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Room acoustics in rehearsal rooms and public areas in the new Norwegian National Opera House

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ABSTRACT

The Norwegian National Opera House has a gross area of 38,500 m2 divided into 1,100 rooms and stage areas covering about 8,300 m2. Great care has been taken to ensure good acoustics in the main auditoriums as well as the rest of the building, including a large number of rehearsal rooms, audience areas, administrative and workshop areas. This paper presents a summary of the most interesting results and experiences from measurements outside the main auditoriums. Construction details and chosen solutions for room acoustic treatment are shown. The following areas are covered:

- Room acoustics / reverberation time in the rehearsal rooms, such as those for the orchestra, choir, ballet and small rooms for one or two singers or musicians. Most of these rooms have the possibility of varying the room acoustics. It was important to achieve the right reverberation time, the right diffusion and maintain the option of varying the reverberation. The measurements show that the reverberation time in different rehearsal rooms can be adjusted in a range of 0.2 – 0.4 seconds using curtains and banners.
- Room acoustics / reverberation time in the audience areas such as the foyer and restrooms. In these areas, special solutions are used to integrate architectural expression and acoustic treatment.

ABOUT THE OPERA HOUSE

The Norwegian National Opera & Ballet is the largest stage for music theatre and dance in the country. The house opened on April 12, 2008. In addition to the main auditoriums, the building contains many different types of rooms e.g., large public areas, various rehearsal rooms, workshops and offices. Clear requirements were set for the acoustics in most of the rooms in the building. This paper focuses on the room acoustics in rehearsal rooms and public areas.

Photo: Erik Berg
Figure 1 The Opera house

MEASURING METHODS AND CALCULATIONS

Calculations were done with 3D-simulations using Odeon for the foyer, the rest rooms and orchestra rehearsal hall. For the other rehearsal halls, Sabine and Eyring formulas were used to calculate the needed amount of absorption. Some calculations for sound absorbers were done in Winflag v2.0.

Reverberation time measurements were carried out with starting pistol, or loudspeakers, in large rooms, and by popping balloons in smaller rooms.

THE FOYER

The foyer is the main public area where people buy tickets and meet before performances. The area includes a restaurant and wardrobe. The foyer is also used for informal performances. The volume is about 40 000 m^3.

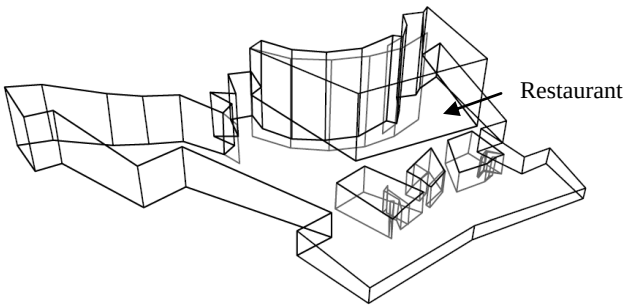
Photo: Jaro Hollan (Statsbygg)
Figure 2 The foyer

Several other known foyers were studied and measured in order to determine the requirements for the room acoustics. Important properties should be:

- Good conditions for communication / good speech intelligibility
- Reduced noise level when many people are in the room.
- The reverberation time requirement was finally set to 1.2 seconds, relatively strict for a room this size.

The architects wanted a marble floor, a façade of glass and a smooth white ceiling. This presented a challenge: how to get sufficient absorption in the room while at the same time achieving the desired architectural expression.

Calculations and auralisations were done with the 3D-modelling software ODEON. A model of the room is shown below.



Source: Anders Buen (Brekke & Strand akustikk)
Figure 3 Odeon model of the foyer

Auralisation was used to show other participants in the project how different materials on the wall would impact the sound environment and speech intelligibility. One of the conclusions from listening tests was that a sound absorbing wall was needed in order to get satisfactory speech intelligibility. Chosen materials in the foyer were as shown below:

- Barrisol Stretch ceiling made of micro-perforated sheets with insulation above, highly absorbing.
- The floor is made of white marble.
- The façade is mostly glass.
- The inner wall has a sound absorbing wooden slat panel with 5 cm mineral wool behind it. The panels have a width of 4 cm, 2 cm space and varying depth. The mineral wool behind the panels is covered with Glava fiberglass clothing.

