Abridged version of research report B-BA 2/2008

# Acoustic refurbishment of residential buildings with additional linings and additional lining constructions - calculation, design, and optimization

L. Weber, A. Buchele
Fraunhofer Institute for Building Physics (IBP), Stuttgart

The research report was funded by the Federal Office for Building and Regional Planning (Bundesamt für Bauwesen und Raumordnung, BBR), reference number Z6 - 10.07.03-05.13 / II 13 - 80 01 05 - 13.
The author is responsible for the contents of the report.

## 1 Objective of the research project

Additional linings - i.e. lightweight flexible boards arranged at a distance of several centimetres in front of heavy base walls - are frequently used in buildings. Their production is simple and cost-efficient, and therefore they are applied, where enhanced sound reduction is required or constructions without adequate sound insulation must be renovated. Furthermore, additional linings are also used in the field of thermal insulation (e. g. as external thermal composite insulation systems), thus fulfilling a double building physical function.

There is a large variety of additional lining constructions, from additional linings attached to walls over floating floors to suspended ceilings. Despite the different type of construction the acoustic effect is always based on the same principle, where the base wall and the additional lining act as masses and the intermediate air or insulating layer as spring (mass-spring principle).

Although this is a well-established type of construction, the acoustic behaviour of additional linings is not at all completely understood. Existing design and calculation tools are relatively inexact and suited for practical application only to a limited extent. This is why errors in design and manufacture frequently occur, which have a remarkable impact on the sound insulating effect of additional lining constructions.

The research project performed was therefore aimed at thoroughly investigating acoustic correlations as well as clarifying the influences on sound insulation due to the construction in particular. Based on the resulting findings improved calculation methods were developed for situation-related design and dimensioning of additional linings. Moreover, instructions for practical implementation of the research results were developed to achieve the optimal acoustic effect of additional linings adjusted to the structural boundary conditions.

## 2 Implementation of the research project

The research project involved the following working steps, partly interlocking, partly, however, following independent goals:

- Literature research to complete present knowledge on additional linings. Apart from experimental investigations acoustic calculation models were considered primarily.
- Preparation of a database with sound insulation measurements on additional lining constructions. All data sets (about 110 for direct transmission and 100 for flanking transmission) were derived from measurements in building acoustic test facilities. Besides of

the acoustic characteristics all relevant information on component construction was collected.

- Analysis of data to determine acoustic correlations, decisive factors and construction parameters. The analysis was mainly performed by comparing similar constructions that differed only with regard to the respective investigated influencing variable.
- Additional sound insulation measurements to complete data and to answer extensive questions. In the process, the correlations between the structure and the acoustic characteristics of the additional lining constructions were investigated in particular.
- Development of improved calculation models with enhanced precision on the basis of the findings from the previous working steps. The models were designed as engineering methods for practical application. Since single number quantities (frequently) as well as frequency spectra (occasionally) are necessary for building acoustic design, the investigations were performed using a two-track strategy, resulting in the development of a simplified calculation method for the improvement the weighted sound reduction index as well as of a detailed method for frequency-dependent calculations. Validation of the calculation methods was performed by comparison with the measurement results of the database.
- Development of instructions for professional dimensioning and installation of additional linings. The instructions serve as a means to optimize the situation-related acoustic efficiency of additional linings.

The large variety of different additional lining constructions requires the reduction of the range of investigation. Therefore, additional linings attached to solid walls were selected due to the wide-spread use and representative acoustic characteristics. The basic types of additional linings attached to solid walls are shown in Fig.1. External thermal insulation composite systems were not considered, since extensive investigation results are already available on this topic [1, 2].

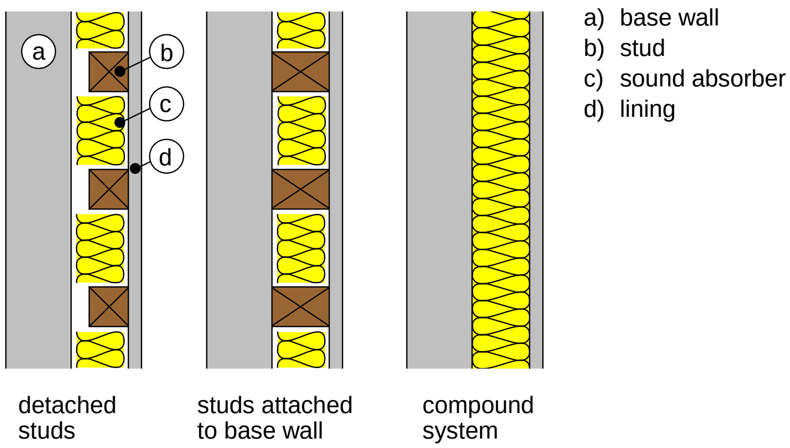


**Fig. 1** Types of additional linings attached to solid walls. It has to be distinguished between detached studs (left), studs attached to the base wall (middle) and compound systems (right). In case of compound systems the insulation is glued to the lining as well as to the wall.

