Uncertainty of room acoustic parameters caused by air movement and temperature changes

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Introduction

The main assumption for typical sweep measurements in rooms is the time invariance of the measured system. This precondition might be violated due to the air movement caused by the ventilation system in the auditoria. Temperature and humidity changes (caused by and active or inactive air conditioning system) also leads to a time invariant system. This study will investigate two effects. The measurement uncertainty of room acoustic parameters caused by the active ventilation system and changes in the measured reverberation time caused by the change of temperature and relative humidity.

Measurement Arrangement

Measurements have been conducted in the General Assembly Hall of RWTH Aachen University (rectangular shape, 600 seats, 5500 m³). A dodecahedron loudspeaker was placed on the stage. It was driven with a high output level to be able to keep the length of the excitation signal short (6 seconds). This will ensure that time variances within one measurement can be neglected. At the same time the output level of the loudspeaker is kept sufficiently low to ensure that nonlinearities have no influence. The receiver positions were spread over the audience area in different distances to the ventilations slots in the room.

During the measurement period of about 24 hours there were no persons present in the auditorium. Every 45 seconds a transfer function measurement was started and stored. The evaluation of the room acoustic parameters according to ISO 3382-1 [1] has been made afterwards by using the ITA-Toolbox [2].

The air conditioning system was programmed to change state every 4 hours. Eight temperature and three humidity sensors were placed in the auditorium to monitor the meteorological conditions in the room. Temperature and relative humidity was saved with the measured transfer functions to allow a detailed analysis afterwards.

Measurement Results

Figure 1 shows the evaluated reverberation time T_{20} as a function of time. The (red) highlighted areas indicate the time when the ventilation system was active.

Two effects can be observed: A random rapid fluctuation (in periods of few minutes) and slower variations of the parameter over time. These two effects will be investigated in detail in the following subsections.

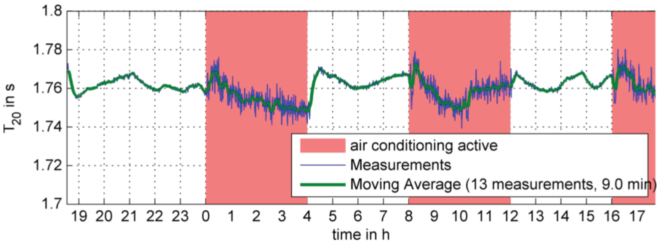

Figure 1: Evaluated reverberation time T_{20} in the 2 kHz octave band as a function of time. The two effects, random rapid fluctuations and slower variations, can be observed.

Fluctuations

The random changes in the evaluated parameter that occur from one measurement to the next are called fluctuations. Long-term trends of the parameter are regarded in the next subsection and not considered here.

Figure 2 show a moving average of the parameter (top) and a moving standard deviation (bottom). The windows size is 12 minutes which correspond to 16 measurements. The reverberation time is normalized to the mean value of the measurement to allow a direct evaluation of the magnitude of the changes. The just noticeable difference of reverberation time is 5 % [1].

There is a clear difference between the phases with active and inactive ventilation system. The relative standard deviation is approximately three times higher for active ventilation system. The higher the frequency band the larger the difference.

A larger evaluation range for the linear regression (i.e. T_{30} instead of T_{20}) leads to less fluctuation. The maximum relative standard deviation rarely exceeds 1 % for active and 0.3 % for inactive ventilation system.

The window size of the analysis can be changed in a range from 8 to about 24 measurements, without having an influence on the result. For larger window sizes the slower variations of the results also influence the standard deviation.

It can be excluded that the additional background noise of the ventilation system has an influence on the fluctuations because there is no difference in the peak-signal to noise ratio (PSNR) for the different phases of the measurements. In addition, it has been shown that the noise has no influence on the reverberation time for high PSNR values (here > 85 dB for T_{20}) [3].

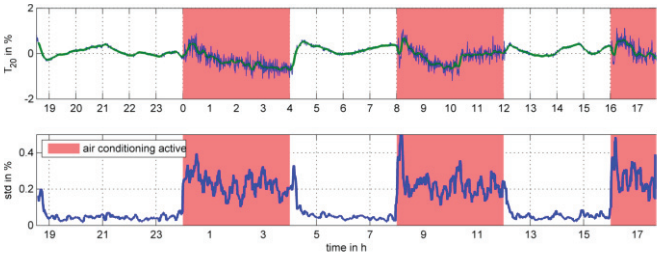

Figure 2: Moving average (top) and moving standard deviation (bottom) of reverberation time T_{20} (2 kHz octave band, windows size: 16 measurements = 12 minutes).

