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ABSTRACT

A previous study by the author showed that varying the geometric detail level across a normal range for room acoustic computer modeling has little effect on the results of those computer simulations, if major surfaces in the hall are still constructed accurately. Scattering coefficients were kept constant across all detail levels. If one were using lower levels of detail, though, one might assign different material scattering coefficients to compensate for the less mixing geometry. To study the interaction between model detail level and scattering coefficient selection, three performance spaces in Omaha, Nebraska have been modeled in ODEON at varying levels of detail. The lowest level studied represents the spaces simply as six-sided boxes. Each level of detail is tested with five scenarios of scattering coefficients. Of all the objective parameters studied, reverberation time is confirmed to be the most sensitive to scattering coefficient selection, and preliminary results show that it is more so in rooms of lower model detail level. Across the different rooms, however, parameters do not consistently change in an increasing or decreasing manner with varying scattering coefficient; this behavior may depend on the room's absorption characteristics.
KEYWORDS : Computer Modeling, Scattering

INTRODUCTION

Computer modeling of room acoustics has become a popular tool in the past two decades. The process involves entering a geometric model of the room into the software program, characterizing the material properties of its surfaces (both absorption and scattering coefficients), defining the locations and directional characteristics of sources and receivers, and then running a prediction algorithm to predict the impulse response between source-receiver combinations. Two of the most highly-regarded programs, ODEON and CATT-Acoustic, implement a hybrid prediction method that involves both the image source method and the ray tracing method [1-3]. From the impulse response, many objective parameters may be calculated, such as the reverberation time (T30) and clarity index (C80).

Previous studies have documented the accuracy of the results from these programs against actual measured data, demonstrating a sensitivity to user experience and choice of absorption coefficients [4-6]. Less well understood is how results are affected by the level of model detail. A previous study by the author sought to quantify the level of model detail, based on the number of surfaces in a model divided by the total volume [7]. After polling users of room acoustic computer modeling software, the levels of model detail typically utilized were stratified into three ranges, as shown in Table 1. A recital hall was modeled at each of these three levels, while all other user inputs, such as absorption and scattering coefficients, were kept constant between the models. Comparison of the objective results showed that varying the detail level across this typical range has little effect on the results of the computer simulations, if major surfaces in the hall are still constructed accurately.

Table 1. Suggested characterizations of a computer model's level of detail using the ratio of number of surfaces over total volume.

Level of Detail	**# of Surfaces/Volume (m^{-3})**
Low	0.003 to 0.010
Medium	0.010 to 0.015
High	0.015 to 0.030

The lower the model detail becomes, however, the more likely it would be for a user to compensate by assigning different (presumably higher) scattering coefficients to the surfaces, so that simulated results would match actual outcomes. The current study focuses on the interactions between the level of model detail and selection of scattering coefficients.

The use of scattering coefficients is not popularly understood, although much research has recently been focused in this area. Sound energy in an enclosed space may be specularly or diffusely scattered at room boundaries; contributions of the diffusely scattered energy are significant and can be perceived [8]. This energy should therefore be modeled in acoustical prediction software. Software developers have found multiple ways of accounting for non-specularly reflected energy [9], most commonly involving the assignment of a scattering coefficient to each surface. The scattering coefficient is defined as the ratio of non-specularly reflected energy over total reflected energy. Ambiguity exists on how to quantify this coefficient for various materials and surfaces in rooms. ISO standards have been promulgated, based on work by Vorländer and Mommertz [10]; others suggest visual inspection [11-12]. The User's Manuals of both CATT-Acoustic and ODEON provide general guidelines as well [13-14].

