The effects of occupancy on acoustical conditions of university classrooms

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ABSTRACT

In the present study, the effects of occupancy on acoustical conditions of 12 university classrooms were experimentally investigated. The effects of the added sound absorption by the occupants were compared in two different groups of classrooms (6 reflective classrooms and 6 absorptive classrooms). And then, the incremental changes to the values of a number of room acoustics parameters due to adding occupants to the two different groups of classrooms were compared. In rooms that are more reflective, larger variations in the acoustical conditions occur when occupants are added. For the 6 reflective classrooms with a mean volume of 253 m^3, the more ideal reverberation times for speech (typically 0.4 to 0.7 s in classrooms) were achieved with added occupants having a mean occupancy of 53%.

Keywords: Occupancy, Acoustical conditions, Classrooms I-INCE Classification of Subjects Number(s): 51.1.4

1. INTRODUCTION

The seated occupants are usually the largest single component of the absorption in a classroom, especially for classrooms with more reflective surface materials. Because the effects of adding occupants vary with the acoustical conditions of the rooms, one cannot always expect similar effects of adding occupants even if the occupants are seated on the same type of chairs. That is, the changes to the values of acoustical parameters due to added occupants in classrooms may not be accurately predicted from typical values of absorption coefficients measured in a reverberation chamber.

In this work, the effects of occupancy on acoustical conditions of 12 university classrooms were experimentally investigated. The details of how the addition of occupants influenced the values of a number of room acoustics parameters measured in two different groups of classrooms (6 reflective classrooms and 6 absorptive classrooms) were examined.

2. MEASUREMENT PROCEDURES

2.1 12 University Classrooms

The measurements of occupied and unoccupied conditions were carried out in 12 classrooms in 5 different buildings at Kangwon National University in Korea. Most of the occupants were wearing thick winter jackets during the measurements of the occupied classrooms. The mean number of occupants was 47 (54% occupancy) for the measurements of the occupied classrooms.

Table 1 presents the data describing the 12 university classrooms used for the measurements. The mean T_{30} values at mid-frequencies (500-1000 Hz) for both occupied and unoccupied classrooms, as measured without air conditioners operating, are also included in Table 1. Six classrooms (#1 to #6 in Table 1) had similar room finishes with reflective surface materials such as, painted concrete walls and terrazzo floors, and were mostly used for small to medium size classes with less than 100 occupants. These classrooms had plastic tablet-arm chairs or wood desks and chairs. The other 6 classrooms (#7 to #12 in Table 1) were mostly treated with porous absorbing surface materials and had vinyl or fabric covered chairs. Four of these 6 classrooms were lecture theatres for larger sized classes including up to 240 occupants. Figure 1 shows photos of the two classrooms #6 and #10 in Table 1.

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Table 1 – Data for 12 university classrooms used for the measurements including mean mid-frequency (500-1000 Hz) T_{30} values

Rooms	Uses	Volume, m^3	Number of occupants occupancy)	Mean T_{30} unoccupied, s	Mean T_{30} occupied, s
#1	Lectures	199	15 (50%)	1.29	0.89
#2	Computers	193	11 (46%)	0.83	0.72
#3	Lectures	284	22 (38%)	1.18	0.82
#4	Lectures	248	13 (20%)	1.15	0.84
#5	Lectures	354	62 (66%	1.81	0.83
#6	Lectures	238	46 (100%)	1.68	0.77
#7	Lectures	1,310	84 (36%)	0.56	0.55
#8	Lectures	1,227	80 (100%)	0.74	0.57
#9	Lectures	690	61 (25%)	0.44	0.39
#10	Tele-conferences	226	48 (100%)	0.31	0.26
#11	Conferences	2,535	53 (37%)	0.92	0.84
#12	Lectures	888	74 (31%)	0.65	0.58
Mean		699	47 (54%)	0.96	0.67
s.d.		707	27 (30%)	0.47	0.20

Figure 1 – Photos of the two classrooms #6 and #10 in Table 1.

Table 2 – Measurement equipment used in the present study

Equipment	Model	Manufacturer
Loudspeaker	Dodecahedron loudspeaker Nor276	Norsonic
Microphone	1/2"Free-field microphone set Type 46AF	G.R.A.S
Conditioning amplifier	Nexus microphone power supply Type 2690	Brüel & Kjær
A/D board	Lynx Two	Lynx Studio Technology
Measurement software	Dirac V.6.0	Brüel & Kjær

2.2 Classroom Measurements

The reverberation times (T_{30}), the early decay times (EDT), the early-to-late-energy ratios (C_{50}), and the strength values (G), were measured in accordance with ISO 3382 (1) using the Dirac software (2). Measurements were made at 6 to 9 receiver positions, at a height of 1.2 m in both occupied and unoccupied room conditions. One centre source position at a height of 1.5 m was used. All source-receiver distances exceeded the critical distance (3) in each room. The average background A-weighted noise levels from the 125 Hz to 8000 Hz octave band measurements for occupied and unoccupied rooms were 41.2 dB(A) and 40.2 dB(A) respectively. Table 2 presents the equipment used for the measurements.

