MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Estimation of the impact noise level in wood constructions: choice of a global acoustic indice

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ABSTRACT

This work concerns the characterization of the impact sound level in wood constructions from in situ measurements. Two global acoustic indices have been estimated and compared with each other, one associated with the excitation source that is the tapping machine, the other related to the excitation source that is the impact ball, likely to better characterize footsteps. These global acoustic indices were estimated over the frequency range [100 Hz: 3150 Hz] and over the frequency range [50 Hz: 3150 Hz], A-weighted or A-unweighted. A statistical study was then carried out on the difference between the global acoustic indice related to the tapping machine and that related to the impact ball. According to the choice of the frequency range and the use of the A-weighting, this statistical study made it possible to conclude on the sensitivity of these global acoustic indices with respect to the correction term normalizing the influence of the reception room and, with respect to the low frequencies [50 Hz: 100 Hz]. Finally, this statistical study concludes on the relevance of the use of a global acoustic indice compared to the other in order to characterize the impact sound level in these wood constructions.

Keywords: Acoustic indice, Wooden buildings
I-INCE Classification of Subject Number: 45

1. INTRODUCTION

This work focuses on building acoustics. More specifically, it aims to focus on acoustic indicators of the level of impact noise for light wooden constructions. To date in France, the impact noise level is estimated from measurements using a tapping machine as excitation source. This is the same excitation source used for heavy concrete construction. However, several works seem to question this excitation source in favor of the impact ball. The sound signal of this excitation source is here supposed to be closer to that resulting from the noise of step, often troublesome in the light constructions.

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This work compares an acoustic indicator associated with the "tapping machine" excitation source with an acoustic indicator linked to the "impact ball" excitation source. A series of measurements have been made on wood constructions. The impact noise levels associated with each of these excitation sources were then measured. Standardized and non-standardized acoustic indicators, A-weighted and A-unweighted acoustic indicators, integrating or not the low frequencies [50 Hz : 100 Hz], were then estimated, as well as the deviations between these different acoustic indicators. The present work is based on the study of these deviations. At first, the influence of the A-weighting and the low frequencies on these deviations were studied by directly observing the value of these deviations, but also by carrying out a statistical analysis. The latter is based on a non-parametric test which, by definition, doesn't assume that these deviations obey a particular distribution. In a second step, this work ends with the study of the relevance of the choice of the acoustic indicator for these wood constructions. As before, a statistical analysis is performed.

2. MEASUREMENT CAMPAIGNS AND ACOUSTIC INDICES

The sites selected for this study are individual houses with wood floors with different types of floor coverings (Figure 1). The emission rooms and the reception rooms are superimposed on each other or diagonally. A measurement campaign is associated with a emission room and a reception room. Nine measurement campaigns were carried out. For measurement campaign number 1, five emission positions and five reception positions were considered. For all other measurement campaigns, three emission positions and three reception positions were only considered. For each pair "emission position / receive position", the impact noise level was estimated for the two commonly used excitation sources: the impact machine and the impact ball [1–4]. The emission positions and the reception positions chosen are the same for the case where the excitation source is the tapping machine and for the case where the excitation source is the impact ball.

For the tapping machine, the recording time is fifteen seconds. For the impact ball, the recording time is adapted to the case of a single drop from a height of one meter, the height corresponding to the distance between the underside of the ball and the ground surface considered. Regarding the measurement of the reverberation time in the reception rooms, it is made from a impulse noise. Three reception positions were systematically considered. Finally, the reverberation time introduced within the expressions of the impact noise level is arithmetically averaged over these three measurements.

The acoustic indicators chosen are based on international standards [5,6]. The acoustic indicator associated with the "tapping machine" excitation source is the standard sound pressure level L'_{nT} (see Table 1). The acoustic indicator associated with the "impact ball" excitation source is the maximum sound pressure level L_{FMax} (see Table 2). The frequency ranges studied are [100 Hz : 3150 Hz] and [50 Hz : 3150 Hz]. The frequency range [50 Hz : 100 Hz] corresponds in our study at low frequencies. This choice is common [7, 8] even if it can be questioned in the context of the noise annoyance in wood constructions [2, 9, 10]. Finally, these acoustic indicators were estimated with or without A-weighting.

