# SOUND INSULATION OF HOMOGENEOUS SINGLE PANELS: A COMPARISON BETWEEN REAL CONSTRUCTION MATERIALS AND SEVERAL PREDICTION MODELS

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Sound insulation due to single panel walls has been studied since the 1940's. Several models have been developed using wave based methods, statistical energy analysis, and electro-acoustic analogies. The differences between the models include the way the incident field or the properties of the wall are considered. Most of them have already been validated separately with real construction elements. In this work, various models are reviewed and compared with measurements done according to the ISO 140-3 standard. They are classified into two groups based on heavy and lightweight materials. Several global parameters, such as the weighted sound reduction index Rw(C, Ctr), are examined. Results show that the deviation of each third octave band from 100 to 5000 Hz is more relevant than the global parameter values, and must be taken into account for a correct approximation of the panel insulation. The Sharp model shows the best fit with the selected measurements.

Keywords: building acoustics, simple wall, insulation prediction, models comparison

## 1. Introduction

The transmission of sound through a building element is a complex phenomenon. The mass per square meter $m$, Young's modulus $E$, the internal loss factor $\eta$, and the sound frequency $f$ are the most relevant variables to be considered, but sound insulation also depends on the angle of incidence of the wave and the existence of inhomogeneities in the building element. In a real structure, internal changes in the rigidity or damping, the flanking transmission with the surrounding elements, and the interaction between the panel and the adjacent room also affect sound transmission.

Jäeger [1], Lord Rayleigh [2], Berger [3], and Wintergerst [4] were the first researchers who studied the sound insulation problem. The first models to evaluate the sound insulation properties of a single panel were simplified analytical approaches that do not take into account the considerations mentioned previously and are based on wave theory. Cremer's model [5] of 1942 already considered that the behaviour of an infinite single panel differs above, below, and in the proximity of the coincidence frequency of the structure. This model was later revised and other factors were taken into account. London [6] evaluated the influence of the angle of wave incidence. The "Mass Law model" of thick walls was improved and a correction factor for low frequencies was included [7, 8]. In 1973 Sharp [9] showed there was a good agreement between prediction and measurements below the critical frequency using a limiting incidence angle equal to about 78º, instead of considering all incidence angles. This empirical correction assumed that the sound field in a reverberation chamber is not totally diffuse. Sharp's model [10] of 1978 showed an improved prediction procedure with this limited incidence angle correction. Tadeu and António [11] introduced the coupling effect between a single panel bounded by two fluid media. The previous models only considered infinite structures that make possible an analytical calculation [12]. A simple improved model for finite panels was then proposed by

Davy for diffuse field incidence [13]. He extended Cremer's model, particularly below the critical frequency [14].

Statistical energy analysis (SEA) can be used to take into account the interaction between the panel and the adjacent elements. It was first used by Crocker and Price [15], and later refined by Brekke [16] and Craik [17]. The vibrations of the panel were considered using a modal approach by Josse and Lamure [18], Sewell [19], and Nilsson [20]. Another model proposed by Arau [21] applied electro-acoustic analogies to study the behaviour of a single wall using Cremer's impedances. A combination of different calculation methods is described and used in ISO 12354-1 [22].

These models show a good correlation with some measurements, but the authors of this study could not find a comparison among all of them on a same panel. In this paper, sound insulation measurements of homogeneous single walls performed according to the ISO 140-3 [23] standard are selected. The theoretical insulation is computed using nine different models in third octave bands from 100 to 5000 Hz. The results are compared with the global parameters described in the ISO 717-1 [24]. The aim of this study is to evaluate which models give better sound transmission loss estimations for a future implementation in sound insulation software.

## 2. Procedure

The selected prediction models are listed in Table 1. They were compared with laboratory measurements coming from different databases [25-27]. All the measurements comply with the ISO 140-3 specifications [23].

