OPTIMIZATION IN THE VALIDATION OF THE ROOM ACOUSTIC MODEL

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Abstract
The correctness of the room acoustic parameters simulation always depends on the accuracy of sound absorption coefficients adopted on surfaces. For existing rooms it is usually impossible to specify that values due to limited information about the construction and materials used there. It should be also noted, that acoustic parameters of materials depends on their age, what makes information taken from the literature not accurate. The only help is to measure acoustic parameters of modeled interior, and to calibrate model by changing sound absorption coefficient of surfaces manually to obtain the same values in the numerical model as measured. That methodology could increase the accuracy of the acoustic treatment prediction. In the paper, optimization methods in modification sound absorption coefficients were used for rooms with measured acoustic parameters. Different parameters of chosen optimization algorithm were analyzed as well as a varied condition of a numerical simulation of acoustic parameters. The proper choice of the acoustic parameters for fitness function was also examined.

Keywords: acoustic simulation, optimization, validation

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1 Introduction

Sound absorption coefficient α is the most important parameter discribing materials in room acoustics. It was defined in on the beginning of the XX century by Sabine [1]. Almost one century of using that parameter, reveils, that sound absorption by the structure in real condition is much more complex and could not be described by one parameter and one equation. Using geometrical method allow to increase the precision of the results, by omitting a lot of limitation existing in Sabine formula.
The main source of errors in geometrical methods are not precise values of absorption coefficients of materials. In spite of the detailed procedure described in ISO 354 standard [2], obtained values could differ even over a dozen of percent between laboratories. Diffused acoustic field that is required for the measurement could not be obtained, what results in not uniform distrubution of sound intensity over the sample different in each reverberation chamber. To minimalize that problem, standard require

the chamber volume to be more than 180 m^3. As it was shown before, that value is not sufficient, and the results of α are unreliable especially for a low frequency range [3].
Another source of errors in sound absorption coefficient measurements and modelling is not uniformelly distrubuted density of acoustic energy over the angle of incidence on the sample. Jeong published some corrections that allow to increase the accuracy of modelling the sound absorption in reverberation room [4]. Even small errors in sound absorption coefficients influence especially for low absorbing materials like concrete or wood, as usually there are large surfaces of that kind of materials in enclosure so impact on acoustic parameters are noticeable [5].
In real enclosure, discrepancies in sound absorption coefficient could be a results of the age of materials, montage inaccuracy, different surface area as well as an individual distribution of the sound energy over the space and angle. Sound absorption coefficient measured in a laboratory could be only a basis to real value of the structure in a room. The only possibility of obtaining the actual absorption coefficient are measurements of the sound field of the room, and basing on it, modification of absorption coefficients measured in laboratory in order to obtain the same room acoustic parameters in measurements and numerical model. This method could improve the simulation correctness in the case of renovation of existing interior.
There are two methods of model validation. Pelzer and Vorlander [6] suggested to compare decay curves in ray tracing methods and from the measurement. The main fault of that method is that it require measurement and simulation parameters, that are known only to the programmers and measurement team. More available parameters were used by Christensen and Rinel [7], gaining high compatibility of the mean value of measured and simulated value for all combination of sound source and receiver positions.
In this paper, Christensen's method is developed taking into account different combinations of room acoustic parameters considering correlation between them. Validation of the model was made by modifying the absorption coefficients of structures used in the room in order to obtain the best agreement between distributions of room acoustic parameters in measurement and simulation. The main aim of the paper is to compare the possibility of validating the acoustic model for different acoustic parameters and to find the most favorable combination of them for validation. Scattering coefficient modification was not included in the optimization process, as it has less impact on room acoustic parameters, and characterizes bigger uncertainty of measurements [8]. Optimization function and acoustic simulation different parameters were considered in order to obtain the best results in a reasonable time.

