# Effect of temperature and humidity on sound absorption measurements in a Reverberation chamber

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**Abstract**

Random incidence sound absorption measurements are carried out in Reverberation chamber as per standards like ASTM C 423 / ISO 354. ASTM C 423 requires that decay rates at 1000 Hz and above has to be corrected for air absorption as per ANSI S1.26. Air absorption is calculated as a function of temperature, relative humidity and barometric pressure. This study investigates effect of temperature, relative humidity and barometric pressure on sound absorption measurements. A very common method of determining the sound absorption of a material is ASTM C 423, which utilizes a qualified reverberation room with controlled temperature and humidity. It is well known that air absorption of sound has a very significant effect on absorption measurements, particularly at higher frequencies of interest. For the purposes of ASTM C 423, ANSI S1.2 is used to correct measurements for the effects of changes in room temperature, relative humidity and barometric pressure. This paper concentrates on the contribution of changes in temperature and humidity and neglects the contribution of changes in barometric pressure for two reasons – first, barometric pressure fluctuation has a small effect on air absorption as compared with temperature and relative humidity, and second, it cannot be readily controlled as temperature and relative humidity can be. At the end, the paper presents effect of temperature and humidity on measured sound absorption coefficient in a reverberation chamber.


**Keywords:** Sound absorption; Reverberation chamber; Simulation

## Introduction

A realistic sound absorption coefficient of acoustic materials is measured in a qualified reverberation chamber. The chamber volume should be at least 125 m$^3$ in case of ASTM C 423 and 200 m$^3$ in case ISO 354. Both these standards talk about a correction factor to be considered at the calculation of sound absorption coefficient for air absorption which is due to changes in room temperature, relative humidity and barometric pressure. For this purpose, ANSI S1.2 is used to correct measurements for the effect of changes in the reverberation room. Recent papers have investigated the effect of these ambient changes on high frequency absorption (5000 Hz and above) and the consequences of failing to make corrections for changes in ambient conditions. In some ambient conditions the air absorption at high frequencies is high enough to prevent accurate determination of sound absorption of much beyond the air itself. Using ASTM C 423 the absorption of an acoustic material can be determined by measuring the absorption of the empty reverberation room and the absorption of the same room with the sample installed in the prescribed manner. The difference in total absorption between these two measurements is the absorption of the sample material. If ambient conditions do not change between "without sample" and "with sample" states then it does not matter if the air absorption correction is used. A change in ambient conditions, however, can cause a change in absorption by the air in the room to be attributed to the sample unless air absorption is now considered in the calculation. This paper concentrates on the contribution of changes in temperature and humidity and neglects the contribution of changes in barometric pressure for two reasons – first, barometric pressure fluctuation has a small effect on air absorption as compared with temperature and relative humidity, and second, it cannot be easily controlled as temperature and relative humidity.

## Reverberation Chamber

The test method is based on the fact these measurements are made in a reverberation room. A reverberation room is defined as a room where the sound field is diffuse and uniform throughout the room. Diffuse means sound waves approach from any direction at any time with equal probability, and therefore the sound field is the same everywhere. For sound absorption measurements, the diffusion has one more challenge. This has to do with the fact the decay signal is transient and not steady state, where normally the diffusion is best understood. Therefore the reverberant sound field needs to closely approximate the diffuse sound field not only for steady state sound with the source on, but also for the decay of sound when the source is turned off. A reverberation room may be constructed of a massive masonry, concrete materials, massive steel panels, as well as light weight building construction materials. Walls should be painted to seal any pores and to increase diffusion in the room. In addition, external sound reflecting panels or objects (commonly called diffusers) are required to achieve adequate diffusion in the room for stationary and transient sound signals in the room.

**Method of Calculation**

The method is based on the calculation of two reverberation times $T_1$ and $T_2$ with and without the sample. The equivalent sound absorption area of the empty reverberation room of area $A_1$ is calculated as

$$A_1 = \frac{55.3V}{c_0 T_1} - 4Vm_1 \quad (1)$$

Where $V$ is the volume of the empty reverberation room in cubic meters, $c_0$ is the speed of sound in meters per second, $T_1$ is the reverberation time in seconds of the empty reverberation room and $m_1$ is the power attenuation coefficient in reciprocal meters calculated according to ANSI S1.26 or ISO 9613-1 using climatic conditions using formula

$$m = \frac{\alpha}{10\log(e)} \quad (2)$$

Next step is the calculation of equivalent sound absorption of area of the reverberation room containing a test sample $A_2$ as

$$A_2 = \frac{55.3V}{c_0 T_2} - 4Vm_2 \quad (3)$$

where $T_2$ is the reverberation time in seconds of the empty reverberation room after the specimen is placed inside the room and $m_1$ is the power attenuation coefficient in reciprocal meters.

