Room acoustic measurements in a swimming hall at different atmospheric conditions

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Introduction

When measuring the reverberation time in a room, it is well known that the result, especially at high frequencies, depends on the temperature and relative humidity (RH) of the air. Room acoustic measurements were made with the integrated impulse response method in a swimming hall under different atmospheric conditions, ranging from 31,2 °C and 88,1 % RH to 27,7 2 °C and 35,5 % RH.

The air absorption can be quite high in case of very dry air. A method to normalise acoustic measurement results to a standard atmosphere (20 °C and 50 % RH) has been suggested [1]. Although the measurements in the current case were made under quite extreme conditions, the influence of the air absorption turned out to be quite limited due to high humidity. Only the results at the 8 kHz octave show a significant variation with the atmospheric conditions.

The swimming hall

The swimming hall is located at the Lysebu Hotel and Conference Centre in Oslo, Norway. The main dimensions are 22,8 m * 9,9 m * 2,5 m, and the volume is 567 m^3, see Fig. 1.

Figure 1: The swimming hall. The sound source is seen to the left. Photo by the author July 2024.

The first measurements (A) were made at unusual high temperature and high RH due to a failure in the air condition system, see Table 1 and Fig. 2. Three air drying machines were operating constantly. Due to water condensation on the window panes, there were towels in the window sills to soak the water, see Fig. 2.

Later, the measurements were repeated in the same positions, but at more normal atmospheric conditions (B and C), see Table 1. The measurements were made in two source-receiver positions with the integrated squared impulse response method using sine sweeps of 30 s or 60 s length. The sound source was the Odeon Omni source and the microphone was the Zoom H3-VR using the Ambisonics B-format (FuMa).

The atmospheric conditions were measured with Hygrometer Testo 608-H1, which has an accuracy of ± 0,5 °C and ± 3 % RH.

Table 1: Conditions of the measurements

Mark	Date	Temperature (°C)	RH (%)	*c* (m/s)
A	2023-11-27	31,2	88,1	349,7
B	2024-07-02	28,7	44,7	348,5
C	2025-01-06	27,7	35,5	347,7
S	Standard atm.	20,0	50,0	343,2

Figure 2: The swimming hall with high temperature and high humidity. The sound source is seen in the middle of the picture. Photo by the author November 2023.

Air absorption as function of temperature and relative humidity

The air absorption is calculated according to ISO 9613-1 [2]. These results are valid for single frequencies (pure tones), but not necessarily for broadband sound in frequency bands.

Fig. 3 provides an overview of the air attenuation coefficient at 4000 Hz as it varies with temperature and RH. A steep increase of absorption is noted for humidity below 35 % RH. However, for humidity between 35 % RH and 75 % RH the absorption does not change much; it is within 0,005 m^{-1} and 0,01 m^{-1} (the orange area).

In Fig. 4 is displayed the air attenuation coefficient per wavelength as function of frequency for each of the measurement situations. For comparison, the curve for the standard atmosphere is also shown. It is noted that there is almost no variation at 4000 Hz. At 8000 Hz the absorption is significantly lower in the measurement A, whereas the absorption in measurement C is close to that of the standard atmosphere.

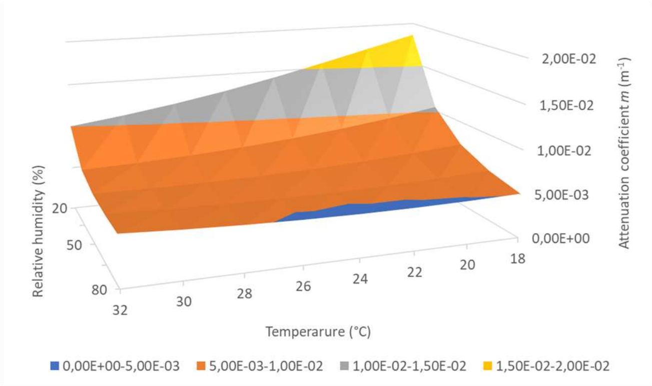

Figure 3: Air attenuation coefficient at 4 kHz and its variation with temperature and relative humidity.

