Acoustic quality of classrooms: influence of the ceiling

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Introduction
The Flemish government decided to make up the shortfall in decent learning environments by 2014. 211 schools will be built or renovated in the next five years, with a total investment of 1 billion euro. Focus in this improvement project of the Flemish school infrastructure is energy efficiency. Practical experiences have shown that combining good acoustics with modern energy efficient building methods is particularly challenging.

However, good acoustics in teaching spaces are crucial for quality learning environments [1]. Background noise and reverberation can create problems for students, especially younger students who haven’t yet developed the skills that allow them to differentiate between what the teacher is saying and competing background noise. Students can easily miss key words, phrases and concepts. Students with hearing problems have difficulty listening and concentrating in classrooms with poor acoustics. And it can be especially hard for students for whom the teacher’s language is not their native language to understand the teacher.

This paper addresses the influence of the ceiling type and properties on the acoustic quality in classrooms.

Acoustic quality of classrooms
The acoustic quality of a classroom shall mainly be evaluated in view of verbal communication between the teacher and the students. In a classroom with good acoustics the students will more easily understand what the teacher is saying, the teacher won’t have to raise his voice under normal circumstances, the students will be less distracted by outside noise (like fellow students in the corridors or on the playground), ... In short the efficiency of the teaching process will drastically increase, resulting in students with a higher competence level and more motivated teachers.

The reverberation time
The sound of speech is reflected on hard surfaces, such as painted walls and vinyl floors, so that listeners hear several indistinct, overlapping versions, which smear the original message. Sound that continues for a time, reflecting around after the sound source has stopped, is called ‘reverberation’. The length of time it takes to die away is called the ‘reverberation time’. Reverberation time is measured in seconds. The ideal reverberation time depends on the room volume [7].

If the reverberation time is too long the extended reflected sounds mask or blur the direct sound, which makes it hard to understand what someone is saying. Some reflected sound is good for understanding what someone is saying because it may reinforce their voice, but it’s a matter of careful balance.

The combination of lots of ambient noise and a long reverberation time can lead to a situation known as the ‘cocktail party effect’. This is where a speaker raises his/her voice to be heard above the level of background noise. This can result in everyone trying to speak ‘above’ the volume of everyone else. The outcome is an extremely noisy environment, which makes it hard to understand what people are saying. Despite the name, the cocktail party effect doesn’t only occur on parties. It can also occur in classrooms, especially during ‘group work’ or in classrooms of a nursery school, and the effect is increased even further if the room has a ‘long’ reverberation time.
The teacher’s voice
The signal-to-noise ratio ‘SNR’ is the ratio of the teacher’s voice to the ambient noise. The recommended minimum necessary for students to hear efficiently in a classroom is +12 to +15 dB (+20 dB is preferred when there are students with hearing impairments). This means that if the background noise level is, say, 55 dB, the teacher would need to speak at 70 dB, which is almost shouting. The louder the background noise, the louder the teacher must speak so the students can hear clearly.

The speech intelligibility
The speech intelligibility can be in general represented by several parameters. The ratio between the portion of ‘early’ sound and the portion of ‘late’ sound determines to a large extent the speech intelligibility. Early sound is sound that travels from the speaker to the listener (via reflections against walls) in less than 50 msec. This early sound is useful for understanding speech. Late sound, which arrives at the listener after more than 50 msec, has an adverse effect on the speech intelligibility. The Deutlichkeit ‘D50’ (%) gives the percentage of early sound in the total sound arriving at a listener. The Speech Transmission Index ‘STI’ (%) [6] is a machine measure of intelligibility whose value varies from 0 (completely unintelligible) to 1 (perfect intelligibility). The RASTI (Rapid Speech Transmission Index) is a simplified version of the STI (from a calculation perspective), but it produces almost the same results as the STI. The RASTI is directly dependent of the background noise level, of the reverberation time, and of the size of the room. RASTI (and STI) values can be readily interpreted with the following table:

<table>
<thead>
<tr>
<th>RASTI</th>
<th>Speech intelligibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 30%</td>
<td>Bad</td>
</tr>
<tr>
<td>30% – 45%</td>
<td>Poor</td>
</tr>
<tr>
<td>46% – 60%</td>
<td>Fair</td>
</tr>
<tr>
<td>61% – 75%</td>
<td>Good</td>
</tr>
<tr>
<td>76% – 100%</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

Table 1: Interpretation of RASTI values

Calculation model
Acoustic properties have been analyzed for a typical classroom with the CATT Acoustic software for room acoustics prediction and auralization [4]. The classroom is 2,7 m high, its floor surface is 9 by 10m. The ideal reverberation time for a classroom with these dimensions is between 0,6 and 0,8 sec. The classroom furniture consists of 4 rows of 3 double tables of 1,8 by 0,9 m and 0,75 m high. Each table has two chairs. Next also the teacher’s table and chair have been represented in the model. The floor, the walls and the blackboard are represented as acoustically hard surfaces, with absorption coefficients from to 2 to 8 % in the octave bands from 125 Hz to 4 kHz. The classroom has one door of 0,9 by 2 m and three windows of 1,5 by 1,8 m. The door and the windows are acoustically hard in the high frequency bands, but their limited sound insulation in the lower frequencies is represented by a slightly higher absorption coefficient, up to 15%. The following pictures show this classroom from different angles.
The teacher is seated at his/her desk, and is represented as a sound source at a height of 1.2 m above the ground, and with the characteristic directivity of human speech aiming at the students. The teacher’s voice is attributed a female speech spectrum (according to IEC 2003 60286-16) with a sound pressure level of 59.5 dB(A) at 1 m distance.

