inter.noise HAMBURG 2016

An Empirical Study of the Spatial Uncertainty of Reverberation Time Measurement Below 50 Hz

Fredrik LJUNGGREN[1]; Rikard ÖQVIST[1,2]; Christian SIMMONS[1,3]

[1] Luleå University of Technology, Sweden

[2] Tyréns, Sweden

[3] Simmons akustik & utveckling, Sweden

ABSTRACT

The relevance of performing reverberation time measurements at very low frequencies became an issue in Sweden when the national standard recommended that impact sound insulation should be evaluated from 20 Hz for sound classes above the minimum requirement. Even though the standard states that $L'_{n,T}$ is not to be normalized with respect of reverberation time for frequencies below 50 Hz, it could be argued to include such a correction term to handle any possible variation in the absorption properties of the room. But this can be done only if the reverberation time can be accomplished with reasonable accuracy. The present paper presents an empirical study where reverberation time has been measured from 20 Hz in two different bedrooms with more than 100 microphone positions in each in order to determine the spatial variation. A comparison is made between the uncertainty as a function of frequency and it is indicated that the standard deviation is larger for the lowest frequencies, below 50 Hz, compared to higher. From an engineering point of view, this can be compensated by adding additional positions to the already existing ISO measurement procedure.

Keywords: Reverberation time, Impact sound insulation
I-INCE Classification of Subjects Numbers: 72.6, 51.3

1. INTRODUCTION

Results from the Swedish national research project *AkuLite* (2009-2013) indicated the benefit of a further extended frequency range, down to 20 Hz, when impact sound is evaluated, particularly concerning lightweight buildings (1). From 2015, the Swedish standard (2) recommends to include frequencies from 20 Hz in the highest sound classes A and B while the minimum requirement, given in the Swedish building code (BBR), equivalent to sound class C, refers to $L_{nT,w} + C_{I,50\text{-}2500}$, i.e. evaluated from 50 Hz. In the process of determine L_{nT} or L_n the reverberation time should according to established procedures be measured in each of the included one-third octave bands. However, it is often assumed to be cumbersome to measure reverberation times at low frequencies, approximately below 100 Hz and especially below 50 Hz. At theses lowermost frequencies, each one-third octave band contains too few modes to obtain a diffuse sound field (3) and it is also common to find very short reverberation times in lightweight constructions. In fact, there is a risk that the reverberation time of the room is shorter than the reverberation time of the filters in the analyzer used for the measurements (4).

To overcome these potential difficulties, the reverberation times for the one-third octave bands 20-40 Hz are not consider at all in the Swedish standard. Or equivalently: the reverberation time is set to the reference value 0.5s when L_{nT} is determined. On the other hand, if the reverberation time could be determined with similar accuracy for the lowest frequencies compared to the higher, such a procedure should, for given reasons, lead to a more precise determination of L_{nT} for the same lowermost one-third octave bands, 20-40 Hz. In the ongoing research project Aku20, an empirical study – here reported – has been performed to get indications of the reverberation time variation in

1 fredrik.ljunggren@ltu.se
2 rikard.oqvist@tyrens.se
3 info@sim+mons.se

different positions in two different rooms. The obtained data makes it possible to compare the spatial variation in between various frequencies.

2. MEASUREMENT METHOD

The master bedroom in two apartments was used for the measurements. The apartments relate to different buildings with different construction techniques. One apartment belongs to a concrete building (a) while the other belongs to a building with a lightweight wooden construction (b). The dimension of room (a) is 3.7x3.0 m with a height of 2.6 m and the size of room (b) is 4.2x3.0 m and 2.5 m height. In total 104 measurement positions were used in rom (a) and 120 positions in room (b), this corresponds to a measurement grid close to 60x60x60 cm. The layout of the two rooms is shown in Figure 1.

