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ANTIQUE VIOLINS: EFFECT OF THE PLAYER ON THE MOISTURE CONTENT

Giacomo GOLI [1*], Bertrand MARCON[2], Lorenzo BUSONI[3], Bruce CARLSON[4], Alberto CAVALLI[1], Alberto GIORDANO[5], Paola MAZZANTI[1], Pio MONTANARI [6], Marco TOGNI [1], Marco FIORAVANTI [1]

[1] GESAAF - University of Florence, Via S. Bonaventura 13, 50145, Firenze, Italy
[2] LaBoMaP - Ecole Nationale Supérieure d'Arts et Métiers, Rue porte de Paris, 71250 Cluny, France
[3] INAF - Osservatorio Astronomico di Arcetri, Largo Enrico Fermi 5, 50125, Firenze, Italy
[4] CCN - Carlson & Neumann SNC, 26100, Via Francesco Robolotti 16, Cremona, Italy
[5] Alberto Giordano & C, Piazza dei Garibaldi 24r, 16123, Genova, Italy
[6] Montanari violins. Vico delle Compere 2, 16123, Genova, Italy

Abstract

In this research the inside and outside relative humidity and temperature of the violin Guarneri "del Gesù" (1743) known as the "Cannone", were monitored during nine concerts. The environmental variations during concerts were analysed showing how the internal relative humidity tends to an average value between the conservation conditions and the external conditions. The violin internal temperature is highly influenced by the contact between the player and the violin resulting in a typical saw-tooth graph during a concert because of the discontinuous contact with the player's body. The violin internal relative humidity presents a typical drop when the player stops playing. The mass variations consequent to the concerts were also recorded and analysed. This analysis has shown how the difference between the conservation average relative humidity and the violin external average relative humidity during a concert are good predictors of the mass variation. Relative humidity and Equilibrium Moisture Content have shown the same ability to predict the mass loss showing how the temperature (for the variation measured in this research) is not an important factor. The analysis suggests that the presence of the violinist does not play a relevant role on the violin mass transfer during a concert.

Keywords: *Violinist; Moisture content; Concert; Mass; Guarneri; Violin; Hygrothermal transfers.*

Introduction

Variations in moisture content have important consequences on the dimensions, shape, physical and mechanical properties of wooden objects [1, 2]. Anisotropic behaviour of wood, asymmetric moisture adsorption as well as moisture gradients play a fundamental role in the internal stresses formations inside wooden objects and consequently on the appearance or growth of damage [3]. In the case of wooden instruments, moisture content variations affect their following properties: shape, density, strength and stiffness, hardness, rheology, vibrational properties. Hygro-thermal variations contribute also to the ageing of wood that with time

* Corresponding author: giacomo.goli@unifi.it

passing modifies some of its properties [4, 5]. Shrinkage and swelling, as well as moisture gradients, can also result in mechanical constrains and damages [6]. An approach to understand the role of moisture gradients, constrained deformations and resulting stresses has been undertaken in the field of panel paintings [7–12], musical instruments [13–18], timber structures [19] and waterlogged wood [20]. The understanding of these behaviours is of fundamental relevance when it comes to consider the conservation of wooden artefacts from cultural heritage such as the historical instrument of this study, the Guarneri "del Gesù" violin (1743) known as the "Cannone". Understanding the typical hygro-thermal variations a violin undergoes during its use (even if occasional) and the consequent mass flow are fundamental tools for conservation purposes. Except for some studies performed on the effects of the moisture content on the acoustical properties, until now the hygro-thermal stress a violin undertakes during a concert is not investigated yet. A tentative study is reported in [21] where the photograph of a violin with a hygro-thermal probe installed inside is shown, however no data are available from this experience. To define the conservation requirements of the Guarneri "del Gesù" violin, some studies were planned. In particular, the typical conservation conditions, the typical hygro-thermal stress the violin endures during events outside the conservation case, the effect of the violinist during an event and the mass variations consequent to the hygro-thermal variations were studied.

