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Empirical calculation of sound insulation in lightweight partition walls with separate steel studs

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ABSTRACT

In our fieldwork, we have measured sound insulation of lightweight partition walls with separate steel studs for years. The results are stored in our database, which contains more than 350 measurements of lightweight partition walls. In this study, 50 measurements and two wall configurations have been selected. The first configuration consists of 3 x 13 mm gypsum board on each side and a 250 mm void partly filled with mineral wool. The second configuration is identical except that it consists of 2 x 13 mm gypsum boards on each side and a 200 mm void. These measurements are made primarily at various performing arts centers around Norway. These rooms have a "box-in-box" solution, but measurements from other locations are also present. Measurements with obvious flanking transmissions were excluded from the study. We present some case studies where we describe the room configuration and compare the predicted values to the measured results. Our prediction is based on equations in the European Standard EN 12354-1 and well-known empirical models, with empirical corrections from the measurements. Articles have also provided us with both guidance on how to calculate the sound insulation and simplified methods for handling uncertainties and safety margins.

INTRODUCTION

The walls in our research are constructions with two independent leaves separated by a cavity. The panels on each side are lightweight gypsum boards connected to separate steel studs, and the cavity between the leaves is partly filled with mineral wool. The lightweight partition walls should be free from mechanical coupling, which means they have no known structural connection. Ideally, the energy transmission from one leaf to the other will take place by a forced excitation through the cavity only.

The sound reduction index for double walls

If we assume diffuse sound fields in both sending and receiving rooms and in the cavity between the leaves,

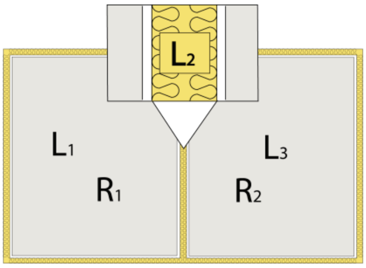


Figure 1 Double wall with separate leaves.

the sound reduction indexes can be expressed (as shown in [1]) as

$$R_1 = L_1 - L_2 + 10\lg\frac{S}{A_2} \tag{1}$$

$$R_2 = L_2 - L_3 + 10\lg\frac{S}{A_3} \tag{2}$$

where S is the partition area and L and A denote the sound pressure level and the total absorption area.

This gives us the sound reduction index R_d for the double wall:

$$R_d = R_1 + R_2 + 10\lg\frac{A_2}{S} \tag{3}$$

Equation (3) shows that the sound reduction index for double walls can be predicted from the sound reduction to the separate leaves and a term related to the absorption between the leaves.

The acoustic coupling across the cavity gives us a resonance frequency that can be estimated from the equation shown in [1]:

$$f_0 \approx 60\sqrt{\frac{m_1 + m_2}{m_1 \cdot m_2 \cdot d}} \tag{4}$$

where m_1 *and* m_2 is the mass per unit area of the two leaves and d is the distance between them.

Over this resonance frequency, the sound reduction index would ideally increase by approximately 18 dB/octave up to a given frequency, f_d. Through laboratory measurements, it has been found that the sound reduction index only increases by approximately 12 dB/octave over f_d and up to the coincidence frequency for the separate leaves [1]. This frequency is estimated empirically to be $f_d=55/d$, where d is the distance between the leaves.

An empirical model introduced by Sharp in 1978 as cited in [1] predicts the sound reduction index for these types of partition walls. Using classical expressions and a large measurement database, he presented a set of equations to predict double walls without structural connection, but with mineral wool in the cavity. This model has shown to be true for laboratory measurements.

The European standard EN 12354-1

The European standardization organization has collected models to predict airborne apparent sound insulation between adjacent rooms in field, based on the performance of the involved building elements. The models are presented in the European standard EN 12354-1 [2]. These models take into account flanking transmission through structural connections between elements of adjacent rooms. In this study, we have no known structural connections, thus no flanking elements, so applying these methods to our situation has shown to give roughly the same result as the laboratory element data.

"Lab/field"-correction

Although we almost have ideal conditions without flanking relation to the surrounding rooms, we achieve a lower apparent sound reduction through the double lightweight partition walls than what is obtained for laboratory measurements of the elements. To predict the sound reduction index for field measurements, we can add a "lab/field"-correction to the predicted laboratory results.This paper establishes a simple empirical correction that can be used to give a rough estimate for the performance of the walls in field.

