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Assessment of sound insulation of sealing solutions, window slits and openings

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Summary
During decades, the sound insulation of sealing solutions of windows and glass facade solution have been a important acoustic topic. Due to Norwegian requirements of various types of buildings, it is necessary to increase the knowledge regarding the sound insulation limitations due to slits and openings for ventilation purposes. The paper presents a collection of results from laboratory measurements of the airborne sound insulation of both single frame windows and double frame windows with various degree of openings. Measurement results are compared with a selection of data from theoretical calculations including the effect of slits and openings. The prediction method is based on analytical equations relevant for this purpose. Several parameters are included in the calculations, but the geometrical parameters describing the slits and openings play an essential part of if. Comparison of measurements and calculations shows a high degree of correlation, generally at low frequencies and when the slits are small. For medium and large size slits, there are deviations at medium and high frequencies, and the calculations generally underestimate the sound insulation at high frequencies. Therefore, it is necessary to do further research on this and include more advanced calculation tools for comparison with available measurement results.

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1. Introduction

The Norwegian building code includes requirements on noise protection in new buildings from exterior noise sources. For residential buildings as well as schools, hotels, hospitals and offices, minimum requirements are given according to tabulated values in the Norwegian Standard NS 8175, see [1]. The sound insulation properties are very often limited by the window solutions and ventilation openings. During decades, the sound insulation of sealing solutions of windows and glass facade solution have been an important acoustic topic. For some years, an additional topic has been limitations due to window slits and openings for ventilation of sleeping rooms in residential buildings. During the last years, introduction of hybrid or naturally ventilated buildings introduces a third argument for studying the sound transmission through slits and openings. Due to the Norwegian requirement also for office buildings, research is needed on this topic. The paper presents a collection of results from different projects and compare the data with theoretical calculations including the effect of slits and openings.

2. Laboratory measurements

The laboratory measurements on the different window solutions were performed in the sound transmission laboratory at SINTEF Building and Infrastructure in Oslo in accordance with standard NS-EN ISO 10140, part 1-5, see [2] and evaluated according to NS-EN ISO 717-1, see [3]. Results presented in this paper is a collection of data from two independent test setups carried out over some years, see [4] and [5]. The two test setups totally include about 45 measurements on different combinations of window type, sealing solution, slits and openings. The goal of this presentation is to quantify the effect of defective sealing, slits and openings and secondly to present data relevant for verification of calculation tools. For this paper, we have therefore selected some of the most interesting data among these. Table 1 shows an overview of the different test setup presented in this paper, while figure 1 and 2 shows essential drawings.

Table 1. Configuration of measurement objects

Test	*Glass panels*	*Sealing solution*
A, see figure 1	G1: 4-40,5-4 G2: 4-22-(4-12-4) L1: (8-20-4/1/4) L2:(4-12-4-12-4) N1: (4-15-4) N2: (4-10-4/1/4)	All I and II
B, see figure 3	V1: Double glazing V2: Double glazing with one layer of laminate M1: Double glazing with two layers of laminate	III III IV

I: 10 mm opening in the sealing gasket, two at the upper and two at the lower sealing, see figure 2.

II: Sealing gasket removed giving a slit opening of 5 to 6 mm.

III: Window in tilting position. 50–100 mm space between frame and sill at top (inward opening).

IV: Window in tilting position. 50–100 mm space between frame and sill at bottom (outward opening)

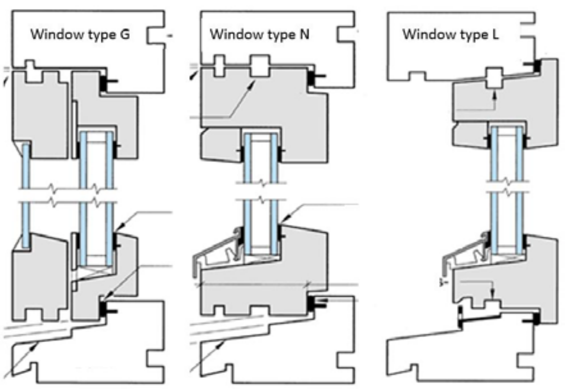

Figure 1. Principle drawing of a coupled frame window (G1 and G2), outward opening window (N1 and N2) and inward opening window (L)

Figure 2. Picture of window N from test A with 10 mm opening in the sealing gasket.