3. RESULTS AND DISCUSSIONS

3.1 Sound Absorption per Occupant in Two Different Groups of University Classrooms

The sound absorption contributed by the occupants of each classroom was calculated and compared the values in the absorptive classrooms with the corresponding values in the reflective classrooms. The occupants were allowed to choose where they wished to sit. No measurements were made with different arrangements of occupants in the partially occupied seats, which was beyond the scope of this work. The sound absorption per occupant was determined from the measured occupied and unoccupied reverberation times calculated using the Sabine equation in equation (1),

$$A = \frac{0.16 \times V}{N} \times \left(\frac{1}{RT_{occ}} - \frac{1}{RT_{unocc}}\right), m^2/person, \tag{1}$$

where A is the sound absorption per occupant (m^2/person), V is the room volume (m^3), N is number of occupants, and RT_{occ} and RT_{unocc} are the reverberation times (s) in the occupied and unoccupied rooms.

Figure 2 shows the mean effective absorption per occupant determined from the measured reverberation times. The mean sound absorptions per occupant determined from the measured values in 30 elementary school classrooms (4) were also included in Fig.2. The results in Fig.2 for the 6 reflective rooms show the differences of sound absorption between occupied and unoccupied classrooms increase systematically with increasing frequency. However for the 6 absorptive classrooms, the added absorption per occupant was largest in the 125 Hz octave band and less in the other octave bands. At 250 and 500 Hz, the mean absorption per occupant values in Fig.2 are nearly the same for both groups of classrooms. The values are very different in the 125 Hz octave band and also in the 1000, 2000, and 4000 Hz octave bands. The 125 Hz octave results are often difficult to explain because they are frequently affected by various interference effects. The results in the 1000, 2000, and 4000 Hz octave bands could be influenced by P/A effects (5). This is supported by the trend for larger room volumes for the more absorptive classrooms and hence larger sized blocks of chairs. Adding occupants to the absorptive classrooms had little effect on the total sound absorption of the classrooms because the occupants contributed only relatively small amounts of absorption relative to that of the room surfaces at most frequencies.

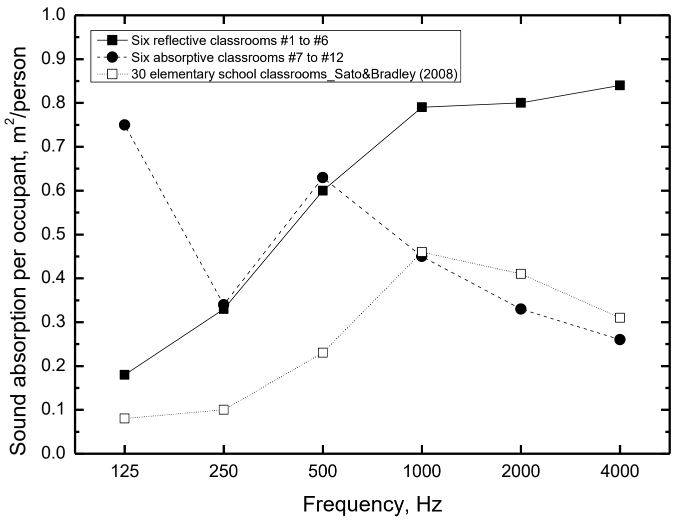

Figure 2 – Mean sound absorption per occupant from the measured reverberation times in the 12 university classrooms.

The mean sound absorptions per occupant for the 6 reflective university classrooms in Fig.2 were much higher than the measured values for the elementary school classrooms. The mean volume and number of students for the 30 elementary school classrooms was 198 m^3 and 20.6 students. This was probably because the elementary school students were much younger (6, 8, and 10 year olds or slightly older) and hence smaller than the university students. The elementary school classrooms had shorter reverberation times (0.45 s at 500-1000 Hz) for unoccupied conditions than those for the university classrooms (1.33 s at 500-1000 Hz) indicating they were more absorptive rooms than the more reflective university classrooms. Adding occupants to the elementary school classrooms had a much smaller contribution to the total sound absorption of the classrooms (5.83 m^2 at 500-1000 Hz) than those for the university classrooms (18.4 m^2 at 500-1000 Hz). The result indicates that the effective sound absorption contributed by added occupants varies with room acoustical conditions, i.e. with the amount of sound absorption added by room finishes, or types of chairs.

3.2 Incremental Effects on the Acoustical Parameters with Added Occupants to the Reflective and Absorptive Classrooms

Tables 3 and 4 summarize incremental effects on the room acoustical parameters due to adding occupants to both the 6 reflective and the 6 absorptive classrooms, i.e. these data are the differences between the classrooms with and without added occupants. The frequency-averaged results (500-4000 Hz) for acoustical parameters are included in Tables 3 and 4 show the more general trends of how the added occupants affected the variations in the acoustical parameters of the two groups of 12 classrooms.

