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MEASUREMNT OF FACADE SOUND INSULATION: INFLUENCE OF LOUDSPEAKER TYPE

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ABSTRACT

The measurement of the sound insulation of facades is standardised in ISO 16283-3. There, the measurement direction is from outdoors to indoors. The facade is excited either by existing traffic noise or by a loudspeaker. The standard permits the use of a facade speaker or an omnidirectional one. To investigate the sound fields in the plane of the facade produced by different loudspeaker types, measurements with a dodecahedron and a facade speaker are performed in the hemianechoic room at PTB on a hemispherical surface. Measured sound pressure levels are then projected to hypothetical facades. Observed sound pressure level differences on the facades are then compared to the maximum permitted values given in ISO 16283-3 and to the directivity of both speaker types measured in free field.Furthermore, results from an interlaboratory test with about 90 participating laboratories are analysed. In this test, the element loudspeaker method was used to determine the apparent sound reduction index of a terrace door made of glass. Since participants used either dodecahedrons or facade speakers, possible differences between results obtained with different loudspeaker types can be analysed. Since these measurements took about three years, additional effects like temperature changes are also considered.

Keywords: *sound insulation, facade, measurement, dodecahedron, facade speaker.*

1. INTRODUCTION

Within the ongoing revision of ISO 16283-3 [1], the question was raised what the influence of the loudspeaker type and especially its directivity is on the measured sound insulation of facades. This question is investigated in this contribution by performing directivity measurements in a hemianechoic room with a dodecahedron and a facade speaker and by analysing a large data set of measured facade sound insulations.

2. REQUIREMENTS FOR LOUDSPEAKERS TO BE USED IN FACADE MEASUREMENTS

The current version of ISO 16283-3 [3] gives two general options for the choice of the loudspeaker type. One is to use an omnidirectional one - usually a dodecahedron - where its directivity is qualified according to a procedure given in the standard. The other is to use a loudspeaker with such a directivity in a free field that the local differences in the sound pressure level in each frequency band of interest are less than 5 dB. These local differences are measured on an imaginary surface of the same size and orientation as the test specimen. For large specimens where one dimension exceeds 5 m, differences of up to 10 dB are accepted.

These requirements raise the question whether the resulting inhomogeneity of the sound field on the imaginary facade is in the same order of magnitude for both loudspeaker types. This question is addressed in [2], [3] and [4]. There, the directivity of different common loudspeaker types is modelled by an appropriate set of pistons of different size. This emission data is then used to predict the sound field on the facade including the effect of a reflecting ground plane and a reflecting facade. It turns out that the free field directivity of the speaker is not a good indicator for the sound field inhomogeneity in real field situations and that usual dodecahedrons produce sound pressure levels on the facade which violate the maximum deviations defined by

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the standard. These findings relate to free field and real field situations.

3. LABORATORY MEASUREMENTS

3.1 Basic idea

The basic idea is to check the above findings by measuring the threedimensional directivity of a dodecahedron and a facade speaker. Fortunately, an existing scanning array [5] with 24 microphones in the hemianechoic room can be used for this purpose. From the measured sound pressure levels on an enveloping hemisphere, the sound pressure level distribution in imaginary facade planes can be calculated and compared to the standardised criteria.

3.2 Measurement setup in the hemianechoic room

The measurement geometry is shown in Figure 1. Measurements are performed with pink noise at one-third octave bands between 50 Hz and 5 kHz. The microphones are mounted on an arc at discrete angles a in a way that each microphone path represents the same surface area. The arc moves continuously in the direction of the angle b. One scan from $b = 0°$ to $b = 180°$ takes 20 minutes. 200 spectra are measured during one scan giving a resolution of 0.9° for the angle b. During the scan, microphones are at a radius of 2.75 m.

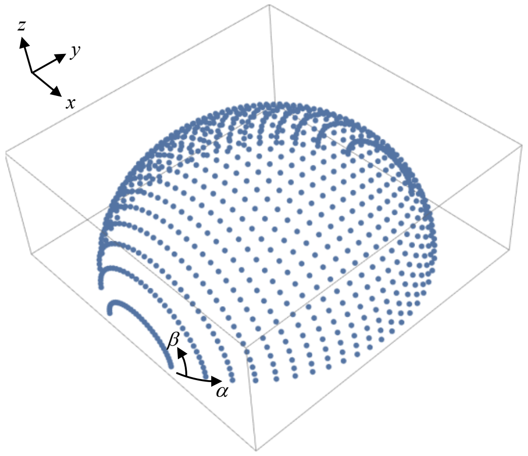

Figure 1. Sketch of the measurement points on the hemispherical surface, displayed resolution of the angle b is 5° whereas the used resolution is 0.9°.

