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Determination of airborne sound insulation by reference curve method. Are reference curves still useful in the context of new building materials?

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***Abstract*—For the description of airborne sound insulation, a frequency-dependent sound insulation standard *R* (dB) is generally used. It is defined by the logarithmic ratio of the sound output on one side of a component to the sound power emitted on the other side. To get a practical measure a single value is generated from the frequency course of the sound insulation, the so-called sound insulation standard R_w or R'_w. The reference curve has the idealized course of the sound insulation dimension of a full brick wall 25 cm thick. The measured sound insulation measure is then the value of the shifted reference curve at 500 Hz. This reference method was established in the 50th based on heavy materials and heavy constructions. Nowadays, however, due to thermal demand of the building, materials and constructions are getting lighter and more complicated, i.e. compound martials. Also, the single number value of a construction is the same the subjective impression is not. This is due to the method of how the individual number evaluation is performed This paper discusses the method of obtaining a single number quantity in conjunction with new materials.**

Keywords—Airborne sound insulation, reference curve, single number rating

I. THE STANDARD PROCEDURE

The procedure for evaluating single-number quantities for airborne sound is described in ISO 717-1 [1]. This is a well-known procedure, but it was established long before newly invented materials and constructions were available on the market. In Figure 1 the reference curve is shown for airborne sound at octave bands.

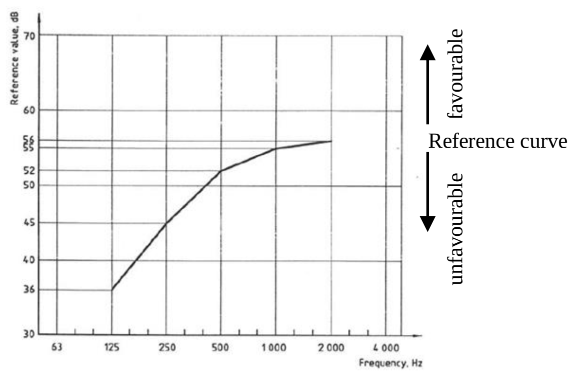

Fig. 1. Curve of reference values for airborene sound at octave bands

The evaluating procedure of ISO 717-1 is a summary of the measured frequency spectrum in a single quantity. This is a simplification of calculations by reducing the amount of data. The problems are, however:

- Low frequencies below 100 Hz remain unconsidered
- Tailored to common noises
- Correlates little with subjective evaluation
- No more state of the art (over 60 years old)

Already at the beginning of the studies on reference curves it was recognized that the mid frequency range is most critical concerning subjective regards [2]. Fasold [2] presented the most effective sound insulation curve and its idealization, which is shown in Figure 2 compared to the standard reference curve.

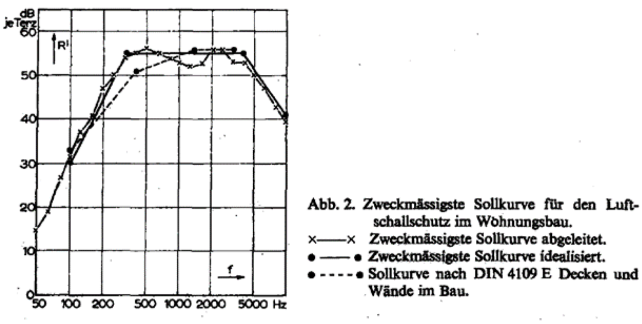

Fig. 2. Most appropriate reference curve for the airborne sound insulation in housing. Copy of the original graph, taken from [2].

The most important result of Figure 2 is the exceeding of the most appropriate reference curve in the frequency range from 200 Hz to 800 Hz of the standard reference curve. That means, stringent noise protection requirements have to be set here if a uniform sound insulation is to be achieved throughout the frequency range of interest. Fasold stated in [2]: "*One could accept the reference curve and its course in the mid frequency range as a necessary concession of the cost-effectiveness of the effort*". This statement shows that from the very beginning, it was well known that the use of a reference curve will lead to some complaints, but this has been accepted for economic reasons. In more recent times, however, the complaints become more frequent and the question arises whether a different rating than a reference curve would be useful.

II. REMEDYING THE SHORTCOMINGS OF THE STANDARD PROCEDURE

There have been several attempts to overcome the difficulties of a single number rating. In 2012, a replacement for ISO 717-1, designated as ISO 16717-1 [3] was proposed. It contains changes to the frequency range included in the single-number ratings. However, no evaluation has been introduced into the proposed new standard that classifies hearing sensation [4]. Due to resistance from some countries, this proposal was withdrawn by ISO in 2014. Another attempt to improve at least statistically, was presented in [5] and established a modified reference curve based on the "best fit" correlation between objective and subjective judgment of airborne sound insulation. A short review is given in [6] and has revealed that the results from these investigations may actually be different judged. Particularly if music with bass is accepted as a relevant sound source in relation to dwellings, single number quantities generated with a reverence curve is not a suitable procedure to judge the airborne sound insulation correctly. And it has been known since long time that speech and music will need to be evaluated with different rating system [6].

