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To cite this version:

Dominik Kisic, Vojtech Chmelik, Jakub Benklewski, Herbert Muellner, David Knittl, et al.. Comparison of single-number quantities for impact sound insulation to the subjective rating of different floor configurations. e-Forum Acusticum 2020, Dec 2020, Lyon, France. pp.293-296, 10.48465/fa.2020.0662 . hal-03231757

HAL Id: hal-03231757

https://hal.archives-ouvertes.fr/hal-03231757

Submitted on 25 May 2021

COMPARISON OF SINGLE-NUMBER QUANTITIES FOR IMPACT SOUND INSULATION TO THE SUBJECTIVE RATING OF DIFFERENT FLOOR CONFIGURATIONS

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ABSTRACT

The traditional descriptors of impact sound insulation such as $L_{n,w}$ evaluate tapping machine measurements on a floor construction by shifting the reference curve which provides a frequency-dependent weighting of the measurement. Additional single-number quantities have been developed over the years to offer a more accurate representation of the quality of impact sound insulation between dwellings. This article shows the comparison of some of the already proposed reference curves and adaptation terms found in literature to the results of subjective rating of three different floor configurations: concrete masonry structure, cross-laminated timber, and a lightweight timber structure. A subjective evaluation was made by matching the perceived loudness of sounds coming through the floors with identical $L_{n,w} + C_{I,50-2500}$ values. The comparison of single-number quantities to the results of the listening test was not able to produce a match. An approach to finding the optimal reference curve for matching the listening test results is also presented in the paper. The results of the curve-matching algorithm showed that its best fitting solutions were not able to coincide with the listening test results, which indicates that alternative methods to the shifting of the reference curve should be explored. Insights to an alternative approach to finding a satisfying adaptation term is also mentioned.

1 INTRODUCTION

The main motivation for this work is the hypothesis that traditional single-number quantities for impact sound insulation do not reflect how impact noise transmitted through building structures is perceived in real life. With new constructions of floors and different materials used for building them, the traditional parameters used for the characterization of impact sound insulation, namely, the $L_{n,w}$ and C_I adaptation terms [1,2], became less reliable, compared to the era of heavy constructions.

This article is a continuation earlier work [3], which presents more detail explanation of the listening test methodology. Here the focus is on the comparison of the listening test results to the existing single number quantities (SNQ) (e.g. $L_{n,w}$, $L_{n,w} + C_{I,50-2500}$, [4], [5]). Attempts of finding a corrected version of impact noise reference curve are also presented.

2 METHODOLOGY OF THE EXPERIMENT

Different floor constructions were measured according to standard in three different configurations:

- Concrete masonry structure (CON)
- Cross-laminated timber (BSP)
- Lightweight timber structure (HBD)

For the purpose of the analysis, each floor configuration was coded either as CON, BSP or HBD, accompanied by a number pertaining to the different floors measured (i.e. CON1, CON2, CON4, BSP1, BSP3,BSP4, HBD7, HBD8, HBDS).

Measurements were conducted with a tapping machine and a rubber ball (a heavy impact source). Additionally, a set of footsteps was recorded for each floor construction. These footstep recordings were used in a listening test comparison of said floors. The listening test was conducted by asking participants to match the loudness of the noise of the footsteps recorded with different floor constructions, two at the time. One sound sample was declared the reference, and the level of the other one could be changed in 1dB steps, so that their loudness could be matched. Every pair of floor constructions has been tested twice, so that both floors in each pair assumed the role of the reference. The listening tests were made in TGM Vienna and FER Zagreb, in order to expand the number of participants and to verify the methodology of the test. The results obtained on both locations are in good agreement.