## 3 Fundamentals

The sound insulating effect of additional linings is described by the improvement of sound insulation

$$\Delta R = R_{bw+al} - R_{bw} \tag{1}$$

where $R_{bw+al}$ and $R_{bw}$ denote the sound reduction index of the base wall (bw) with and without additional lining (al). The improvement $\Delta R$ is a frequency-dependent parameter and mostly indicated as third octave spectrum in building acoustics. To obtain a single number quantity for the acoustic effect of additional linings, mostly the improvement of the weighted sound reduction index

$$\Delta R_w = R_{w,\,bw+al} - R_{w,\,bw} \tag{2}$$

is used [3, 4].

The acoustic effect of additional linings is primarily based on the mass-spring principle, where the base wall and the additional lining act as masses and the intermediate air or insulating layer as spring. The resulting frequency response is illustrated schematically in Fig. 2:

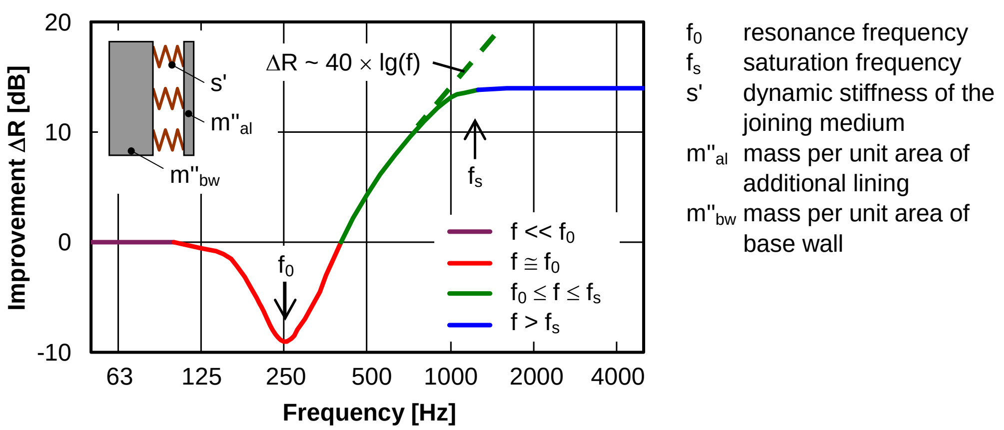


**Fig. 2** Improvement of the sound insulation of a solid wall by an additional lining as a function of frequency (schematic drawing)

In Fig. 2 it can be distinguished between four characteristic frequency ranges:

$f << f_0$: Far below resonance additional linings show - with the exception of a slight increase of the total mass - a neutral acoustic behaviour, i.e. $\Delta R \cong 0$.

$f \cong f_0$: Within the range of the resonance frequency the sound insulation is deteriorated resulting in a negative improvement ($\Delta R < 0$).

$f_0 < f < f_s$: Above resonance the improvement theoretically increases by 40 lg($f/f_0$) = 12 dB/octave. However, in practice the increase is mostly somewhat lower.

$f \geq f_s$: At high frequencies flattening or even an inversion of the direction of the increase occurs. The causes for this effect are not yet completely understood.

According to Fig. 2 the acoustic behaviour of the additional linings is primarily determined by the resonance frequency $f_0$ and the saturation frequency $f_s$. The smaller $f_0$, the better the acoustic effect.

## 4 Summary of results

### 4.1 Influences on sound insulation due to the construction

The acoustic effect of additional linings depends on the construction as well as on the structural boundary conditions to a large extent. The investigations performed (analysis of the existing data in connection with additional measurements and calculations) provided the following results:

