

# Control of sound insulation in glass facades at Oslo's Opera House

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## ABSTRACT

Oslo's opera house, new in 2008, has several large glass areas in the facades. The site is located in an area with heavy traffic. At the design stage, it had to be taken into consideration that the opera house might have to be useable with traffic noise at a level of  $L_{Aeq} = 70$  dB outside through a period of many years. The façade to the east has large glass areas for several rehearsal halls. Sound insulation against traffic noise into these halls is critical for the success of the opera project and had to be tested. Three of these halls are on level 4 with no access to the outside of the building. The field testing of the actual sound insulation in the finished building presented severe practical challenges. It was not practically possible to measure outdoor and indoor levels simultaneously. Thus great care had to be taken to insure that the sound field was as similar as possible during outdoor and indoor measurements. Two sets of amplifier and loudspeaker were needed to achieve a sufficiently diffuse and repeatable sound field on the outside of these facades. The paper will deal mainly with a description of the practical arrangement of and the results from the measurement. Other aspects of sound insulation in facades have been treated in earlier papers which will be referred to.

## INTRODUCTION

There are three rehearsal halls on the east façade of Oslo's new opera house. All these halls have an external wall with a glass-only facade. The outside of these glass walls are exposed to steady traffic noise of around 70 dB daytime  $L_{Aeq}$ . Strict requirements had been given for the sound insulation of these facades and the indoor levels. The final requirements were as given in the table below.

**Table 1.** Sound insulation and sound level requirements

Room	$L_{Aeq}$ in room	$R_w + C_{tr}$
Rehearsal hall A	20 dB	43 dB
Rehearsal hall B	20 dB	33 dB
Rehearsal hall 4	30 dB	33 dB

Source: Note 68 on sound insulation requirements for facades, last revised januray 5th, 2005 [1]

## MEASUREMENT METHOD

### Situation

The east wall of the opera has no external access. This means that the microphone must be mounted either up from the ground or down from the roof of the building. It would not have been practical at the time the measurements were made to use a lift to make the measurements from the ground up. The measurements thus had to be made lowering the microphone from the roof.

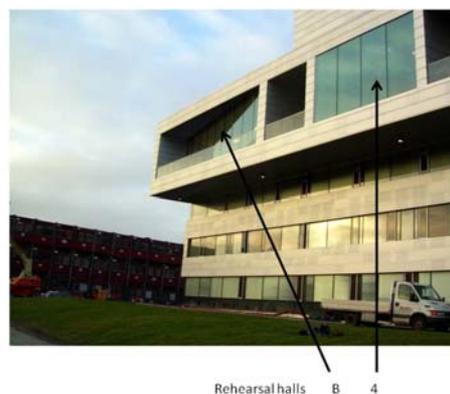


Figure 1, Rehearsal halls B and 4



Figure 2, Rehearsal hall A

### Survey of possible methods of measurements

The main purpose of the measurements was to ascertain that an acceptably low indoor noise level from passing traffic would be achieved.

The international standard for sound insulation measurements of facades in the field [2] gives several options with different accuracy. The options cannot always be compared with laboratory measurements. For these measurements, only two of the options were relevant:

1. Measurements of the sound transmitted through a building element which has substantially poorer sound insulation than the rest of the façade (like a small window in a concrete wall) using a loudspeaker as the sound source, method 1 in the standard, “element loudspeaker”
2. Measurements of the sound through the whole façade using traffic as the noise source, method 6 in the standard, “global road traffic”.

Option 1, “element loudspeaker”, was not possible because the whole façade in question is a uniform glass solution. Option 2, “global road traffic”, was not possible as the measurements would have to be made in daylight for safety reasons. In daytime there’s significant activity on the building site and thus a problem with background noise. There would be no practical way to achieve an acceptable signal to noise ratio through the façade in question using road traffic noise as the source.

Another option could be the “global loudspeaker method” from ISO 140-5. It would not be practical to make the measurements fully according to standard, so a similar method was chosen.

This well tried method of measuring sound insulation through whole facades [3] uses a loudspeaker as the signal source, and measurements are made with a sufficient number of combinations of microphone positions and loudspeaker positions on the outside and microphone positions on the inside. This method was chosen because it was the only known practical way to make the measurements. An important application of the method is when indoor noise level is more important than compliance with laboratory test results for the building elements of the facade.

### Practical execution of the measurements

The main purpose of the measurements was to achieve a good estimate of the indoor level. The chosen method of façade sound insulation measurement is based on mounting the microphone 1-2 m in front of the façade. There’s a known theoretical problem with the method in that there may be a comb filter effect. This is due to destructive interference between direct sound from the loudspeaker and reflected sound from the façade to be tested. The ISO 140-5 [2] mentions a problem with measurements of façade insulation with microphones in front of the façade instead of fastened directly onto the façade. However, the standard only says that this might cause unknown systematic errors at low frequencies.

The measurements were necessary in order to ensure a satisfactory indoor level. For this critical measurement two separate approaches were used to reduce the problem of the comb filter:

- Two loudspeakers were used simultaneously to give a more uniform and diffuse sound field.
- The facades are at an oblique angle, so the microphone was at somewhat varying distances in front of the facades.