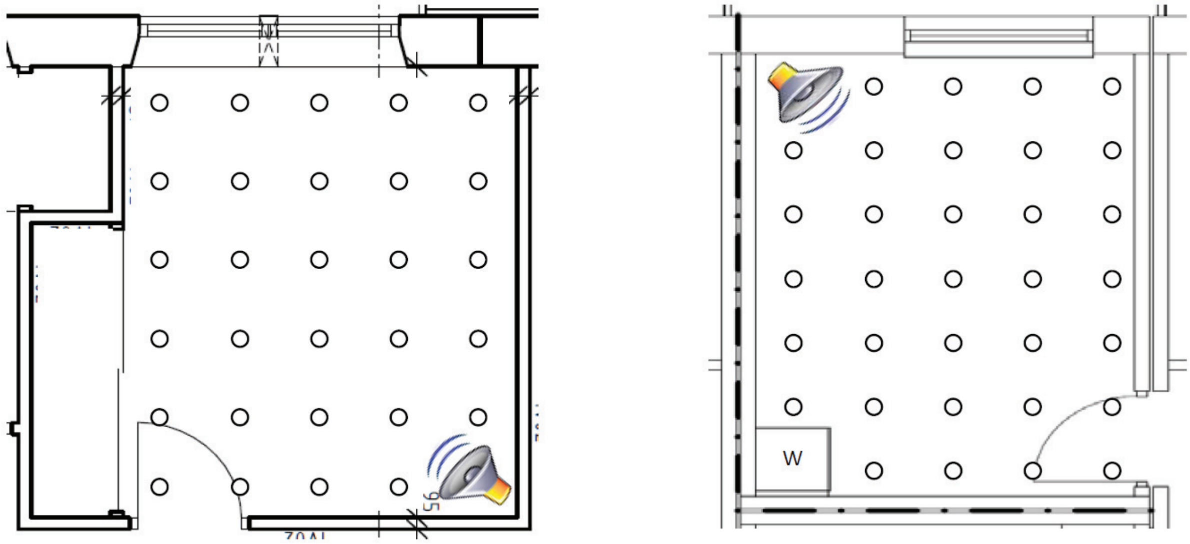


Figure 1 – Layout of the two rooms. Microphone positions are shown for one out of four horizontal planes. The room with concrete construction is to the left and the wooden construction to the right.

A single loudspeaker position was chosen to be near one of the corners and all microphone positions were not closer than 1.0 m from the speaker, which should be in agreement with ISO 3382 (5). Besides a traditional broad-banded loudspeaker, a subwoofer, dedicated for frequencies below 50 Hz, was used as complement.

The interrupted noise method was used for evaluating the reverberation time. For each microphone position, the measurement was repeated twice where the mean value was used for further analysis. All used measurement equipment and methods are in accordance with appropriate ISO standards, except for the interval 20-40 Hz where no guidance is available. For the lowest frequencies, below 50 Hz, measurements were taken in octave bands in order to fulfill the criterion BT>8 which were assumed to be fair enough (6). BT is the product of the filter bandwidth and the reverberation time. Thus, octave bands are required in this frequency range in order not to get in conflict with the inherent reverberation time of the used measurement system.

3. RESULTS

The results for all frequencies from 100 Hz and below and a selection of higher frequencies are here presented in terms of mean reverberation time, averaged over all microphone positions. The mean reverberation time and its corresponding standard deviation are found in Figure 2. Obtained minimum and maximum reverberation times are shown in Figure 3.

The shortest mean reverberation time is 0.46 s at 50 and 63 Hz and the longest is 2.29 s at 16 Hz, all found in the wooden building. Actually the reverberation times of 50 and 63 Hz are too short to fulfill BT>8 which correspond to 0.70 and 0.57 s respectively. Therefore, these results have probably been achieved from somewhat distorted decay curves. As can be seen in Figure 2, the reverberation time is more stable for frequencies from about 100 Hz compared to lower.

