Sonoran Institute Main Office-Tucson, Arizona

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Tucson, Arizona 85701

Noise Analysis and Treatment

Version 1.0

Commissioned by The Sonoran Institute

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Abstract

This document summarizes the acoustical and noise characteristics of an office space in a commercial building. The office is located on the third level. In particular, it focuses on the Executive Directors' office, the large conference room and a smaller conference room.

The purposes of this study are: (1) to summarize noise complaints via interviews of the office users; (2) to report on measurements relevant to the noise complaints; (3) to present an analysis of the noise issues; (4) to propose cost-effective solutions to the most pressing of the noise complaints; (5) to propose a staged set of recommendations, prioritized by their impact, that achieve a significant reduction in the noise.

The report has been commissioned by the office Operator. Measurements were conducted on January 6, 2012, 10:15am-11:45am. The date is significant because the measurements were made when the climate control system was not producing any noise.

The Operator has requested a cost-effective noise abatement strategy that addresses the noise issues, focusing first on the office, and then on the conference rooms. Furthermore, the Operator has determined that architectural blue prints of the recommendations are not necessary and thus this report does not provide them.

1 Executive Summary

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2 Background

The Sonoran Institute is located on the third floor of an office building in downtown Tucson AZ. The building was recently renovated. Its interior is characterized by hard surfaces, glass, metal, concrete. Some of the interior walls are brick face. A conference room and a meeting room have a wall that is fully made of glass. The glass wall consists of 2-pane thin glass. The ceiling structure is topped by corrugated metal, below which are the air conditioning, electrical, sprinkler, and alarm conduits. At a height of approximately 13 ft there is a hanging metal grid. The height of the ceiling is approximately 17 ft. Figure 1 shows a detail of the ceiling structure. Some of the wall is brick-face, but most of the partition walls are made of standard stud and sheetrock. The floors are concrete, however, the User has installed industrial-grade carpet in the rooms being scrutinized in this report.

Measurements were performed when the climate control system was not producing any noise. The climate control system, if in operation, would increase the background noise levels. However, the noise due to the climate control system would mask, somewhat, conversations heard from one office to another. The outcome is thus that an even worse noise profile would have been recorded, perhaps with a slight improvement on inter-office privacy.

3 Scope of Work and User Description of the Noise Problem

The User has tinnitus and is thus very adversely affected by the acoustics of the office space. The tinnitus is experienced as continuous high frequency

(a)

(b)

Figure 1: *Ceiling details. The ceiling structure is common to all of the rooms. (a) In the meeting room, (b) in the conference room.*

buzzing. Other users of the facility may be affected by tinnitus as well. A quick interview was conducted with the User. We catalogued the following complaints, listed in no particular order:

- High background noise.
- Speech intelligibility issues.
- Difficulty concentrating.
- The User has a well-developed mechanism for coping with the internal distraction of tinnitus. However, when this mechanism is engaged, it also affects external perception and thus content discernment in speech and media-related work.
- Cross-talk between offices.
- Awareness of external noise, however, this source of noise is accepted.
- Noise from neighbors.
- Poor office privacy.
- Multi-media issues are experienced in the conference room. For example, problems using tele-conferencing equipment.

The executive office is considered the worst place to work in, insofar as acoustics/noise is concerned. The acoustics in the large conference room improve with the presence of many people. We did not turn on the multi-media equipment in the large conference room in order to evaluate its effectiveness (evaluation of this equipment was deemed beyond the scope of this analysis. However, AEP Acoustics can offer a technical evaluation of the media equipment, separately).

The media presentations in the conference room are also adversely affected by the sun light, coming in from the North wall, which is nearly completely glass with a view of the exterior.

4 Reasonable Acoustics and Noise Targets

According to ANSI S12.60-2002, "Acoustical Performance Criteria, Design Requirements and Guidelines for Schools" we require a threshold (reverberation time) T_{60} of 0.6 seconds, and noise no higher than 35 dBA. With regard to noise isolation, we require an STC-45 for partitions with the corridor or an office, and a (Sound Transmission Class) STC of 50 for partitions with another lecture room, and an STC of 45-60 for the envelope construction. Finally, we require an (Impact Insulation Class) IIC of 45-50. These requirements can be adopted for an office space as well.

Achieving reverberation times T_{60} that are adequate may be within the realm of feasibility. On the other hand, achieving low noise levels will be expensive. Moreover, gains become exponentially more expensive the closer you get to very quiet conditions. Ideally noise levels should be as low as possible.

