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# Acoustic Intervention in a Live Music Club

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**Summary**
This study describes an attempt to lower the sound levels at a live music venue. Acoustic measurements of live music concerts, feedback monitor loudspeakers, stage amplifiers and acoustic drums were made. The sound attenuation, when using screens of different heights in front of the drums, was measured. An acoustic renovation of a small live music venue was accomplished, with new wall and ceiling material installed. The sound system was replaced and the stage was enlarged. The direct sound from the stage was lowered by 50%. Sound level measurements made during concerts before and after the intervention showed a sound level reduction of 9 dB.

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## 1. Introduction

It has been common knowledge for many years that the sound levels present in live performances of pop/rock music are often much too high. A number of studies have reported measurements of high sound levels at nightclubs and concerts [1, 2, 3]. Reports from the early 1970's of sound levels at pop concerts which exceeded an Leq of 100dBA, with equipment easily managing sound levels of 120–130 dBA, show that this is not only a recently occurring phenomenon [4].

For people working in nightclubs, high sound levels cause difficulties in the communication with customers and constitute a clear risk of acquiring severe hearing impairment [5, 6, 7]. The people most likely to be at risk are those working in environments with amplified music and those subjected to loud noise on a daily basis [8]. Kähäri et al. has discovered a prevalence of hearing disorders in 74% of 139 studied rock- and jazz-musicians. The occurrence of tinnitus and hyperacusis was more common than hearing loss [9].

As far as we know, there has been no focus on acoustic intervention in small live music clubs (accommodating 150–300 guests) in the literature so far. However, when visiting such an establishment, one realises that attempts must be made to lower the sound pressure levels. Due to the high sound levels, the risk of hearing loss is often present but depends on several factors. Sound level, exposure time and individual sensitivity to sound are all contributing factors to the development of hearing loss. In a study by Axelsson and Prasher, it was suggested that if the exposure time is limited, it may be relatively safe to listen to sound levels of 97–100 dBA [10]. On the other hand, records of temporary threshold shifts (TTSs) and noise induced tinnitus show that although the listeners may be safe from hearing loss, high sound level exposure may very well cause other hearing disorders [10, 11, 12]. Other factors that could be of importance for the high sound levels in these types of small clubs are that the ceiling is often very low, the stage is small and the close proximity to the stage and loudspeakers. Metternich and Brusis have concluded that the most effective way to lower the risk of hearing problems is to simply remove the loudspeakers from the audience or vice versa [2]. Other problems often occurring in small venues are the negative effects caused by a reflecting stage, resonant stage floor or sound radiation from instrument loudspeakers and feedback monitor loudspeakers [13, 14]. The lack of knowledge (in acoustics, effects on hearing and technical sound level control), music genre and the number of musicians on stage, the audience noise and sometimes also more or less inadequate technical equipment are other factors that may contribute to a poor and hazardous sound environment [13, 15].

In Sweden, leisure time noise is regulated by the National Board of Health and Welfare and the environmental law [16, 17, 18]. The limits for loud music are set at 100 Leq dBA during the performance and 115 dB $L_{Afmax}$ at "the loudest possible location where the audience is allowed to be" or so called "worst position" in venues where children under the age of thirteen are not allowed [16].

A project was started in 2005 following an ongoing conflict between event organizers and environmental department officials regarding the sound level restrictions versus the artistic freedom of the musicians to perform their music at any sound level intended. A rock club in Göteborg was selected as the target for acoustic treatment and reconstruction.

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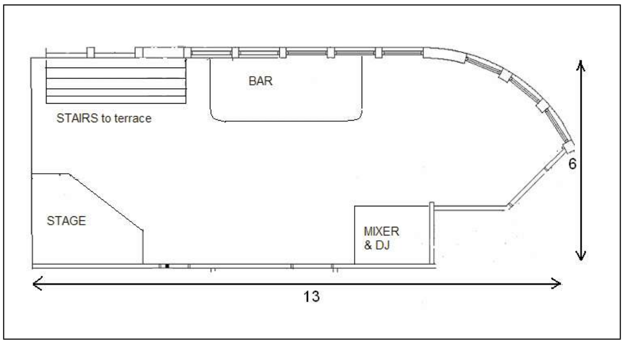


Figure 1. The figure shows a sketch of the live music club before acoustic intervention. Measurements are shown in metres.

