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Room acoustic conditions in primary schools

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Through measurements of sound pressure levels during educational activities (L_{Aeq} and L_{A90}) in classrooms, relationships between activity sound levels and room acoustic conditions have been investigated. The study is based on measurements from 40 lectures in 20 different classrooms in 8 different primary schools in Trondheim, Norway. Reverberation time is a key parameter in building regulations, but no significant correlation was found between L_{Aeq} (speech level) or L_{A90} (activity noise level) and RT in these classrooms. For the other key parameter, unoccupied background noise, significant correlation was found with signal-to-noise ratio ($L_{Aeq} \div L_{A90}$) in plenary activities. It is suspected that rating RT of 0.4 s as superior conditions, as in the Norwegian building regulations, can be misleading. Allowing a slightly higher RT increases vocal comfort, and with the results in this study in mind, such an increase could be considered. Significant correlation was found between activity noise and room height, indicating that room height is also a critical parameter.

1 Introduction

Classroom acoustics is about designing rooms to fit various educational activities. The importance of acoustic comfort in these rooms can hardly be understated. For children in primary school, both hearing and vocabulary is under development, and acoustic conditions supporting high speech intelligibility and low noise annoyance is therefore important. In addition, the room acoustic design has to support vocal comfort for both teachers and pupils. Having to raise the voice to high levels is detrimental to voice health. Most countries have building regulations, which define limits for reverberation time and background noise from technical installations, and some also include speech transmission parameters. By measuring and analysing sound pressure levels during various activities and in different rooms, correlations between room design and activity sound levels can be studied. Similar studies have been conducted in England[1] and Canada[2], but not much data is found from Norwegian classrooms. Building regulations in Norway have stricter limit values for room acoustic conditions than many countries outside the Nordic countries. This study therefore provides insight into how the room acoustic design affects speech and noise levels in typical Norwegian classrooms.

2 Methodology

The data collection for this study took place in primary school classrooms in the municipality of Trondheim, Norway. Grades five to seven were chosen, assuming that they have more established patterns of classroom behaviour than pupils in the lower grades. Measurements were conducted in 8 schools between February and April 2019. In total, sound pressure levels in 40 lectures across 20 different classrooms were measured. A wide selection of schools and room types were chosen, with buildings dated from 1915 to 2018. This made it possible to compare different acoustic conditions.

Three components of the measured levels are used in the analysis; the average sound pressure level during lectures (L_{Aeq}), the activity noise level during lectures (L_{A90}) and the background noise level in unoccupied classrooms (L_{Aeq}). Separating and analysing the average sound pressure level and the activity noise level during lectures has previously been done by Shield et al.[1]. In plenary activities, the equivalent sound pressure level can be considered the signal component, the person speaking. L_{A90}, the level being exceeded 90% of the time, is the noise component, the sum of background noise and activity noise. A method introduced by Hodgson et al.[2] was also used during pilot measurements. This method involved curve fitting of three normal distribution curves on histograms of recorded sound pressure levels. By comparing results from the two methods, it was found that their level components were significantly correlated, favouring Shield et al.'s method due to easier calculations.

The sound levels during lectures were also categorised in types of educational activities. Through observing the lectures, sound levels were categorised as the following educational activities: plenary activity (where presentations or discussions were conducted), individual work, group work, practical activity and playback of audio/video. Also, observation made it possible to avoid other activities or disturbances to be included in the measurements.

2.1 Sound pressure level measurements

The sound pressure level was recorded using a class 1 sound level meter with fast time-weighting, and the equivalent level, L_{eq} was output with 200 ms sample time in 1/3 octave bands. When positioning the sound analyser, the aim was to find a place where it did not disturb any educational activities. Different room sizes and furnishing required different positioning from room to room, however, the sound analyser was always placed in the reverberation field when considering the average position of the teacher as the position of the sound source. The height of the analyser was set to 1.2 m to correspond with an average ear height of a sitting pupil, and a minimum of 1 m distance to reflecting surfaces like walls and desks was used. Following these guidelines, the analyser most often ended up in the back or along the sides of the classrooms. Of course, when considering the pupils as sound sources, some would always be in the direct sound field of the analyser. However, it is important to include the contribution of direct sound when analysing the activity noise, since this is a substantial factor in the experienced level for the pupils.