Figure 1: Old house in France: wood construction

$L_{(A)eq,i,j}$	(A-weighted) sound pressure level for the i third-octave band and for the j measure
$L_{(A)eq,j} = 10\log\left(\sum_{i=1}^{n} 10^{L_{(A)eq,i,j}/10}\right)$	(A-weighted) global sound pressure level for the j measure
$L'_{n(A)T,i,j} = L_{(A)eq,i,j} - 10\log(\frac{\bar{TR}_i}{TR_{ref}})$	(A-weighted) standardized sound pressure level for the i third-octave band and for the j measure
$L'_{n(A)T,j} = 10\log\left(\sum_{i=1}^{n} 10^{L'_{n(A)T,i,j}/10}\right)$	(A-weighted) global standardized sound pressure level for the j measure

Table 1: Acoustic indicator related to the impact noise level measured from the tapping machine, with $\bar{TR}_i$ the average reverberation time in the reception room and $TR_{ref} = 0.5s$.

$L'_{(A)FMax,i,j}$	(A-weighted) maximum sound pressure level for the third octave band i and for the j measure
$L'_{(A)FMax,j} = 10\log\left(\sum_{i=1}^{n} 10^{L'_{(A)FMax,i,j}/10}\right)$	(A-weighted) maximum global sound pressure level for the j measure
$L'_{(A)FMaxV,T,i,j} = L'_{(A)FMax,i,j} + 10\log(\frac{V}{V_{ref}}) - 10\log\left(\frac{1-C_{ref}^{-1}}{1-C^{-1}}\left(\frac{C^{(1-C)^{-1}} - C^{-(1-C^{-1})^{-1}}}{C_{ref}^{(1-C_{ref})^{-1}} - C_{ref}^{-(1-C_{ref}^{-1})^{-1}}}\right)\right)$	(A-weighted) maximum standardized sound pressure level for the i third-octave band and for the j measure
$L'_{(A)FMaxV,T,j} = 10\log\left(\sum_{i=1}^{n} 10^{L'_{(A)FMaxV,T,i,j}/10}\right)$	(A-weighted) maximum global standardized sound pressure level for the j measure

Table 2: Acoustic indicator related to the impact noise level measured from the impact ball, with $C_{ref} = TR_{ref}/1.7275$, $C = \overline{TR}_i/1.7275$ and $V_{ref} = 50m^3$.

3. RESULTS AND ANALYSIS

3.3.1. Influence of the correction term - Comparison of standardized and non-standardized levels

The first study concerns the influence of the correction term on the value of acoustic indicators. For each indicator, the deviation Δ_{corr} between the standardized noise level and the non-standard noise level is estimated:

$$\Delta_{\text{corr}} = L_{\text{standardized}} - L_{\text{non-standardized}}. \tag{1}$$

The non-standard noise level corresponds to the standardized noise level (see Tables 1 and 2) for which the logarithmic terms related to the reception room are not taken into account. These deviations were estimated for the cases where the indicators are calculated over the frequency ranges [50 Hz : 3150 Hz] and [100 Hz : 3150 Hz], A-weighted or A-unweighted.

Concerning the acoustic indicator associated with the "tapping machine" excitation source (see Table 1), the figure 2 shows, for example, the deviations calculated from the measured impact noise levels on the range of frequencies [50 Hz : 3150 Hz], A-weighted and A-unweighted. The mean deviation was also estimated. Finally, in all cases ([50 Hz : 3150 Hz] or [100 Hz : 3150 Hz], A-weighted and A-unweighted), the mean deviation is negative and of the order of -1.5 dB (or dB(A)). The standardized impact noise level is lower than the non-standardized impact noise level. The influence of the correction term therefore seems significant. This means that the expression of the proposed correction term makes it possible to take into account a certain influence of the reception room. Moreover, the fact that these deviations are of the same order of magnitude whether the A-weighting is taken or not int account, implies that the correction terme semms independant of the A weigthing. This result is in good agreement with the fact that the correction term is theoretically only related to the influence of the reception room.

