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Acoustic requirements vs experienced sound in wood structures

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ABSTRACT

Wood, in particular CLT, is increasing as structural material in buildings, improving the conditions for circular economy within the construction sector. However, structural wood is still creating doubts amongst many developers and one issue is the difficulty to easily fulfil equal sound insulation requirements as we are used to from the history with concrete. The difficulty increases when the buildings are high. To secure the Swedish sound insulation class B, either the walls have to be very thick or elastomers have to be installed between the different storeys. Often high design margins are needed since the real efficiency of the layers is unknown when the wall elements are tightly connected due to static reasons. Therefore, it is the duty of acousticians to ensure that the requirements we are stating in the design process really correspond to the annoyance of the habitants for different building categories. We should not lower the overall quality but instead refine the requirements to be more spot on in each single situation. Therefore, increased knowledge is necessary, in particular regarding annoyance in different housing categories. This paper gives examples of the challenges that we need to take into account for the future development of wood technology.

Keywords: Sound, Insulation, Transmission

1. INTRODUCTION

Wood buildings are becoming more and more common and the number of storeys in buildings with wood as structural material are also increasing. It is important to further develop this industry not least due to environmental issues. Simultaneously, the concrete industry is changing and the development to find new modern solutions to reduce the environmental impact is often connected to lower structural density. Acoustics in buildings have severe design impact which implies that the building regulations have to be correct and also predictable. Therefore, building regulations must become more adapted to annoyance in the buildings for whom we produce.

The foundation for regulatory framework on acoustics should have its basis on how humans perceive sound, but in a broad context. Current regulations (at a global scale) are applicable and adapted to building design in the case of heavy constructions. However, in order to secure a proper residential acoustic standard in general, covering a wide range of housing formation, an option is to use correct levels in the extended frequency range referring to ISO 717:2013 (1, 2). That was also agreed upon within the COST network COST TU 0901 (3).

The thoughts presented in this paper have its origin in (4) in which various surveys were analysed to find out the extent of inhabitants annoyed of sound insulation in their homes. These surveys are useful for future development of regulations, but also to estimate the need for extension of frequency range (towards low and very low frequencies) in various types of future homes.

Due to the raised activity within the wood industry over the past five years, specifically CLT structures, an increased need for development of regulations has been updated. Parallel to the lifting of the 100 year old ban of wood buildings in 1994, a number of research projects have been carried out in Sweden since then. The research has covered several fields within acoustics, however subjective response to impact-/structure borne sound in wood buildings being specifically investigated. The conclusions were that the low frequency evaluation for impact sound according to ISO 717-2 (2) underestimated the annoyance even if the extended frequency range are included in the limit values. By keeping the frequency range 50-3150 but by focusing even more to low frequencies, it was shown to be possible to receive even better correlation between objective impact sound insulation measure and perceived sound insulation. The focus on impact sound insulation but also the difficulty to investigate annoyance of airborne sound result in the fact that it is less clear which airborne sound

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insulation requirements that are sufficient in modern residential units.

The demographic change of the population and request of smaller apartments for different groups of people makes it necessary to investigate various housing formations and their need for high requirements. And it is honestly worrying what will be the consequences of too strict requirements for new buildings, in general, and misuse of high sound classes for various applications. One important thing is the cost for the end user.

2. OVERVIEW CURRENT RESEARCH

2.1 Impact sound

Below in table 1 is an overview of the single number quantities (SNQ´s) and their correlation to walking noise as evaluated from listening test in laboratory during the AcuWood project, presented in (5). The correlation represents a comparison between recorded signals representing different SNQ´s and annoyance due to human walking noise.

Table 1 – The coefficient of determination, R^2, between different SNQ´s (tapping machine as a source) and perceived annoyance of walking noise

SNQ	R^2	Frequency range [Hz]
$L'_{nT,w}$	0,38	100-3150
$L'_{nT,w} + C_{I,100\text{-}2500}$	0,48	100-3150
$L'_{nT,w} + C_{I,50\text{-}2500}$	0,58	50-3150
$L'_{nT,Bodlund}$	0,58	50-1000
$L'_{nT,Hagberg}$	0,63	50-3150
$L'_{nT,Fasold}$	0,56	50-5000
$L'_{n,w} + C_{I,AkuLite,20\text{-}2500}$	0,56	20-3150
$L'_{nT,w} + C_{I,AkuLite,20\text{-}2500}$	0,57	20-3150

Concluding the findings from (5) results in the statement that; if walking noise is the main excitation source, the frequency range from 50 Hz is sufficient. There are no doubts that it is necessary to include frequencies between 50 – 100 Hz, at least for the housing units included in the actual surveys.

