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Correlation between sound insulation and occupants' perception – Proposal of alternative single number rating of impact sound, part II

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ABSTRACT

A previous Swedish research project indicated the potential need for evaluating impact sound insulation from 20 Hz in buildings with lightweight constructions. This is a discrepancy compared to the commonly used frequency intervals starting from 50 or 100 Hz. The statistical significance of this groundbreaking suggestion was however not satisfactorily strong since the result was based upon a limited number of building objects.

The scope of the present paper is to secure the previous study by adding additional objects to the underlying database, thereby increasing the confidence of the results. The methodology is to perform impact sound insulation measurements in apartment buildings of various construction types and to perform questionnaire surveys among the residents. The measured sound insulation is compared to the subjective rating by the occupants in order to find the parameter giving the highest correlation with respect to frequency range and weighting.

The highest correlation was found when the impact sound insulation was evaluated from 25 Hz using a flat frequency-weighting factor. Frequencies below 50 Hz are of great importance when evaluating impact sound insulation in lightweight constructions.

1. Introduction

Impact sound insulation has been evaluated within the frequency range 100–3150 Hz ever since the single number quantities $L'_{n,w}/L'_{nT,w}$ were standardized in 1968 (ISO/R 717). These parameters are based upon a comparison with a specified reference curve originally designed for heavy building construction materials like masonry and concrete. Eventually it became apparent that the method was ill suited to lightweight constructions having frames of wood or thin steel profiles. The mismatch is explained by the lightweight constructions, at the time, normally suffered from significantly lower impact sound insulation at frequencies below 100 Hz. This mismatch was partly overcome by the introduction of the low frequency spectrum adaptation term in 1996 (ISO 717), $C_{I,50-2500}$, i.e. by considering frequencies down to 50 Hz. The use of $L'_{n,w} + C_{I,50-2500}$ was introduced as mandatory into the Swedish building code 1999 and has also been voluntarily used within other regulations. Even though the adaptation term was seen as an important improvement by the building industry and lightweight multi-storey residential housing constructions have been continuously developed during the last decades, there is still a mismatch in the correlation between objective measurements and subjective perception of sound insulation among residents. This was one of the key topics in the Swedish research project AkuLite (2009–2013) where it was found that the coefficient of determination, R^2, between $L'_{n,w} + C_{I,50-2500}$ and the subjective perception from residents was just 32%, a correlation so low that no statistical relation between the parameters could be established [1]. But when the frequency span was extended down to 20 Hz in terms of $L'_{n,w} + C_{I,20-2500}$ the corresponding correlation increased to 74%, a remarkable improvement that strongly indicated the need to evaluate frequencies below 50 Hz. In fact, the coefficient of determination got even higher, 85%, using a modified spectrum adaptation term called $C_{I,AkuLite,20-2500}$ which emphasizes the importance of the lowermost frequencies by successively adding 2 dB extra weight for each third-octave band at 20–40 Hz. In this frequency region, lightweight constructions are prone to having poor impact sound insulation. The adaptation terms also put 1 dB extra weight for each third-octave band at 500–2500 Hz to cover potential problems in concrete buildings, e.g. where tiles are glued on the top of the slab. The weighting curves are shown graphically in Fig. 1. The

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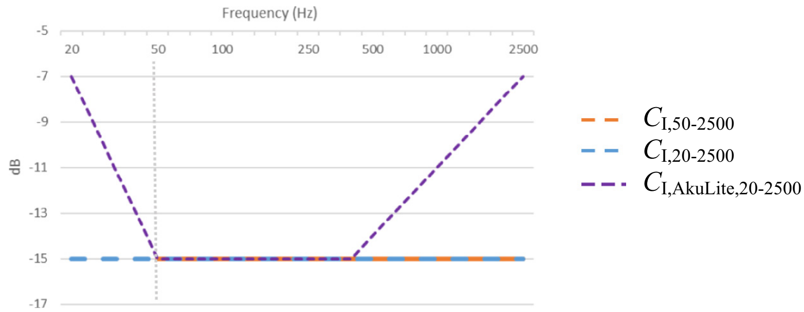

Fig. 1. Weighting curves of the spectrum adaptation terms $C_{I,50–2500}$, $C_{I,20–2500}$ and $C_{I,AkuLite,20–2500}$.

result was adopted into the Swedish standard for sound classification 2015 [2], where impact sound insulation, on voluntarily basis, is evaluated from 20 Hz for higher sound classes than the minimum requirement.