Measurements of reverberation time shows that the mean $T_{125\text{-}4000Hz}$ is 1.1 – 1.2 seconds. The graph below shows measured reverberation time in octave bands.

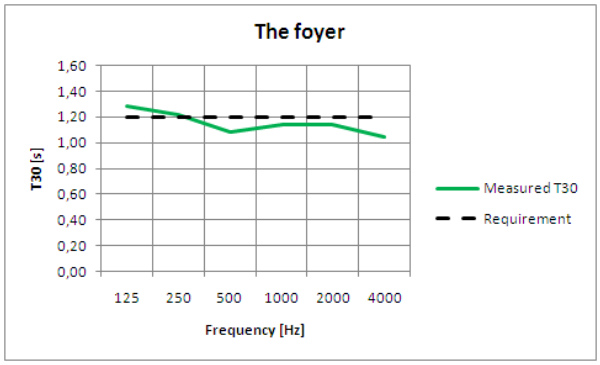


Figure 4 Reverberation time in the foyer

The measured reverberation time meet the requirements very well. Our experience is that the room is perceived as pleasant and comfortable to be in.

THE RESTROOMS

The restrooms are placed as three artistically decorated boxes in the foyer, the men's room, the ladies' room and the handicap toilets.

The architects wanted a solution without doors between the main restrooms and the foyer. The surfaces inside the restrooms should be smooth and polished. The challenges were to:

- Dampen the room acoustically to make it comfortable, despite the demand for smooth polished concrete surfaces.
- Ensure that noise from the restrooms was sufficiently reduced out to the foyer, despite the fact that there are no doors between the foyer and the main restrooms.

The solutions were:

- The ceiling was covered with highly absorbing acoustical plaster, colored dark grey to look like concrete. Polished concrete was used for the walls and floor.
- Lengthen the entrances to the toilets with bends and acoustical plaster in the ceiling. This way the noise is reduced sufficiently out to the foyer.
- The sound insulation for the doors to each toilet cubicle is quite good, even though the doors have no threshold.

The figure below shows plan for the ladies' room.

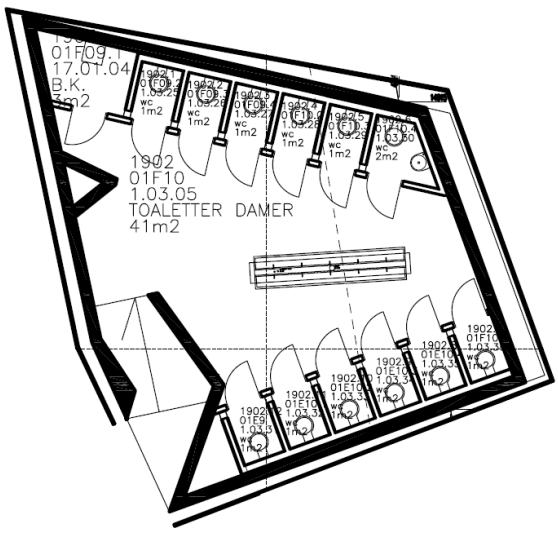


Figure 5 Ladies' room plan

Photo: Per Kåre Limmesand
Picture 6 The men's room

The average reverberation time in the men's room was measured to $T_{125\text{-}4000Hz}$ = 0.6 seconds. The graph below shows the reverberation time in octave bands. The room size is about 40 m^2 with a room height of 2.7 meters.

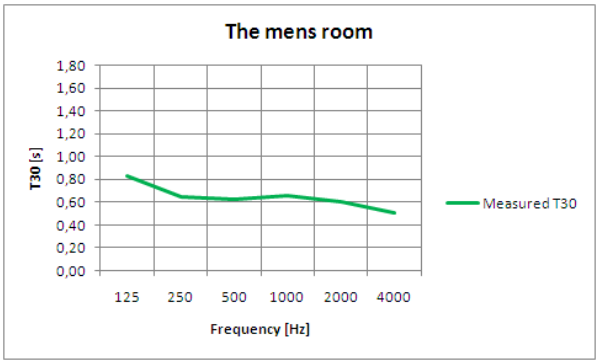


Figure 7 Reverberation time in the men's room

The rest rooms are perceived as acoustically comfortable compared to what you might expect when seeing the room surfaces.

