KULTURPALAST DRESDEN

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1 INTRODUCTION

Only three months after the opening of the Elbphilharmonie in Hamburg a few hundred kilometers up the river another new concert hall was opened: the Kulturpalast in Dresden.
In the existing building, a monument from the East-German sixties, the former congress hall was demolished and a new vineyard concert hall was realized.
In this paper it is described how the acoustics goals evolved and how they lead the ground structure for this concert hall design. In Dresden the orchestra was strongly involved in the formulation of the acoustic goals. Although it was quite clear that from an architectural perspective the hall should have a vineyard shape, acoustically the demands came closer to the famous classical shoebox halls. Extensive research and intensive design cooperation with the architect led to a hall that can be seen as a combination of the existing vineyard type of hall, but with a sound quality, spaciousness and envelopment that more resembles the classical shoe box type.
This article will contain the formulation of acoustic goals, the redevelopment of the competition design, the influence of the acoustical research on the design and the final measurement results.

2 ACOUSTIC OBJECTIVES FOR THE CONCERT HALL

The program of requirements according to the brief stated:
- "the highest priority of the design is to meet the best room acoustic geometry with regard to the leading concert halls"
- 1,800 seats
- additional 100 choir seats
- 220 m² stage for 110 musicians

As the new hall would be built within the existing building, it was to be preferred that the design of the hall would fit inside the existing hexagon structure of the former hall with a maximum length of 44 m and a maximum width of 51 m.

2.1 Global acoustic objectives, first step

Acoustic parameters are described within the well known standard ISO 3382-1. But apart from the description, there are no specified values which can be called upon as a definite goal for a concert hall, not in this standard, but also not in literature.

In order to set up acoustic requirements for the hall, the first step was to take the average values of the acoustic parameters of 5 well known concert halls which were a good example for the design of the Kulturpalast. Among those halls was the Gewandhaus Leipzig, which was a close by venue and was often named by the client as an example for being an acoustically very pleasant concert hall.

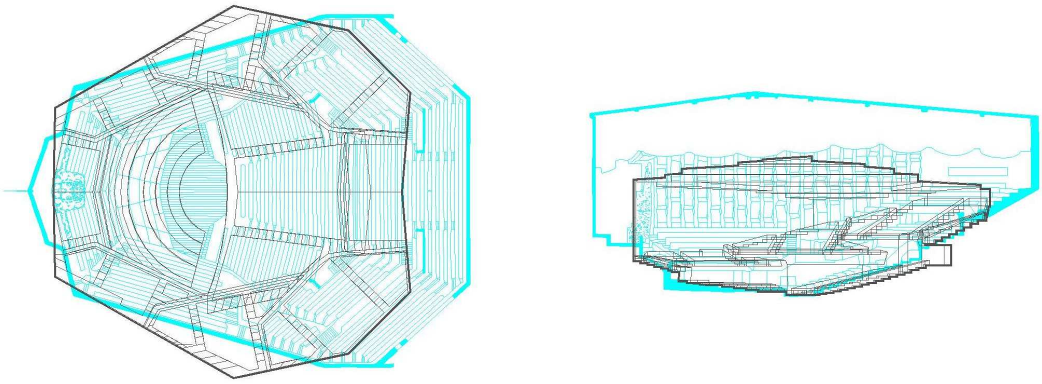


Figure 1. Comparison of the first Kulturpalast' architectural design (in black) to the geometry of Gewandhaus Leipzig (turquoise).