Material and methods

The relative humidity (*RH*) and the temperature (*T*) inside the conservation showcase were monitored by a Rotronic Higroclip probe (accuracy: ± 0.3 K and ± 1.5 % respectively) and the data acquired every 5 minutes. A Hobo U12 series data logger (accuracy ±0.35 K and ±2.5 %) monitored the environmental *RH* and *T* during concerts with a sampling rate of 5 seconds. The violin internal *RH* and *T* during concerts were monitored by a radio device developed on purpose and embedded into a chinrest as described in Fig. 1. The electronics used for data sampling and wireless transmission were two Moteiv Tmote sky radio modules set respectively as transmitter and receiver. Tmote sky radio modules were (they are no longer produced) ultra low-power IEEE 802.15.4 compliant wireless sensor modules. The hardware was programmed with TinyOS facilities. The sender module was set to acquire and send an averaged set of data every 5 seconds while the receiver was set to listen to data. The data were collected on a PC. The sensor installed on the chinrest was a Sensirion SHT75 (accuracy ± 0.3 K and ± 1.8 %). The sensor was as small as required to be introduced into the violin body through the bore of an empty end button. The chinrest was designed by Alberto Giordano and produced by the facilities of Bogaro & Clemente (see Fig. 1) by routing a pocket for hosting the wireless board and by drilling a bore in order to contain a 1/3N 3.0V lithium battery. The sensor, connected to the board by a telephone cable, entered through the violin end-button bore for about 50 mm and stayed suspended inside the violin thanks to its own stiffness (see Fig. 2).

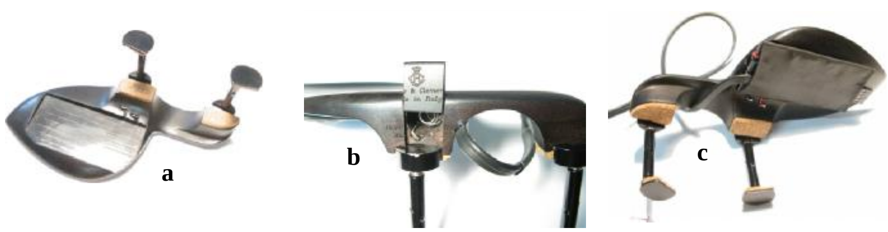


Fig. 1. The chinrest prepared for the electronics mounting (a),
the battery housing (b) and the electronics integrated into the chinrest (c).

a

b

Fig. 2. The chinrest mounted on the violin with the sensor inside the body (a). The sensor (b).

The mass of the violin was also determined at the conservation case opening and at the concert end just before entering the violin back inside the display case. This procedure allowed to precisely determine the moisture exchanges of the violin during the concert. The mass was measured by an Ohaus analytic precision balance with 0.01 grams of accuracy.

Experimental

Nine concerts were monitored. The concerts were held in 2007 and 2008 in May, June, September, October, November and December (for detailed information see Table 1).

Table 1. List of the concerts monitored: concert date, player and time the violin spent out from the case (Time Out from the showCase - TOC).

#	Concert date	Player	*TOC* (hh:mm)
1	27/06/2007	Mario Trabucco	03:00
2	21/09/2007	Feng Ning	02:45
3	22/09/2007	Feng Ning	02:45
4	17/10/2007	Peter Sheppard Skærved	02:00
5	18/10/2007	Peter Sheppard Skærved	04:00
6	23/05/2008	Mario Trabucco	03:15
7	01/11/2008	Salvatore Accardo	04:15
8	14/12/2008	Mario Trabucco	04:00
9	13/12/2009	Mario Trabucco	04:30

In order to compare the conservation conditions with the playing conditions, the conservation *RH* and *T* were recorded by a data-logger during the year 2008. Monthly averages were computed (Table 2) for the available periods and used as reference for the same month the concert was held, even if in different years. The Equilibrium Moisture Content (*EMC*) was computed according to [22-25].

Table 2 Reference values of Relative Humidity (*RH*), Temperature (*T*) and Equilibrium Moisture Content (*EMC*) during violin conservation inside the showcase, computed as a monthly average on the year 2008.

Year	Month	$\overline{RH}_{ref}$ (%)	$\overline{T}_{ref}$ (°C)	$\overline{EMC}_{ref}$ (%)
2008	May	55.0	23.2	10.0
2008	June	54.8	25.1	9.9
2008	July	53.6	24.1	9.7
2008	August	53.6	24.3	9.7
2008	September	56.0	24.8	10.1
2008	October	55.9	23.2	10.2
2008	November	54.7	19.6	10.1
2008	December	53.3	18.2	9.9

