Comparisons of Computer Simulations of Acoustical Conditions in Classrooms

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Introduction

Acoustical specifications for classrooms are usually established solely on the basis of reverberation time. Although in general the conditions for speech communication improve as an optimum reverberation time is approached, reverberation time by itself does not provide the best direct measurement of speech intelligibility. Many metrics have been developed and used to measure speech intelligibility such as the Speech Transmission Index (STI), Definition (D), Early/Late Ratios (C_{50}), and Useful/Detrimental Ratios (U_{50}). All of them can be measured in real rooms, but predictions of these parameters can best be obtained by computer simulations. This work consists of comparisons of computer simulations of acoustical conditions in classrooms for a number of newer parameters and using two different computer models.

Computer Programs and Simulated Classroom

Many room acoustical computer simulation programs are available today that can be used for this purpose. To study the relation among the newer speech intelligibility metrics, as well as to obtain some indications about the reliability of this type of room acoustic simulation tool, we use two computer programs available to us namely: Odeon 2.6 and Raynoise 2.1A. Both programs use so-called hybrid models in that they combine different procedures for calculating the earlier and later parts of the impulse response. The modeled classroom had dimensions of 7.6m x 10.0m and 3.3m height. Four different sound absorption material configurations, using mineral wool, were simulated to investigate the relation between reverberation and speech intelligibility. The ceiling and the back wall surfaces were respectively covered: 1: 100%, 100%; 2: 35% (outer ring), 100%; 3: 0%, 100%; 4: 0%, 0%, in each configuration.

Speech Intelligibility Metrics

Both Odeon and Raynoise give values for Reverberation Time and Definition, and Raynoise also gives the Sound Transmission Index. With Definition defined as:

$$D = \frac{\int_{0}^{50ms} p^2(t)dt}{\int_{0}^{\infty} p^2(t)dt}, \qquad (1)$$

where p(t) is the room impulse response; C_{50} and U_{50} were calculated using the formulas:

$$C_{50} = 10\lg\left[D/(1-D) \right], \qquad (2)$$

and

$$U_{50} = 10\lg\left\{ \frac{D}{1 - D + \left[10^{(\mathrm{Noise}-\mathrm{SPL})/10}\right]} \right\}, \qquad (3)$$

where **Noise** is the overall background noise level in dBA and **SPL** is the octave band speech sound level .

Results and Discussion

The speech intelligibility metrics and reverberation time were determined at eight different microphone positions uniformly distributed inside the classroom. The classroom was supposed to be empty with no pupils or furniture, and the overall background noise level was 32 dB(A). The speech level and directivity was that of a male talker with a normal vocal effort. The results from the eight microphone positions were averaged in each octave band. The final results are displayed for a specific metric as an octave band spectrum for each sound absorption configuration. Figure 1 shows the results for the Reverberation Time. As expected, RT decreases with the increase of sound absorption. The agreement between the results furnished by both programs is good with the exception of configuration 4. This corresponded to a classroom with no sound absorbing material. For this very reverberant room, Figure 1 also shows the RT as given by the Sabine equation. It is seen that neither Odeon nor Raynoise estimated the expected RT, as given by Sabine equation very acurately. For Odeon, changing the coefficient of diffusion of the room surfaces did not result in significant differences of RT. For Raynoise, diffusion is not taken into account for calculations at specific microphone positions (IMAGE Option Calculation). This situation is said to have been changed in Raynoise Rev3.0. It was found during the simulations that, for both programs, diffusion does not seem to have a significant effect on the speech intelligibility metrics. Figure 2 shows comparative results for D, as given by both computer programs. Figure 3 shows calculated values of C_{50}, using Equation (2). Figure 4 shows calculated values for U_{50}, using Equation (3), with the speech SPL values as given by the programs. The agreement is quite good and shows that speech intelligibility improves as the room sound absorption increases, but an upper limit might exist as shown by the U_{50} values on Figure 4. As can be seen, U_{50} begins to decrease at high frequencies due to the reduction in the speech levels with added absorption inside the classroom. The same fact can be seen on Figure 5, which shows values of STI, as given by Raynoise, for the four different absorption configurations. An upper limit on STI seems to have been reached a 4000 Hz for the absorption configuration 4. Figure 6 shows values for the overall U_{50} in dBA calculated using the frequency band levels given in Figure 4. Figure 7 shows microphone position-averaged overall STI as given by Raynoise. The same trend is observed on these overall results; that is, there is an increase on the values of U_{50} and STI with sound absorption. However this might vary if the ambient noise level was increased.

Conclusions

The simulations showed that the speech intelligibility metrics have been consistently estimated using two different room acoustic computer programs. The prediction of reverberation time seems to deviate from expected values at high frequencies, with both programs, for a very reverberant room. The position-averaged results were in quite good agreement, and the general trend seems to have been correctly predicted; that is, an increase of speech intelligibility occurs with added sound absorption, with an upper limit at high frequencies for the most absorbing sound configuration.