The first proposal for the acoustic requirements was:

	Reverberation time [s]	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Average 125Hz-2kHz
1	Without audience	2.6	2.5	2.4	2.4	2.2	2.1	**2.4**
2	Seated	2.4	2.3	2.2	2.2	2.0	1.9	**2.2**

Early Decay Time EDT	Equal to the reverberation time
Average Strength G	+5 to +6 dB (0.5 – 2 kHz, distance > 10m from source)
Average Clarity C_{80}	-2 to -0 dB (0.5 – 2 kHz)
Support ST	between -15 (-14 preferred) and -12 dB (0.5 – 2 kHz)
Ensemble	Early reflections (< 80ms) from above
Background noise	≤ 20 dB(A)

2.2 Acoustic objectives, second step

Acoustics on itself can't be completely described or understood with the known parameters alone. As with music, acoustics needs to be heard and experienced to get fruitful discussions on what the goal exactly is. Therefore the next step to formulate the acoustic objectives was to organise a concert hall tour to 5 very different kind of concert halls:

- one well known shoebox type hall from around 1900.
- one well known vineyard type hall from the seventies.
- one modern, recently opened vineyard type hall.
- two more or less hybrid type of halls, in between the straightforward shoebox and vineyard type halls.

In all halls we attended concerts with delegates from the client, the architect, other consultants and most important, delegates from the Dresdner Philharmonic Orchestra. All those present filled out a survey with questions on the acoustic perception. The questions did not comprise acoustic parameters, but more comprehensive terminology like reverberance, loudness, balance, intelligibility, direction, audibility (of several instruments), sound quality and so on.
The seats of the participants were spread across the hall in stalls and balcony (in front of the stage), at the sides of the stages and behind the stage. During the brakes, the participants changed seats if possible, which basically doubled the amount of questionnaires.

From the analyzed surveys, it was quite clear that a mix of both hybrid hall types would at average lead to the best combination of reverberation, loudness and transparence. The most recent vineyard type of hall was clearly not the ideal acoustics of the average participant.
For all vineyard and one hybrid kind of halls there was a quite common opinion that the balance was too much in favor of the high frequencies and the low frequencies were low in balance. This seems to be strongly related to the audibility of the low strings, which was judged as insufficient in these halls. For the real vineyard type of halls, the listener envelopment of the sound was judged as (too) modest. The opinion of the participants was that the homogeneity could be improved in all the halls, but was particularly modest in the hybrid kind of halls and bad in the most recent vineyard hall.
An interesting result was that the participants were quite critical about the separate acoustical values of the shoebox hall, but in the overall acoustical opinion it was only the shoebox hall that was judged as "very well" - vs. 3x "sufficient" and 1x "moderate" for the other halls.

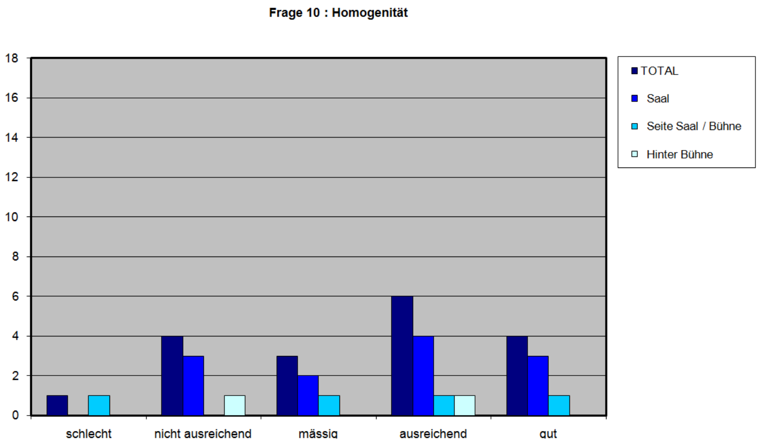


Figure 2. example of an answer of the survey of the concert hall tour.

As for the acoustic requirements of the hall, the original idea to have Leipzig as the best example was sustained, but with the following additions:

- more emphasis on the lower frequencies to improve the audibility of the low strings and to naturally support the "dark sound" which the Dresdner Philharmonic is famous for.
- more warmth in sound quality.
- improved balance and homogeneity from the orchestra on stage.
- very good acoustic conditions on stage for hearing your own and the other instruments and playing together (in time and in sound quality).