- The acoustic effect of additional linings is primarily determined by the resonance frequency and the mass of the base wall. The lower the resonance frequency and the smaller the mass of the wall, the greater the improvement of the weighted sound reduction index $\Delta R_w$. Calculation of $\Delta R_w$ can be performed by approximation according to DIN EN 12354-1, Annex D. To improve precision the revised formula in paragraph 4.2 should be applied.
- An air gap between additional lining and base wall requires cavity attenuation by means of sound absorbing material. The filling level of the cavity should amount to at least 50 %. Filling levels of more than 50 % provides only insignificant improvement of the sound insulation according to Fig. 3.
- As mass-spring systems additional linings are sensitive towards sound bridges. The more connections there are between additional lining and base wall, the worse is the acoustic efficiency. Single sound bridges are generally not critical. But if the additional lining is connected to the wall by means of a large-area post and beam structure, the effect is reduced by approximately 50% (see Fig. 4).
- The effect of additional linings depends on the fact whether sound transmission takes place in longitudinal direction or directly through the wall. In case of flanking transmission the improvement of the weighted sound reduction caused by the same additional lining is on average by a factor 1.37 higher than in case of direct transmission.
- If additional linings are installed on both sides of the wall, the second lining will contribute only part of the normal effect to the resulting improvement of the sound insulation. A value of approximately 50 % was determined for this part in case of direct transmission, which complies with the values according to DIN EN 12354-1 (see example in Fig. 5). In contrast, a value of about 64 % occurs for the part in case of flanking transmission.
- To improve the acoustic effect, additional linings are frequently constructed with double covering. In comparison to an additional lining consisting of a single board an improvement of approximately 3 dB could be expected according to DIN EN 12354-1. The average measured values, however, are clearly lower and amount to 1.8 dB for direct transmission and 0.8 dB for longitudinal transmission.
- The acoustic effect of additional lining constructions can be remarkably improved by damping layers with rigid and holohedral connection to the additional lining. Preliminary investigations showed an improvement potential of at least 3 dB.
- In contrast to a building acoustic test facility, where sound transmission exclusively takes place through the partition wall, in normal buildings also flanking transmission occurs. Since the additional lining influences only part of the flanking paths, the effect is lower in comparison to the value measured in the test facility. A reduction of approximately 4 to 8 dB was determined for usual additional linings in dependence of the mass per unit area of the base wall and the flanking elements (see Fig. 6).

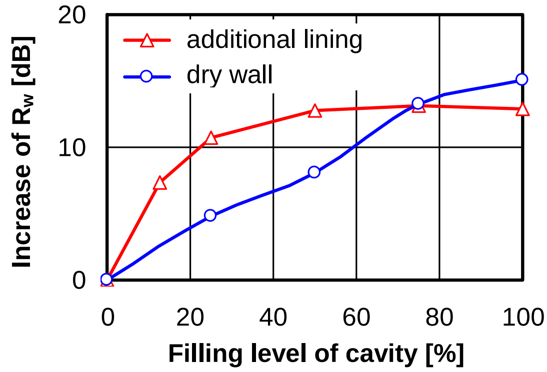


**Fig. 3** Increase of the weighted sound reduction index with gradual filling of the cavity using mineral wool. The measurements were performed on a solid wall with detached additional lining. For comparison similar results for a dry wall are included in the diagram [5].

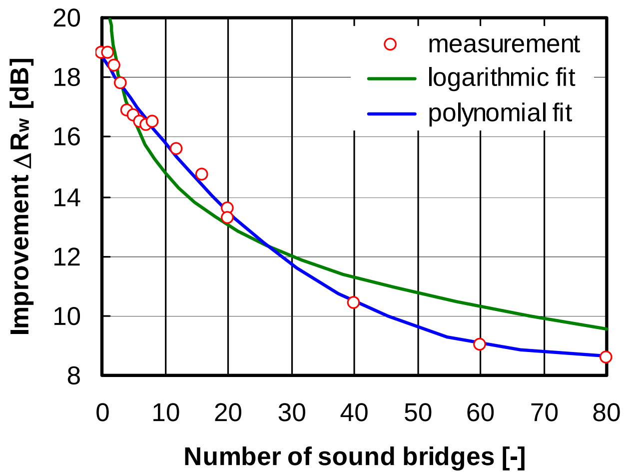


**Fig. 4** Improvement of the weighted sound reduction index by an additional lining as a function of the number of structure-borne sound bridges. The best agreement with the measuring data is reached by a polynomial fit with the formula $\Delta R_w = [18.7 - 0.324\ n + 0.00344\ n^2 - 0.000012\ n^3]$ dB, where n denotes the number of sound bridges.