Results

Qualitative analysis

Fig. 3 shows a complete data set in correspondence to violin set-up operations (strings tensioning, bridge positioning, tuning), rehearsal, concert and violin maintenance operation performed during the event #7. During the set-up the internal sensor is introduced inside the violin (at the early beginning, the values of the internal and external sensors are similar because both were measuring room conditions) and the instrument is prepared for the concert. During this phase, the violin is heated by manipulations and the internal *RH* shows a tendency to decrease. The *RH* in this phase is between 51 % and 55 %, higher than the environmental one (about 49 %) but not far from the monthly average of 54.7 %, for the given reference period. During the idle period, the violin is left untouched on a table and the internal temperature decreases progressively to get closer to the environmental one. This leads to a progressive increase in *RH* that, once the temperature gets stable, a constant value around 53 % is attained again very close to the reference *RH*. During the rehearsals and during the concert an increase of the internal temperature because of the continuous contact between the violin and the player body is recorded. Violin internal *RH* in this phase is very close to the external environment showing how the player seems not to introduce relevant quantities of humidity inside the system. *RH* during rehearsals and concert attained an average value between 52 % and 55 %, again very close to the reference *RH* and to the external environment. A scattered behaviour of *RH* is observed during rehearsals and concerts highlighting, to some extents, an effect of the player that will be discussed later on this paper. The small difference between the conservation conditions and the playing conditions is confirmed by a very small mass variation of -0.15 g.

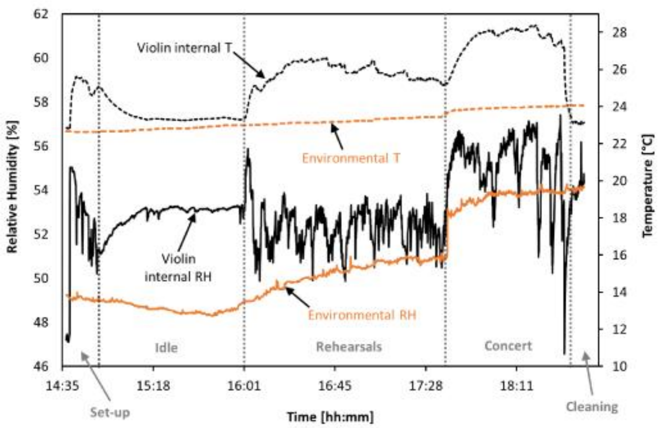


Fig. 3. Evolution in time of the humidity and temperature in the environment and inside the violin during the violin set-up, rehearsals and concert of Salvatore Accardo held the 1st of November 2008

The effect of the player is better highlighted in Fig. 4 where the event #1 is shown. When the musician starts playing (R) the temperature begins to increase while when the musician stops playing (S) the temperature begins to decrease. For the violin internal *RH*, at (S) it falls down while at (R) it goes back to the values measured before. *RH* falls can be explained by the entering of external air into the instrument body when the player interrupts playing and moves the instrument far from his body. The external air, getting heated by the contact with the violin body, drops down in relative humidity. This behaviour can be observed both with an external *RH* higher (as in Fig. 4) or lower (as in Fig. 5) than the reference *RH* conditions. Once the player restarts playing the humidity goes back to a value closer to the one it was before stopping (S).

Apart from this momentary effect, the player does not seem to play a relevant role in the instrument internal *RH* variations that seems to be mainly dependent on the reference and on the external conditions. Both for Figure 4 and for Figure 5, the internal *RH* is in between the reference humidity and the environmental one.

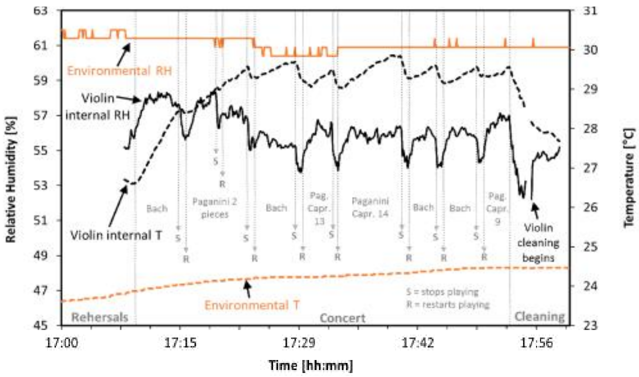


Fig. 4. Evolution in time of the humidity and temperature in the environment and inside the violin during the concert of Mario Trabucco held the 27th of June 2007