THE ORCHESTRA REHEARSAL HALL

The orchestra rehearsal hall is used by the opera orchestra, possibly also with soloists and a choir. Up to 200 persons can use the hall, which can also be used for recordings. According to the building program, acoustic properties for the hall should be:

- Good sound distribution.
- Enough room volume and room height to control the sound level with a large orchestra and loud instruments.
- Avoid flutter echo.
- Avoid strong room modes.
- Possibility to vary the reverberation, which should be varied between 0.8 – 1.2 seconds.
- Very low background noise, $L_{p,max} \leq 17$ dBA

Chosen solutions were:

- Floor area 400 m^2 and room height about 13 meters
- Non parallel walls to avoid flutter echo and reduce room modes, see plan below.
- Diffusing elements on walls from 0 to 2 meters. Thick absorbing woolen carpets can be extracted manually to cover the walls.
- Wooden slat panel from 2 up to 12 meters on 4 walls. Carpets behind the wood panels can be automatically extracted to add absorption.
- Large arc-shaped lights suspended from the ceiling work as reflectors. The height of these can be adjusted.
- The ceiling has a combination of absorbing and reflecting diffusing elements.

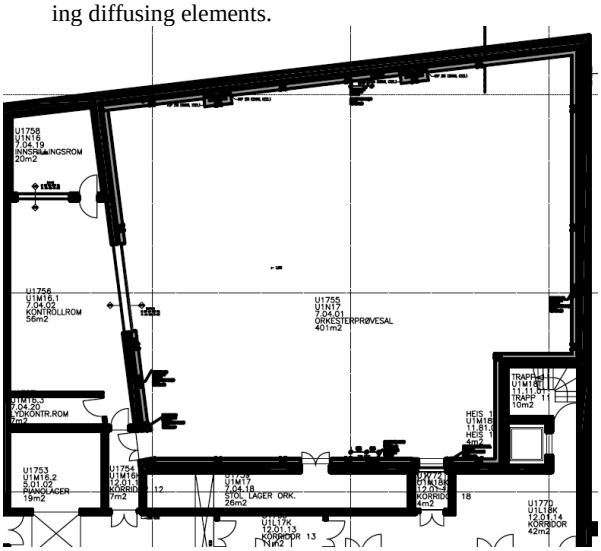


Figure 8 Plan for the orchestra rehearsal hall

Photo: Anders Buen
Figure 9 Orchestra rehearsal hall

Measured reverberation times are shown in the graph below. The measurements were taken in an empty hall, with some of the carpets yet to be mounted, so that the reverberation times could be slightly lower after mounting the last carpets. The dotted lines show calculated reverberation times when the full orchestra is in the hall, based on the measurements of an empty hall.

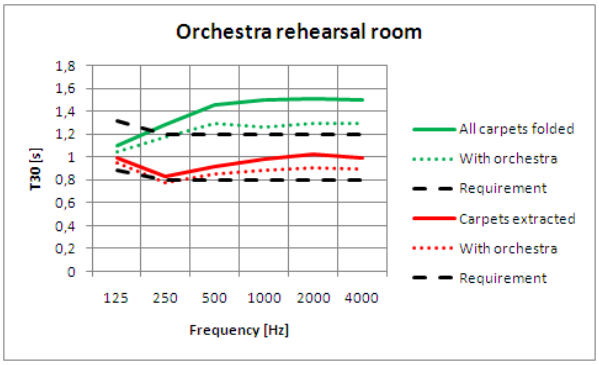


Figure 10 Reverberation time in orchestra rehearsal hall

The results show that the reverberation times are slightly longer than the desired values in an empty room, but meet the requirements well with the orchestra present. The reverberation time can be varied from 0.9 – 1.3 seconds with the orchestra in the hall.

The hall has windows facing heavily trafficked roads passing 70 meters from the façade. In order to achieve high sound insulation in the façade, the windows are made with 2 thick heavy glasses separated with about 70 cm of space, with sound absorbents in the inner frame. Background noise was measured at 17.9 dBA (possibly lower in reality because of noise from the sound meter itself). You can see the big trucks passing outside, but it is impossible to hear them.