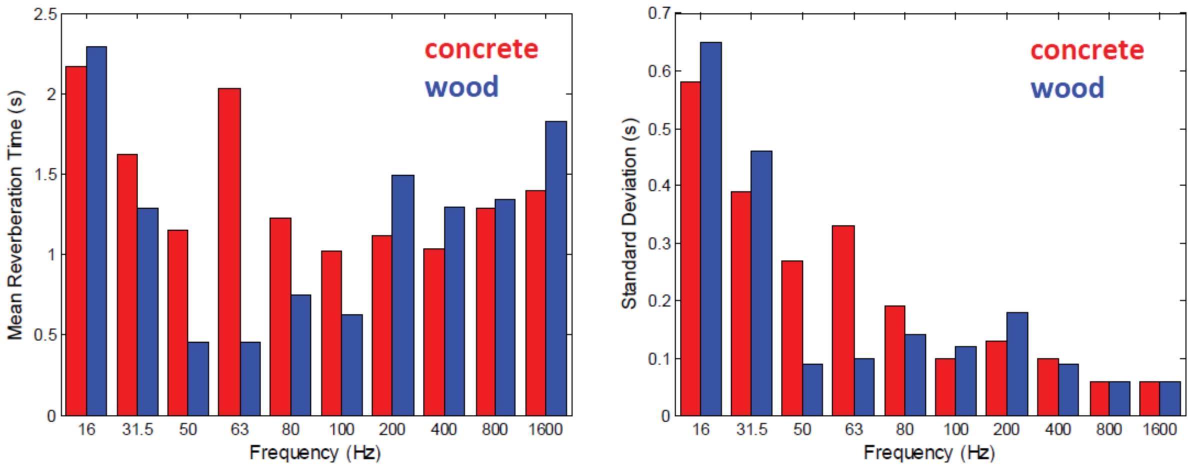


Figure 2 – Mean reverberation time to the left and standard deviation to the right. 16 and 31.5 Hz refer to octave band, higher frequencies to one-third octave band.

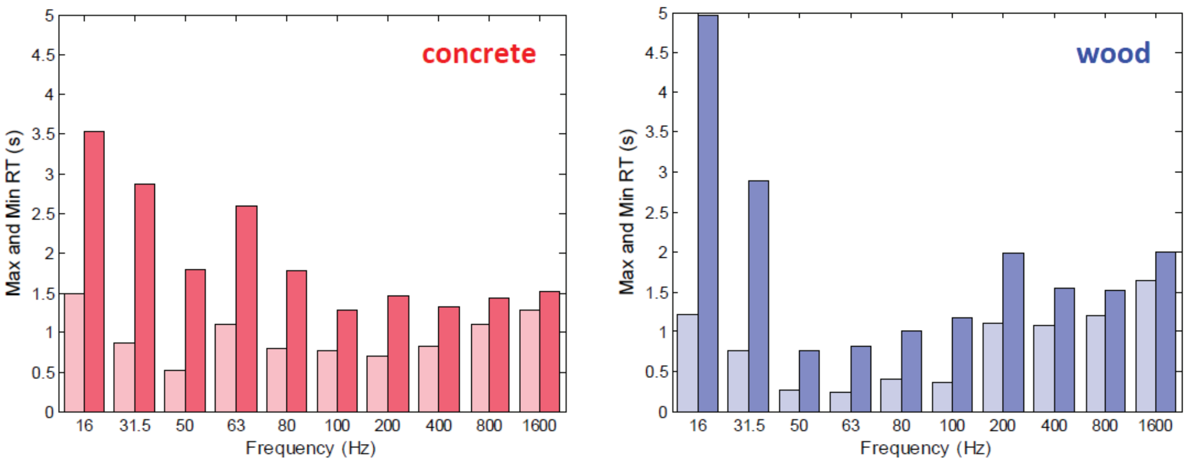
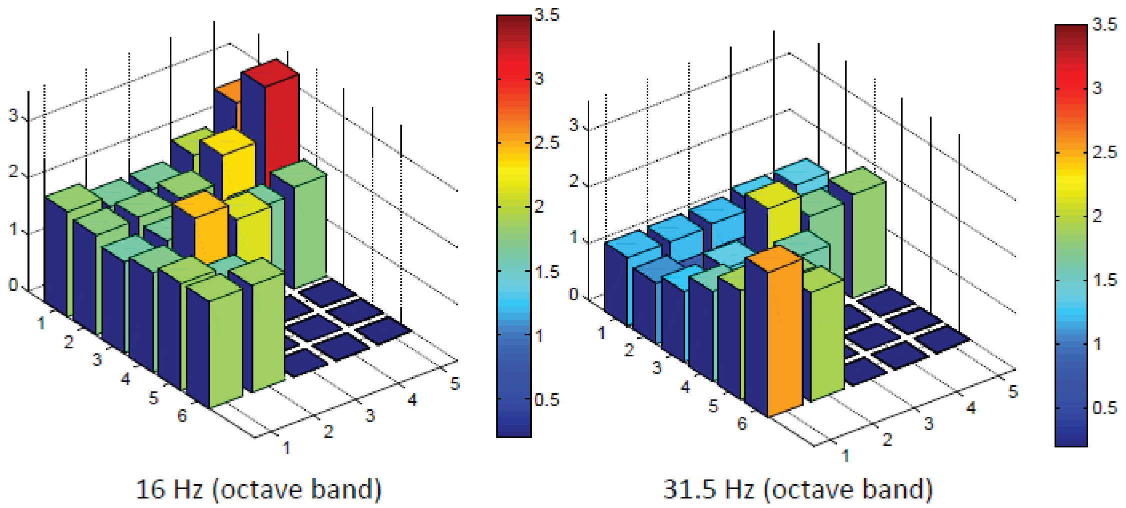


Figure 3 – Minimum and maximum reverberation time. The concrete room is to the left and the wooden room to the right.