2 Methodology

Two rooms with different geometry and function were analyzed. Acoustic measurements as a basis for the numerical model validation, were conducted according to ISO 3382-1 standard [9] but with very dense grid of receiver to increase the precision of modelling. Omnidirectional sound source was on the heigth of 1.5 m, microphones on the heigth of 1.2 m with required in Standard distances from any surfaces. Geometry and initial setup were prepared in I-SIMPA software. Acoustic simulations were made in SPPS tool, which uses ray-tracing method with integrated sound scattering [10]. The software is available on GPL version 3 license. Open source structure let us to include some necessary changes in the program code. Ray tracing algorithm was run from command line with given parameters of surfaces, receivers and sound sources. Thanks to that it was possible to conduct the simulation with different absorption coefficients calculated in optimization algorithm in Matlab (Figure 3). SPPS tool export echogram, which was used to calculate Schroeder's decay curves and basing on it, ISO 3382 acoustic parameters. Averaging of parameters with different units was possible thanks to the conversion of the values to just noticeable difference values (JND) according to ISO recomendations

(Table 1). As a cost function, absolute value of chosen ISO 3382 parameter distribution difference between measurements and simulation was applied [7].
First analyzed room was a classroom for 60 people with the volume of 215 m^3 where 9 positions of receivers were analyzed. The second room was a concert hall for 650 people with the volume of 6700m^3 for which 44 positions of receivers equally distributed over the room were used [11].

2.1 Optimization

Some nonlinear optimization algorithms were analyzed, but finally Differential Evolution (DE) method was applied. Similarly as in other genetic algorithms, new agents are created on the base of existing ones by some kinds of mutations of the best existing ones. The most important parameters for DE are number of agents for each generations (NP), crossover probability (CR) and differential weight (F). Their proper choice could significantly influence the results and the convergence of generations [12].

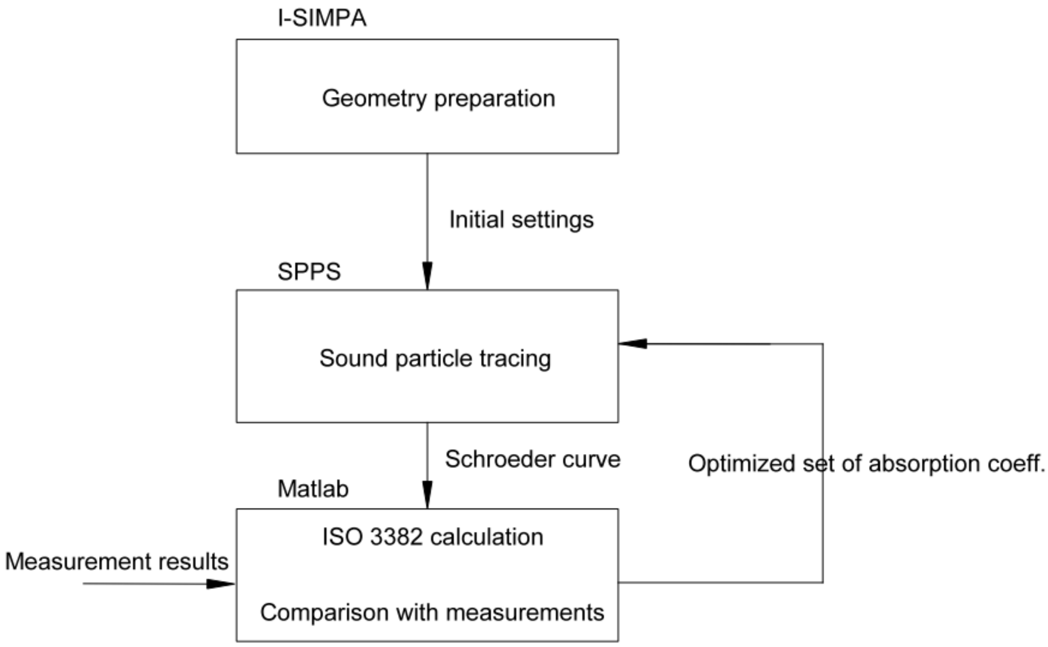

Figure 1 - General scheme of calculation. On arrows there are types of data, in blocks types of calculation made in particular software.