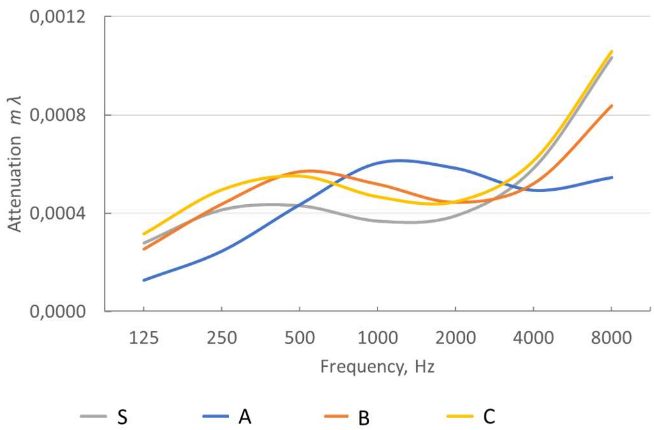

Figure 4: Air attenuation per wavelength as function of frequency. The curves represent different atmospheric conditions as during the measurements (A, B, and C) and for the standard atmosphere (S).

Air absorption in octave bands

The air attenuation coefficient m has the unit of reciprocal metres [2]. The pure tone attenuation δL in dB due to air absorption increases linearly with the distance of sound propagation r and is calculated as in Eqn. (1):

$$\delta L = 4{,}343\, m\, r \qquad \text{[dB]} \qquad (1)$$

However, measurements in octave bands are attenuated by the air absorption in a non-linear way. The reason for this is the steep increase of the absorption with the frequency. Near the sound source a flat spectrum within the octave band can be assumed, and the attenuation follows that of a pure tone equal to the centre frequency of the octave band. But during the sound propagation the high frequencies are attenuated more that the low frequencies and the spectral energy within the octave band is gradually shifted towards the lower limiting frequency of the band. This is seen in Fig. 5 for the octave bands 2000 Hz, 4000 Hz, and 8000 Hz in the case of 20 °C and 80 % RH. The non-linear attenuation is obvious at 8000 Hz, but up to 2 s, it is negligible at the lower frequencies.

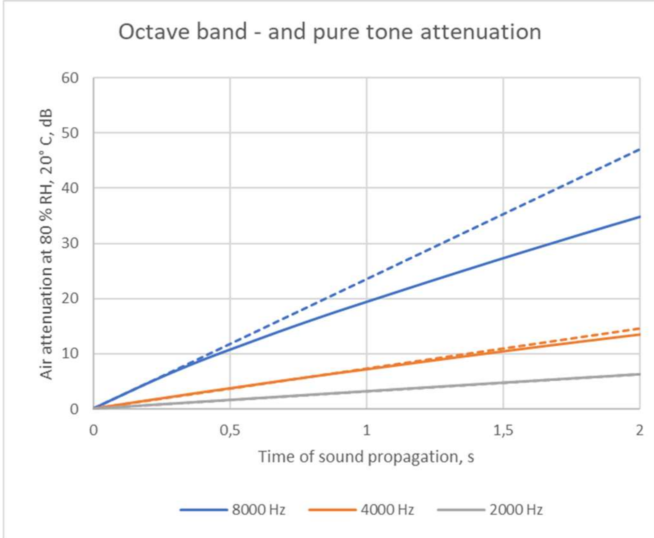

Figure 5: Air attenuation up to 2 s propagation time in very humid air. Octave bands (full lines) and pure tone centre frequency (dashed lines).

