# Sound Reduction Index of Clay Hollow Brick Walls

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## Abstract

This paper investigates the sound insulation properties of clay hollow brick walls with low void fraction, horizontal/vertical mortar joint and plaster finishing. Methods based on homogeneous walls (Sharp theory and ISO 12354 procedure) are evaluated. A reference curve obtained as the mean of normalised sound reduction index curves measured in laboratory on real brick walls is proposed and its suitability for sound insulation estimations is discussed.

## 1. Introduction

The use of clay hollow brick walls is widespread in the building construction sector, especially in southern Europe, due to the availability of raw material, consolidated production capacity and its high thermal and acoustic performance. Thanks to their large mass per unit area, such elements are particularly suitable for limiting low frequency noise, the importance of which has been pointed out by Caniato et al. (2015-2020).

There are different types of blocks on the market, the differences being related to composition, dimensions, geometry and void fraction, mass per unit area, and the fact that the blocks can be laid with or without a vertical mortar joint. In ISO 12354-1 (International Organization for Standardization, 2017), there are several semi-empirical correlations describing the sound insulation performances of some walls, but they are mostly dedicated to the derivation of the single weighted sound reduction index, $R_w$. In this standard, the sound reduction index $R$ in one-third octave bands is defined only for homogeneous walls (ISO 12354-1 annex B). Nevertheless, a sound reduction index is necessary when a detailed prediction model of the in-situ sound transmission according to the ISO 12354-1 standard is required.

The analysis of the sound reduction index in one-third octave bands could in principle be performed analytically, but this is not an easy task due to the difficulties in modelling the geometry of the block, the laying technique and the non-isotropic behaviour of the structure. All of these aspects may strongly influence the sound reduction index of the wall, as shown in the work of Fringuellino and Smith (1999). The types of blocks meant for a building envelope are developed so as to provide good thermal and acoustic properties, and their optimisation is a complex problem that cannot be solved by simple comparisons which aim to match the best values chosen among a selection of parameters based on the material properties (Di Bella et al., 2015). Di Bella et al. (2014) found that, in general, the increase in sound insulation is not directly dependent on the thermal insulation performance.

Several studies can be found in the literature on the sound reduction index of hollow brick walls. For example, Del Coz Díaz et al. (2010) investigated the insulation properties of a multilayer concrete hollow brick wall by Finite Element Method (FEM), while Jacqus et al. (2010) showed how mass law does not properly represent the acoustic behaviour of the walls examined, and used a homogenisation technique to model the element as an orthotropic block with equivalent sound insulation properties.

Semi-empirical models based on vibrational tests can be used to obtain reliable predictions. Piana, Milani and Granzotto (2014) used a method based on the measurement of natural frequencies of beam samples to determine the sound insulation characteristics of gypsum panels; a similar technique was

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Pernigotto, G., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). (2020). Building simulation applications BSA 2019. bu,press. https://doi.org/10.13124/9788860461766

applied by Fortini, Granzotto and Piana (2019) on multilayer panels for the shipbuilding industry featuring an innovative foam core; Piana, Granzotto and Di Bella (2017) compared the predictions obtained using a method based on the determination of the natural frequencies of a specimen with mobility measurements performed on drywall panels; finally, Ruggeri et al. (2015) determined the loss factor of multilayer glazing panels using the procedure outlined in ISO 6721-3 standard.

This paper investigates the sound insulation properties of different types of clay hollow brick walls. Methods based on Sharp's (1973) homogenous walls theory and ISO 12354-1 procedure are evaluated. The procedure proposed by Di Bella et al. (2016, 2018), who obtained reference curves of walls and floors made of cross laminated timber based on experimental measurements, is used to define a reference curve as the mean of normalised sound reduction index curves measured in laboratory on real brick walls. The applicability of this curve to actual sound insulation estimations is discussed.

## 2. Experimental Analysis

### 2.1 Sound Reduction Index

The transmission coefficient $\tau$ is defined as the ratio between the transmitted power and the incident power on a wall:

$$\tau = W_{\text{transmitted}} / W_{\text{incident}} \tag{1}$$

The sound reduction index, $R$, is defined as

$$R = 10 \log_{10} (1/\tau) \tag{2}$$

The sound reduction index $R$ can be measured in the laboratory through a procedure requiring that a diffuse sound field is established in two adjacent rooms (Fig. 1). Through measurements of the sound pressure level and the sound absorption characteristics of the receiving room, the sound reduction index $R$ can be determined as

$$R = L_1 - L_2 + 10 \log_{10} (S / A) \tag{3}$$

The equivalent absorption area $A$ can be determined experimentally as

$$A = 0.16 \, (V / T) \tag{4}$$

with $T$ reverberation time of the receiving room.