Table 1 – Just noticeable difference for ISO 3382 parameters. For classroom and concert halls mean values for all receivers for mid frequency (500 - 1000 Hz) are given

ISO 3382 parameter	JND value	Classroom	Concert hall
T20	5%	0,59	1,99
EDT	5%	0,48	1,99
C80	1 dB	10,0	-2,2
G	1 dB	16,3	7,0

3 Results

3.1 Optimization parameters

Number of agents (NP) was considered as the most important parameter in DE algorithm. For the same simulation parameters, results of validations for different numbers of NP were compared. At frequency 2000 Hz, optimizations were conducted for NP from the range of 2 to 20 (Figure 2). For each optimization process, there was the same time limit, namely 3000 seconds.

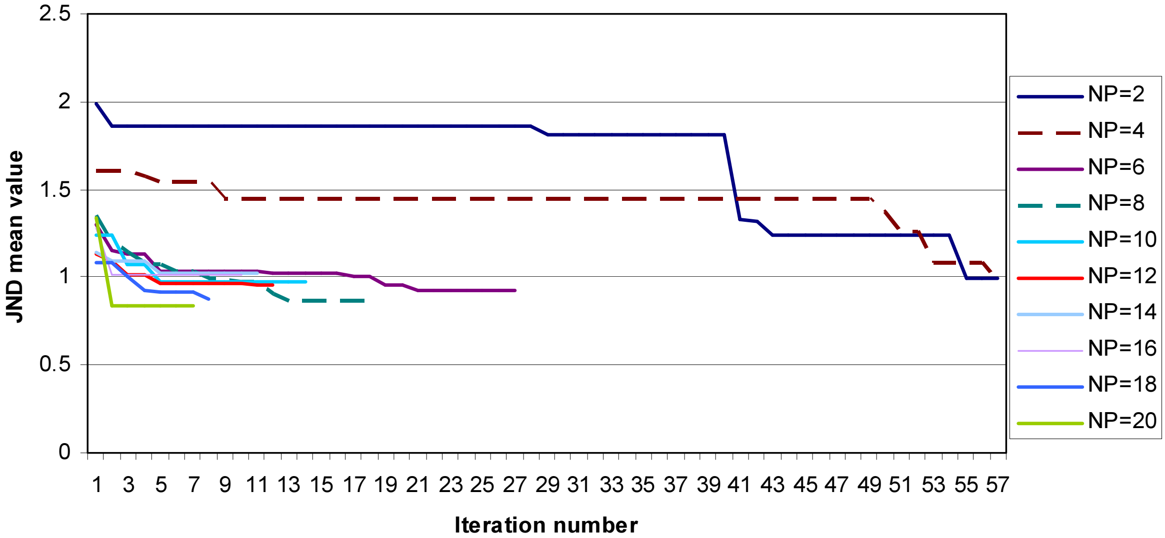

Figure 2 - Mean value of JND depending on the number of agents in each iteration. Optimization made for classroom, as a cost function reverberation time distribution was set.

In the given time, there were similar results for all analyzed NP values. The worst results were obtained for NP=2 and 4, where the final mean value of JND were 0.99 and 0.98. The best results were obtained for NP=8, 18 and 20, respectively 0.87, 0.88 and 0.83. According to literature [12], NP should be at least 10 times bigger than number of input parameters of a given function. In analyzed case, there were 7 different acoustic materials, so 70 agents for each generation gives calculation taking more than hour per generation. As a compromise, NP=8 was taken for which there were good compatibility of final simulation results with measurements and relatively high number of iterations (18), what improve the repeatability of results comparing with 7 iteration for 20 agents.