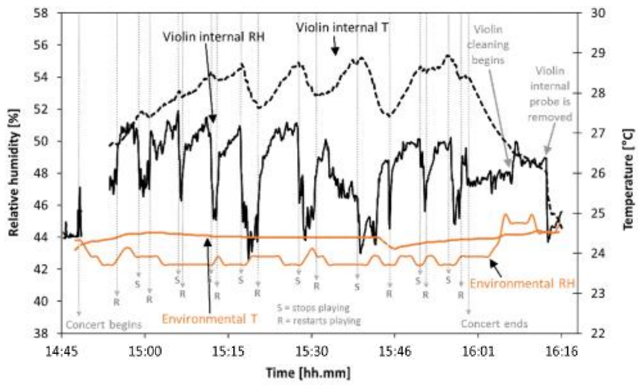


Fig. 5. Evolution in time of the humidity and temperature in the environment and inside the violin during the rehearsal of Peter Sheppard Skærved held the 17th of October 2007

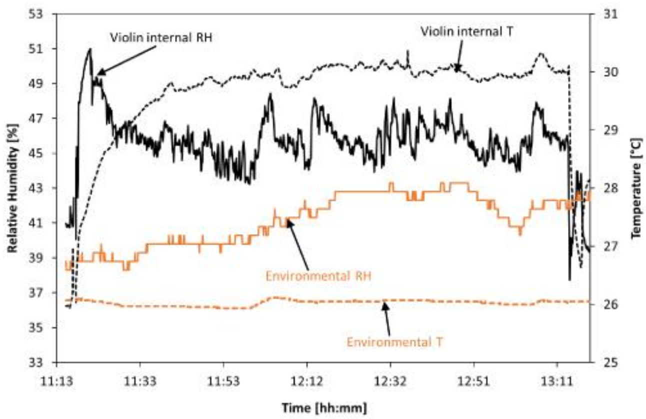


Fig. 6. Evolution in time of the humidity and temperature in the environment and inside the violin during the rehearsal of Feng Ning 22nd September 2007

The humidity falls are not visible if the player does not move the violin from his body. In Fig. 6 is shown a performance where the player plays continuously for about two hours. The result is that the temperature increases until an asymptote is reached and the internal relative humidity stays constant at a value around 46%. Once again this value is in between the conservation relative humidity (56%) and the environmental relative humidity (about 37%).

Quantitative analysis

The difference between the references values (monthly average conservation conditions) and the average environmental and violin internal conditions during concerts are shown in Table 3. *EMC* is computed in order to verify if the temperature plays a relevant role or not. Monthly reference values are used for the ΔRH and ΔEMC computations. The variations from the reference values are computed as follows:

$$\Delta var = \overline{var}_{out} - \overline{var}_{ref} \quad (1)$$

where Δvar is the average variation of a given variable (*RH* or *T* or *EMC*) because of an event or a series of events (instrument set-up, rehearsals, concert), $\overline{var}_{out}$ is the average value of the given variable during the period the violin was kept outside the showcase and $\overline{var}_{ref}$ is the reference value inside the display case as reported in Table 2. The mass variation (ΔM) during a concert was determined as the difference between the mass measured at the showcase opening and the mass measured immediately before closing the showcase after the event. The mass variation referred to the time the violin has spent outside the showcase (Time Out from the showCase - *TOC*) is computed being the adsorption/desorption processes time-dependent. $\Delta_{environment}$ is the difference between the chosen parameter (*RH*, *EMC*) inside the display case and the concert room environment. Δ_{violin} is the difference between the chosen parameter (*RH*, *EMC*) inside the display case and the violin internal condition.

Table 3. Variations in terms of Relative Humidity and Equilibrium Moisture Content (*EMC*) between the average conservation conditions and the average conditions measured during concerts.

#	$\Delta RH_{environment}$ [%]	$\Delta EMC_{environment}$ [%]	ΔRH_{violin} [%]	ΔEMC_{violin} [%]	ΔM [g]	$\Delta M/TOC$ [g.h^{-1}]
1	8.31	1.44	4.51	0.71	0.38	0.13
2	-13.06	-2.14	-5.77	-0.92	-0.65	-0.24
3	-12.47	-2.04	-6.82	-1.11	-0.37	-0.13
4	-10.96	-1.82	-8.33	-1.32	-0.39	-0.19
5	-6.43	-1.13	-2.41	-0.40	-0.25	-0.06
6	8.77	1.49	2.91	0.46	0.47	0.14
7	-1.73	-0.45	1.89	0.23	-0.15	-0.04
8	4.12	0.68	2.35	0.45	0.08	0.02
9	-12.33	-1.96	-7.26	-1.13	-0.86	-0.19

According to data reported in Table 3 it is clear that:

- the internal *RH* is highly sensitive to the external *RH*. If $\Delta RH_{environment}$ is negative then ΔRH_{violin} is negative. The opposite if $\Delta RH_{environment}$ is positive.
- the *RH* buffer effect of the violin body is utterly clear as the violin internal *RH* is always in the middle between the reference *RH* and the external *RH* (see Fig. 7).

