Influence of Atmospheric Conditions on Sound Propagation - Mathematical Modeling

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Abstract: *Propagation of sound in atmosphere is influenced by many factors such as air temperature, relative humidity, air velocity and direction as well as temperature inversion. Intensity of sound disappears in depending on distance by atmospheric absorption and atmospheric turbulence. Many times it is difficult and sometimes impossible to determine the values of equivalent sound pressure levels (A) under different atmospheric conditions. To identifying changes caused by atmospheric conditions is preferred to use the programs for mathematical modeling. The differences of measured values of equivalent sound pressure levels (A) under various atmospheric conditions are not insignificant. When comparing favorable and unfavorable atmospheric conditions for propagation of sound, difference of values of equivalent sound pressure levels (A) may be up to 10 dB. Obviously under conditions that are placed on these measurements like relative humidity <95 % and air velocity <3* $m.s^{-1}$*. This article aims modeling the impacts of different atmospheric conditions with use the software Cadna A, which is used to mathematical modeling of exterior noise maps.*

Keywords: *mathematical modelling; noise maps; equivalent sound pressure levels (A); atmospheric conditions*

1 Introduction

With the problematic of propagation of sound in outdoors are already address the several world autors, e.g., [1-12]. Also on the basis of their knowledge and scientific outputs, it is clear that sound propagation outdoors is affected by several main factors such as geographical landscape relief, atmospheric sound absorption, weather conditions and the occurrence of various obstacles. Regarding the meteorological conditions, they need to divide and describe their effect individually. Among the most significant meteorological conditions that affect sound propagation in the external environment are: air temperature, air speed and direction, atmospheric pressure and relative humidity as well as the turbulent effect. The sound that propagate in the atmosphere is attenuate depending on the distance. The attenuation due to distance varies for different kinds of sound sources. Most of the sounds with which they come into contact, are point and line sources. For point and line sources it is true that sound pressure level is reduced by 6 dB for every doubling of distance from it. The purpose of this paper is study, how sound propagation outdoors with different frequencies is affected by variables meteorological conditions at different distances of receiver and noise source.

1.1 Atmospheric Absorption of Sound

Atmospheric absorption depends on frequency, relative humidity, temperature and atmospheric pressure. (e.g., as discussed by [1, 10, 11]). By atmospheric sound absorption, sound energy is dissipated in the air by following two mechanisms:

- Viscous losses caused by friction between air molecules. The direct conduction of the vibration into the medium as heat caused by the conversion of the coherent molecular motion of the sound wave into incoherent molecular motion in the air or other absorptive material.
- Relaxation process - sound energy is absorbed by molecules in the air, resulting in the vibration and rotation. The molecules can re-emit the absorbed sound energy, which can make interference of incoming sound.

1.2 Effect of Air Flow

The wind speed provided that they are no turbulence, usually changes up to height 100 m, then the changes are minor. Sound waves propagating, in the direction of the wind, will be bent downward. In the upwind direction, the sound speed decreases with altitude, sound waves are directed upward, away from the ground.

1.3 Effect of Temperature

As described in the document [10], a common atmospheric occurrence is a negative temperature gradient (temperature decreases with altitude). This is typical of a sunny afternoon, when significant solar radiation causes high surface temperatures and significant heat transfer from the ground to the adjacent air. This event is also known in meteorological terms as a superadiabatic or positive lapse. In this situation, sound waves will be bent upward in all directions from the source, forming a circular shadow zone. The reverse situation often occurs at night, when a positive gradient is common. This is caused by the rapid cooling of air at the surface as heat is now absorbed by the ground. This is called an inversion or negative lapse and the sound waves are bent downward. This explains why sounds resound much better at night, because it is focused along the ground instead of radiating upward.

1.4 Effect of Relative Humidity

Relative humidity also has influence in sound waves, higher in case of propagation of high-frequency sound (> 1000 Hz). This case represents the following figure 1.

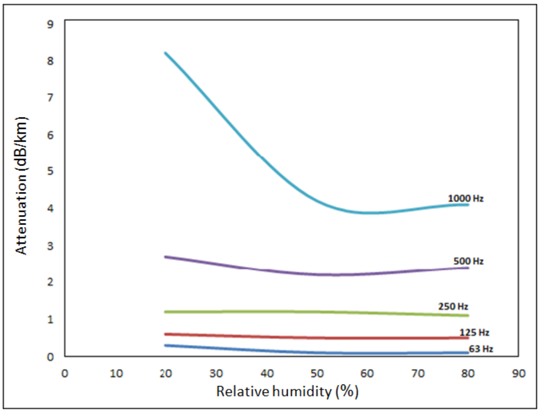

Figure 1
Dependence of the sound attenuation [dB/km] on the relative humidity at different frequencies