In order to normalise room acoustic measurements to a standard atmosphere, it is possible to use the so-called summation method, see [1]. This implies that each sample of the decay curve is corrected. Fig. 6 provides an example of the octave-band attenuation curves for humid air and for the standard atmosphere. In the 8000 Hz octave band the correction is around 5 dB at 0,5 s and around 8 dB at 1 s of sound propagation.

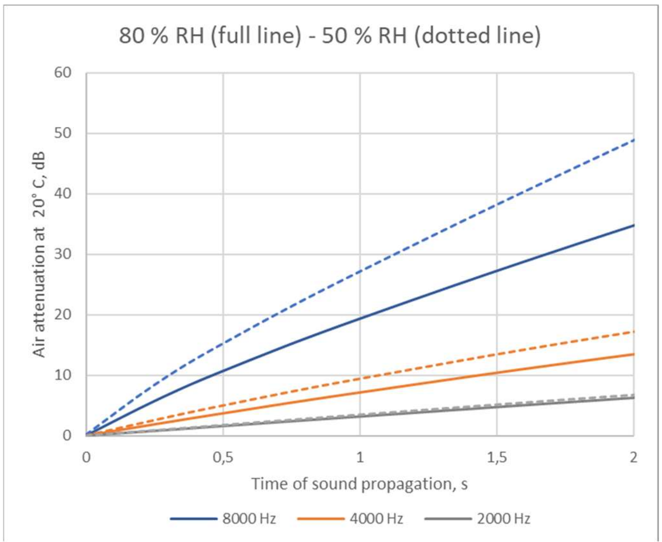

Figure 6: Air attenuation at 20 °C in octave bands up to 2 s propagation time. 80 % RH (full lines) and 50 % RH (dashed lines).

Measurement results

The measurements were made in the frequency range 125 Hz to 8000 Hz. The reverberation times T_{20} as measured in the situations A and B are seen in Fig. 7 for the same source-receiver position (S2 – R1). The full line curves show the results after normalisation to the standard atmosphere.

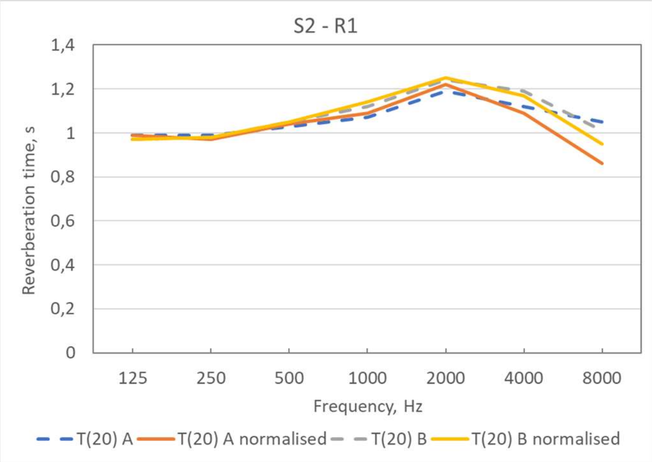

Figure 7: Reverberation time T_{20} as measured in octave bands from 125 Hz to 8000 Hz (dashed lines). Results normalised to a standard atmosphere (full lines). Measurements A with high humidity. Measurements B with low humidity.

The correction needed for the normalisation is significant at 8000 Hz for the measurement A and noticeable for the measurement B, see Fig. 7. At frequencies below 8000 Hz the corrections are small. The detailed results with and without normalisation for two measurement positions and three days of measurement are presented in Table 2 and 3. The non-linearity parameter ξ according to ISO 3382-2 Annex B [3] is presented for all results. When this is higher than 10 ‰ the result is not fully reliable.

If the conditions of the room were identical during the measurements A and B, the normalised results should be the same or at least in close agreement. However, the normalised reverberation times in measurement A are shorter than those in measurement B between 1000 Hz and 8000 Hz. The reason for this is probably the absorption due to the towels in the window sills and additional absorption from the drying machines that were present during measurement A.

