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SPATIAL DECAY OF SPEECH HAS AN IMPORTANT ROLE IN OPEN AND ENCLOSED LEARNING SPACES

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Abstract

Open learning spaces, OLSs, which enable teaching more than one group of students at a time, have become increasingly popular. Enclosed learning space, ELS, (conventional classroom) is still the most popular learning space type. Our purpose was to report on the room acoustic properties of both learning space types using measurements according to ISO 3382-3. This method was justified since Finnish regulations set distance-dependent target values for STI in OLS and distance-independent target values for ELSs. Measurements concerned speech transmission index, STI, background noise level, L_{Aeq}, and reverberation time, T. Variation in results in both OLSs and ELSs was rather large. In OLSs STI was 0.47–0.91, L_{Aeq} 29–44 dB, and T 0.44–0.72 s. In ELSs STI was 0.64–0.83, L_{Aeq} 25–47 dB, and T 0.34–0.82 s. The results of L_{Aeq} and T in OLSs and ELSs were surprisingly similar. STI values were within target values in most ELSs, unlike in most OLSs, where the target values were violated at longer distances, because STI did not decrease as steeply as required. Our finding suggests that measurement of spatial decay is justified in both learning space types because it reveals how STI behaves at different distances from the speaker.

Keywords: *schools, classrooms, room acoustics, speech intelligibility, speech transmission index*

1. Introduction

Enclosed learning space, ELS, e.g., conventional classroom, is the most popular learning space type in Finland. However, open learning spaces, OLSs, have become increasingly popular. Many OLSs are flexible spaces in a way that they can be turned into smaller ELSs when needed. Typical dividing solutions are sliding or folding walls, movable screens, and curtains. These have different usability and sound insulation performance.

Recent research has suggested that STI should be at least 0.7 in OLSs within group (short distance) but below 0.2 between groups (long distance) [1]. In ELSs, STI should be at least 0.7 in all the students' positions [2]. Finnish building regulations require STI>0.7 in the whole ELS. In OLSs, STI requirements are distance-dependent: >0.7 within 5 m and <0.5 beyond 8 m from speaker. Therefore, it would be reasonable to measure STI as a function of distance.

A recent survey of 20 Finnish schools showed lower acoustic satisfaction among teachers working in OLSs compared to ELSs [3]. This raises questions about the role of room acoustic conditions in these experiences.

Our purpose was to investigate room acoustic properties of typical learning spaces chosen from these 20 schools using the method applied in ISO 3382-3. This is justified since the method inspects STI at different speaker-listener distances. The full version of the work is available in Ref. [4].

2. Materials

The learning spaces studied were 62 ELSs and 11 OLSs from the learning spaces in the school buildings that participated in the survey of Ref. [3]. The volume of ELSs varied within 97–286 m^3 and OLSs within 103–797 m^3. The room height varied within 2.4–3.9 m both in ELSs and OLSs. The learning spaces are described in detail in Ref. [4].

3. Methods

The learning spaces were furnished and unoccupied during the measurements. The background noise level was caused by building services, usually mechanical ventilation system operating in normal daytime mode. Windows and doors were shut during the measurements, and the students had already left the school. Therefore, the reported background noise levels did not contain any sounds from school activities.

Spatial decay of the sound pressure level (SPL) of speech and speech transmission index (STI) were

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determined according to ISO 3382-3 standard [5]. The omnidirectional sound source (Norsonic 276) and amplifier (Norsonic 280) were placed in the teacher's position, and measurements were conducted in five positions on a diagonal measurement path. Typical distances from the sound source in ELSs were 2, 3, 4, 5, 6, and 9 m (Fig. 1).

Impulse responses were measured in the same positions using sine sweep method [6]. Reverberation time, T_{20} [s], and modulation transfer functions for (indirect) STI [7] were determined from the impulse responses. The reference A-weighted SPL of omnidirectional speech was 57.4 dB at 1 m from the speaker according to ISO 3382-3. STI was determined indirectly using SPL of speech, SPL of background noise, weighting factors, redundancy factors, and modulation transfer functions. The measurement system was controlled using a laptop with room acoustic measurement software (ARTA 1.9.4.1, Artalabs). The measurements were made in octave bands 125–8000 Hz. SPL calibrator (Brüel&Kjaer 4231) was used to calibrate the system before measurements.