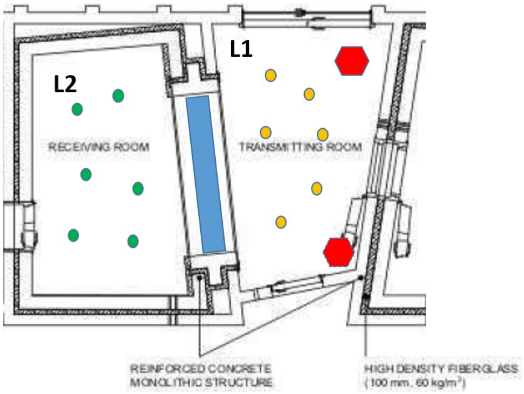

Fig. 1 – Acoustic laboratory at Padova University

### 2.2 Analysed Types of Hollow Brick Walls

The sound reduction index $R_k$ of seven different types of clay hollow brick walls with vertical and horizontal mortar joints were investigated (subscript '$k$' indicates the specific wall type). Sound insulation measurements were carried out in the laboratory, according to the ISO 10140 series (ISO, 2010a, 2010b, 2010c, 2016). The mass per unit area $m'$ of the plastered walls was 305–377 kg/m², the thickness $t$ was 206–330 mm and the void fraction was 37–55% (Table 1).

Table 1 – Characteristics of the walls

| Type | Thickness [mm] | Mass per unit area [kg/m²] | Void fraction [%] |
|---|---|---|---|
| A | 280 | 330 | 44 |
| B | 206 | 321 | 37 |
| C | 240 | 305 | 53 |
| D | 280 | 343 | 55 |
| E | 270 | 359 | 45 |
| F | 280 | 327 | 45 |
| G | 330 | 377 | 45 |

An example of installation for a brick wall during the tests performed in sound transmission rooms is given in Fig. 2 and Fig. 3.

Fig. 2 – Clay hollow brick with horizontal and vertical mortal joints mounted in laboratory

Fig. 3 – Wall mounted in the laboratory

Young's modulus for the different walls, $E$, can be derived by applying the following equation (Italian Ministry of Infrastructure and Transport, 2018):

$$E = 1000\, f_k \tag{5}$$

where the compressive strength of $k$-th type wall, $f_k$, is calculated with an M5 mortar type according to the declared compressive strength of the block, $f_{bk}$. Table 2 shows the values of the compressive strength and the resulting $E$ modulus.

Fig. 4 gives the sound reduction index curves and the resulting weighted sound reduction index values $R_w$ after the laboratory tests were computed according to ISO 717-1 standard (International Organization for Standardization, 2013). The resulting $R_w$ values are in a range between 51 and 54 dB.

Table 2 – Compressive strength of the blocks, compressive strength of the wall and Young's modulus of the walls

| Type | $f_{bk}$ [MPa] | $f_k$ [MPa] | $E$ [GPa] |
|---|---|---|---|
| A | 10.0 | 4.70 | 4.70 |
| B | 10.0 | 4.70 | 4.70 |
| C | 10.0 | 4.45 | 4.45 |
| D | 10.0 | 4.51 | 4.51 |
| E | 10.0 | 4.70 | 4.70 |
| F | 10.2 | 4.75 | 4.75 |
| G | 10.4 | 4.80 | 4.80 |

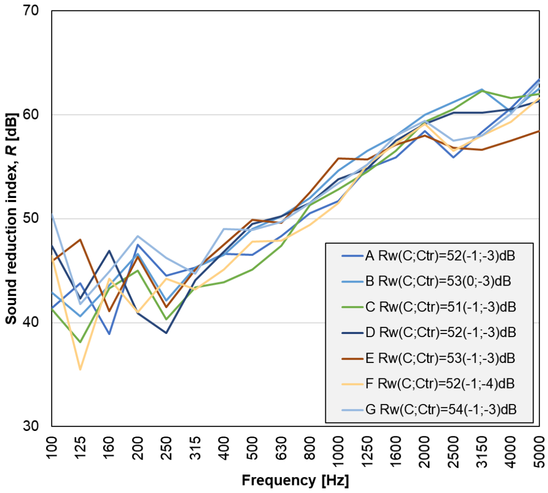

Fig. 4 – Sound reduction index laboratory measurements

The effect of the different sizes and thicknesses is evident for the low-frequency range (below 315 Hz), while the different behaviour for the high-frequency range (above 2000 Hz) may be caused by the boundary conditions (mounting) and inner brick geometry.

