The influence of less available physical parameters on the sound insulation calculation according to EN 12354

Draško Mašović[1], Dragana Šumarac Pavlović[2] and Miomir Mijić[3]

Abstract – **EN 12354 standards propose complex procedures for prediction of sound insulation in buildings. Mathematical models describing sound energy flow between the adjacent rooms incorporate many parameters, real values of which are often unavailable. Possible influence of varying empirical values of these parameters on the calculation results is in the focus of this paper.**

Keywords – **calculation of sound insulation, sound insulation parameters, sound insulation prediction software.**

I. Introduction

European standards EN 12354 [1] describe models for prediction of sound insulation in buildings. Parts 1 and 2 describe models for airborne and impact sound insulation between rooms, respectively. As such, many of the parameters included in the models are described in ISO 140 [2] and ISO 10140 [3], which propose methods for laboratory and field measurements. EN 12354, therefore, proposes methods for predicting the values of sound insulation parameters, instead of measuring them. The parameters can be expressed in octave and third-octave band values, but simplified models are also described, which deal with single-number parameters only. If detailed models are used, weighted single-number values can be obtained from octave or third-octave values by following the procedures given in ISO 717 [4].

As noise protection regulations in European countries normally define allowed values of sound insulation descriptors in terms of their weighted values [5], the weighted results of EN 12354 calculations can be used for assessing whether future buildings will comply with national requirements before it is built.

However, to include many complex acoustic phenomena related with sound energy flow between rooms in buildings and arrive with sufficiently accurate results, the models have to deal with large number of parameters describing acoustic performance of building elements. The complexity of such calculations is illustrated in Fig. 1, which lists main parameters in the models and relations between them. Parameters which depend on other parameters are placed higher in the graph with arrows symbolising this dependency. According to this, four levels of parameters can be distinguished, with basic physical quantities at the lowest one and final sound insulation descriptors at the top.

As the prime quantities to be calculated, *R'* (apparent sound reduction index) and L_n' (normalized impact sound pressure level) are chosen for airborne and impact sound insulation between rooms, respectively. Both direct (through the separating element) and indirect transmissions (through other paths) are considered. Their contributions are calculated independently, as R_{Dd} and R_{ij} for airborne and $L_{n,d}$ and $L_{n,ij}$ for impact sound insulation (*d* representing the path through the separating element and *i* and *j* flanking elements). These four quantities, however, depend on many other quantities. These include sound reduction index of the elements (*R*), normalized impact sound pressure level (L_n), sound reduction index improvement and reduction of impact sound pressure level of additional layers (ΔR and ΔL), and normalized sound level difference of small building elements and flanking systems ($D_{n,e}$, $D_{n,s}$, $D_{n,f}$). Most of these parameters can be measured in laboratory using standardized procedures given in [2] and [3], and the data for many elements and constructions on the market exist, which can be used as an input for the models.

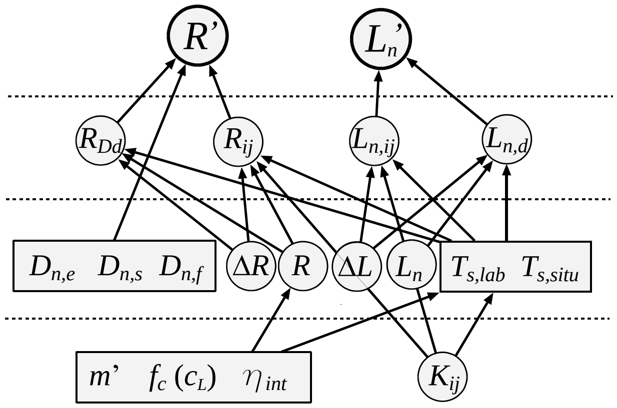

Fig. 1. Main parameters for calculation of sound insulation according to EN 12354

In addition, elements, especially massive homogeneous partitions, can show significantly different acoustic properties in the field and under laboratory conditions. Therefore, more quantities are needed for taking this into account, which have not been measured frequently, if at all, until recently and thus are less known about. These are laboratory and "in situ" structural reverberation times ($T_{s,lab}$ and $T_{s,situ}$). Since their values are very rarely available or measured, EN 12354-1:2000 [1] in its Annex C describes methods for their calculation. These methods include some physical quantities related to the basic material of the element, such as density (ρ) or mass per unit area (*m'*), critical frequency (f_c), longitudinal

[1]Draško Mašović is with the School of Electrical Engineering at the University of Belgrade, 73 Bul. kralja Aleksandra, Belgrade 11000, Serbia, E-mail: dmasovic@etf.rs.

