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Intelligibility in classrooms

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Abstract: When e.g. an auditorium, lecture room or theater has to be judged acoustically, one will find the reverberation time plays an all-important part. In reality the reverberation time is a secondary size. The primary is the intelligibility of speech. It is shown, how it is possible in a school room not only to rate the intelligibility of the teachers speech towards the students, but also give an indication of where to put up absorbing material, which will improve the intelligibility. To install absorbing

material in the middle of the ceiling for example, will have a damaging effect on the intelligibility.

During the last few decades, schools in Scandinavia have come under increasing criticism, that children do not learn enough and that discipline is poor. At the same time, increasing work-loads have placed greater demands on teachers, causing fatigue and a rise in the amount of sick-leave.

Part of the problem arises from the design of classrooms in recent years. Demands have been made that the classrooms should be more hygienic, easier to clean and "airy". This "airiness" has resulted in high ceilings and comparatively large floor areas. Also, the materials used in building schools should be particularly "robust", in order to withstand the modern tendency to mild vandalism. These factors combined, give a room with poor acoustic properties and intelligibility.

The fact that pupils have difficulty in hearing and understanding the individual syllables of spoken words, makes it necessary for the teacher to speak louder and it make the pupils restless. This raises the general noise level, making the situation worse. It is therefore of central importance, that classrooms are designed in a way, that gives good intelligibility, or at the very least greatly improves on the situation, which is normally found in modern schools.

Intelligibility is difficult to define and measure. This is probably one of the reasons, why it has not been discussed whether the acoustic properties of classrooms, could be a contributing factor to the problems of teaching today. In telecommunications research, however, a measurement method has been found, where trained speakers say disconnected syllables in the room under investigation. A trained panel of listeners note the syllables, as they hear them. The percentage of correct syllables is a measure of the quality of the room or transmission channel, with respect to intelligibility. By definition, the value which is found, is a number between zero and one and is called the Speech Transmission Index (STI).

Even though some syllables are lost, it may still be possible to understand words. Fig. 1 shows how

Fig. 1.

Octave band (Hz)	125	250	500	1 k	2 k	4 k	8 kHz
$F_1 = 0,88$							
$F_2 = 0,8$							
$F_3 = 1,0$							
$F_4 = 1,25$							
$F_5 = 1,6$							
$F_6 = 2,0$							
$F_7 = 2,5$							
$F_8 = 3,15$							
$F_9 = 4,0$							
$F_{10} = 5,0$							
$F_{11} = 6,3$							
$F_{12} = 8,0$							
$F_{13} = 10$							
$F_{14} = 12,5$							

Fig. 2. A complete STI analysis requires investigation of 7 octaves, each with 14 modulation frequencies. The simplified RASTI method uses only the octave bands at 500 and 2000Hz, with 4 and 5 modulation frequencies, respectively.

Fig.3. Qualitative Intelligibility compared to RASTI values.

many syllables must be heard correctly in order to understand a given percentage of words. For example, if 70% of the syllables are heard correctly, then 94% of the words will be understood. We can say that speech consists of vowel sounds, which are tones that change in strength. We say that the vowel sounds are modulated with a number of lower frequencies. This modulation creates the consonants. In speech, the vowel sounds range from 125Hz to 8kHz, while the modulation frequencies range from 0,6 Hz to 12 Hz. See fig.2. With a simplified method it is sufficient with two carrier frequencies and 9 modulations frequencies.

The value for intelligibility arising from these, is given as a number between zero and one or in percentage from 0% to 100%. It is called the RASTI Index. Fig.3.

Fig. 4.

By reducing the measurement task to such an extent, it has been possible to build both a transmitter and a receiver, which automatically in approximately 8sec, can determine the degree of modulation of all nine combinations, find a weighted average and display it on a screen. The transmitter is formed in such a way, that the directional characteristics of the transmitted sound, closely correspond to those of a human speaker. Fig.4.

A series of intelligibility measurements were made in a typical Scandinavian classroom, intended for 20 to 25 pupils and built, as the majority of other classrooms, without special attention to the acoustics of the room. The classroom is quite old, and therefore not as large as a modern classroom. The room has plaster

walls. Consequently, we can say, that there are many modern classrooms which are considerably poorer, because they are larger and have harder walls.

