Speech intelligibility in Swedish forests

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Summary

For thousands of years we have lived outdoors and developed our senses in the outdoor environment. Hearing works very well outdoors where natural sounds from singing birds, gurgling sound from small streams, wind sound from the trees and human voices are common. The problem is that we spend the major part of our time indoors today, in an environment with very few natural sounds. This affects us a lot, especially pupils in the learning situation. Outdoors there are no hard flat parallel surfaces that reflect sounds. In the classrooms however, reflected sound is very common and this raises sound levels and deteriorates speech intelligibility. The effect is problems for students to understand what the teacher is saying and voice problems for teachers. Being able to listen without effort is important for good learning and we know that poor room acoustics is a burden that impedes learning. Therefor it's important that teaching spaces provide good speech intelligibility for listeners and good speech comfort. A good example is forests where we can talk to each other over long distances without having to raise our voice. I have made several listening tests in Swedish forests and also measured the sound reflections from trees and other reflecting surfaces. I have then compared the sound reflections in the forest with reflections in Swedish classrooms. The results are interesting and I mean that "forest acoustics" can be a source of inspiration for good classroom acoustics. This paper will focus on why forest acoustics provides so good speech intelligibility, and which acoustic parameters that is interesting to measure. Consonants carry a lot of information in most languages, therefore it is important that the room-reflections support consonants. Vowels, on the other hand, don´t carry information and need no support. My measurements show that "forest-rooms" support consonants but not vowels. By doing a lot of measurements in classrooms I discovered that classrooms with the same reverberation time (RT) can be experienced very differently. Comparing classrooms by measuring only RT (T_{20}) is not enough, because it´s a blunt measure. T_{20} starts the evaluation first after the sound pressure level has dropped 5 dB. This "waiting time" is often quite long and we miss a lot of information from the early important part of the decay. I mean we have to measure both RT (T_{20}) and clarity, C_{50}, to investigate if the room acoustics is good enough for teaching.

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1. Introduction

Hearing works very well in the forest where natural sounds from singing birds, gurgling sound from small streams, wind sound from the trees and human voices are common. The problem is that we spend very little time in forests today. Instead we live in cities with many artificial sounds such as traffic noise and other manufactured sound. Another problem is that we spend the major part of our time indoors, in an environment with very few natural sounds. Spending so much time indoors affects us a lot, especially pupils in the learning situation. In Sweden we can very often read articles in newspapers about how bad the acoustic environment is in our educational premises. Many classrooms have poor room acoustics for modern teaching. Most rooms have a lot of reflected low frequency sounds that raises the sound level and deteriorates the speech intelligibility. In recent years there have been several studies, reports and papers showing how the acoustic environment in Swedish schools affects students and teachers. HRF (Swedish association for hard of hearing people), published 2010 the report "Kakofonien"[1]. This report shows that 67% of the teachers say that the sound environment is a problem. 44% say they often find it difficult to talk and communicate in the classroom. Fredrik Sjödin shows in his thesis, "Noise in the preschool, Health and preventive measures" [2], that the acoustic environments in Swedish preschools are the most troublesome safety factor. A poor acoustic environment that masks speech impedes the educational work, and this is a big reason for illness among preschool staff. Teacher's voices are an important tool in teaching and Viveka Lyberg Åhlander thesis, "Voice use in teaching environments Speaker's comfort" [3], shows that Swedish teachers, more than others professionals, have voice problems. This leads to increased sickness absence with human suffering and huge costs. Robert Ljung shows in his thesis, "Room Acoustics and Cognitive Load When Listening to Speech" [4], what classroom acoustics affects student's ability to remember what they heard. This shows that ambitious teachers and motivated students' performance may be degraded by the acoustical properties in the classroom. My father, who worked as a teacher, in math and physics, all his life, got a hearing loss in old age. It gave him great trouble to hear and communicate, especially indoors. One summer my father and I were walking in a forest, and suddenly I noticed that he did not hear that badly. He told me that in forests, he could often hear and communicate quite well, but almost never indoors. – The only things I can hear indoors are vowels, and they carry very little information, he said. The information in speech is carried by the consonants. Rooms with poor room acoustics often reflect vowels, and this masks consonants and deteriorates the speech intelligibility. But in the forest, consonants are easy to hear because the masking vowels are not reflected. In the autumn same year, I was in a forest and tried to find mushrooms with my son, and then I noticed that he could hear what I said at long distance, even though I deliberately spoke with a low voice level. Swedish teachers often complain about the acoustic environment in classrooms, canteens and corridors. Instead of continuing to examine how bad the acoustic environment is in Swedish schools, I have tried to find schools with good acoustics for teaching and learning. I have asked Swedish teachers if they know any room or place with a good sound environment. Certainly there are Swedish schools with good acoustic environment, but the interesting response from teachers is that they often experience the best acoustic environment outdoors, in the forest. Therefore I have investigated how good the acoustic environment is in Swedish forests by making listening tests, and also measure the "room acoustics" in different forests.

