Why it is important to keep the humidity constant around violins for acoustic experiments - by Anders Buen

Wood is hygroscopic and will exchange moisture with the surrounding environment. The relative humidity in air varies with the temperature and the amount of water damp present. The hotter the air the more water it can hold. When the air cools down, the ability to hold water decreases and, if the dew point is at a higher temperature than the air, then water will be liquified on any surfaces in contact with the air having a lower temperature than the dew point.

There is a direct relationship between the amount of moisture in wood and the RH in air, if the wood and air are left to reach equilibrium [The Encyclopedia of wood]. For thin plates of wood it takes about two days to reach equilibrium, if the RH suddenly is raised or decreased [Rex Thompson, CASJ article]. Most of the change happens within a few hours. Water molecules are relatively small and will penetrate the wood through almost any varnish or sealer, although thick layers can slow the process a little [The Encyclopedia of Wood].

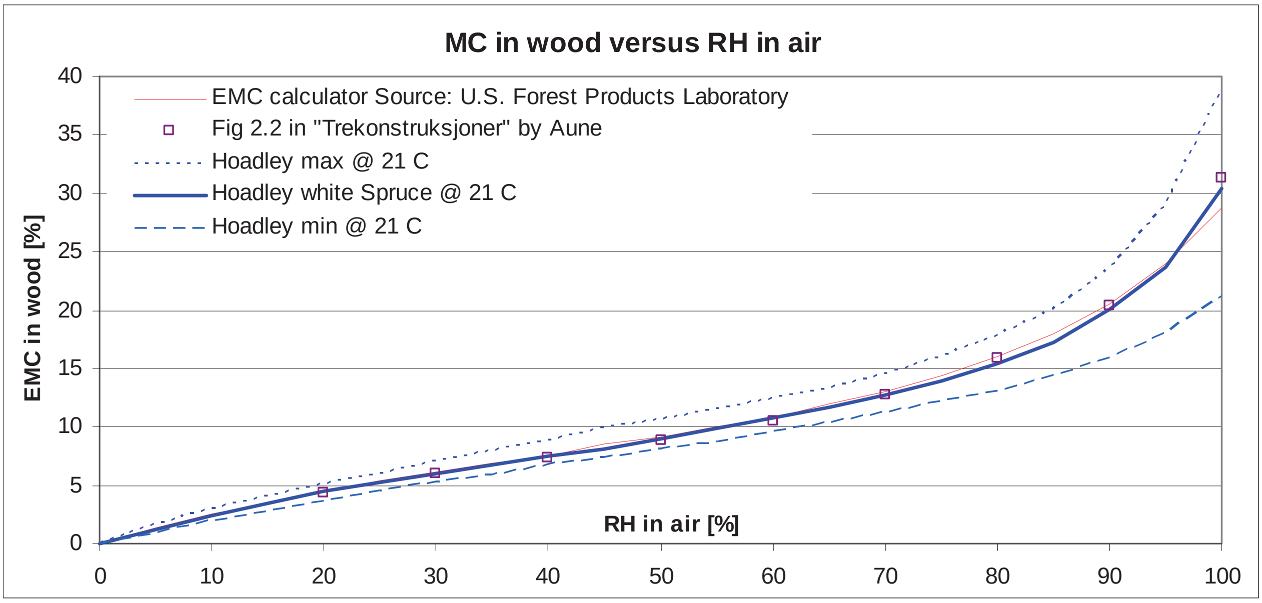


Figure 1: Relation between RH in air and equilibrium moisture content in wood (EMC) from three sources. The EMC calculator can be found at: http://www.woodbin.com/ref/wood/emc.htm

The elastic properties, damping and the density of wood are quite strongly dependent on the MC, and thus the RH in the air. The dimensions of wood also vary with the MC, more so in the tangential direction than in the across-grain (radial) direction. The smallest effect is along the grain. Anisotropic variations in dimensions will have an effect on the shape of the arches and the neck projection angle. At higher MC the neck projection is said to drop, but the arch is also probably rising.

Elastic constants, damping, density and the geometry, like the arch shape, are well known to have an effect on the vibrations, and thus the acoustics, of wooden instruments.
As the RH naturally varies from day to day, also indoors, it must be taken into account in any acoustic measurements of instruments made of wood, especially when the intent is to compare small effects of any intended influence.