After all attempts to establish a new single number quantity, it remained what was already in practice, namely the spectrum adaptation terms.

A. *Spectrum Adaptation Term*

Based on the demand to have a better sound insulation in subjective regards, it is necessary to have an extended frequency range from 100 Hz down to 50 Hz [7]. While in the standard procedures to describe sound insulation, such as in ISO 717-1, the weighting curves do not consider frequencies below 100 Hz, in the standard there is a spectral adaptation term which is used to cover the frequency down to 50 Hz. The spectrum adaptation term C and C_{tr} denote a value according to ISO 717-1, in decibels, which is to be added to the single number quantity (e.g. R_w) in order to consider a specific sound spectrum while the full extended frequency range is from 50 Hz up to 5000 Hz. That is, the single number value is replaced by the sum of the single number value and the spectrum adaptation term, e.g. $R_w + C_{tr,50\text{-}5000}$ instead of R_w for example. The complete specification of the sound insulation of a component, e.g. a window, is according to ISO 717-1. R_w (C; C_{tr}) = 40 (-2;-5) dB. The process of assessing sound insulation with spectra is common in eight European countries (e.g. England & Wales, France, Hungary, Netherlands, Spain and Poland) [8,9]. Requirements for C or C_{tr} are currently not being used in Germany.

B. *Value Range for $C_{tr,\ 50\text{-}5000}$*

A rough summary for different constructions shows the subsequent range of the value of $C_{tr,\ 50\text{-}5000}$.

- Solid walls: -7 dB to -2 dB
- Lightweight walls: -20 dB to -10 dB
- Windows: -11 dB to -3 dB

Rindel showed in [10] that the spectrum adaptation terms in ISO 717 with extended frequency range down to 50 Hz mean a significantly better correlation between subjective and objective evaluation of sound insulation.

III. Example of New Material

Due to thermal demand of the building, materials and constructions are getting lighter and more complicated. The most used material providing acoustic problems are brick and lightweight constructions like timber frame walls. An example is given in Figure 3 showing a thermal optimized brick. This kind of brick is used to build the outer wall, usually plastered on both sides. The typical thicknesses of a thermal optimized brick used in Germany for houses are 365 mm and 425 mm. Other examples found in European countries for improved sound insulation are presented and discussed in detail in [9.11]. This includes, among other things, prefabricated components, beam and block constructions as well as in-situ composite materials.

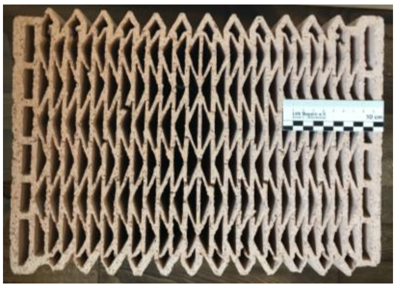

Fig. 3. Example of a thermal optimized brick, the thermal conductivity is 0.08 W/(mK) and the density class is 0.65, $R_{w,\ Bau,\ ref}$ = 48 dB

Frequently built wall constructions as well as floor constructions in today's housing sector vary considerably in European countries. Examples of lightweight timber frame constructions are shown in Figure 4.

Fig. 4. Examples of timber and lightweight frame wall and floor structures found in European countries, taken from [9].

IV. Airborne Sound Insulation

In buildings, the internationally standardised method to measure the airborne sound insulation in-situ is provided in ISO 16283-1 [12]. This standard specifies procedures to measure the airborne sound insulation between rooms in a building using sound pressure measurements. The sound insulation is assessed in terms of the apparent sound reduction index R' or the standardised level difference D_{nT}, and the results are weighted and expressed as a single-number quantity, e.g., R'_w, respectively, $D_{nT,w}$, in accordance with ISO 717-1. The primed symbol of the apparent sound reduction index indicates a value obtained in the presence of flanking transmission.

In Figure 5, a typical frequency depending sound insulation is shown measured in-situ with flanking transmission of a thermal insulation brick according to ISO 16283-1. It is seen that at mid frequencies a large frequency dip occurs. This frequency dip is very usual for that kind of "light" and thick brick and, this frequency dip or plateau is the reason for the increasingly emerging cases of complaints.

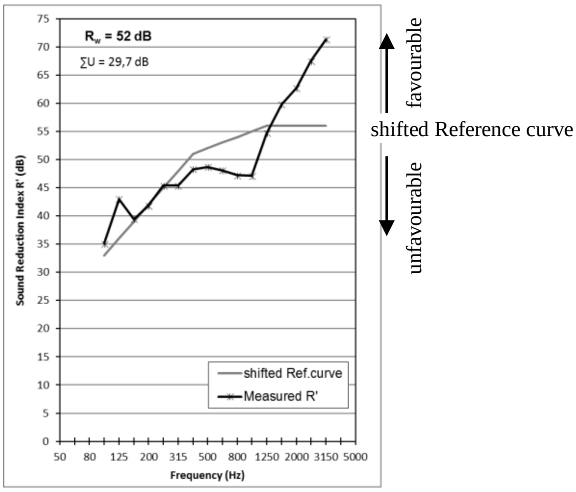

Fig. 5. Measured apparent sound reduction index of R'_w = 52 dB of a ceiling (180 mm concrete floating floor with floating cement screed on tread insulation) between two rooms showing at mid frequencies a dip leading to complaints between residents. The outer walls were 365 mm thermal brick.