For NP=8 analysis of crossover probability (CR) parameter was conducted. Absorption coefficients of materials are not correlated, so CR should be low. Lowest value of JND of reverberation time T20 and sound clarity C80 for all receivers, were obtained for CR=0.6 (Figure 3). While searching the best differential weight F, values from the range of 0.4 to 2.0 were analyzed. Lowest mean difference between measurements and simulation was obtained for F=2.0 (Figure 4). But that value of F is not recommended, as it gave high values for 4000 Hz, with 0 for 250 Hz. On the other hand, optimization for F=0.4 does not give so spectacular improvement (mean value 7,64 %), but results are the most similar to measurements (mean value of JND is equal to 1.17), and there is improvement for all frequencies.

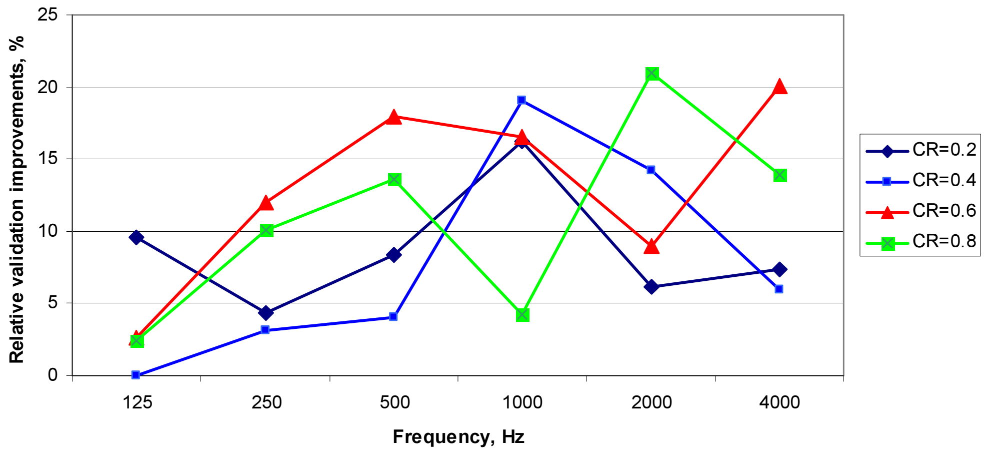

Figure 3 - Relative validation improvements for different crossover probability CR.

Another very important parameter in optimization is a range of input parameters. As it was written before, sound absorption coefficient measurements are quite imprecise, and that parameter could change over time or sound field spatial parameters. Of course, for sound absorbers with measured acoustic parameters, the uncertainty of parameter is much lower, than for materials such as concrete or wooden floor, for which absorption coefficients are usually around 0.1, but the variation could be more than 50 %. That is why in the study for materials such as acoustic panels or ceiling made of mineral wool, there was +/-25% range of possible absorption coefficients applied, while for the rest, +/-50 %. It seems very big, but e.g. for concrete, with α=0.05 at 2000 Hz, it is only between (0.025-0.075). Audience is a special case, where for low frequency, there are big uncertainties due to too small sample size used in reverberation room [13], so for 125 and 250 Hz there was also +/-50% range used.

