25-29 August 2024
inter.noise
NANTES FRANCE

Room acoustic survey of open and enclosed learning spaces in Finland

Jukka Keränen[1]
Turku University of Applied Sciences, Acoustics
Joukahaisenkatu 7, FI-20520 Turku, Finland

Kaisa Ahonen[2]
Turku University of Applied Sciences, Acoustics
Joukahaisenkatu 7, FI-20520 Turku, Finland

Valtteri Hongisto [3]
Turku University of Applied Sciences, Acoustics
Joukahaisenkatu 7, FI-20520 Turku, Finland

Jenni Radun[4]
Turku University of Applied Sciences, Acoustics
Joukahaisenkatu 7, FI-20520 Turku, Finland

ABSTRACT

Use of open learning spaces for education has increased in schools while enclosed learning spaces are still used in most schools in overall. There is some debate that these two learning space types might differ in acoustic perceptions. If they do, room acoustic quality might be one explaining factor. Therefore, our purpose was to determine, whether these learning space types differ in room acoustic properties. We studied 10 schools with mostly enclosed and another 10 schools with open or flexible learning spaces in Finland. Altogether 73 learning spaces were investigated among the 20 schools. Measurements concerned reverberation time, Speech Transmission Index, and background noise level. Most of enclosed learning spaces (63%) met the new requirements of Finnish building regulations for enclosed learning spaces. Opposite to that, most of open learning spaces (91%) did not meet the regulations for open learning spaces. The results can be used in the root cause analysis of a teacher survey conducted in the same 20 schools. Teacher survey will be reported in another study. Parallel analysis of objective and subjective results is necessary to judge whether the current regulations are justified.

1. INTRODUCTION

Enclosed learning space means a room of 35–85 m^2 floor area (height about 3.0 m). Most of these are so called traditional classrooms. Teacher's desk and teaching devices are often

[1] jukka.keranen@turkuamk..fi
[2] kaisa.ahonen@turkuamk..fi
[3] valtteri.hongisto@turkuamk..fi
[4] jenni.radun@turkuamk..fi

permanently placed in one end of the room, and 20–30 pupils' desks (usually mobile ones to allow group working) take the rest of the space. There is usually one teacher per classroom. Two examples are shown in, e.g., Radun et al. (2023) [1].

Open learning spaces have appeared in addition to enclosed learning spaces in many schools in Finland. An open learning space can fit more than one typical group of 20–30 pupils with no solid floor-to-ceiling walls between them. Size of an open learning space varies (e.g., 70–270 m^2 in our study) and the number of teachers and teaching groups can vary. In addition, the teachers' desks can be located freely.

In addition, some learning spaces are **flexible**, which means that they can be opened to fit more than one group of 20–30 pupils or divided to enclosed learning spaces when needed. That is, flexible learning spaces can be in open or enclosed mode. Typical solutions to divide learning spaces are sliding or folding walls, movable screens, or curtains that can separate the classroom visually. These solutions have different usability and sound insulation qualities. In our study, flexible learning spaces were considered as open learning spaces, when they were measured in an open mode. When they had a floor-to-ceiling sliding or folding wall that was dividing the spaces, they were considered as enclosed learning spaces.

The purpose of open learning spaces is to enable pupils to learn in several or larger learning groups than an enclosed learning space allows. This may provide versatility for the use of learning space but can also lead to different acoustic environment due to behavioral changes. Enclosed learning spaces are still used in most schools in overall.

New Finnish building regulations for the acoustics of learning spaces are declared for environmental noise, airborne and impact sound insulation, building service noise (background noise), reverberation time, and speech transmission index (STI) [2]. Environmental noise is usually absent in Finnish learning spaces and the background noise comes from building services. This study considers only room acoustics so that we report the requirements for building service noise, $L_{pA,B}$, reverberation time, T, and STI.

Finnish regulations involve separate guidelines for enclosed and open learning spaces. The A-weighted background noise requirement in enclosed learning spaces is less than 33 dB, but in open learning spaces background noise is allowed to be within 35–40 dB when produced by masking sound system. The requirement of reverberation time is 0.5–0.7 s (the highest T within 250–2000 Hz octave bands) for enclosed learning spaces, but in open learning spaces the requirement is less than 0.5 s. STI must be at least 0.7 in enclosed learning spaces. In open learning spaces, STI should be at least 0.7 within a learning group (short distance from speaker), but less than 0.5 between learning groups (at 8-m-distance from speaker).

