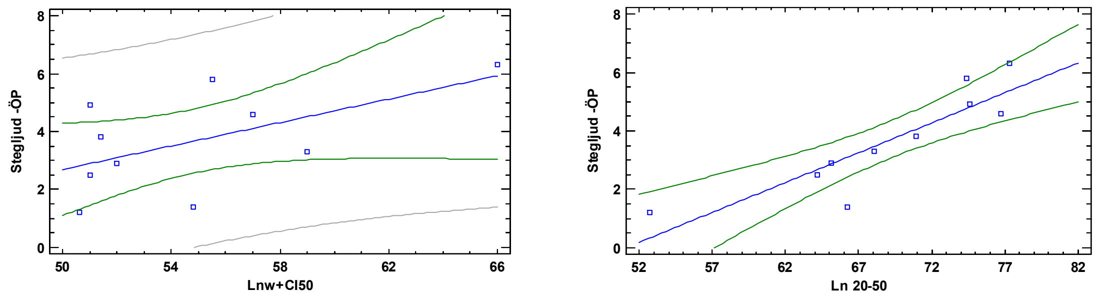
2.2 Other structures (wooden structures)

There exist a number of different structures such as hybrid concrete / steel or wood / concrete and other possible combinations of material and lot of development is ongoing in order to reduce costs and create efficient structural combinations. A lot of money is invested to develop structures fitted to single numbers that are completely out of interest.

Today **wood** has become more and more important as a structural material not least due to that it is environmentally friendly to use as building material, doubtless contributing to a more sustainable society. The wooden industry is a driving force when it comes to industrialization and the industry contributes to a large extent to a more modern building industry. However, the wooden industry needs new acoustic tools, new way to think since a larger frequency range has to be considered or maybe the frequency range only has to be moved some octaves lower? The frequencies causing annoyance for pure wooden constructions are mainly below 100 Hz, or even lower, below 50 Hz. As a result from AkuLite – project a new spectrum adaptation term was introduced (1). This spectrum adaptation term covers the frequency range from 20 Hz and emphasizes the very low frequencies when evaluated and the correlation between annoyance and the single number increases dramatically. The determination coefficient becomes (ten housing blocks included in the study)

$$L'_{n,w} + C_{I,AkuLite,20-2500} \Rightarrow R^2 = 85\ \% \tag{1}$$

However, to give an even better picture regarding the importance of the low frequencies when studying wooden constructions, the determination coefficient is still very high (R^2=78 %) when only considering the lowest frequencies when evaluating a single number, still far better than when using the ISO single number and spectrum adaptation term $L'_{n,w}+ C_{I,50-2500}$. The alteration is illustrated in figure 1 below.



A.) ISO ➔R^2=32 % B.) energy sum 20-50 Hz ➔R^2=78 %

Figure 1 – For the ten housing units included in the national project *AkuLite* the determination coefficient R^2 was shown to be still acceptable, R^2 = 78 %, by only considering the very low frequencies below 50 Hz, B.). Using ISO single number from 50 Hz, A.) the determination coefficient was only R^2 = 32 %.

Due to the limited number of residential units in the AkuLite field study (however confirmed by laboratory listening tests) this is only an indication. Nevertheless, it is no doubt that it is possible to design a wooden construction that fulfill a high requirement in terms of ISO single number but is not judged as satisfactory by the tenants. Hence, only considering the lowest frequencies for wooden construction could give a good overview of the predicted annoyance in the building.

There are not many constructions measured or evaluated in the frequency range 20 – 3150 Hz, however there are alternatives that can be used to estimate the risk for annoyance better than the ISO single number (2), in the frequency range 50-3150 Hz. Using the weighting curve to evaluate $L'_{\mathrm{nT,Hagberg,03}}$, the risk for annoyance can be estimated and a "risk evaluation" can be carried out. The single number, $L'_{\mathrm{nT,Hagberg,03}}$, should not exceed 62 dB (2). It has later been confirmed in the AcuWood project (3) that this single number rating results in the best determination coefficient when the standard tapping machine is used as a sound source. The AcuWood project was a European project comprising evaluation of buildings within Germany and Switzerland.

3. Examples

In order to give a picture of the results when designing wooden houses that will meet low frequency ISO 717 requirement down to 50 Hz, two examples are shown in this section. The two examples are both two storey buildings erected in Sweden each of them including six residential units, three on each storey. However, they differ when it comes to structural design. Building no 1 is designed by using lightweight I-beams in the floor structure and building no 2 is using CLT elements in the floor structure. The buildings are both designed to meet the minimum requirements between dwellings in Sweden, which currently equals the following figures for impact sound level

$$L'_{\mathrm{n,Tw}} \text{ and } L'_{\mathrm{n,Tw}} + C_{\mathrm{I,50\text{-}2500}} \leq 56\,\mathrm{dB} \tag{2}$$

To illustrate and estimate the risk for low frequency annoyance, $L'_{\mathrm{nT,w,Hagberg,03}}$ is evaluated in addition to the ISO single numbers in the examples below.