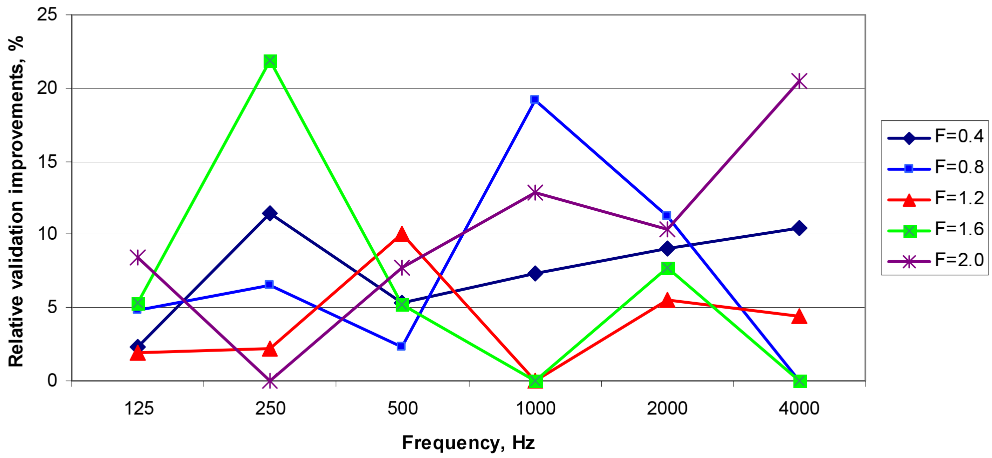

Figure 4 - Relative validation improvements for different differential weight F.

3.2 Acoustic simulation parameters

The most important parameter in ray tracing method is the number of generated and traced rays for each analyzed frequency. That parameter influence not only the time of calculation, but also precision and repeatability of simulation. The proper choice of that parameter is central to proper validation of the acoustic model. Lower number of rays allows to conduct more iterations and results in better agreement with measurements, but obtained values of absorption coefficients are not reliable. In Figure 5 there is a mean value of JND in the function of number of rays used for classroom acoustic simulation presented. Similarly as in the 3.1 paragraph, total time for one optimization process was the same. According to calculation, using less than 30000 rays, gives similar mean values of JND (below 0.8). For more rays, the results are also comparable in the range 0.92 to 1.05. It could be said, that the minimal number of rays for analyzed room should be set to 30000. For next calculations, 40 000 was taken.

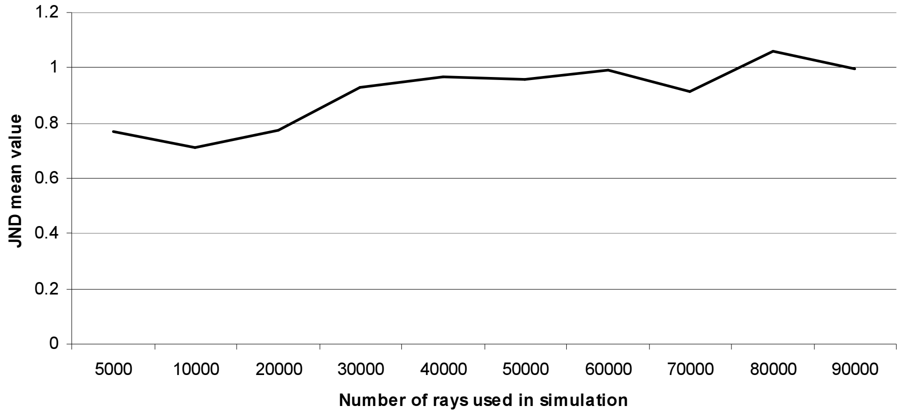

Figure 5 - Correctness of the simulation results versus number of rays used in simulation.

The accuracy of the model's geometry was also analyzed. Results for model with rough and detailed audience were compared (Figure 6). For rough model, only audience block was modeled, while for detailed, construction of tables and chairs were modeled as separate surfaces. In Figure 7 it could be seen, that detailed model gives results closer to measurements for almost all acoustic parameters. The biggest differences are for sound strength G and reverberation time T20.