According to Gunnar Ihlen, one of the 1st violinists in the orchestra, the musicians are highly impressed with the rehearsal hall. He is amazed by how superior this hall is compared to other rehearsal halls they have played in, including Dresden, Munich, Helsinki and Copenhagen. Important properties are:

- The large volume and room height give the room the right attenuation and reverberation level.
- The wooden slat panels on the walls helps to thin out the reflections in combination with good spread of sound.
- The possibility of varying the reverberation is used frequently, depending on the size of the ensemble and music genre.

An interesting experience is that after using the hall for more than 2 years they now tend to prefer a more damped version of the room when playing music from the Romantic period (often large ensembles), and a more reverberant setting for music from earlier periods (often smaller ensembles). This is the opposite of what is often expected for these music styles.

CHOIR REHEARSAL HALL

The choir rehearsal room is used by the opera choir and can be used by up to 100 singers along with conductor and accompanist (grand piano). Acoustic properties for this room should be:

- Enough room volume and height to control the sound level with many singers.
- Possibility to vary the reverberation time, which should be within 0.7 – 1.1 seconds.
- Good sound diffusion and avoid flutter echoes.

Studies from other choir rehearsal rooms show that the reverb sound level was often too loud for the singers.

Chosen solutions were:

- Room height 6 meters.
- Thick folding carpets for varying the reverberation.
- Diffusing elements on the walls.
- Partly reflecting and partly sound absorbing ceiling.

Notice that the design of the diffusers on the walls is inspired by the architecture of the opera house itself.

Photo: Nina Reistad (Statsbygg)
Figure 11 The choir rehearsal room

Measurements show that the mean reverberation time can be varied from 0.7 up to 1.0 seconds using the carpets. The graph below shows measured reverberation time in octave bands. The measurements were done with no singers in the room, and the graph for 50 persons is calculated based on the measurement with carpets drawn together.

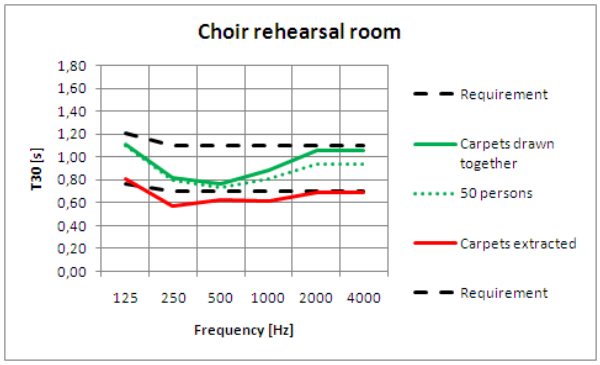


Figure 12 Reverberation time in the choir rehearsal room

According to Allister Kindingstad, one of the singers in the opera choir and an acoustic consultant, the singers are satisfied with the way they can hear themselves and the sound interaction in the choir. The sound level and the reverberation seem to be at an appropriate level. They are also satisfied with the amphi slope that makes the singers at the back sing right above the heads of the singers in the front. A minor disadvantage with the hall is that the speech intelligibility from the conductor to the singers at the back row is perceived as somewhat weak, probably due to limited support. For the singers, an important feature of the carpets is that it can be pulled in front of the corridor windows in order to prevent insight.

BALLET REHEARSAL HALLS

There are 5 ballet rehearsal halls in the building. The room size varies from about 150 m^2 up to 325 m^2. According to the building program, the acoustic properties for these halls should be:

- Good speech intelligibility, as the rooms are used for instruction
- Avoid flutter echoes. This was a challenge because the rooms should have large mirrors on 2 walls, large windows in the façade, and the dancers did not want disturbing items at ear level on the walls.

Photo: Per Kåre Limmesand
Figure 13 Ballet rehearsal room A

Chosen solutions were:

- Room height 6 meters.
- Sound absorbing mineral wool ceiling.
- Light cotton curtains that can be extracted in front of the mirrors to reduce the reverberation and avoid flutter echo.
- Diffusing elements on the walls above the mirrors.