Concerning the acoustic indicator associated with the "impact ball" excitation source, in all cases ([50 Hz : 3150 Hz] or [100 Hz : 3150 Hz], A-weighted and A-unweighted), the mean deviation is less than one decibel (or dB(A)). The standardized impact noise level is therefore of the same order of magnitude as the non-standardized impact noise level. Thus, the influence of the term of correction seems here not very significant. This suggests that the proposed expression of the correction term is inadequate since it doesn't seem to reflect the influence of the receiving room. On the other hand, as previously, A-weighting doesn't affect the value of the correction term.

As a result, the statistical analysis performed and based on these Δ_{corr} deviations uses the Wilcoxon test. This is a non-parametric test which aims here to check the validity of the hypothesis "the mean deviation is zero" (hypothesis H0) from the sample of measurements. So if the hypothesis H0 is verified then the deviation Δ_{corr} can be considered as zero. As a result, the standardized level $L_{\text{standardized}}$ is equal to the unstandardized level $L_{\text{non-standardized}}$. It follows that the associated correction term has no influence on the value of the acoustic indicator. If the hypothesis H0 is not verified (hypothesis H1), the conclusion is reversed. Classically, accepting or rejecting the H0 assumption is based on the value of the estimated p-value (noted p) by the Wilcoxon test:

$$\begin{cases} p \leq 0.01 : \text{very strong presumption against the hypothesis H0} \\ 0.01 < p \leq 0.05 : \text{strong presumption against the hypothesis H0} \\ 0.05 < p \leq 0.1 : \text{weak presumption against the hypothesis H0} \\ p > 0.1 : \text{very weak presumption against the hypothesis H0} \end{cases} \tag{2}$$

The table 3 summarizes the results obtained. First, these results show that, for the two acoustic indicators, the A-weighting doesn't seem to play a role on the value of this correction term which was expected. Secondly, if the frequency range considered is [100 Hz : 3150 Hz], then the correction term have an impact on the value of the acoustic indicator, whether it is the "tapping machine" noise level or the "impact ball" noise level. Thirdly, if the low frequencies [50 Hz : 100 Hz] are integrated, the acoustic indicator associated with the "tapping machine" excitation source remains sensitive to the correction term but not the acoustic indicator associated with the "impact ball" excitation source. This suggests that the expression of the associated correction term must be reviewed at least in this frequency range [50 Hz : 100 Hz]. This is however not clearly established with regard to the values of p-value.