The previous building regulations [3] did not recognize the open learning spaces but only the enclosed ones. The requirement for A-weighted background noise and reverberation time were 33 dB and 0.6–0.9 s (within octave bands 500–4000 Hz), respectively. In respect to this, the new regulations are also tighter for enclosed learning spaces.

Our purpose was to determine, whether the enclosed and open learning space types differ in room acoustic properties and how the results relate to the new Finnish regulations.

2. MATERIALS AND METHODS

2.1. Investigated schools

The study was conducted in 20 basic education schools in Finland. Ten schools with mostly enclosed learning spaces and ten schools with several open or flexible learning spaces were investigated. Most (64%) of the enclosed and 40% of the open learning spaces were built or renovated before 2018. Room acoustic measurements were conducted in 62 enclosed and 11 open learning spaces which were used for teaching of 9–12-year-old children. Number of enclosed learning spaces was larger, as also schools with open and flexible learning spaces had enclosed learning spaces to enable separation of teaching groups. The definitions for the learning space types were given in Sec. 1.

2.2. Room acoustic measurements

The room acoustic measurements were conducted following the same principle as in Ref. [1]. Reverberation time, sound pressure level (SPL) and Speech Transmission Index (STI) were investigated according to ISO 3382-2 [4] and ISO 3382-3 [5]. Measurements involved six positions on at least one straight measurement path. The path length depended on room size, but typical distances between microphone and omnidirectional loudspeaker were 1, 3, 5, 7, and 9 m. In enclosed learning spaces, there was only one diagonal measurement path from the teacher's position to the end of the room. Two or three measurement paths were used in open learning spaces depending on the size and furniture orientation. The rooms were unoccupied (except operator) during the measurements. Because measurements were done in late afternoons, facility manager was instructed that ventilation system must operate at the same power as during teaching hours.

SPL of background noise, $L_{\mathrm{p,B}}$ [dB], reverberation time, T [s], and modulation transfer functions (MTFs), were measured using a laptop computer and ARTA measurement software (Artalabs 1.9.4.1). A measurement microphone (NTI Audio M2010) was connected to the input of an external soundcard (Roland Rubix22). An omnidirectional loudspeaker (Norsonic NOR276) and a power amplifier (Norsonic NOR280) were connected to the output of the soundcard. The whole measurement system was controlled by ARTA. The measurement system was calibrated before measurements using a sound level calibrator (Brüel&Kjaer 4231). The impulse responses in the octave bands 125–8000 Hz were measured using swept sine technique [6]. Both T and MTFs were calculated by ARTA based on the energy decay of backward integrated impulse responses [6,7].

The SPL of speech, $L_{\mathrm{p,S}}$ [dB], was determined indirectly according to ISO 3382-3 [5]. The SPL of pink noise, $L_{\mathrm{p,P}}$ [dB], produced by the omnidirectional loudspeaker was measured in the above-mentioned positions using ARTA as an octave band sound level meter. The sound power level of the omnidirectional sound source was constant in all the measurements. Therefore, the spatial decay of SPL could be determined and applied to the sound power level of normal effort speech [5] to obtain $L_{\mathrm{p,S}}$ in the octave bands 125–8000 Hz in the measurement positions. STI was determined using $L_{\mathrm{p,S}}$, $L_{\mathrm{p,B}}$, and MTF in each measurement position. The calculation of STI is described in detail in Ref. [7].

3. RESULTS AND DISCUSSION

The executive summary of the measurement results for the two different learning space types are shown in Table 1 indicating data range and percentage of rooms passing the new Finnish regulations.

Majority (63%) of the enclosed learning spaces met the new Finnish building regulations that concern schools permitted after 2018. Many enclosed learning spaces were built before 2018. Still, they fulfil also new regulations, although the STI requirement was not mentioned in previous regulations [3].

Opposite to that, majority of open learning spaces (91%) did not meet the new regulations. Especially, the new regulations concerning STI caused challenges in our data. Less than half of the studied open learning spaces were built before 2018, when open learning spaces were not recognized in building regulations. Therefore, our result does not claim that regulations are violated, but it shows that the new regulations for open learning spaces are not automatically fulfilled in schools built before 2018. Although our data is very limited (only 11 open learning spaces), our results probably change the way how open learning spaces will be renovated and built in the future.