Figure 3. Picture of the tilting position of the outward opening window from test B.

3. Measurement results

In this chapter, different results from the laboratory measurements from [4] and [5] is presented. Figure 4 shows the measured sound reduction index for windows from test A. The collection of data is from measurements with standard configuration of the sealing gaskets.

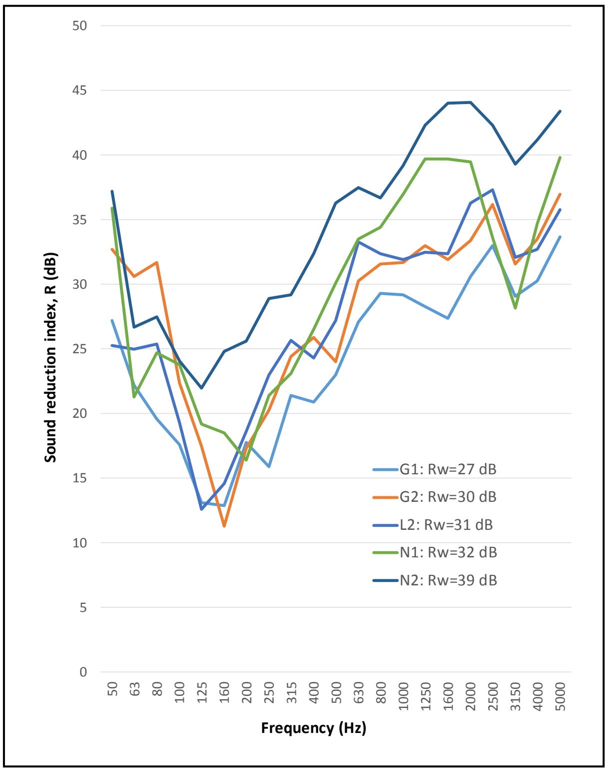

Figure 4. Sound reduction index of five standard configuration windows.

As we can expect, the limitation of the sound reduction index in the frequency range from approximately 100 to 250 Hz is likely determined by the double and triple wall resonances of the different glass panels. In the high frequency range, the limitations are mainly determined by a combination of the critical frequencies of the glass panels and limitations of the sealing solution. This paper only focuses on the effect of the sealing and openings, and further evaluation of the overall sound insulation properties will are therefore not given. However, in table 2, the single number values are given for all relevant objects presented in this paper.

Figure 5 shows the difference between measured sound reduction index for the standard configuration of sealing gasket and similar results with 10 mm opening in the sealing gaskets. Figure 6 shows similar difference between results from the standard configuration of sealing gasket and results with the gaskets removed, giving a slit of 5 to 6 mm in the space between the frame and sill.

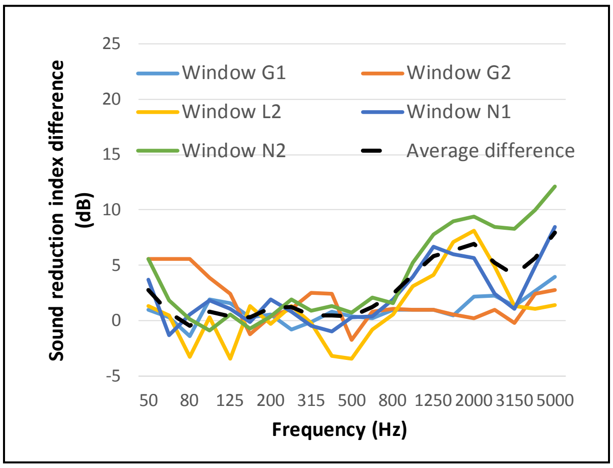

Figure 5. Sound reduction index differences due to 5 x 10 mm spaces in the sealing gaskets

