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Acquisition of boundary conditions for a room acoustics simulation comparison

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Abstract

Room acoustics simulations are often validated by comparing the simulation results with measurement results of an existing room. The results obtained with the simulations, however, strongly depend on the input data, in particular the boundary conditions. For geometrical acoustics simulations, it is generally sufficient to describe the acoustical properties of walls and surfaces by absorption coefficients. These can be determined by classical methods, such as impedance tube measurements or by conducting a reverberation chamber measurement. For existing rooms however, it is preferred to acquire the boundary conditions by in-situ measurements or look up the data in absorption coefficient databases. Another option is to determine the absorption coefficient by an inverse calculation based on the measured room impulse responses of the investigated room. This work presents and compares the boundary conditions determined by the different mentioned methods and their impact on the simulation results in case of a practical scenario.

Keywords: room acoustic simulation, validation, input data, boundary conditions

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1 Introduction

If room acoustics simulation models are applied in research and/or the industry these models should have been validated for similar use cases. Such a validation can be done by referencing simulation results to measurements of an existing space. While a standardized room acoustics measurement is regarded as an established tool to describe the acoustical behaviour of the room with sufficient accuracy, the simulation process includes a great amount of variability and uncertainties leading to substantially different results [1]. The user has to choose from several methods to acquire and define data for the boundary conditions, has to model the room geometry appropriately and a suitable simulation model has be selected and configured. All these aspects might lead to relevant deviations of simulation results ran by two different users, even if all other parameters are kept identical.

Several validations of room acoustics simulations have been conducted in the past, often containing very simple, controlled scenarios (e.g. [2]) or representing typical examples for the application of the investigated simulation model [3][4].

The three previous international Round Robins on room acoustical simulations represent the most comprehensive comparison of several simulation solutions to measurements. Recently, a new comparison of simulation software, the first international Round Robin on Auralization was initiated by the SEACEN research group (see http://rr.auralisation.net for more information). Within this project, multiple rooms and scenarios relevant to room acoustics simulation are analysed and compared in listening experiments.

Round Robin on room acoustical simulation

The first organized comparison of room acoustic simulation software was conducted in the mid-90s by the PTB Braunschweig [5]. In total 14 participants submitted simulation results for a mid-sized auditorium. Single number room acoustic parameters for the 1 kHz octave band were compared. In the later round robins the evaluation was extended to more octave bands, the investigated room was a Swedish concert hall in the second Round Robin [6] and a music studio in the third Round Robin [7][8]. The first two comparisons each contained two phases, in which the boundary conditions of the rooms were either described verbally and by images, or by providing a set of absorption (and diffusion/scattering) coefficients. As in the first two round robins the phases containing a free parameter choice lead to large deviations of the results, in the third round robin, only one phase was conducted using a predefined set of values for the boundary conditions of the room.

Although results of the established modern simulation software might be more consistent today, variations are still to be expected, especially for sensitive parameters and auralizations. In the first phase of the current round robin boundary conditions are provided, in the second phase the measured results of the scenarios will be published and all participants will get the chance to match their simulation results to the measured data. This work discusses the procedures for the acquisition of both phases, measurements of materials as well as inverse calculations based on room acoustics measurements. The focus of this paper is on the impact of different absorption coefficient datasets on the room acoustics simulation results.

2 Acquisition methods of boundary conditions

2.1 Standardized measurements of absorption coefficients

The two standard measurement methods for determining absorption coefficients of materials are the reverberation chamber method [9], which has the restriction that only a diffuse sound field absorption coefficient can be determined and a large laboratory room is required, and the impedance tube method [10], which can only be used to determine the normal incidence absorption. The reproducibility of these measurements is rather poor. Significant deviations between repeated measurements of the same laboratory and also between laboratories have been observed [11] [12]. These uncertainties dominate the overall uncertainty of computer simulations [1]. Furthermore, these methods are not suited for validation projects in practice, because it is challenging to prepare samples for the measurements, as surfaces and objects in rooms often do not have the suitable dimensions cannot be easily extracted.

2.2 In situ methods

To be able to measure the materials as used in the application it is necessary to measure in situ absorption coefficients. There exist a number of different approaches to make this possible. For instance, the subtraction method [13] where the incident and reflected sound wave are separated in the time-domain to determine the reflection coefficient. Another approach is to use a measurement probe with both a pressure and velocity sensor (PU probe) to directly calculate the local impedance [14][15]. The general problem with these existing in situ methods is the necessity to make an assumption of the type of wave field. Since it is not possible to identify or control the type of wave field as in the methods mentioned in 2.1, this results in different results for the same material, but placed in different wave fields. Limitations due to the selection as well as the positioning of sound sources and sensors as well as calibration issues also lead to substantially different results for some materials and to a limited valid frequency range of in situ methods [16].