[2]Dragana Šumarac Pavlović is with the School of Electrical Engineering at the University of Belgrade, 73 Bul. kralja Aleksandra, Belgrade 11000, Serbia.

[3]Miomir Mijić is with the School of Electrical Engineering at the University of Belgrade, 73 Bul. kralja Aleksandra, Belgrade 11000, Serbia.

wave speed (c_L) and internal loss factor (η_{int}). As the values of most of these quantities are also often unavailable, Annex B of the same standard gives several empirical values for certain homogeneous building materials. These are the values of ρ, c_L and η_{int}, and a formula for calculating f_c from them. All these parameters can also be used for calculating R and L_n values for homogeneous elements, if these data are missing as well.

As a result, such complex calculation procedure and large number of parameters included can lead to high uncertainty of the prediction. Not only that each laboratory measured quantity brings its own measurement uncertainty in the calculation, but empirical values, which most often cannot be avoid in practice, may not match the real situation. Such “less available” parameters are in the focus of this paper. Its aim, however, is not to determine the level of agreement between their empirical and real values. Instead, it tries to determine to what extent the chosen values of some of the parameters influence the calculation and change its final results.

II. Calculations Settings

The following scenario of two adjacent rooms is used for calculations according to the models presented in EN 12354. Both rooms have the same dimensions (5x4x2.7 m) and both cases of rooms “next to each other” (separating wall) and “above each other” (separating ceiling) are covered. All separating and flanking elements are massive, homogeneous and the junctions between them are rigid cross junctions. No doors, windows, small elements or additional layers are included. Basic material of all the walls, floors and ceilings is a 16cm-thick concrete. For the reference case, which is a starting point for variations of the parameters, the following values of relevant physical parameters, taken from Annex B of EN 12354-1 [1], are chosen:

- density ρ=2300 kg/m^3 (therefore, mass per unit area m'=368 kg/m^2),
- internal loss factor η_{int}=0.006, and
- longitudinal wave speed c_L=3500 m/s (therefore, according to Annex B, critical frequency f_c=114.7 Hz).

Sound reduction index (R) of the elements and normalized impact sound pressure level (L_n) of the floors are calculated according to Annex B, sound reduction index (K_{ij}) according to Annex E and structural reverberation times (T_s) according to Annex C.

Since the contribution of the parameters in the calculations is in general non-linear, the influence of their variation on the final results is inspected by simulations. At first, for each specific simulation one of the parameters is varied. This is done by making its value a random variable with Gaussian distribution, thus representing the deviation of parameter values due to measurement uncertainty, for example. Mean value of the distribution is equal to the value of the parameter in the reference case. Standard deviation is chosen to agree with common dispersion of their measured values reported in the literature [6-8] or reasonably expected in real circumstances. They are given in Table I (*std1* to *std5*). Since K_{ij} and $T_{s,situ}$ are, generally, frequency dependable, the values of these parameters are varied in each third-octave frequency band independently. Additional care has to be taken so that structural reverberation time values always stay positive. Although, its standard deviation is kept low in comparison with absolute values, at high frequencies in some simulations large negative deviations can result in negative structural reverberation time, which are then made positive. Since each simulation is repeated 1000 times, with the same value of standard deviation of each parameter, before the standard deviation of the results is calculated, this does not make a statistically significant contribution to the overall results.