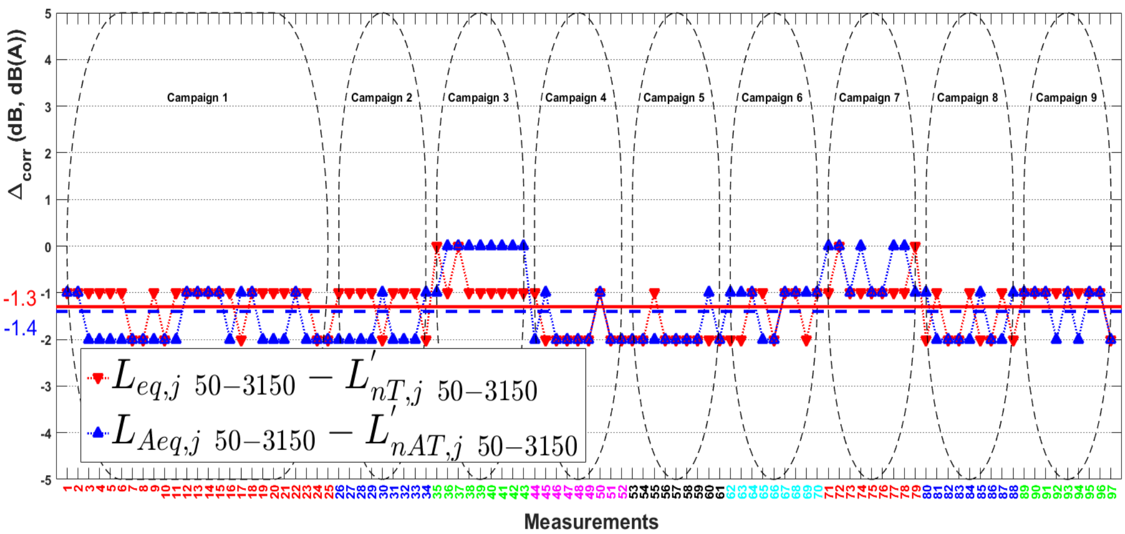

Figure 2: Tapping machine: deviation between the standardized impact noise level and the non-standardized impact noise level for the case where the acoustic indicator is estimated over the frequency range [50 Hz : 3150 Hz], A-weighted and A-unweighted. The mean deviation is equal to -1.4 dB(A) and -1.3 dB, respectively A-weighted and A-unweighted.

Sensitivity to the correction term			
Frequency	Ponderation	Tapping Machine	Impact Ball
$[100Hz : 3150Hz]$	-	**Yes** (H1, p < 2.2e-16)	**Yes** (H1,p=5.4e-4)
$[100Hz : 3150Hz]$	A	**Yes** (H1, p < 2.2e-16)	Yes (H1,p=0.04884)
$[50Hz : 3150Hz]$	-	**Yes** (H1,p < 2.2e-16)	No (H0, p=0.09859)
$[50Hz : 3150Hz]$	A	**Yes** (H1,p < 2.2e-16)	No (H0, p=0.08701)

Table 3: Sensitivity to the correction term.

3.3.2. Influence of low frequencies on the value of acoustic indices

The second study concerns the influence of low frequencies [50 Hz : 100 Hz] on the value of acoustic indicators. For each acoustic indicator, the deviation Δ_{low} between the estimated impact noise level over the frequency range [50 Hz : 3150 Hz] and the estimated impact noise level over the range Frequency [100 Hz : 3150 Hz] was estimated, A-weighted and A-unweighted:

$$\Delta_{\text{low}} = L_{[50\text{ Hz}:3150\text{ Hz}]} - L_{[100\text{ Hz}:3150\text{ Hz}]}. \tag{3}$$

Concerning the acoustic indicator associated with the "tapping machine" excitation source (see Table 1), the figure 3 shows the calculated deviations from the impact noise levels calculated, weighted A and unweighted A. In the case where the A-weighting is not considered, the mean deviation is positive and equal to 1.1 dB. The estimated impact noise level over the frequency range [50 Hz: 3150 Hz] is therefore higher than the estimated impact noise level over the frequency range [100 Hz : 3150 Hz] (see Equation 3). In other words, the introduction of the frequency range [50 Hz: 100 Hz] finally leads to an increase of the order of the decibel of the "tapping machine" noise level. For the case where the A-weighting is considered, the mean deviation is close to zero (0.1 dB(A)). The influence of the frequency range [50 Hz : 100 Hz] is finally greatly reduced by the introduction of the A-weighting. This is logical since the A-weighting greatly reduces the level of impact noise measured at low frequencies.

Concerning the acoustic indicator associated with the "impact ball" excitation source (see Table 2), for the case where the A-weighting is not considered, the mean deviation is equal to 4.8 dB. The introduction of the frequency range [50 Hz : 100 Hz] thus generates a mean deviation much greater than that obtained for the other acoustic indicator. This acoustic indicator is therefore much more sensitive to low frequencies. The fact that it is positive induces that the estimated impact noise level over the frequency range [50 Hz : 3150 Hz] is higher than the estimated impact noise level over the frequency range [100 Hz : 3150 Hz]. For the case where the A-weighting is considered, this mean deviation becomes close to zero (0.3 dB(A)). As before, the introduction of the A-weighting strongly attenuates the possible influence of the low frequencies.