The listening test consisted of 6 listening pairs (12 listening test examples) that had floors with a deviation of

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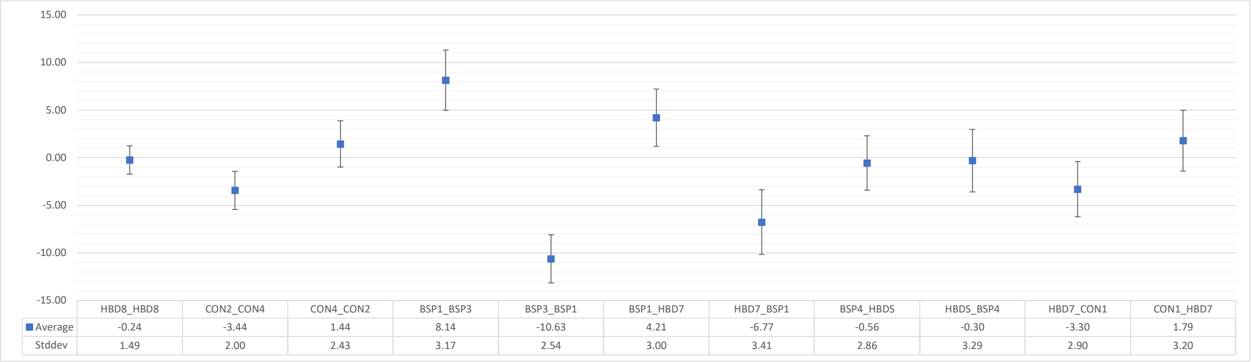
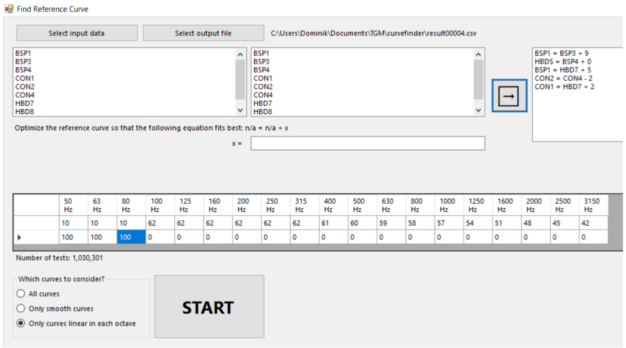


	HBD8_HBD8	CON2_CON4	CON4_CON2	BSP1_BSP3	BSP3_BSP1	BSP1_HBD7	HBD7_BSP1	BSP4_HBDS	HBDS_BSP4	HBD7_CON1	CON1_HBD7
■ Average	-0.24	-3.44	1.44	8.14	-10.63	4.21	-6.77	-0.56	-0.30	-3.30	1.79
Stddev	1.49	2.00	2.43	3.17	2.54	3.00	3.41	2.86	3.29	2.90	3.20

Figure 1. Results of the impact noise listening test



C:\Users\Dominik\Documents\TGM\curvefinder\result00004.csv

BSP1
BSP3
BSP4
CON1
CON2
CON4
HBD7
HBD8

BSP1
BSP3
BSP4
CON1
CON2
CON4
HBD7
HBD8

BSP1 = BSP3 + 9
HBDS = BSP4 + 0
BSP1 = HBD7 + 5
CON2 = CON4 - 2
CON1 = HBD7 + 2

Optimize the reference curve so that the following equation fits best: n/a = n/a + x

x =

	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz
	10	10	10	62	62	62	62	62	62	61	60	59	58	57	54	51	48	45	42
▸	100	100	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Number of tests: 1,030,301

Which curves to consider?
○ All curves
○ Only smooth curves
● Only curves linear in each octave

Figure 2. Find reference curve application interface

no more than 1dB in their $L_{n,w} + C_{I,50-2500}$ SNQ per pair. An additional dummy test pair was introduced with the same walking sample being both the reference and the tested sample. This test pair was used to remove the outlier participants from the overall analysis. One of the six listening pairs has also been removed as an outlier from the further analysis.

3 ANALYSIS AND RESULTS

Firstly, the results have been depicted as an average and standard deviation of the answers. This can be seen in figure 1.