Figure 3, loudspeakers and amplifiers in place

For each of the halls, 5-6 microphone positions were used on the outside of the façade. Both the loudspeakers were Norsonic 250’s. One Norsonic 260 and one Norsonic 280 amplifier were used. For the sound level and reverberation time measurements a Norsonic 118 was used.



Figure 4, outdoor microphone position

The measurements were made in November 2007 to allow time for possible adjustments before the opening of the Opera House in April 2008.

**RESULTS OF MEASUREMENTS**

Measured values for the facades were as given in table 2 below.  $R'w$  and  $R'w+Ctr$  are given as standard familiar parameters. The level difference is more relevant for the actual use of the halls.

**Table 2.** Actual measured sound insulation

Room	$R'w$	$R'w+Ctr$	Level difference (A)
Rehearsal hall A	44 dB	37 dB	42 dB
Rehearsal hall B	42 dB	33 dB	41 dB
Rehearsal hall 4	41 dB	37 dB	37 dB

The level difference is calculated using locally measured traffic noise as the source according to a previously described procedure [3].

The analysis was done with the NorBuild software. The measurements method is intended to simulate a measurement between two rooms, so the option of apparent field measurement between two rooms was used.

The  $R'$  curves from the three measurements are shown below together with the reference curve. For all the three measurements the frequency range 200 – 800 Hz is critical for the achieved sound insulation. Figure 5 shows rehearsal hall A, figure 6 shows rehearsal hall B and figure 7 shows rehearsal hall 4.

Rehearsal hall A

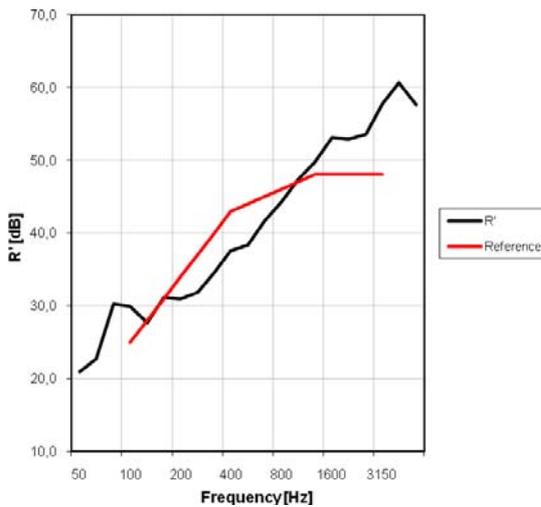


Figure 5, rehearsal hall A

Rehearsal hall B

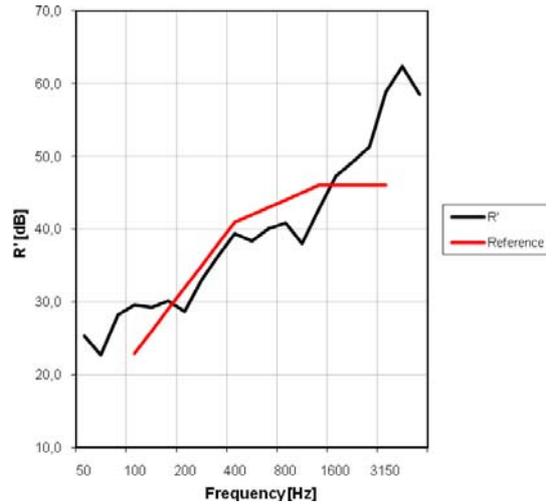


Figure 6, rehearsal hall B

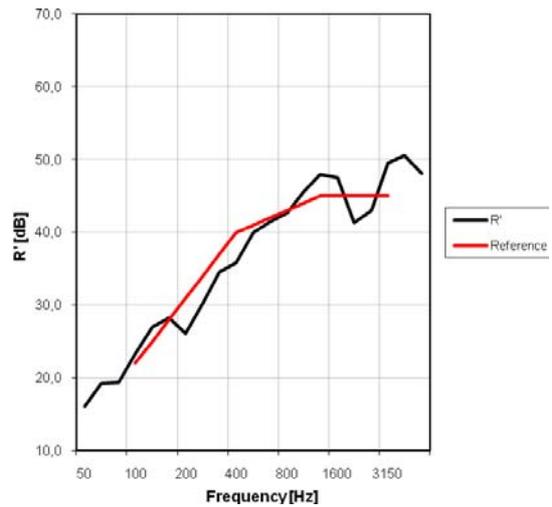


Figure 7, rehearsal hall 4

## MEASURED VALUES COMPARED TO CALCULATIONS AND LABORATORY TESTS

The glass formula used in the facades were expected from laboratory measurements and theoretical analysis to give a value of  $R'_{w+Ctr}$  of 41 dB [4]. The results were  $R'_{w+Ctr}$  of 33-37 dB as shown in table 2. Figure 8 below shows our field results compared to the laboratory results.