In a similar way to the study of the influence of the correction terms (see section 3.1), a statistical analysis based on the estimated deviations Δ_{low} is carried out here. Hypothesis H0 is identical (zero mean deviation). If the hypothesis H0 is here verified, then this means that the value of the impact noise level $L_{[50\text{ Hz}:3150\text{ Hz}]}$ is equal to the value of the impact noise level $L_{[100\text{ Hz}:3150\text{ Hz}]}$. In other words, the introduction of the frequency range [50 Hz : 100 Hz] has no impact on the value of the acoustic indicator tested. Another possible interpretation is that this acoustic indicator is not sensitive to low frequencies. If the hypothesis H0 is not verified (hypothesis H1), the conclusion is reversed.

The obtained resulsts are summarized in the Table 4. Finally, the hypothesis of a zero mean deviation is rejected by Wilcoxon's test for the two acoustic indicators, A-weighted or A-unweighted. The introduction of the frequency range [50 Hz : 100 Hz] therefore has an impact on the value of the acoustic indicators. For the case of the A-weighted acoustic indicator associated with the "tapping machine" excitation source, this result is however to qualify because the value of the p-value is much higher than for the other cases. Thus, in order to better underline the influence of low frequencies in light wood constructions, it would be undoubtedly more reliable to consider the acoustic indicator associated with the "impact ball" excitation source. This result is however to be taken with caution since the study of the influence of the term of correction showed that its expression is not necessarily adequate on this range of frequencies (see section 3.1).

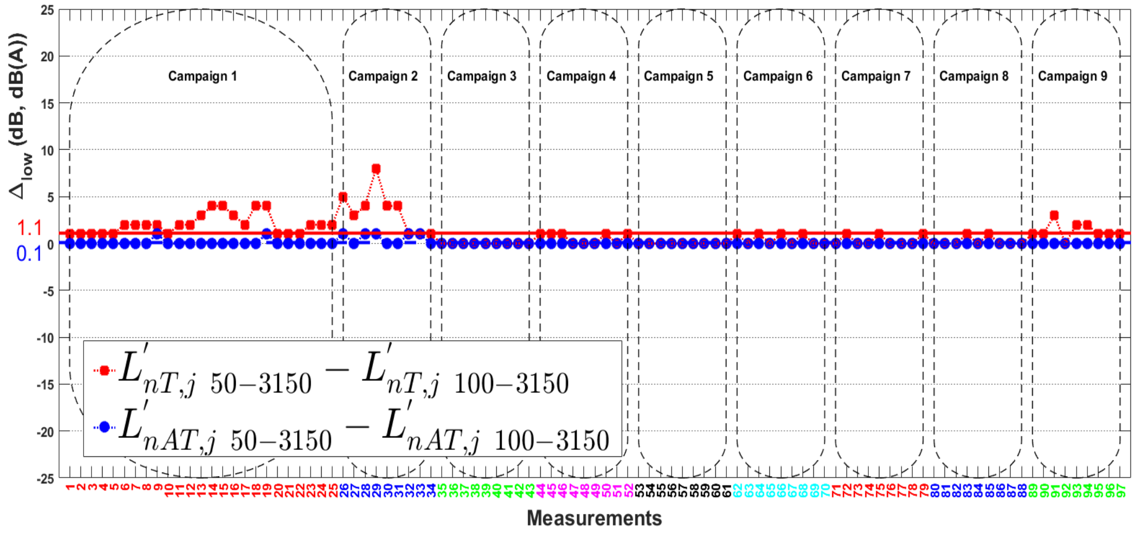

Figure 3: Tapping machine: deviations between the impact noise level based on the frequency range [50 Hz : 3150 Hz] and that related to the frequency range [50 Hz : 3150 Hz]. The acoustic indicator is estimated, A-weighted and A-unweighted. The mean deviation is equal to 0.1 dB(A) if A-weighting is taken into account and to 1.1 dB otherwise.