Some measured acoustic effects of variation in MC

I have conducted some experiments with instruments in humidified conditions and will report some data from one of the instruments subjected to variations in RH and thus MC. Response graphs and weight was recorded for a few values of the MC.

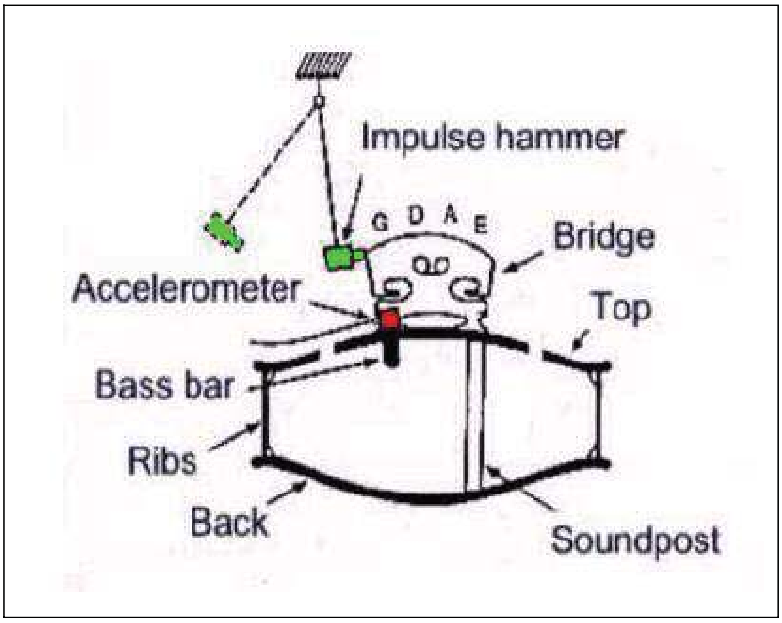
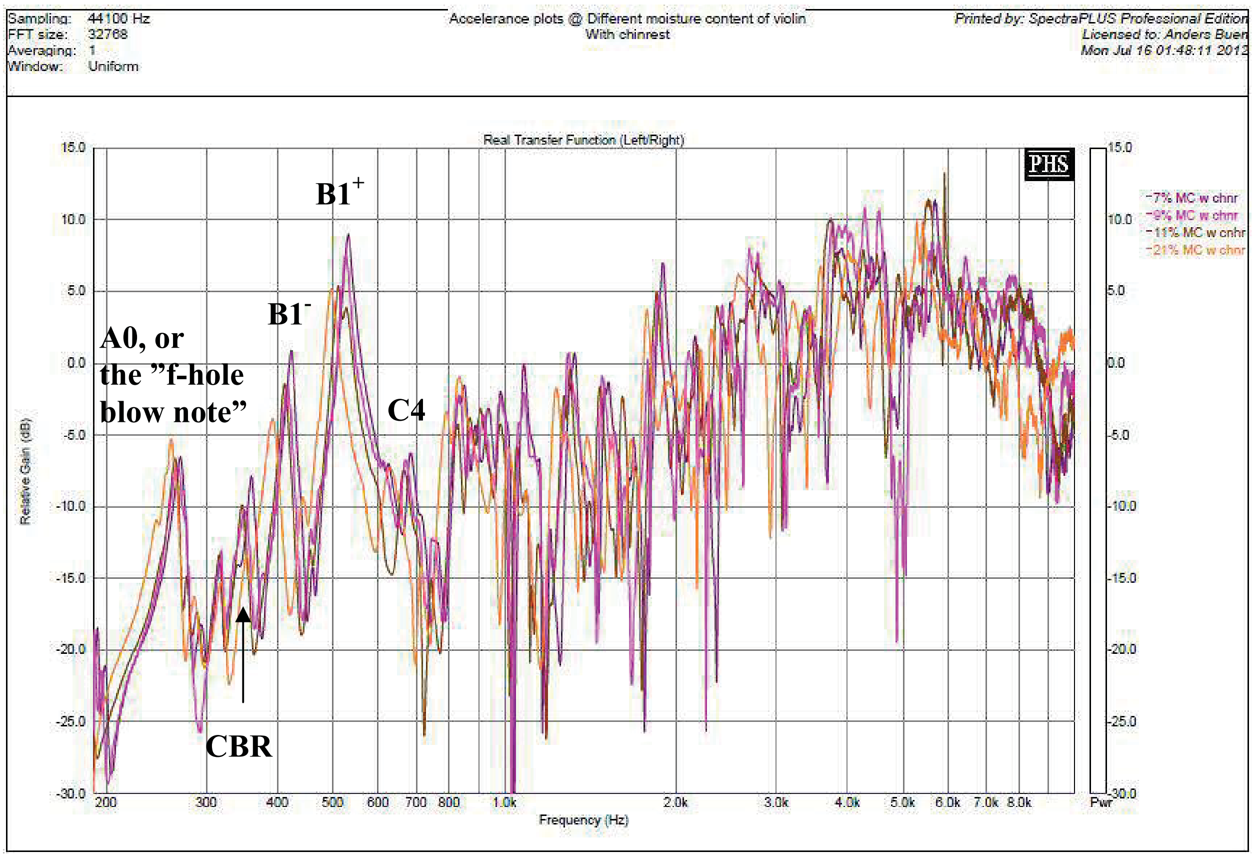