Table I
Chosen standard deviations of the analysed parameters

X \ std(X)	std1	std2	std3	std4	std5
ρ [kg/m^3]	25	50	75	100	125
c_L [m/s]	100	200	300	400	500
η_{int} [/]	0.00100	0.00125	0.00150	0.00175	0.00200
K_{ij} [dB]	1	2	3	4	5
$T_{s,situ}$ [s]	0.01	0.02	0.03	0.04	0.05

At second, to test the most unfavourable scenario of bias error, i.e. constant difference between chosen parameter values and the real ones, a different approach is taken. Parameter values are increased or decreased by a certain value for all the elements (or junctions in the case of K_{ij}). In this way, bias error presented as the difference between the adopted empirical and real values of the parameters can be simulated. The difference between the results obtained with these values of input parameters and the reference case results then represents the resulting error. These value “shifts” for all the analysed parameters are given in Table II. The table represents their range from the largest negative (*b1*) to the largest positive value (*b11*), and the size of the step between two successive values. In total, eleven shifts, including the 0 value (*b6*), which corresponds to the reference case, is considered for each parameter.

Table II
Range of the simulated biases of the analysed parameters and the step between the two bias values

X \ bias(X)	b1	b11	step
ρ [kg/m^3]	-375	375	75
c_L [m/s]	-1000	1000	200
η_{int} [/]	-0.005	0.005	0.001
K_{ij} [dB]	-10	10	2
$T_{s,situ}$ [s]	-0.15	0.15	0.03

III. Results

Figs. 2 and 3 show standard deviation of apparent sound reduction index (a) and normalized impact sound pressure level (b) as the function of standard deviation of each of the analysed parameters. Values of *std1* to *std5* of the parameters are given in Table I. Fig. 2 covers the case of rooms “above each other” and Fig. 3 rooms “next to each other”.

If the chosen standard deviation values are taken to represent typical variability of analysed parameters in practical circumstances, they can be compared by their influence on the prediction results. If so, it follows that most critical are the values of K_{ij} and $T_{s,situ}$, especially for the impact sound insulation calculations and rooms one next to each other. For example, standard deviation of “in situ” structural reverberation time of only 0.03 s can lead to standard deviations of $L_{n'}$ value of 1 dB. R’ values seem to be less sensitive to “reasonable” parameter variations, although small influence of longitudinal wave speed (c_L) is observable.

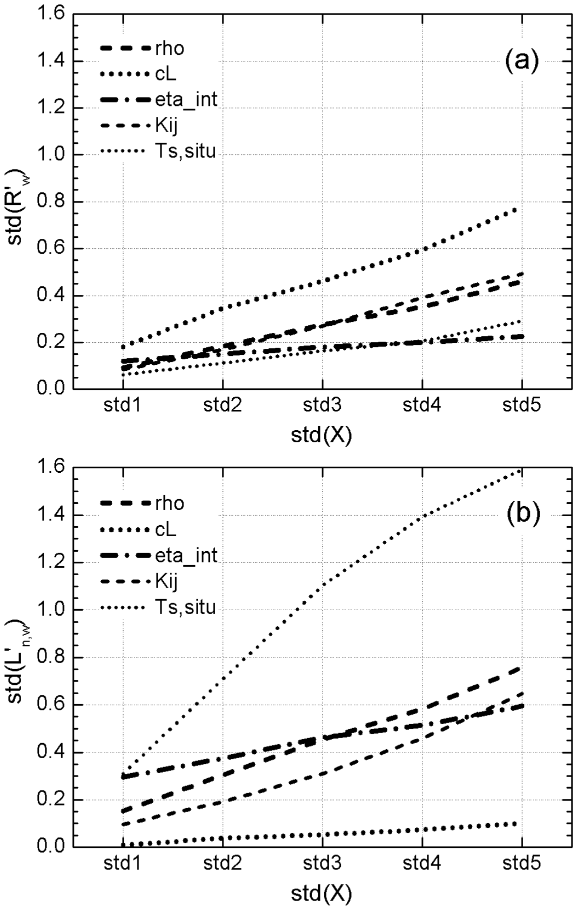

Fig. 2. Relation between standard deviations of the analysed parameters and sound insulation descriptors (separating ceiling)

The bias calculation errors, representing the difference between the calculation results obtained with shifted values of input parameters (see Table II) and the reference case results, are shown in Figs. 4 and 5. The former one presents results for separating ceiling scenario and the latter one for separating wall. The four largest negative values of $T_{s,situ}$ biases are omitted, since they caused $T_{s,situ}$ values at higher frequencies to fall below zero and thus produce meaningless final results.