Lam has conducted research on the selection of scattering coefficients for good correlation between computer modeled and physical spaces. In one study using physical scale models, he found that the appropriate scattering coefficients for accurate results were practically the same across seven halls of various sizes and shapes, except slightly higher in models of more complicated shapes and at lower frequency bands of larger models [15]. The research involved the use of ODEON, so the choice of transition order also had an effect. The transition order, where the image source method transitions to the ray tracing method in

ODEON, appeared to be more dependent on hall shape than size, particularly in those where early reflections are important. Another interesting finding is that reverberation time was the parameter most affected by scattering coefficients, in comparison to clarity index and sound level. The study was extended to correlate simulated data from ODEON to measured results in eight full-size halls with similar results [16]. Defining scattering coefficients across frequency and including directivity of scattered energy were suggested to further improve computer modeling accuracy.

The above work did not specifically describe how the choice of scattering coefficients may affect different models of varying level detail, though. Dalenbäck has described that a room with non-uniformly distributed low absorption and a non-mixing geometry would have a reverberation time most sensitive to scattering coefficient selection [17], since a higher scattering coefficient would redirect sound energy to other surfaces with higher absorption coefficients. A "non-mixing geometry" describes a space in which the shape of the room and the architectural elements within it do not cause a diffuse sound field; a room model of lower detail level could be considered as such.

This study focuses on the interaction of scattering coefficient with the level of model detail. We are interested in determining how objective parameters from computer room models of different detail level vary, depending on selection of scattering coefficients. Creating models of lower detail may save users of room acoustic computer simulation programs a great deal of time, but does the selection of scattering coefficient become more critical in these cases?

METHODOLOGY

Three existing spaces in Omaha, Nebraska were modeled in ODEON Version 6.5 for this project: two recital halls and a black box theater. The models were built at varying levels of detail, as shown in Table 2. For the lowest levels of detail, the halls were simply represented as six-sided boxes. The materials in each hall were noted by inspection and then absorption coefficients were assigned to the computer model's surfaces, based on the most appropriate data available in ODEON and/or literature. Note that no attempts were made to calibrate the models to the real halls, since none of the predicted data are to be compared with measured data.

Table 2. The various models used in this project, their geometric characteristics and associated ratings for detail level.

Room	# of Surfaces	Volume (m^3)	# of Surfaces/Volume (m^{-3})	Detail Level
Witherspoon Hall (W1)	6	7876	0.76×10^{-3}	Very Low
Strauss Recital Hall (S1)	6	6329	0.95×10^{-3}	Very Low
Black Box Theater (BB)	6	4286	1.4×10^{-3}	Very Low
Witherspoon Hall (W2)	54	7876	6.8×10^{-3}	Low
Strauss Recital Hall (S2)	114	6329	18.0×10^{-3}	High

The purpose of this study is instead to focus on the differences between objective results from the computer simulations of each room using various scattering coefficient scenarios. The objective measures studied include reverberation time (T30), early decay time (EDT), clarity index (C80), and lateral energy fraction (LF80). The scattering coefficients (SC) of all surfaces in the halls were varied simultaneously from 0 to 0.1, 0.3, 0.5 and 0.8. The uniform assignment of scattering coefficient certainly does not simulate reality, but provides an initial simplification to create circumstances in which differences may be clearly observed.

Results between a source on the front center of the stage and a receiver position approximately midway back in the audience and slightly off-center were analyzed in each model, using a transition order of 2 for all cases as generally recommended by ODEON [14]. Comparisons have been made between parameters predicted at SC = 0.1, 0.3, 0.5, and 0.8 to the parameters predicted at SC = 0. The variations from the base case of SC = 0 have then been evaluated against the just noticeable differences (JND) that have become commonly accepted for these objective measures [5, 18], as listed in Table 3.

Table 3. The just noticeable differences (JND) for each objective measure, against which differences from varying scattering coefficient scenarios are compared.

Objective Measure	**Just Noticeable Difference (JND)**
Reverberation time (T30)	5%
Early decay time (EDT)	5%
Clarity index (C80)	1 dB
Lateral energy fraction (LF80)	5%

RESULTS

Figure 1 shows the results from the models closer to and within the range of normal detail levels (BB, W2 and S2). The data shown are averaged across all frequency bands and presented in absolute number of JNDs. This plot corroborates previous findings that the scattering coefficient selection affects the reverberation time prediction much more than the other three parameters [15-16]. Clarity index and lateral fraction changes are less than one JND for almost all cases of SC selection.