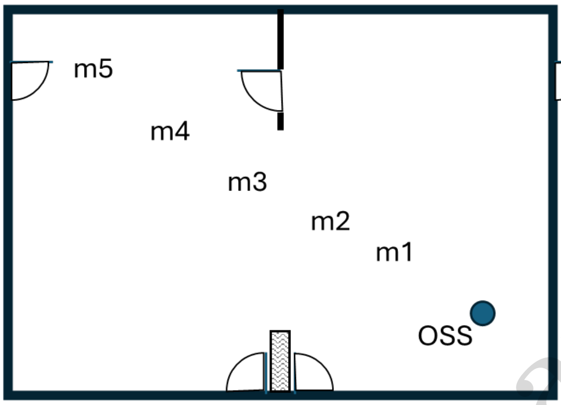

Figure 1. Measurement path in OLS. The omnidirectional sound source is OSS and the measurement positions are m1-m5. There was a movable wall between the two ELSs.

4. Results

Range of spatial decay of A-weighted SPL of speech in OLSs and ELSs is presented in Fig. 2. Ninety percent of the results were inside the colored area. Similarly, range of spatial decay of STI in OLSs and ELSs is presented in Fig. 3.

The range of reverberation time in OLSs and ELSs is presented in octave bands 125–8000 Hz in Fig. 4. The range of background noise levels in OLSs and ELSs is presented in the same way in Fig. 5. The distribution of A-weighted background noise level in OLSs and ELSs is presented in Fig. 6.

5. Discussion

5.1 Spatial decay of speech

Between-room variations were rather large in both OLSs and ELSs. In most of the ELSs A-weighted level of speech L_{AS} was within 49 – 59 dB while in most OLSs the range was 43 – 56 dB (Fig. 2).

In ELSs, STI was 0.64–0.83 which could be interpreted as good speech intelligibility in classrooms (Fig. 3). In OLSs STI was 0.47–0.91. According to Finnish regulations, STI should be >0.7 at distance under 5 m but less than 0.5 at distance over 8 m. High value near the speaker represents good speech intelligibility within learning group, while values less than 0.5 at longer distances represent less distraction by speech from other learning groups in the same OLS. The results (Fig. 3) indicate that STI did not decay sufficiently as the distance from the individual speaker increased.

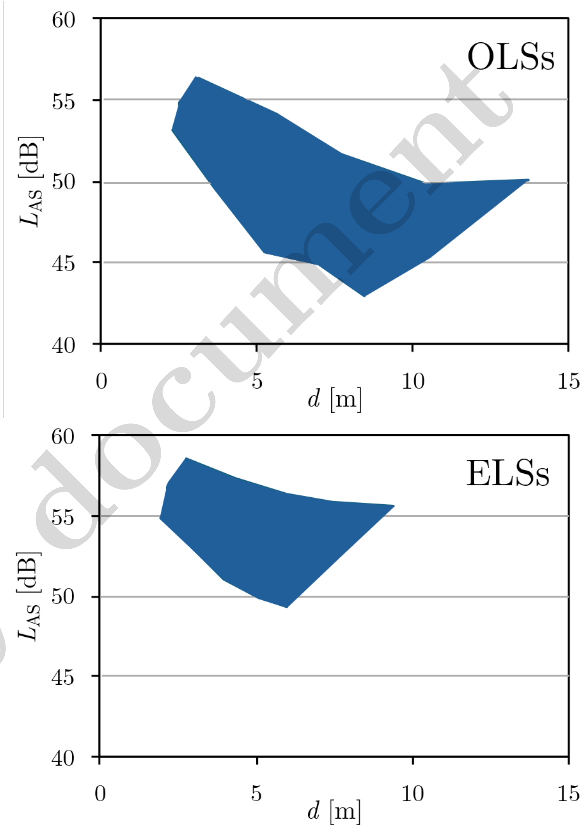

Figure 2. Spatial decay of A-weighted SPL of speech, L_{AS}, as a function of distance, d, to the speaker in 11 OLSs and 62 ELSs. The colored area represents statistical variation between 5% and 95% of all data.

5.2 Reverberation time

The results of reverberation time in OLSs and ELSs were surprisingly similar. In OLSs, T varied within 0.44–0.72 s in octave bands 250–8000 Hz (Fig. 4). In ELSs, T varied within 0.30–0.82 s in octave bands 250–8000 Hz. In over 90% of the ELSs the reverberation time was less than 0.7 s which is recommended maximum value in classrooms [8]. In a few ELSs, T was over 1.0 s in 125 Hz octave band which is not recommendable for classrooms.