Sensitivity at low frequencies [$50Hz$: $100Hz$]		
Ponderation	Tapping Machine	Impact Ball
-	**Yes** (H1, p=2.854e-11)	**Yes** (H1, p<2.2e-16)
A	Yes (H1, p=0.01073)	**Yes** (H1, p=1.413e-6)

Table 4: Sensitivity at low frequencies [$50Hz$: $100Hz$].

3.3.3. Comparison of acoustic indicators

The following study concerns the influence of the choice of acoustic indicator. For each acoustic indicator, the difference between Δ_{ind} is calculated between the standardized impact noise level associated with the "impact ball" excitation source and the standardized impact noise level associated with the "tapping machine" source excitation:

$$\Delta_{ind} = L_{\text{ball standardized}} - L_{\text{machine standardized}}. \tag{4}$$

These deviations were estimated for the cases where the indicators are calculated over the frequency ranges [50 Hz: 3150 Hz] and [100 Hz: 3150 Hz], A-weighted and A-unweighted.

Concerning the results based on the frequency range [50 Hz : 3150 Hz] (see Figure 4), the mean deviation is equal to -1.5 dB(A) for the case where A-weighting is taken into account. It is equal to 2.2 dB for the case where the A-weighting is excluded. If the frequency range is [100 Hz : 3150 Hz], the mean deviation is equal to -1.7 dB(A) for the case where A-weighting is taken into account and -1.5 dB otherwise. This suggests that the choice of the acoustic indicator here has an influence in all cases. If the low frequencies [50 Hz : 100 Hz] are not taken into account, then the value of the A-weighted acoustic indicator associated with the "impact ball" excitation source is weaker than that of the acoustic indicator associated with the "tapping machine" excitation source. If the low frequencies are taken into account and the A-weighting is excluded, this result is reversed.

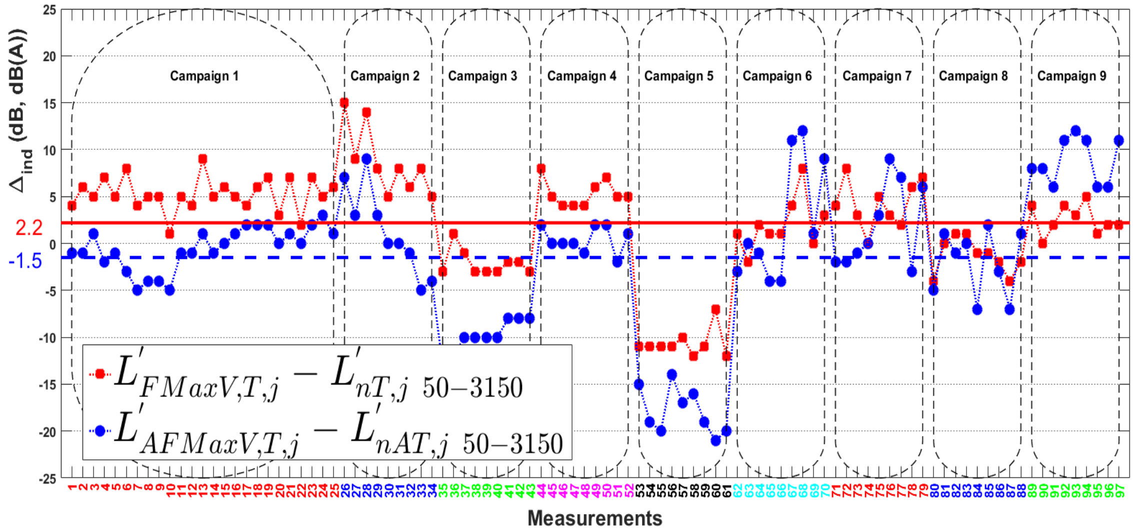

Figure 4: Deviation between the standardized impact noise level related to the "impact ball" excitation source and the standardized impact noise level related to the "tapping machine" excitation source. These levels are estimated over the frequency range [50 Hz : 3150 Hz], A-weighted and A-unweighted. The mean deviation is equal to -1.5 dB(A) if A-weighting is taken into account and to 2.2 dB in the opposite case.

