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Effects of the distribution of occupants in partially occupied classrooms

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ABSTRACT

The effects of the distribution of occupants in partially occupied classrooms were experimentally investigated in four university classrooms. The frequency-averaged (500–4000 Hz) absorption values per occupant were largest for the 50% occupancy cases among four percentage occupancies, 25%, 50%, 75%, and 100%, in the four classrooms. The frequency-averaged (500–4000 Hz) sound absorption per occupant values were linearly related to the perimeter values of the seating blocks in the classrooms. Perimeter values of seating blocks were proposed as a measure of the expected differences in absorption values between various seating blocks having the same areas in the classrooms. The incremental changes in other classrooms due to varying percentage occupancy can be estimated from the resulting regression equations. If the frequency-averaged (500–4000 Hz) T_{30} values of unoccupied classrooms values are known, one can predict the incremental changes due to varying occupancy, to several room acoustical parameter values. These would include early decay time, *EDT* values, early-to-late sound rations, C_{50} values, and sound strength, *G* values.

1. Introduction

It is often possible to measure occupied conditions with available audiences that only partially fill the seats. One would also like to design for minimal effects of audience size in many types of rooms such as classrooms and lecture theatres. That is, one would prefer that the room acoustics conditions do not change greatly with the size of the audience. To understand these issues better, one needs to be able to estimate the effect of such partial audiences on room acoustics and to relate conditions back to some more standard occupancy configuration. Understanding the effects of varied percentage occupancies would help to understand how to meet this goal.

A number of studies have reported that the mean sound absorption per occupant varies with frequency, chair type, classroom design, and the ages of the occupants [1–4]. These show that, the changes to the values of room acoustics parameters due to added occupants in classrooms are influenced by the percentage change of the total sound absorption [3] and also by the size of sample blocks of chairs [3,5]. The results of the two university classroom acoustics studies [1,3] also showed a significant effect of the presence of occupants on the acoustical conditions in classrooms, emphasizing the need for design criteria for occupied classrooms.

A previous study [6] has proposed a simple method that uses the added absorption per person values to predict the expected values of the acoustical parameters in classrooms. However, the effects of different arrangements and distributions of occupants in seats and different percentage occupancies were not considered in the previous work. The seated occupants are usually the largest single component of the absorption in a classroom, especially for reflective classrooms. Because the effects of adding occupants vary with frequency, chair type and classroom [1,3,4], one cannot always accurately estimate the changes to the values of acoustical parameters due to added occupants in classrooms. The effects of these variables are not fully understood and need further investigation. Predicting the effects of changed occupancy can also be influenced by the perimeter-to-area ratio of sample blocks of chairs in classrooms. Considering these effects on the prediction of occupied acoustical conditions were explored in the new results of this paper. The goal of the present work is to propose a simple method to use frequency-averaged (500–4000 Hz) T_{30} values of unoccupied classrooms values to estimate the expected changes due to varying occupancy to room acoustical parameters in occupied classrooms.

In the present study, the effects of the distribution of occupants in partially occupied classrooms were experimentally investigated. First, the effects of the added sound absorption by the occupants were compared in four different classrooms. Second, the details of how varied percentage occupancy influenced the absorption per occupant values measured in the four classrooms were examined. Next, a measure of the expected differences in absorption values between various seating blocks having the same areas in the classrooms, was proposed. Finally, the application of the present results to estimate the acoustical effects of varied occupancy of classrooms is discussed.

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Table 1
Data for 4 university classrooms used for the measurements including mean 1000 Hz T_{30} values for both fully occupied and unoccupied cases.