Table 1: Models used for the comparison.

| ***Author*** | ***Year*** | ***Physical Model Description*** |
|---|---|---|
| Cremer L. | 1942 | Plane wave – Diffuse Field Incidence 0< θ < 90° |
| London A. | 1949 | Plane wave – Diffuse Field Incidence 0< θ < 90° |
| Josse R. y Lamure C. | 1964 | Ondulatory analysis |
| Nilsson A. C. | 1972 | Ondulatory analysis |
| Brekke A. | 1981 | SEA |
| Sharp B. | 1978 | Plane Wave - Diffuse field incidence limited to 0<θ<78° |
| Davy J. L. | 2009 | Plane Wave -Diffuse Field Incidence limited to angles as a panel size function |
| Arau H. | 1982 | Electro-acoustic analogies |
| ISO 12354-1 | 2000 | Combination of models |

The way the critical frequency is taken into account by the models gives different Transmission Loss (TL) estimations. This critical frequency is defined by:

$$f_c = \frac{c_0^2}{2\pi}\sqrt{\frac{m}{B}} \tag{1}$$

where $c_0$ is the speed of sound in air, m the mass per square meter, and B is the panel's stiffness to bending, defined by:

$$B = \frac{Eh^3}{[12(1-\upsilon^2)]} \tag{2}$$

where E is the Young modulus, h is the panel thickness and υ is the Poisson ratio.

The internal loss factor was calculated considering laboratory condition [22, 28]:

$$\eta_{tot,lab} \approx \eta_{\text{int}} + \frac{m}{485\sqrt{f}} \tag{3}$$

In total four materials with different thickness were used for the comparison. Only the materials having laboratory measurements of Transmission Loss (TL) in third octave bands have been selected. These materials and their respective characteristics are shown in Table 2. A total of 23 measurements were used.

Table 2: Physical characteristics of the studied materials.

| *Material* | *Thickness [mm]* | *Density [Kg/m$^3$]* | *Young's modulus [N/m$^2$]* | *Poisson coefficient* | *Internal loss factor* |
|---|---|---|---|---|---|
| Concrete | 50.8; 101.6; 140; 160 (x2); 180; 200; 220; 240 | 2400 | 3 e10 | 0.2 | 0.05 |
| Glass | 3; 4; 6; 8; 10; 12; 19 | 2500 | 6.8 e10 | 0.23 | 0.05 |
| Gypsum | 6.35; 9.525; 12.7; 15.875 | 800 | 2 e9 | 0.24 | 0.006 |
| wood | 3.175; 6.35; 12.7 | 650 | 1.2 e10 | 0.15 | 0.01 |

## 3. Results

Figures 1 to 4 compare the TL calculated from the prediction models with the laboratory measurements. For each material just one thickness has been selected. These comparisons show differences mostly around the critical frequency.

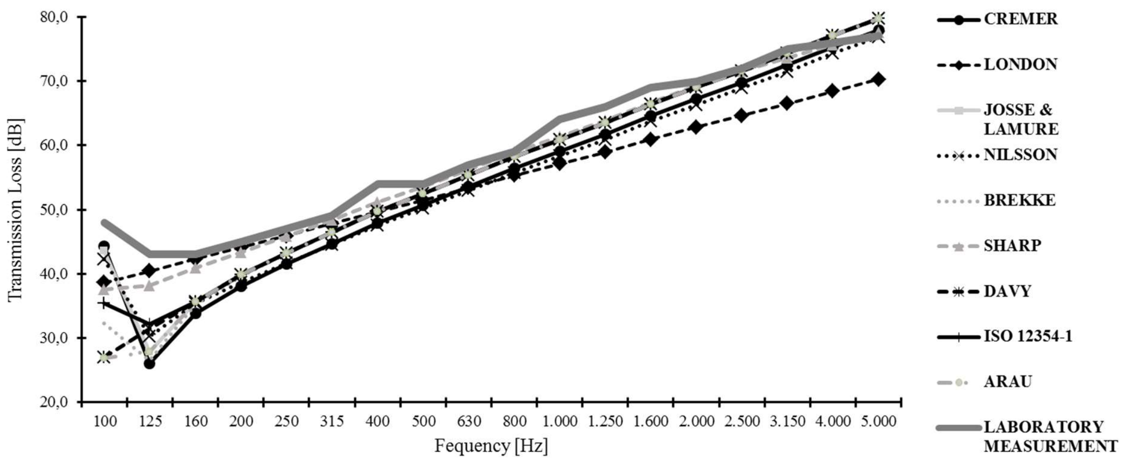


Figure 1: TL comparison for concrete of 160 mm.