Sensitivity to the choice of the acoustic indicator		
Frequency	Ponderation	
$[100 Hz : 3150 Hz]$	-	No (H0, p=0.03028)
$[100 Hz : 3150 Hz]$	A	No (H0, p=0.05648)
$[50 Hz : 3150 Hz]$	-	**Yes** (H1, p=2.621e-5)
$[50 Hz : 3150 Hz]$	A	**No** (H0, p=0.1282)

Table 5: Sensitivity to the choice of the acoustic indicator.

The statistical analysis based on the deviations Δ_{ind} is summarized in table 5. Hypothesis H0 is always the same. If it is accepted here, then this means that the impact noise levels $L_{\text{ball standardized}}$ and $L_{\text{machine standardized}}$ are equal to each other. In other words, the choice of the acoustic indicator to be used for acoustical studies in wood constructions is not important. If the hypothesis H0 is not verified (hypothesis H1), the conclusion is reversed. Finally, the test results associated with the frequency range [100 Hz : 3150 Hz] show that the choice of the acoustic indicator has no influence, A-weighted or A-unweighted. The same applies to the frequency range [50 Hz : 3150 Hz] if A-weighting is considered. In other words, if the A-weighting is applied, the introduction of the low frequencies [50 Hz : 100 Hz] doesn't make it possible to differentiate these two standardized acoustic indicators. For the frequency range [50 Hz : 3150 Hz], if the A-weighting is not considered, then the choice of the standardized acoustic indicator has an influence on the results. In other words, if the A-weighting is not applied, the introduction of the low frequencies [50 Hz : 100 Hz] can make it possible to differentiate these two standardized acoustic indicators.

4. SYNTHESIS AND CONCLUSION

At first, the influence of the correction term and that of the low frequencies [50 Hz : 100 Hz] were considered. The following results have been highlighted:

- A-weighting doesn't seem to influence the value of acoustic indicators;
- The acoustic indicators are sensitive to the correction term, except that associated with the "impact ball" excitation source and estimated by introducing the low frequencies [50 Hz : 100 Hz]. In this case, this seems to mean that the standardized impact noise level is equal to the non-standardized impact noise level, *ie* the impact noise level is independent of the receiving room. But this is impossible. This suggests that the expression of the associated correction term should probably be revisited over the frequency range [50 Hz : 100 Hz];
- The introduction of the frequency range [50 Hz : 100 Hz] has an influence on the value of acoustic indicators. This influence seems slightly more pronounced for the acoustic indicator associated with the "impact ball" excitation source. This could suggest that, in order to better highlight the influence of low frequencies in light wood constructions, the use of this acoustic indicator would be more appropriate. This result is to be taken with caution with regard to the previous point relating to the correction term.

Finally, this study focused on the relevance of the choice of acoustic indicators in the context of measurements in wood constructions. The following results have been highlighted:

- The choice of the A-weighted acoustic indicator has no influence that the low frequencies [50 Hz : 100 Hz] are taken into account or not;
- The choice of the A-unweighted acoustic indicator has no influence if the low frequencies [50 Hz : 100 Hz] are not considered;
- The choice of the A-unweighted acoustic indicator has influence if the low frequencies [50 Hz : 100 Hz] are considered;
- For this specific case, the value of the acoustic indicator associated with the "impact ball" excitation source is greater than that associated with the "tapping machine"excitation source. As previously, these results are to be taken with caution with regard to the previous point relating to the correction term.

5. ACKNOWLEDGEMENTS

The author of this article wishes to thank Mr FALWISANNER and Mr BRENDEL who carried out the measurements.

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