At the time of the project, the experiment of acoustically remodelling a rock club to meet government standards without compromising the artistic freedom and listening experience was, as far as we know, the only one of its kind.

## 2. Aim

The aim of this study is to present the technical and acoustical procedures as well as the results of a complete acoustic intervention in one small club, where live music was played.

Specific aims were to:

- measure sound levels during live music concerts at the club before and after the acoustic intervention.
- measure the acoustic radiation of an acoustic drum- set.
- measure the impact of attenuation on acoustic radiation by using screens of different heights around a drum-set.
- measure the acoustic radiation from feedback monitor loudspeakers before and after the acoustic intervention.
- measure the sound level variations at different audience positions before and after the acoustic intervention.

## 3. Material

As the subject of our experiment, the venue had to fulfil the following criteria:

- There had to be enough room to accommodate 150–300 guests of varying age, but have a focus on "young" people in the age group of 18–25.
- Different styles of live music needed to be played several times a week.
- The club owners had to be cooperative and willing to accept certain modifications in the club's interior design and have a long-term contract with the landlord of the building so that there would be no sudden change of business in the premises, at least during the project.

Six different clubs in Göteborg were considered as possibilities. One club fulfilled the decided criteria completely. The room was long and narrow, the ceiling height was low and the stage was triangular and small (Figure 1). The absorption in the room was low due to the acoustically hard surfaces on the walls, ceiling and floor. The sound system in the room consisted of four modified loudspeakers containing two Celestion 15" units each, with a domestically inserted tweeter horn placed at "ear height" (175 cm above the floor surface), one Alto Macro 2400 amplifier, two LAB 1300 amplifiers and one Spirit Live 4, 16 channel mixer board. The loudspeakers were stacked together in two columns, one on each side of the stage. All of the amplified sound from the PA-system was delivered through these stacks and straight into the audience closest to the stage.

The bar was placed in the same room and situated close to the stage (Figure 1). The ceiling was covered with sound absorbing but painted tiles.

## 4. Method

This was an applied, intervention study implemented in an explorative way. All sound level measurements, calculations and technical assessments were carried out, or supervised, by well-known acousticians/ sound designers and sound technicians with many years of experience in the field, each with great knowledge of the live music scene and the cultural values that it holds. The measuring equipment used in this study was thoroughly calibrated before each measurement, and all measurements were made following standardized methods commonly used in Sweden [16]. For all measurements done on acoustic drums, in laboratory as well as at the venue, an experienced drummer was chosen. The drum-set consisted of one bass drum, two tom-toms, a snare drum, cymbals, crash and hi-hat.

### 4.1. Measurements of sound levels at live music concerts

A Larson and Davies Spark$^{TM}$ 703 dose meter was put behind the absorbing tiles in the ceiling 1 meter from the loudspeaker, with a microphone hanging down 25 centimetres from the ceiling in worst position. The dose meters were calibrated before being installed, and were programmed to collect data during the entire concert. Sound levels were measured during two concerts before the renovation and six concerts after the acoustic intervention.

Body-worn Larson and Davies Spark$^{TM}$ 703 dose meters were also used during the course of one additional evening with three concerts before renovation, where two persons wore them and were instructed to stand in "worst position" immediately in front of the speaker stack.

During one concert before the intervention, random samples of sound levels were taken. The positions chosen were at the edge of the stage, at the bar and at worst position (immediately in front of the speaker stack). The instrument used for random sampling was a calibrated Brüel & Kjær 2225 sound level meter. Short time LAeq measurements were carried out using a Brüel & Kjær 2260 sound level meter.

### 4.2. Acoustic radiation of a drum-set, and measurements of screen attenuation in a laboratory setting

In order to establish the acoustic radiation of an acoustic set of drums, the acousticians performed measurements

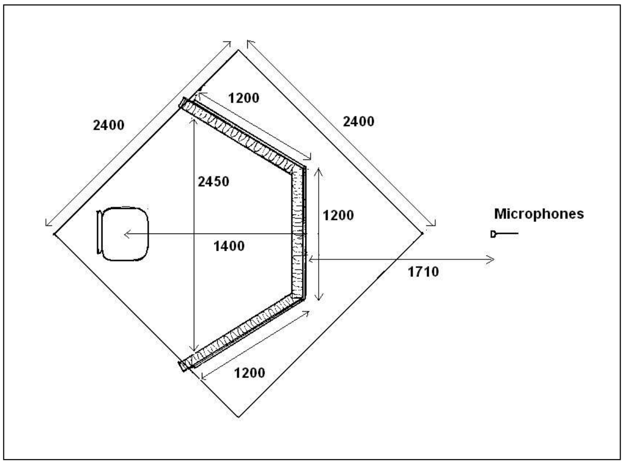


Figure 2. The figure shows a sketch of the drum podium placed in an anechoic chamber (as seen from above and with all length measures in millimetres). The screen consists of 18 mm thick plywood with 100 mm Ecophon industry modus 6143 absorbent. Podium is 400 mm high and consists of 22 mm thick particleboard.