2 Methods and Mathematical Model

The mathematical model created in program Cadna A, calculated using the equation 1 [10],

$$L_P = L_W - 20\log r - 11 + DI - A_{abs} - A_E \quad \text{[dB]} \tag{1}$$

where: A_{abs} - atmospheric absorption [dB]
A_E - excess attenuation [dB]
r - distance from source to receiver [m]
DI - directivity index [dB]
L_W - sound power level [dB re 10^{-12} watts]

The total excess attenuation A_E [dB] is a combination of effects, shown in equation 2 [10].

$$A_E = A_{weather} + A_{ground} + A_{turbulence} + A_{barrier} + A_{vegetation} \quad \text{[dB]} \tag{2}$$

For mathematical modeling of influence of atmospheric conditions the propagation of sound, in program Cadna A, was drawn up the simple model (see fig. 2, fig. 3). They were set values of relative humidity of 40%, 60% and 90%, at temperature 0°C, 10°C and 20°C, frequency octave band 100 Hz, 300 Hz, 500 Hz, 1000 Hz and 2000 Hz and direction of sound to the west and east. The first receiver (immission point) was from the sound source in distance of 50 m, second and third receiver 200 m and 250 m from the source and at a height of 1,5m from ground. Point sound source was placed at a height of 31 m (on the roof of the building). Sound power level of this sound source was set to 100 dB (A).

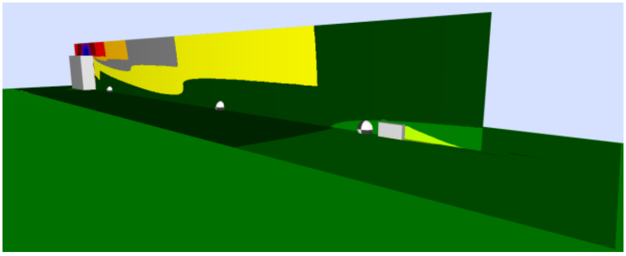

Figure 2
3D model in 3D view

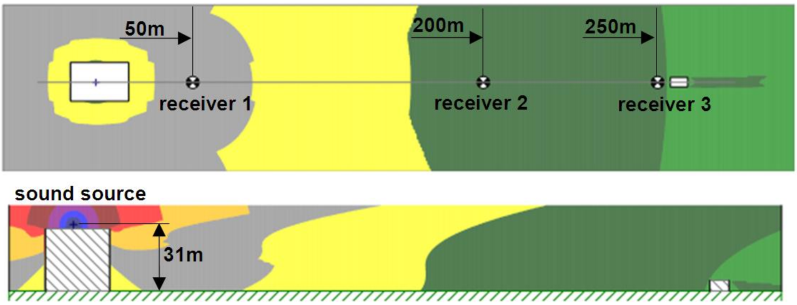

Figure 3
Top view and side view of the created model

3 Results

Experimental results of mathematical modeling were created in graphical form. Graphical results were created for the frequencyies of 100 Hz, 300 Hz, 500 Hz, 1000 Hz and 2000 Hz. The calculated equivalent sound pressure levels (A) (on the graph L_{Aeq}) at immission points (recievers) are at different distances at different relative humidity and different temperature. Results of calculated equivalent sound pressure level (A) for 500 Hz are in figure 4 and 2000 Hz in figure 5.