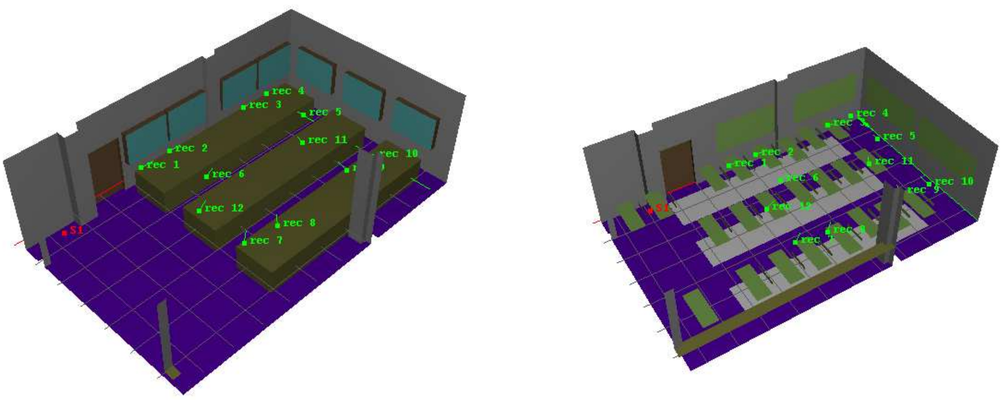

Figure 6 - Rough (on the left) and detailed (on the right) model of analyzed classroom.

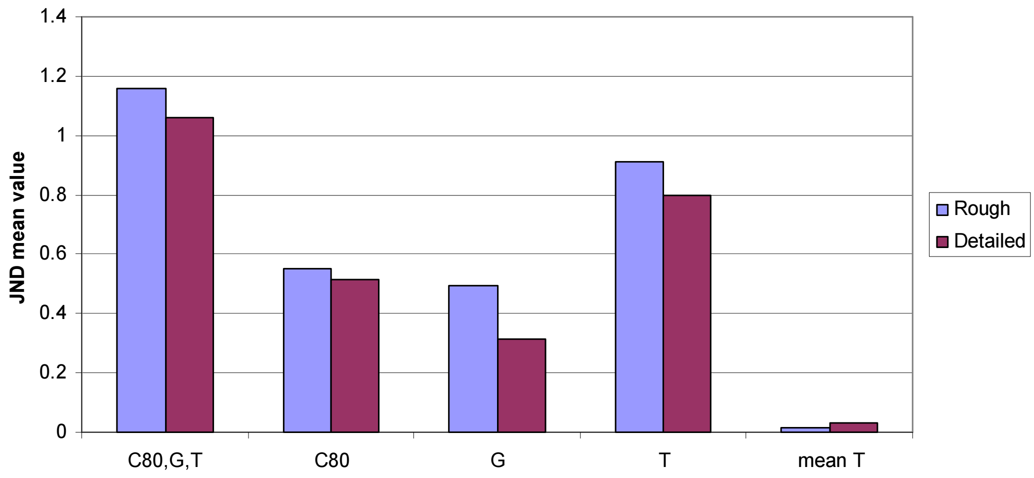

Figure 7 - Optimization versus different acoustic parameters for rough and detailed model of audience

3.3 Acoustic parameters

In choosing parameters to be analyzed, the correlation coefficient between them should be taken into account. Taking many correlated parameters can give very small mean difference between measurements and simulation. Important is also to use only parameters that could be measured and modeled relatively easily and exact. Beranek, basing on measurements in 42 concert halls, shows that the most correlated parameters are early decay time EDT and reverberation time T20 [14]. But it was calculated only for mean value per hall, not for a distribution. Analyzing distribution of parameters in one room, the most similar from measured ISO 3382 parameters are sound clarity C80 and early decay time EDT as well as C80 and sound strength G (Figure 8). To measure G, it is required to calibrate a system in anechoic or reverberation room, what could be a source of additional errors. In the case of EDT, there could be some additional errors in simulation because of problems in simulating exactly the first reflections. So as the most important parameters for validation the acoustic model, reverberation time T20 and sound clarity C80 were chosen.