Focusing now on reverberation time and its trends across frequencies (low, mid and high), one finds that the equivalent number of JNDs observed due to SC selection is least at the high frequencies (Figs. 2-4). This is to be expected because air attenuation has a greater effect at high frequencies. Air attenuation is constant regardless of the amount of scattering, so scattering coefficients ought to affect parameters less.

Figures 2-4 also demonstrate clear differences in behavior across halls. The data for BB and W2 remain fairly constant across SC within each frequency range and in the positive numbers of JND range (indicating an increase in T30 compared to the base case of SC = 0). The data for S2, though, tends to vary more and is situated in the negative numbers of JND range (indicating a decrease in T30).

Figure 1. The effect of scattering coefficient selection on the four objective measures studied for three models that are close to or within the normal range of model detail level. Data are shown as absolute numbers of JNDs in comparison to a base case of SC = 0, averaged across all frequency bands.

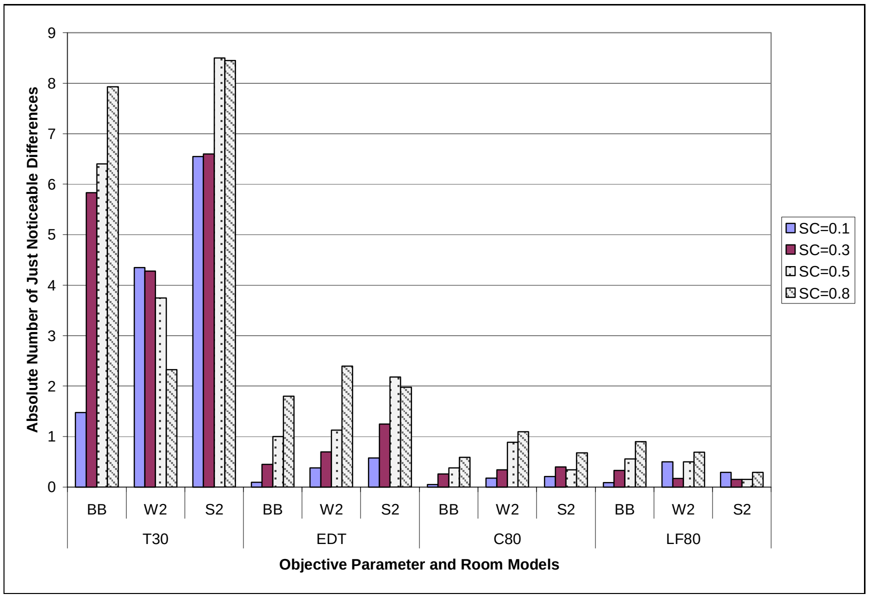


Figure 2. The effect of scattering coefficient selection on reverberation time (T30) in the low frequency range (averaged across the 63 Hz to 250 Hz octave bands). Data are shown as numbers of JNDs in comparison to a base case of SC = 0.