## 3. Prediction of Acoustic Insulation of Clay Hollow Brick Walls

Three procedures were evaluated to predict the acoustic behaviour of the measured walls:

1) a commercial software package based on Sharp's homogeneous wall theory (Sharp, 1973);
2) the analytical method indicated in ISO 12354-1: 2017 standard, annexes B and C;
3) a reference curve derived from the measured values.

In particular, the reference sound reduction index curve for hollow brick walls was obtained by aggregating the individual measured sound reduction index curves $R_k$ with the following procedure. First, each $R_k$ curve obtained from laboratory measurements was shifted so as to obtain a 'normalised' spectrum, $X_{0,k}$, with a weighted sound reduction index of $R_{w,k} = 0$ dB. The normalised value relative to the $i$-th one-third octave band is, for the $k$-th wall, $X_{0,i,k}$.

Subsequently, for each $i$-th one-third octave band ranging from 100 Hz to 5000 Hz, the arithmetic mean of the normalised values obtained for all the walls was calculated, in order to provide a mean value $X_{0,i}$ for the specific frequency band.

Fig. 5 shows the seven normalized curves, the mean value and the uncertainty limits ($U = 2.3\ \sigma$).

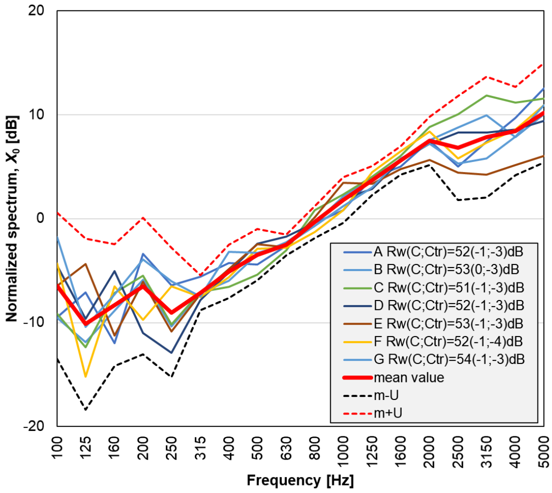

Fig. 5 – Normalized sound reduction indices and mean normalized sound reduction indices

Finally, the reference curve $X_0$ was shifted by a certain value $R_0$ in order to obtain the estimate of the sound reduction index for a given wall. A mass-dependent correlation for the parameter $R_0$ was derived by regression analysis of the data from the seven tested walls:

$$R_0(m') = 20.9 \log_{10}(m') \qquad (4)$$

A shift was applied for each $i$-th one-third octave band according to the formula:

$$R_{0,i} = X_{0,i} + R_0(m') \qquad (5)$$

The results were compared with the measurements of the sound reduction index performed in sound transmission suites.

The following graphs (Figs. 6–12) show the comparisons between the results of the application of the three procedures applied to different types of wall.

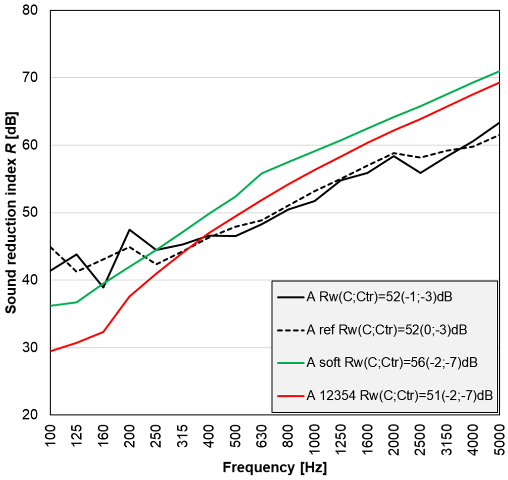

Fig. 6 – Comparison between method results for wall type A. Solid green: Sharp's theory; solid red: ISO 12354-1; dashed black: reference curve; solid black: measured data