2.3 Inverse approaches to calculate parameters

Recently, some approaches have emerged to inversely determine absorption coefficients for room acoustic simulations [17] [18]. These approaches are based on an optimization process adjusting the absorption coefficients of a room acoustical simulation until the simulated results match the room acoustic measurement. If the assumption is made, that the applied simulation model accurately models the sound propagation in rooms, this technique provides another way of determining the characteristics of the room materials. Such a method, using a genetic algorithm, was also integrated in the room acoustic software ODEON [19]. Here, the optimization stops if a target parameter, e.g., T30, has reached the measured value. In

Section 3.2, this method is referred to as *inverse Odeon*. For the *Raven* simulation software [20], a more detailed method was proposed, which optimizes the reflection paths of ray tracing particles in an efficient process until the energy decay curve of the measurement is matched ("*Raven EDC")* [17]. The method used for the *Raven RAP* input data uses a simplified optimization process comparing only the resulting room acoustic parameters of the *Raven* simulations instead of considering reflection patterns. More details and comparisons regarding these approaches will be part of future publications.

3 Example comparison of acquisition methods

3.1 Absorption coefficients of an absorber measured with different methods

Whenever the boundary conditions for room acoustics simulations have to be acquired, it is not only the question of the measurement method, but also of the selection of the investigated situation. The distances from source to the materials and the angle of incidence of the reflection are two parameters which describe the situation of the acoustical reflection in more detail. While for geometrical acoustics simulation, the application of random incidence absorption coefficients, measured in reverberation chambers, is established, other research investigates the relevance of angle dependant absorption or reflection modelling for the simulation models [21][22]. Thus, in addition to the measurement uncertainties and reproducibility problems of standardized laboratory methods (see Section 2.1), the discrepancy between measured situation and the situation in the simulated scenario is another source for deviations of simulated results. To demonstrate the range of these effects, four different measured absorption coefficients of the same material (stone wool ceiling tiles) are compared in Figure 1.

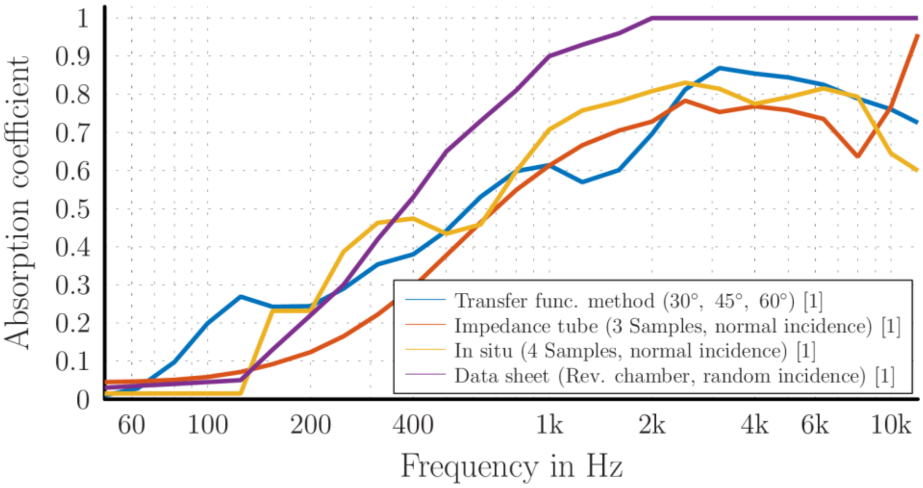


Figure 1: Absorption coefficients determined by four different measurement methods

