Experimental investigation of the combination of absorptive and diffusing treatments in classrooms

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ABSTRACT

The present study investigates the more successful configurations of sound-absorbing and diffusing treatments for achieving good acoustics in classrooms. The measurements were carried out in a 1/10 scale model classroom systematically adding diffusers to one or more of four surfaces of the room. 13 different configurations of diffusers with absorptive treatments were investigated. Adding diffusers on the ceiling were more effective to increasing the early arriving reflection energy (G_{50}) than adding absorptive materials on the entire ceiling. The late arriving reflection energy (G_{late}) was decreased with increasing amounts of diffusing treatments of upper front or rear wall and this resulted in achieving higher early-to-late ratios (C_{50}). Adding diffusers on the upper front wall ($AC_{100}DUFW_{26}$) achieved more uniform acoustical conditions over the receiver positions than adding diffusers on the upper rear wall ($AC_{100}DURW_{26}$). Adding diffusers on the ceiling and absorptive materials on the lower front wall ($AC_{75}DC_{25}ALFW_{26}$) achieved better acoustical conditions than adding the absorptive materials on the entire ceiling and lower front wall ($AC_{100}ALFW_{26}$).

INTRODUCTION

Early reflections are important for achieving good speech intelligibility in classrooms and hence the acoustical design of rooms for speech must concentrate more on achieving useful early reflection energy rather than on obtaining a very short reverberation time [1, 2]. Some previous studies [3-5] have proposed the optimum configurations of sound absorptive treatment and concentrated on achieving a short reverberation time rather than obtaining useful early reflection energy. However, the results revealed that having some reflective ceiling surfaces helped to achieve better STI values due to useful early reflections from the ceiling [5, 6]. Therefore, there should be design guidelines for minimizing the sound absorption and maximizing early reflections in classrooms to provide high intelligibility of speech. The present study examines the design method for achieving useful early reflections by including diffusers in a classroom and proposes an optimum combination of absorptive and diffusing treatments for achieving more uniform acoustical conditions within classrooms.

MODEL CLASSROOM MEASUREMENTS

A 1/10 scale model classroom (volume: 148 m^3 full scale) was built using 10 mm thick expanded PVC board. Sound absorbing and diffusing materials in the model classroom were varied by adding different amounts of sound-absorbing and diffusing materials to the ceiling and walls of the room. Diffusers were added systematically to one or more surfaces of the room: the ceiling, the upper walls, the lower walls, and the side walls. Periodic type diffusers, having ribs that were 22 cm Ｘ 22 cm in cross section (full scale), were installed. The measured scattering coefficients of periodic type diffusers averaged at mid-frequencies (500 Hz and 1 kHz) were 0.58. The maximum amounts of absorptive and diffusing materials used were 51.04 m^2 and 27.16 m^2, respectively, which corresponded to areas of 100% and 27% of the total ceiling area of 51.04 m^2. The sound-absorbing materials were mostly added on the ceiling of the room in different amounts, corresponding to 100%, 75%, and 50% of the total ceiling area and are referred to as configurations AC_{100}, AC_{75}, and AC_{50}, respectively. Periodic type diffusers were added on the ceiling, front, rear, and side walls of the model classroom. The two configurations, DC_{25} and DC_{50}, represent covering 25% and 50% of the total ceiling area, respectively with diffusing material.

A 1.37-s logarithmic sweep from 1 kHz to 100 kHz was used, which corresponds to full-scale frequencies from 100 Hz to 10 kHz. Measurements were made at eight receiver positions, at a height of 1.2 m in occupied room conditions. One centre source position at a height of 1.5 m was used. All source-receiver distances exceeded the critical distances in the room. A total of 13 different configurations of 4 different types of room treatment were measured. The reverberation times (T_{30}), the early decay times (EDT), the early-to-late-energy ratios (C_{50}), and the strength (G) values were measured in accordance with ISO 3382 [7]. Air absorption in the model classroom was minimized by replacing the air with nitrogen during measurements. The model classroom was kept at a constant temperature of 23° C and at a relative humidity of 3%.

RESULTS AND DISCUSSIONS

Table 1 summarizes the mean values averaged over the four octave bands from 500 to 4 kHz of the measured acoustical parameters for all 13 treatments of the model classroom. The strength of the early-arriving (G_{50}) and late-arriving (G_{late}) sounds were calculated from the measured G values and C_{50} values. The sound strength, G, was measured without calibration of the sound source and therefore, the G values presented are relative to the measured G values for configuration AC_{100} which was assigned a value of 0 dB. To better understand the trends they are listed in two groups. The upper group first lists the mean results for the AC_{100} condition and then the various treatments that include further additions to the basic AC_{100} condition. The second block first lists mean results for the $AC_{75}DC_{25}$ condition and then the various treatments that included additions to the basic $AC_{75}DC_{25}$ condition.