METHOD

Since my son could hear my voice over long distances, I did a test to experience the speech intelligibility in the forest myself. I live in south Sweden were we have some nice forests far away from traffic roads, airports and railways, the only sounds that occur there are natural. I placed a loudspeaker on a stand in the forest. With an mp3-player, I played an audio book and checked that the sound level 1 meter in front of the loudspeaker was 60 dBA. This corresponds to normal speech level.

Picture 1. Measuring sound level at 1 meter.

Then I took a chair and sat down 10 meters away from the loudspeaker and listened, I could easily hear and understand all words.

Picture 2. Listening position in the forest.

It turned out that I could sit up to 20 meters away from the loudspeaker and still understand what was said. Background sound level, created by natural sounds like bird songs and wind from trees varied between 25-35 dBA. I have done the same test with different people, and all of them are astonished about how easy it is to hear and understand a voice in the forest even when the loudspeaker is quite far away. Sweden have a sound classification standard for schools, SS 25268 [5], the verification of room acoustics is made by measuring the reverberation time according to EN ISO 3382-2 [6]. I have therefore made room acoustic measurements in some Swedish forests, and compared the result to the required values in SS 25268.

Picture 3. Measuring impulse response in pine forest.

Picture 4. Measuring impulse response in fir forest.

Picture 5. Measuring impulse response in beech forest.

RESULT

I have measured the reverberation time (T_{20}) in different forest types like; pine, fir and beech. The typical result is shown in figure 1.

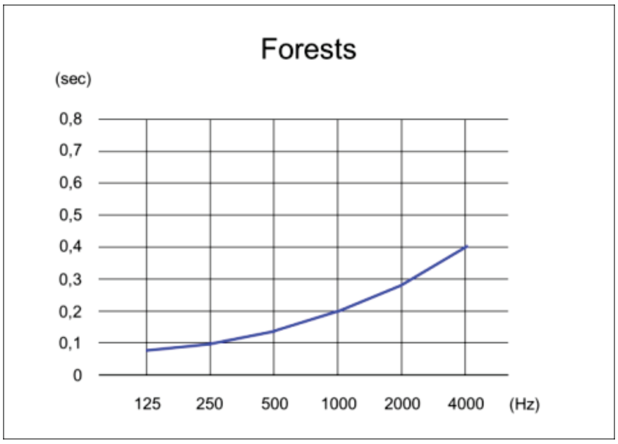

Figure 1. Common RT in forests.

In forests there is a reverberance in the higher frequencies, but in the lower frequencies, especially at 125 Hz, there is almost no reverberance at all. In this environment the speech intelligibility is very good. Unfortunately this result is very unusual in Swedish classrooms. Very often the reverberation time in regular classrooms turns out to be like the red line in figure 2.

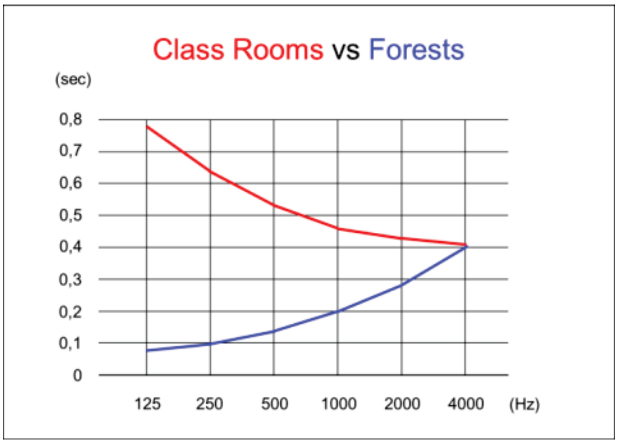

Figure 2. Common RT in Classrooms and Forests.

In typical Swedish classrooms the reverberation time is longer in the lower frequencies compared to the higher frequencies. The “reverberation time-curve” in classrooms is reversed to the “reverberation time-curve” in the forest.

The Swedish sound classification standard for schools, SS 25268 put requirement on reverberation time at different sound classes, class A, B, C and D. Class A is the best and class C is the Swedish authority's requirement. The requirement in class C is shown with the dashed line in figure 3.

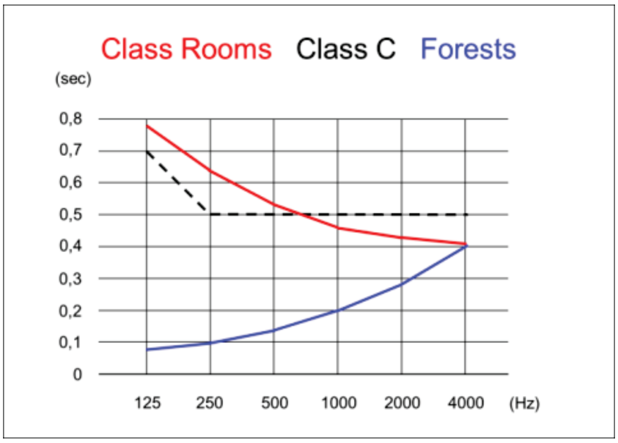

Figure 3. Classroom, Sound class C and Forest.