Variation of the parameter

In contrast to the previous section, where the short time fluctuations are discussed, this section deals with the long term variations. It is investigated if changes in temperature and relative humidity are responsible for these changes.

The temperature and relative humidity over the measurement period can be seen in Figure 3. The measurements have been conducted on a hot summer day which is the reason for a rise in temperature during deactivated ventilation system.

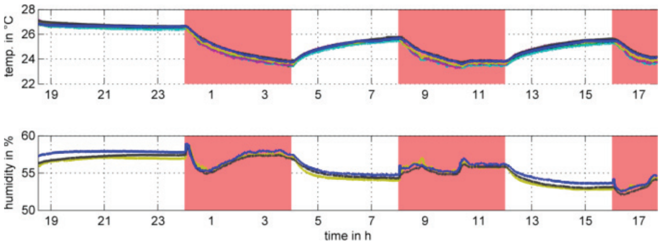

Figure 3: Temperature and relative humidity during the measurement session.

The temperature has varied in a range of about 3 °C and the relative humidity about 10 %. These changes cause a variation in the speed of sound c and in the air attenuation m [4]. With the Sabine's reverberation formula (Eq. 1) the changes in the reverberation time for an ideal sound field can be predicted [5]:

$$RT = \frac{24 \cdot \ln(10)}{c} \cdot \frac{V}{A + 4mV} \qquad (1)$$

Figure 4 shows comparison of the predicted and the measured change in the reverberation time T_{20} in the octave band of 1 kHz. For the equivalent absorption area A a mean value over the complete measurement session is taken for the frequency band.

Three different microphone positions are chosen as an example to show the existing diversity of the results. For the first example (top) both results match well. The tendencies and the magnitude of the changes of theory and measurement are equal. For the second microphone position (middle) the tendencies are equal but the magnitudes of the changes are significantly larger for the measurements. In the third microphone position (bottom) both graphs are contrary. When the theoretical prediction increases the measured parameter decreases and vice versa.

There is no visible dependency between the goodness of prediction and the frequency band or the microphone position. For very high frequencies (> 2 kHz) the effect of the air attenuation becomes dominant. This effect is predicted well by the Sabin's Equation which results in good agreement for high frequencies.

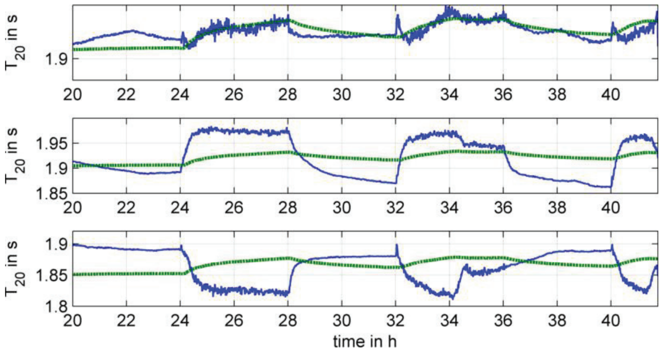

Figure 4: Comparison between theoretical and measured variation of reverberation time T_{20} (1 kHz octave band) caused by temperature and humidity changes. Three examples for a good (top), undersized (middle) and opposed (bottom) prediction of the effect are show.

Conclusions and Outlook

The measurements show a significant increase of the standard deviation of repeated measurements for an active ventilation system. This is synonymous with the increase of the measurement uncertainty caused by the ventilation system. However, the magnitude of the fluctuations are rather small (standard deviation < 1%) that it will not have a major influence on the total measurement uncertainties.

In future work further auditoria should be investigated to verify if there is an influence of the size of the room and/or ventilation system. Since ventilation system are laid out for the room, it is assumed that both factors will have minor influence because the relation between ventilation system and room size is always in the same range.

The long-term variations caused by changes of temperature and humidity can be predicted by Sabine's reverberation formula, but seem often to be overlaid by other larger effects. A relationship between the measurement position relative to the ventilation slots or the frequency band could not yet be established.

References

[1] ISO 3382-1: Acoustics – Measurement of room acoustic parameters – Part 1: Performance spaces. International Organization for Standardization (2009).

[2] ITA-Toolbox. A MATLAB Toolbox for the needs of acousticians, http://www.ita-toolbox.org/ (2014)

[3] Guski M., Vorländer M., Comparison of Noise Compensation Methods for Room Acoustic Impulse Response Evaluations, Acta Acustica united with Acustica 100 (2014), 320-327

[4] ISO 9613-1, Acoustics - Attenuation of sound during propagation outdoors - Part 1: Calculation of the absorption of sound by the atmosphere, International Organization for Standardization (1993).

[5] Kuttruff, H., Room Acoustics. Taylor and Francis, London, 2000