4.1 Reasonable Targets for the Three Rooms

- *A target STC of 50 for all partitions that separate the office suite from the adjoining one as well as from the suite directly below it. Further-*

more, an STC as close to 50 as possible for envelope of each of the offices within the suite.

- *A target average noise level in the executive office should be 35 dBA. The reverberation time should be* $T_{60} = 0.6s$.
- *A target average noise level in the large conference room could be 35-45 dBA (NC=40-45). The* $T_{60} = 0.8s$.
- *A target average noise level in the meeting room could be 35 dBA (NC=35). The* $T_{60} = 0.7s$.

Achieving an STC of 50 for the suite is probably out of the financial and practical realm of possibilities, as it requires extensive building modifications. Hence, the report will not focus on this issue. An STC of 50 for the inter-office partitions is not out of the question, but achieving such high value might be cost prohibitive. The report will thus suggest ways to increase significantly inter-office separation and privacy.

5 Noise Measurements and Observations

In what follows, we denote the executive office as "the executive office," the large conference room as the "conference room," and the small conference room as the "meeting room." We did not avail ourselves with "as-built" prints of the office and thus we will use pictures in the descriptive narrative.

Table 1 summarizes the noise measurements. The noise levels do not reflect the additional noise that would come from the operation of the climate control system. With the climate control system we expect a slight increase

Table 1: *Summary on noise levels. The last entry is a measurement taken in the hallway, taken near the executive office. The climate control system was not in operation.*

Location	Sound Pressure Level (dBC)	(door closed) Sound Pressure Level (dBA)	(door open) Sound Pressure Level (dBA)
Executive Office	56.7	44.4	48
Conference Room	58.4	41.5	45
Meeting Room	55.3	42	47
Hallway Noise	56	44	-

in low frequency noise, and a significant one in the high frequency range. The increase noise from the air conditioning might be welcomed as it increases slightly privacy by a noise-masking effect. For people with good or poor hearing, the addition of high frequency noise might interfere with their ability to discern percussive phonemes (*i.e.*, discern a phoneme with a "p" and a "t" sound). For people with tinnitus the addition of high frequency noise might also interfere with the internal "tuning out" mechanism, making it more challenging to concentrate on other people's conversations.

It is going to be possible to bring the executive room to specifications, close to those in the recommendations, both with regard to noise and reverberation specifications. On the other hand, it cannot be reasonably expected that the conference room and the meeting room will conform to noise specifications, unless the glass windows that make up the North Wall are replaced. It is possible that the meeting room and the conference room can be brought to within specification with regard to the reverberation time.

5.1 Executive Office Noise and its Analysis

Figure 2 shows a few views of the executive office. The executive office has

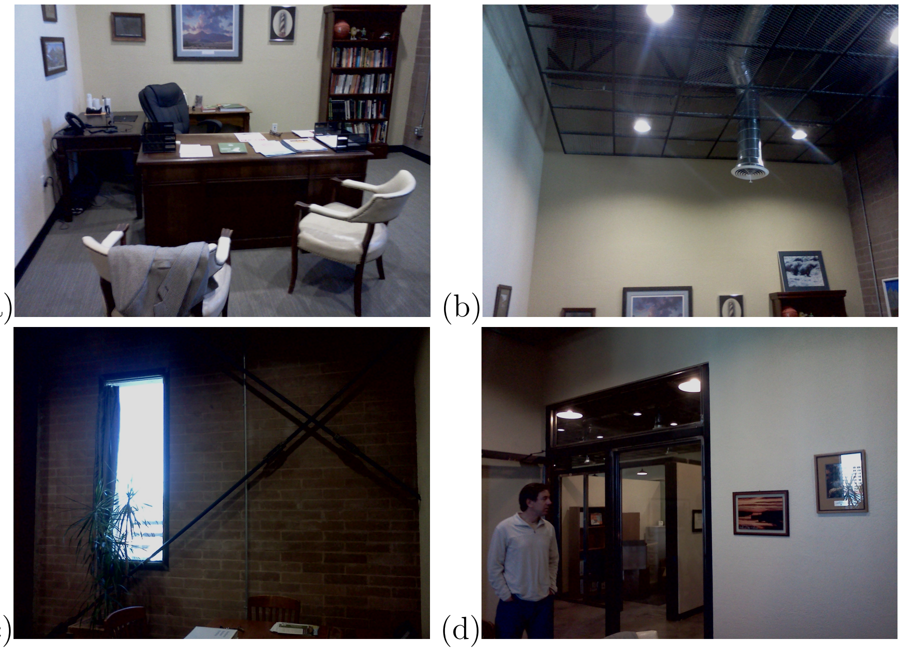

(a) (b) (c) (d)

Figure 2: *Executive office. (a) Viewing South. (b) North wall, (c) West and (d) East walls.*

approximate dimensions, 14ft × 20ft × 17ft.