The smallest standard deviation is 0.06 s at 800 and 1600 Hz in both room and the largest is 0.65 s for the wooden building room. From Figure 2 it is clear the standard deviation is higher for the lowest frequencies compare the higher.

A couple of examples of reverberation times from individual positions are shown in Figure 4. Again, the lowermost frequencies show larger variation compare to higher.



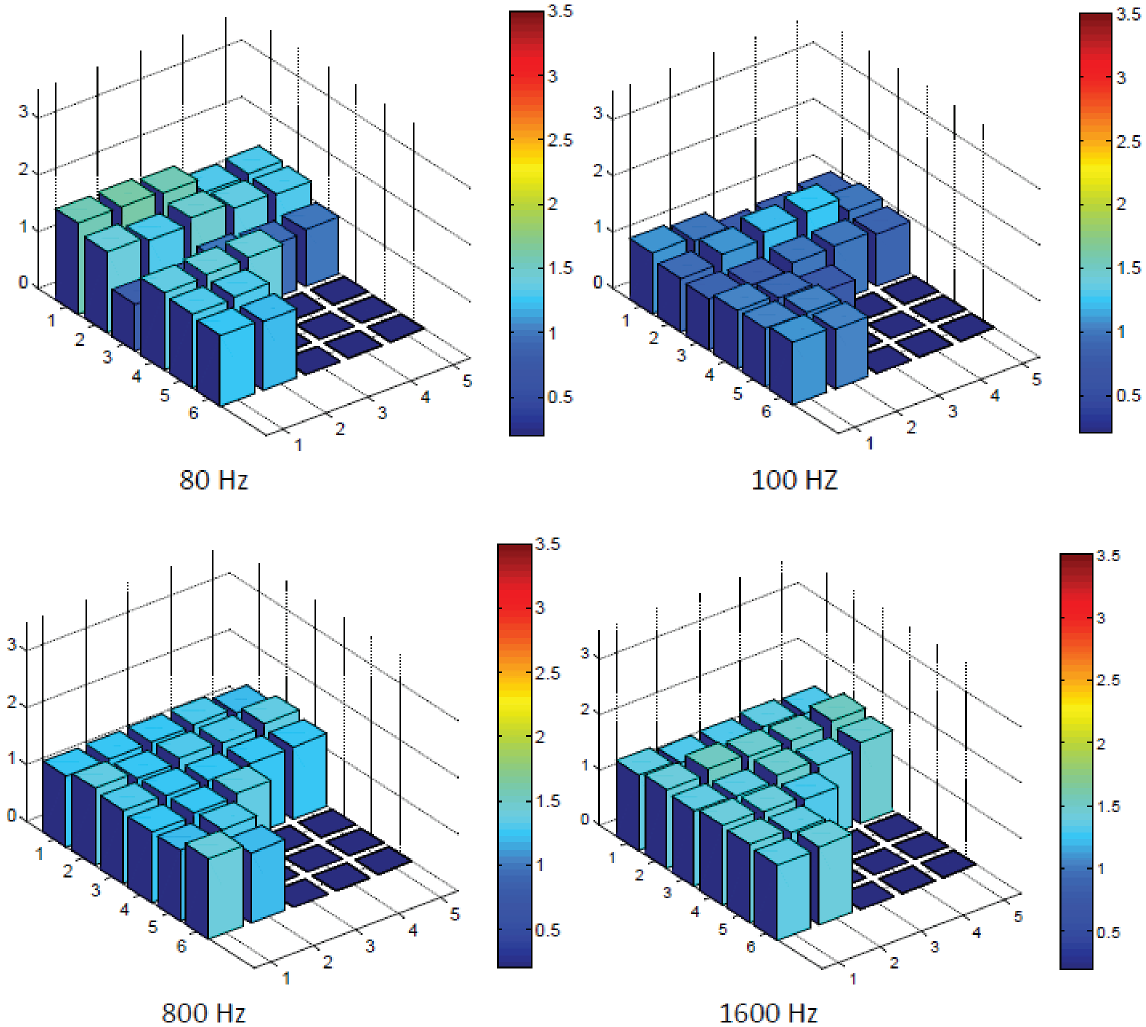


Figure 4 – Reverberation times from individual microphone positions, at various frequencies. All positions refer to the lowest horizontal measurement plane, about 90 cm height. The data were obtained from the concrete room