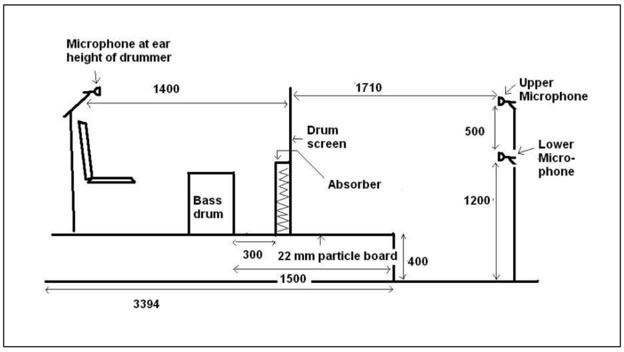


Figure 3. The figure shows a sketch of the drum arrangement during measurements with and without a screen in the anechoic chamber. The drum screen consists of 18 mm thick plywood of different heights (800, 1000, 1200, 1500 mm). Absorber on the inside of the drum screen consists of 800 mm high, 100 mm thick Ecophon Industry modus 6143. All length measures are shown in millimetres.

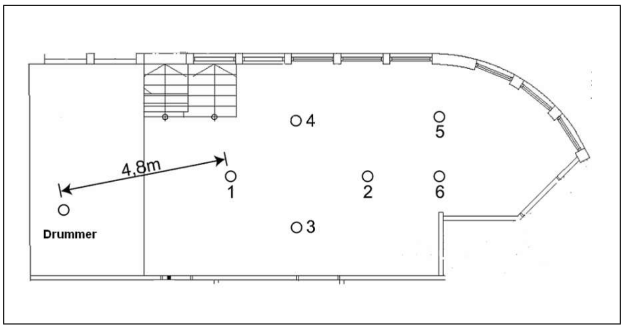


Figure 4. The figure shows a sketch of the microphone positions when measuring sound levels from acoustic drums and feedback monitor loudspeakers at the live music club.

in an anechoic chamber (sized 8×8×10 meters, 640 cubic meters) at the Chalmers University of Technology, the Department of Applied Acoustics in Göteborg. The technical equipment was a Brüel & Kjaer 4189 sound level meter, 4190 microphones and a Portable Pulse (7700) analyzer with front end 3109.

The drummer's accuracy was ensured before the measurements were made. One microphone positioned near the right ear of the drummer and two other microphones at a distance in front of the drummer recorded the sound levels, (Figure 2, 3). The drummer played a drum sequence of 50 seconds, six times, and included the use of all of the different drums in the set.

Next, measurements using screens of different heights in front of the drums commenced. The drum sequence was played two times for every screen height (80, 100, 120, 150 centimetres high), with and without an absorber on the inside of the screen. The drummer differed 0.5 dB in sound level between the fourteen sequences (6 sequences without screens, and 8 sequences using screens). The microphone behind the drummer's ear was used to monitor whether the sound exposure changed with different screen heights. The screens consisted of 18 millimetres (mm) thick plywood and covered three sides of the drum-set (Figure 3).

### 4.3. Acoustic emission from a drum-set and feedback monitor loudspeakers at the live music club

The sound levels resulting from the acoustic radiation from the drums were measured at six selected positions at the venue and analyzed in third-octave bands.

The drummer played the same drum loop as in the anechoic chamber, and the acousticians measured the sound levels at the six different measuring points (Figure 4).

In order to investigate the acoustic leakage from the feedback monitor loudspeakers into the audience, which affects the general sound levels, pink noise was sent through the monitoring system while measuring the sound levels at the six measurement points. Instead of a real musician on stage, a tripod with a microphone at "ear height" was used to confirm that the sound levels from the feedback monitor loudspeakers were constantly at 100 dBA. The monitor was turned toward the tripod.