Figure 3 shows the decay of sound energy as a function of time. Based upon a best interpolation, the reverberation time in this room is about $T_{60} = 1.1s$. However, the room has a sustained reverberant field which leads to two different rates of decay for sound. In Figure 3 we see that at time $3s$ the source is first perceived by the microphone, it is then sustained for about $0.16s$, after which we have regular reverberation decay. In view of this, one should adjust the reverberation time to $1.3s$, approximately. The reverberation time needs to be brought down to about $0.6s$. Using Sabine's formula,

$$T_t = 0.049 \frac{V}{S_{\alpha,t}},$$

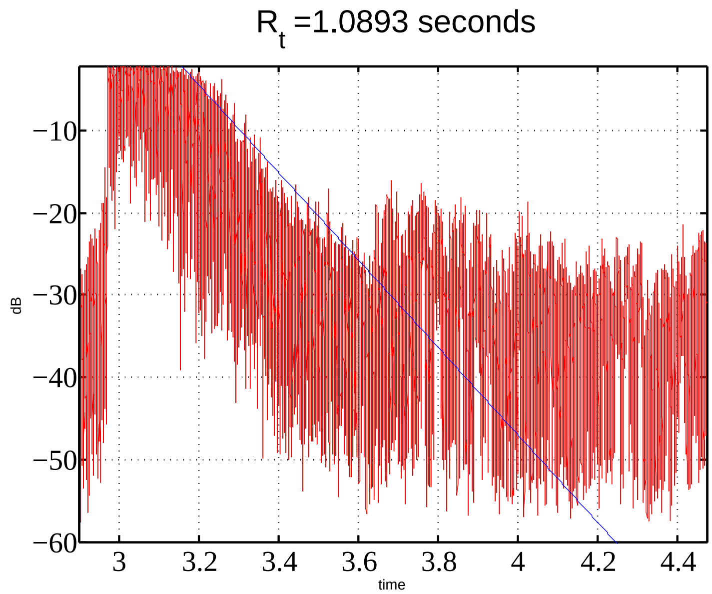


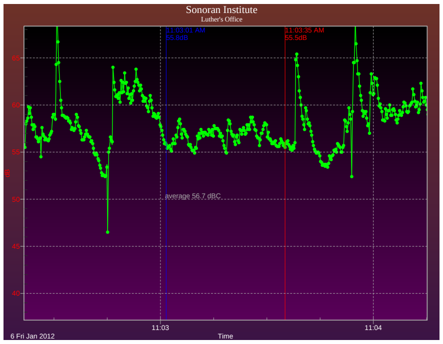
Figure 3: *Reverberation time T_{60}, executive office. Note anomalous decay at the beginning of impulsive noise. Clapper was used in this test.*

where

$$S_{\alpha,t} = \sum_{i=1}^{n} s_i \alpha_{i,t},$$

such that $S = \sum_{i=1}^{n} s_i$ is the total surface area in sq. ft. of the room. The units of T_t are seconds, and it is arbitrarily defined to be the time it takes for a pulse of sound to decay by 60 dB, after the pulse ceases to be powered. The units of the room volume V are ft^3, and the units of the effective surface area $S_{\alpha,t}$ are Sabins. They are equal to the sum total of surface elements s_i times the dimensionless absorption coefficients $0 \leq \alpha_i \leq 1$. If the reverberation time of the executive is currently 1.3 seconds and we want to reduce it to 0.6 seconds, we can then do the following calculation to find how much more absorption is required: Let $T_{1.3} = 1.3$ and $R_{0.6} = 0.6$. Then

$$R_{0.6}/R_{1.3} = 0.46 = \frac{S_{\alpha,1.3}}{S_{\alpha,0.6}}.$$

(a) 

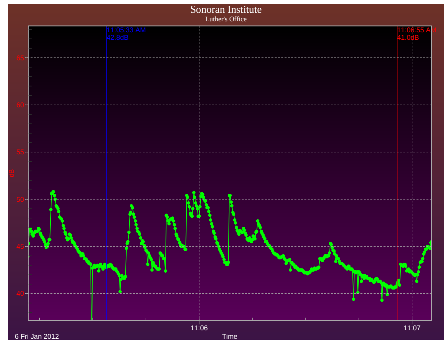
(b) 

Figure 4: *Noise measurements, taken in the executive office, door closed.*

Thus

$$S_{\alpha,0.6} = 2.2 S_{\alpha,1.3}.$$

In other words, we need to increase the effective absorption of the room by a factor of about 2.2 in order to achieve the desired results. The absorption coefficient of different materials is frequency dependent. The challenge thus is to achieve the same reverberation time for a broad band of frequencies.