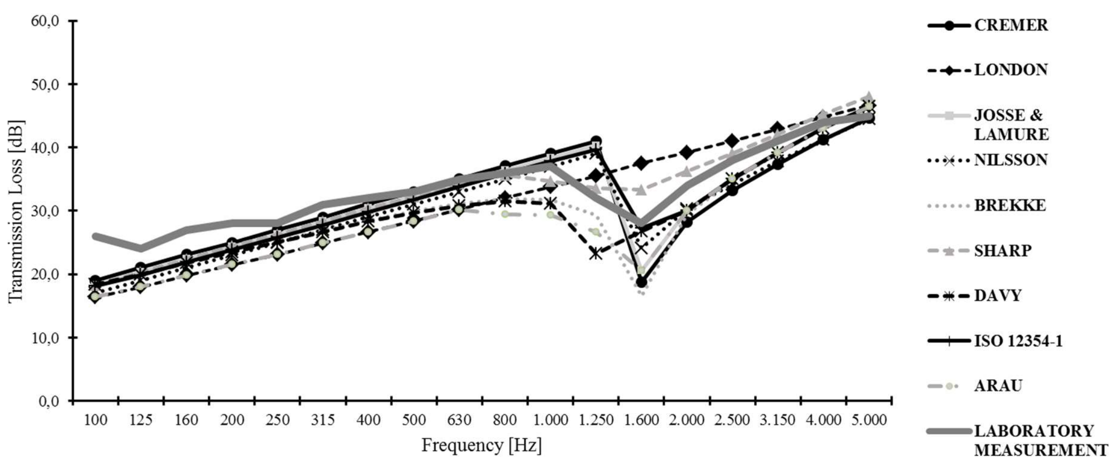


Figure 2: TL comparison for glass of 8 mm.

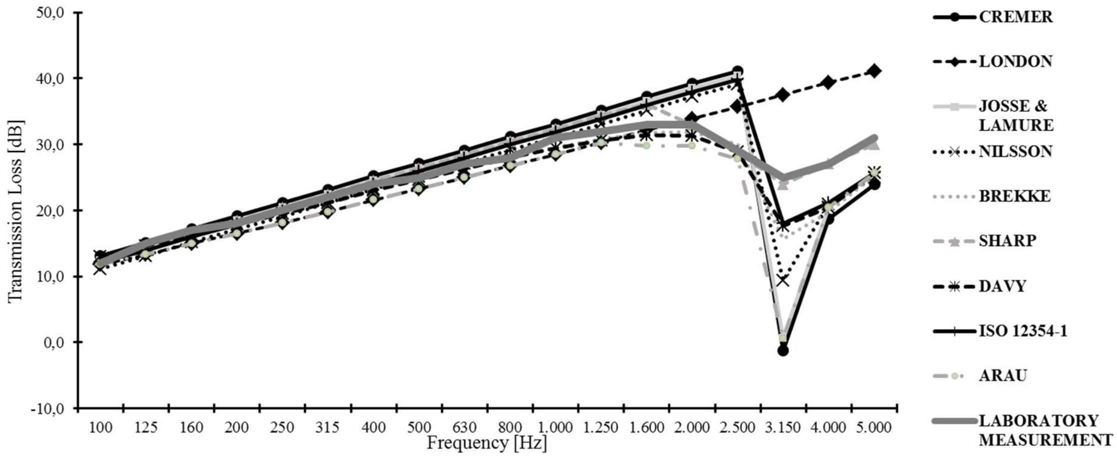


Figure 3: TL comparison for gypsum of 12.7 mm.

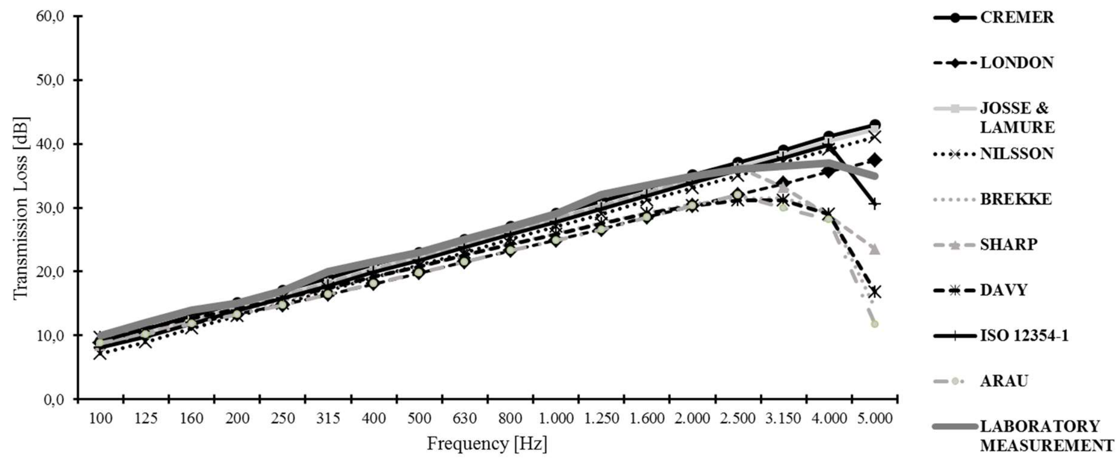


Figure 4: TL comparison for wood of 6.35 mm.