The acoustic requirements were extended with the following:

Average Strength G	≥ +5 at average with a minimum of + 2 dB for separate positions	
		(0.5 – 2 kHz, distance > 10m from source)
Average Clarity C_{80}	-2 to - 1 dB with a maximum spread of +/- 2 dB	
		(0.5 – 2 kHz, seated)
Early Reflection Strength G_{5-80}	+3 to +6 dB	(125 - 2000 Hz, at stage)

Besides the acoustical parameters we also find the shape of the impulse responses itself an important acoustical aspect, which we judge on evenness of reflections, strong early reflections, height of reverberation level and of course possible acoustic defects.

3 DESIGN OF THE CONCERT HALL

3.1 Surround sound in a vineyard type hall

Because Peutz up till this project mainly had experience with rectangular or almost rectangular concert halls, we asked Hans Peter Tennhardt and Helgo Winkler to participate. Together with former colleague Rob Metkemeijer they were our "expert team" to whom we presented our ideas and investigation results in order to have our own intern feedback.

Mr Tennhardt was very open and informative about his experiences in the design process and the results of the Gewandhouse Leipzig, of which he, together with Mr. Winkler and Mr Fasold, was the acoustic consultant. His ideas on for instance maximum depth of vineyard terraces helped shape our ideas on how to combine a vineyard hall with reflections from all sides to create a surround sound at all audience places.

The 1st price winning design for the concert hall by gmp Architects had a too small volume (ca. 18,500m³) to accomplish the desired combination of reverberation time (RT) and strength. Theoretically a room volume of about 21.000 m³ is necessary to realize this combination of RT and strength. Besides that, the competition design lacked vertical wall surfaces, as the seating areas had quite a steep angle. Without side and rear wall reflections, there can be no surround sound. The main targets to incorporate the acoustic goals the design process were very much related to:

- increasing the volume
- increasing the amount of vertical wall reflections
- flattening the ceiling shape
- lowering the steepness of all audience areas
- enlarging the stalls, where usually is easiest to create the desired acoustics
- increasing horizontal overhangs to realize 90º angles for reflections in the audience
- decreasing the width of the hall, in order that side wall reflections arrive at the ears before ceiling reflections
- reducing the depth of the terraces in order to provide plural horizontal reflection at all seating areas
- creating early, multiple reflections for the stage area within 80 ms.

A very schematic design concept was drawn to visualize the implementation of these starting points. This schematic design concept was discussed with the architect and led to a further development of the hall's design.

3.2 Calculations with ray-tracing

The main goal of the first ray-tracing investigations was to investigate the influence of several design changes which included the above mentioned aspects, but without losing the important architectural ideas that suited the client very much: intimacy, with the focus on the musicians, warmth and the impression of being close-by.

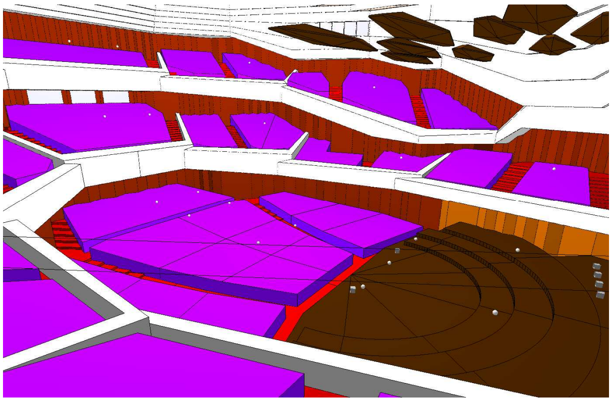


Figure 3. 3D calculation model 2014.