Another recently finalised research project, Aku20, managed from the technical University of Luleå (Sweden) is of interest in the present context (6). The aim of that project was to gather additional acoustic data together with subjective data, using the same principle with questionnaires and measurements on site as was carried out in previous project (AkuLite). By adding a substantial number of new residential blocks and including them in the material, the statistical significance could be made stronger. In total, thirteen new residential blocks were included, five of those were heavy structures (concrete) and eight of them were different types of wood structures. The determination coefficient of different objective evaluations as related to perception of noise from footsteps, is given in table 9 (6).

Table 2 – The coefficient of determination, R^2, between different SNQ´s (tapping machine as a source) and perceived annoyance of walking noise (6).

SNQ	R^2	Frequency range [Hz]	Weight 20-40 Hz [a)]
$L'_{nT,w}$	0,18	100-3150	
$L'_{nT,w,50}$	0,49	50-3150	
$L'_{nT,w,40}$	0,53	40-3150	
$L'_{nT,w,31}$	0,64	31-3150	
$L'_{nT,w,25}$	0,72 [b)]	25-3150	
$L'_{nT,w,20}$	0,71	20-3150	
$L'_{nT,w,25}$	0,75	25-3150	1
$L'_{nT,w,20}$	0,67	20-3150	1
$L'_{nT,w,25}$	0,77	25-3150	2
$L'_{nT,w,20}$	0,65	20-3150	2
$L'_{nT,w,25}$	0,75	25-3150	3
$L'_{nT,w,20}$	0,61	20-3150	3

a) The weighting concerns increased dB per third octave band relative to -15 dB.

b) If one outlier is removed due to the fact that it exhibited strange results due to the high age of the respondents, the determination coefficient increases up to 0.85, exhibiting almost similar determination coefficient as the *AkuLite* proposal (0.86).

To conclude the results from Aku20, the adaptation term as proposed in the previous Swedish project AkuLite, $C_{I,AkuLite,20\text{-}2500}$, which was much more strongly "punishing" low frequencies, seems to overestimate the low frequency impact, generally speaking. As more residential blocks were added to the original building samples, the low frequencies are still important, however less stringent than what can be seen from the originally limited number of residential blocks, comprising almost only lightweight structures.

Furthermore in (6) the author concluded that it might be appropriate to not necessarily push the frequency limit below 50 Hz at present, since a holistic overview of wood as building material is important, e.g. impact sound insulation is one characteristic amongst other technical aspect. That was concluded even though a flat spectrum adaptation term $C_{I,25\text{-}2500}$ creating the SNQ $L'_{nTw,25}$, exhibited the best correlation for the actual sample of buildings. Consequently, if $L'_{nT,w,50}$ is used, and if current research is used to convince the global community that it is a suitable (and still a rather careful) general requirement on a global market for impact sound insulation for any structural material, it will bring a great benefit to future development. The industry will gain much more than if one small country like Sweden introduces even more strict regulations. Promoting the ISO descriptor ($L'_{nT,w}$+$C_{I,50\text{-}2500}$) has several advantages:

1. It is globally standardised.
2. A lot of data and experience are collected and are already available regarding this descriptor.
3. The industry will unify their efforts in the same direction.
4. Though not perfect in terms of low frequencies, it is proven to be far better than $L'_{nT,w}$ or $L'_{n,w}$ and simultaneously a moderate step, that perhaps can be accepted globally within a limited amount of years, is taken.

$L'_{nT,w}$ should be used, in addition, to avoid big negative values of $C_{I,50\text{-}2500}$.

2.2 Airborne sound

For airborne sound insulation, several studies have been carried out lately, summarised by Rindel in (7). Rindel concludes, contradictory to the paper he reviewed, that they prove that the low frequency components are of great importance and that it would be of benefit to provide SNQ´s adapted to the source of sound, i.e. one SNQ to protect from music comprising bass tones and one SNQ for other sources comprising less sound in low frequencies. In dwellings, if the main purpose of the SNQ for airborne sound insulation is to define a minimum level of sound insulation that can ensure a reasonable protection against annoying sounds from the neighbours, then it is sufficient to have the stronger of the two requirements, i.e. spectrum adaptation term included. In (8) Rindel proposed R'_{w} 56 dB as an "acceptable" level, though not satisfactory. The corresponding level if introducing adaptation terms can be withdrawn from figure 1, emanating from (9).

