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Effect of occupancy on acoustical conditions in university classrooms

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Acoustical measurements were made in 12 university classrooms with and without occupants at Kangwon National University (KNU), Korea to investigate how the occupants influence the acoustical conditions of the classrooms. The mean sound absorption per occupant was calculated from the measured T_{30} values and compared in two different groups of classrooms (6 reflective and 6 absorptive classrooms). At 250 and 500 Hz, the mean sound absorption per occupant was nearly the same for both groups of classrooms, but not in the other octave bands. The results showed that the effect of the added absorption of occupants is dependent on the acoustical conditions of the classroom. The changes in acoustical parameter values, due to added occupants in the classrooms, tended to be largest for the more reflective classrooms. The occupants may contribute to achieving more ideal reverberation times for speech (typically 0.4–0.7 s in classrooms) in the more reflective classrooms, but not in the more absorptive classrooms. A simple process is described to predict the expected effects of adding occupants to other classrooms based on the total sound absorption of unoccupied rooms.

1. Introduction

The sound absorption contributed by occupants is expected to decrease room reverberation by absorbing more reflected sounds in a classroom. In a previous study [1], Hodgson confirmed that the acoustical quality of university classrooms varied with occupancy. He suggested that a classroom acoustical design should focus on limiting background noise levels and increasing speech levels at the back of classrooms rather than adding sound absorption into classrooms to control reverberation. Previous studies [2,3] showed that early reflections are important for good speech intelligibility in classrooms and hence the acoustical design of rooms for speech must concentrate on achieving useful early reflection energy as well as on obtaining an optimum reverberation time. Perceptually important improvements can be made without the negative effects of excessive absorption and lower speech levels by appropriately including diffusers in the acoustical treatment of a classroom [4].

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 frequency, chair type and classroom [5], 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. The changes to values of room acoustics parameters are influenced by the percentage change to the total sound absorption and also by the perimeter-to-area ratio of each block of occupied chairs [6].

In the present study, the effects of occupancy on acoustical conditions of 12 university classrooms were experimentally investigated. First, 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). Second, the details of how the addition of occupants influenced the values of a number of room acoustics parameters measured in the classrooms were examined. Next, a reasonably simple process for predicting the expected effects of adding occupants to other classrooms, that are similar to the two types of 12 university classrooms, was proposed. Finally, the application of the present results to the acoustical design of a classroom is discussed.

2. Measurement procedures

2.1. The 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. Of the 12 classrooms, 9 were typical classrooms, and 3 were used for computers,

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teleconferences and conferences. Seven classrooms had rectangular shapes with windows on one side and 5 classrooms had non-rectangular shapes. The measurements for both occupied and unoccupied classrooms without air conditioners operating were carried out from December 2014 to March 2015. 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.

The mean mid-frequency T_{30} values for the 6 reflective classrooms (#1 to #6 in Table 1) with and without occupants were 0.81 and 1.32 s respectively. The mean number of occupants was 28 (53% occupancy) for the measurements of occupied classrooms. The mean T_{30} value was decreased by approximately 39% when occupants were added to these more reflective classrooms. For the 6 more absorptive classrooms (#7 to #12 in Table 1) the mean mid-frequency T_{30} values were 0.53 and 0.60 s for occupied and unoccupied cases respectively. The mean number of students for the more absorptive classrooms was 67 (55% occupancy) for the measurements of the occupied classrooms. The resulting mean T_{30} value was only decreased by 12% with added occupants. Fig. 1 shows some examples of classroom floor plans of the small to medium sized classroom, #3 and lecture theatres #7 and #9.