Figure 4 shows the background noise levels in the executive office. It is readily seen that the noise levels in the room are exceedingly high (about 44.5 dBA), moreover, they have unacceptably high variability (about 5 dB). At the time of measurement there was a construction crew working on the adjoining office suite. Granted, they were using power equipment and metal cutters, however, the workers voices could also be clearly heard. **It is expected that when the construction in the adjoining suite is completed that there will be a problem with flanking between the two offices. This report does not tackle this issue, however, AEP Acoustics can tackle this problem as a separate challenge, once the construction is completed**.

Figure 5 shows the background noise levels in the executive office. The

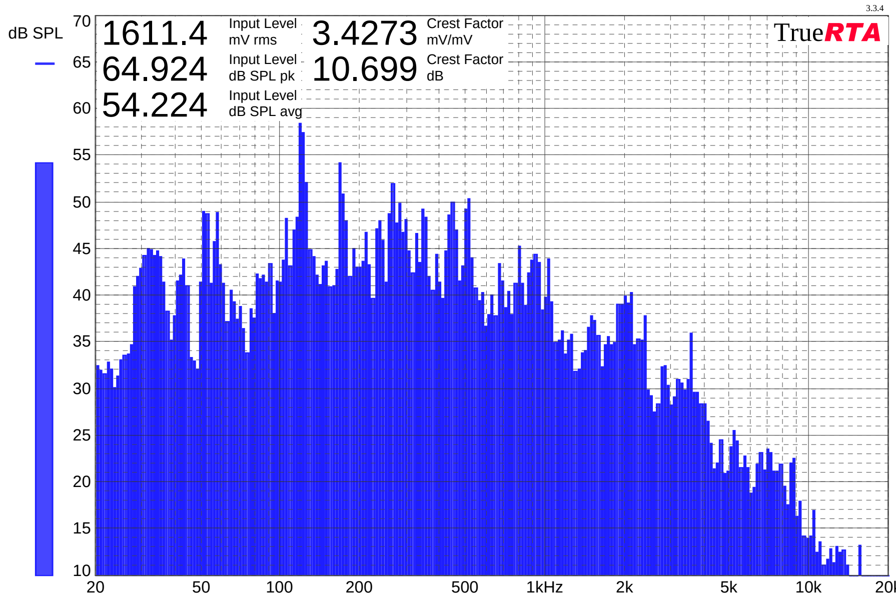


Figure 5: *Noise spectrum in the executive office.*

noise has a very wide spectrum, with some notable peaks around 120, 170, 270, 510 Hz. There are large low frequency contributions, which originate from the outside of the building (traffic on Broadway, etc). Clearly, a significant reduction in noise levels in this office cannot be achieved with simple acoustical tiles and panels.

A comparison of noise levels inside of the office to those in the corridor showed that they were comparable, even with the office door closed. See Table 1. Since the door is substantial, this indicates a serious flanking problem. Measurements were taken, when a meeting was taking place in the adjoining office. The conversation in that office bled through into the executive office with little difficulty: the main source of the flanking was the air conditioning ducts, followed by the dividing walls. Other sources of the flanking originate in poor gasket practices of the door.

(a) (b) (c) (d)

Figure 6: *Conference Room. (a) Windows on the North Wall. (b) South and West Walls, (c) conference table; (d) ceiling detail.*

When loud noises were made in the room it was possible to get the decorative metal grill in the ceiling area to produce noise.

5.2 Conference Room Noise and its Analysis

Figure 6 shows some views of the conference room. The dimensions of the room are, approximately, 24ft $\times$ 36ft $\times$ 17ft. A large glass window makes up the North wall. This glass wall is made of large double-paned window, unlike what is generally used in commercial ”glass” buildings in cities. Glass is also present in the South Wall, beyond which is the corridor and the general access area.