The tested facade speaker is a bass reflex box with a speaker of 28 cm diameter combined with two exponential horns. The "diameter" of the dodecahedron is 43 cm and its speakers have a diameter of 10.8 cm. The sources are measured in configurations as given in Figure 2. The floor of the hemianechoic room was once used in its usual reflecting state and once covered by porous absorbers of about 100 mm thickness.

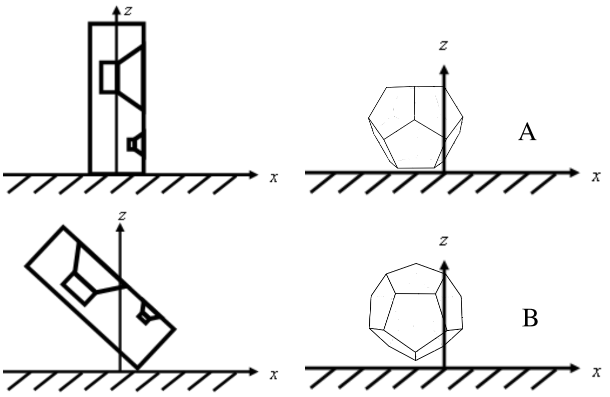

Figure 2. Orientations and positions used for the facade speaker and the dodecahedron.

3.3 Results for the situation "front"

For further analysis, the situations "front" and "side" from [4] are used. The front position means that the imaginary facade is situated in the plane (see also Figure 1).

$$x = D \tag{1}$$

In Eqn. (1), D is the perpendicular distance between the loudspeaker and the facade as defined in [1]. To analyse sound pressure level distributions in this plane, the facade speaker was oriented at an angle of 45° to the reflecting floor as shown in the lower left graph of Figure 2. For the dodecahedron, both displayed configurations A and B are applicable. The sound pressure levels measured on the hemisphere are then projected to the plane of the imaginary facade. For graphical representation they are normalised in a way that only the allowed range between ± 5 dB is displayed (Figures 3 and 4). The size of the displayed form then gives a direct impression of the focussing effect. In the situation "front", the geometric focus is at $y = 0$ m and $z = 5$ m which is marked in Figures 3 and 4. It is obvious that both speaker types exhibit very different sound pressure level distributions. The orientation of the dodecahedron is of a large influence. The absorber on the ground increases the area within ± 5 dB significantly at 500 Hz for all speaker types (Figure 3). At 2 kHz, such an increase is only observed for the facade speaker whereas for the dodecahedron the homogeneous area becomes significantly smaller (Figure 4).

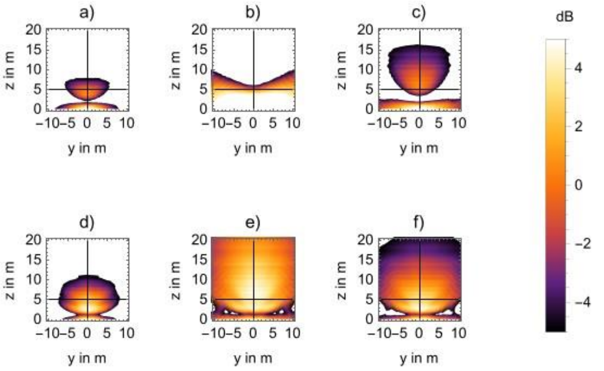

Figure 3. Calculated sound pressure level distributions in the plane of the imaginary facade at 500 Hz in situation front; reflecting floor: a), b), c); absorbing floor: d), e), f); facade speaker at 45°: a) and d); dodecahedron A: b) and e); dodecahedron B: c) and f).

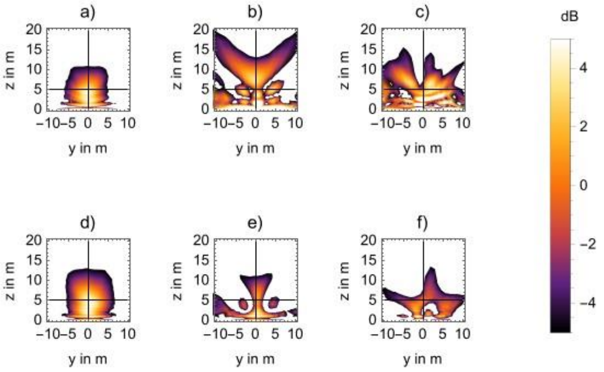

Figure 4. Identical to Figure 3 but at 2 kHz.