The four treatments that added only diffusers to the basic AC_{100} condition (treatments 2 to 5 in Table 1) led to only very small increases in G_{50} values. However, all had reduced EDT values and some increase in C_{50} values. Of the four treatments, adding diffusers to the side walls ($AC_{100}DSW_{28}$) and the upper front wall ($AC_{100}DUFW_{26}$) increased C_{50} values the most and also reduced EDT values the most. When absorption was added to the basic AC_{100}

treatment, as in treatment numbers 6 and 7, there were also increases in G_{50} and C_{50} values as well as reductions in EDT values.

Table 1. Summary of mean values of measured acoustical parameters for all treatments.

N	Configuration	Mean values of Acoustical parameters					
		T_{30} (500-4k), s	EDT (500-4k), s	C_{50} (500-4k), dB	G_{50} (500-4k), dB	G_{late} (500-4k), dB	G (500-4k), dB
1	AC_{100}	0.93	0.68	3.3	-1.7	-5.0	0.0
2	$AC_{100}DSW_{28}$	0.87	0.58	4.0	-1.5	-5.5	0.0
3	$AC_{100}DUFW_{26}$	0.68	0.58	4.1	-1.6	-5.7	-0.1
4	$AC_{100}DURW_{26}$	0.71	0.61	3.8	-1.6	-5.4	0.0
5	$AC_{100}DLFW_{26}$	0.67	0.59	3.8	-1.7	-5.5	-0.2
6	$AC_{100}ALFW_{26}$	0.68	0.57	4.4	-1.1	-5.5	0.3
7	$AC_{100}ASW_{28}$	0.86	0.56	4.5	-1.4	-5.9	0.0
8	$AC_{75}DC_{25}$	0.92	0.75	2.4	-1.2	-3.6	0.8
9	$AC_{75}DC_{25}DUFW_{26}$	0.70	0.64	3.5	-1.3	-4.8	0.3
10	$AC_{75}DC_{25}DLFW_{26}$	0.71	0.62	3.3	-0.4	-3.7	1.4
11	$AC_{75}DC_{25}DSW_{28}$	0.87	0.67	3.1	-0.3	-3.4	1.5
12	$AC_{75}DC_{25}ALFW_{26}$	0.70	0.57	4.2	0.2	-4.0	1.7
13	$AC_{50}DC_{50}$	0.93	0.79	2.0	-0.5	-2.5	1.7

The basic $AC_{75}DC_{25}$ treatment had a small increase in G_{50} values, but decreased C_{50} and increased EDT values, relative to the AC_{100} condition. Adding diffusers to the basic $AC_{75}DC_{25}$ treatment (treatments 9-11), increased C_{50} values in all cases and increased G_{50} in two cases (treatments 10 and 11). These results indicate that adding diffusers on the lower front walls ($AC_{75}DC_{25}DLFW_{26}$) and on the side walls ($AC_{75}DC_{25}DSW_{28}$) were most effective at increasing G_{50} values for this group of additions to the $AC_{75}DC_{25}$ condition.

When absorbing material and diffusers were added to the basic $AC_{75}DC_{25}$ treatment, in treatment number 12, ($AC_{75}DC_{25}ALFW_{26}$) the highest G_{50} value was produced. This condition also had among the highest C_{50} values and lowest EDT values and was the most successful treatment condition. Treatment number 13 ($AC_{50}DC_{50}$) had less ceiling absorption which led to higher EDT values and lower C_{50} values along with a smaller increase in G_{50} values than for the more successful cases.

CONCLUSIONS

Adding diffusers to the surfaces of the classroom achieved higher early-to-late arriving sound ratio (C_{50}) corresponding to higher clarity. Diffusers were beneficial for enhancing the early arriving reflection energy (G_{50}) at more distant seats and they resulted in achieving more uniform acoustical conditions across the room. Adding diffusers on the front or side wall slightly increased G_{50} and G values, and decreased G_{late} values. The treatment of the front wall with diffusers was found to lead to better conditions than treating the rear and side walls with diffusers. Adding diffusers on the lower front wall achieved more uniform conditions over the receiver positions than for the diffusing treatments of the upper front wall.

Adding diffusers on the ceiling and lower front wall or side wall ($AC_{75}DC_{25}DLFW_{26}$, $AC_{75}DC_{25}DSW_{28}$) and adding diffusers on the ceiling and absorptive materials on the lower front wall ($AC_{75}DC_{25}ALFW_{26}$) achieved better acoustical conditions for speech than adding absorptive materials on the entire ceiling (AC_{100}). The AC100 condition can be considered as representative of a more typical acoustical treatment of a classroom. Compared to this condition the most successful treatment led to G_{50} and C_{50} values increased by more than 1 JND and EDT and T_{30} values decreased by more than 1 JND [8, 9].

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