Figure 2: Transfer accelerance, acceleration(ω)/Force(ω), measured with the accelerometer behind the G-string side of the bridge while the force was applied as an impact at the side of the bridge.

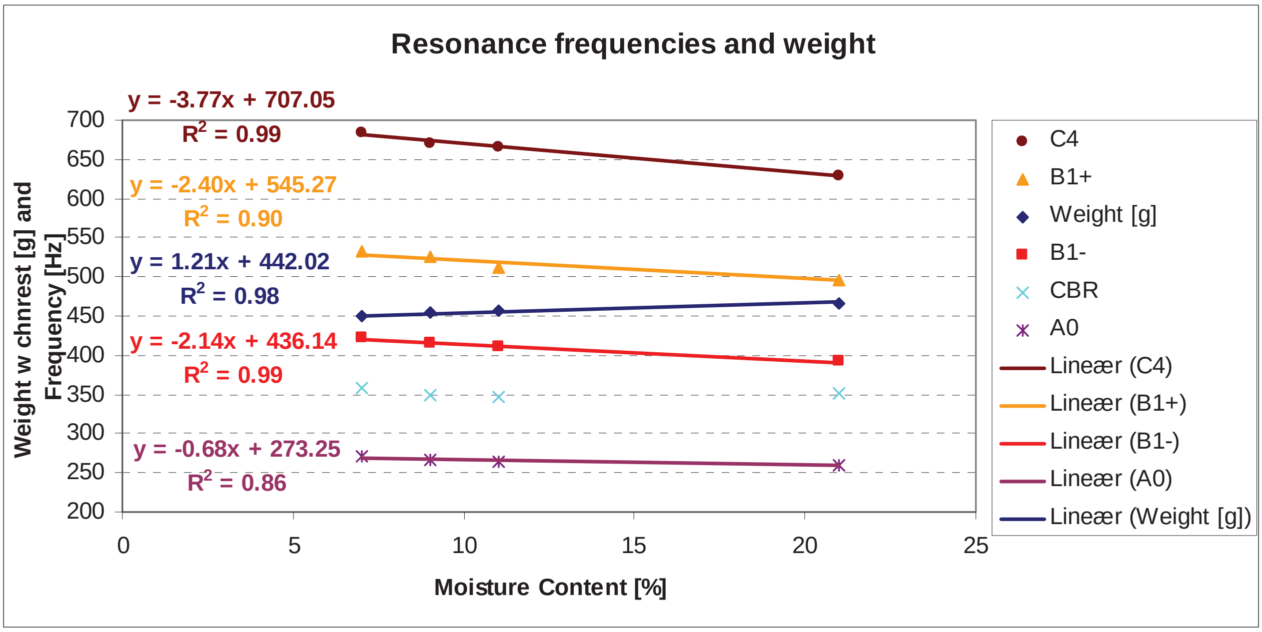
The measurements were done with the instrument mounted in a "Curtin rig" on textile covered rubber bands, vibration insulating the instrument from any supporting masses. The strings were damped using foam rubber pieces between the strings in the region between the fingerboard and the bridge. The moisture content of the wood was measured using a resistance-based contact meter with electrodes put into the grip region of the neck. (This must be done before any direct hand contact)



Figur 3: Transfer accelerance, acceleration(ω)/Force(ω), from the same violin at varying MC from 21% (orange), 11% (brown), 9% (pink) and 7% (violet). Signature modes are indicated.