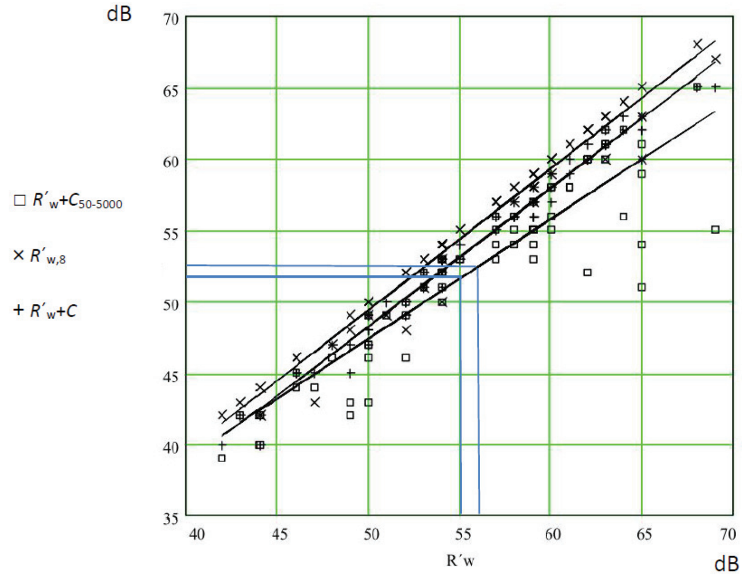

Figure 1 – Correlation between each of the SNQ´s $R'_{w}+C_{50\text{-}5000}$, $R'_{w}+C$, $R'_{w,8}$ and R'_{w}. Assuming requirement based on the weighted sound reduction index according to (8) (56 dB), horizontal axis, corresponds to $R'_{w}+C_{50\text{-}5000}$ = 53 dB which equals $R'_{w}+C_{50\text{-}3150}$ = 52 dB.

With normal sized square rooms and with a common normal size partition the value R'_{w} are close to the value of $D_{nT,w}$ which means that 52 dB could be used also for $D_{nT,w}+C_{50\text{-}3150}$, being aware that it is not always the case.

3. ANALYSIS

The questionnaire surveys referred to above suffer from limitations, also noted in (4). They all refer to more or less "normal flats", of course with a diversity of inhabitants in terms of age and gender and cultural habits, but still limited. Listening tests that have been carried but is often made without connection to the risk for annoyance in specific dwellings. In future, there will be more need for dwellings for the elderly and the percentage of single-person households might increase. Student dwellings is another type of household where the costs are very important and must be deeply included in the evaluation. And what is really needed for hotels and temporary residential units? Surveys must also include cultural differences (many countries). This, in turn, implies that other considerations than those accounted for in the previously mentioned studies are of interest which probably will affect the requirements needed. Adapting requirements for one type of dwellings and then transmit those to other types of dwellings with other preconditions and use them as minimum requirements might imply high costs, without any verified benefits.

The building industry is also facing challenges in terms of environmental issues. Following ongoing environmental discussions throughout the world regarding building industry and their impact on CO_2 emission, these have to be solved urgently. Wood is one material that will reduce the environmental impact from the building industry. But it is also obvious that the traditional concrete industry will face the same challenges. New lightweight concrete solutions will enter the market (it has already started).

Historically, low frequencies have not been part of the evaluation in building acoustics. The lower limit has always been 100 Hz but nowadays many countries at least measure and evaluate down to 50 Hz even if there are no requirements in building regulations. There are uncertainties and difficulties to predict and measure in the low frequencies that have to be taken into account when stating requirements and developing prediction tools. However, as a general basis, following the outcome from current research over the past 35 years the minimum requirement for normal residential units / dwellings should be (at least in Nordic countries):

- $D_{nT,w}+(C_{50\text{-}3150})\geq 52$ dB
- $L'_{nT,w}$ and $L'_{nT,w}+C_{I,50\text{-}2500}\leq 56$ dB (±?)