Expectedly, bias errors in the assessment of analysed parameter values can cause much larger calculation errors than small deviations around the real values. This is partially due to the cumulative effect of the bias errors, since they are superimposed over all of the elements and junctions involved. The calculation results are again especially sensitive to $T_{s,situ}$ and K_{ij} values and R' values seem to be equally influenced as L_n'. Bias K_{ij} value error of -4 dB can cause a calculation bias error of +3 dB in the case of airborne sound and -2 dB in the case of impact sound insulation, thus leading to higher values of sound insulation. This becomes especially interesting considering that some data from the literature [6, 7] report that K_{ij} values calculated according to Annex E of EN 12354-1:2000 tend to underestimate its real values by about 5 dB and even more, depending on the junction type.

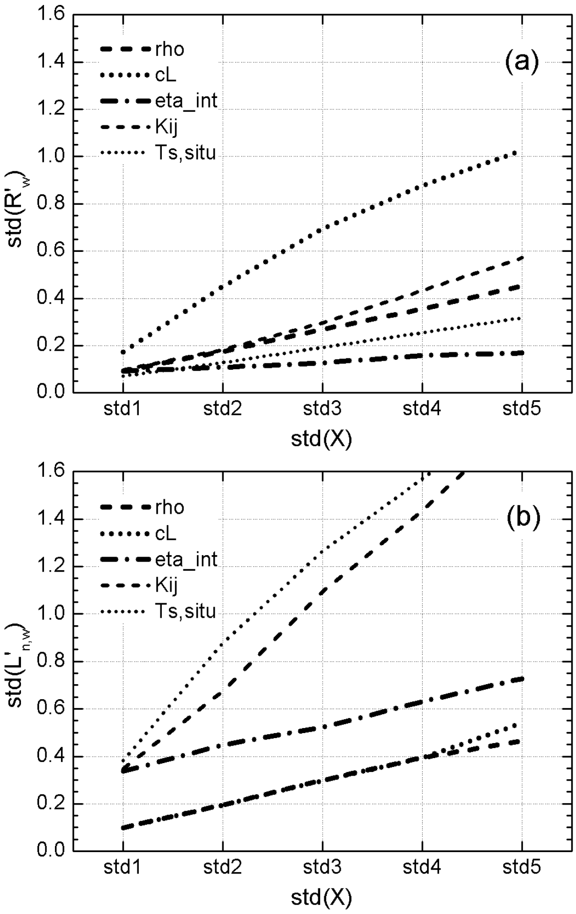

Fig. 3. Relation between standard deviations of the analysed parameters and sound insulation descriptors (separating wall)

IV. Conclusion

According to EN 12354-1:2000 and EN 12354-2:2000 [1], calculated weighted values, obtained by using the described methods, should show dispersion around real values with standard deviation of around 2 dB and a bit higher in the case of horizontal transmission of impact sound. Standard deviation values obtained here as a consequence of reasonable parameter deviations (such as relatively small measurement uncertainties) are lower. Therefore, relatively small variations of parameter values should not influence the final results significantly, although, K_{ij} and $T_{s,situ}$ seem to be more influential than other analysed parameters. However, bias errors of input data, such as wrong empirical values adopted, can lead to significantly changed calculation results. Again, the results seem to be especially sensitive to adopted K_{ij} and $T_{s,situ}$ values, relatively new quantities still less known. The conducted analyses show that changes of their empirical values, which are still under a debate, can change calculated sound insulation descriptors values by several decibels and, hence, should be chosen very carefully. One should take this into account when implementing EN 12354 models for sound insulation calculations, since the accuracy of empirical formulae for K_{ij} still has to be improved.