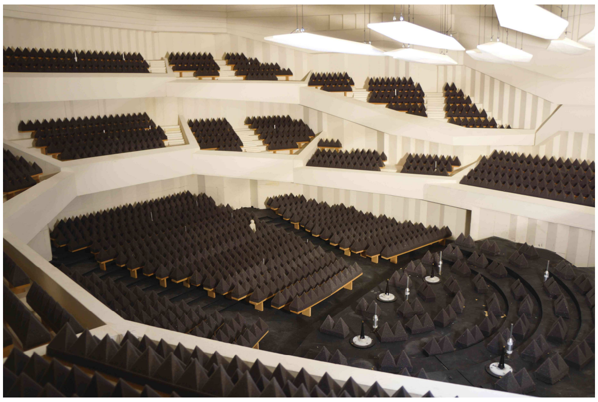


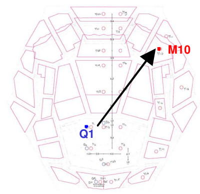
Figure 4. 1:10 Scale Model 2014.

During the development of the design we could achieve a volume increase until about 21,000 m³ and obtain the desired balance between RT, Strength G and Clarity C_{80}. In successive design steps the calculation model was updated to keep control of this balance. Furthermore, the calculation model was used to investigate the best possible combination of materials and their absorption characteristics. Large parts of the walls and floor have a weight of 35 kg/m² with a silenced cavity behind it, a smaller part of the walls is constructed from 100 kg/m² and the ceiling is 20 kg/m² with a large, low reverberant technical floor above it.

3.3 Scale model research

In order to incorporate the wave character of sound, the initial research through calculations was extended with a scale model. A scale model 1:10 was made, details with size 10 cm, in many cases also smaller, were taken into account. Reflecting surfaces are wood with varnish, audience by pyramid foam, simulating an occupied hall, see figure 4.
The scale model was used as a design tool, and not just to check for echoes afterwards. Therefore the first scale model was build at the end of the preliminary design phase in 2012. The main goal of these investigations was to confirm the ground shape of the hall so that the design of the outer concrete construction could continue.
In the first scale model it turned out that in general the results were good, but there was room for improvement as well:
- the reflections from the ceiling were too strong for several positions on the terraces;
- the impulse responses around the stage were highly irregular
- the impulse responses on stage lacked early reflections.

These improvements were realized with increasing scattering structures, around the stage, the choir surroundings and ceiling and a stage reflector.



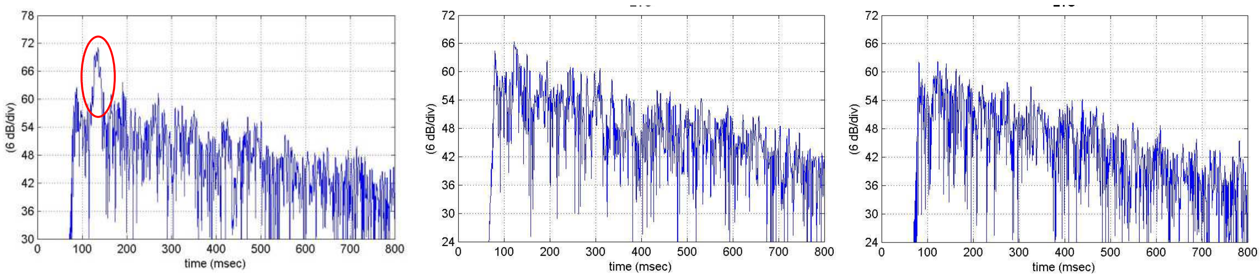


Figure 5. Removal of the very strong ceiling reflections from source Q1 (cello) to microphone M10 in 2013 (left) to a much more regular IR through increasing scattering ceiling structure 2014 (middle) and 2015 (right), (scaled to) 1kHz, scale model measurements.

The second and third phases of the scale model investigation incorporated mainly enhancing the scattering, especially in the ceiling. At one point the duration of the surround reflection in the stalls had the risk of being overwhelming, resulting in a C_{80} of -4 dB. This was reduced by dispersing the abundant side wall reflections over a larger area.

3.4 Stage reflector

From different directions there was heavy resistance against stage reflectors. Bottom-line in this was that a lot of people agreed on the design being more beautiful without reflector and the fear of the reflector blocking the visibility of the organ.