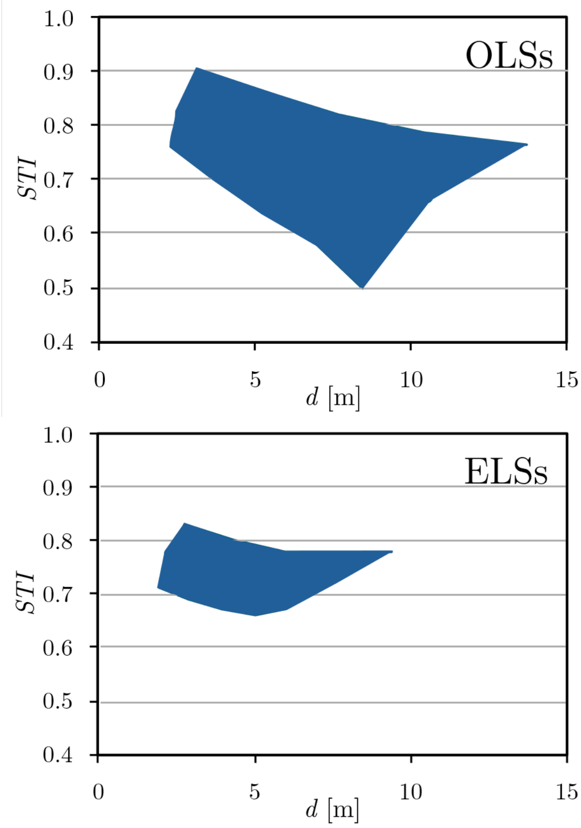

Figure 3. Spatial decay of speech transmission index, STI, as a function of distance, *d*, to the speaker in 11 OLSs and 62 ELSs. The colored area represents statistical variation between 5% and 95% of all data.

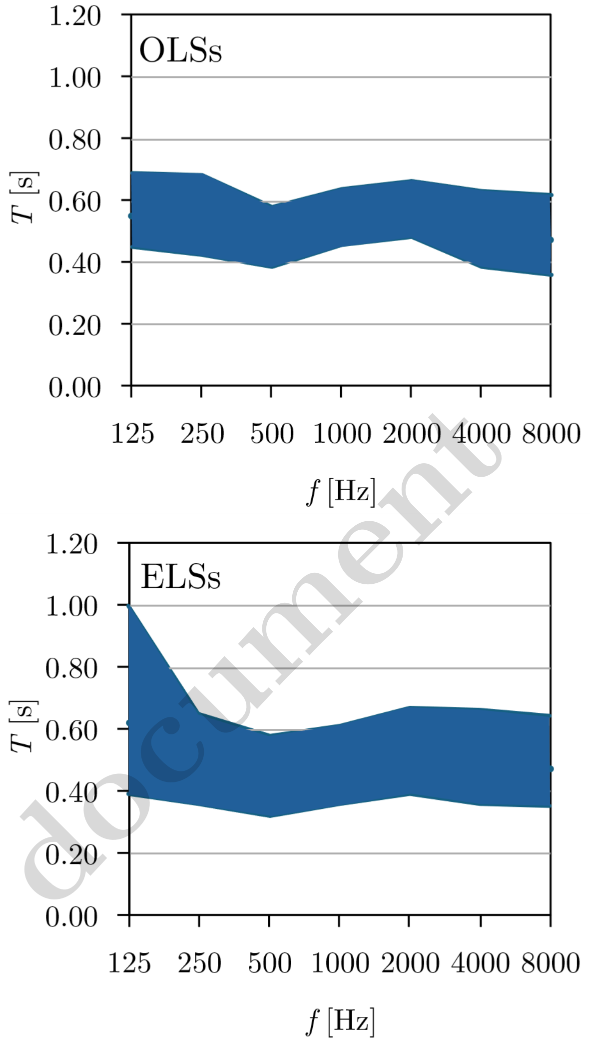

Figure 4. The reverberation time, T_{20}, in octave bands 125–8000 Hz in 11 OLSs and 62 ELSs. The colored area represents statistical variation between 5% and 95% of all data.