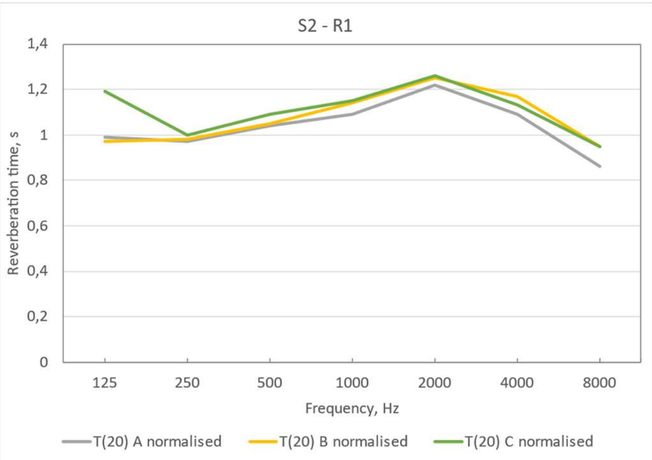

Figure 8: Reverberation time T_{20} in octave bands from 125 Hz to 8000 Hz normalised to a standard atmosphere. Results from three days A, B, and C.

At 125 Hz the reverberation time is longer in measurement C than in the measurements A and B. The reason for that is unknown.

The measured decay curves in one position at 8000 Hz from each of the three days are seen in Fig. 9. While the measured decay curve from measurement A is quite different from those from measurements B and C. The decay curves are close together after normalisation, see Fig. 10.

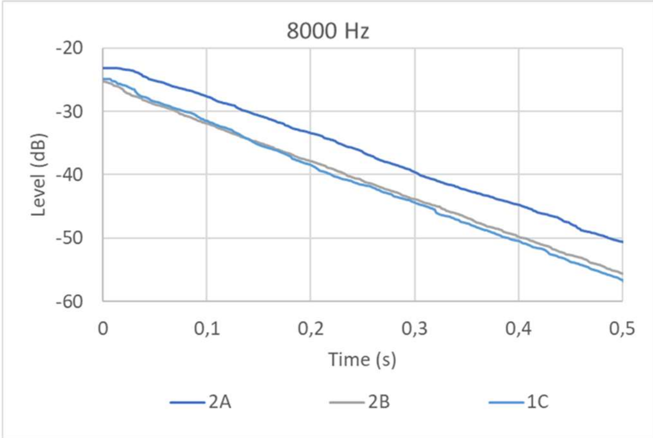

Figure 9: Decay curves measured at 8 kHz without normalisation. Measurements A with high humidity. Measurements B and C with low humidity.

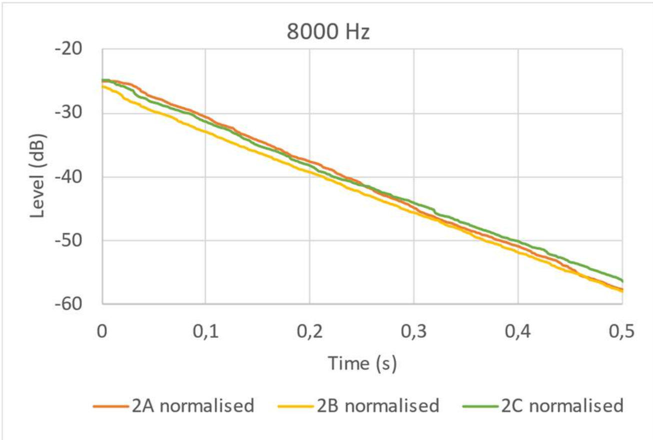

Figure 10: Decay curves at 8 kHz with normalisation to a standard atmosphere. Measurements A with high humidity. Measurements B and C with low humidity.