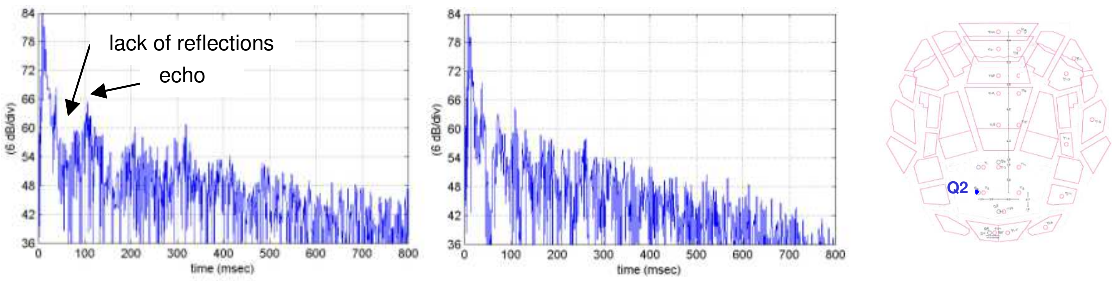


Figure 6. Typical difference in scale model impulse response of a 1m position on stage (hearing your own instrument) at Q2 (trumpets) without stage reflector 2012 (left) and with stage reflector 2015 (right), (scaled to) 1kHz.

To get more insight on the necessity of a stage reflector, we were asked to do measurements in a very well known hall without stage reflectors. The measurements showed that there was a clear lack of early reflections. This measurement result was substantiated by the (subjective) opinion of the users of this particular hall. Besides that, there was a common opinion in the former mentioned survey that the blend of the instruments was insufficient at the side and the rear of the stage.
In the end the desired stage reflectors were incorporated in the design, and can be retracted up to and integrated into the ceiling structure for organ concerts.

3.5 Small scale variability

In order to have the possibility to slightly adjust the acoustics, a part of the vertical ceiling elements (ca. 200 m²) got the possibility to change between reflective and (broad band) absorbing surface. This is not meant as variable acoustics, but to have the possibility to reduce the reverberation time about 0,1 s, in the case such a change would be desirable.

4 ACOUSTICS DURING THE BUILDING PROCESS

4.1 Control of sound absorption - chairs

One of the most difficult aspects to get good control of, is the design of the chairs and their absorption value. As the chairs are almost the only really absorptive element in a concert hall, a slight change of the absorption values has a large impact on the reverberation time, not only in the unseated situation, but often also in the seated situation.
The latter is confirmed by numerous measurements in our laboratory.
Two main aspects prevail in this regard: the reverberation time for the seated situation should comply the requirements and the reverberation time for the unseated situation should not differ too much from the seated situation.

By the time the chairs are designed, the building process of the hall has usually advanced to such a degree, that there is no possible trade off anymore with regard to absorption characteristics. This means that the acoustic requirements of the chairs must be fulfilled, within the bandwidth of laboratory accuracy. With recent developments in foams and textiles, the acoustic possibilities of chairs seem to vary endlessly and it is difficult to control or to predict just by means of foam thickness and air tightness of the textiles. From measurements in the reverberation chamber it turned out that, in this case, the first prototype of the chairs was too absorptive, especially in the seated situation. In several steps, also using interfero measurements of textile and foam, the chairs were changed into an acceptable acoustic result. Reduction of the sound absorption in the seated condition meant a slight increase in the difference between seated and unseated situation.

4.2 Control of sound absorption - slits and holes and other surprises

During the building process several suggested design changes were verified. There was a demand for a raised balcony edge of glass, which was acoustically rejected for too strong reflections. Openings for build-in elements like lights and smoke detectors were closed or covered with an enclosure when necessary, either for the room acoustics or sound insulation. In a mock-up the air-tightness of the joints between building elements was examined with ultra-sound, in order to control unaccounted (low frequency) absorption.