The data of the blue curve was measured using a transfer function methods. The reflection at the material (size: 4.2m*4.2m) was measured in a hemi-anechoic chamber for a reflection path length of 6 m and compared to a free field response of the same source and distance. This was done for three angle of incident (30°, 45° and 60°), the average of these three measurements is displayed. The second absorption coefficient dataset (red curve) was measured according to ISO10534 in the impedance tube (four microphones in a tube with a diameter of 2”) and can be directly compared to the in situ measurement (yellow curve) as both are measured for normal incidence. The in situ measurement was done with an *impedance gun* including a *microflown* PU-probe. The distance of the sensor to the material was 20 mm; the loudspeaker-material distance was 535 mm. The last dataset (purple curve) is provided by the manufacturer of the material for the frequency range from 125 Hz up to 4000 Hz. Lower and higher frequencies are estimated according to a typical expected behavior of a porous absorber. The measured values are based on a reverberation chamber measurement according to ISO354. The comparison shows that not only the angle of incidence can have a substantial effect on the measurement results, but also the selection of different measurement methods (impedance tube vs. in situ measurement) can lead to absolute deviations of more than 10%. Additionally, it should be considered, that the kind of material, a porous absorber is less prone to relative deviations as a large amount of the reflected energy is absorbed, especially in the higher frequencies.

3.2 Impact of differently acquired boundary conditions on simulation results

A practical scenario was investigated by a student who is experienced with room acoustics simulation. Without knowledge of the room acoustics measurement results, he was instructed to simulate the room acoustics using two different simulation tools. The first task was to inspect the room and collect datasets for the boundary conditions from available databases and literature. In a second step additional input data sets based on in-situ measurements and inverse calculation models were provided and should be also be applied for the room simulations.

3.2.1 Investigated scenario: Empty seminar room

The room (see Figure 2) was chosen as an example for a small enclosure ($V=145\ \mathrm{m}^3$, $S=188\ \mathrm{m}^2$) within the recently initiated round robin on auralization. It is unfurnished and does not contain any room acoustic treatment or special materials. The room shape can be roughly characterized by a shoebox, two corners contain cuts leading to ten main faces in the 3d model. Five different materials were assigned to the surfaces of the room for the room acoustical simulation.

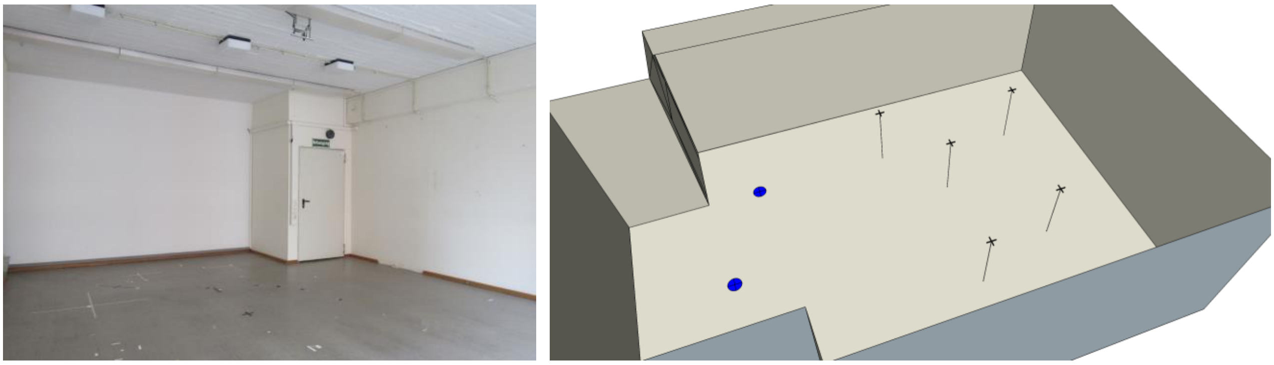
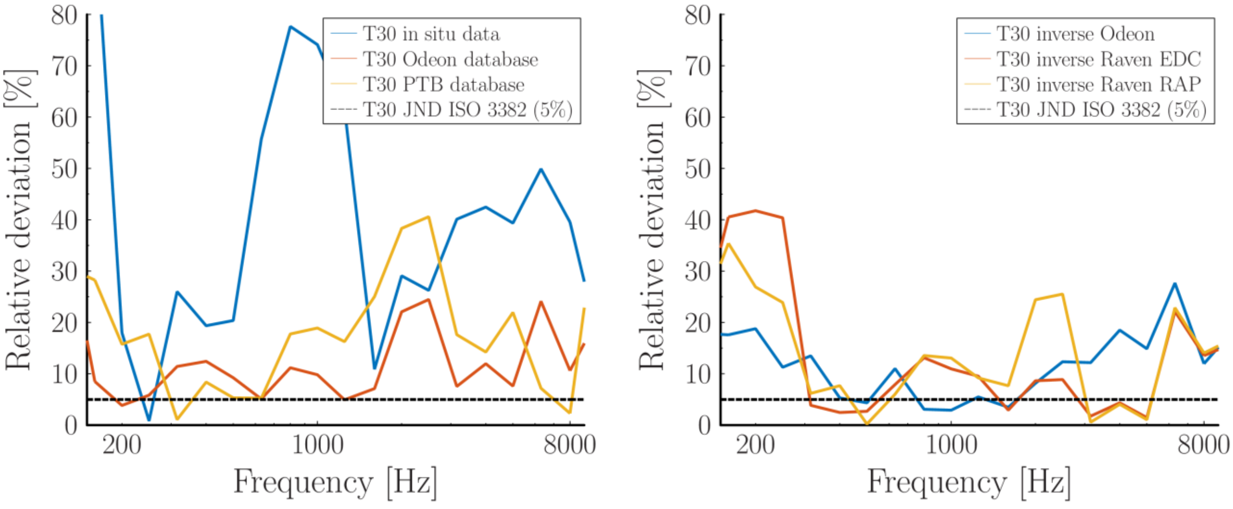