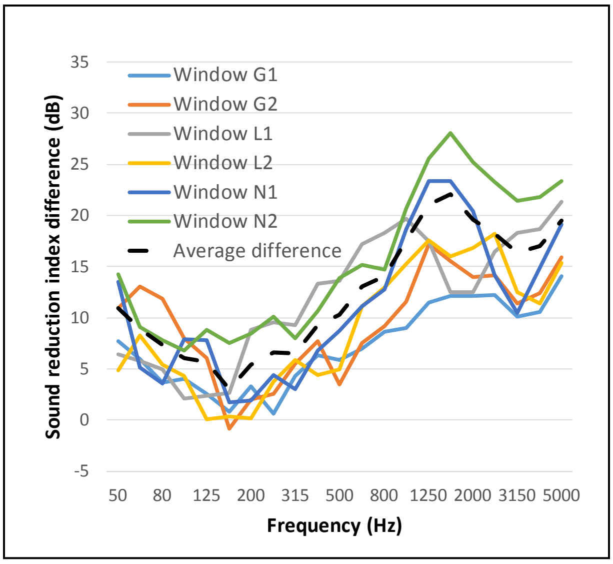

Figure 6. Sound reduction index differences due to 5 to 6 mm space between frame and sill

Generally, the measurement results from figure 5 shows a significant difference only at higher frequencies. For object G2 the difference is significant only at low frequencies, probably due to the coupled frame window type. Below 630 Hz, the average values of the differences becomes non-significant. Above approximately 630 Hz there is a significant decrease of the sound reduction index due to the openings in the sealing gaskets. Measurements results presented in figure 6 shows generally a significant difference at all frequencies, but with a spread of 5 to 10 dB in the whole frequency range. As we can expect, the difference increase towards higher frequencies.

Figure 7 shows measured sound reduction index for windows from test B. The collection of data is from measurements with standard configuration of the windows and with the same windows in the tilting position.

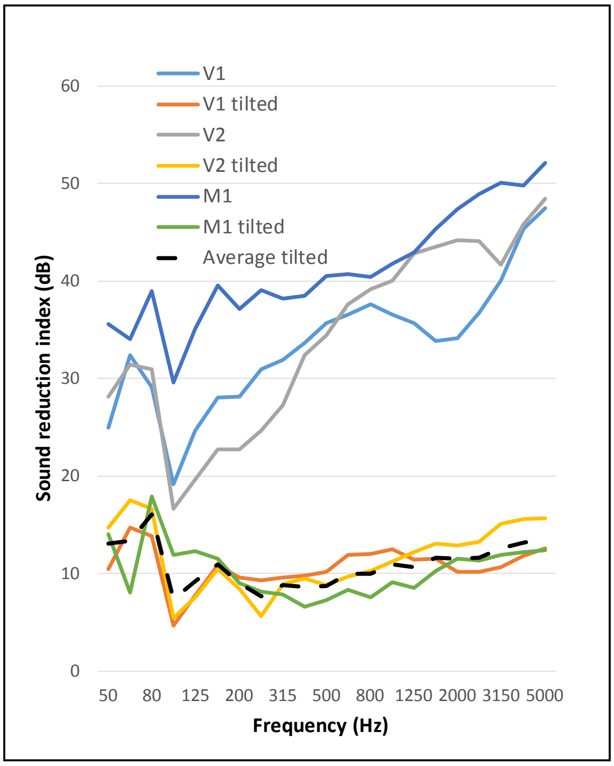

Figure 7. Sound reduction index from test B with windows in respectively closed and tilting position.

Figure 7 shows that the tilting position have a major influence on the total sound reduction index of the window, independent of the sound insulation properties of the glass panels itself. In the low frequency range there are some spreading, probably due to geometrical differences of the tilting frames. Towards higher frequencies, the sound reduction index become slightly increasing.

Table 2. Single number values from measurements of windows in test A and test B

Window type	*R_w (dB)*			
	Closed position	*Nx10 mm space* [1)]	*Sealing gasket removed*	*Tilting position*
G1	27	26	19	-
G2	30	29	20	-
L2	31	29	18	-
N1	32	30	19	-
N2	39	34	19	-
V1	36	-	-	11
V2	37	-	-	12
M1	43	-	-	9

[1)] In sealing gasket

4. Sound insulation calculations

Several calculation methods exist concerning sound transmission through apertures and slits. Some of the methods limit the calculations to open apertures and slits, while other takes some type of sealing or fillers into account. In this case, the method presented in [6] has been used. The reason for this is the absence of sealing gaskets of objects both from test A and test B. Essential formulas are given in equation (1) to (4).

