Measurement of the airborne and resonant radiation efficiencies
Mahn, Jeffery; Hoeller, Christoph; Zeitler, Berndt

Publisher's version / Version de l'éditeur:

The 22nd International Congress on Sound and Vibration, ICSV 22 Florence, Italy, 12-16 July 2015, 2015

Measurement of the Airborne and Resonant Radiation Efficiencies

Jeffrey Mahn, Christoph Hoeller and Berndt Zeitler

National Research Council of Canada, 1200 Montreal Rd, Ottawa ON K1A 0R6, Canada

The determination of the total and the resonant components of the radiation efficiency have been shown to be necessary for the accurate prediction of the resonant sound reduction index for the calculation of the flanking sound reduction according to a proposed revision of the ISO 15712 series. However, the total and the resonant radiation efficiency of lightweight building elements can be difficult to determine experimentally and there is often confusion about what has actually been measured. In this paper, measurements in the laboratory of the components of the radiation efficiency are presented for different lightweight walls. The measurements were made using both sound intensity and sound pressure to determine the sound power radiated from the walls. Different methods of excitation are compared. A standard for the measurement of the components of the radiation efficiency of lightweight walls is necessary.

---

1. Introduction

One of the difficulties in applying the standard, ISO 15712-1 [1] to lightweight building elements is that lightweight elements typically have critical frequencies in or above the frequency range of interest. The standard requires that the resonant component of the sound reduction index (R_R) be estimated. Several of the proposed methods of estimating R_R have been reviewed [2–4] for use in ISO 15712. The correction factor proposed by Villot and Guigou-Carter [5] was found by the studies to result in the best predictions of the flanking sound reduction index according to ISO 15712-1. The correction factor, referred to as the CSTB correction factor is determined from the total, airborne radiation efficiency σ_T and the resonant radiation efficiency σ_R such that:

(1) $$R_{R,CSTB} = R_T + 10\log\left(\frac{\sigma_T}{\sigma_R}\right)$$

where R_T is the sound reduction index measured in the laboratory according to the ISO 10140 [6] or ISO 15186 [7] series. The difficulty in applying $R_{R,CSTB}$ is the determination of the radiation efficiencies. A number of methods of calculating the radiation efficiency components have been suggested (see for example [1,8]), but comparisons between predictions and measurements below the critical frequency show only rough agreement. Until the predictions can be improved, the calculation of R_R will depend on the measurement of the components of the radiation efficiency.

However, a standardized method for determining the total and resonant radiation efficiencies does not yet exist. The components of the radiation efficiencies of a building element must be determined using different methods of exciting the element. This paper reviews different methods of exciting lightweight, double leaf walls to recommend procedures for standardized measurements.

2. Experimental Estimation of the Radiation Efficiencies

The sound power P radiated from a vibrating panel excited with airborne noise is:

(2) $$P = S\rho_o c_o \left(\langle\overline{v_R^2}\rangle\,\sigma_R + \langle\overline{v_{NR}^2}\rangle\,\sigma_{NR}\right) = S\rho_o c_o \left(\langle\overline{v_T^2}\rangle\,\sigma_T\right)$$

where S is the surface area of the panel, $\rho_o c_o$ is the characteristic impedance of air, $\langle\overline{v_R^2}\rangle$, $\langle\overline{v_{NR}^2}\rangle$ and $\langle\overline{v_T^2}\rangle$ are resonant, non-resonant and total components of the time and spatially averaged mean square velocity, respectively and σ_{NR} is the non-resonant component of the radiation efficiency.

For both the σ_R and σ_T , the panel is excited and the power radiated from the panel in a baffle is measured. If sound intensity is used following ISO 15186, then the measured radiation efficiency may be determined according to:

(3) $$\sigma = \frac{I}{\rho_o c_o \langle\overline{v^2}\,\rangle}$$

where I is the sound intensity. Although a standardized method of determining $\langle\overline{v^2}\,\rangle$ for the radiation efficiencies doesn't exit, following the guidelines of the ISO 10848 series for the number and location of measurement positions is recommended. Alternatively, if pressure is used based on the standards ISO 3741 [9] for the determination of the sound power in a reverberation room with the panel as the sound source, then:

(4) $$\sigma = \frac{P_{ref} 10^{(L_W/10)}}{\rho_o c_o \langle\overline{v^2}\,\rangle}$$

where L_W is determined from ISO 3741 and P_{ref} = 1 pW.