### 4.4. Measurements of sound level variations in the room

During a concert before the intervention, the sound levels were measured in worst and quietest positions. When the venue was empty, measurements using pink noise through the PA-system were made at the six microphone positions according to Figure 4.

### 4.5. Computer aided acoustics, renovation in virtual reality

The computer software used for exploring alternatives for remodelling the club was the "Computer Aided Theatre Technique" (CATT) [19]. Specific types, numbers, positions and directivity for the speakers were chosen to achieve an A- weighted sound pressure level as evenly distributed as possible over the entire audience surface. It was also possible to simulate different materials on the walls and the ceiling in order to see the absorption and directivity of the room.

### 4.6. Statistics and ethics

Only descriptive results are reported for this study. No significance levels have been calculated due to the small number of measurements completed, and lack of comparative material. All dose meter data was transferred to a computer and analyzed with the Larson and Davies computer software Blaze$^{TM}$. Other sound level measurement calculations were done using Microsoft Office Excel 2003.

No specific ethic questions were raised in this study, except for one. The test persons were exposed to hazardous sound levels during our measurements. The risk was minimized by the use of hearing protectors during all exposure to loud music.

## 5. Results

### 5.1. Measurements of sound levels at live music concerts

Before the intervention, sound levels from two concerts were registered. The mean sound level value in "worst position" was 107,7 Leq dBA (114,2 Lfmax dBA). At the six concerts following the intervention the mean sound level value was 99,0 Leq dBA (109,7 Lfmax dBA) at "worst position", when measuring with dose meters (Figure 5).

Portable dose meters were only used before the intervention. The mean sound level value from six concerts was 110,6Leq dBA (119,9 Lfmax dBA),ranging from 108–114,3 Leq dBA (117,3-123,6 Lfmax dBA).

Results from random samples at one concert before intervention, showed short time sound levels of 107Leq dBA immediately in front of the stage, 112Leq dBA in "worst position" and 102Leq dBA at the bar. Sound level measurements done by the environmental and safety department at two concerts after the intervention showed sound levels of 98 Leq dBA (Lfmax dBA) and 95 Leq dBA (Lfmax dBA) in worst position.

### 5.2. Acoustic radiation of a drum-set and measurements of screen attenuation in a laboratory setting

The average sound level from the drum set was 97,7dBA at the measurement point two metres away. The measuring point was two metres away, and 170 centimetres from the ground (Figure 3). This is a distance from the drums that in a small club could approximate the location of the edge of the stage and "worst position" for the audience.

Sound levels were further reduced by the aid of screens (Figure 6). The sound level at the ear of the drummer was on average 108,3 dBA, but increased slightly with the height of the screen. When a screen with no absorber covering the inside with a height of 150 centimetres was used, the sound level at the ear of the drummer was 110 dBA. A screen with the height of 80 centimetres and an inside absorber showed no difference in sound level at the drummer's ear compared to playing without screens (107 dBA).

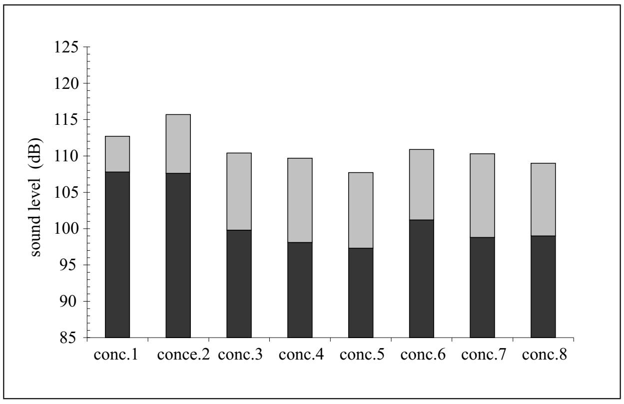


Figure 5. The figure shows the results from sound levels measurements from two concerts prior to (concerts 1 and 2) and six concerts after intervention (concerts 3–8). Measurements are performed with a fixed microphone placed in "worst position". Leq dBA: ■ Lfmax dB (A): ■.