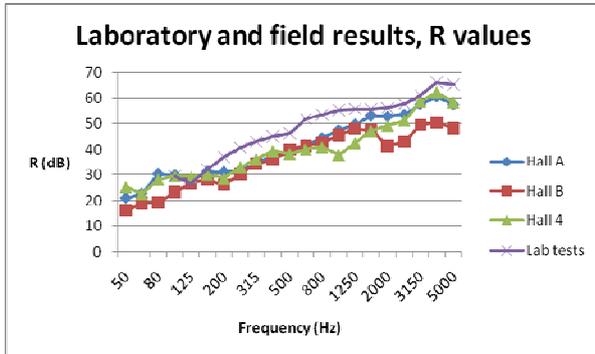


Figure 8, laboratory and field results

Laboratory results from Glaverbel have been quoted.

Three different possible explanations of this have been considered:

- Systematic error due to the measurement procedure
- Quality of design and craftsmanship of details
- Double wall resonances between the glasses

### Possible error due to the measurement procedure

Two loudspeakers were used in order to average out possible problems with destructive interference between direct sound from the loudspeakers and reflected sound from the facade. The outdoor levels from the measurements have been checked.

The most critical frequency range as shown in the curves for the  $R'$  values, is 200 - 800 Hz. ISO 140/5 states that systematic errors may occur in measurement of sound insulation using microphones in front of the façade. Theoretical calculations, not yet published, indicate that these problems could show up as a comb filter effect.

In figure 9 below the measured values outside the facades are shown.

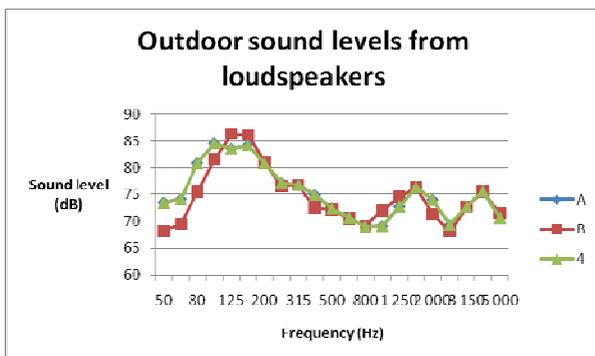


Figure 9, outdoor levels

The spectra look quite what could be expected from the specifications of the loudspeaker and possible ground effects, but there is no indication of a comb filter with repeating dips in the spectrum of the outdoor level. The dip at 2500 Hz has no effect on the resulting sound insulation index, at that frequency range the measured insulation is clearly above the reference curve anyway.

For rehearsal hall A and B the glass façade is at an angle with the rest of the façade leading to a sound field which is difficult to describe. The same applies, however, to loudspeaker noise and traffic noise. Thus it seems safe to assume that the level difference with loudspeaker noise will be the same as with traffic noise.

### Quality of design and craftsmanship of details

It has been shown [5] that the quality of details can effect the achieved sound insulation of glass facades to a large extent. The measurements from rehearsal halls A and B show no clear dips that indicate leakages, the measurement from rehearsal hall 4 has a dip at 2000 – 2500 Hz which could be due to a small leakage.

There was no obvious sign of audible sound leakage during the measurements.

The glass area is very large, and the frame system used in the building is not identical to the one used in laboratory measurements. It's quite likely that this affects the measured sound insulation, but the consequences are difficult to see.

The design and the craftsmanship on site may have influenced the achieved sound insulation.

### Double wall resonances between the glasses

Double wall resonances are well known, and have also been shown to have effect on the sound insulation of a window [6]. This effect, however, would be expected to give the same results in the field as in a laboratory test.

A theoretical modal analysis was performed on a model of the glasses supplied. It's possible that the glasses may exhibit weak sound insulation at low frequencies. Details of the mounting of the glasses may significantly affect the low frequency sound insulation.

## FURTHER WORK

### General knowledge about how to measure façade sound insulation

The field measurements indicate a lower value for sound insulation in the windows than what is expected from laboratory measurements and theoretical calculations. Possible reasons for this discrepancy have been discussed. None of these reasons can be discarded, and none of them can be considered to be shown to be the cause of the discrepancy.

There's a lack of knowledge about the sound field in front of a façade. Thus there is no agreed standard for measurements in cases where it's not possible to comply fully with the requirements of ISO 140/5.

Work is in progress to investigate how this situation can be handled in practice.

## Actions at the Opera House in Oslo

The users find the halls considered to have a quite acceptable indoor noise level from the traffic outside. The traffic is already substantially reduced compared to the design criteria, and further reductions are expected in the coming months as new parts of central Oslo's new underground highway system are taken into use.

## ACKNOWLEDGEMENTS

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## CONCLUSIONS

The sound insulation measurements on the eastern façade of Oslo's new Opera House have been described. The glass walls do not have quite the sound insulation expected from laboratory measurements and theoretical considerations. Possible reasons for this discrepancy have been discussed.

## REFERENCES

- 1 Notat 68. Forenkling av lydkrav i fasader (in Norwegian only). Last revision January 5th, 2005.
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