5 THE RESULTS

5.1 Measurement results

In March 2017 measurement were carried out. The hall was not completely finished, several rows of chairs were still missing. Therefore the measurements were repeated in June. The measurements were executed without audience and with audience simulation (special curtains) and in both situations with orchestra furniture on stage.
Measurements of the RT were done with interrupted noise and with a 9 mm pistol, mainly for the 63 Hz octave band. Impulse response measurements were done with an MLS signal and MLSSA computer, and with an omnidirectional sound source. From these data the different parameters, such as clarity were derived. The 1 m positions were used to determine the strength. The measurement positions are shown in figure 7.

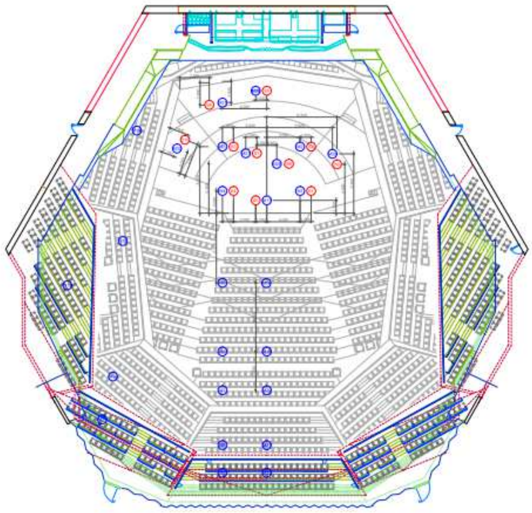


Figure 7. measurement positions, red = source, blue = microphone

	Reverberation time Measured, with 9mm pistol [s]	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Average 125Hz-2kHz
1	Without audience	2.8	2.8	2.6	2.4	2.4	2.3	1.9	**2.5**
2	Seated (simu)	2.6	2.3	2.3	2.2	2.2	2.0	1.9	**2.2**

	Average stalls:	Average terraces:	Minimum:	
Measured Strength G	+5.7 dB	+5.2 dB	+3.6 dB	(seated)
Clarity C_{80}	-1.4 dB	-0.2 dB	-2.6 dB	(seated)

Support ST between -15.1 and - 12.8 dB
Early Refl Strength $G_{5\text{-}80}$ + 5.9 +/- 1.2 dB

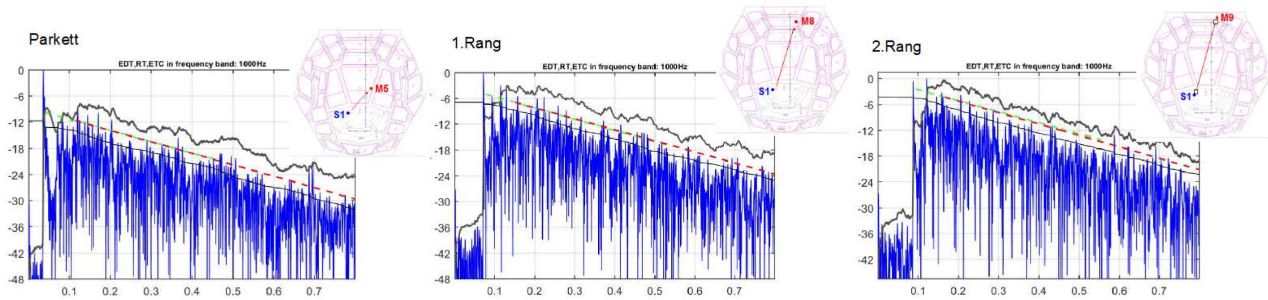


Figure 8. Three measured impulse responses in the final hall, unseated, 1kHz.
left: stalls middle: 1st balcony right: 2nd balcony

Figure 8 show a few but representative measured impulse responses. The early reflections are strong and relatively long lasting, which is related to spaciousness. The reflection density is high, without strong peaks or gaps in the reflection pattern.