Fig. 5 shows the classroom and the position of the speaker (teacher). The modulation was measured in nine places where pupils sit. The transmitter was placed 120cm above the floor and was directed towards the pupils' positions. The receiver was 100cm above the floor. Three figures are given for each listener position: the two on the left are Early Decay Times (EDT) at 500 and 2000Hz. In this completely normal (unchanged) classroom, the intelligibility is not good, on average 0,54. Teaching in this classroom requires great attention on the part of both teacher and pupils.

The reverberation time must be reduced considerably by adding acoustically absorbent materials. These materials must be placed out of reach of the pupils, but must not prevent useful sound from reaching the pupils on the back row. The sound rays drawn in fig. 6 show that the central part of the ceiling gives useful reflections towards the back row. Consequently, this area must not be covered by absorptive materials. To increase the sound level even more at the back of the classroom, it would be desirable if the sound, which hits the back wall could be reflected downwards towards the back row. This requires a slanted back wall, which can, however, be made of a lightweight acrylic material or plywood. The ceiling areas at both the front and rear thirds of the classroom are suitable for using absorptive material. These areas are beyond the reach of the pupils. Many tests have been performed, involving positioning of absorbing materials as well as different types of materials. This is described in Ref.7. In fig. 6 a most efficient result is shown.

Fig. 5. Classroom 317 as it is used for teaching without special attention to the acoustics. A typical Scandinavian classroom. The average value of RASTI for three measurements at nine locations is 0,54 with a standard deviation of 0,02.

Fig. 6. Classroom 317 with slanting rear panel and absorbing cones on the front and rear thirds of the ceiling. The central part of the ceiling is used as a reflector to increase the level of speech in the back rows. This is also valid for the rear panel. Average RASTI is 0,71 with a standard deviation of 0,04.

Fig. 7
AcoustiCone.
Top:
Assembled
and mounted.
Bottom:
Before assembly.

The absorptive material may, as in this case, be cone shaped aluminum bodies, which are perforated with slits. Inside the cones are placed a layer of mineral wool, which is 12-15mm thick (see fig. 7). The installation of the cones are done in order to lower the noise-level and to improve the intelligibility in a schoolroom.

Since the cones only need to cover one half of the ceiling space (one cone per m^2), there will always be space enough to leave other installations like lamps, fire alarms, ventilation vents or sprinkler systems where they are, and install the absorbers around these. The cone-form design provides an unregular ceiling level, which distribute the sound and improve the absorption of the high frequencies.

Table 1

Teachers Level →	Room A 60 dB _A	Room M 58,5 dB _A
Noise Level dB _A ↓	STI Rasti	STI Rasti
0	0,74	0,72
50	0,67	0,65
54	0,62	0,61
60	0,56	0,48

Noise Level dB _A ↓	STI Rasti	STI Rasti
0	0,67	0,66
50	0,63	0,62
54	0,59	0,56
60	0,50	0,44

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Table 1 shows the results of some measurements made in two rooms, A and M, which have a higher intelligibility than room no.317. This experiment shows how noise affects intelligibility, when the teacher is facing the pupils (upper) and when a sound-reflecting board is used and the teacher faces away from the pupils (lower). Intelligibility is measured in RASTI units in STI, without noise and with noise levels of 50, 54 and 60dB (A), that is, 10, 6, and 0 dB lower than the speech level.

The following important results can be seen: a noise level 10dB lower than the speech level only reduces the intelligibility by 5 to 7%, but if the noise level is increased by 10dB, so it becomes as high as the speech level, the intelligibility is drastically reduced. It can also be seen, not unexpectedly, that when the speaker faces away from the pupils, the intelligibility is also reduced by 3 to 7%. This means,

turning away from the pupils is equivalent to introducing a noise level approximately 10dB below the speech level.

In conclusion:

1. The acoustic qualities of most of our classrooms are too poor. This reduces the effectivity of lessons and makes them unnecessarily fatiguing for both teacher and pupils.
2. Classrooms can be inexpensively improved without compromising hygiene or "robustness".
3. Intelligibility should be determined at both the front and rear of the classroom and also along the sides. In a room without pupils and without external noise, the RASTI value should not be below 0,70 and should preferably be greater than 0,80.
4. It is a shame that we make education difficult and tire both teacher and pupil, simply because the intelligibility is poor, when it can so easily be corrected.

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