Absolute differences of TL were calculated between the laboratory measurements and each model.

The materials were divided into two groups: heavy (concrete) and lightweight (glass, gypsum, wood). Figures 5 and 6 show the mean of the absolute differences between each model and measurements for each group of materials in third octave bands. All the thicknesses listed in Table 2 have been used for this comparison. In total 9 and 14 measurements have been used for Figs. 5 and 6, respectively.

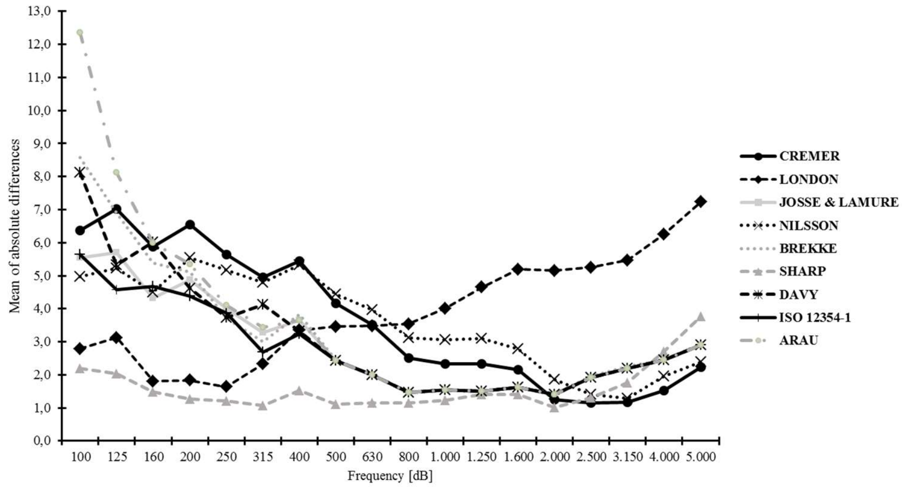


Figure 5: Mean of absolute differences between each model and measurements for heavy materials.

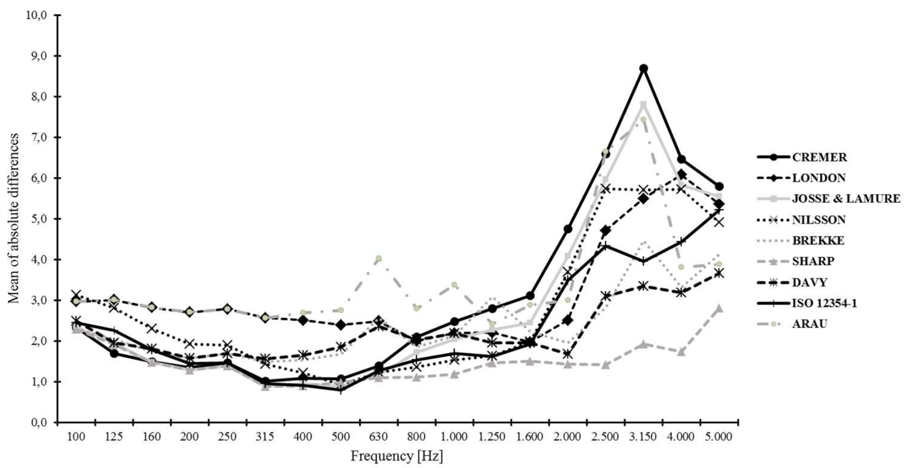


Figure 6: Mean of absolute differences between each model and measurements for light materials.

For both heavy and lightweight materials the Sharp model shows the lowest values of absolute differences with the measurements. The ISO 12354-1, the Brekke, and the Davy models also show a good correlation with measurement, with higher error near the critical frequency. All the other models have worst prediction. In particular, the Arau model is shows the highest values of absolute differences.

Weighted sound reduction Rw and the spectral adaptation terms C and Ctr were then calculated in accordance with the ISO 717-1 standard. These parameters have been selected because they are commonly used in building acoustics to describe the TL of a partition with a single number descriptor. Mean and deviation of absolute differences were evaluated to determine which model is closer to real measurements. Figures 7 and 8 show the mean and the deviation of absolute differences between each global parameter and the measurement data. A global frequency parameter is also shown. It corresponds to the mean of absolute differences between 100 and 5000 Hz.