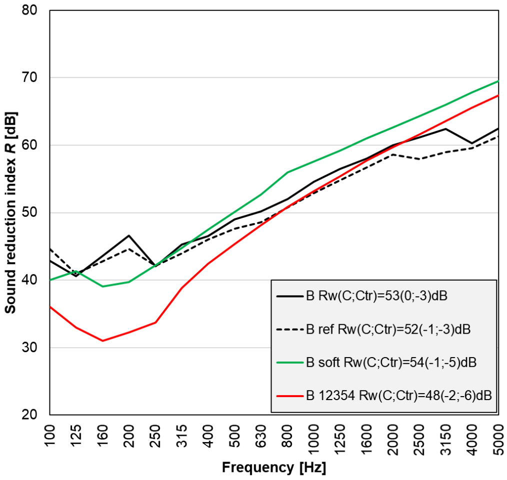

Fig. 7 – Comparison between method results for wall type B. Solid green: Sharp's theory; solid red: ISO 12354-1; dashed black: reference curve; solid black: measured data

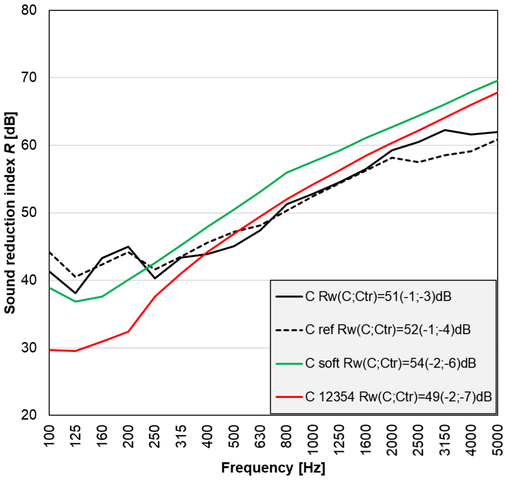

Fig. 8 – Comparison between method results for wall type C. Solid green: Sharp's theory; solid red: ISO 12354-1; dashed black: reference curve; solid black: measured data

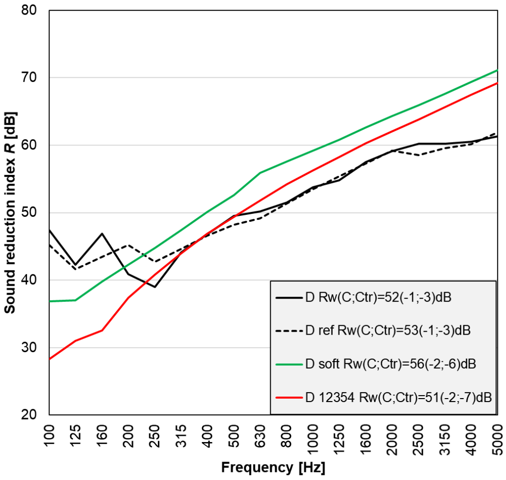

Fig. 9 – Comparison between method results for wall type D. Solid green: Sharp's theory; solid red: ISO 12354-1; dashed black: reference curve; solid black: measured data

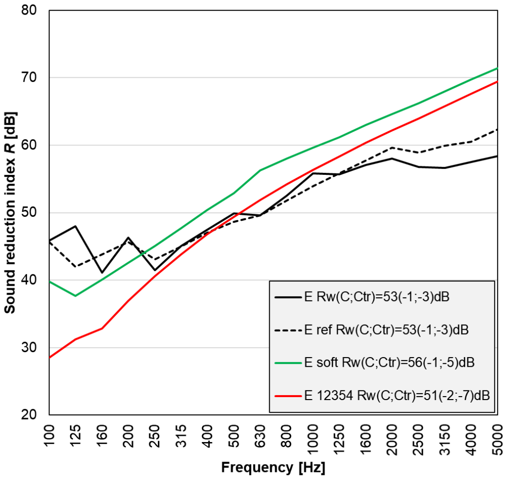

Fig. 10 – Comparison between method results for wall type E. Solid green: Sharp's theory; solid red: ISO 12354-1; dashed black: reference curve; solid black: measured data

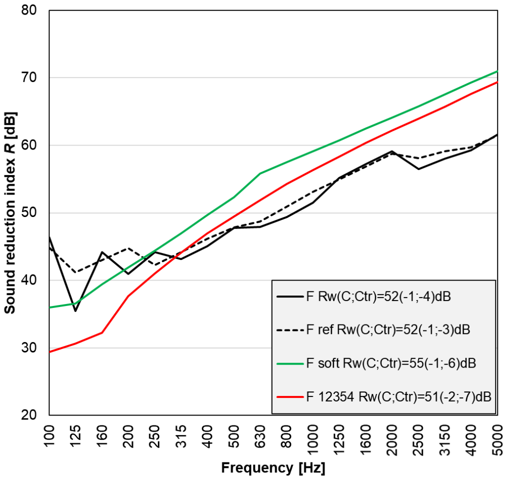

Fig. 11 – Comparison between method results for wall type F. Solid green: Sharp's theory; solid red: ISO 12354-1; dashed black: reference curve; solid black: measured data