The choice of excitation of the panel will determine which component of the radiation efficiency will be measured. Measurements made using airborne noise will excite both resonant and non-resonant vibrations in the panel [10]. This would be the case if the panel was mounted between two reverberation rooms according to ISO 10140 or a reverberation room and a semi anechoic room according to ISO 15186 with the airborne noise in the source room. Therefore, the radiation efficiency estimated using Eq. 3 or Eq. 4 due to airborne excitation will be σ_T and will include both the non-resonant and resonant components.

The σ_R can not be determined using an airborne noise source to directly excite the panel, but instead must be determined using mechanical excitation (such as a shaker) of the panel or using airborne noise to indirectly excite the panel though a coupled element. The location and number of positons for the excitation with a shaker should follow the guidelines of ISO 10848-1. In the case of single leaf panels, the extra point force radiation contribution form the shaker can be avoided by exciting the panel indirectly. For this study, a second panel was joined to the panel being investigated at one edge, creating an L shaped construction. The panel under investigation was mounted in the opening between a reverberation room and a semi-anechoic room and the attached panel extended into a semi-anechoic room at a right angle to the panel under investigation.

3. Measurements

The measurements for this study were made using L shaped constructions which were created by joining two panels at one edge. The panels were double-leaf constructions with 13mm gypsum board screwed to 50 mm x 100 mm wood studs spaced at 600 mm. Panel i of the L shaped panel was mounted into an opening between a reverberant room and a semi-anechoic room as shown in Figure 1.

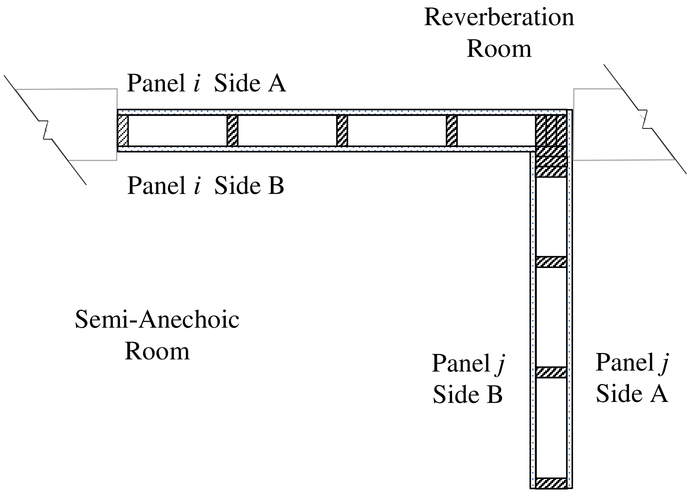

Figure 1. L shaped panels where panel i is mounted between a reverberation room and a semi-anechoic room and panel j extends into the semi-anechoic room.

Panel i had an area of 11.52 m^2 and panel j had an area of 7.87 m^2. The panels were identical except that panel j was shorter (3.34 m) than panel i (4.80 m).

The radiation efficiencies of the panels were measured using different excitation position and sources as shown in Table 1.

Table 1. Measurement Configurations

Case	Excitation	Excitation Side	Measurement Side	Measured
1	Airborne	Panel i Side A	Panel i Side B	σ_T
2	Airborne	Panel i Side A	Panel j Side A	σ_R
3	Mechanical	Panel i Side A	Panel i Side B	σ_R
4	Mechanical	Panel i Side A	Panel j Side A	σ_R
5	Mechanical	Panel j Side B	Panel j Side A	σ_R

As shown in the table, a number of different methods of measuring σ_R are included in the evaluation. When mechanical excitation was used, three excitation positions were used per panel and sixteen accelerometer positions were used on each panel or each shaker position, resulting in forty-eight velocity measurements per panel included in the calculations.