2.2 Room acoustic measurements

Room acoustic conditions were measured during breaks. A time-effective method was tested during pilot measurements and considered useful for this project. A paper bag was used as excitation signal, and it was excited around the average teacher position 3 times, using a different measurement position. Guidelines from ISO 3382-2:2008 were used for source and receiver positioning.

The background noise in unoccupied rooms was measured in 3 receiver positions, using a time interval of 15 seconds. For this study, background noise was measured during breaks in the school day. A similar method of background noise measurement was used by Shield et al. and defined as the unoccupied ambient noise level[1]. In some buildings it was difficult to measure background noise due to poor sound insulation between areas. However, it was possible to find times when measurements were possible, either with measuring an empty classroom during lecture time (when the pupils were using a different classroom), or by making sure that neighbouring rooms and the school yard outside was empty during a break.

2.3 Statistical analysis

To analyse correlation between sound levels and room acoustics, the corr-function in Matlab was used. This function returns the linear correlation coefficient, r_s, and the level of statistical significance, p_s, when given two sets of measurements, e.g. reverberation time and activity noise. In this study, $p_s < 0.05$ is considered statistically significant.

3 Results

The room acoustic conditions had reverberation times from 0.39 s to 0.82 (avg. 0.54 s) and background noise from 22.2 dB to 39.2 dB (avg. 33.6 dB). The average reverberation time was lower than what has been found in studies in other countries (e.g. British classrooms, Shield et al.[1]: 0.64 s). However, background noise levels seem to be more similar.

The time distribution of activities shows that plenary activities occupy nearly 50 % of the time spent on educational activities. Figure 1 shows the distribution, and it is observed that individual work also occupied a substantial amount of time.

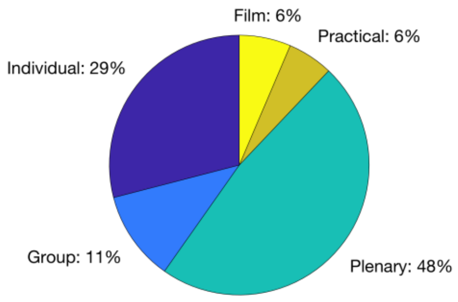

Figure 1: Time distribution of activities

3.1 Activity noise, plenary activity

The activity noise level during plenary activity is an important parameter due to its impact on speech intelligibility and general acoustic comfort. Unfortunately, this parameter is difficult to measure and analyse. It has been important to find the room acoustic conditions effect on activity noise. However, other parameters like individual- and cultural differences across groups of pupils can also affect the level. The aim was therefore to reduce the latter parameter's impact by measuring in many different groups. For the enclosed classrooms in the study, the average activity noise level was 40.3 dB. One could expect the activity noise to correlate with reverberation time and background noise. Significant correlation for these relationships were found in Shield et al.'s study[1], and through their presence in the building standards, reverberation time and background noise are important parameters to consider. However, in this study, activity noise was not significantly correlated to either reverberation time (p_s = 0.16) or background noise (p_s = 0.20). Figure 2 shows activity noise with respect to reverberation time (T_{mf}) and background noise.

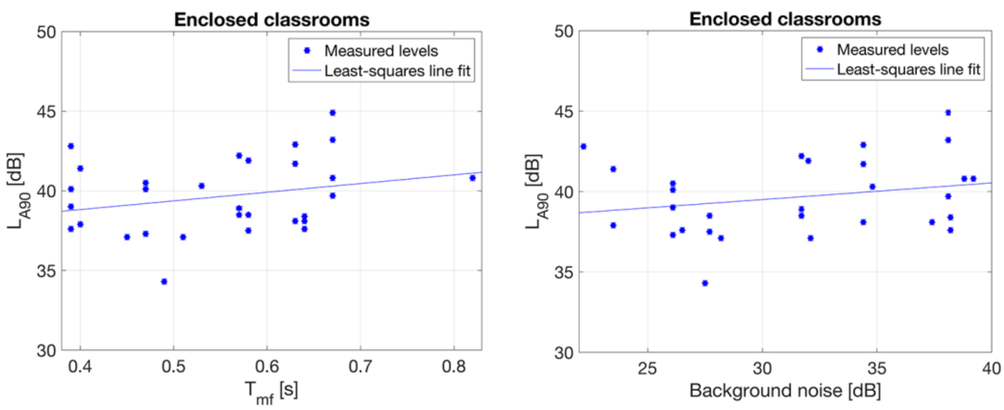

Figure 2: L_{A90} with respect to T_{mf} (r_s = 0.26, p_s = 0.16) and background noise (r_s = 0.24, p_s = 0.20)