Despite these novel findings, the result should not be interpreted as the "final conclusion" but rather as an indication. The reason is that the referred study included only ten building objects, of which nine were of lightweight or semi-lightweight type and one made of concrete. It was concluded necessary to increase the number of building objects in order to verify the obtained indications.

The present study is a part of the Swedish national research project known as Aku20, an acronym for *New improved building technique neutral criteria for sound insulation evaluation*. The results presented below can be regarded as a direct continuation of the referred study [1]. In total, it involves 23 building objects that will give a considerably stronger statistical power to the analysis.

From here on, the original study [1] including 10 objects is referred to as part I and the present combined study of 13 additional building objects, 23 in total, is referred to as part II. Thus, part I involves the objects from AkuLite while part II deals with objects from both AkuLite and Aku20.

1.1. Objective

The objectives of this paper are:

- To find out whether it can be statistically shown that impact sound insulation evaluated from 20 Hz gives a higher correlation to subjectively rated annoyance compared to the standardized evaluation from 50 Hz.
- To find out whether an alternative, optimized frequency weighted spectrum adaptation term, can bring additional conformity between measured and perceived impact sound insulation.

2. Building objects

The 23 involved objects are located in different parts of Sweden, representing a variety of modern building techniques. All buildings are categorized as multi-storey residential houses with 2–8 storeys. A majority of the objects are newly produced while some of them were a few years old when they were selected for this study, although none was older than ten years. With respect to their building techniques, the objects are divided into three subcategories:

1. *Lightweight* – loadbearing structure of wooden or thin steel beams together with various types of boards.
2. *Cross laminated timber* (*CLT*) – structure based upon layers of timber, glued together.
3. *Concrete* – homogenous or hollowed core concrete framework.

11 of the objects are of lightweight type while CLT (semi-lightweight) and concrete hold 6 objects each. A summary is shown in Table 1 where objects 1–10 originate from AkuLite and objects 11–23 are the additional ones from Aku20.

3. Field measurements

3.1. Method – field measurements

For each object, extensive field measurements have been performed concerning both sound and vibrations, see [1] for further details. The measurements with direct or indirect connection to impact sound are:

(a) Impact sound insulation using the standardized tapping machine:

Measurements and evaluations were performed according to the present standards ISO 16283-2 [3] and ISO 717-2 [4] and/or the former ISO 140-7 [5] and ISO 717-2 [6]. All measurements were recorded in the extended frequency range: 20–5000 Hz.

(b) Impact sound insulation using the rubber ball:

Measurements and evaluations were performed according to ISO 16283-2 [3]. All measurements were recorded in the extended frequency range: 20–630 Hz.

(c) Static deflection of the floor:

Measurements of the deflection due to a 1 kN point load in the center point, alternatively in the weakest point, of the floor.

The impact sound insulation was measured in 4–6 rooms for each object, typically evenly distributed between living rooms and master bedrooms. A couple of the objects though, are represented by a fewer number of measured rooms while the opposite occurs for an equal number of objects. The static deflection deviates in this respect since only *one* measurement was taken for each object.

3.2. Results

Unless otherwise stated, the results in the following diagrams are presented as the arithmetic mean value for each of the 23 objects presented in Table 1.

3.2.1. Impact sound using the tapping machine

The results are based upon the standardized impact sound level L'_{nT}, i.e. the impact sound level is normalized with respect to the