Figure 2: Photograph of the empty seminar room (left), 3d room model of seminar room (right). Blue circles indicate the sound source positions; black crosses show the microphone positions

3.2.2 Simulations with the room acoustic software *Raven*

The first applied simulation model is the software *Raven*, which uses a hybrid model combining image sources and a ray tracing algorithm [20]. For all simulation results, early reflections up to the second order were calculated, the ray tracing used 10,000 rays per octave band. A diffuse-rain scattering model was applied, although for most materials, the scattering coefficients were rather low (between 0.05 and 0.1). *Raven* uses third octave absorption coefficients from 20 Hz to 20 kHz. Missing data in some datasets (i.e., for low and high frequencies) was inter- and extrapolated. The simulation engine provided monaural room impulse responses which were processed in MATLAB with the ITAToolbox [23] to obtain the room acoustic parameters T30 and C80 in third octave bands.

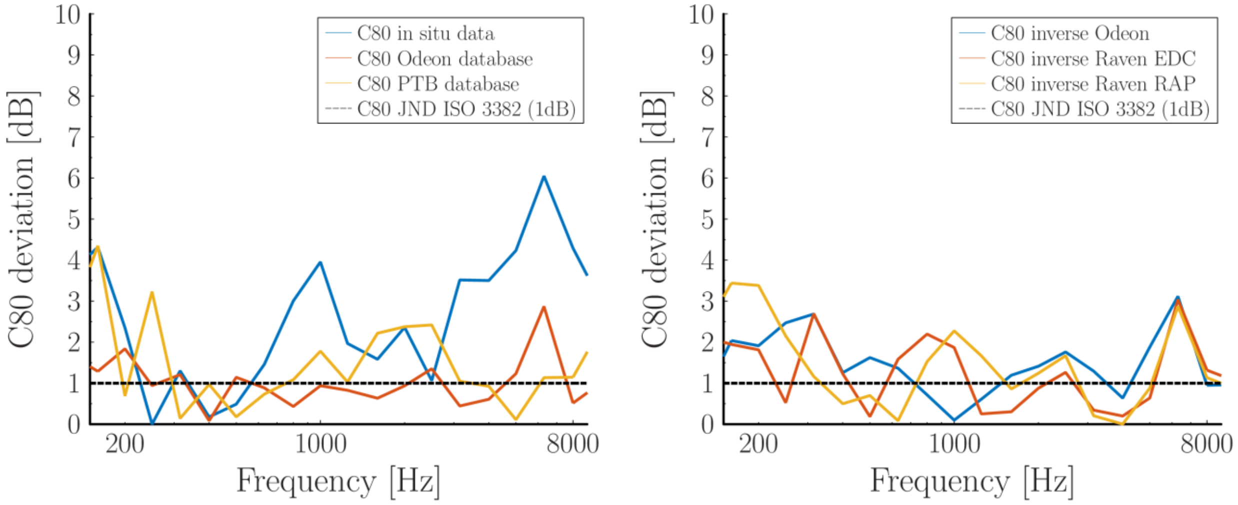
Figure 3 shows the relative deviation of the simulated T30 values compared to the results of the measurement for identical receiver and source positions. In total six different material datasets were selected for the simulations. In the plot on the left hand side (a), an absorption coefficient dataset is based on an in situ measurement with a *microflown* PU probe (sensor distance: 20 mm, loudspeaker distance: 535 mm) and two database datasets are compared to the measured values. The first selected database is the one included in the ODEON software, the other coefficients are originated from the database provided by the PTB Braunschweig [24]. Graph (b) shows the deviations for three input datasets determined by different inverse techniques, as described in Section 2.3. The same six input datasets are also shown for the remaining figures 5-7. No absolute values of simulated and measurements are given as the investigated room is part of the current round robin on auralization and no information about the measured results will be published during the first phase of the comparison.



