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EVALUATION OF IMPACT SOUND INSULATION FROM 20 HZ

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A couple of years ago, results from the Swedish research program AkuLite indicated the importance to measure and evaluate impact sound insulation down to 20 Hz. This in order to get high correlation against the rated annoyance form residents living in lightweight, primarily wooden based, apartment buildings. Although highly interesting, the indication was based upon a limited number of 10 building objects. In the ongoing research project Aku20 the study has been expanded to 23 objects – including both lightweight and heavyweight constructions. The increased number of objects leads to more statistically reliable results. Within the project, extensive field measurements were performed with the tapping machine and the rubber ball as the sound sources. A questionnaire survey with a variety of questions related to sound and vibration issues were distributed among the tenants. Thereafter, correlation analysis between the objectively measured and subjectively rated parameters were carried out to find out what quantity that gives the highest statistical correlation. The conclusion is that most of the reported findings from the originating research project holds, although some minor revisions, in terms of frequency range and frequency weighting, were carried out to obtain the highest possible correlation.
Keywords: Impact sound insulation, low frequencies, questionnaire survey

1. Introduction

Lightweight buildings with wooden or thin steel gauge frame construction are nowadays often a competitive alternative to concrete constructions when apartment houses are concerned. The popularity of lightweight constructions has increased in many countries during the last decades and the technique got a renaissance in Sweden when the authorities in 1994 gave permission for wooden houses higher than two stories.

As the total number of lightweight multi-family houses has increased ever since, it has been observed, with a continuously increased experience, that today's legal framework regarding sound insulation is not fully applicable to lightweight constructions [1]. The often used, and in Sweden mandatory, single number rating $L'_{nT,w}+C_{I,50\text{-}2500}$ ($L_{nT,w,50}$) for impact sound insulation, is not always consistent in the relation to residents' perception. When two building objects of identical single number ratings are compared, one made of concrete and one of lightweight technique, the residents of the concrete building are prone to be more satisfied with the sound insulation performance compared to

the residents of the lightweight building. Such a sound insulation evaluation procedure is for given reason unwanted and refined methods are therefore needed

In the Swedish research project AkuLite (2009-13), the unsatisfactorily condition to evaluate impact sound insulation by $L_{nT,w,50}$ was indicated as no statistical relation against the rated annoyance by residents could be found [2]. The coefficient of determination, R^2, between $L_{nT,w,50}$ and annoyance was just 32%. However, the correlation was increased dramatically when the impact sound was evaluated from 20 Hz, R^2=74% for $L_{nT,w,20}$. With the suggested alternative spectrum adaptation term, $C_{I,AkuLite,20-2500}$, the correlation was even higher, 85%. $C_{I,AkuLite,20-2500}$ puts additional weighting to the 20-40 Hz by successively adding 2 dB per third-octave band. The weighting also increase at frequencies above 500 Hz in order to take care of potential issues related to concrete floors. The spectrum adaptations terms are shown graphically in Fig. 1.

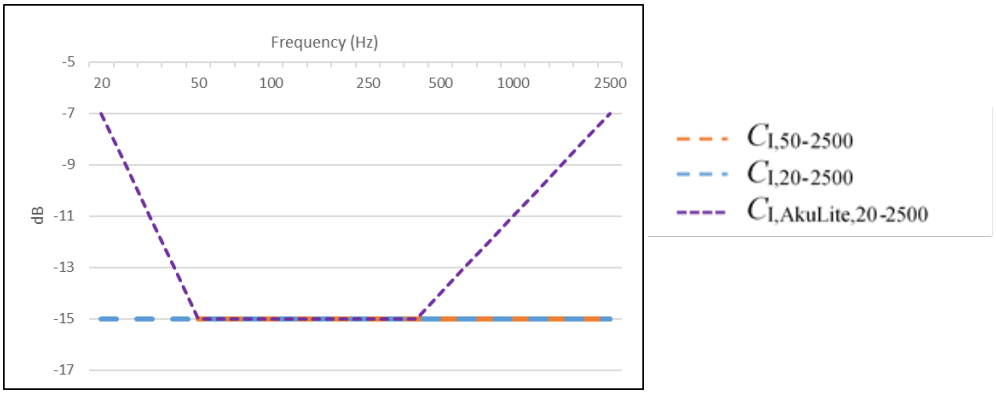

Figure 1: Weighting curves of the spectrum adaptation terms $C_{I,50-2500}$, $C_{I,20-2500}$, and $C_{I,AkuLite,50-2500}$.