4. Evaluation

4.1 Excitation Methods

The measured radiation efficiencies are compared in Figure 2.

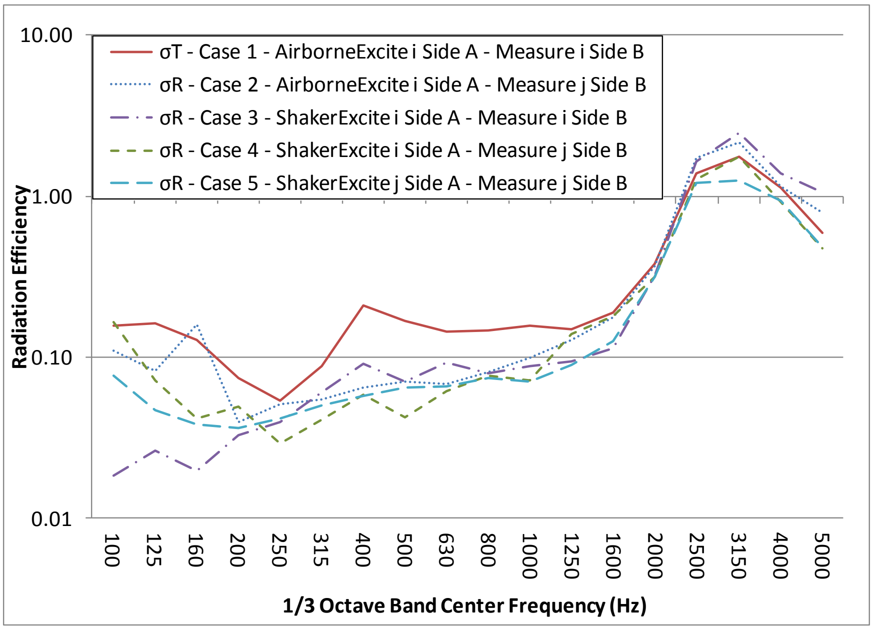

Figure 2. Measured radiation efficiencies. The notation σ_R - *Airborne* indicates that the resonant radiation efficiency was measured and that airborne excitation was used. The measurements using a shaker used at least three excitation positions. The measurement σ_R - *Airborne - Excite j Side A - Measure j Side B* used six excitation positions.

The figure shows that the magnitude of σ_T below the critical frequency is higher than the majority of the measurements of σ_R as would be expected. The differences between the magnitudes of σ_T and σ_R in the figure demonstrates the importance of using the correct excitation for the measurement of the terms.

Exciting panel j indirectly via panel i (Cases 2 and 4) or with the shaker directly attached to panel j does not make a significant difference in the magnitude of σ_R other than at 160 Hz. The curves of σ_R are similar in shape and have 95% confidence intervals which mostly overlap as shown in Figure 3 with the exception of Case 3 below 200 Hz. The lower values for Case 3 could be attributable to the different dimension ratios of the two panels or affected by the workmanship. For example, if the gypsum board was screwed with different tightness on the two panels, the radiation efficiencies could be affected.

The uncertainty of the measurements as determined from the standard deviation of the velocity and intensity measurements are compared in Figure 4. The uncertainty for Case 5 includes six times the number of measurement positions of the velocity as compared to the other measurements and therefore was expected to have a lower uncertainty which is shown to be the case over much of the frequency range.

The uncertainties of all of the σ_R are shown to be much higher than the uncertainty of σ_T around the critical frequency. The higher uncertainty was due to the larger variance around the critical frequency in repeat measurements of the intensity rather than due to the variance of the measurements of the velocity.