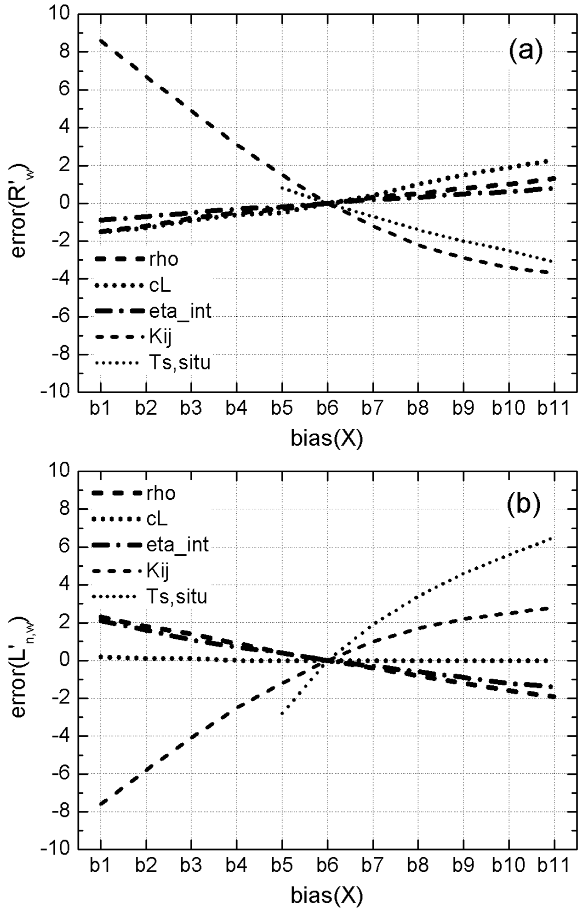

Fig. 4. Error of the sound insulation calculations as a function of analysed parameters bias error (separating ceiling)

The conducted analyses are incomplete in many terms. The lightweight elements were not included. Calculation of sound reduction index (R) and normalized impact sound pressure level (L_n) according to Annexes B of EN 12354-1:2000 and EN 12354-2:2000 were executed for each element, although, it is a common case in practice that their values are available from laboratory measurements. If so, the influence of analysed parameters such as density (ρ), longitudinal wave speed (c_L) and internal loss factor (η_{int}) could be smaller, only through the involvement in structural reverberation time ($T_{s,situ}$ and $T_{s,lab}$) calculations (see Fig. 1). Other room dimensions, wall thicknesses and junction types should also be inspected, in order to get more complete picture of the calculation results sensitivity to the variation of input parameters.

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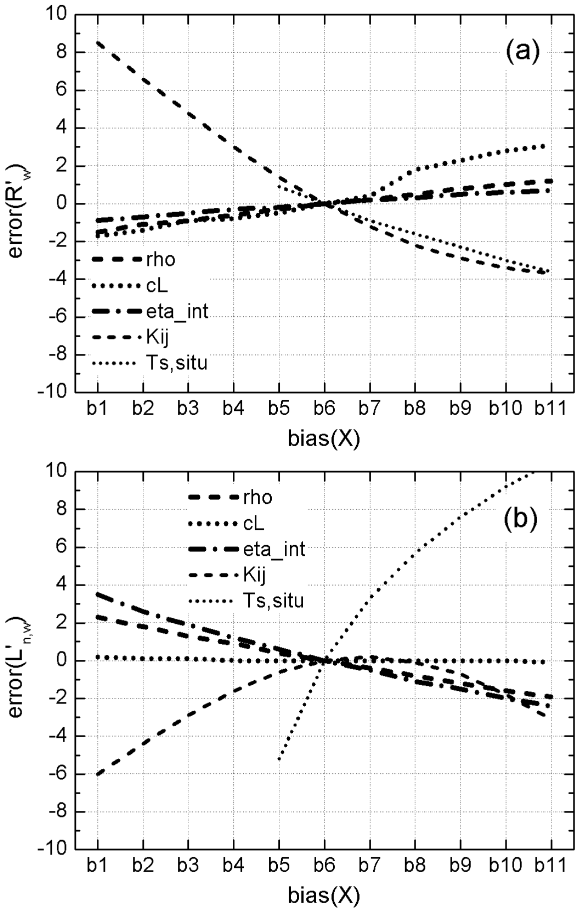

Fig. 5. Error of the sound insulation calculations as a function of analysed parameters bias error (separating wall)

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