Then using equations 2 and 3, it is possible to calculate the equivalent sound absorption area of the test specimen $A_T$ as

$$A_T = A_2 - A_1 = \frac{55.3V}{c_0}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) - 4V\left(m_2 - m_1\right) \quad (4)$$

The sound absorption coefficient $\alpha_s$ of a plane absorber can be calculated as follows

$$\alpha_s = \frac{A_T}{S} \tag{5}$$

where $S$ is the area of the test specimen is not expressed as a percentage because it can have values larger than 1.0 (e.g. because of diffraction effects) when evaluated from reverberation time measurements. The attenuation coefficient is calculated using following equations.

$$f_r O = \frac{P_a}{P_r}\left\{24 + \left[\frac{\left(4.04\times10^4 h\right)\left(0.02+h\right)}{0.391+h}\right]\right\} \tag{6}$$

$$f_r N = \frac{P_a}{P_r}\left(\frac{T}{T_r}\right)^{-1/2} \times \left(9 + 280h\exp\left\{-4.170\left[\left(\frac{T}{T_r}\right)^{-1/3} - 1\right]\right\}\right) \tag{7}$$

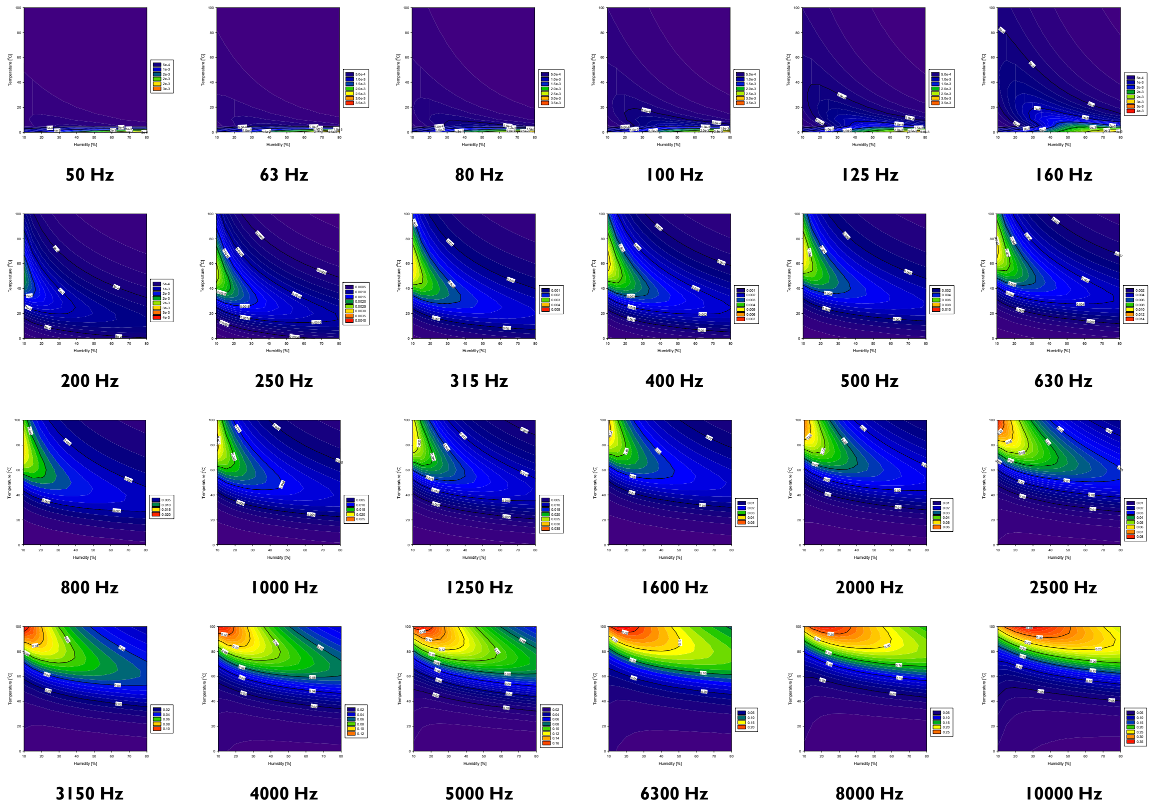
$$\alpha = 8.686 f^2\left(\left[1.84\times10^{-11}\left(\frac{P_a}{P_r}\right)^{-1}\left(\frac{T}{T_r}\right)^{1/2}\right] + \left(\frac{T}{T_r}\right)^{-5/2} \times \left\{0.01275\left[\exp\left(\frac{-2239.1}{T}\right)\right]\left[\frac{f_{rO}}{f^2_{rO}+f^2}\right] + 0.1068\left[\exp\left(\frac{-3352.0}{T}\right)\right]\left[\frac{f_{rN}}{f^2_{rN}+f^2}\right]\right\}\right) \tag{8}$$

Where $f_r O$ and $f_r N$ are vibration frequencies for Oxygen and Nitrogen respectively

$f$ -frequency of sound in Hz, $T$ - ambient atmospheric temperature in Kelvin, $h$ - molar concentration of water vapor in %, $P_a$ - ambient atmospheric pressure in kPa, $P_r$ - reference atmospheric pressure in kPa, $T_r$ - reference atmospheric temperature in Kelvin

## Results and Discussions

For a polyatomic gas such as air, molecular thermal relaxation causes increased absorption up to 100 kHz, where air absorption approaches the classical model. Water absorbed in the air in very small quantities, affects the relaxation frequencies of oxygen and nitrogen. Although the deviation from the classical model is very large at low frequencies, the absolute values are very small and not a practical concern for sound absorption measurements in a reverberation room. Higher audible frequencies 1000 Hz and above, are progressively more affected, and ANSI S 1.26 or ISO 9613 suggests correction for these frequencies. Figure 1 shows variation in temperature and humidity with respect to frequencies.