Conclusion

The atmospheric conditions in the swimming hall varied from an extreme situation with very high temperature and high humidity to moderate conditions. The influence of the air absorption is clearly noticed at 8 kHz, but is small at frequencies below 8 kHz. A method to normalise acoustic measurements to a standard atmosphere was applied. The normalised reverberation times are in better agreement than without the normalisation. The decay curves at 8 kHz were almost identical after normalisation.

References

[1] J.H. Rindel: Air Attenuation in Octave Bands and How to Normalize Room Acoustic Measurements to a Standard Atmosphere. Applied Sciences, 2024, 14, 22, 10139. DOI: 10.3390/app142210139.

[2] 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: Geneva, Switzerland, 1993.

[3] ISO 3382-2; Acoustics — Measurement of room acoustic parameters — Part 2: Reverberation time in ordinary rooms. International Organization for Standardization: Geneva, Switzerland, 2008.

Table 2: Reverberation times measured in position S1 – R1 on three different days. Source-receiver was distance 6,1 m. N means normalised results. The non-linearity parameter ξ is according to ISO 3382-2 Annex B [3].

		Frequency						
		125	250	500	1000	2000	4000	8000
2023-11-27	T_{20} (s) A	0,98	0,94	1,05	1,08	1,11	1,11	1,00
31,2 °C	ξ (‰)	19,9	16,1	5,5	6,1	0,7	0,2	0,4
88,1 % RH	T_{20} (s) A, N	0,98	0,94	1,05	1,10	1,15	1,08	0,83
	ξ (‰)	19,9	15,9	5,6	6,2	0,9	0,2	0,7
2024-07-02	T_{20} (s) B	1,17	1,05	1,10	1,12	1,24	1,19	0,96
28,7 °C	ξ (‰)	10,8	3,7	2,4	3,1	0,5	1,3	3,0
44,7 % RH	T_{20} (s) B, N	1,17	1,05	1,10	1,14	1,25	1,18	0,89
	ξ (‰)	10,6	3,7	2,3	3,2	0,5	1,4	2,2
2025-01-06	T_{20} (s) C	1,13	0,88	0,98	1,10	1,20	1,14	0,89
27,7 °C	ξ (‰)	6,3	11,9	1,8	2,3	1,4	0,6	1,8
35,5 % RH	T_{20} (s) C, N	1,13	0,88	0,99	1,11	1,22	1,15	0,91
	ξ (‰)	6,3	11,9	2,0	2,6	1,4	0,5	1,7

Table 3: Reverberation times measured in position S2 – R1 on three different days. Source-receiver was distance 10,3 m. N means normalised results. The non-linearity parameter ξ is according to ISO 3382-2 Annex B [3].

		Frequency						
		125	250	500	1000	2000	4000	8000
2023-11-27	T_{20} (s) A	0,99	0,99	1,03	1,07	1,19	1,12	1,05
31,2 °C	ξ (‰)	10,1	24,5	4,7	3,1	1,4	3,1	1,4
88,1 % RH	T_{20} (s) A, N	0,99	0,97	1,04	1,09	1,22	1,09	0,86
	ξ (‰)	10,1	24,3	4,7	3,0	1,3	3,5	0,9
2024-07-02	T_{20} (s) B	0,97	0,98	1,05	1,12	1,24	1,19	1,01
28,7 °C	ξ (‰)	19,9	6,5	2,4	1,0	0,3	0,1	0,1
44,7 % RH	T_{20} (s) B, N	0,97	0,98	1,05	1,14	1,25	1,17	0,95
	ξ (‰)	20,1	6,4	2,5	1,1	0,3	0,1	0,2
2025-01-06	T_{20} (s) C	1,19	1,00	1,09	1,14	1,25	1,11	0,94
27,7 °C	ξ (‰)	13,8	10,3	2,5	1,5	1,3	0,5	2,4
35,5 % RH	T_{20} (s) C, N	1,19	1,00	1,09	1,15	1,26	1,13	0,95
	ξ (‰)	13,7	10,2	2,5	1,5	1,4	0,4	2,4