In order to highlight possible relations between normalised ΔM ($\Delta M/TOC$), ΔRH and ΔEMC, the normalised ΔM was plotted versus ΔRH and ΔEMC (see Fig. 8). A linear trend is witnessed highlighting how the hourly violin mass variation is directly dependent on $\Delta RH_{environment}$ or $\Delta EMC_{environment}$ with the same degree of predictability (R^2 of 0.95 and 0.94 respectively).

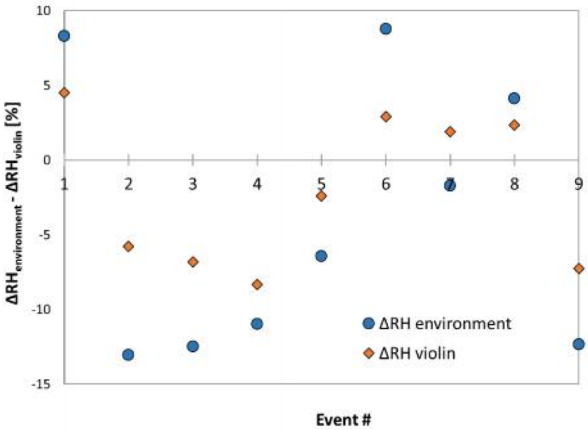
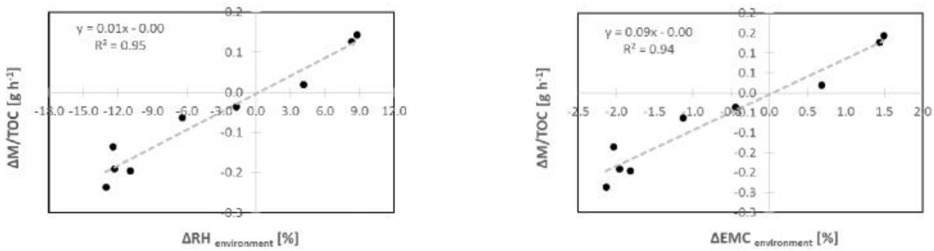


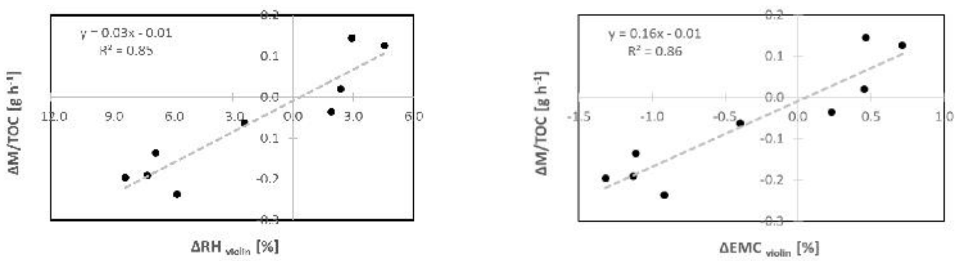
Fig. 7. Difference between the average conservation relative humidity and the external average relative humidity during an event ($\Delta RH_{\text{environment}}$) and violin internal average relative humidity during an event ($\Delta RH_{\text{violin}}$).



a b

Fig. 8. Variation in relative humidity (a) and equilibrium moisture content between the average environmental conditions and the violin showcase average conservation conditions vs. mass variation consequent to a concert (ΔM) divided by the time the violin was kept outside the showcase (*TOC*).

The same assessment/statement was verified for the internal conditions ($\Delta RH_{\text{violin}}$ and $\Delta EMC_{\text{violin}}$) as exposed in Figure 9.



a b

Fig. 9. Variation in relative humidity (a) and equilibrium moisture content (b) between the violin average internal condition and the violin showcase average conservation conditions vs. mass variation consequent to a concert (ΔM) divided by the time the violin was kept outside the showcasee (*TOC*).