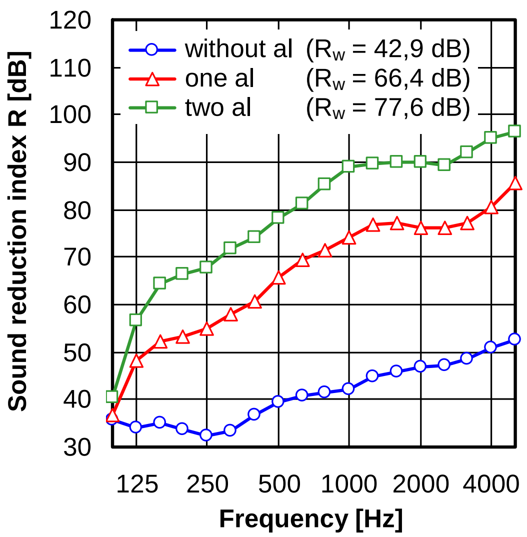


**Fig. 5** Sound insulation of a base wall with equal additional linings (al) installed on one and both sides of the wall, respectively. The corresponding values of the weighted sound

reduction index are shown in the legend: $\Delta R_{w,2al} / \Delta R_{w,1al} = (77.6 - 42.9) / (66.4 - 42.9) = 1.48$.

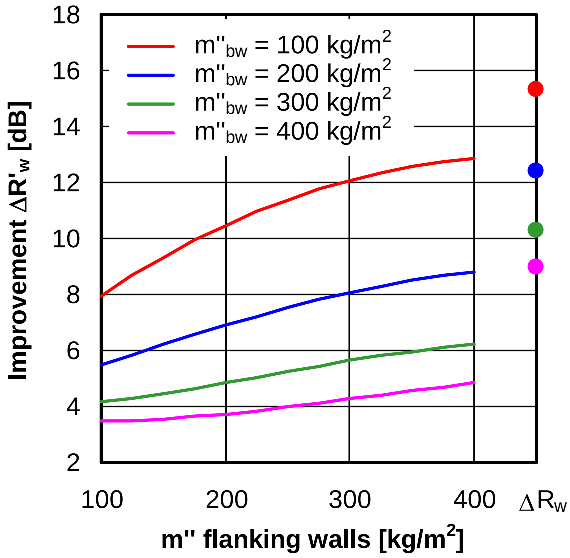


**Fig 6** Improvement of the apparent sound reduction index of a partition wall by an additional lining, $\Delta R'_w$, as a function of the mass per unit area of the flanking walls. Results of a calculation following DIN EN 12354-1 carried out in third-octave bands. The calculation was performed for an additional lining with a resonance frequency of $f_0$ = 80 Hz. The four curves shown in the diagram refer to different masses of the base wall, $m''_{bw}$. The points on the right axis of the diagram describe the improvement reached without flanking transmission (for instance in a building acoustic test facility).

## 4.2 Development of improved calculation methods

To allow for the requirements of practical application, calculation methods were developed along two lines: Besides a simplified method for determination of the improvement of the weighted sound reduction index a detailed method was developed for frequency-dependent calculations.

The development of the simplified method was based on the calculation method described in DIN EN 12354-1, Annex D. Comparison with the existing data showed, however, that a systematic deviation occurred between measurement and calculation (average calculated values almost 4 dB too low). After the deviation was eliminated by revising the formulae the method is now a reliable tool for building acoustic design. The corrected formulae are:

for $f_0 \leq 30$ Hz: $\Delta R_w = [45 - R_{w,bw}/2]$ dB $\geq 0$, (3)

for 30 Hz $< f_0 \leq 160$ Hz: $\Delta R_w = [74.4 - 20 \lg(f_0) - R_{w,bw}/2]$ dB $\geq 0$, (4)

where $f_0$ denotes the resonance frequency and $R_{w,bw}$ the weighted sound reduction index of the base wall. Above the indicated frequency range the original formulae given in DIN EN 12354-1 are still valid. The precision of calculation of the revised method (standard deviation of the difference between calculation and measurement) is within the normal scope and amounts to about 2.7 dB.

For development of the frequency-dependent calculation method different approaches were combined and adjusted to the measured data by additions and corrections. The method is more complex than the simplified method and requires detailed information on the technical properties of the investigated constructions. It is, however, the so far only method that allows to predetermine the frequency response of the sound insulation of additional linings with adequate precision. As concerns the improvement of the weighted sound reduction index precision of calculation results in a value of 2.4 dB.

Due to the complexity of the method only the fundamentals can be presented here. The method is based on a model of Gösele [6], where the improvement of the sound insulation results from the sum of the sound reduction index of the additional lining $R_{al}$ and an expression for consideration of the elastic coupling between additional lining and base wall:

$$\Delta R = R_{al} + 20 \lg\left(\frac{4\pi f \rho_0 c_0}{s'}\right) \text{dB} \qquad (5)$$

Here $\rho_0$ and $c_0$ denote the density and sound velocity of air, whereas s' represents the dynamic stiffness of the connecting medium.