In a further step, facade elements of different sizes are assumed around the geometric focus. All these elements have a rectangular shape with a ratio between width and height of 3:2. The maximum sound pressure level differences D$L_{p,\mathrm{max}}$ detected in that plane are shown in Figures 5 and 6 for the dodecahedron in situation A and for the facade speaker, respectively, both with reflecting floor. As expected, D$L_{p,\mathrm{max}}$ increases with the specimen width significantly. The requirement from [1] is met when blue points are below the blue line (for specimens smaller than 5 m) and when brown points are below the brown line (for specimens larger than 5 m). Both sources meet the requirements from [1] at certain frequencies but do not meet the requirements at other frequencies. It cannot be deduced from these graphs that one source gives a more homogeneous sound field in the plane of the facade than the other one. For comparison, also the results of an ideal omnidirectional source at the origin of coordinates is included (marked as ideal and plotted at 6.3 kHz). This source meets the criteria from [1]. Results for the dodecahedron in position B or with absorbing floor are qualitatively similar. They are therefore not displayed.

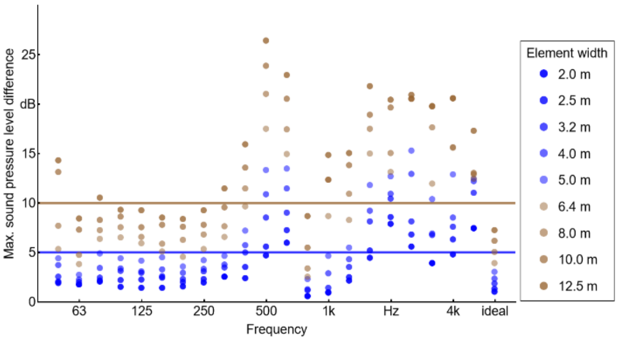

Figure 5. Maximum sound pressure level differences on imaginary facades of different width, dodecahedron A on reflecting floor, situation front

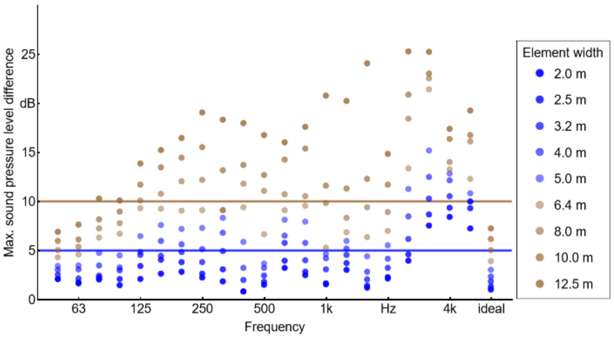

Figure 6. Identical to Figure 5 but facade speaker

3.4 Results for the situation "side"

For the side position, the facade is assumed to be in the plane (see Figure 1).

$$y = x - \sqrt{2}\,D \qquad (2)$$

The respective analysis is based on measurements with the facade speaker in the orientation shown in the upper left graph of Figure 2. For the dodecahedron, again both orientations are applicable. As expected, the resulting sound pressure level differences at 500 Hz (Figure 7) and at 2 kHz (Figure 8) are skewed compared to the situation "front". Furthermore, highest sound pressure levels occur at locations far away from the geometric focus which is caused by the smaller distance to the source in that particular geometry. This effect is more pronounced at 500 Hz (Figure 7) where the sources radiate nearly omnidirectional.

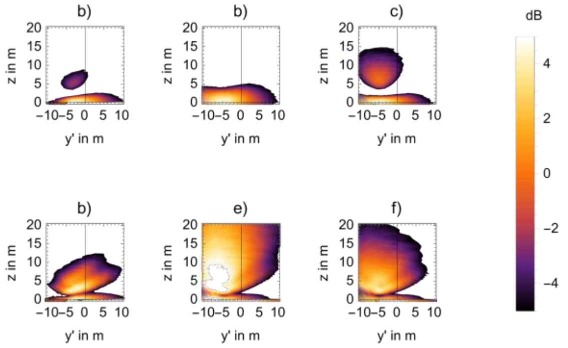

Figure 7. Calculated sound pressure level distributions in the plane of the imaginary facade at 500 Hz in situation side; reflecting floor: a), b), c); absorbing floor: d), e), f); facade speaker at 0°: a) and d); dodecahedron A: b) and e); dodecahedron B: c) and f).