Since the Norwegian building regulation NS 8175:2012 mention rooms with reverberation time in the range from 0.4 s to 0.6 s, it could be useful to exclude rooms with longer reverberation time in the analysis. Still, no significant correlation is found between activity noise level and reverberation time (p_s = 0.90). The data in this study indicates that no reduction in activity noise level can be expected when reducing reverberation time within this interval. Figure 3 shows activity noise with respect to reverberation time (T_{mf}) in the interval between 0.4 s and 0.6 s. Combined with previous results showing a significant correlation between activity noise and reverberation time, it could be suspected that it is an increasing correlation for reverberation times longer than 0.6 s.

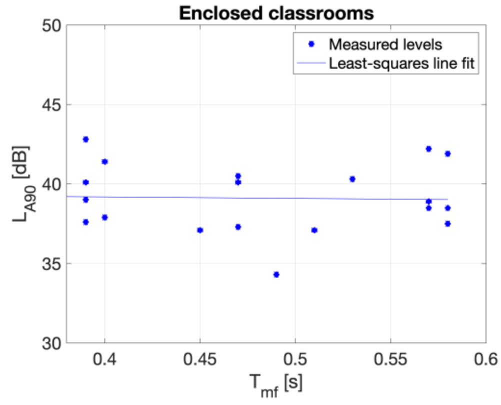

Figure 3: L_{A90} with respect to T_{mf} (r_s = -0.03, p_s = 0.90)

Activity noise was found to be significantly correlated to room height (p_s = 0.02), as shown in Figure 4.

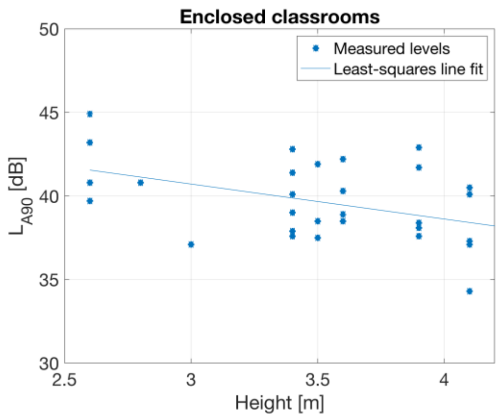

Figure 4: L_{A90} with respect to room height (r_s = -0.44, p_s = 0.02)

3.2 Speech level, plenary activity

The average sound pressure level, L_{Aeq}, can be used as a measure of the speech level in plenary activities. Considering all the schools in the study, the average speech level was 59.4 dB in enclosed classrooms. Again, no significant correlation was found with reverberation time or background noise. However, a significant correlation was found with activity noise (p_s < 0.01), indicating that the Lombard effect is present in the classrooms. Figure 5 shows the relationship between speech level and activity noise.

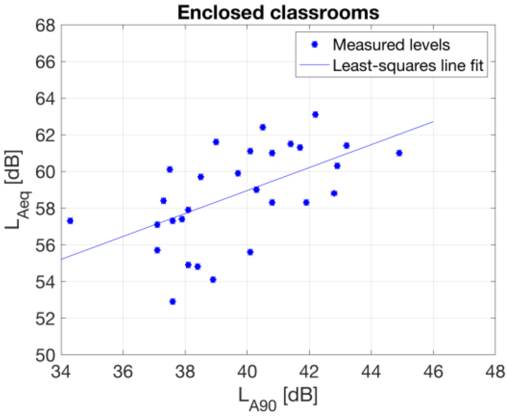

Figure 5: L_{Aeq} with respect to L_{A90} ($r_s = 0.55$, $p_s < 0.01$)

3.3 Signal-to-noise ratio, plenary activity

One can also consider L_{Aeq} and L_{A90} combined, and by using the deviation between the levels we find the signal-to-noise ratio. The signal-to-noise ratio was 19.0 dB on average in enclosed classrooms. No significant correlation was found with reverberation time ($p_s = 0.27$), but a significant correlation was found with background noise in unoccupied rooms ($p_s = 0.01$). Figure 6 shows the relationship between signal-to-noise ratio and background noise.