The graph below shows measured reverberation time in one of the ballet rooms (room D). The room size is 215 m^2. The reverberation time is slightly longer than the requirement when the curtains are drawn together, but the deviation is minimal. The graph for 20 persons is calculated based on the measurement with curtains drawn together.

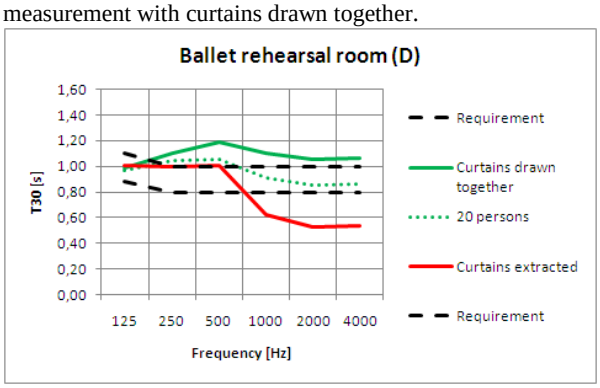


Figure 14 Reverberation time in ballet rehearsal room D

MUSIC REHEARSAL HALL 4

Rehearsal hall 4 is used for musical and director exercises, with floor size about 85 m^2. The room should be suitable for small groups of musicians. The reverberation time should vary between 0.7 and 1.0 seconds.

Chosen solutions were:

- Room height 6 meters.
- Combination of sound absorbing and reflecting ceiling.
- Thick sound absorbing wool carpets that can be extracted on 3 walls.
- Diffusing elements on the walls.

Photo: Per Kåre Limmesand
Figure 15 Music rehearsal hall 4

Measurements show that the mean reverberation time can be varied by as much as 0.4 seconds from $T_{125\text{-}4000Hz}$ = 0.6 up to 1.0 seconds using the carpets. The graph below shows measured reverberation time in octave bands. The dotted graph for 10 persons is calculated based on the measurement with curtains drawn together.

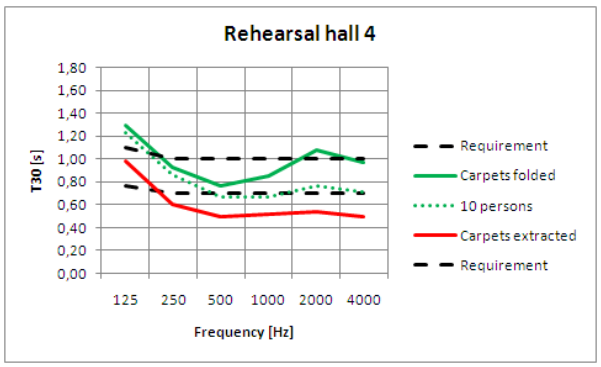


Figure 16 Reverberation time in rehearsal hall 4

OTHER REHEARSAL ROOMS

There are also several other rehearsal rooms in the building that have not been described in this paper. Two large multi-purpose rehearsal halls can be used for director rehearsals, choir with soloists or ballet. These halls also have carpets for varying the reverberation.

There are also several small rehearsal rooms for musicians and singers. These are equipped with sound absorbing plates that can be hooked on rails on the wall, or they can be removed for more reverberation.

CONCLUSIONS

The measurements show that the room acoustic requirements have been met quite well in both public areas and rehearsal rooms.

Experiences from the foyer show that auralisation can be an effective way to communicate to other participants in the project how different materials affect the room acoustics and speech intelligibility.

Experiences from musicians and singers are that they are very satisfied with the acoustics in the rehearsal halls. Measurements show that the reverberation times can be varied 0.2 to 0.4 seconds using carpets and curtains. The possibility to vary the reverberation seems to be used most in the orchestra rehearsal hall, some less used in the smaller rehearsal rooms.

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REFERENCES

1 Per Kåre Limmesand, *Nytt Operahus Oslo - Målinger lydisolasjon, etterklangstid og støy fra VVS*, 2008, (in Norwegian only)
2 Lars Strand, *Nytt Operahus Oslo – Hovedrapport akustikk*, 2004, (in Norwegian only)
3 Anders Buen, *Nytt Operahus Oslo – Romakustiske målinger og tester Scene II og Orkesterprøvesal*, 2008 (in Norwegian only)