5.2 Balance adjustments

After a few months of rehearsals and concerts, the conductor had the opinion that the balance of the different instruments at his positions differed too much from the seats in the audience. Investigation showed that it was not exactly his position that was unbalanced, but that there was an unbalance in the hall. On the middle axes, the sources in the middle at the rear of the stage were apparently more enhanced than the other sources. The variable absorption on the sides of the ceiling elements were partly turned to absorptive, and we added a few absorbing panels at the white band of the stage rear wall. The combination of both drastically improved the balance of the Strength. The reverberation time was reduced by about 0.1s.

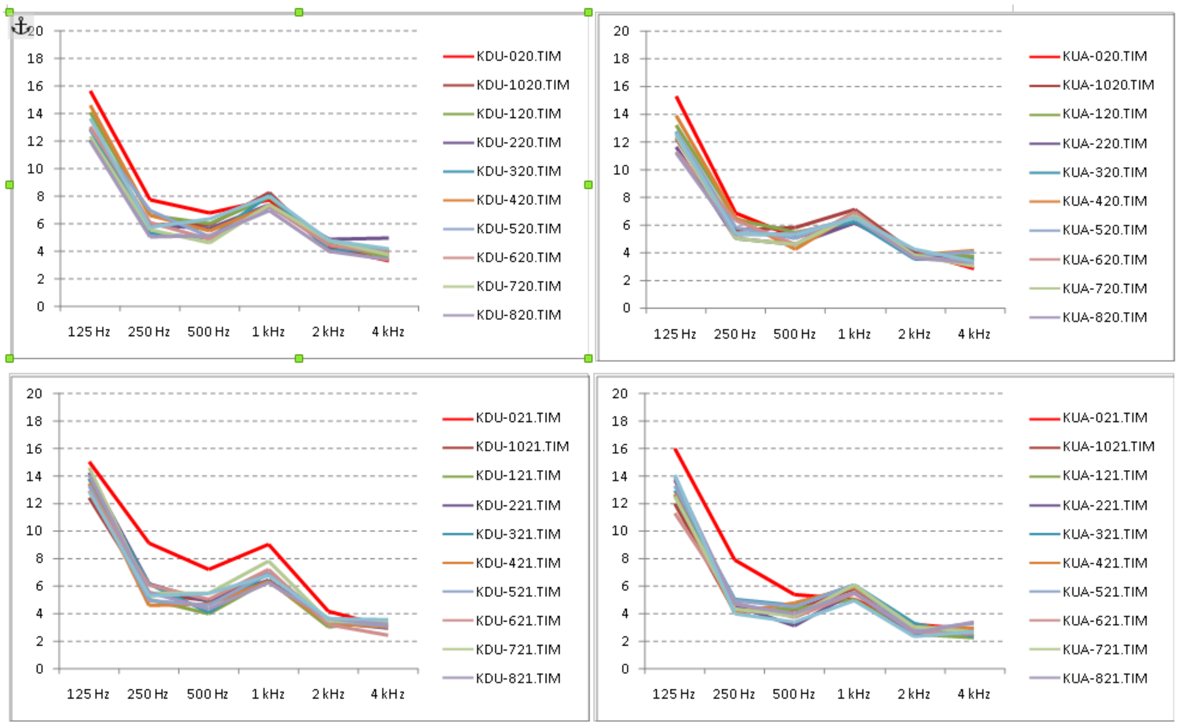


Figure 9. Measured strength G from 9 sources on state at two positions in the middle axes of the hall. Above at the rear of the stalls, below at the 1st terrace.

6 CONCLUSION

In this paper it is described how the acoustical design of the Kulturpalast Dresden developed over the years, what was investigated and how it was investigated. Also the final results are shown. The acoustical goals were achieved: to realize a vineyard hall with a perfect balance between transparency and a strong, warm sound quality with a high degree of envelopment and spaciousness. The visual intimacy perfectly combines with the acoustical envelopment. The musicians are excited about their stage environment and the development and blending of the orchestra sound.

The general opinion on the acoustics is very, very positive.