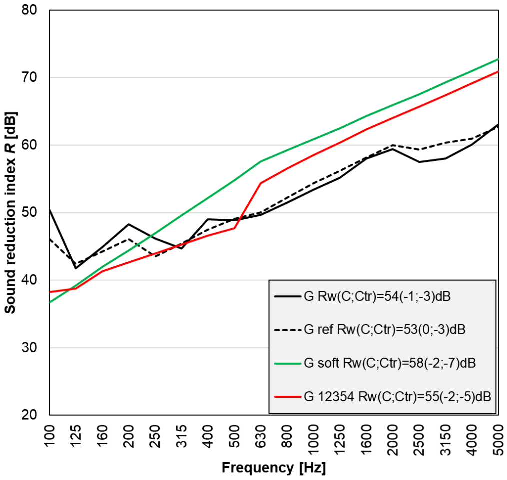

Fig. 12 – Comparison between method results for wall type G. Solid green: Sharp's theory; solid red: ISO 12354-1; dashed black: reference curve; solid black: measured data

Table 3 shows a comparison of the $R_w$ values determined according to the three methods and the laboratory measurements.

Considering the wall as a homogeneous plate leads to an overestimation of the sound reduction index above the critical frequency and to an underestimation of the sound reduction index below the critical frequency. The software based on the Sharp's theory overestimates the $R_w$ value from 1 to 4 dB while the analysis according to the ISO 12354-1 standard leads to differences from −5 to +1 dB. Similar differences can be observed if one-third octave band values are compared.

The use of the proposed reference curve leads to differences between −1 and +1 dB. These values can be considered within the measurement uncertainty (International Organization for Standardization, 2014).

Table 3 – Weighted sound reduction indexes comparison (measured, reference curve, software, ISO 12354-1 method)

| | $R_w$ [dB] | | | |
|---|---|---|---|---|
| **Type** | **Measured values** | **Sharp's theory** | **ISO 12354-1** | **Reference curve** |
| A | 52 | 56 | 51 | 52 |
| B | 53 | 54 | 48 | 52 |
| C | 51 | 54 | 49 | 52 |
| D | 52 | 56 | 51 | 53 |
| E | 53 | 56 | 51 | 53 |
| F | 52 | 55 | 51 | 52 |
| G | 54 | 58 | 55 | 53 |

## 4. Conclusion

This paper has focused on the acoustic insulation performances of clay hollow brick walls.

A reference curve for the family of plastered walls with mass per unit area 305-377 kg/m$^2$, thickness 206-330 mm, void fraction 37-55% and a mass-dependent shifting correlation based on experimental measurements was derived.

It was observed that the difference between experimental and estimated values never exceeds ±1 dB, indicating that the reference curve fairly represents the sound insulation behaviour of this family of brick walls.

Software based on Sharp's theory and ISO 12354-1 method (annex B), both developed for homogeneous thick walls, seems not to be suitable for reliably representing the acoustic behavior of hollow brick walls.

## Nomenclature

### Symbols

| | |
|---|---|
| $\tau$ | sound transmission coefficient (-) |
| $W$ | sound power (W) |
| $R$ | sound reduction index (dB) |
| $L$ | mean equivalent sound pressure level (dB) |
| $S$ | surface of the specimen |
| $A$ | equivalent absorption area of the receiving room (m$^2$) |
| $V$ | volume of the receiving room (m$^3$) |
| $T$ | mean reverberation time of the receiving room (s) |
| $m'$ | mass per unit area (kg/m$^2$) |
| $t$ | thickness of the wall (mm) |
| $f_{bk}$ | compressive strength of the *k*-th type block (MPa) |
| $f_k$ | compressive strength of the *k*-th type wall (MPa) |
| $E$ | Young's modulus (GPa) |
| $X$ | spectrum (dB) |

### Subscripts/Superscripts

| | |
|---|---|
| 1 | transmitting room |
| 2 | receiving room |
| *k* | *k*-th type wall |
| *i* | *i*-th one-third octave band |
| w | weighted value |
| 0 | normalised quantity |

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