Comparing the results in the forest (blue line), the classroom (red line), with the standard requirement (dashed line) there are some interesting differences. A typical Swedish classroom often fulfills the requirement in the standard above 1000 Hz, but in the lower frequencies the reverberation time is too long. One interesting thing about sound problems in Swedish classrooms is that very often teachers and pupils complain about high sound levels. A teacher explained it very good when she said: "*Outdoors the children talk with normal voice levels, but when we come indoors they start to shout because they need to hear themselves among all the sound. And since the room amplifies the sounds from active children, they start to shout."* This gave me the idea to measure how many decibels different rooms amplify the sound level. I took a sound source, with known sound effect, and placed it outdoors on a pier and measured the sound level at different distances (3-7 meters).

Picture 6. Measuring the sound level on a pier.

Then I took the same sound source in to different rooms and measured the sound level.

Picture 7. Measuring the sound level in a room.

By comparing the result between the room and the pier one could see how the reflections from the room amplified the sound level. This is a pedagogic way to explain for teachers and architects how different building materials and furniture affect the sound level. And all teachers know that when we put children in a room with a lot of sound, the pupils will raise their voices (the Lombard effect). The expected connection between a short RT and low sound level (low amplification) is not always fulfilled. I have compared 22 rooms and there is a strong connection between the amount of sound absorption in the room and the room amplification, where absorption lowers the amplification. This connection is not always found between sound absorption and reverberation time. One example is 2 rooms with the same measured T_{20}, but the room amplification was not the same. At the distance of 5 meters from the sound source, the sound pressure level was 3 dBA lower in one of the rooms. Despite that these rooms had the same RT.

2. Conclusions

In a classroom with good acoustics it´s easy to hear what the teacher is saying. Poor room acoustics makes it difficult for the students to hear, listen, understand and remember what the teacher said. Having bad room acoustics in classrooms is an unnecessary cognitive burden and requires a lot of energy from the pupils just to listen understand and remember. Being able to listen without effort is therefore a prerequisite for good learning. Speech intelligibility in the forest is very good, despite sound reflections in the higher frequencies. In almost all languages, the information in speech is carried by the consonants. Consonants are in the high frequencies, and vowels are in the low frequency range. Indoors, it is often a lot of reflections in the low frequencies, so the room amplifies the low frequency vowels which then mask the consonants, and this degrades speech intelligibility. In the forest however, there are no reflected vowels and therefore no masking of consonants. My experience is when people complain of poor acoustics in classrooms, it is very often because the room has too little absorption in the low frequencies. I mean that it´s the lack of reflected vowels that creates the excellent speech intelligibility in Swedish forests. I have studied some national European standards (guidelines) and notes that most of them allow a longer reverberation time in the lower frequencies in classrooms. Shouldn't it be the opposite in rooms where speech intelligibility is important? Is reverberation time according to EN ISO 3382-2:2008 the right thing to measure to investigate the room acoustics? The problem is that T_{20} is a blunt measure. Because T_{20} start to evaluate first after that the sound pressure level has dropped 5 dB. This "waiting time" is often quite long, so we miss a lot of information about the sound reflections from the room in the early part of the decay. In Sweden we have classrooms with short reverberation time but still the students and teachers complain about the sound environment. I have examined 22 of these rooms and I found some interesting results. The average RT (T_{20},) at 1000 Hz was 0,49 seconds. The average "waiting time" for this reasonably short RT was 36 ms. The balance between the early reflections, within 50 ms, and the later reflections is important for how we perceive the room acoustics. If we only measure T_{20} we miss a lot of the important information about the early reflections. If we measure Clarity, C_{50}, according to EN ISO 3382-1:2009 [7], we don't miss this very important information Therefore I mean we have to measure both T_{20} and C_{50} to investigate if the room acoustics is good enough for teaching. The problem in preschools is often high sound levels. How different rooms affects the sound level can be measured with G according to EN ISO 3382-1:2009 [7]. G is not always easy to explain because the reference level for G is "10 meters away from the sound source in free field conditions". This reference level is hard to understand for a person with "normal" acoustic knowledge. To describe how different acoustic treatments in the buildings affect the sound level I suggest that we use *room amplification*. Room amplification is a version of G but it is easier to understand for teachers and architects. My suggestion is to show how many dB the room amplifies at a distance of 5 meters from the sound source. Room amplification can be expressed in octave bands or A-weighed.

References

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