As for the situation front, the maximum sound pressure level differences are calculated for test specimens of different size (Figure 9 and 10). At low frequencies, the requirements from [1] are mostly met whereas considerable discrepancies occur at higher frequencies. This means that only small specimens may be measured in that configuration according to the standardised criteria. In contrary to this, the ideal point source at the origin meets the critera from [1]. It is furthermore obvious that both speakers used in the test provide a similar amount of inhomogeneity.

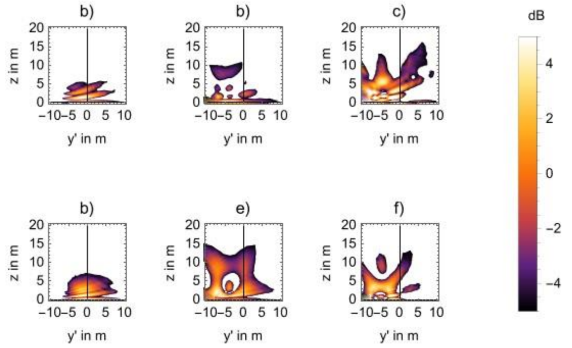

Figure 8. Identical to Figure 7 but at 2 kHz.

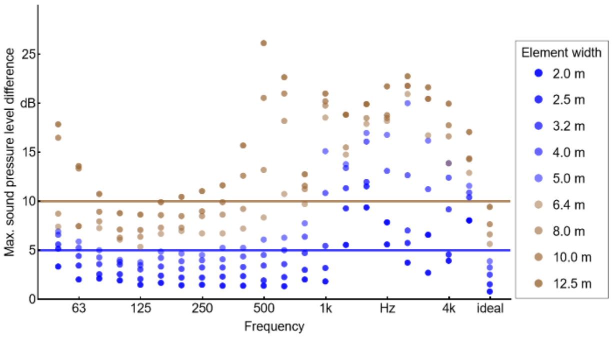

Figure 9. Maximum sound pressure level differences on imaginary facades of different width, dodecahedron A on reflecting floor, situation side.

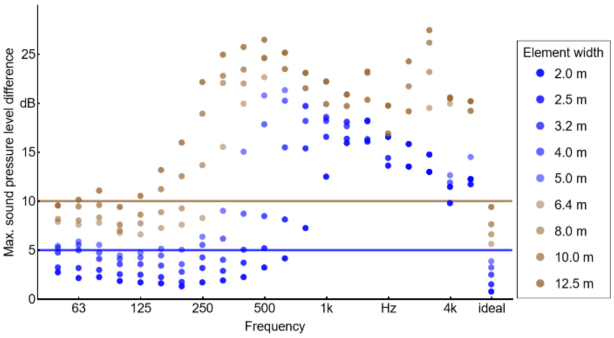

Figure 10. Maximum sound pressure level differences on imaginary facades of different width, facade speaker on reflecting floor, situation side.

4. FIELD TESTS

4.1 Comparison Measurements by VMPA

In view of the above findings, it is interesting to analyse existing results from comparison measurements. They are obtained by testing laboratories which are checked and listed by an association called “Verband der Materialprüfungsanstalten” (VMPA). These testing laboratories are required to take part in comparison measurements once every three years. Over time, these comparison measurements have proven to be an important building block of quality assurance. The measurements encompass three tasks: an airborne sound insulation, an impact noise level and an installation noise level. Furthermore omnidirectional loudspeakers and tapping machines are tested. For each comparison measurement, test specimens are newly selected. The measurement results of the test centers are compared with a reference value from PTB.

4.2 Measurement situation

In the measurement campaign in the years from 2019 to 2021, the apparent sound reduction index of a terrace door had to be determined. This door, shown in Figure 11, is made of a triple glazing 4-6-4 and has two leaves. Individual panes are not laminated. In front of the door, a small roofing was built to protect the microphones from rain. The receiving room is an office with a volume of 63 m^3. The office is placed in the corner of a one-storied production hall.