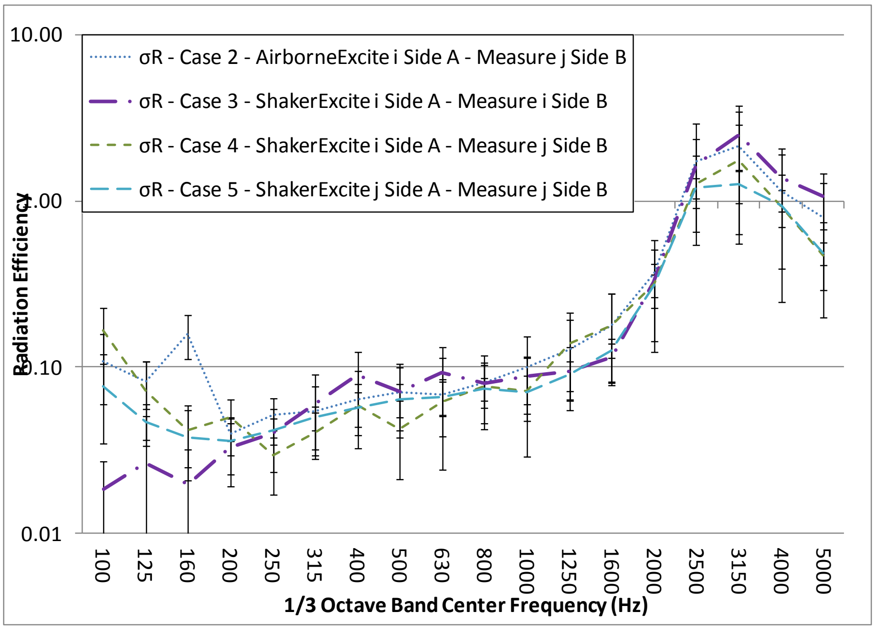

Figure 3. Measured values of σ_R with 95% confidence intervals.

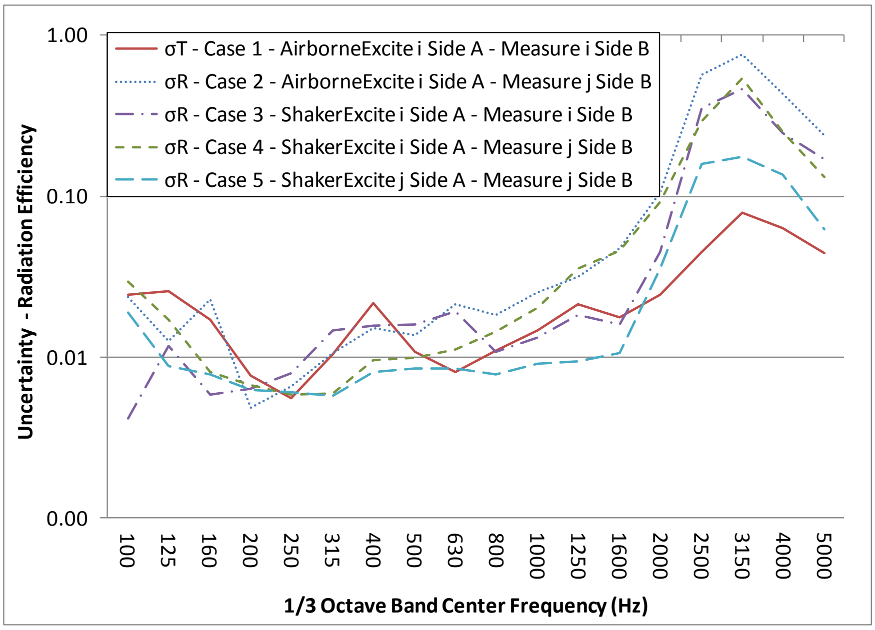

Figure 4. Uncertainty of σ.

The uncertainty of σ_R for Case 2 where airborne excitation was used was higher than for the other values of σ_R over much of the frequency range. Using the shaker instead of the airborne noise source to excite panel j through the connection with panel i for Case 4, resulted in an uncertainty which was similar to Case 5 up to 500 Hz despite Case 5 including more samples.

Exciting the double-leaf wall directly on the side opposite the velocity measurements resulted in the lowest variance in the intensity measurements. However, if the experiment were repeated with single leaf panels, the differences between Cases 2 and 4 and Case 3 would be expected to be much larger due to the influence of the point force on the velocity level for Case 3.

4.2 Measurements on Studs Versus between Studs

A shaker was attached in three positions on Side B of panel j which were on the wooden studs and at three positions on Side B which were between the wooden studs. The velocity level and intensity level were measured on side A of panel j to determine σ_R. The magnitudes and uncertainties of σ_R for these six measurements are compared in Figure 5 and Figure 6.

