USING THE STRUCTURAL REVERBERATION TIME IN STANDARDIZING LABORATORY MEASUREMENTS OF THE SOUND REDUCTION INDEX

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ABSTRACT
The sound reduction index as measured in different laboratories show rather large variations for heavy building elements. Since long it has been recognised that the properties of the boundary of the test opening are largely responsible for this. So far a reliable and practical method to solve this problem has not really been found. However, more recent studies have indicated the feasibility of possible solutions by using the structural reverberation time, while the established prediction methods (EN 12354) has specified the use of those structural reverberation times. This paper discusses some aspects of the practical application of the structural reverberation time in standardizing measurement results of the sound reduction index of building elements.

INTRODUCTION
Since about half a century the sound reduction index of building elements can be measured in laboratory facilities in accordance with well-established standards [1]. The results can be used to compare products and as input data for prediction methods for field performance [2]. However, it is known for already quite a while that with heavier building elements, like brick walls or concrete floors, the measurement results are not as well suited for these purposes as would be hoped for [3], [4], [5]. The main reason being that the sound reduction index depend on the total loss factor and that factor, as determined from the structural reverberation time, depends largely on the boundaries of the tested element. These boundaries vary between laboratories, hence making the results incomparable, and vary between laboratory and field situations, hence making predictions more troublesome. Attempts in the past to improve this situation and new possibilities to apply corrections are discussed in this paper.

HISTORY
The influence of the total loss factor on the measured sound reduction index was already tested in an international Round Robin in the beginning of the 70's [4]. It was hoped that the measured structural reverberation time could explain the found differences in sound reduction index. That could than lead to additional requirements for laboratory facilities, making the measurement results more invariant. However, the results were not as conclusive as was hoped for.

During the revision of ISO 140 in the 80’s somewhat more evidence and experience was available with loss factor measurements. It was realised that in order to reduce the variation in results between laboratories for heavier elements, something had to be standardized concerning the energy loss at the borders of the tested element. It was proposed to specify the allowable losses by a laboratory facility. This could be done by setting limits to the total loss factor of a heavy reference wall. The proposal was that for a reference wall of 400±40 kg/m^2, the total loss factor in the laboratory should be within ±2 dB of a mean value given by:

$$10\lg\eta_{tot} = 10\lg\left(0{,}01 + 0{,}5/\sqrt{f}\right) \qquad (1)$$

This was based on some available data at that time as given in figure 1. In the final version of the document only the lower limit is specified, resulting in the factor 0,3 in stead of 0,5 in eq. (1).

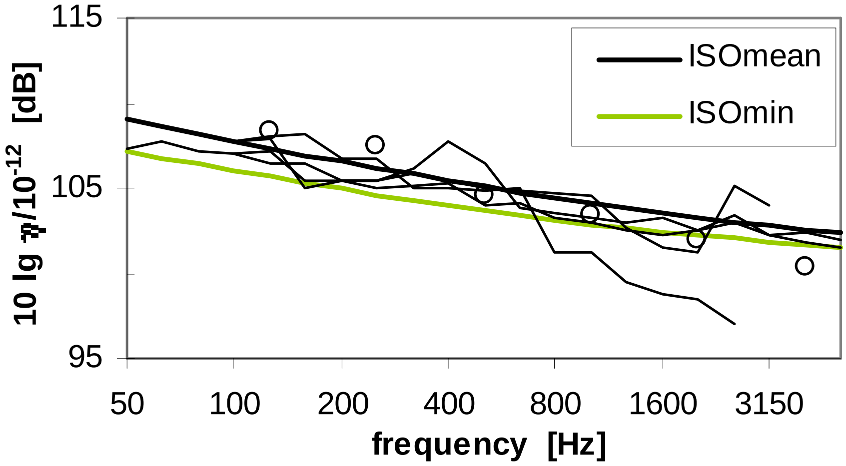

Figure 1: Available data in 1989 on the total loss factor in several laboratory facilities with heavy elements (400-500 kg/m^2), used to specify the required minimum loss factor in ISO 140-1.

This was a first attempt to reduce the variations for laboratory measurements, which should make R_{lab} more or less the product quantity that could be used in estimations of field performance.