4.3 Data analysis

All measurements were carried out with the element loudspeaker method according to [1]. 37 laboratories used their own facade speakers, 40 have chosen their dodecahedrons. The measurements covered a period of three years so that there may be an influence of temperature changes. The outer temperature was measured and covered a range from 6 °C to 29 °C. To compare the measurement results obtained with different loudspeaker types, this temperature influence must be taken into account. The temperature coefficients were calculated for each one-third octave band of all results and then this influence was eliminated. An example is shown for the dodecahedron measurements at 2.5 kHz in Figures 12 and 13 before and after the temperature correction, respectively.

Figure 11. Test specimen terrace door.

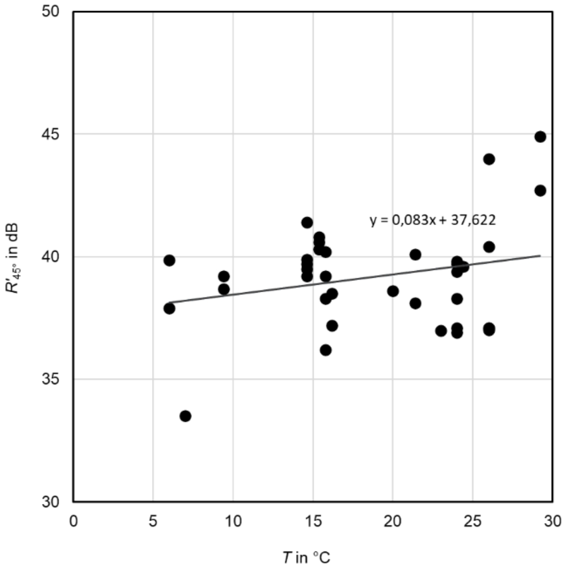

Figure 12. Apparent sound reduction index at 2.5 kHz measured with dodecahedrons.

The corrected results for all measurements are shown in Figure 14, grouped by sound source types. The measurements agree well. The results obtained with facade speakers show a slightly smaller spread. The mean values of both speaker types agree well, except in the vicinity of the critical frequency at 2 kHz (Figure 15) where the difference is about 2 dB. It can be speculated that the measured sound reduction at the critical frequency is more sensitive to the angle of sound incidence than at other frequencies and that different speaker types in combination with the reflecting ground may lead to the observed difference.

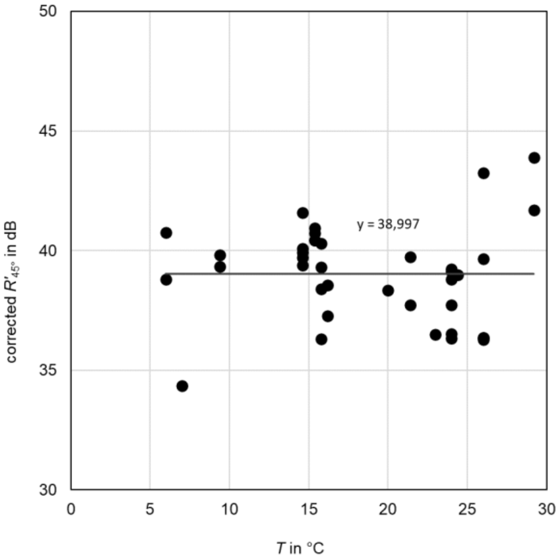

Figure 13. Sound reduction index at 2.5 kHz measured with dodecahedrons and corrected to a temperature of 17 °C.

Also, the in-situ standard deviation is calculated from these measurements. The calculation is performed twice, with and without the temperature correction. It is observed that the correction reduces the standard deviation, but this reduction is very weak at many frequencies (Figure 16). The largest influence of the temperature correction is found for the facade speakers between 800 Hz and 4 kHz. This could mean that facade speakers are more sensitive to temperature changes in that particular configuration or that general standard deviations for the dodecahedrons are so large that temperature effects become invisible or that temperature effects are statistically not independent from the choice of the loudspeaker type. It is furthermore to be considered that reported temperatures are air temperatures outdoors. Due to direct solar irradiation, the temperature of the glazing was significantly higher for some measurements which may also influence the measured sound insulation.