Rooms	Width, m	Depth, m	Height, m	Volume, m^3	Number of occupants for fully occupied conditions	Mean $T_{30\ \text{unoccupied},\ s}$	Mean $T_{30\ \text{occupied},\ s}$
#1	9.1	7.2	2.9	193	24	0.84	0.58
#2	8.9	10.6	3.0	284	56	1.24	0.64
#3	7.4	11.9	2.7	238	48	1.63	0.75
#4	6.4	13.1	2.7	226	48	0.22	0.19
Mean	8.0	10.7	2.8	235	44	0.98	0.54
s.d.	1.3	2.5	0.2	38	14	0.60	0.24

2. Measurement procedures

2.1. Classrooms

Table 1 presents the data describing the 4 university classrooms used for the measurements of the acoustical effects of varied occupancy. Of the 4 classrooms, 2 were used for university lectures (#2 and #3 in Table 1), and 2 were used for computers (#1 in Table 1), and teleconferences (#4 in Table 1). Two classrooms, #1 and #2, had rectangular shapes and the two other classrooms, #3 and #4, had non-rectangular shapes. Three classrooms, #1, #2, and #4 had windows on one side wall, and the one classroom, #3 had windows on rear wall. Classroom #1 had a 5 mm-thick glass wall on the other side. The volumes of classrooms varied from 190 m^3 to about 280 m^3. Three classrooms #1, #2, and #3 had similar room finishes with reflective surface materials such as: painted concrete walls and terrazzo floors. They were mostly used for small size classes with less than 60 occupants. The other classroom, #4 had mostly porous absorbing surface materials. The ceiling of the 4 classrooms was treated with a 12 mm-thick fiber board. The mean 1000 Hz T_{30} values for the four fully occupied and unoccupied classrooms were 0.54 s and 0.98 s respectively. Fig. 1 shows a photo of unoccupied (with furniture) and occupied (with furniture and occupants) classroom #1. Most of the occupants were wearing heavy winter jackets during the measurements of the occupied classrooms.

Table 2 presents the mean 1000 Hz total sound absorption values for occupied and unoccupied classrooms determined from the measured occupied and unoccupied reverberation times using the Sabine Eq. (1).

$$A = 0.16V/T_{30} \tag{1}$$

where, A is total sound absorption in m^2, V is the room volume in m^3, and T_{30} is the reverberation time in s.

These values are used to calculate the ratios of occupied-to-unoccupied total room sound absorption at 1000 Hz for each classroom, which are also included in Table 2. Here the results used were the mean measured 1000 Hz values because the optimum reverberation time for achieving high intelligibility of speech is often given as the value at 1000 Hz in occupied classrooms [7]. The ratios of occupied-to-unoccupied total room sound absorption varied from about 1.17–2.17 for the 4 classrooms.

Table 2
Mean 1000 Hz total sound absorption for 100% occupied and unoccupied classrooms and the ratios of occupied-to-unoccupied total room sound absorption.

Classrooms	Mean 1000 Hz total sound absorption, m^2		The ratio of occupied-to-unoccupied total room sound absorption
	Occupied	Unoccupied	
#1	53.2	36.8	1.45
#2	71.3	36.7	1.94
#3	50.5	23.3	2.17
#4	189.3	162.2	1.17

2.2. Measurements of room acoustics parameters

The distributions of occupants seated in the chairs were varied by adding different numbers of occupants to the seats varying from the 100% fully occupied case to three partially occupied cases, (25%, 50%, and 67% or 75% occupied) in each classroom. Various types of changes were made to the 19 or 20 configurations of occupied seats in each classroom. The configurations of three partially occupied cases were varied by arranging occupants to be more or less exposed by an aisle or an unoccupied row of chairs. The different configurations of occupied seats used in the four classrooms, along with the overall density of occupants in the chairs, are presented in Table 3. In Table 3, the overall density of occupants in the chairs (people per square meter, p/m^2) was calculated assuming evenly spread distributions of occupants in the classrooms. For 100% occupied cases, the overall density of occupants in the 4 classrooms ranged from 0.79 to 1.40p/m^2. Fig. 2 illustrates each of the 20 configurations of occupied seats tested in classroom #2.

Room acoustical quantities were determined from the measured impulse responses in both the occupied and the unoccupied 4 classrooms. A 2.7-s logarithmic sine sweep was used as the source signal and was radiated into the classroom from a dodecahedron loudspeaker (Norsonic, Nor276). Fig. 3 shows classroom floor plans of the 4 classrooms. Measurements were made at four receiver positions using 1/2″

Fig. 1. Unoccupied (left) and occupied (right) classroom #1.