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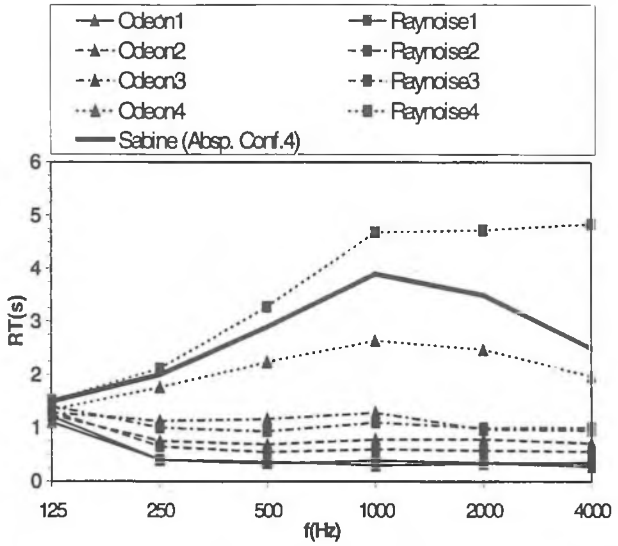

Figure 1: Reverberation Time in Octave Frequency Bands for Four Sound Absorption Configurations as Given by Odeon and Raynoise.

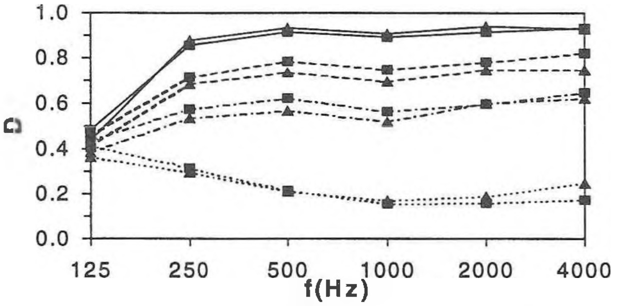

Figure 2: Definition in Octave Frequency Bands for Four Sound Absorption Configurations as Given by Odeon and Raynoise.

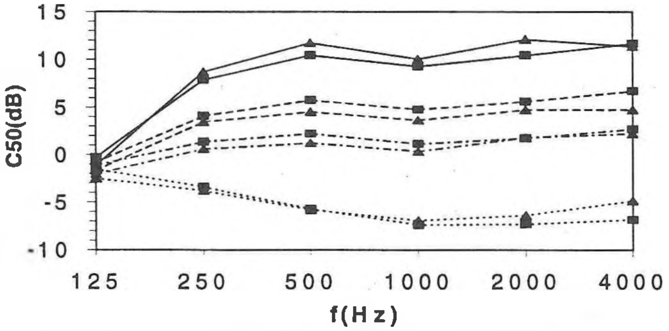

Figure 3: C_{50} in Octave Frequency Bands Calculated Using Equation (2) for Four Sound Absorption Configurations.

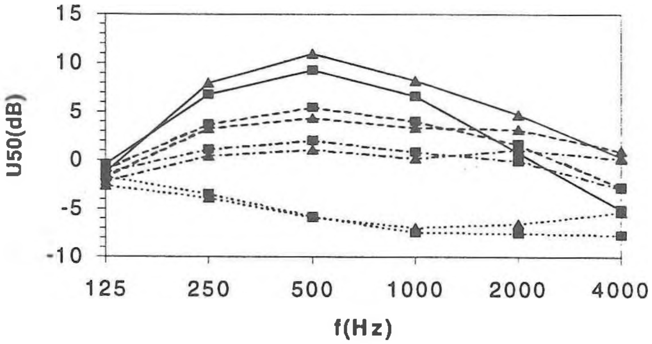

Figure 4: U_{50} in Octave Frequency Bands Calculated Using Equation (3) for Four Sound Absorption Configurations.

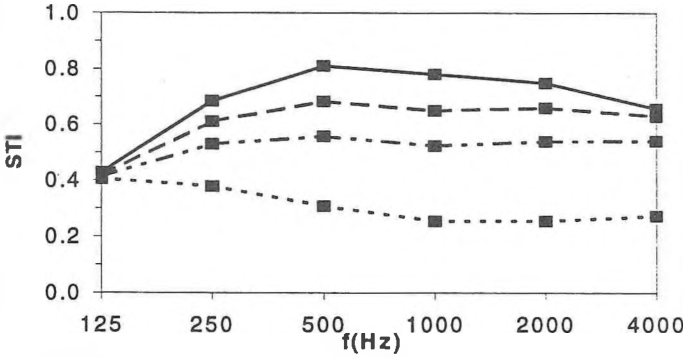

Figure 5: STI in Octave Frequency Bands as Given by Raynoise for Four Sound Absorption Configurations.

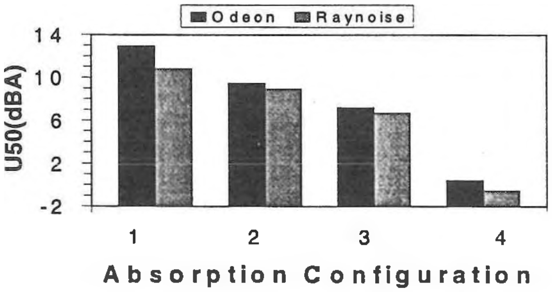

Figure 6: Overall U_{50} Calculated Using the Frequency Band Levels of Figure (4) for Four Sound Absorption Configurations.

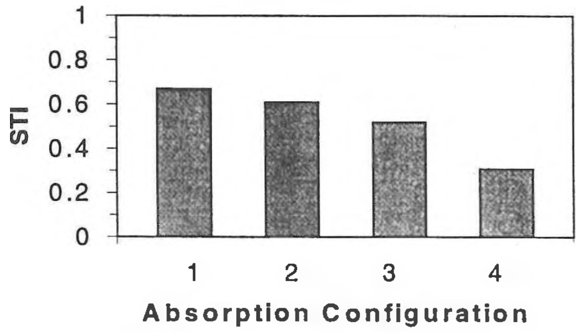

Figure 7: Raynoise Overall STI for Four Sound Absorption Configurations.