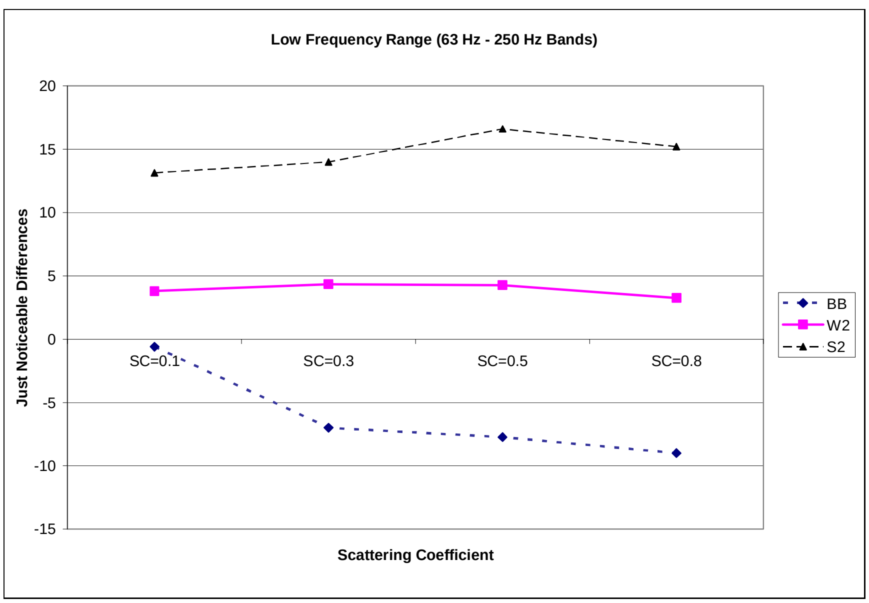


Figure 3. The effect of scattering coefficient selection on reverberation time (T30) in the mid frequency range (averaged across the 500 Hz to 2 kHz octave bands). Data are shown as numbers of JNDs in comparison to a base case of SC = 0.

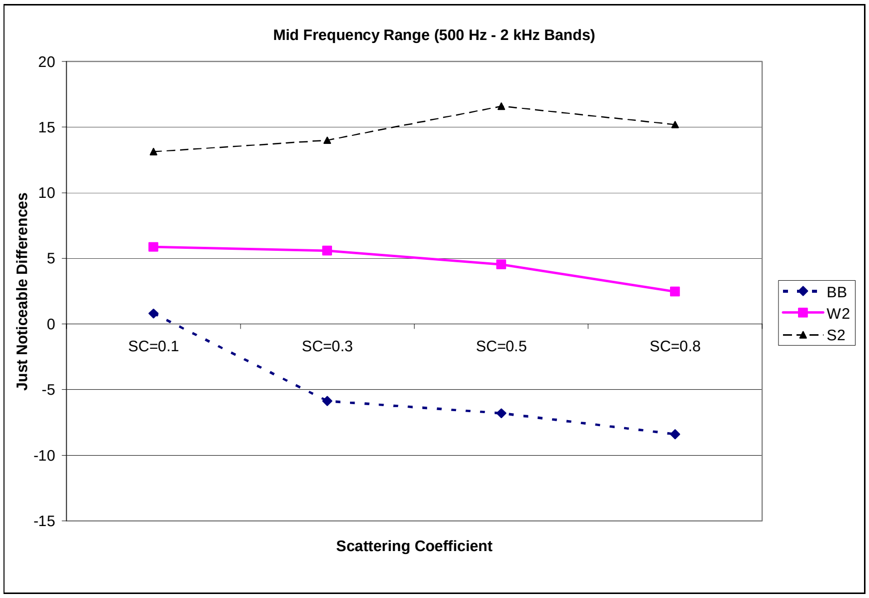


Figure 4. The effect of scattering coefficient selection on reverberation time (T30) in the high frequency range (averaged across the 4 kHz to 8 kHz octave bands). Data are shown as numbers of JNDs in comparison to a base case of SC = 0.