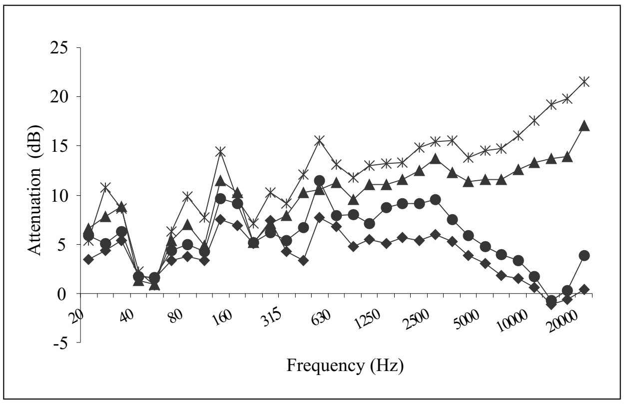


Figure 6. The figure shows the results of the screen attenuation for four different screen heights as measured in an anechoic chamber. The recording microphone was placed at the height of 170 centimetres above the stage floor. Diamonds: 80 cm (average sound level 92,7 dBA), Circles: 100 cm (average sound level 90,6 dBA), Triangles: 120 cm (average sound level 87,8 dBA), Asterisks* 150 cm (average sound level 85,3 dBA).

### 5.3. Acoustic radiation of a drum-set and feedback monitor loudspeakers at the live music club

Before the intervention, the average sound level recorded from drums at the venue was 96,3 dBA. When recording the average sound level after the intervention, it was 92,6 dBA. The measurements were calculated as the mean value of the six measurement points as seen in Figure 4.

The sound levels emitted from the drums were further reduced when using a screen. By using the lowest screen (80 cm), the average sound level from the drums was lowered by 4dBA, which equals a reduction in sound energy by more than 50% (Table I).

Before the remodelling of the club, the sound level at the ear of the drummer was 104,8 dBA on average. After the renovation, the sound levels at the drummer's ear were 105,5 dBA.

When measuring the sound levels emitted from the feedback monitor loudspeakers (kept at a constant level of

Table I. The table shows the screen attenuation, presented in dB A, from measurements done at the music club. For positions see Figure 4.

| | Before | After | After, screen | After, screen 80 cm | After, screen 100 cm +abs. | After, screen 120 cm |
|---|---|---|---|---|---|---|
| position 1 | 96,9 | 94,1 | 90,4 | 88,9 | 87,8 | 87,2 |
| position 2 | 96,6 | 92,3 | 88,6 | 87,3 | 86,5 | 85,2 |

100 dBA on stage), the mean value of the six positions at the venue before the intervention was 82,9 dBA, and after, the mean value was 76,3 dBA (Table II).

### 5.4. Measurements of sound level variations in the room

During a concert before the intervention sound levels at worst and quietest position were 112 Leq dBA and 96 Leq dBA respectively. After the intervention, sound levels at worst position were below 100 Leq dBA.

In the empty venue where sound level measurements of the PA sound were made, the largest difference between the six microphone positions before intervention was 3,6 dB (microphones 3 and 5, see Figure 4 for positions) with neither of the microphones placed in worst position. After the intervention, the sound level measurements in the empty venue were repeated. Four new loudspeakers had then been installed, which led to the fact that one of the microphones (microphone 4) automatically ended up in worst position below and slightly in front of one of the rear loudspeakers. The difference between the six microphone positions was at the most 2,9 dB (microphones 1 and 4) after the intervention.

Table II. The table shows the results from sound level measurements from drum sound and monitor emissions taken at the six measuring points before and after the intervention at the music club. The results are shown in dB A. * Monitor sound levels are adjusted to emit 100 dBA at the singer's position on stage. ** For positions see Figure 4.

| | Drums | | Monitors* | |
|---|---|---|---|---|
| | Before | After | Before | After |
| position1** | 96,9 | 94,1 | 84,1 | 76,7 |
| position2** | 96,6 | 92,3 | 83,4 | 77,1 |
| position3** | 96,9 | 93,4 | 83 | 79,1 |
| position4** | 97,5 | 92,1 | 83,2 | 74,9 |
| position5** | 93,4 | 89,2 | 80,5 | 73,1 |
| position6** | 95,5 | 90,2 | 82,4 | 74,2 |

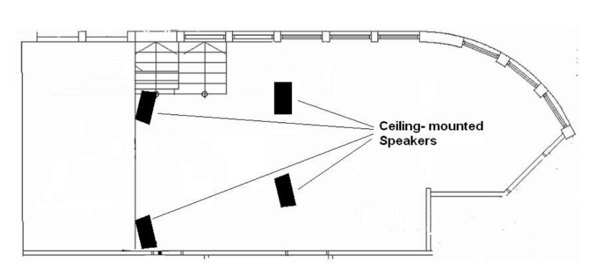


Figure 7. The figure shows where the four loudspeakers were mounted in the ceiling.