The curves in Figure 3 are transfer acceleration curves from the same instrument at different levels of moisture content in the wood. It is quite evident that any acoustic experiments where repeatability is important, should be done under the same humidity conditions.

In the following figure the resonance frequencies of the signature modes as given in Figure 3 are extracted. Linear regression is done to get sensitivity figures to use for preliminary assessments of how the MC influences the signature resonance frequencies.



Figur 4: Signature mode resonance frequencies and weight of a violin with a chinrest measured at four different MC levels. The regression formulas have the same colors as the regression lines and data points. ("Lineær" = Linear, Norwegian text due to a Norw. version of MS Excel)

From the regression formulas in Figure 4 we can predict the following changes in the frequencies of the signature modes for 1% change in the MC:

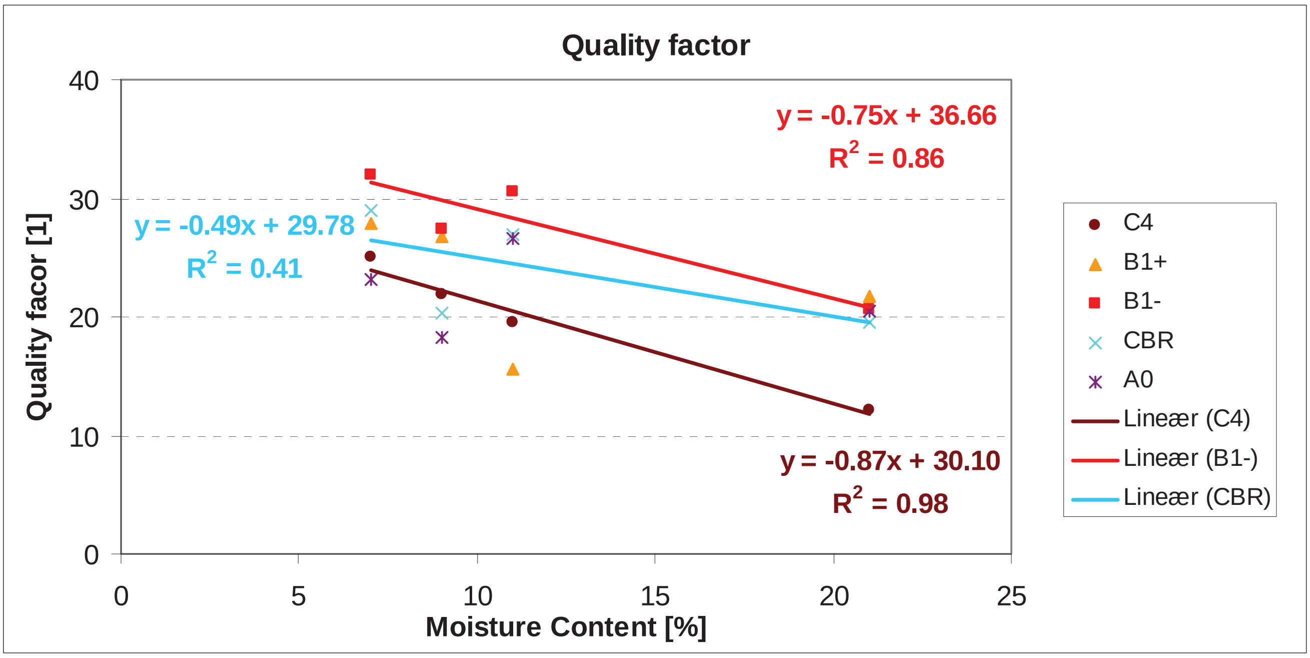
C4: -3.8 Hz per % ΔMC
B1+: -2.4 Hz per % ΔMC
B1-: -2.1% Hz pr % ΔMC
A0: -0.7 Hz per % ΔMC
Weight: 1.2 g per % ΔMC

The CBR did not show large changes in the resonance frequency, possibly indicating that the full body bending and twisting are depending less on the MC than the more plate related modes. Surprisingly, even the main air resonance, A0, or "the f-hole bow resonance" is somewhat dependent on the MC in the wood. More flexible plates will also affect the air plate system to reduce the resonance frequency.