$$R_{slit-gen} = 10log[(2n^2 sin^2(K_s(L_s + 2e_s) + 2K_s^2)/mK_s)] \; when \; K_s < 1{,}5$$

$$\text{and} \;\; R_{slit-gen} = 0 \; when \; 1{,}5 < K_s < \infty \qquad (1)$$

$$K_s = \frac{2\pi f \beta}{c} \qquad (2)$$

$$L_s = L\,\beta \qquad (3)$$

$$e_s = \frac{1}{\pi}\left(L\,n\left(\frac{8}{K_s}\right) - 0.58\right) \qquad (4)$$

$$m = 8 \; for \; a \; thin \; slit$$

$$n = 1 \; for \; a \; slit \; at \; a \; plane \; wall$$

$$\beta = slit \; width \; (\text{m}): L = slit \; dept \; (\text{m})$$

$$L = 50 - 70 \; mm \; for \; window \; G \; and \; N$$

This method does not take the length of the opening into account, only the slit with and depth. For the cases with 10 mm spaces in the sealing gasket, the slit width has been "normalized" to an evenly distributed slit width. Initial calculations showed that the calculation results were inconclusive for objects with a certain slit width. To improve the performance, a second calculation procedure has been introduced. From reference [7], equation (5) has been used to improve the calculation results at lower frequencies. According to this method, the sound reduction of the slit itself only depends on the total opening area between the frame and sill and the frequency.

$$R_{slit-lf} = 10log\left[1{,}09\cdot10^{-4}\left(\frac{\sqrt{S}}{2}\right)^{2} f^{2} + 0{,}72\right] \quad (5)$$

$$when\ \pi\cdot\frac{f\cdot S}{c} \ll 1$$

$$S = slit\ area\ (m^2)$$

The total sound reduction index has been calculated for a combination of the individual sound reduction index of each window panel and the corresponding sound reduction index from calculation of $R_{slit\text{-}gen}$ (general) and $R_{slit\text{-}lf}$ (low frequencies) according to the basic expression (6) for the combined sound insulation, from [8].

$$R_{tot} = 10log\left[\frac{S_{window} + S_{slit}}{\sum\left(S_{win}\cdot10^{\frac{-R_{win}}{10}} + S_{slit}\cdot10^{\frac{-R_{slit}}{10}}\right)}\right] \quad (6)$$

5. Comparison

Comparison of measured and calculated sound reduction numbers are presented in the following. Results concerning window type G1 and G2 are presented in figure 8 and results concerning window type N1 and N2 are presented in figure 9, all of them with 10 mm openings in the sealing gaskets.

The comparison shows that the calculation of the total sound reduction index combining contributions from R_{window} and $R_{slit\text{-}gen}$ correlate very well with measurement results in the entire frequency range, except in the low frequency range of window G2. This is also supported by similar calculations and comparison presented in [9].

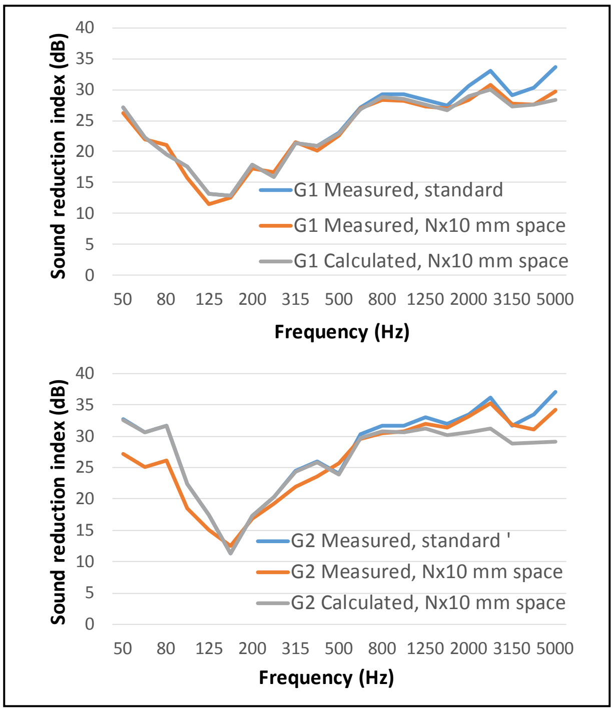

Figure 8. Comparison of measured and calculated sound reduction index of G1 and G2 window with 5 x 10 mm openings in the sealing gaskets.