Table 3 – Increments of EDT, C_{50}, G, SNR, and STI values due to adding occupants to the six reflective classrooms #1 to #6

Acoustical parameters	Frequency, Hz						
	125	250	500	1000	2000	4000	500-4000
ΔEDT, s	-0.16	-0.32	-0.46	-0.57	-0.55	-0.32	-0.47
ΔC_{50}, dB	0.4	1.7	2.8	3.3	3.3	2.4	2.9
ΔG, dB	-0.7	-1.2	-2.4	-3.0	-2.7	1.9	-2.5
ΔSNR, dB	-1.4						
ΔSTI	0.05						

Table 4 – Increments of EDT, C_{50}, G, SNR, and STI values due to adding occupants to the six absorptive classrooms #6 to #12

Acoustical parameters	Frequency, Hz						
	125	250	500	1000	2000	4000	500-4000
ΔEDT, s	0.00	-0.05	-0.03	-0.07	-0.10	-0.08	-0.07
ΔC_{50}, dB	0.5	0.4	0.3	1.1	2.0	1.4	1.2
ΔG, dB	-0.2	-0.3	-1.3	-1.4	-1.4	1.0	-1.3
ΔSNR, dB	-2.8						
ΔSTI	-0.02						

The 6 reflective classrooms and the 6 absorptive classrooms had 53% and 55% mean occupancy ratings respectively. For the 6 reflective classroom results in Table 3, the sound absorption added by occupants produced large decreases in EDT values with the largest effects at mid- to high-frequencies. This corresponded to decreasing the frequency averaged EDT values by 0.47 s at these frequencies. The results in Table 4 for the 6 absorptive classrooms showed a small decrease in the mean EDT values by 0.05 s at mid- and high-frequencies when occupied. Adding occupants increased the mean C_{50} values by 2.9 dB averaged over the 500-4000 Hz octave bands in the 6 reflective classrooms. The effects of adding occupants to the 6 absorptive classrooms were smaller (1.2 dB averaged over the 500-4000 Hz octave bands) than for the 6 reflective classrooms case. When classrooms are occupied, the overall level changes in the 500-4000 Hz octave bands in Tables 3 and 4 for G values are larger for the 6 reflective classrooms (2.5 dB) than the changes for the 6 absorptive classrooms (1.3 dB).

The measured impulse responses of the classrooms were used to determine the modulation transfer function, m(F), for the STI calculation according to IEC 60268-1611(6). The results in Table 3 show that occupancy causes a mean increase in STI values of 0.05 in the 6 reflective classrooms. However, adding occupants led to smaller decrease in STI values (ΔSTI of 0.02) for the 6 absorptive classrooms in Table 4. That is, STI values are influenced by both the effects of room acoustics such as reverberance and clarity and the speech and noise ratios. The addition of occupants led to a larger decrease in perceived reverberance for more reflective classrooms and this resulted in larger increases in STI values. The mean overall speech-to-noise ratios for the 6 reflective classrooms were decreased 1.4 dB with added occupants. Adding occupants led to larger changes in SNR values up to 2.8 dB for the 6 absorptive classrooms. The results in Tables 3 and 4 clearly show that the variations of acoustical parameters between unoccupied and occupied classrooms tend to be largest when the classrooms are less absorptive.

4. CONCLUSIONS

The present results demonstrate that the effect of the added absorption of occupants in chairs is dependent on the acoustical properties of the room. When the added absorption of the occupants is a significant fraction of the total absorption of the unoccupied room, the effect on the room acoustics characteristics will be more significant. Text books (7, 8) often include a table of octave-band absorption coefficients usually for unoccupied chairs. These data are typically obtained from measurements of small groups of chairs in a reverberant test chamber and hence are not directly representative of their effective absorption in larger rooms, since the absorption of samples of chairs varies with the perimeter-to-area ratio of the sample. There is quite limited data assessing the sound absorption of chairs measured in real classrooms and even less data for the absorption of occupied chairs.

The percentage occupancy and the distribution of occupants in partially occupied rooms are also expected to influence the effects of adding occupants. These parameters are not fully understood. Because the effects of added absorption contributed by a classroom's occupants varies with the acoustical characteristics of the classrooms, occupants even in the same type of chairs, may have smaller or larger effects in different rooms.

In the present study, larger classrooms such as lecture theatres mostly treated with porous types of absorbing materials, used speech-reinforcement systems to increase instructor speech levels. This kind of acoustical design produced unusual reverberation time patterns over frequency for speech, with decreasing speech levels mostly at mid- and high-frequencies. Although, speech-reinforcement systems are not usually necessary for all seats in the classroom, they can be used to increase the speech levels at more distant seats in large lecture theatres. Because the occupants contribute much absorption, the optimum conditions required for good speech intelligibility may not be achieved in more fully occupied classrooms.

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