The importance of the results have been understood and the Swedish standard recommend from 2015 to include impact sound evaluation from 20 Hz concerning higher sound classes (B and A) [3]. It should be noted though, that in the Swedish standard the reverberation is not standardised to 0,5 s. for frequencies 20-40 Hz. This is in contrast to the underlying research [1].

Even though the results may be treated as novel, the statistical evidence was limited since it was based upon 10 building objects where of 9 was of lightweight or semi-lightweight type. Therefore, the continuation project Aku20 (New improved building technique-neutral criteria for sound insulation evaluation) was initiated (2014-2017) in order to further strengthen, or possibly reject, the findings.

2. Method

A major part of the continued study was to enlarge, and broaden, the database. In all, 23 building objects located in various Swedish cities was included. 11 of them were classified as being lightweight – loadbearing structure of wooden or thin steel beams together with various types of boards, 6 semi-lightweight – cross laminated timber (CLT) and 6 heavy – concrete framework.

For each building object, a number of different vibro-acoustical parameters was measured and evaluated. Relevant for this paper is: Impact sound insulation according to present ISO standards using the tapping machine, but in the extended frequency range 20-5000 Hz.

The sound insulation was typically measured in 4-6 rooms for each object even though a couple of the objects are represented by fewer measurements. An equal amount of living rooms and master bedrooms was involved for each object and the mean value of these measured rooms was taken as the quantity representative for that particular object.

All residents were asked to complete a survey. The questionnaire was originally developed within the European COST action TU0901 [4]. In its latest version, it contains 17 questions related to various sound and vibration aspects. The residents rate the annoyance on a numerical scale from 0-10 where "0" means *not at all bothered, disturbed or annoyed* and "10" means *extremely annoyed*. The mean

value of each question is taken as the representative quantity for each object. In total, about 800 questionnaires were return filled with a typical response rate of about 50%.

In the analysis phase, linear regression is used to investigate the correlation between rated annoyance and various impact sound insulation parameters.

3. Results

3.1 Field measurements

A summary of the resulting single number quantities (SNQ) averaged over all objects and divided into construction type, is shown in Fig. 2. It is clearly seen for the lightweight and CLT group that the SNQ increases as the frequency range is expanded and as the low frequency weighting is increased. The trend is not that obvious for the concrete constructions though. For reference, the minimum requirement in the Swedish building code, corresponding to sound class C, is $L_{nT,w,50}$=56 dB, with a successively drop of 4 dB for the higher sound classes B and A followed by the recommendation to use the SNQ evaluating from 20 Hz.

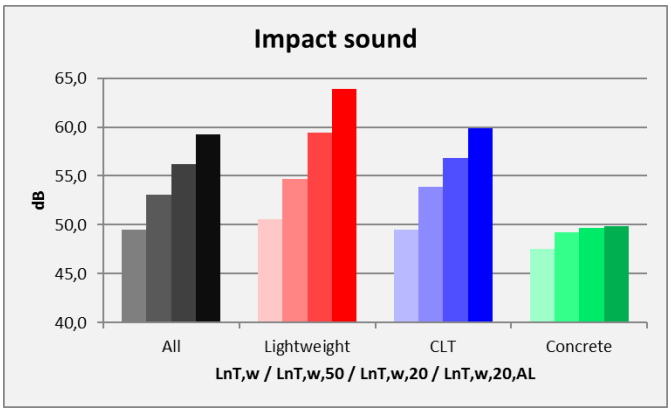

Figure 2: Single number quantities grouped into construction type. From left to right within each group: $L_{nT,w}$, $L_{nT,w,50}$, $L_{nT,w,20}$ and $L_{nT,w,AkuLite,20}$.