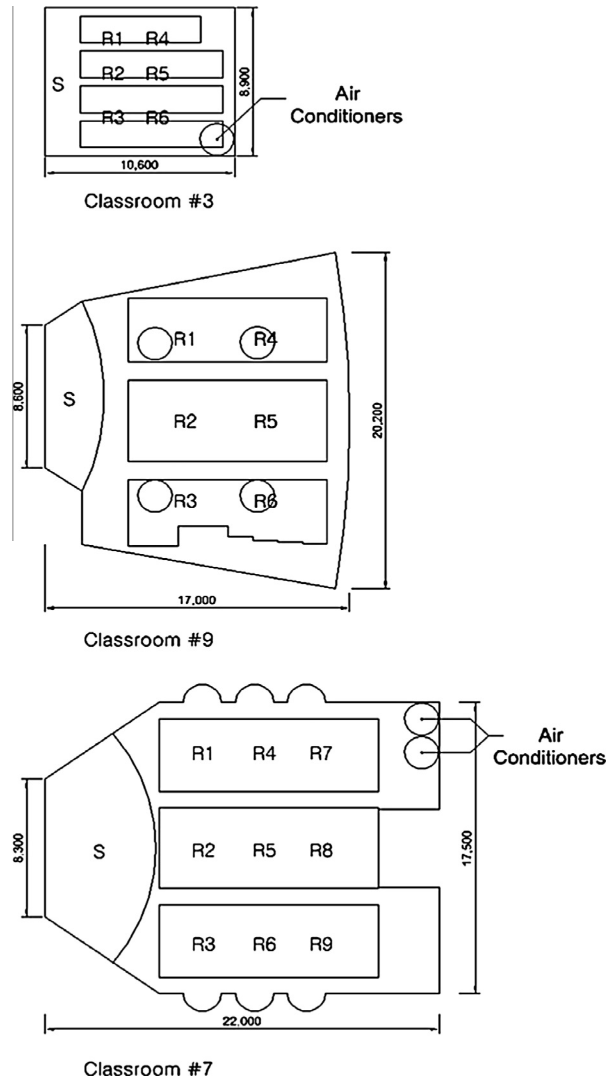

Fig. 1. Floor plans of three classrooms: #3, #9, and #7, of the 12 university classrooms.

2.2. Measurements of room acoustics parameters

For the measurements in the classrooms, a 1.37-s logarithmic sine sweep was used as the source signal. Measurements were made at 6–9 receiver positions, at a height of 1.2 m in both occupied and unoccupied room conditions (see Fig. 1). One centre source position at a height of 1.5 m was used. All source-receiver distances exceeded the critical distance [7] 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, without air conditioners operating, were 41.2 dB(A) and 40.2 dB(A) respectively.

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 [8] using the Dirac software [9]. To provide a more detailed understanding of the effects of adding occupants, the strength of the early-arriving (G_{50}) and late-arriving sounds (G_{late}) were calculated from the measured G values

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

Rooms	Uses	Width, m	Depth, m	Height, m	Volume, m^3	Number of occupants (occupancy)	Mean $T_{30\ unoccupied}$, s	Mean $T_{30\ occupied}$, s
#1	Lectures	9.0	7.1	3.1	199	15 (50%)	1.29	0.89
#2	Computers	9.1	7.2	2.9	193	11 (46%)	0.83	0.72
#3	Lectures	8.9	10.6	3.0	284	22 (38%)	1.18	0.82
#4	Lectures	8.8	10.1	2.8	248	13 (20%)	1.15	0.84
#5	Lectures	7.9	16.6	2.7	354	62 (66%)	1.81	0.83
#6	Lectures	7.4	11.9	2.7	238	46 (100%)	1.68	0.77
#7	Lectures	17.5	17.2	4.4	1310	84 (36%)	0.56	0.55
#8	Lectures	13.9	15.8	5.6	1227	80 (100%)	0.74	0.57
#9	Lectures	17	16.2	2.5	690	61 (25%)	0.44	0.39
#10	Tele-conferences	6.4	13.1	2.7	226	48 (100%)	0.31	0.26
#11	Conferences	16.5	21.1	7.3	2535	53 (37%)	0.92	0.84
#12	Lectures	17.5	15.9	3.2	888	74 (31%)	0.65	0.58
Mean		11.7	13.6	3.6	699	47 (54%)	0.96	0.67
s.d.		4.4	4.3	1.5	707	27 (30%)	0.47	0.20