Figure 7 depicts the energy decay, as a function of time, in the room. The adjusted reverberation time, taking into account an anomaly of $0.25s$,

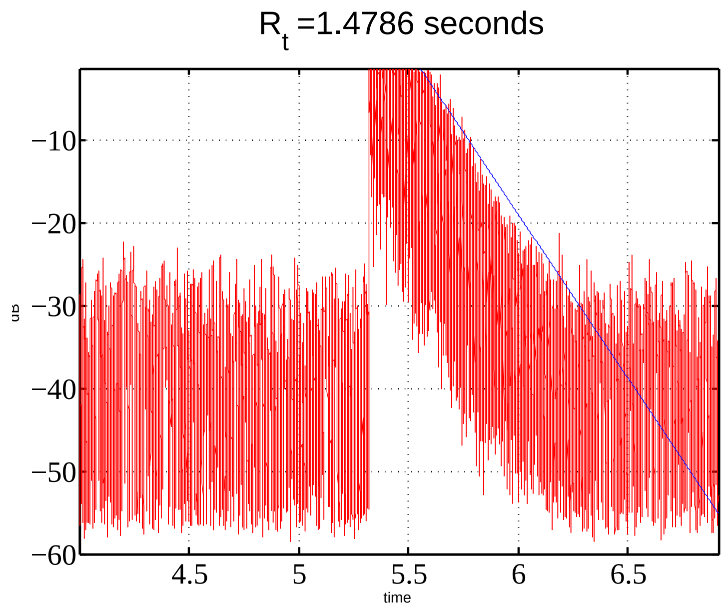


Figure 7: *Reverberation time T_{60}, conference room. Note anomalous decay at the beginning of impulsive noise. Clapper was used in this test.*

is about 1.75s. According to the formula due to Sabine, we will require an increase in absorption of 2.2 times the existing absorption.

Reduction of this very high reverberation time to the recommended value will be exceedingly challenging if the ceiling is not used in some way in obtaining the reduction. Acoustical paneling can be employed in this room, however, it requires that the sprinkler heads be extended downward. However, the User has been looking into purchasing a retractable light curtain for the North Wall. The typical light curtain will not have all that much impact on noise and on the reverberation in that room. However, a heavy theater curtain can have tremendous impact on both noise and speech intelligibility. **If a heavy theater curtain is within the realm of consideration, this purchase will impact considerably the recommendations made in this report with regard to acoustics and noise.**

(a) 

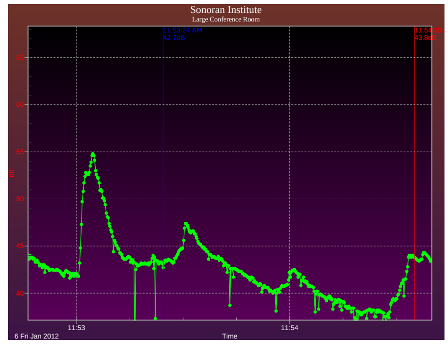
(b) 

Figure 8: *Noise measurements, taken in the conference room, door closed.*

Figure 8 shows the background noise levels in the conference room. The noise levels and their fluctuations are both exceedingly high. See Table 1. Figure 9 shows the background noise levels in the conference room. The preponderance of noise energy in the low frequency range indicates that the most significant noise source is external to the building: outside traffic and street noise. Hence, a major focus of noise abatement should be to tame the transmission of noise from the outside world. Short of replacing all of the glass on the North Wall, the best thing to do would be to purchase a retractable curtain for that wall, which cuts down on both light as well as sound. In order for it to affect the sound it will have to be a very heavy curtain. Retractability will thus have to be to the sides rather than of the type that rolls up and down.

A heavy curtain will make nearly every recommendation on noise and acoustics in that room, presented in Section 6, unnecessary[1].

[1]It should be emphasized that if the problem related with outside noise is resolved, noise transmission from the hallway will become more apparent and remediation that addresses noise transmission from the corridor via the South Wall, the vents, and the East Wall, would also be required if the goal is to reach the suggested noise goal of 35-45 dBA.