OUR FIELD MEASUREMENTS

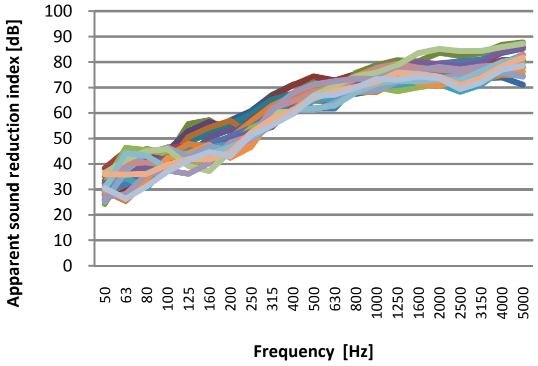
The apparent sound reduction index

We have used the term "apparent sound reduction index" in this research, denoted R', for our field measurements. This value includes both transmission through the partition itself and all other transmission paths. The partition takes the "blame" for all the transmission paths that contribute.

Our internal database, StairWay [3], contains more than 350 field measurements of lightweight partition walls. In this study, 50 measurements and two wall configurations have been selected:

The first wall

Results from 28 sound insulation measurements for the construction DD 303 100/100 M200 (250 mm spacing) are gathered from StairWay. Three results with obvious flanking transmission are omitted.



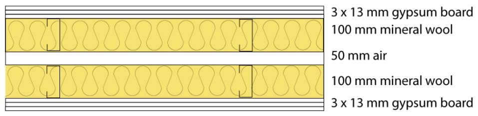


Figure 2 Measurements from 25 sound insulation measurements are shown for the construction DD 303 100/100 M200 (250 mm spacing). An illustration of the partition wall is also shown.

A common way to express this double wall is with the phrase 'DD 303 100/100 M200'. DD denotes a double wall with separate steel studs. 303 denotes the use of 3 gypsum layers on each side. 100/100 refers to 100 mm sole and header plate and 100 mm studs and M200 gives the mineral wool thickness.

The second wall

Results from 22 sound insulation measurements for the construction DD 202 100/100 M190 are gathered from StairWay. Two results with obvious flanking transmission are omitted

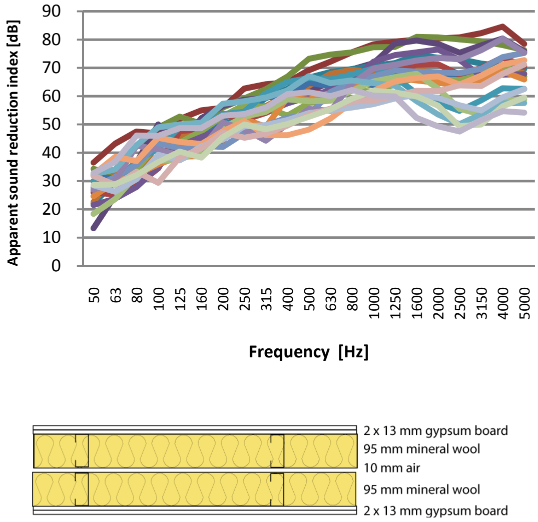


Figure 3 Measurements from 20 sound insulation measurements are shown for the construction DD 202 100/100 M190. An illustration of the partition wall is also shown.

The sample mean and standard deviation for the measurements are shown in the table below.

Table 1 Statistical calculation for the sample data

Sample mean $\bar{x}$	*Sample standard deviation S*	*Wall type*
65	2,8	DD 303 100/100 M200
60	4,0	DD 202 100/100 M190

PREDICITON METHODS

We have used two prediction methods for this research to calculate the sound reduction for the ideal double wall, which can be the situation in laboratories. The first method is based on Sharp's model together with methods for calculating monolithic elements found in EN 12354-1. The second prediction method is based on modern software programs and some "calibration" of the achieved results.

Prediction, method 1

Equations for the sound reduction index for monolithic elements can be found in EN 12354-1 Annex B [2]:

$$
\begin{aligned}
&R = -10\lg\tau \\
&\tau = \left(\frac{2\rho_0 c_0}{2\pi f m}\right)^2 \frac{\pi f_c \sigma^2}{2 f \eta_{tot}} && f \geq f_c \\
&\tau = \left(\frac{2\rho_0 c_0}{2\pi f m}\right)^2 2\sigma_f + \frac{(l_1 + l_2)^2}{l_1^2 + l_2^2}\sqrt{\frac{f_c}{f}}\,\frac{\sigma^2}{\eta_{tot}} && f < f_c
\end{aligned} \qquad (5)
$$

where l_1 and l_2 are the lengths of the boarders of the element and σ and σ_f are the radiation factors for the free bending waves and the forced transmission.