The adaptation term for airborne sound insulation is put within brackets since more research is needed to prove that it is really needed in all residential units. On the other hand, with experience from real buildings, the adaptation term for airborne sound does not cause any big trouble in, at least if the requirement level is not raised above 52 dB. Compared to impact sound, airborne sound is easier to predict even for lightweight structures and prior to reduce requirements without more research, it is better to keep a good standard, for instance to reduce risk for low frequency HIFI equipment. For impact sound we should strive to at least fulfill the requirement above.

However, for specific residential units and some specific buildings (for example hotels/temporary residential units) the requirements should be further elaborated and explored to optimise the levels to the buildings and the inhabitants they are aimed for.

4. APPLICABILITY TO SMALL DWELLINGS / ROOMS?

In many projects the specifications are simply stated in a manner that sound class B according to Swedish Standard SS 25267 should be fulfilled. Sometimes the minimum requirements are accepted (4 dB less stringent). That is valid no matter which type of housing unit to be produced. That can create solutions with very thick walls and floors if choosing light structural material, compared to the size of the dwellings / rooms, which also means that the choice will be another structural material. Below an example for student dwellings in figure 2 with few square meters to use for walking.

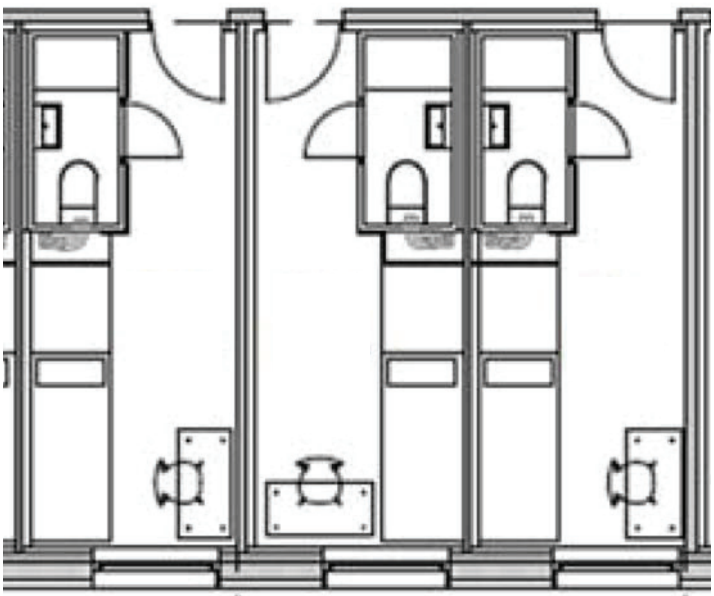

Figure 2 – Student rooms of each 13 m^2 (but the floor area is even smaller). Is it necessary to aim for the similar requirements as for big dwellings?

Small rooms mean less distance to sound sources (TV / radio / HIFI equipment), maybe reducing risk for raised noise levels inside the room. Hotels and temporary residential units are not even equipped with HIFI equipment. It also means less opportunity to create impact sound since the floor space is limited.

A number of different building systems are entering the market very fast currently, specifically various modular prefabricated options. Some modules / volume elements produced in factories fit very well for specific residential units, hotels and similar. However, the requirements in acoustics often limits their possibility to compete to other structural material being negative not least due to environmental aspects. Additionally, the process to change requirement levels in regulatory framework are very long compared to the speed of new housing factories starting. Therefore, to promote development within the building industry and to reduce the risk exposure for the developer and the team involved it should be possible to create acceptance for larger deviation from the minimum requirements for specific housing units. An option could be to establish a risk analysis for specific building categories implying acceptance for minor failure. That means keeping similar basic requirement levels, but if a risk analysis is carried out a larger deviation could be accepted. The return should be that measurements have to be carried out and shared with authorities, and maybe a simple questionnaire after 6 months of usage to receive information from the people living in the flats.

There are two main reasons for establishing some system promoting new technique:

- The uncertainty in prediction of impact sound insulation of light structures, both due to complicated build ups of the floor structure and junctions but also due to errors that can appear between the design phase and the completion of the building. The prediction of buildings must be further developed and the learning process requires practical experience - it will result in improved prediction accuracy over time.
- Encourage more developer to try new building systems and develop new future technology for more environmental and sustainable buildings.

5. CONCLUSIONS

Acoustic requirements are stating the design of a building. They have to be based on risk for annoyance. But we need various residential buildings and sometimes the requirements must be questioned since they might not correspond to the expected risk for annoyance, at least there are reasons to suspect that.

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