PRESENT SITUATION

The required loss factor for laboratory facilities has not received much attention, maybe due to the fact that it is not easy to adjust a laboratory to a desired loss factor. However, the importance has now clearly been demonstrated by a German Round Robin [6]. In that context also the measurement method for the loss factor has been studied and well established [7]. Furthermore, the established prediction method actually requires the use of the total loss factor (structural reverberation time) in the laboratory and the field situation [8]. This would be simplified if the structural reverberation time in the laboratory situation would be measured and presented for all heavier elements. To simplify that presentation, it has been proposed to convert all measurement results to a reference structural reverberation time, being representative for a typical field situation [9]. The advantages would be that - at least for simplified prediction models - the converted sound reduction index could be used without any adjustment to the actual structural reverberation time. The obvious disadvantage is of course that a 'typical field situation' does not exist. The values proposed in [9] deviate for instance substantially from those mentioned by Craik [10] as 'typical field values'. Furthermore, converting the measurement results to a reference situation is not as straight forward as it seems. Some more problems need to be solved

FUTURE POSSIBILITIES

The aim of converting the measurement results for the sound reduction index in the laboratory to a fixed loss factor should not be to standardize to a typical field situation, but to convert to a standard laboratory facility. It would be advantageous if this could be done in a way that makes the transfer of the data to the field situation, according to EN 12354, simple and straightforward. But measuring the structural reverberation time in the laboratory is one thing, converting the measurement results in a correct and fair way to a reference laboratory is yet another. Some important aspects need to be considered:

(a) a relevant reference value for the loss factor in a standard laboratory (reference) is to be defined;
(b) the loss factor is only relevant for the resonant response of the element, while at low frequencies (below the critical frequency) also a forced response is occurs;
(c) converting data should relate to the laboratory influence only and not to internal losses of the elements.

Loss factor

As the reference loss factor η_{ref} the minimum loss factor for a 400 kg/m^2 element (wall or floor), as already specified in ISO 140-1 could be chosen, though choosing the corresponding average value would be more appropriate. However, to characterise the effect of a standard laboratory for various walls it is more realistic to express the reference loss factor as a function of the mass of the tested wall. With a fixed laboratory boundary the surface mass *m'* of the test wall determines the energy transmission at the borders. Corresponding to the existing requirements, using equation (1), the average loss factor could than be expressed as:

$$\eta_{ref} = \left(0{,}01 + \frac{m'}{800} \frac{1}{\sqrt{f}} \right) \qquad (2)$$

With the term 800 as a reference mass in kg/m^2 this is identical to eq. (1) with the reference wall of 400 kg/m^2. In EN 12354-1 an estimation of the total loss factor for the laboratory situation is given in the same way with a reference mass of 485 kg/m^2 in stead. That would thus indicate a laboratory at the upper boundary of the allowed variations according to the original intentions (see chapter history).

The actual loss factor η follows from the measured structural reverberation time T_s in each frequency band with mid frequency f by:

$$\eta_{ref} = \frac{2{,}2}{f T_s} \qquad (3)$$

Low frequency

In order to apply the loss factor conversion only to resonant transmission, the contribution of forced transmission at low frequencies should be subtracted before conversion and added again in the same way after conversion. This applies to the measured data around the critical frequency and below. The basis for this division shall be simple mass-law behaviour: it is easy to estimate, not critical in the frequency range and not critical in the exact value since it is first subtracted and then - after conversion - added again. Any effect leading to higher values than mass law behaviour at low frequencies should be left untouched by the procedure. The converted value R_c follows from the measured value R by equation (4):

$$R_c = -10 \lg \left[\tau_m + \frac{\eta}{\eta_{ref}} \left(10^{-R/10} - \tau_m \right) \right] \quad ; f \le 2 f_c$$
$$R_c = R - 10 \lg \frac{\eta}{\eta_{ref}} \quad ; f > 2 f_c \qquad (4)$$

The transmission coefficient τ_m for forced transmission (mass-law) is taken from EN 12354-1 annex B [8] as.

$$\tau_m = \left(\frac{2 \rho c}{2 \pi f m'} \right)^2 2 \sigma_f \; ; R_m = -10 \lg \tau_m \qquad (5)$$

This depends only on mass, frequency and the radiation efficiency σ_f for forced transmission, which depends only on frequency and dimensions. That last influence is not very large for common dimensions and materials as is illustrated in figure 2. Hence, the value for an element of 2,5 x 4 m^2 can be used in all laboratory cases. If below the critical frequency the measured R is larger than R_m no correction is to be applied.