(a) **(b)**

Figure 3: Relative deviation of reverberation times (T30) for *Raven* simulations based on differently acquired absorption coefficients (a) and based on different inverse models (b)

All input datasets show substantial deviations mostly above the JND of the reverberation time. Especially the *blind* estimation based on the in situ data and the database values show errors ranging from 10% up to almost 80% in case of the in situ data. This situation is improved, as expected, for the inversely determined dataset; the deviations however are still mostly above the JND of 5%. Here, one would expect that for the inverse datasets of the *Raven* methods, the deviations would converge towards 0% as T30 was the parameter the absorption coefficients were matched to. There are several reasons why this is not the case: The inverse model did not consider scattering in the simulation, and it was done by another person who used a different configuration of the simulation. As this research has the goal to investigate the practical implications of using different input data for room acoustic simulation, there was no communication beforehand between the person preparing the *Raven* inverse datasets and the person conducting the simulations. Figure 4 shows the clarity parameter evaluated for the same simulations. The database values from ODEON and PTB databases do not strongly differ from the measurements. For the inverse calculations, the same tendency can be observed as for the T30 results: Deviation decreases and is in the range of 1 dB above or below the JND of 1 dB.



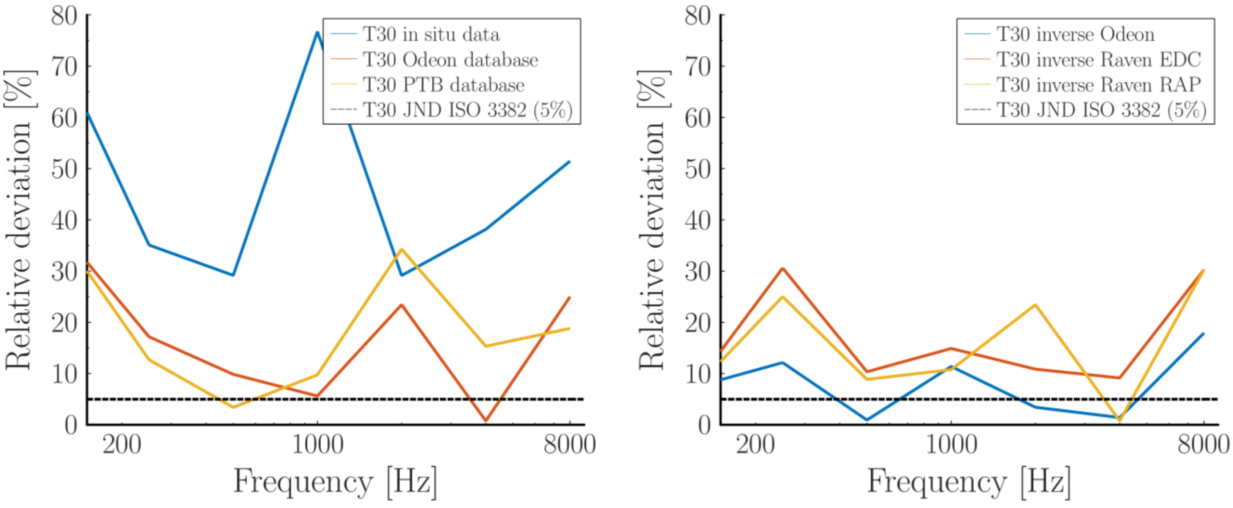
(a) (b)

Figure 4: Deviation of clarity parameter (C80) for *Raven* simulations based on differently acquired absorption coefficients (a) and based on different inverse calculation models (b)

3.2.3 Simulations with the room acoustic software ODEON

The simulations were conducted with the software ODEON 14 *Auditorium*, the number of rays was set to 10,000 and the transition order was 2. A single valued scattering coefficient was selected to approximately match the curves for the scattering coefficients used in *Raven*. To generate the input parameter set *inverse Odeon* the *Genetic Material Optimizer* was selected to optimize the material for the parameter T30. Not all measured positions were passed to the optimizer, but only one representative position was selected to also emulate insufficient documentation of measurements and simulation in practice. In ODEON absorption coefficients are defined for octave bands in the frequency range from 63 Hz to 8 kHz.