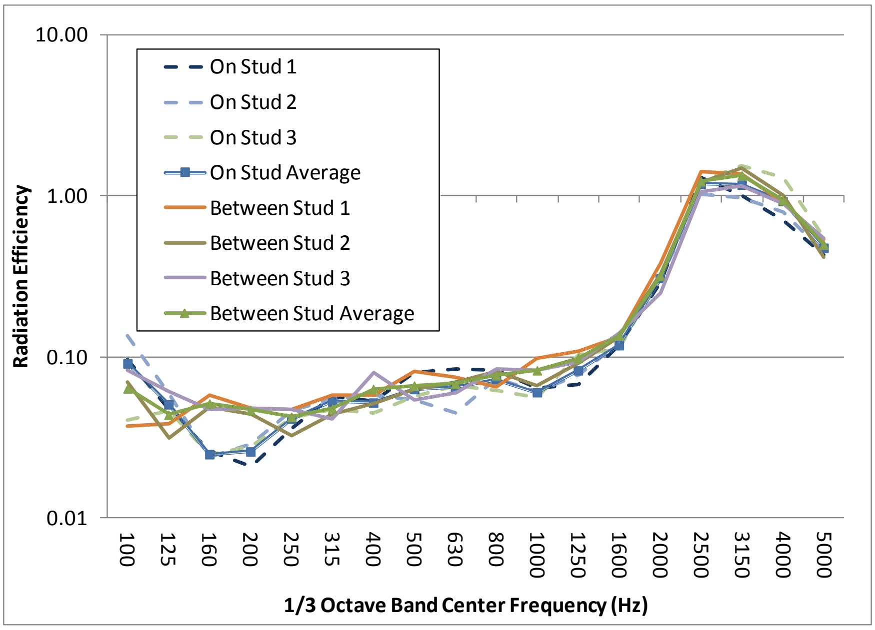

Figure 5. Magnitude of σ_R when the shaker was connected on studs and between studs for Case 5.

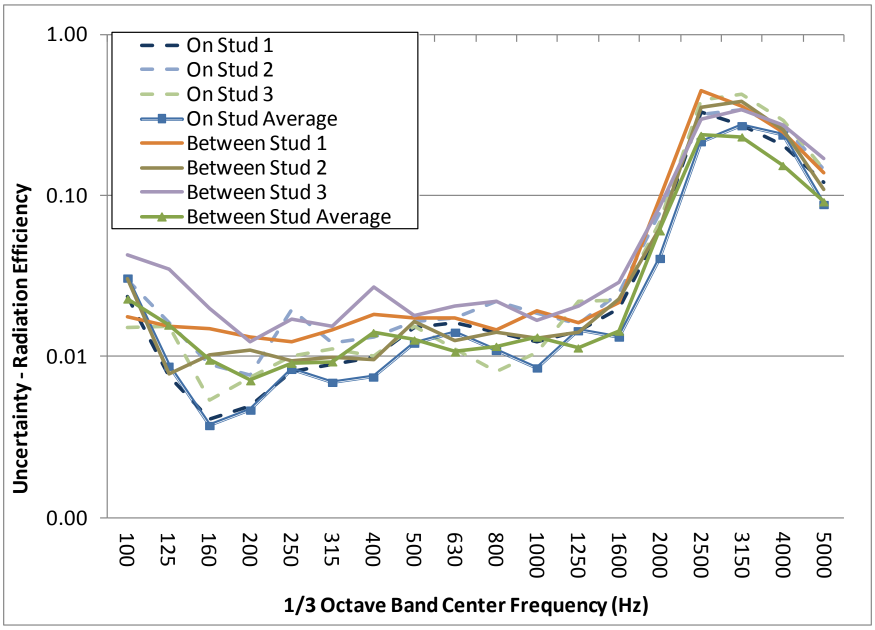

Figure 6. Uncertainty of σ_R when the shaker was connected on studs and between studs for Case 5.