Table 1: Mean of the measurement results in enclosed and open learning space types. Numbers in the brackets represent the range of measured values. The background noise, $L_{Aeq,B}$, is the A-weighted value within frequency range 125 – 8000 Hz. The reverberation time, T, is the highest value within frequency range 250–2000 Hz. STI is the mean value in the classroom. N is the number of measured classrooms. *PP* is the percentage of classrooms that passed the Finnish regulations (see Sec. 1). *PP* is indicated for each quantity separately and for all three quantities in overall.

Room acoustic quantity	Enclosed	Open
$L_{Aeq,B}$	**33** (25–47) dB	**35** (27–44) dB
T	**0.55** (0.34–0.82) s	**0.52** (0.40–0.72) s
STI	**0.76** (0.64–0.92)	**0.76** (0.47–0.96)
N	**62**	**11**
PP, $L_{Aeq,B}$ [%]	**63**	**55**
PP, T [%]	**66**	**36**
PP, STI [%]	**71**	**9**
PP, Overall [%]	**63**	**9**

There is extremely large variation in the background noise level in both learning space types, although, the ventilation was operating in every classroom during the measurements. Some of the variation may be explained by different ventilation systems. One open learning space had a masking sound system (42 dB L_{Aeq}) but it did not cause the largest sound level. Our study suggests that the ventilation noise should be better controlled in all future schools.

The reverberation times were mostly within the requirements, which was to be expected as mostly new or recently renovated schools were included in the study and acoustic consultant has been involved in most school design teams after 2000.

The STI values were high since the reverberation times were short and the background noise levels were significantly lower than the speech sound pressure levels with normal effort speech. Thus, the enclosed learning spaces mostly fulfilled the Finnish building regulations. However, in open learning spaces the requirement of STI <0.50 at 8-m-distance failed in all but one measurement. The new guidelines were not well considered even in schools permitted after 2018. More attention should be paid on the room acoustic design of open learning spaces to meet the regulations of especially STI but also T and $L_{Aeq,B}$.

Our sample size was limited (62 + 11 spaces) and covered much less than 0.1% of education spaces in Finland. Therefore, the results cannot be generalized to cover the whole Finland, especially since the sample was not randomly selected but clustered sampling with certain selection criteria had to be applied (20 schools proposed mainly by the education administration officers from Turku and Helsinki). The representativeness of our findings can also be assessed in the following way. The studied schools located in South Finland where acoustic consultants are easily available. In addition, studied schools were, on average, newer or recently renovated than schools in Finland on average. Therefore, our results give an indication of the room acoustic quality of new or recently renovated schools in the South of

Finland. Anyhow, our results do not give any indication about perceived quality, which is the topic of our forthcoming work (teacher survey).

4. CONCLUSIONS

Majority of the enclosed learning spaces met the new requirements of Finnish building regulations. Instead, majority of the open learning spaces did not. The forthcoming teacher survey outcomes are absolutely needed to confirm that the new Finnish regulations, separately for enclosed and open learning spaces, are justified.

ACKNOWLEDGEMENTS

This study was a part of research project “Schools’ sound environment from teachers’ perspective” funded by Finnish Work Environment Fund, Saint-Gobain Ecophon, University of Turku, and Turku University of Applied Sciences Ltd.

REFERENCES

1. J. Radun, M. Lindberg, A. Lahti, M. Veermans, R. Alakoivu, V. Hongisto. Pupils’ experience of noise in two acoustically different classrooms. *Facilities*, 41(15/16), 21–37, 2023. Open access at: https://doi.org/10.1108/F-03-2022-0036.
2. Kylliäinen, M., Hongisto, V. (2019). *Rakennuksen ääniolosuhteiden suunnittelu ja toteutus.* Ympäristöministeriön julkaisuja 2019:28, 50 pp., Helsinki. ISBN PDF 978-952-361-035-4. ISSN PDF 2490-1024. https://julkaisut.valtioneuvosto.fi/handle/10024/161953.
3. C1:1998 *Finnish building regulations collection. Sound insulation and noise control in buildings.* Regulations and instructions 1998. Ministry of the Environment, 4 Jun 1998, Helsinki, Finland.
4. ISO 3382-2:2008 *Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms*, International Organization for Standardization.
5. ISO 3382-3:2012 *Acoustics – Measurement of room acoustic parameters – Part 3: Open plan offices*, International Organization for Standardization.
6. I. Mateljan. *ARTA program for impulse response measurement and real time analysis of spectrum and frequency response*, User manual version 1.9.3, Artalabs, 2019.
7. EN IEC 60268-16:2011 *Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index*, European Committee for Electrotechnical Standardization.