5.3 Background noise level

The background noise level from building services, L_{Aeq}, was within 29–44 dB in OLSs and 25–47 dB in ELSs (Fig. 5). In octave bands 125 Hz and 250 Hz, the L_{eq} -values were higher than in the octave bands 500–8000 Hz (Fig. 6). The results in OLSs and ELSs were very similar. Masking noise system was used only in one OLS. The highest background noise levels were caused by operating mechanical ventilation system. It should be noted that the SPL due to ventilation shall be under 33 dB L_{Aeq} in all kinds of learning spaces. However, the SPL of artificial sound masking system can be set within 35–40 dB L_{Aeq}.

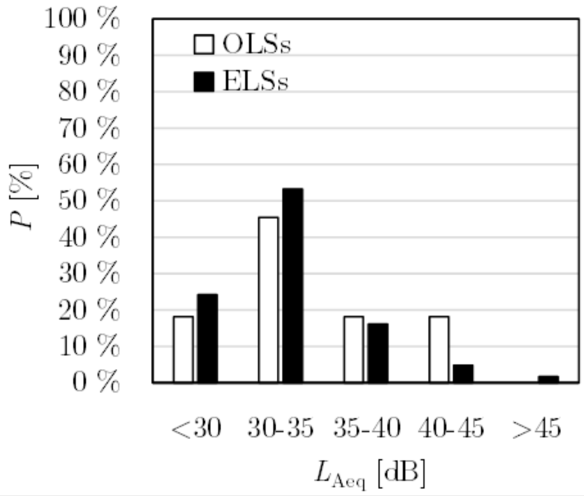

Figure 5. The distribution of A-weighted SPL of background noise, L_{Aeq}, in 11 OLSs and 62 ELSs. *P* is percentage of learning spaces.

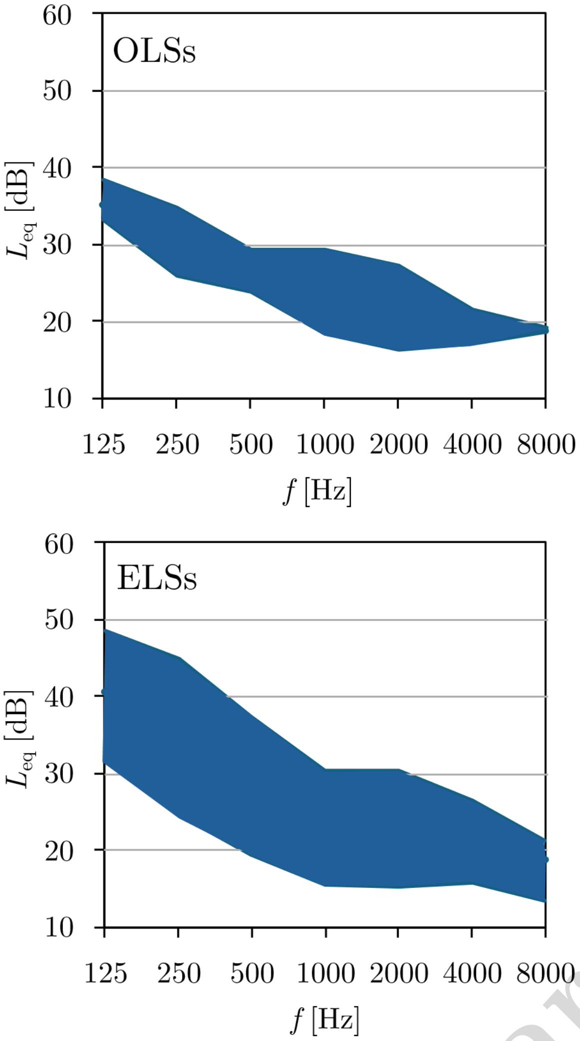

Figure 6. The unweighted SPL of background noise as a function of frequency in 11 OLSs and 62 ELSs. The colored area represents statistical variation between 5% and 95% of all data.

6. Conclusions

Our study is one of the first, which has applied spatial decay measurements in several enclosed and open learning spaces. Our results suggest that measurement of spatial decay is justified in both learning space types because it reveals how STI behaves at different distances from the speaker. We recommend the method for future studies since the method is rapidly applied and it gives a good understanding of the whole space.
Our data also shows that the STI values do not fall below 0.5 at large distances from the speaker which violates the Finnish building regulations of open learning spaces. There seems to be a need to improve the practical acoustic design guidelines.

7. Acknowledgments

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