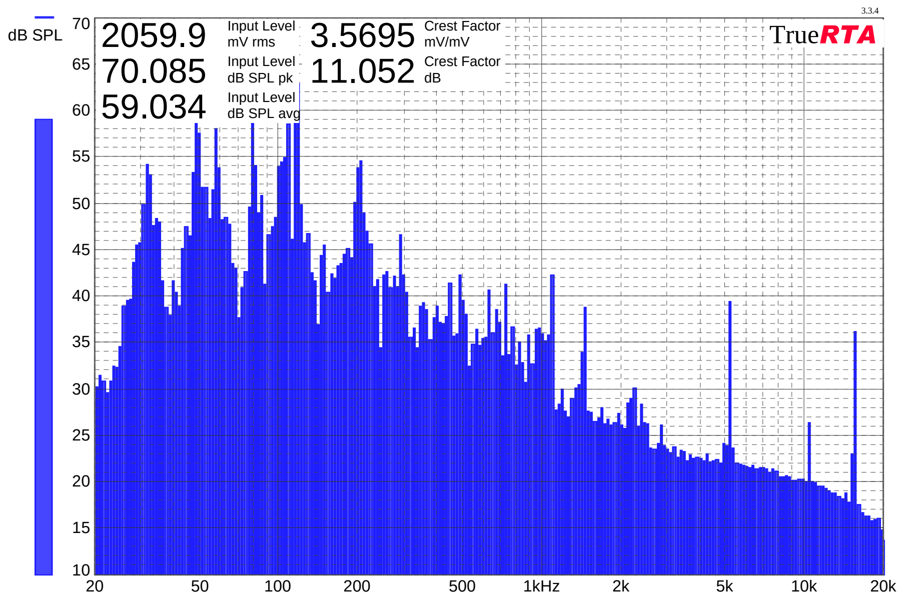


Figure 9: *Noise spectrum in the conference room.*

If a heavy curtain is not an option for that room, it will only be possible to reduce the noise, marginally, in the room by the application of acoustical treatment to the ceiling and improving noise decoupling to the hallway.

5.3 Meeting Room Noise and its Analysis

Some photos of the meeting room are featured in Figure 10. The dimensions of the room are, approximately, 11ft $\times$ 22.5ft $\times$ 17ft.

Figure 11 shows the sound energy decay as a function of time, in the meeting room. With the reverberation time anomaly of $0.21s$, the effective $T_{60} = 1.2s$, approximately. In this case an increase in absorption of 1.7 is required.

Figure 12 shows the background noise levels in the meeting room. There is a marked difference between the noise levels in the room with the door


(a) (b) (c)

Figure 10: *Meeting Room. (a) West wall; (b) East wall; (c) North window wall, and West wall.*

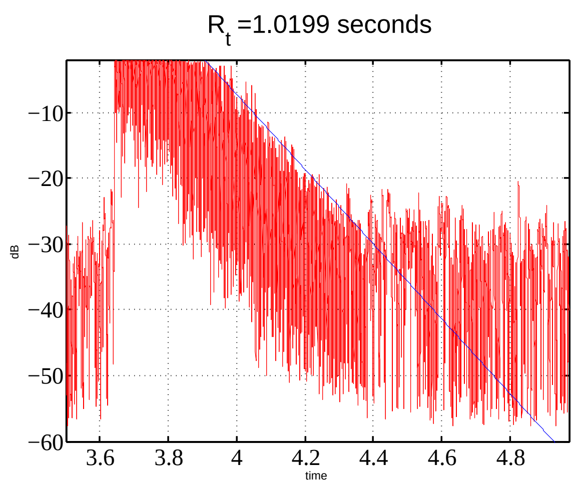
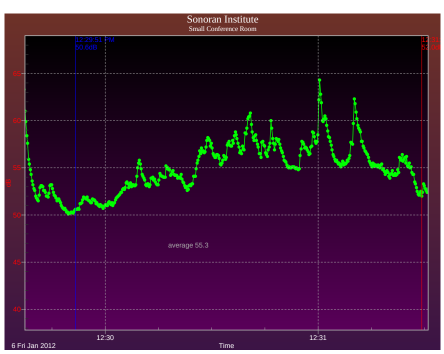


Figure 11: *Reverberation time T_{60}, meeting room. Note anomalous decay at the beginning of impulsive noise. Clapper was used in this test.*

(a) 

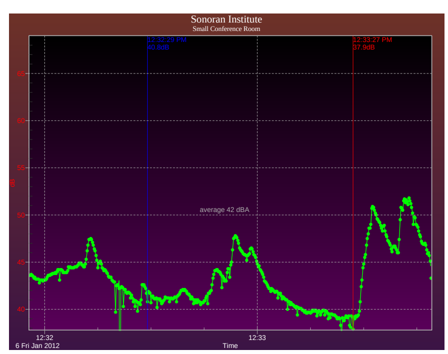
(b) 