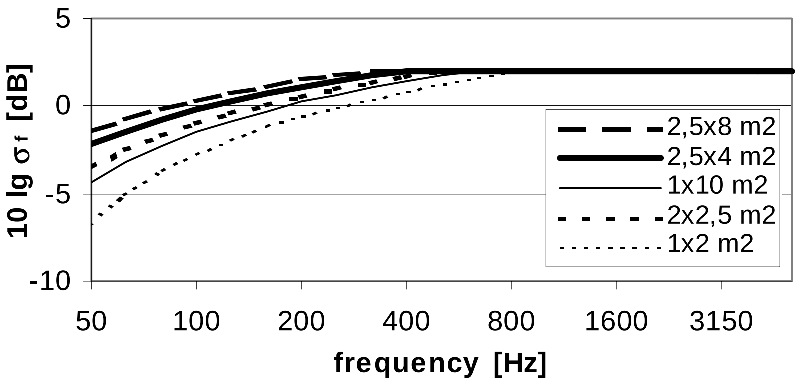

Figure 2: Radiation efficiency for forced transmission as given in EN 12354-1 annex B for various dimensions of an element.

Since the measured data around the critical frequency are much lower than the mass law result at these frequencies, it is not critical to which higher frequency the correction is applied. Thus a rough estimate of the critical frequency will do. Such an estimate can be deduced from the surface mass m' in kg/m^2 of the element by

$$f_c = 44000/m' \quad (4)$$

This opens the possibility of applying the procedure also for less heavy elements or even lightweight elements [11], making a general procedure easier to describe and apply.

The conversion has been applied to the data of the German Round-Robin [6]. In figure 3 the measured data are presented and the converted data for the whole frequency range as well as the conversion for the resonant transmission only. In [6] the conversion has also been presented for the whole frequency range, but with a different reference loss factor.

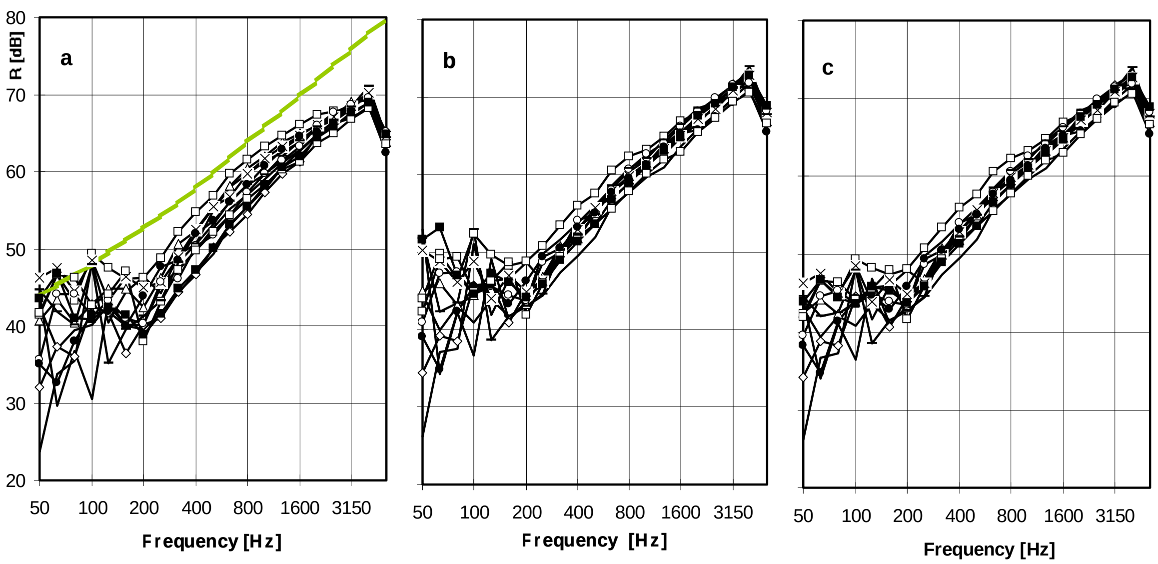

Figure 3: Sound reduction index from German Round-Robin [6] with a 440 kg/m^2 wall; (a) as measured with mass-law curve indicated, (b) converted to reference loss factor for whole frequency range and (c) converted with mass-law correction.

It is clear that with the conversions according to equations (4) and (5), the converted data show about the same variation at low frequencies as at higher frequencies, while without the mass-law correction (figure 3b) the variation is larger. Furthermore, in figure 3b the values at low frequencies are generally higher than measured, even exceeding mass-law values, while that is hardly the case in figure 3c.

The measured and converted values from figure 3 have also been expressed in the single number rating R_w, together with the results for some other walls. That single number rating, from the measured and the converted curves, is shown in figure 4 as function of the surface mass. Also shown is the curve from EN 12354-1, annex B. This clearly shows that the conversion reduces the variation and improves the comparison with the theoretical curve.