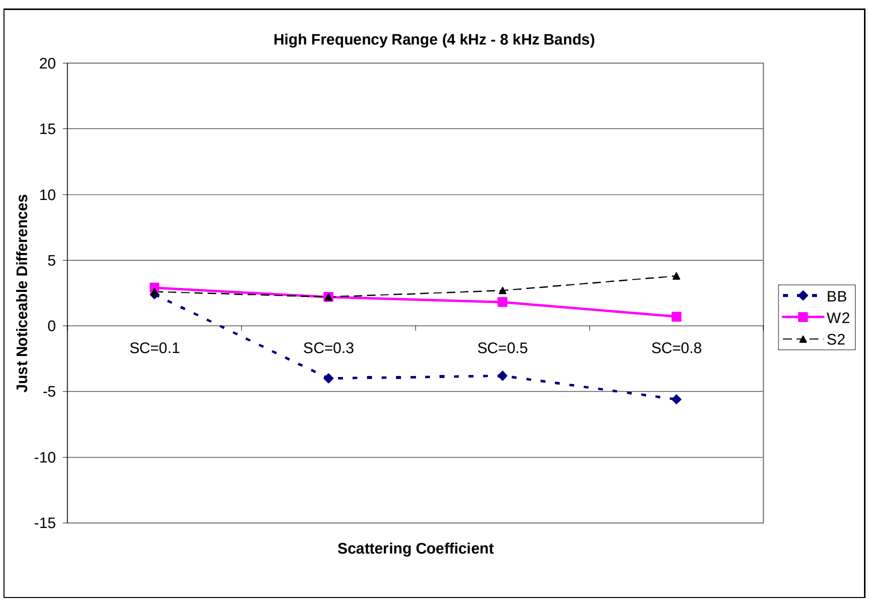
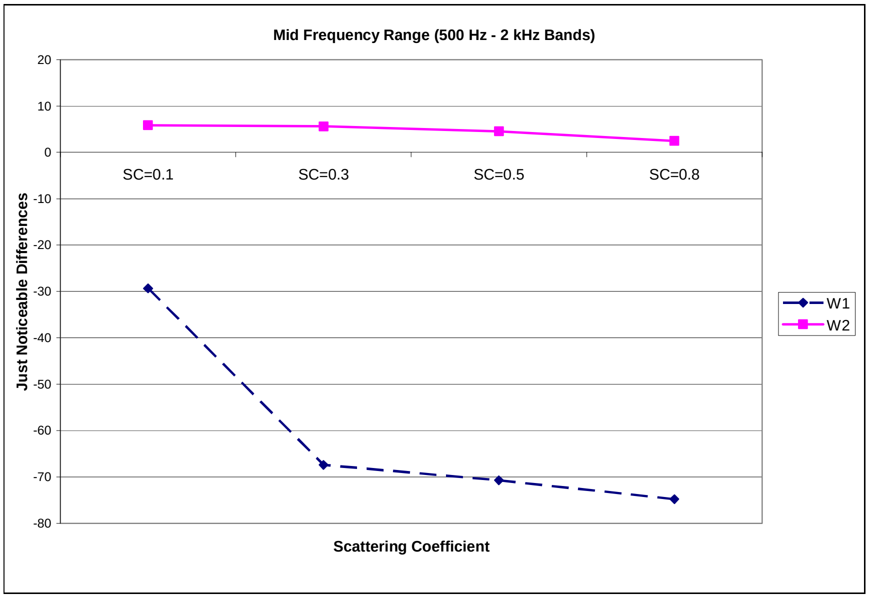


Figure 5 shows one example of how the reverberation time results vary across scattering coefficient selection between two levels of model detail for one of the halls (W1 and W2). Clearly the effect of scattering coefficient selection is much more prominent at the lower detail level.

Figure 5. The effect of scattering coefficient selection on reverberation time (T30) in the mid frequency range (averaged across the 500 Hz to 2 kHz octave bands) for two different levels of model detail. Data are shown as numbers of JNDs in comparison to a base case of SC = 0.



SUMMARY

Compiled results confirm that the choice of scattering coefficients affects reverberation time more greatly than early decay time, clarity index, or lateral energy fraction. The sensitivity to scattering coefficients appears to be more prominent at the low and mid frequency ranges, than at high frequency ranges. Models with lower level of geometric detail do appear to have greater sensitivity to scattering coefficient selection, but the changes that are observed in the parameters do not occur in a consistent manner across all of the halls studied.

Further research is being pursued to investigate how these effects vary at different receiver locations in the hall, particularly those that are closer to the boundaries. Also, it seems that the absorption characteristics of a model (in terms of magnitude of average absorption and distribution of absorption) interact with scattering coefficient and level of model detail to influence sensitivity to scattering coefficients. The authors are exploring how these aspects can be combined in such a way to measure or quantify a model's sensitivity to scattering coefficient.

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