5 receiver positions have defined throughout the classroom, at different student tables.

The ambient noise in the classroom is caused by two independent sources:

1) External noise, for instance in the street, entering the classroom mainly through the windows, and

2) Internal noise from the ventilation system.
Jelineka et al. [5] show that the influence of the spatial distribution of this ambient noise on the acoustic parameters in the classroom is limited in the case of external noise penetrating large windows. For that reason the ambient noise level is assumed to be constant over the classroom in the present analysis.

The sound power spectrum of the total ambient noise inside the classroom is given in the following table.

<table>
<thead>
<tr>
<th>Octave band</th>
<th>125 Hz</th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
<th>A-weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lw</td>
<td>50 dB</td>
<td>47 dB</td>
<td>46 dB</td>
<td>46 dB</td>
<td>47 dB</td>
<td>47 dB</td>
<td>53 dB(A)</td>
</tr>
</tbody>
</table>

Table 2: sound power spectrum of the ambient noise in the classroom

Note that this ambient noise power spectrum is significantly lower than the one used by Jelineka.

Influence of the ceiling properties on acoustic quality

The acoustic quality of the classroom is analyzed with three different ceilings: a concrete ceiling (with hardly any acoustic absorption), a (non-perforated) plasterboard ceiling with 5 cm mineral wool in the plenum (providing only in the low frequencies some acoustic absorption), and a ceiling with soft mineral wool panels (with an acoustic absorption close to 1) 20 cm below the concrete structural ceiling.

Following table summarizes the calculation results for the classroom with three different ceilings. The reported values are the averages over the 5 receiver points distributed across the classroom.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concrete ceiling</th>
<th>Plasterboard ceiling</th>
<th>Soft mineral wool panels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverberation time</td>
<td>1,7 sec</td>
<td>1,7 sec</td>
<td>0,8 sec</td>
</tr>
<tr>
<td>Deutlichkeit D50</td>
<td>30%</td>
<td>42%</td>
<td>70%</td>
</tr>
<tr>
<td>RASTI</td>
<td>Poor (45%)</td>
<td>Fair (48%)</td>
<td>Good (63%)</td>
</tr>
<tr>
<td>SNR</td>
<td>13 dB</td>
<td>14 dB</td>
<td>11 dB</td>
</tr>
<tr>
<td>Ambient noise level</td>
<td>45 dB(A)</td>
<td>44 dB(A)</td>
<td>38 dB(A)</td>
</tr>
</tbody>
</table>

Table 3: summary of the calculation results of the acoustic quality in the classroom for three different ceiling types

These results very clearly indicate the importance of the ceiling on the acoustic quality of the classroom.

The reverberation time decreases with 50% when mineral wool panels are applied, and only in that case, the optimal reverberation time of 0,6 to 0,8 sec is realized. Ideally, some additional acoustic absorption material should be applied to the back wall of the classroom.

The Deutlichkeit D50, which indicates the portion of meaningful sound energy in the total sound energy for a listener, more than doubles from 30% in the case of a concrete ceiling, to 70% with a soft mineral panel ceiling.

The speech intelligibility as measured by the RASTI improves from ‘poor’ in the case of the concrete ceiling to ‘good’ in the case of a soft mineral wool panel ceiling.

Note that the ambient noise level itself also depends on the reverberation time: when the reverberation time is long, a given ambient noise outside the room will generate a higher inside ambient noise level than with a short reverberation time. So the acoustic absorption in the room, as measured by the reverberation time, has a double effect on the speech intelligibility: first it increases the portion of the early (direct) energy, and secondly, it reduces the ambient noise from external sources.

Next to the average acoustic quality of the classroom in the 5 receiver points, also the spatial distribution of the speech intelligibility has been investigated. The RASTI in a plane at the same
height as the heads of the students is represented in the figures below. These figures again clearly show that the speech intelligibility and the acoustic quality of the classroom is ‘poor’ in the case of a flat concrete ceiling, while it is ‘good’ with the soft mineral wool panels.

Conclusion

This study addresses the influence of the ceiling type and properties on the acoustic quality in classrooms. The acoustic quality of a classroom is evaluated in view of verbal communication between the teacher and the students. A representative classroom is modeled in the CATT Acoustic software. Three different ceilings are considered: a hard concrete and plasterboard ceiling, and a soft mineral panel ceiling.

The calculation results clearly indicate that the ideal reverberation time can only be reached with the soft mineral wool panels. The speech intelligibility is ‘poor’ in a classroom with a hard ceiling, and ‘good’ in the case of a soft mineral wool panel ceiling.

The conclusions of this study indicate that at least a ceiling with the same high absorption properties as the soft mineral wool panels is required for obtaining a decent acoustic quality in classrooms.

References

7. Ministerie van openbare werken, Bestuur der Gebouwen, TYPE-BESTEK 110 van 1979, geldend als vaste bijlage bij de bijzondere bestekken betreffende offerteaanvragen voor geïndustrialiseerde gebouwen (administrative and technical regulations).