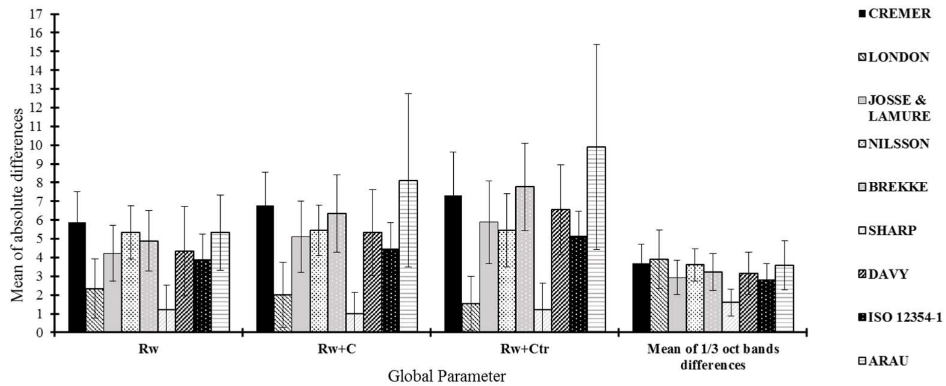


Figure 7: Mean of absolute differences and deviation for each global parameter in the case of heavy materials.

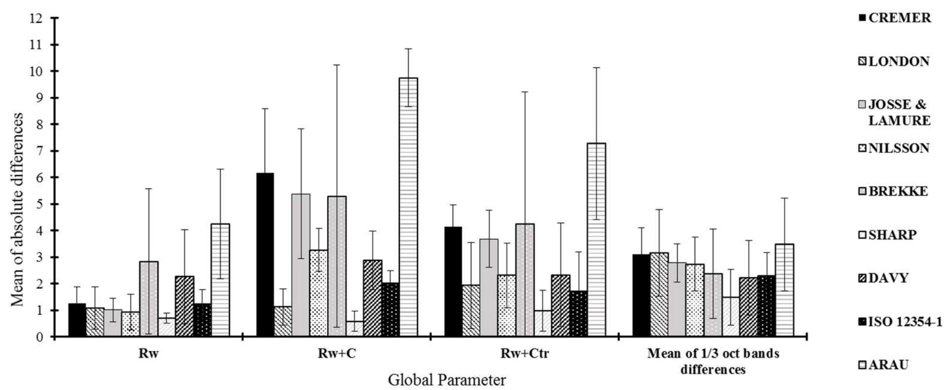


Figure 8: Mean of absolute differences and deviation for each global parameter in the case of light materials.

From Figs. 7 and 8 it can be concluded that Sharp's model is in better agreement with real measurements of heavy and lightweight partitions. This model has the lowest mean of absolute differences with low deviations. The Arau model shows the highest differences, probably because the TL difference around the critical frequency. Small variations among the models can be noticed in the Rw and the mean of third octave band differences parameters. From these global parameters the London model seems to give a good estimation of real measurements. However, the mean of absolute differences of Figs. 5 and 6 and results plotted in Figs. 1 to 4 show that this model does not correctly estimate the TL of a measured material. In the case of the London model, the "Mass Law" was considered in the whole range of frequencies.

## 4. Discussion

The physical parameters used in the investigation (mass for square unit, Young modulus, internal loss factor and Poisson ratio) have been estimated from standard values. The laboratory acoustic measurements do not always inform these values for the measured panels. All the prediction models, unless the Davy model, consider an ideal situation with infinite, homogeneous and isotropic materials, while in laboratory measurements, materials have finite dimensions.

The highest differences among the measurements and the models occur near the critical frequency. The internal loss factor, generally unknown for these materials because it depends on the frequency, and the inhomogeneity of the panels are the principal causes of these differences.

More measurements should be used to confirm these initial results.

## 5. Conclusions

A comparison between several prediction models and real measurements of simple homogeneous and isotropic panels has been investigated. The results of the models were compared using different materials, and taking into account heavy and lightweight materials commonly used in real constructions. The analysis considered the third octave band TL values between 100 and 5000 Hz and several frequently used global descriptors.

A good approximation of the TL in the mass law frequency range is observed for most of the models far from the critical frequency. From all the selected models, the Sharp approach shows the best approximation of the measured panels.

Future works will continue this investigation adding more simple panels. The same study should be performed for double walls.

## 6. Acknowledgements

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