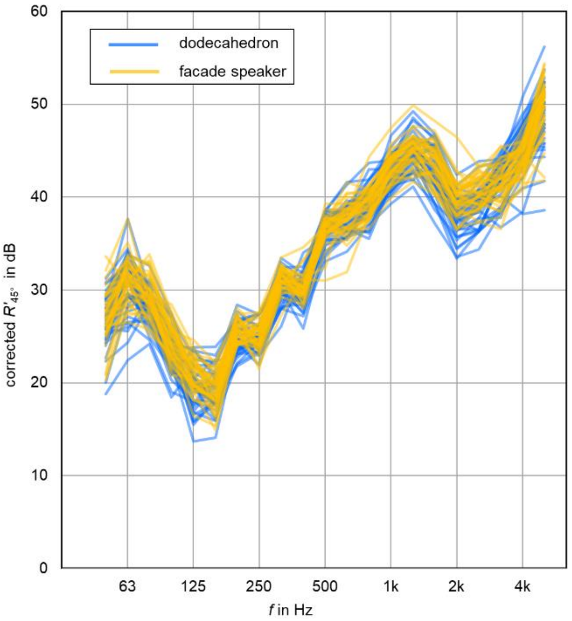

Figure 14. Sound reduction index, all measurements corrected to a temperature of 17°C.

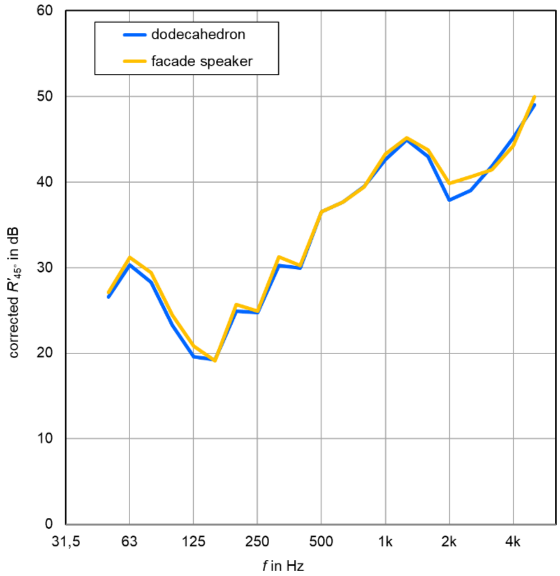

Figure 15. Mean value of the corrected sound reduction index.

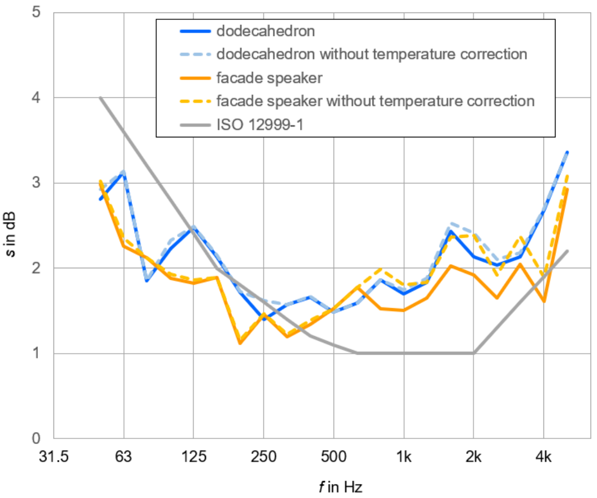

Figure 16. Standard deviation of $R'_{45°}$ for both speakers with and without temperature correction.

Standard deviations from this analysis furthermore exceed the standard deviations given in ISO 12999-1 [7] for frequencies above 250 Hz. This result is obtained for the loudspeaker element method for one particular situation. Nevertheless, if standard deviations from other situations confirm this, an adaptation of the values given in ISO 12999-1 may be appropriate in the future.

5. SUMMARY

Threedimensional directivities were measured for a dodecahedron and a facade speaker. From this, sound pressure fields in the imaginary plane of a facade were calculated. They exhibit significant inhomogeneities for both speaker types which confirms the findings from [2], [3] and [4]. From the above results it cannot be decided which speaker type is to be preferred. With respect to the revision of [1] this means that the current way of handling loudspeaker directivity should be revised.

An analysis of 77 apparent sound reduction indices measured by the element loudspeaker method revealed only minor differences between results obtained with dodecahedrons or with facade speakers.

6. ACKNOWLEDGMENTS

The authors thank VMPA and the participants of the comparison measurements for providing the information on the used loudspeaker type.

7. REFERENCES

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