The magnitudes the measurements are all similar with the exception of the dip between 125 Hz and 250 Hz in the measurements made on the studs. The uncertainties of the measurements show that there was more uncertainty in the measurements below 500 Hz when the shaker was located between the studs.

5. Discussion

A standardized method for determining the components of the radiation efficiency is needed if the use of the radiation efficiency components are to be promoted as part of the revision of ISO 15172. Two different methods of exciting the panel must be used to determine the components of the radiation efficiency for building elements with critical frequencies in or above the frequency range of interest. While requirements for the location and number of positions for the measurement of the velocity level may be adapted from ISO 10848, requirements for the method of exciting the panel being tested must also be explicitly specified for the radiation efficiency measurements.

The use of mechanical excitation of a double-leaf panel, either directly or indirectly through a coupled element result in less uncertainty in measurement of the resonant radiation efficiency. The use of airborne noise to indirectly excite the double-leaf panel through a coupled connection (panel i) resulted in a resonant radiation efficiency with a magnitude that was slightly higher than the other excitation methods and which had higher uncertainty. The difficulty in adequately exciting the panel i using airborne noise was the most likely source of the differences between the excitation methods. Higher (but more localized) velocity levels on panel i could be achieved by directly attaching the shaker. Therefore, for the determination of the resonant radiation efficiency shakers are preferred over using airborne noise to indirectly excite the panel being evaluated.

Locating the shaker at the studs as opposed to between the studs resulted in different radiation efficiencies at the low frequencies. Therefore, it is recommended that excitation at points both on studs and between studs be required and averaged when mechanical shakers are used to excite double-leaf panels for the measurement of the radiation efficiency

6. Conclusions

A new standard for the measurement of the components of the radiation efficiency is needed. Different methods of exciting a lightweight building element for the determination of the radiation efficiency components can result in different values. Directly exciting a double leaf element on the opposite side to the velocity level measurements using a shaker and including excitation points both on and off studs are recommended.

REFERENCES

1 "ISO 15712-1:2005 -- Building acoustics -- Estimation of acoustic performance of buildings from the performance of elements -- Part 1: Airborne sound insulation between rooms", International Standards Organization, Geneva, Switzerland (2005).

2 Mahn, J. and Pearse, J., Separation of resonant and non-resonant components-part I: Sound reduction index, *Building Acoustics*, **15**(2), 95–116, (2008).

3 Davy, J.L., Mahn, J.P., Guigou-Carter, C., and Villot, M., The prediction of flanking sound transmission below the critical frequencya), *The Journal of the Acoustical Society of America*, **132**(4), 2359–2370, (2012).

4 Mahn, J. and Pearse, J., The calculation of the resonant sound reduction index for use in EN12354, in: Proceedings - European Conference on Noise Control, (2012), pp. 168–173.

5 Villot, M. and Guigou-Carter, C., Measurement Methods Adapted to Wood Frame Lightweight Constructions, *Building Acoustics*, **13**(3), 189–198, (2006).

6 “ISO 10140-2:2010 -- Acoustics -- Laboratory measurement of sound insulation of building elements -- Part 2: Measurement of airborne sound insulation”, International Standards Organization, Geneva, Switzerland (2010).

7 “ISO 15186-1:2000 -- Acoustics -- Measurement of sound insulation in buildings and of building elements using sound intensity -- Part 1: Laboratory measurements”, International Standards Organization, Geneva, Switzerland (2000).

8 Davy, J.L., Mahn, J., Krajči, L., Wareing, R., and Pearse, J., Comparison of Theoretical Preditions of Radiation Efficiency with Experimental Measurements, in: Proceedings - The 22nd International Congress on Sound and Vibration, Florence, Italy (2015).

9 “ISO 3741:2010 -- Acoustics -- Determination of sound power levels and sound energy levels of noise sources using sound pressure -- Precision methods for reverberation test rooms”, International Standards Organization, Geneva, Switzerland (2010).

10 Heckl, M., The Tenth Sir Richard Fairey Memorial Lecture: Sound transmission in buildings, *Journal of Sound and Vibration*, **77**(2), 165–189, (1981).