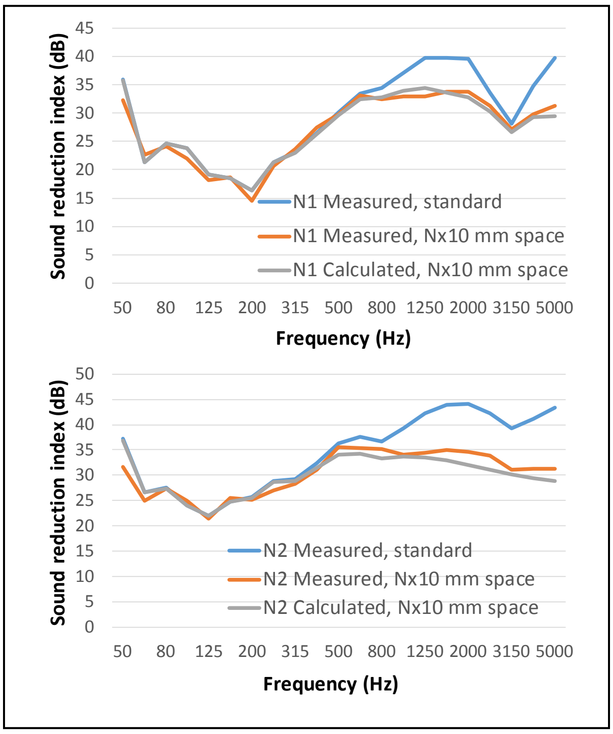

Figure 9. Comparison of measured and calculated sound reduction index of N1 and N2 window with 6 x 10 mm openings in the sealing gasket.

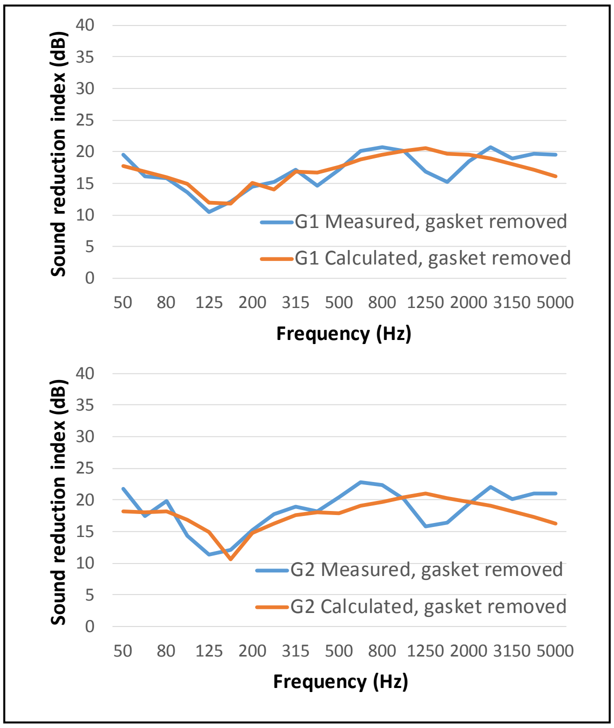

Figure 10. Comparison of measured and calculated sound reduction index of G1 and G2 window with the sealing gaskets removed.

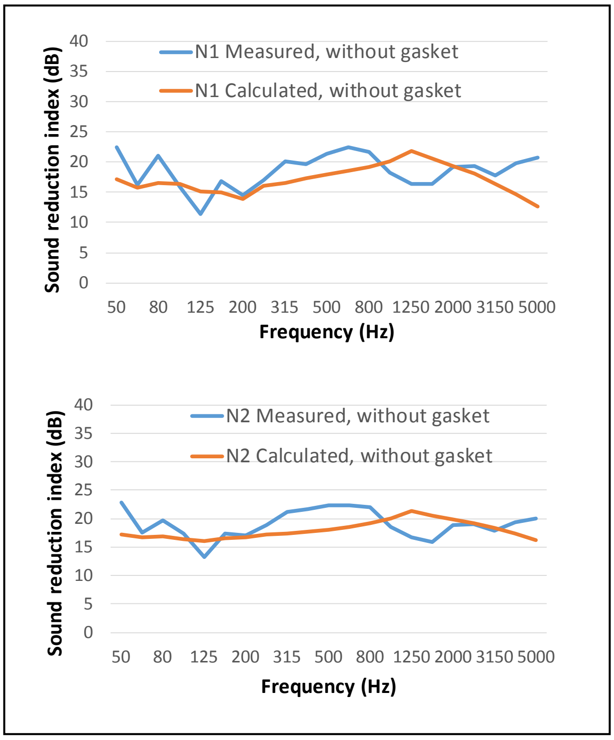

Figure 11. Comparison of measured and calculated sound reduction index of N1 and N2 window with the sealing gaskets removed.