Figure 12: *Noise measurements, taken in the meeting room, door closed.*

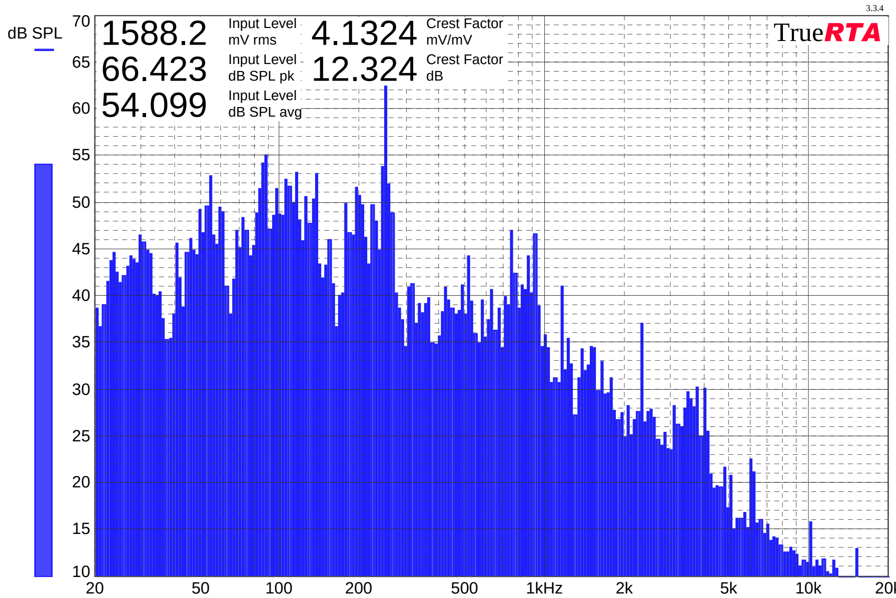


Figure 13: *Noise spectrum in the meeting room.*

closed and the door open. This indicates that the door system, common to all of the offices in the suite, is fairly effective. Nevertheless, gasketing can improve the isolation rating of the doors. The noise levels in this room are considerably better than that of the conference room because of the meeting room's location. There is less leakage from neighboring offices, less noise in the reception area. It is also a smaller room and less capable than the conference room to store outside energy. Figure 13 shows the background noise levels in the meeting room. The spectrum indicates that there is a preponderance of outside noise, however, there is significant internal noise in the 200-300 Hz range as well as in the 700-1000 Hz range, both of which can be targeted selectively for reduction. The lower frequencies, below 150 Hz, are not amenable to interior treatment and can only be under consideration if it were possible to replace the glass system on the North Wall.

6 Recommended Noise Abatement Procedures

Given the User's priorities and the financial costs associated with the acoustics retrofit, it is suggested that the noise issue in the executive office be fully resolved, and that the other two rooms be addressed as much as practical and economic constraints allow for. Given this determination, the staged approach assigns the acoustics retrofit of the executive office to STAGE 1.

With regard to the conference room, there is a significantly different set of recommendations to be put in play if a heavy retractable curtain is installed along all of the North Wall. Two STAGE 2 scenarios are presented below.

Rank-ordered, from highest to lowest impact, the recommendations are:

- STAGE 1: *Focus on the executive office:*

  1. Walls treated. See Section 8.7
  2. Ceiling treated. See Section 8.5.
  3. Ductwork . See Section 8.2.
  4. The South, East, and North walls should be mass loaded. See Section 8.3.
  5. Stagger electrical outlets, caulk. See Section 8.4.
  6. Gasket doors and install door drop hardware. See Section 8.12.
  7. Remove ceiling grid. Although properly a lager stage item, the grid is not offering any advantages and its removal makes installation of the ceiling treatment simpler.

- STAGE 2 (if heavy curtains are installed in conference room):

  1. Conference room curtains installed. See Section 8.1.

2. Gasket doors, install door drops in conference room. See 8.12.

- STAGE 2' (No heavy curtains installed in conference room):

  1. Treat walls in conference room. See Section 8.9.
  2. Treat ceiling in conference room. See Section 8.6.
  3. Gasket doors, install door drops, in conference room. See 8.12.

- STAGE 3

  1. Treat walls in meeting room. See 8.8.
  2. Gasket door and install door hardware. See 8.12.

- STAGE 4

  1. Treat Ceiling in meeting room. See Section 8.10.
  2. Carpet hallways. See Section 8.11.
  3. Mass load South (where there is no glass) and East walls in conference room. See Section 8.3.
  4. Caulk glass in South wall of conference room. Use caulking material specified in Section 8.4.

- STAGE 5

  1. Address ductwork in conference room. See Section 8.2.
  2. Address ductwork in meeting room. See Section 8.2.
  3. Mass load East and West Walls in meeting room. See 8.3.

- STAGE 6

1. Remove ceiling grid in conference room.
2. Remove ceiling grid in meeting room.
3. Mass load walls between offices. See 8.3.
4. Stagger phone/electrical/computer outlets in adjoining offices. See 8.4.
5. Gasket and install drop mechanism for doors in offices. See 8.12.