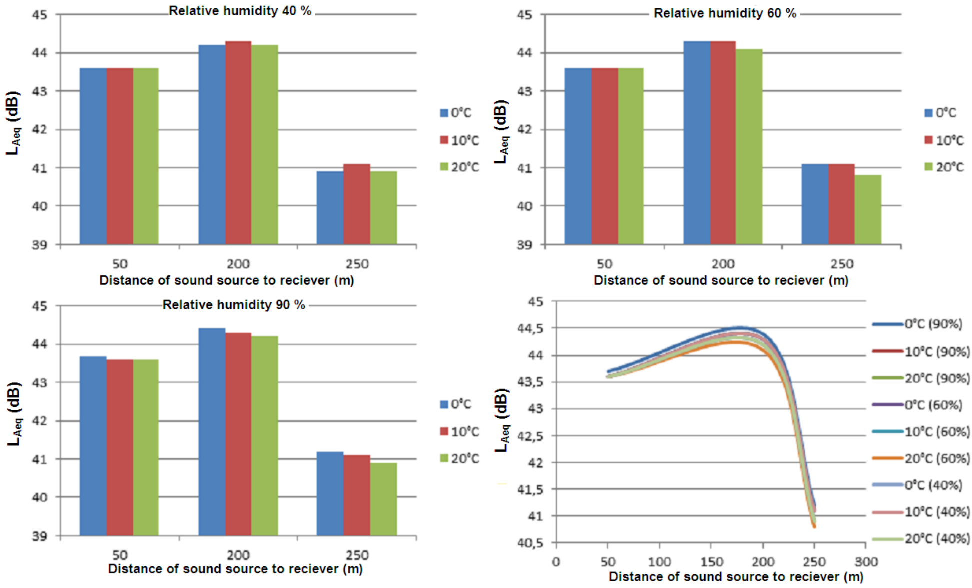

Figure 4

The calculation results for the frequency 500 Hz

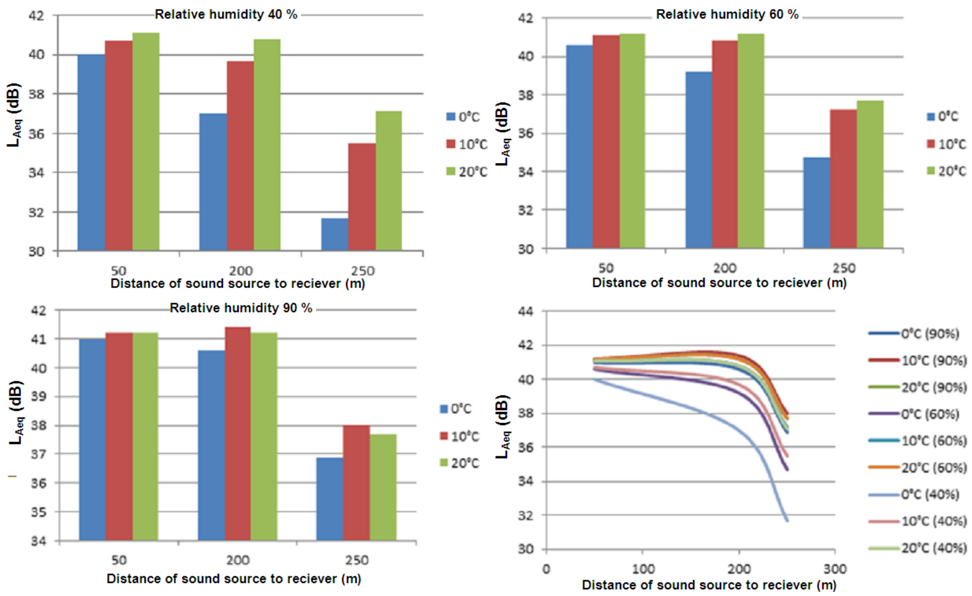

Figure 5

The calculation results for the frequency 2000 Hz

4 Discussion

From the calculated results is concluded, that equivalent sound pressure level (A) by the frequency 100 Hz, did not change with variation of relative humidity from 40% to 90%. (max. of 0,1 dB at 90% relative humidity). To better propagation of 100 Hz sound wave has the great effect of inversion (or negative lapse, or positive temperature gradient) that is when the temperature increases with altitude. Due to the higher temperatures in the upper atmosphere, sound wave bent downwards. Sound source at heigh, witch are located several dozen meters above the ground, the inversion can cause an increase in noise levels at the receiver, which is located a few hundred meters. This is especially true at low frequencies, which have a longer wavelength. This finding was measured and was the subject of our previous research. Our previous research has also confirmed, that the location of the sound source at height of 27 m above the ground, are changed noise level in measurement and computation point up to 10 dB at a distance of 300 m from the sound source, whose character was steady without significant changes of sound power (present tonal component of 160 Hz).

The effect of different relative humidity at the same temperature of air will by induced mainly at the higher frequencies, approximately from 1000 Hz. For example, at the frequency of 2000 Hz, at 0 °C, in the receiver 3 (immission point 250 m), calculated value of equivalent sound pressure level (A) is 31,7 dB by the relative humidity of 40 % and 36,9 dB by the relative humidity of 90 % (the difference is 5,2 dB). That means that the sound waves of higher frequencies will be better supported if the relative humidity of air has an increasing character. This also applies if the air temperature is increased, however, the calculated difference of equivalent sound pressure level (A) is smaller. For example at the temperature of 20 °C, at the frequency of 2000 Hz, is the difference at the relative humidity of 40 % and 90 % approximately 0,6 dB (receiver 3). It also means that high-frequency sound waves propagate better in the winter with higher relative humidity.

Conclusion

With mathematical modeling and calculation of noise maps using a program such as Cadna A is possible, as with sound level meter measurements, detecting of differences in the values of sound pressure levels, when changing atmospheric conditions such as air temperature, relative humidity, wind speed and direction and the like. This issue, however, is more extensive than was possible in this paper to analyze. In conclusion, that with a "favorable" or "unfavorable" conditions for sound propagation, we can see a notable differences in the measured and calculated values of noise level at the same point of measurement.

It is very important to understand these knowledges for correctly and reliable noise measurement. Unscrupulous technicians, performing noise measurement, can measure noise levels at a time when atmospheric conditions are most favorable for "non-propagation of noise" in the company or factory which he represents. If you want that noise levels to be lower the measurement should be done during a hot sunny afternoon, or upwind from the sound source. For measurements of higher noise levels, that are more representative, the measurement should be done during the overcast day or evening.

Acknowledgments

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