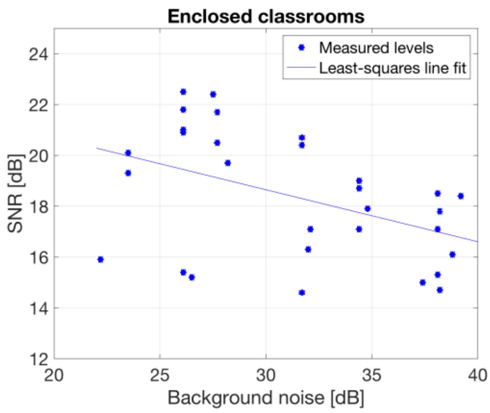

Figure 6: SNR with respect to background noise ($r_s = -0.45$, $p_s = 0.01$)

It was also found that signal-to-noise ratio was significantly correlated to the *acoustic utilisation ratio* ($p_s = 0.01$), meaning the room occupancy with respect to the acoustic capacity, a concept introduced by Rindel ($N_{max} = V/20T$)[3].

3.4 SPL in other activities

For the other activities conducted in the classrooms, the levels were 58.7 dB for individual work, 64.1 dB for group work, 66.9 dB for film and practical activities. All levels are generally lower than levels found in studies from other countries.

4 Discussion

According to data collected in this study, sound pressure levels in Norwegian classrooms are lower than levels found in studies from other countries[5]. The signal-to-noise ratio, which is considered important for speech intelligibility, is also satisfying with 19.0 dB on average. Bradley found that speech intelligibility stopped improving from 15 dB[6], however, higher SNR could be beneficial for the hearing impaired.

Norway holds strict limit values for room acoustic conditions in the building regulations, and the results could be considered a positive effect of this practice. However, it is important to find an optimum range for these limit values. As mentioned in the introduction, defining too strict recommendations for reverberation time can also have a negative effect on e.g. speech comfort. The idea of lower reverberation time being important in classroom acoustics could be debated. It can lead to lower noise levels, which is positive for the general acoustic comfort and a reduced Lombard effect for the speaker. At the same time, it has been found that teachers also raise their voice level due to the absence of room reflections. Pelegrin-Garcia[4] argues that 0.6 s reverberation time could be a better target value.

Considering the time distribution in Figure 1, conditions for plenary activities should be emphasized in the acoustic design of primary school classrooms. The traditional view of classroom activity is the plenary situation, something that is also reflected in the previous research on acoustic conditions in classrooms. However, in a white paper from the Norwegian government in 2008, the development of the teacher role is described as a move from being a mediator of knowledge to becoming a facilitator that supports the pupils in gaining knowledge. In higher education, a recent trend is to design *active learning classrooms* where group work is considered the main activity of the room. This highlights the importance of discussing the room's main activity. Perhaps different standards for different age groups and rooms should be established, and based on the results in this study, the plenary activity should be important when designing room acoustics in primary school.

Results from the measurements in this study does not give support for the argument of reducing reverberation time to 0.4 s in classrooms where plenary activity is the main activity. In the Norwegian building regulation, NS 8175:2012, 0.4 s is considered optimum conditions. No significant correlation between noise levels and reverberation time has been found in the measured rooms, indicating that aiming for the shortest reverberation time is unnecessary for noise conditions and detrimental to vocal comfort.

5 Conclusion

Measurements of reverberation time, background noise and sound pressure levels during lectures in primary schools in Trondheim, Norway, have been used to analyse the room acoustic conditions. The activity noise level, being the level exceeded 90% of the time, is an essential parameter for speech intelligibility during plenary activities. The study shows no significant correlation between either reverberation time nor background noise and the activity noise level for the measured rooms. A high vocal effort is needed for short reverberation times, and it could be argued that increasing the reverberation time would give a better balance between the teacher´s vocal comfort and speech intelligibility in the rooms. Also, it is indicated that increasing room height is reducing activity noise.

Considering signal-to-noise ratio, a significant correlation with the background noise level from technical installations was found. It is therefore important to give strict limit values for background noise in building regulations. The results also indicate improved signal-to-noise ratio for lower background noise levels than 28 dB, which is the limit level in NS 8175:2012.

References

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