4. ACCURACY RELATED TO THE NUMBER OF MICROPHONE POSITIONS

The standardized impact sound level is defined according to equation 1 where L_p is the sound level in the receiving room from a running tapping machine in the sending room, and T_0 is 0.5 s.

$$L'_{n,T} = L_p - 10\log\left(\frac{T}{T_0}\right) \tag{1}$$

As a rule of thumb, ±1 dB is often assumed to be a fair accuracy of sound measurements of this type. With the assumption that all uncertainty in measuring $L'_{n,T}$ is caused by the measurement of the reverberation time, an interval of T that corresponds to ±1 dB of $L'_{n,T}$, can be calculated. The reverberation time must then be within the interval [$0.794T_{true}$ $1.259T_{true}$] where T_{true} is the true value of T, here assumed to be the measured mean reverberation time of three microphone positions in accordance with ISO. If three of the available positions are randomly chosen, we end up with a large amount of possible combinations, approximately 182000 for the concrete room and 281000 for the wooden room. During this conditions, the probability of getting a measured reverberation that fulfills ±1 dB of $L'_{n,T}$ is then 86 and 82% for the octave bands 16 and 31.5 Hz respectively. For the one-third octave bands of 50, 63 and 80 Hz, the probability is 94, 96 and 98% respectively. Frequencies 20-40 Hz thus seems to yield lower accuracy compared to frequencies 50-80 Hz.

It is reasonable to believe that the accuracy will increase if the number of microphone positions involved in the determination of T is increased. If four positions are used instead of three, the probability of getting a measured reverberation within ±1 dB of $L'_{n,T}$ is now 91 and 88% for the octave bands 16 and 31.5 Hz respectively. For the one-third octave bands of 50, 63 and 80 Hz, the probability is 97, 98 and 99% respectively.

If five microphone positions are used, the probability for 16 and 31.5 Hz increases to 95 and 92% respectively. The results are summarized in Table 1.

Table 1 – Probability of obtaining a measured reverberation time corresponding to ±1 dB of $L'_{n,T}$ as a function of number of microphone positions. Average results from the two rooms are shown.

Freq. (Hz)	**16**	**31.5**	**50**	**63**	**80**	**100**	**200**	**400**	**800**	**1600**
3 pos (%)	86	82	94	96	98	98	100	100	100	100
4 pos (%)	91	88	97	98	99	99	100	100	100	100
5 pos (%)	95	92	98	99	100	100	100	100	100	100

5. CONCLUSIONS

The performed experimental study of performing reverberation time measurements in more than 100 positions in each of the two rooms indicates a larger standard deviation in the frequency range 20-40 Hz (octave band) compared to higher frequencies (one-third octave band). The somewhat larger uncertainty for the frequencies below 50 Hz can be compensated by using additional microphone positions. Using five microphone positions within the range of 20 to 40 Hz gives nearly the same accuracy as using three positions – as stipulated by ISO – for the range 50-80 Hz. The probability of affecting the related $L'_{n,T}$ by less than ±1 dB is then more than 90% for the lowermost frequencies.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support from the Swedish research authority *Formas* and the *Sven Tyrén Trust*.

REFERENCES

1. Ljunggren F, Simmons C, Hagberg, K. Correlation between sound insulation and occupants' perception – Proposal of alternative single number rating of impact sound. Appl Acoust. 2014;85:57-68.
2. Acoustics – Sound classification of spaces in buildings - Dwellings, Swedish Standard SS 25267:2015.
3. Rindel J H. Modal energy analysis of nearly rectangular rooms at low frequencies. Acta Acoustica united Acustica. 2015;101:1211-1221.
4. Jacobsen F. A note on acoustic decay measurements. J Sound Vibr. 1987;115:163-170.
5. Acoustics - Measurements of room acoustic parameters - Part 2: Reverberation time in ordinary rooms, International Standard ISO 3382-2:2008.
6. Acoustics - Measurements of the reverberation time of rooms with reference to other acoustical parameters, International Standard ISO 3382:1997.