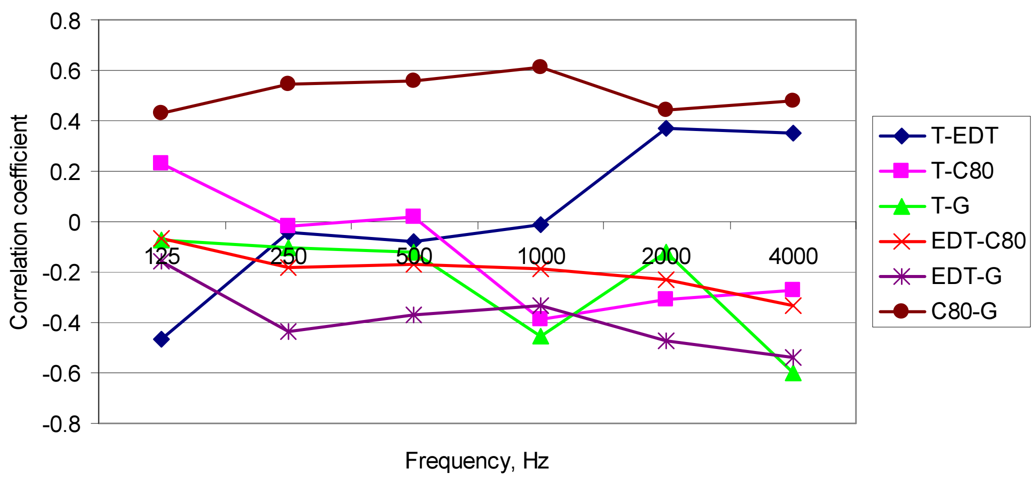

Figure 8 - Correlation coefficients over frequency for distributions of chosen ISO 3382 parameters.

3.4 Optimization results

As it was stated in paragraph 3.3, some ISO 3382 parameters are correlated, so to obtain reasonable values of differences between measurements and simulation, only specific set of parameters should be taken into account. For analyzed concert hall, best agreement between measurements and simulations were obtain for averaged over space value of reverberation time(lower than 0.05 JND for frequencies from 500 - 4000 Hz) (Figure 9). That parameter is used usually in manual validation. Also very low values were calculated for distributions of T, G and C80. But please remember, that G and C80 are correlated, so including them both in optimization process, only decrease results, without validation improvement. Averaging over T and C80 gives the highest values of JND, but is reliable, as that parameters are not correlated. On the other hand, very high difference in distributions of G at 2000 Hz suggest, that for that frequency there could be some calibration error.

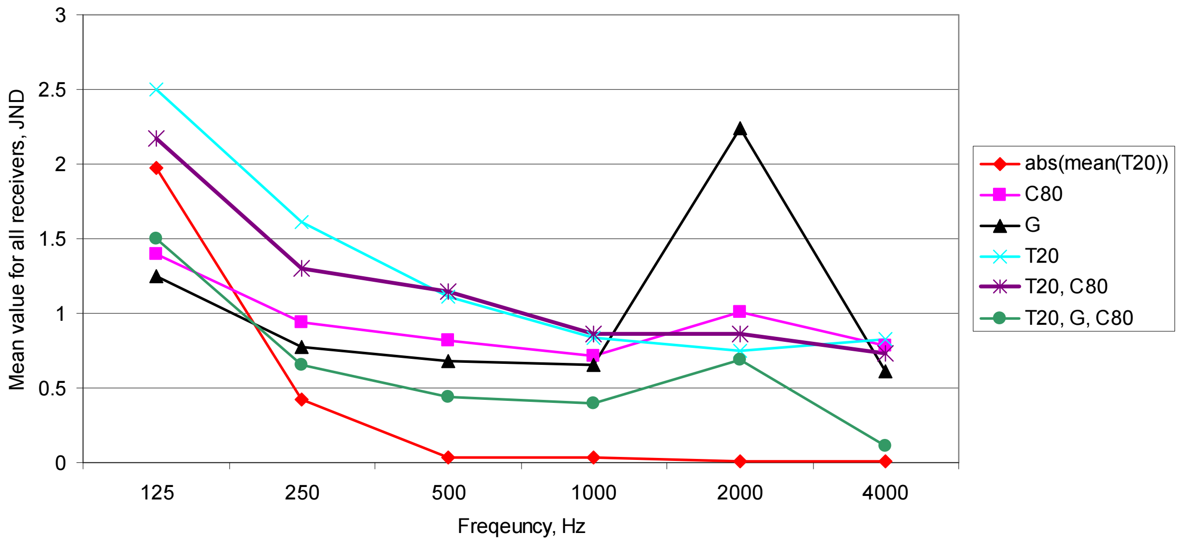

Figure 9 - Mean values of differences between measurements and simulation for optimization taking into account different acoustic parameters. Optimization made for the concert hall.