The above mentioned calculation formula had to be considerably modified and completed for practical application, whereby adjustment of the range above saturation frequency was especially important. Fig. 7 and Fig. 8 show an example for practical application of the calculation method as well as the statistic validation of the method on the basis of existing data:

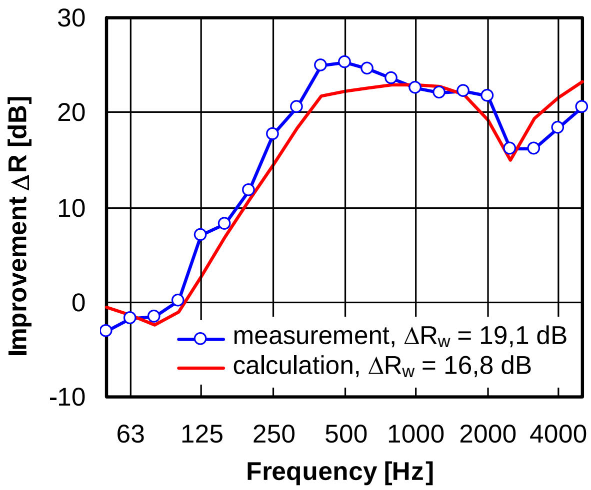


**Fig. 7** Typical example for the use of the frequency dependent calculation method (detached additional lining made of plasterboards in front of a base wall consisting of 100 mm gypsum bricks). With respect to the improvement of the weighted sound reduction index the deviation between calculation and measurement amounts to 2.3 dB.

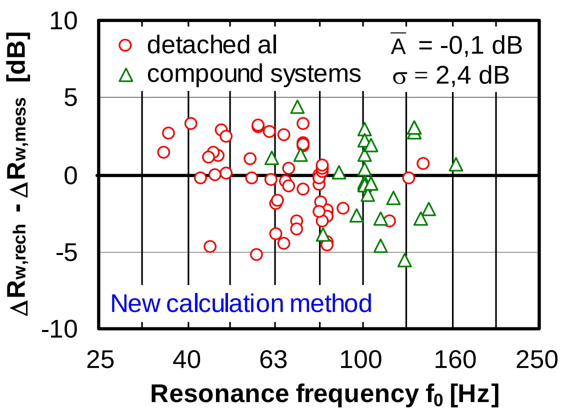


**Fig. 8** Verification of the frequency dependent calculation method by means of the measuring results included in the database. The shown data record altogether comprised about 85

different additional linings, partly attached to differing base walls. All results refer to direct sound transmission through the wall.

## 5 Summary

Despite comprehensive investigations the performed research project could not give answers to all open questions concerning the acoustic characteristics of additional linings. For instance the interaction between additional lining and base wall remains still partly unsolved. Present knowledge, however, was remarkably increased, particularly with regard to the relation of technical properties and sound insulation of additional linings. Instructions for the acoustic design of additional lining constructions based on the determined research results provides an useful tool for practical dimensioning and optimization. In addition, calculation tools developed in the context of the research project remarkably contribute to improve planning reliability and to avoid deficiencies in building acoustic noise control.

## 6 References

[1] Weber, L.; Brandstetter, D.: Einheitliche schalltechnische Bemessung von Wärmedämm-Verbundsystemen. IBP-Bericht B-BA 6/2002 im Auftrag des Deutschen Instituts für Bautechnik (DIBt) und des Fachverbandes Wärmedämm-Verbundsysteme e. V. (2003).
[2] Weber, L.: Einheitliche schalltechnische Bemessung von Wärmedämm-Verbundsystemen - Ergänzung des Berechnungsverfahrens. IBP-Bericht B-BA 4/2005 im Auftrag des Deutschen Instituts für Bautechnik (DIBt) (2005).
[3] DIN EN 12354-1: Berechnung der akustischen Eigenschaften von Gebäuden aus den Bauteileigenschaften - Teil 1: Luftschalldämmung zwischen Räumen. Dezember 2000.
[4] DIN EN ISO 140-16: Akustik - Messung der Schalldämmung in Gebäuden und von Bauteilen - Teil 16: Messung der Verbesserung des Schalldämm-Maßes durch zusätzliche Vorsatzschalen im Prüfstand. November 2006.
[5] Royar, J.: Randvoll bringt noch was. Trockenbau Akustik 1/2003, S. 40 - 42 (2003).
[6] Gösele, K.: Zur Berechnung der Luftschalldämmung von doppelschaligen Bauteilen. Acustica 45, S. 218 - 227 (1980).