Discussion

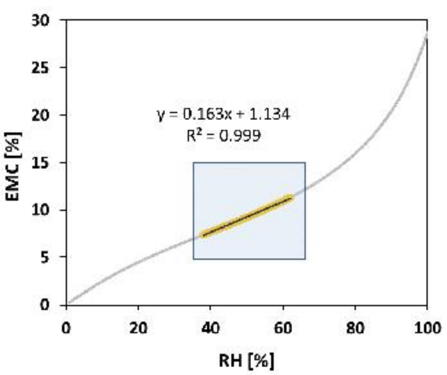
From Fig. 8a and b it can be concluded that environmental *RH* and *EMC* variations compared to conservation conditions are both good predictors of the mass variation during a concert (R^2 0.95 and 0.94). As a consequence the effect of the temperature (at least in the range of our data set going from +3.0 °C to -1.2 °C from the monthly reference temperature) seems to be negligible. The comparison of Figure 8 and Figure 9 leads to conclude that the environmental *RH* and *EMC* variations (R^2 0.95 and 0.94 respectively) are better predictors of the mass variation than violin internal variations (R^2 0.85 and 0.84 respectively). The violin internal conditions are possibly so variable that, being a continuum of transitory conditions, they cannot be simply described by an average. The environmental *RH* and *T* present a very small variability during the concert period and the average can be possibly considered as representative of the whole period.

The three main outcomes from the collected data are:

- the concert environmental conditions are better predictors of the mass variation during a concert than the violin internal conditions;
- the temperature has a very minor role for the conditions tested (and then for the conventional conditions a violin is used) being the predictability of the mass variation the same using ΔRH and ΔEMC;
- the violinist plays a negligible role on the mass variation (i.e. does not have a higro-thermal relevant role) because ΔRH or ΔEMC precisely describe the mass variation without considering the violin player. By the way, the data presented in this paper are the result of 9 concerts played by 4 different musicians playing in very different conditions and no effect of the player has been recorded.

A linear relation between $\Delta M/TOC$ and ΔRH or ΔEMC can result as surprising because the relation among ΔM, time, *RH* and *T* is not linear. The fact that all these complex phenomena could be approximately described by a linear relation comes from three main reasons:

- for the measured *RH* field , going from 38.8 % to 61.7 %, the sorption isotherm at 20 °C, computed as from [22-25] has a linear behaviour with a R^2 of 0.999 (see Fig. 10a);
- the *EMC* variation induced by a range of temperatures varying from 16.5 °C to 26.4 °C is a very low with a variation of ± 0.2 points of *EMC*;
- the mass time dependent behaviour after a *RH* variation for time periods going from 2 to 5 hours (the duration of the events monitored in this paper) is not far from being linear. Second Fick's law computed from 2 to 5 hours for a tangential 3.1 mm thick *Picea abies* board (as the Cannone soundboard) with a diffusion coefficient of $0.452e^{-10}$ (m^2 s^{-1}) fits a linear model with 0.997 of R^2 (see Fig. 10b).



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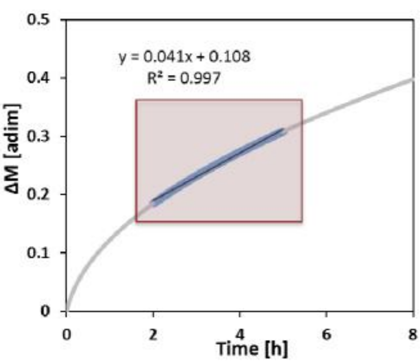

b

Fig. 10. Relation between *EMC* and *RH* that, in the area of our interest, can be described by a linear trend with a good approximation (a), relation between mass variation and time of a 3.1 mm tick spruce board computed according to the second Fick's law where a good linear approximation can be observed between 2 and 5 hours.

Conclusions

The difference between the conservation conditions and the average violin internal and external conditions during an event are good predictors of the mass variations during the event itself. For the variations measured in this study, that are in line with a conventional use of an antique violin, and for events durations going from 2 to 5 hours, the mass variation presents a linear regression with the above mentioned variables. The difference between the conservation conditions and the environmental conditions during a concert is a better predictor of the mass variation if compared to the violin internal conditions. This statement finds its explanation in the fact that the very variable internal conditions cannot be simplified in an average value. Relative humidity and equilibrium moisture content present the same ability to predict the mass variation, showing that the effect of the temperature is negligible. Being the environmental conditions better predictors of the mass variations than the violin internal conditions, it can be concluded that the player role on the hygro-thermal equilibrium can be considered as negligible. The fact that the player heats-up the violin by several degrees during a concert has measurable effects on the violin interior but it seems not to affect the mass exchanges of the violin. The trend seems to be in agreement with the Fick’s law opening perspectives to proceed to the development of future fully meaningful physical models.

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