Since every listening test pair has two instances, so that each of the samples is able to be the reference sample, the results are symmetrical. E.g. the pair of floor constructions coded as BSP1 and BSP3 give the result of 8.14 in case when BSP1 is the reference, and the result of -10.63 when BSP3 is the reference. In both cases the calculation of standard deviation gives similar results. In this graph, if the listener's perception would correspond to the standardized $L_{n,w} + C_{I,50-2500}$, the averages would give a value around 0, which would mean the perceived loudness of sound coming through both floors is the same. Also, alternative SNQs, besides $L_{n,w} + C_{I,50-2500}$, have been tested.

Following the analysis methodology that was used in a previously designed study of sound insulation on airborn sound insulation [6], several different modifications to the reference curve have been tried, expanding it to frequencies below 100Hz.

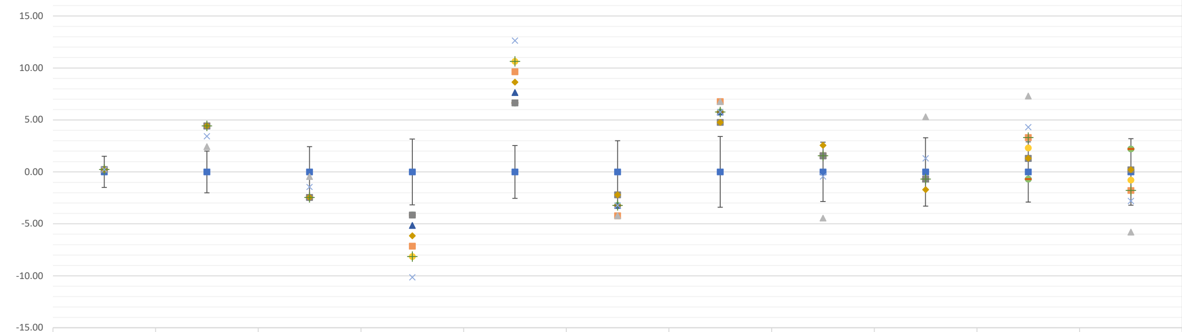
Tested SNQs and reference curves are:

- $L_{n,w} + C_{I,50-2500}$
- $L_{n,w}$
- $L_{n,w}\_50Hz$
- $L_{n,w}\_Hagberg$ [4]
- $L_{n,w}\_Hagberg\_new$ [4]
- $L_{n,w}\_Bodlund$ [5]
- $L_{n,w}\_mod$

where $L_{n,w}\_50Hz$ corresponds to the reference curve with a flat (62dB) expansion of the reference curve down to 50Hz, and $L_{n,w}\_mod$ to the different modifications of the same curve using different slopes in the 50–100Hz octave range.

The summary of this result can be seen in figure 3. The figure shows the results of the listening test, along with their respective standard deviations. Listening test results are presented with their average values normalized to 0dB, e.g. the average comparison of floors with a code CON2 and CON4 gave a difference of -3.44dB, giving, all the values in that column are shifted by 3.44dB, therefore a more comprehensible information. Since the examined values represent the differences between the level of impact noise of two floors, the used single-number quantities are represented as their difference for each of the listening pairs. An ideal single-number descriptor should produce values around 0 in this graph for each of the listening test pairs. The examined reference curves are all plotted with markers and colors in the graph and with their numbers stated in the table underneath the graph.

Several $L_{n,w}\_mod$ curves have been tested manually, but also a more thorough approach has been taken by developing an application for automatic search for the optimal reference curve by testing a very large number of possible curves. The interface of the application can be seen in the figure 2, and it works as following:



	HBD8_HBD8	CON2_CON4	CON4_CON2	BSP1_BSP3	BSP3_BSP1	BSP1_HBD7	HBD7_BSP1	BSP4_HBDS	HBDS_BSP4	HBD7_CON1	CON1_HBD7
■ Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stddev	1.49	2.00	2.43	3.17	2.54	3.00	3.41	2.86	3.29	2.90	3.20
■ Ln,w + CI 50-2500	0.24	4.44	-2.44	-7.14	9.63	-4.21	6.77	1.56	-0.70	3.30	-1.79
▲ Ln,w	0.24	2.44	-0.44	-16.14	18.63	-4.21	6.77	-4.44	5.30	7.30	-5.79
● Ln,w_50Hz	0.24	4.44	-2.44	-8.14	10.63	-3.21	5.77	1.56	-0.70	2.30	-0.79
● Ln,w_Hagberg	0.24	4.44	-2.44	-4.14	6.63	-3.21	5.77	1.56	-0.70	-0.70	2.21
● Ln,w_Hagberg_new	0.24	4.44	-2.44	-4.14	6.63	-3.21	5.77	1.56	-0.70	-0.70	2.21
▲ Ln,w_Bodlund	0.24	4.44	-2.44	-5.14	7.63	-3.21	5.77	1.56	-0.70	1.30	0.21
− Ln,w_mod	0.24	4.44	-2.44	-4.14	6.63	-3.21	5.77	1.56	-0.70	-0.70	2.21
■ Ln,w_mod2	0.24	4.44	-2.44	-4.14	6.63	-2.21	4.77	1.56	-0.70	1.30	0.21
◆ Ln,w_mod3	0.24	4.44	-2.44	-6.14	8.63	-2.21	4.77	2.56	-1.70	1.30	0.21
+ Ln,w_mod5	0.24	4.44	-2.44	-8.14	10.63	-3.21	5.77	1.56	-0.70	3.30	-1.79
× Ln,w_mod6	0.24	3.44	-1.44	-10.14	12.63	-3.21	5.77	-0.44	1.30	4.30	-2.79

Figure 3. Comparison of the impact noise listening test results to different SNQs

First, the user defines the range in which the application should search for the curves. The parameters are defined in the form of the lowest bound per third octave and the amount allowed to be added to it.

Then the application enumerates all possible reference curves in that range. If the curve does not satisfy the restriction (smooth or linear), it is discarded immediately. Otherwise it calculates the single number values for all measurements with a given reference curve.

Then the reference curve gets assigned a score according to the equations defined before running the test, and that score should be satisfied as well as possible. For example, the user defines $X1 = X2-5$. If the single-number quantity for $X1$ is 54, and the one for $X2$ is 57, then $X1 = X2 - 3$ for that particular curve, and the deviation from the original equation is 2. The deviations obtained for all equations are squared and summed up. Larger deviations give a lot worse scores than smaller ones.

During this process the application tracks the best (meaning, of course, the smallest) score found so far. If the score for any given reference curve is bigger than that, it is discarded, otherwise it is kept as one of the outputted curves in the end result. The application usually outputs multiple curves with the same score, which is the reason the smooth or linear per octave restrictions have been implemented to the algorithm.

4 CONCLUSIONS AND FURTHER WORK

As it can be seen, none of the existing descriptors align with the listening test results, nor do the ones newly explored by authors. This motivated the development of a computer algorithm that would be able to find the appropriate reference curve.

Although the curve-fitting algorithm was able to check a large number of reference curves ($> 10^{10}$), its best results were still not able to sufficiently match the listening test results. The algorithm has been developed in such way that not only the changes in the low frequency portion of the reference curve can be investigated, but across the entire frequency spectrum of the reference curve as well. A Problem arises in the form of a number of operations needed for such calculation. Since the algorithm uses a pretty brute force way of solving this problem, its complexity rises exponentially. For checking the entire frequency spectrum with 100dB dynamics, it would need to check over 10^{38} curves, which would correspond to a runtime of over $3 \cdot 10^{25}$ years with current computational resources available. Algorithm improvements which would speed up the runtime should be possible.

These conclusions point out that a different approach of finding an adaptation term should be considered. The introduction of A weighting to the measurements already indicates more promising results.

5 ACKNOWLEDGEMENTS

The authors acknowledge the financial support by the European Commission, (H2020 MSCA RISE 2015 project 690970, “ Advanced physical acoustic and psycho acoustic diagnostic methods for innovation in building acoustics (PAPABUILD).

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