Results concerning window type G1/G2 and N1/N2 are presented in figure 10 respectively figure 11. These examples include solutions with the sealing gasket removed, giving a slit opening of 6 mm respectively 5 mm.

The comparison shows that the calculation of the total sound reduction index combining contributions from R_{window} and R_{slit} correlate well in part of the frequency range, but not that good at medium and high frequencies. All these calculations have been performed with a combination of $R_{slit\text{-}lf}$ and $R_{slit\text{-}gen}$. Generally, the correlation between measurements and calculations are good in the low frequency range. From what we can conclude that the formulae (5) gives a good estimate of the R_{slit} contribution in these cases. But the given frequency limitation due to typical slit dimension is important. At higher frequencies, typically 1250 to 1600 Hz, the calculation overestimate the sound insulation. The measurements show consequently a drop in the sound reduction index at 1250 and 1600 Hz, which is not visible with the gaskets installed, se figure 4. These frequencies correspond to a theoretical space opening of 106 to 136 mm. Above approximately 2500 Hz, the calculations generally underestimate the sound reduction index. A reason for this may be some absorbing effects at high frequencies, which is not included in the theoretical equations.

Results concerning windows in a tilting position are presented in figure 12. The figure shows the average sound reduction index from measurements compared with the calculated results based on R_{window} and $R_{slit\text{-}gen}$. The use of equation (6) regarding $R_{slit\text{-}lf}$ is not relevant because of the frequency limitations due to the opening space dimensions.

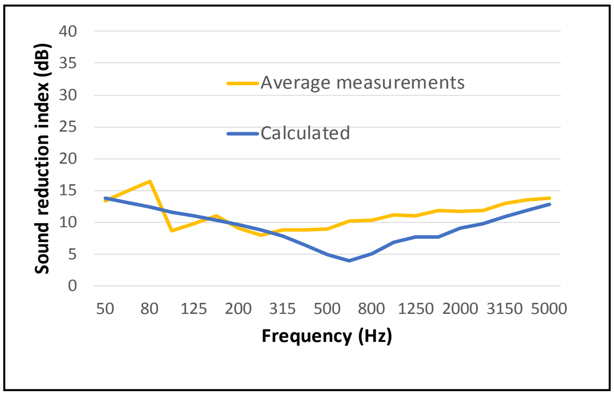

Figure 12. Comparison of measured and calculated sound reduction index of windows from test B in the tilting position.

The comparison shows that the calculation of the total sound reduction index correlate relatively well in the low frequency range and the high frequency range. In the middle frequency range, the calculation underestimate the sound reduction index up to approximately 5 dB. No measures have been taken to improve this calculation result because the opening space is not exact given. The outward or inward tilting direction may also influence the measurement results, but the simplified calculation tool does not include such conditions.

6. Conclusions

In this paper, two analytical methods have been presented to calculate the sound reduction index of the slit in a window, wall or door opening. Due to frequency limitations in equation (6), the formulae are only relevant for relatively small slit dimensions. A combination of the methods shows a high degree of correlation at low frequencies and generally in the entire frequency range for small slit dimensions. For increasing slit dimensions, deviation occur at high and partly medium frequencies. Generally, the calculation method underestimates the sound reduction index in the highest frequency range, probably due to the lack of sound absorption contribution in the formulas.

The analytical methods limit the calculations to open apertures and slits. Neither sealing, fillers or acoustical absorbing materials have been taken into account. For single frame windows this limitation is relevant, but for other purposes as double frame windows, double facades, ventilation components and similar openings in the façade, the contribution from sound absorption need to be included. Therefore, it is necessary to do further research on this and include more advanced calculation tools for comparison with available measurement results. Measurement results from for instance [4] and [7] should be relevant for development and verification of improved calculation tools.

Acknowledgement

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