If we assume that the regression lines could be extrapolated to zero MC, then the constant terms in the regression formulae would indicate where the resonances and weight would end in an oven dry instrument. Using the constant terms as denominators, we can get numbers for % change in frequency (f) and weight (g) for each change in % MC:

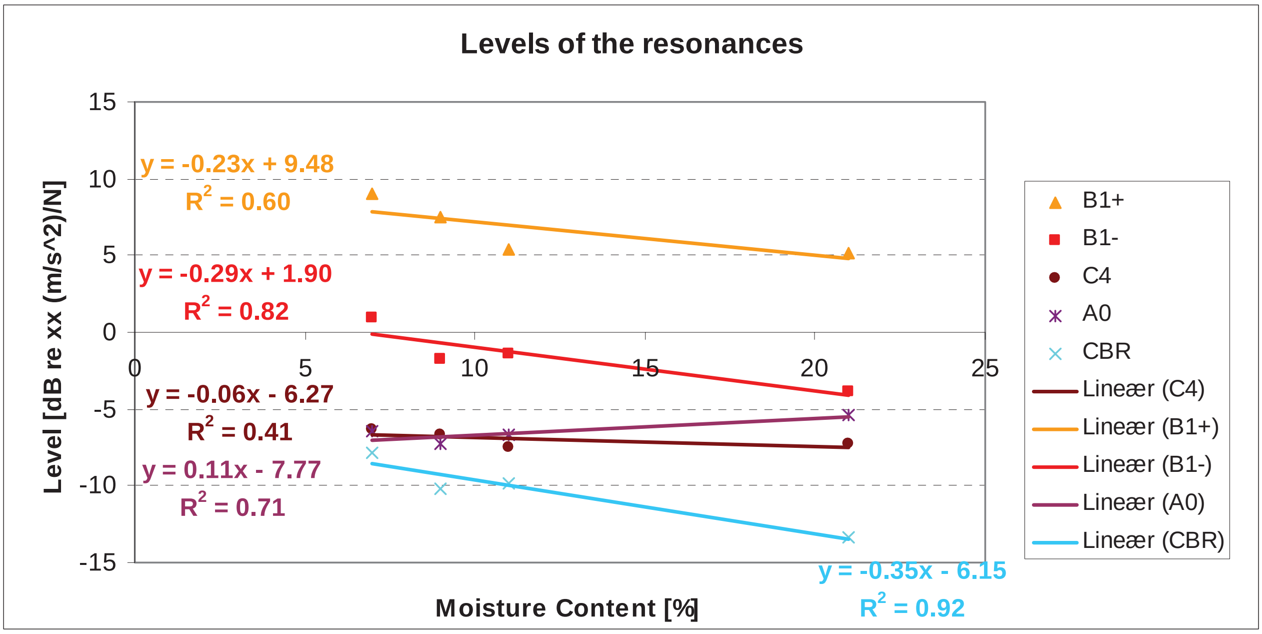
C4: -0.5 % Δf per % ΔMC
B1+: -0.4 % Δf per % ΔMC
B1-: -0.5 % Δf per % ΔMC
A0: 0.2 % Δf per % ΔMC
Weight: 0.3 % Δg per % ΔMC

Interestingly the % Δf per % ΔMC is about the same for the different wood-based modes, which may suggest that the MC effect on the resonance frequencies will be almost constant over the frequency range. (I have tested for a couple other higher resonances too). This effect should make the changes of the resonance frequencies more audible.



Figur 5: Quality factors of the signature modes measured at different MC of the wood. (The damping values here are somewhat influenced by the damping of the strings during the measurements) ("Lineær" = Linear)

As we see from Figure 5 the damping increases with the increasing MC (the damping factor $\eta = 1/Q$) and the levels of the resonances are thus also affected, as well as the effective mass and stiffness. There should therefore also be an effect on the levels of the resonances also from the MC change after correcting for the changes in damping.