Similar behaviour of the frequency depending airborne sound insulation occur for new developed constructions like highly effective thermal isolated windows, new and modern façade constructions, etc. Up-to-date are insulating glass combination for sound protection and thermal insulation. This leads to triple-glazed windows. In Figure 6 computed results of two types of glazing are shown.

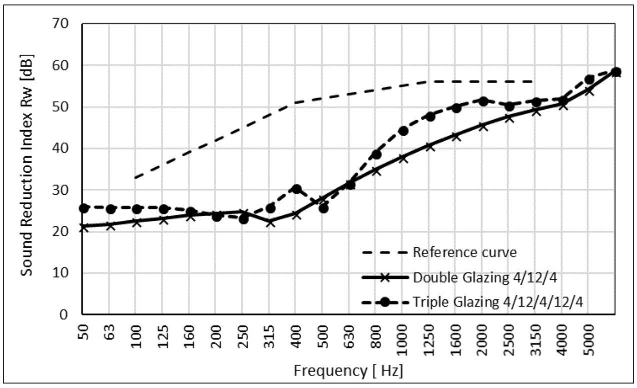

Fig. 6. Example of a double-glazed window 4/12/4, R_w = 36 (-1; -5) dB and a triple-glazed window 4/12/4/12/4, R_w = 38 (-2; -5) dB

It is shown in Figure 6 that the calculated mass-air-mass resonance frequency f_0 of the double glazing also occurs for the triple glazing. Both the double and triple glazing thus have a pronounced dip in sound insulation at this frequency. From Figure 5 it is seen that similar to Figure 6 less damping is observed at mid frequencies. This mid frequency is however a very sensitive frequency range in concern of the procedure with the reverence curve to compute the single number quantity.

The effects of the selection of certain single quantity values compared to those previously used, which are mainly caused by the inclusion of frequencies below 100 Hz, have already been extensively investigated [6,7,13,14,15,16,17].

It seems that the problem lies in the method itself. In Figure 7, some curious frequency sequences of sound insulation are compared which all have the same *R*-value and the same sum of unfavourable deviation.

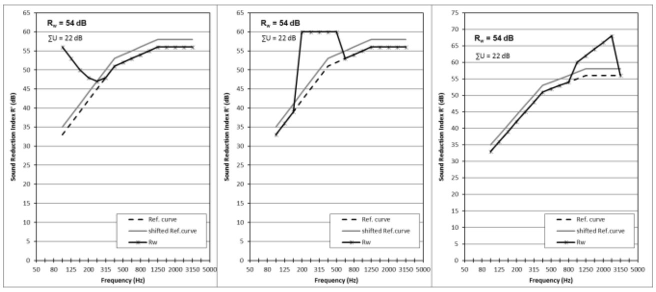

Fig. 7. Example of three cases, all having R_w = 54 dB and the sum of unfavourable difference of 22 dB computed according to ISO 717-1.

It is seen in Figure 7 that at a certain frequency range, i.e. at low, mid and high frequencies no effect on the *R*-value is observed. If this kind of airborne sound insulation had to be judged subjectively, there would be a significant difference. This is one of the main problems of the method obtaining a single quantity value that there is little match with a subjective judgement. In [18] a study was presented showing that a frequency dip in the airborne sound insulation can be pictured using psychoacoustic measures. It was shown in that study that the psychoacoustic measures are most influenced by a frequency dip at mid and high frequencies. In addition, as shown in [19,20], sound insulation is judged differently for different sound samples, so that an objective measure of efficacy is dependent on the type of sound signal. These studies support findings in the literature that airborne sound insulation performance is significantly dependent on what type of sound signal is used. A simple level difference is shown not to exhibit the effects of a given signal to the frequency-dependent airborne sound insulation curve. As a result, psychoacoustic measures may help to improve the description of airborne sound insulation, more related to subjective impression. However, there is no consistency in both the single number rating scheme as well as in the psychoacoustic ratings.

V. Summary

There is a long history trying to improve the reverence curve for the airborne sound insulation. All attempts use however, a similar or almost similar concept or rating scheme. It seems that all established and investigated rating schemes with one or two numbers do not fit well to reflect the subjective impression of a required airborne sound insulation. One reason might be the complexity of the human ear. It is simply not possible to assess all the impressions that arise during a hearing sensation with one or two numbers.

It would be desirable if the ongoing investigations may inspire research for assessing limitations and potential improvements of subjective related airborne sound insulation rating methods based on a single number rating scheme and psychoacoustic measures.

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