For our estimates, we will use some simplifications described in [1]. For rough estimates, we can neglect the contribution from the resonant transmission but include a simplified area effect. Fahy (1987 as cited in [1]) has suggested the following equation:

For frequencies below resonant frequency (f_c) the sound reduction index for forced transmission can be calculated from:

$$R_f \approx 20\lg(m \cdot f) - 10\lg\left[\ln\left(\frac{2\pi f}{c_0}\right) \cdot \sqrt{A}\right] + 20\lg\left[1 - \left(\frac{f}{f_c}\right)^2\right] - 42\text{ dB} \qquad (6)$$

where A is the total area of the wall and m is the mass per unit area.

It is shown in [1] that we can get the following equation for $f > f_c$

$$R = 20\lg(m \cdot f) + 10\lg\left[2\eta_{tot}\frac{f}{f_c}\right] - 47\text{ dB} \qquad (7)$$

where η_{tot} is the total loss factor (The equation is obtained by putting $\sigma \approx 1$ into the first equation in (5))

According to Sharp (1978) cited in [1] the sound reduction index for double walls without structural connections can be found from:

$$R = \begin{cases} R_{M1+M2} & f < f_0 \\ R_1 + R_2 + 20\lg(f \cdot d) - 29 & f_0 < f < f_d \\ R_1 + R_2 + 6\text{ dB} & f > f_d \end{cases} \qquad (8)$$

where f_d is given by $55/d$, as mentioned earlier, and f_0 is given by (4). The index $M1 + M2$ indicates that the sound reduction index should be calculated from the total mass of both leaves. In our predictions, R_{M1+M2}, R_1 and R_2 are calculated from equation (6) and (7).

EMPIRICAL CORRECTION

From our predictions based on methods reviewed in the previous chapter and the mean values from the field measurements, we can see a systematic difference.

An empirical "lab/field"-correction was made from the average difference between the predicted laboratory values and the field measurements, and is shown in equation (9).

$$R'_c = \begin{cases} R - 2\text{ dB} & f < f_d \\ R - 20\lg(f \cdot d) + 23.5\text{ dB} & f_d < f < f_{d2} \\ R - 11.5\text{ dB} & f > f_{d2} \end{cases} \qquad (9)$$

where f_{d2} is estimated to be $\sim 20/d$.

The results are shown graphically in the figures below. Here our predictions are made with S = 10 m^2. The results are compared to the mean values of our measurements. The standard deviations from the measurements are also shown.

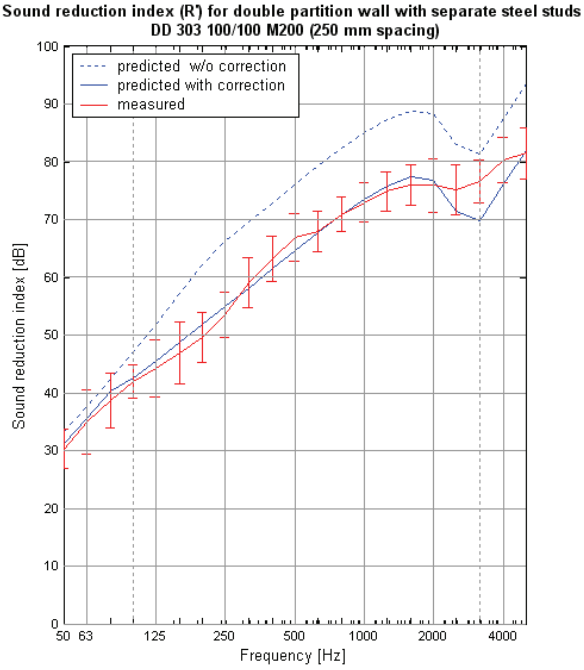


Figure 4 The predicted sound reduction indexes for wall type DD 303 100/100 M200 with and without our empirical correction are shown. The mean values and the standard deviation for the measured values are also shown.