For classroom, mean value of JND over all receiver for reverberation time T20 is very small for all frequencies. For single parameter optimization (G or T20) there are lower values of JND, while for combinations, even for high frequencies, there are values over 1.0. That confirms that these parameters are not correlated and it is more difficult to validate model taking them into account.

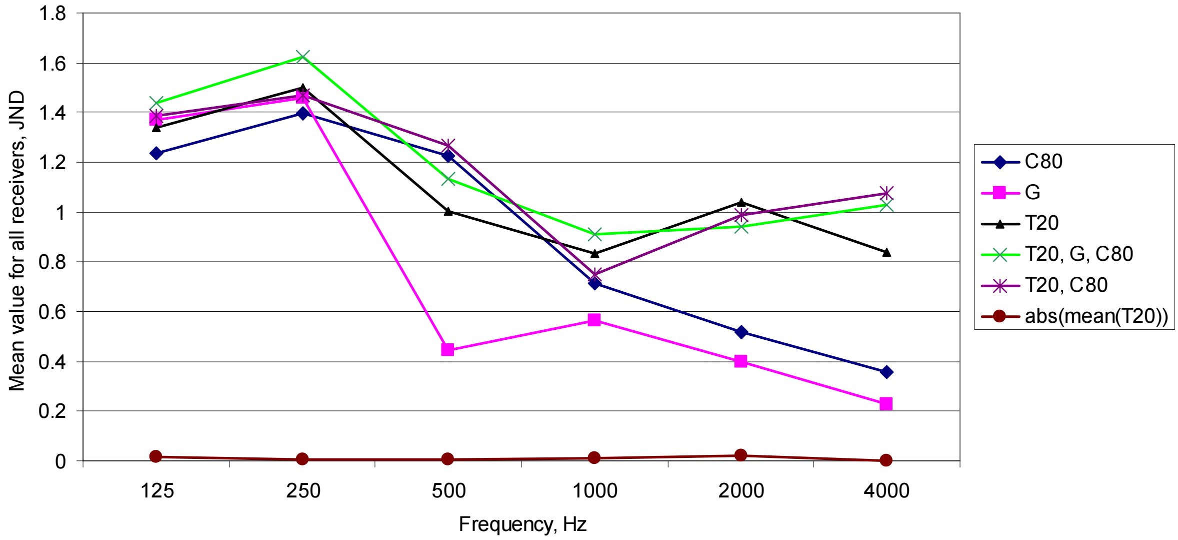

Figure 10 - Mean values of differences between measurements and simulation for optimization taking into account different acoustic parameters. Optimization made for the classroom.

4 Conclusions

Validation of the room acoustic model is a very complex task because of the non repetitive measurement results of absorption coefficient of materials and structures, as well as a variation of parameters over time and position against sound source and acoustic field inside a room.

In the paper, differential evolutionary optimization algorithm was used in finding absorption coefficients of materials used in acoustic model, in order to obtain the best agreement between measurements and simulation. Optimization algorithm used to solve a problem, turn out to be a very effective tool. Best value of crossover probability (CR) and differential weight (F) were find, as well as a suggested number of rays used in simulation of specific room. Basing on correlation between parameters and differences between measurements and simulation, reverberation time T20 and sound clarity C80 were indicated as giving the most reliable results of validation. Mean value of difference between distributions of T20 and C80 for the classroom as well as for the concert hall was about 1 JND.

Future improvement of a method should take into account some spatial parameter like LF or IACC. It require not only additional measurement using figure of eight or binaural microphone, but also spatial information about rays hitting the receiver.

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