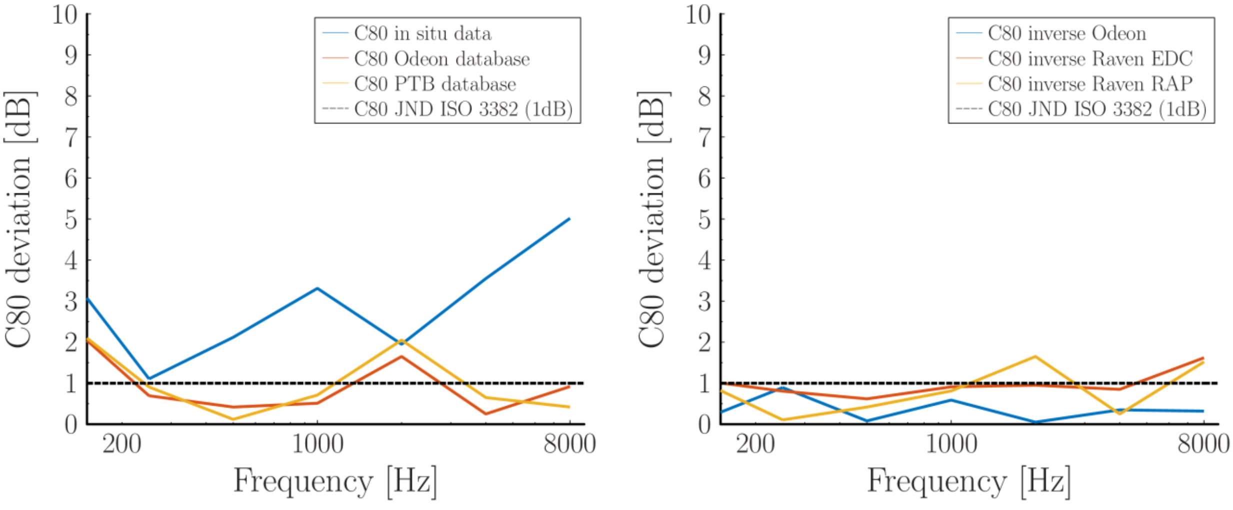
Figure 5 shows the relative deviation of the T30 parameter evaluated for the simulation results using the six different absorption coefficient datasets. The output parameters were directly provided by the ODEON software for octave band frequencies. The general deviation of all input datasets is similar to the T30 curves for the *Raven* software (cf. Figure 3), which indicates that the simulation models do not react differently to varying absorption datasets. Due to the octave band evaluation, the overall deviation seems to be slightly lower and especially the *inverse Odeon* simulation shows acceptable results with deviations below the JND for some frequencies.



(a) (b)

Figure 5: Relative deviation of reverberation times (T30) for ODEON simulations based on differently acquired absorption coefficients (a) and based on different inverse models (b)

The deviation of C80, shown in Figure 6, calculated by ODEON is slightly above or below the JND of 1 dB for all datasets except for the in situ data. The results of the database values of the PTB and ODEON are mostly below the JND, while the absorption coefficients based on the inverse calculations, especially *inverse Odeon* and *inverse Raven EDC*, lead to the best results using ODEON, if evaluated for octave bands.



(a) (b)

Figure 6: Deviation of clarity parameter (C80) for ODEON simulations based on differently acquired absorption coefficients (a) and based on different inverse calculation models (b)

4 Conclusions

In this research, the challenge of providing input data for the validation and comparison of room acoustics simulation software is discussed. Absorption coefficients can either be acquired by collecting and processing data from manufactures of room materials, looking up values in absorption databases or by in situ measurements based on different techniques.

A practical scenario, a relatively small room, was investigated using two established simulation tools. The deviations of two room acoustic parameters, T30 and C80, were analyzed for both simulation tools and for six different absorption datasets. Especially for the reverberation parameter, the deviations are well above an acceptable deviation for the most input data sets. In general, simulations without the knowledge of measurement results are likely to lead to deviations greater than the JND of the analyzed parameters, while inverse processed input data based on room acoustic measurements, lead to a reduced error of the simulation results. Although this is expected, it should be noted that the inverse data, if generated by another software or user with possibly different configurations, will not automatically lead to very good simulation results using this data.

Yet, the idea of optimizing input data is promising and is topic of ongoing research. Especially the applied scattering coefficients and scattering models have to be considered to improve the quality of the optimization result.

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