**Effect of temperature on Air absorption**

Figure 2 shows effect of temperature on air absorption. From this figure, it is clear that temperature has significant most effect on the decay rate due to air absorption. Changes of just a few degree Celsius can have a significant effect on the high frequency results. In this study, humidity kept constant at 50 %, Atmospheric pressure kept constant at 101.325 kPa, Temperature was varied from 0 $^0$C to 100 $^0$C

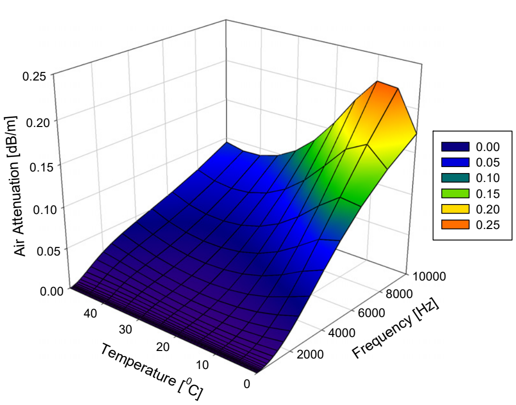



Figure 2: Effect of Temperature

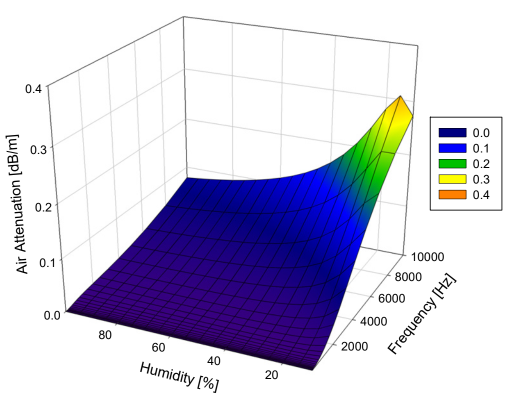



Figure 3: Effect of Humidity

### Effect of humidity on Air absorption

Figure 3 shows effect of humidity on air absorption. Effect of humidity is not drastic as compared to temperature. It has been observed that the variation is very small below 2 kHz. It is also clear that the variation is much less for the 60% relative humidity case as compared to the 40% relative humidity case. In this study, atmospheric pressure was kept constant at 101.325 kPa, humidity varied from 10 % to 100 %, Temperature was kept constant at 250C

### Effect of pressure on Air absorption

Changes in barometric pressure have relatively small effects on the decay rate due to air absorption as shown in figure 4. In this study, humidity kept constant at 50 %, atmospheric pressure was varied from 50 kPa to 150 kPa and temperature was kept constant at $25^0$C

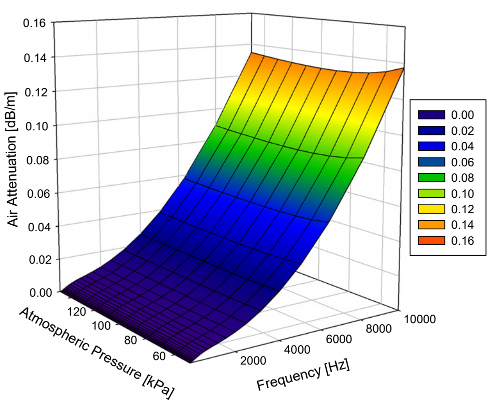



Figure 4: Effect of pressure

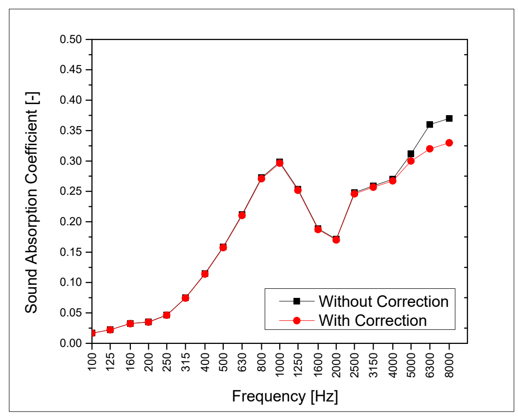



Figure 5: Sound Absorption Comparison

### Conclusion

This study shows that, temperature and humidity affects significantly on sound absorption coefficient measured inside a reverberation chamber.

### References

ISO 354, Measurement of sound absorption n a reverberation room, 2003

ISO 10140-2 / ASTM E 90- Air borne sound transmission loss Measurement, 2010