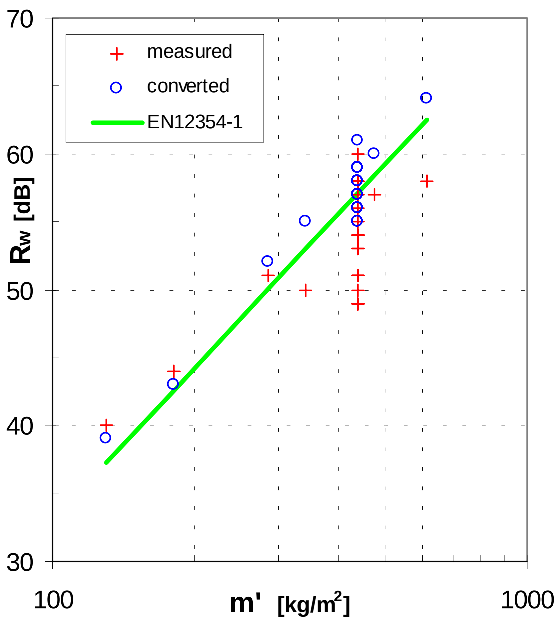

Figure 4: Weighted sound reduction index R_w for various walls as function of surface mass, as measured and as converted; comparison with curve from EN 12354-1.

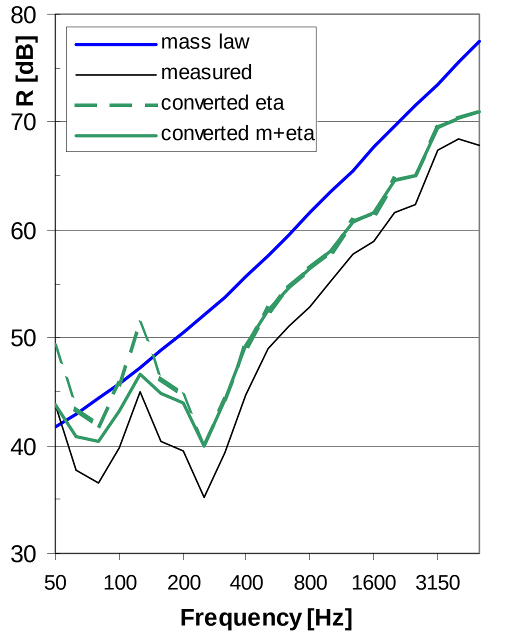

Figure 5 Sound reduction index for a 340 kg/m^2 wall as measured, converted (eta, only loss factor) and converted with mass-law correction (m+eta).

In figure 5 an illustration is given for the insulation curve of one of these walls, showing the measured curve, the calculated mass-law curve and the converted curves. The loss factor conversion is rather substantial in this case, but applying it to the whole frequency range gives rather high results at the low frequencies exceeding even mass-law values. Taking due account of the forced transmission at low frequencies clearly gives more logical converted results. This will of course be even more important for even lighter elements with a much higher critical frequency.

Internal loss

The internal loss factor is a property of the material or the element used. If it is known the reference loss factor should use that value η_{int} instead of the fixed value $\eta_{int} = 0{,}01$ in eq. (2). Possibly a method could be specified to deduce an estimate of η_{int} from the measured total loss factor. That could for instance be the average at the higher frequency bands. The feasibility of such an approach should be studied.

Other causes for a different behaviour at mid and high frequencies than different values for the internal loss factor, could maybe be taken into account in the same way. For instance a wall with hollow elements could show effectively a higher internal loss factor in the measurements. If such a high internal loss factor is taken into account in the conversion procedure, than this will result in converted values that will hardly deviate from the directly measured values. The total loss factor is dominated in this case by the high internal loss factor, the second term in eq. (2) being much smaller at the higher frequencies. So actually no correction is applied in that frequency range, which is what we want in this case were the behaviour of the wall is determined by the elements itself and not by the borders of the laboratory.

CONCLUSIONS

Now that the measurement of structural reverberation time can be performed in a reliable way, it seems useful and possible to convert laboratory measurements of the sound reduction index of more or less heavy, homogeneous walls or floors into results for a standard laboratory situation. The procedure to do so correctly for the entire frequency range is rather simple and straightforward and does not require additional measurements.

In doing this the laboratory results for heavy walls are more invariant and can more easily be transferred to relevant field situations, specific or as global average. If the conversion is well specified in this way, it can be easily used in the reverse way: subtract forced transmission as sued here from the converted measurement results. In that way the sound reduction index for only resonant transmission is derived, as actually required for estimations by EN 12354.

It might well be that this procedure is applicable for a wider range of products and elements, provided the (effective) internal loss factor can be deduced from the performed measurements of the structural reverberation time.

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