## 6. Intervention in reality

In the renovation of the rock club, the bar was moved from the room out into a glassed-in terrace, and the stairs leading up to the rebuilt terrace were widened.

The stage was enlarged and became rectangular (2.6 metres deep × 5.8 metres wide), following the short wall of the room where the old stage was located. The new stage was built on top of the old stage and manufactured in such a way as to not sound hollow or resonant by using attenuating building material. Feedback monitor loudspeakers and stage amplifiers were lifted from the stage floor (onto boxes or the new subwoofers) and directed towards the musicians' ears.

A new technique was implemented consisting of two JBL AM6212/95, 2-way speakers with a 12″-woofer and a 1.5″ horn and a radiation aperture of 90° horizontal and 50° vertical, placed in the ceiling, close to the stage. Further away from the stage an additional pair were placed, consisting of two JBL AM6212/00, similar to the first pair, but with a radiation aperture of 100° by 100°. Other added gear was one BSS FDS366T digital signal processor (3in/6 out), one Soundcraft GB4-24 24 channel mixer board and three Crown CTs3000 power amplifiers, each delivering 2×1500 W at 4 Ohm. There was also four new JBL SRX718S, subwoofers 1x18″ installed. The new subwoofers were incorporated into the new stage. The four loudspeakers were mounted in the ceiling, two in the front of the room on either side of the stage immediately above the basses, and two in the middle of the room (Figure 7).

These loudspeaker positions / directivities were predicted to be the most efficient for spreading the sound evenly above the heads of the people in the audience, by delaying the speakers with 10–20 milliseconds relative to the main PA-system.

A new framework for ceiling absorption was installed, along with new absorbers. In the ceiling, two different kinds of black absorbers were used, Ecophon Extra Bass, which are 100 mm thick and extremely absorbing and Ecophon Sombra A-gamma, which are 20 mm thick and slightly less absorbing. Above these tiles with lower absorption, 100 mm Ecophon Extra Bass was added. Since the room was long and narrow, in the last third of the room the high absorption tiles were mixed with the combination of lower absorption tiles underneath higher absorption tiles, creating as good of a combination as possible between absorption and diffusion. The framework was lowered 100 mm from the ceiling creating a hollow space between ceiling and absorber, to further increase the absorption. On the walls surrounding the stage, two layers of absorbers were installed. The inner layer consisted of 100 mm thick industrial absorbers and further out there was an extra 40 mm of Ecophon Sombra Wall absorber covered with a fire and shock resistant mesh. The thinner wall absorbers were also installed on the wall next to one of the speakers to reduce wall reflexes and it was also necessary that the absorbers covered the back wall of the sound technician's booth.

## 7. Discussion

The simplest solution to the problem of music that is too loud is to turn the sound level down, use earplugs and not care about the quality of sound. This group agreed to do it the difficult way, by lowering the sound levels while upholding or even improving the quality of sound. The acoustic conditions of the chosen room were also the absolute poorest of all six clubs considered and the one most in need of prompt alterations. The sound levels in this club were dangerously high for visitors as well as staff members.

Certain steps were taken in order to minimize sources of error. The drums were initially measured in an anechoic chamber to measure the true properties of the drums prior to entering the venue. Repeatedly measuring the drummer's sequences ensured his accuracy.

Originally, the idea was to use portable dose meters when measuring concerts during the entire renovation process. This became problematic both in an ethical and a measurement accuracy point of view. It would have been hard to ensure that the test persons were standing in the same position and wearing similar clothing at all concerts. It also would not have been ethical to force these persons to stand in "worst position" for however many concerts we decided to measure, no matter how well their hearing was protected. It was therefore decided that the dose meter should be placed in a fixed position in the room.

The measuring opportunities were based on what type of music was being played. All concerts measured included high-energy rock or punk music. The environmental and safety office had previously collected random sound level control samples at several clubs in the city and this club was known to have problems staying within the allowed limits. This was confirmed by measuring the sound levels during concerts with fixed microphones as well as portable microphones.