3.2 Questionnaire survey

Among all the questions, the one concerning footstep noise generates by margin the highest score. The residents are reported to be about twice as annoyed from footstep noise compared to other daily living sounds, e.g. people talking, TV, music, traffic, etc. The particular question reads: *Thinking of the last 12 months in your home, how much are you bothered, disturbed or annoyed by these sources of noise? Neighbors; footstep noise, i.e. you hear when they walk on the floor.*

A summary of the rated annoyance, averaged over all building objects, is shown in Fig. 3 for three questions related to impact sound. Besides footstep, it was asked about annoyance from rattling and tinkling and from impact and scraping. It is clear that annoyance from footstep is a greater problem in lightweight and CLT constructions compared to concrete.

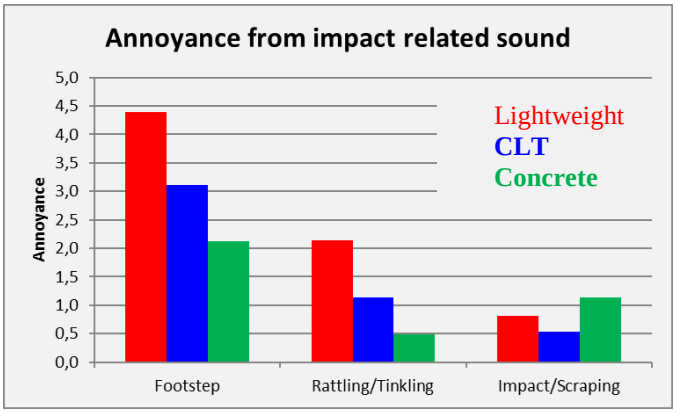

Figure 3: Mean annoyance from three sources related to impact sound insulation.

3.3 Correlation

The resulting coefficient of determination from various SNQs are presented in Table 1 where all 23 building objects are included in the analysis. Two additional SNQs are found in terms of $L_{nT,w,25}$ and $L_{nT,w,AkuLite,25}$, both according to previous definition except that 25 Hz is now the lowest third-octave band included. Evaluation from 100 Hz, i.e. $L_{nT,w}$, gives R^2=18% when correlated against footstep annoyance, while $L_{nT,w,50}$ results in R^2=49%. The correlation is further increased when frequencies from 20/25 Hz are included, with coefficients of determination between 65 and 77%. For full details, we refer to the complete paper [5].

Table 1: Coefficient of determination R^2 between different SNQs and rated annoyance.

SNQ (dB)	Footstep R^2 (%)	Rattling/Tinkling R^2 (%)
$L'_{nT,w}$	18	26
$L'_{nT,w}+C_{I,50\text{-}2500}$	49	43
$L'_{nT,w}+C_{I,20\text{-}2500}$	71	64
$L'_{nT,w}+C_{I,25\text{-}2500}$	72	-
$L'_{nT,w}+C_{I,AkuLite20\text{-}2500}$	65	61
$L'_{nT,w}+C_{I,AkuLite25\text{-}2500}$	77	-

4. Conclusions

A significant increase in correlation between measured SNQs and the rated annoyance from footstep noise was found as the frequency region was expanded below 50 Hz. The results thereby confirm the findings from the original study [2].

The obtained differences between 20/25 Hz as the lowest third-octave band to be included and with/without frequency weighting, were rather small. However, the highest correlation, R^2=77%, was obtained when evaluating from 25 Hz with the so called AkuLite-weighting.

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REFERENCES

1 Acoustics in wooden buildings – State of the art, *SP Report* 2008:16, ISBN 978-91-85829-31-6 (2008).

2 Ljunggren, F., Simmons, C. and Hagberg, K. Correlation between sound insulation and occupants' perception – Proposal of alternative single number rating of impact sound, *Applied Acoustics*, **85**, 57-68, (2014).

3 Sound classification of spaces in buildings – Dwellings, *Swedish standard SS 25267* (2015).

4 Integrating and harmonizing sound insulation aspects in sustainable urban housing constructions, *COST TU0901*, http://www.costtu0901.eu, (2017-03-26).

5 Ljunggren, F., Simmons, C. and Öqvist, R. Correlation between sound insulation and occupants' perception – Proposal of alternative single number rating of impact sound, part II, *Applied Acoustics*, **123**, 143-151, (2017).