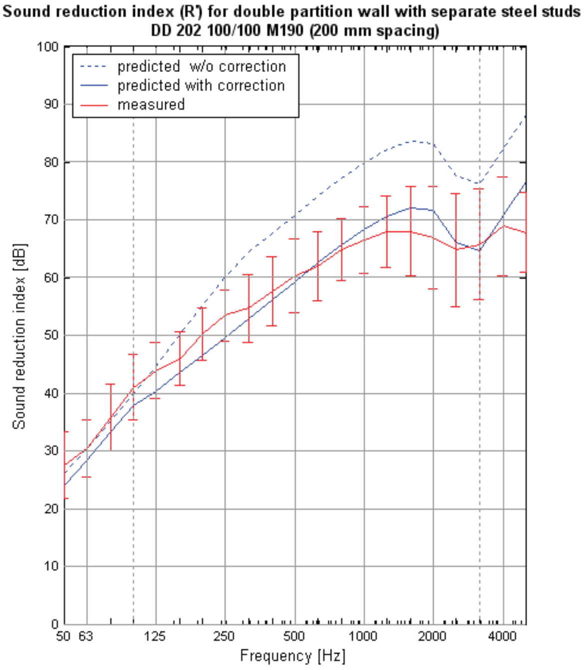


Figure 5 The predicted sound reduction indexes for wall type DD 303 100/100 M190 with and without our empirical correction are shown. The mean values and the standard deviation for the measured values are also shown.

Prediction method 2

There are several sound insulation prediction programs on the market. INSUL calculates elements airborne sound insulation and the developer claims to have extensively compared the calculated values with the well-known NRC database [4]. BASTIAN is based on EN-12354 and calculates the sound insulation in-situ [5]. Efforts to "calibrate" the input data by statistically correcting the INSUL predictions data from the mean value of laboratory measurements are done. An element database with these corrections are given by the Swedish company Simmons akustik & utvekling (SAU) and can be purchased as a component to BASTIAN based on EN-12354.

We have used the "calibrated" data and then applied our correction for the systematic difference between measured rooms and this model.

The "recipe" for the calculation can be describe as follows

- Calculate the sound reduction for the double partition wall with separate steel studs using INSUL software
- Find a nearby element in the BASTIAN database from SAU and calculate this in INSUL.
- Find the empirical correction that has been made on this element and use the same correction for your wall element
- Apply the empirical "lab/field"-correction shown in (9).

The results are shown in the figures below. Here our predictions are compared to the mean values of our measurements. The standard deviations are also shown.

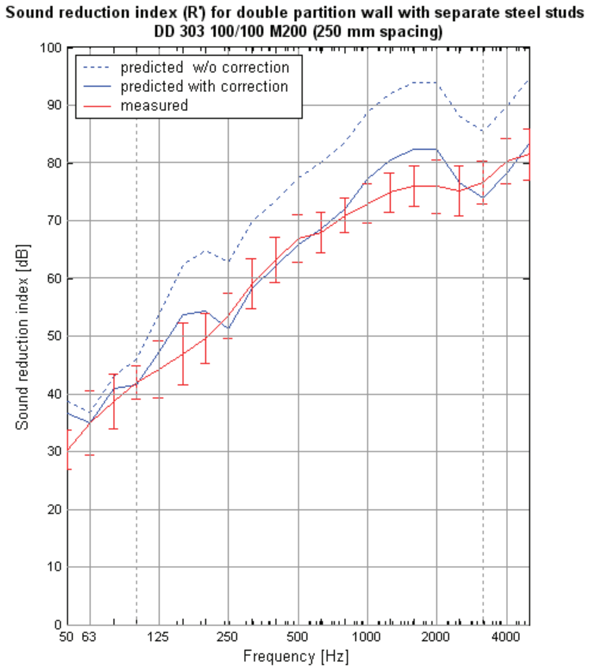


Figure 6 The predicted sound reduction indexes for wall type DD 303 100/100 M190 with and without our empirical correction are shown. The mean values and the standard deviation for the measured values are also shown.