The reduction of the sound levels was substantial after the intervention. Was it possible that the bands that played after the intervention knew that the renovation was mainly acoustic, and therefore they played at lower levels? The measurements of the drums in the empty venue show quite the opposite. Our drummer knew that the venue had been acoustically modified, and records of him playing confirm that he actually played louder after the intervention because he felt that the back wall was extremely attenuating. There was no information given to the booked bands on what had been done in the room and they played just like they would have done at any other concert venue. The most substantial change was that the loudspeakers had been lifted out of the audience into the ceiling.

It was highly unlikely that the sound levels would drop below the recommended guidelines of 100 Leq dBA by just remodelling. At most we had hoped for reducing the sound energy by one half, but the results showed a reduction of almost 10dB and the mean sound levels during concerts stayed just below the 100dB limit without the use of a drum screen. The high sound levels at this venue are not unique in any way. Reports from all over the world show problems with high sound levels where live music aimed at young audiences is being played [1, 2, 3].

The necessity of using an anechoic chamber to measure drums should be discussed. Why didn't we just measure everything at the venue where we were going to apply the test results? The reason for doing these measurements was to find out the true acoustic properties of the acoustic drum set without any reflexes from the walls, ceiling and floor, and to see how high of sound levels each drum emitted. This was important to know before measuring the attenuation of screens, because the drums were located at different heights and, different heights of screens would attenuate the drums' sound differently. It was also important to measure screen attenuation and to find the lowest screen height where attenuation was satisfactory. When testing the use of screens in the anechoic chamber, the screens were made of plywood. A drum screen on stage is usually made of polycarbonate, which is transparent. The density of polycarbonate is twice the density of plywood. This means that it is possible to use a polycarbonate screen that is half as thick as the screens that we used for our measurements.

Although the drummer played 0,5-1 dB louder after the intervention, the fact that the mean sound level in the audience area was reduced by almost 4dB showed that the attenuating steps taken in the room had worked. Another problem with small venues like this was the sound leakage from the feedback monitor loudspeakers on stage. When measuring before and after the intervention, the leakage of sound into the audience area was lowered by almost 7dB. No measurements of sound levels in the quietest position were made after the intervention. The reason for this was that after completing the measurements in the empty room with only the PA system running, very little sound level variation (2,9 dB) between worst position (Figure 4, mic. 4) and the other five measuring points was detected. The fact that the feedback monitor loudspeakers were lifted slightly from the stage floor and closer to the ears along with a larger stage further helped reducing monitor sound levels. Studies on Broadway show musicians also show that when the musicians are further apart from each other, it is easier to hear ones own instrument and not suffer from the loudness of the musician next to you [13].

Live music venues suffer similar problems to factories. Employees can be subjected to extremely high sound levels. Therefore, it was important to make sure that the bar personnel of the venue were protected from the loud "noise" in their workplace. Sadhra reports how noise exposures of bar personnel frequently lead to temporary threshold shifts after work [20]. After moving the bar out to the terrace area, the direct exposure to hazardous sound levels among the personnel was minimized.

During the course of the project, an in-house technician became involved in the entire intervention process. He received proper education on sound level measurements and certain aspects of the hearing system. An educated in-house technician may be seen in the near future as an important part of business competition between clubs and venues. By having a single properly trained member of the staff taking care of the sound, the venue can hopefully guarantee a good sound quality and a safer listening environment for the audience.

## 8. Summary

The mean sound levels during concerts were lowered by 9 dB, to a level below the government-recommended 100 Leq dBA. Measurements of acoustic drums in the club showed a difference in sound level of approximately 4 dB. When using a low screen around the drums, the sound levels were lowered by an additional 4 dB without the sound levels at the ear of the drummer changing noticeably. The sound levels from the feedback monitor loudspeakers into the audience area were lowered by 7 dB after the intervention and the sound level variation was also lowered, primarily as a result of the loudspeakers being moved away from ear height in addition to the direct sound from the stage being diminished. The venue was modified to achieve better acoustic properties, the sound equipment was replaced and as a consequence of this, the working conditions of the bar personnel were improved.

## 9. Conclusion

This intervention project showed that it is possible to decrease sound levels during concerts, the direct sound from stage, and the sound level variation in a typical small live music venue. Hopefully, this project may serve as a source of knowledge and inspiration for future studies as well as in the development of new acoustical and technical sound monitoring solutions.

### Acknowledgements

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