3.1 Building no 1

The floor structure in building no 1 is built up according to figure no 2. The floor structures are supported by a light weight wooden wall shown in the same figure.

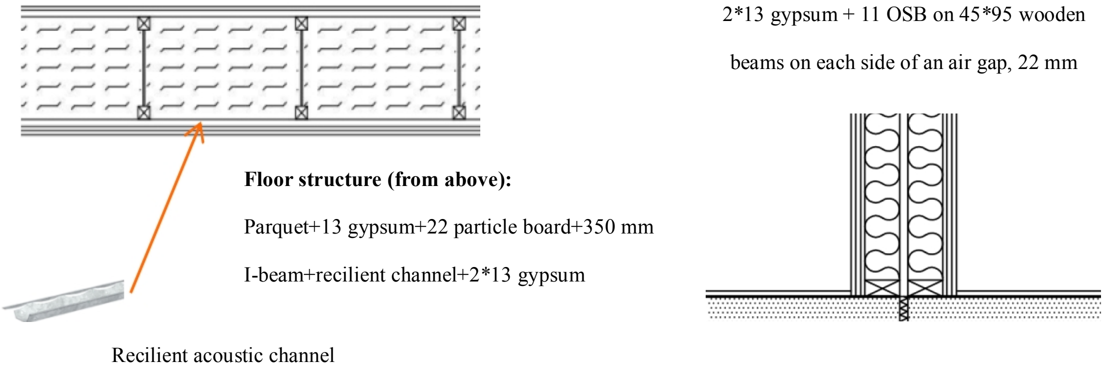
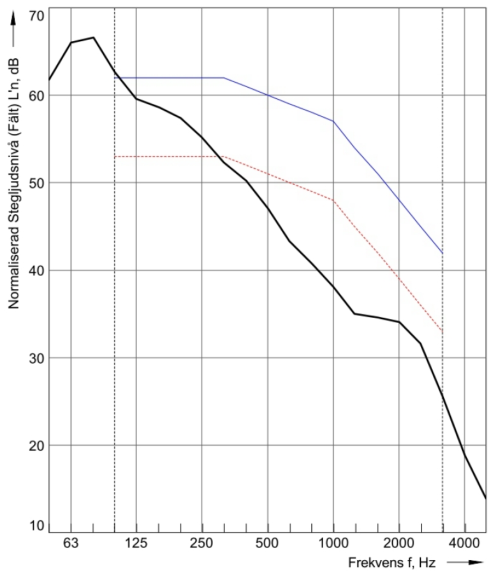


Figure 2 – Principle for the structural build up for building no 1

3.1.1 Impact sound insulation results

Below, one ”typical” impact sound insulation curve is shown from building no 1 is shown. There are minor variations within the house and between flats however the result below can be used as a typical average result for the building.



Single numbers:

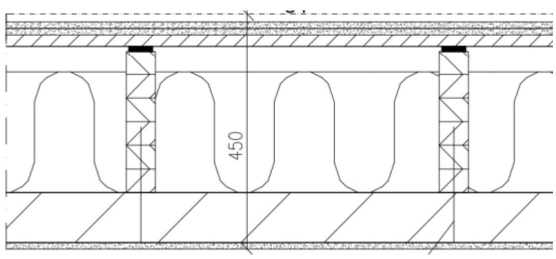
$L'_{nT,w}$= 51 dB
$L'_{nT,w}$+ $C_{I,50\text{-}2500}$= 57 dB

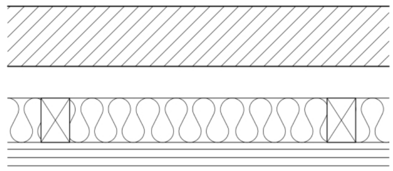
$L'_{nT,w,Hagberg,03}$= 66 dB

Figure 3 – Impact sound insulation example from building no 1.

3.2 Building no 2

The floor structure in building no 2 is built up according to figure 4. The floor structures are supported by a CLT wooden wall shown in the same picture.





Floor structure (from above):

Parquet+2*13 gypsum+22 particle board on Sylomer ©+270 glulam beam on 95 CLT+13 gypsum

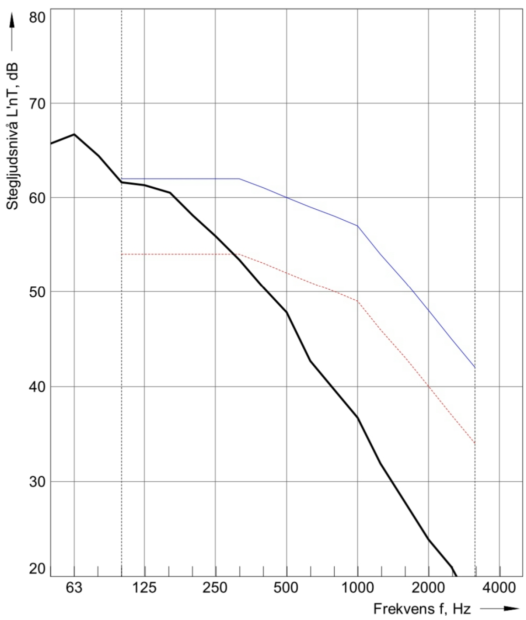
Wall:

95 CLT + airgap 70 mm +11 OSB+2*13 gypsum

Figure 4 – Principle for the structural build up for building no 2

3.2.1 **Impact sound insulation results**

Below, one ”typical” impact sound insulation curve is shown from building no 1 is shown. There are minor variations within the house and between flats, however the result below can be used as a typical average result for the building.



Single numbers:

$L'_{nT,w}$= 51 dB
$L'_{nT,w}+ C_{I,50-2500}$= 57 dB

$L'_{nT,w,Hagberg,03}$= 67 dB

Figure 5 – Impact sound insulation example from building no 2.

4. Analysis

Both buildings exhibit equivalent impact sound insulation standard according to ISO. They hardly fulfill the minimum requirements in Sweden (Maximum 2.0 dB is judged as acceptable in single measurement as long as the average result within each flat is below the requirement level 56 dB). In both these houses it was not really perfectly fulfilled but at the end accepted by the authorities. In the two buildings $L'_{nT,w,Hagberg,03}$ are 66 and 67 dB respectively which is a little bit worrying due to the fact that it should not exceed 62 dB in order to give satisfactory results (2), at least for ordinary dwellings aimed for families with children. And 4 – 5 dB could involve a lot in the low frequency region due to the shape of the phone curves. A few dB in low frequencies could entail a big step in experienced sound level (annoyance). In these two particular rather small buildings, people know each other and naturally they care about each other and hence poor low frequency impact sound insulation can be handled by careful considerations between neighbours. However, in bigger residential complexes this is not always the case.

Probably the figures above should be acceptable also in houses for elderly and student houses. However, the reasons are different. Elderly because they are not walking fast or jumping from sofas, students because their flats are very small and therefore limited floor surfaces. Normally a student dwelling is not made for walking long distances. But this is the authors own reflections but it is important to know the future needs in order to adapt the requirements. It will reduce unnecessary costs for the developer which also implies reduced costs for categories of people that are very cost sensitive.

It is complex to build in wood and due to lack of prediction models it is very difficult to predict the sound insulation for the finished building. However, more and more experience from "real buildings" adapted to Swedish minimum requirements makes it possible to make reliable estimations that fit at least to the current requirements in the building regulations. However, as soon as a manufacturer wants to build different, with higher requirements or fit the building to requirements in another country, severe difficulties appear. How far should the construction be simplified in order to adapt to other regulations (lower levels or another frequency range) without severe complaints appear?

Generally the two examples above fulfill requirements in Sweden by no margin at all! It is of course a risk to design with these "no margins" both for the developer and for the acoustician, but as long as the requirements do not deviate from the Swedish minimum requirement and the constructions stay within "normal standard", the national/local experience is enough to estimate what is needed. As a comparison to Norwegian minimum requirements, $L'_{n,w} \leq 53$ dB, the margin seems to be more than sufficient (perhaps not in big rooms however….), since the requirements are in both cases fulfilled by 2 dB margin in normal rooms. But nevertheless, the habitants experience exactly the same construction. To retain old figures only imply that things are easier for those who are used to work with the "safe" frequency range 100 – 3150 Hz.

5. Final Remarks

The current evaluation according to ISO is only used in Sweden so far. Now there is finally a proposal from the COST action TU 0901 (4) saying that low frequencies should be added in regulations within Europe and it also includes a proposal of a common classification scheme. As an acoustician it is a mystery that the low frequencies are still not considered, since there is so big interest to develop the wooden industry. It is proved that the low frequencies have to be part of the evaluation procedure or the entire wooden building industry will have no success at all for the future!

Now there are a number of initiatives to further extend the number of storeys using wooden structural materials, to up to sixteen storeys. It is challenging and very interesting but the risk exposure for the developer is rather big. When the numbers of storeys are increasing other potential unknown effects might appear. One thing is how various loading on different storeys might affect the sound insulation? Can a CLT structure be considered as homogeneous? In case, is it valid in the entire frequency range? There is certainly a lot of more work left to reduce the uncertainties when designing wooden structures in terms of acoustics. The new project "Silent Timber Build" (5) might give some important new input, however still there is a long way to go.

ACKNOWLEDGEMENTS

Thanks to WoodWisdomNet for recommending further research in acoustics for wooden structures (Silent Timber Build) and also the national funding organizations for their support, all industrial partners in AkuLite AcuWood and Silent Timber Build for supporting the progress of acoustical research in wooden constructions, both financially and by their own contribution.

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