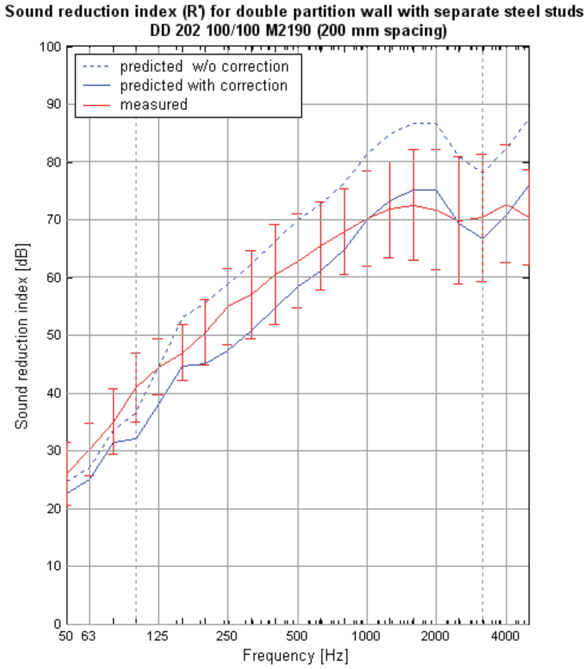


Figure 7 The predicted sound reduction indexes for wall type DD 303 100/100 M190 with and without our empirical correction are shown. The mean values and the standard deviation for the measured values are also shown.

SAFETY MARGINS

As always there are many uncertainties in our research. A real problem was to get the complete set of specifications for the measured objects. Material data and the wall's dimensions were not always completely described. The total loss factor, η_{tot}, for our calculations was only based on estimates given in the literature. Errors may also occur in the measurements. We are investigating walls with very high sound insulation. In field, sound insulation measurements in high frequency bands can be underestimated due to insufficient Signal-Noise-Ratio. Last but not least, errors due to poor workmanship and errors in the description of building elements may also occur.

The results presented in the previous chapter shows only the mean value of the measurements. The empirical correction is valid for the average of many partition walls, but not necessarily for a given wall. To account for random errors and uncertainties we have to add some safety margins to the predicted results.

We have calculated the average difference and the standard deviation between the measured and calculated values for our measurements. This is shown in tables 2 and 3.

Table 2 Difference between calculated and measured data for 25 'DD 303 100/100 M200' walls.

Average	*St. dev*
0,84	2,9

Table 3 Difference between calculated and measured data for 20 'DD 202 100/100 M190' walls

Average	*St. dev*
1,80	3,7

For many of the DD 202 100/100 M190 walls, the partition areas are missing in the dataset. An area of S = 10 m^2 is used for these calculations, which may lead to larger deviations.

In literature, a 3 dB safety margin is often applied for sound insulation calculations of heavy constructions according to EN-12354-1, and several studies have shown that this safety margin is appropriate [6]. For lightweight constructions, a similar constant safety margin does not exist to the best of our knowledge, but the 90 % confidence limits for the difference between lightweight construction predictions and measurements is shown to be between one or two standard deviations [6].

For rough estimations only, a safety margin that corresponds to one standard deviation may be sufficient. For this situation, this would be 3 - 4 dB.

CASE STUDIES

The case studies originate from various performing art centers in Norway. These rooms are used as musical rehearsal rooms and are nearly identical in room size. The building elements used in these rooms are described for each case.

Case 1

Box-in box solution:

- Gypsum walls: DD 303 100/100 M200 (250 mm spacing). Area = 13.5 m^2
- Double doors (R_w = 33 dB and R_w =38 dB)
- Double window solution in the façade
- Floating floor (90 mm concrete on 50 mm mineral wool)
- Separate gypsum ceiling with mineral wool on top

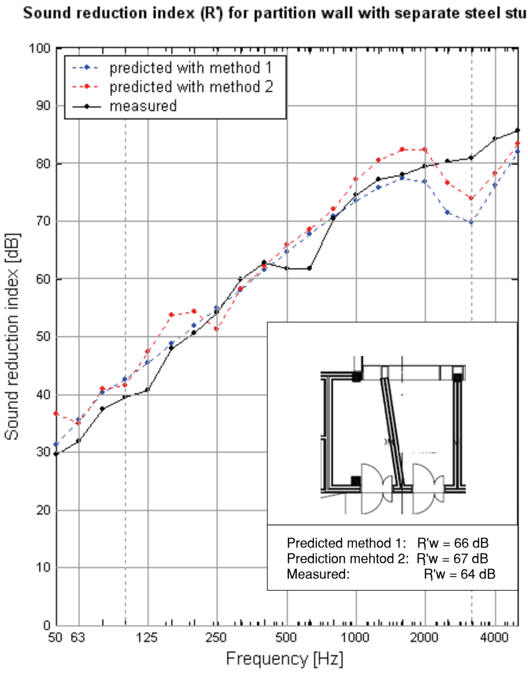


Figure 8 Sound reduction index for case 1

Case 2

Box-in box solution:

- Gypsum walls: DD 303 100/100 M200 (250 mm spacing). Area = 11.1 m^2
- Double doors (R_w = 33 dB and R_w =38 dB)
- Double window solution in the façade
- Floating floor (90 mm concrete on 50 mm mineral wool)
- Separate gypsum ceiling with mineral wool on top