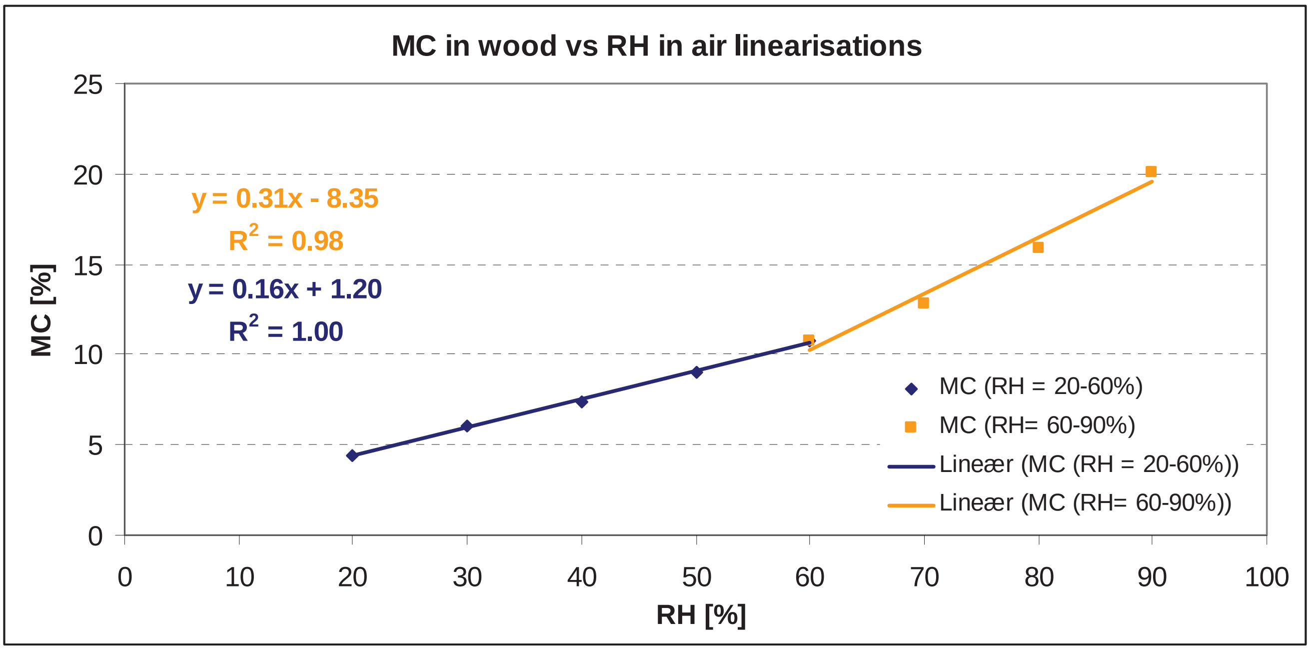
Figur 6: The (uncalibrated) resonance levels for the signature modes at the different MC values of the violin.

The trend of the resonance levels are decreasing with increasing MC for the signature modes, except for the A0 which get somewhat stronger response when the body becomes more flexible. This effect is stronger in the sound radiation measurements.

How important is it to keep track of the MC or RH?

The importance of keeping track and control over the MC will depend on what the measurements are intended for. How much variation in the results from MC variations is acceptable? The smaller the acoustic effects one needs to measure, (and the better the measurement system) the more important it is to keep the instruments in a constant RH environment.

From Figure 1 we see that between some 20 and 60% the RH and MC varies about linearly. For a ± 10 % variation in RH in that range the variation in MC will be some ± 1,6 %. The variation in the measured frequencies will then be some ± 0,8 % and the levels some ± 0,4 dB. Even a variation as small as this (± 4 Hz for a 500 Hz resonance) might lead to a temptation of "seeing an effect" of a given intended influence on the violin in good measurement systems.



Figur 7: Linearisations of the RH – MC relation shown in Figure 1 with regression formulas. (Lineær = Linear)

In the region from 60% and up to 90% RH these numbers will double and it is thus more important to keep the RH values within narrower limits.
Low-cost RH meters are in general unreliable. But weights are usually better. Keeping track of the weight is a simple control of the MC variation.

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