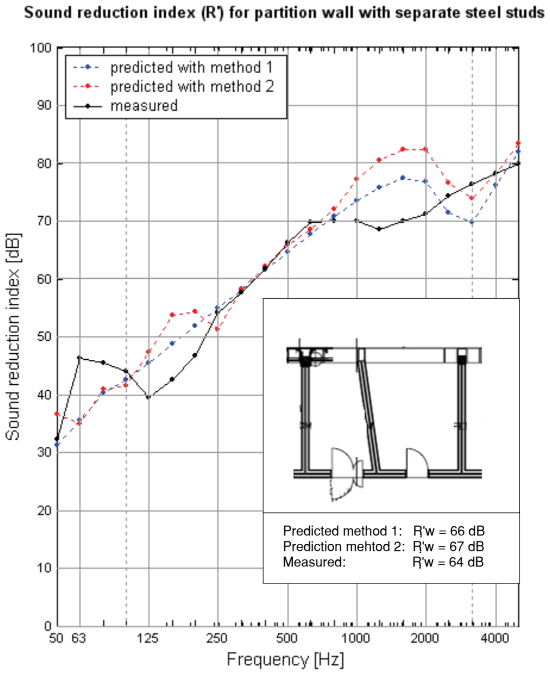


Figure 9 Sound reduction index for case 2

Case 3

Box-in box solution:

- Gypsum walls: DD 202 100/100 M190 (200 mm spacing) S = 10 m^2
- Double doors (R_w = 33 dB and R_w = 38 dB)
- Double window solution in the façade
- Floating floor (Concrete on mineral wool)
- Separate gypsum ceiling with mineral wool on top

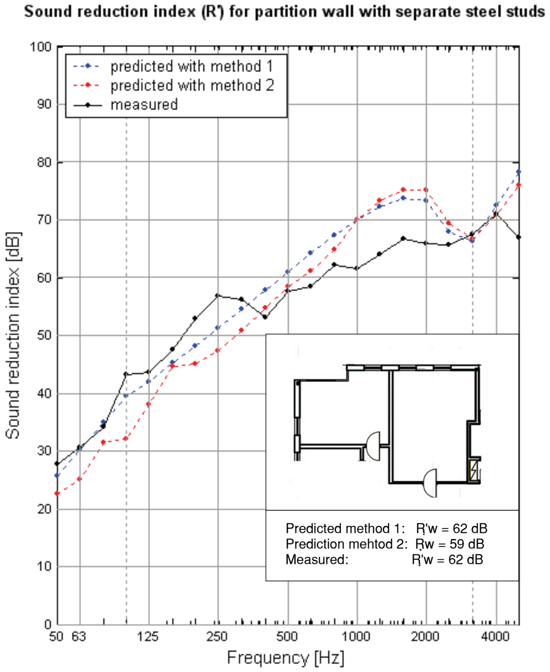


Figure 10 Sound reduction index for case 3

SUMMARY

The theoretical sound insulation for DD 303 100/100 M200 (250 mm spacing) is estimated to be $R'_w = 75$ dB and for DD 202 100/100 M190 (200 mm spacing), $R'_w = 67$ dB. The mean values from our measurements are respectively R'w = 65 dB and $R'_w = 60$ dB for the same configurations in field. To make estimates for the sound insulation with these double partition walls in field, an empirical "lab/field"-correction is made.

Our empirical correction, shown in (9), seems to be reasonable for our case studies, and shows that a safety margin of 3-4 dB can be appropriate for rough estimate purposes. Of course, much more research is required. More rooms with double partition walls with separate steel studs at different construction sites must be measured and compared to predictions, before the empirical correction and guidance for safety margins can be used for practical purposes.

REFERENCES

1 T.E. Vigran, *Building Acoustics* (Tapir Akademisk forlag, Trondheim, 2002)

2 EN 12354-1 *Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms*, CEN 2000

3 STAIRWAY, Internal measurement database, Brekke & Strand akustikk.

4 INSUL, Sound insulation prediction software, Marshall Day acoustics.

5 BASTIAN, Sound insulation prediction software based on EN-12354, Datakustik GmbH.

6 C. Simmons, Ph.D. thesis: *Managing uncertainty in building acoustics – Comparisons of predictions using the EN 12354 standard to measurements* (Luleå University of Technology, Luleå, 2009)

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