7 Staging Improvements

Organized in order of impact, the above are recommendations that can either be implemented fully, or staged. The idea with staging the improvements is that the User can make a cost-benefit analysis, as each improvement is added, in order to determine whether adequate sound quality is achieved, with a partial financial investment. Priority, however, has been given to the executive office situation and thus it has been given STAGE 1 status.

8 Description of the Abatement Structures

8.1 Curtain in Conference Room

The specifications for the curtain shall be: density of 1-1.5 lb sq ft, full coverage, and an excess of 10-20% of material. Curtains should fully cover North Wall, with gaps in curtains made to overlap as much as possible. The curtains should be placed as far from the window as possible (1-2 inches gap would be ideal).

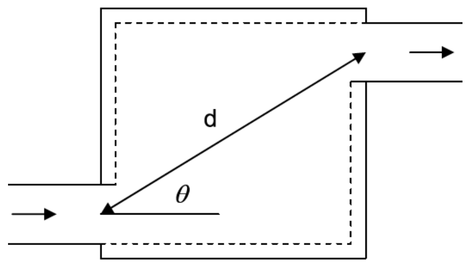


Figure 14: *Schematic of the plenum needed in the executive room. The plenum could be placed over the grid in the ceiling. The plenum should be lined with 1" ductliner. The angle $\theta = 38.7^o$, approximately, for a $4ft \times 4ft$ plenum.*

8.2 Vents

All of the vents should be lined. However, at least areas of the vents close to the diffusers and around bends in the ductwork should be lined. We require at least 3 duct diameter lengths of 1" Ductliner (see for example `www.industrialnoisecontrol.com/materials/hvac-duct-liner.htm`).

Ductwork penetrations should be wrapped with 1" external ductliner or heavily caulked. All suspension cabling should be taught and braces should be rubber gasketed.

There is a significant amount of the ductwork that is undersized, and should be made as wide as the inlet ductwork. Furthermore, it should be made more circuitous in order to create a more intricate sound path for noise from one office to another. Finally, diffuser grills that are quieter should replace the ones presently in operation.

A plenum chamber (see Figure 14) is required for the vents into the executive office. Ideally it should be $4ft \times 4ft$, lined with 1" in ductliner. Plenums in the meeting room and the conference room would also be beneficial. A smaller plenum should be installed in the ductwork in the office adjoining the executive office.

A great deal of cross-talk between the offices occurs because of the ductwork. Rooms, other than the executive office, the meeting room, and the conference room, require a re-design of the ductwork specialized to each office situation. This issue can be brought up and fully specified, should duct work be implementable.

8.3 Office Dividing Walls

Privacy levels between offices needs to increase considerably. The procedures on the walls and the climate control ducts in Sections 8.7 and 8.2 should be followed, for all interoffice walls.

8.4 Outlets and Penetrations in Offices

All electrical, phone, computer outlets in adjoining offices should be staggered, with distances of at least 1 ft between oppositely facing outlets. Penetrations and electrical boxes should be acoustically sealed, using a material such as QuietPutty. See `www.quietrock.com`. QuietPutty is a very good caulking material, one might find at the hardware store. It is heavier than the regular caulking and capable of expanding a bit inside crevices. It's regular counterpart could be used instead, however, there is a degradation in the flanking.

8.5 Executive Office Ceiling Treatment

Whisper Clouds (see `www.whisperwalls.com`) should be added, above the metal grill. See Figure 15 for a sketch of cloud placement. Alternatively, hanging panels can be used, see `tectum.com/hanging_baffles.htm`). The sprinkler system may need to be modified with the installation of extension pipes.

There should be a total of 12ft $\times$ 10ft cloud coverage in the ceiling, or the same amount of surface area in hanging panels.

8.6 Conference Room and Meeting Room Ceiling Treatment

Whisper Clouds (see `www.whisperwalls.com`) should be installed, above the metal grill. See Figure 15 for a sketch of their placement. Alternatively, hanging panels can be used, see `tectum.com/hanging_baffles.htm`). The sprinkler system may need to be modified with the installation of extending pipes. Sprinklers may not have to be modified if hanging panels are used (the fire marshall should be consulted, to be sure).

For the conference room we specify 4 cloud systems, each of size 6ft $\times$ 16ft. Alternatively, hanging panels with an equivalent surface area of 24ft $\times$ 16ft.

For the meeting room we specify 3 cloud systems, of size 8ft $\times$ 2ft, 8ft $\times$ 4ft, and 8ft $\times$ 6ft. Alternatively, hanging panels could be considered, with an equivalent surface area of 8ft $\times$ 16ft.

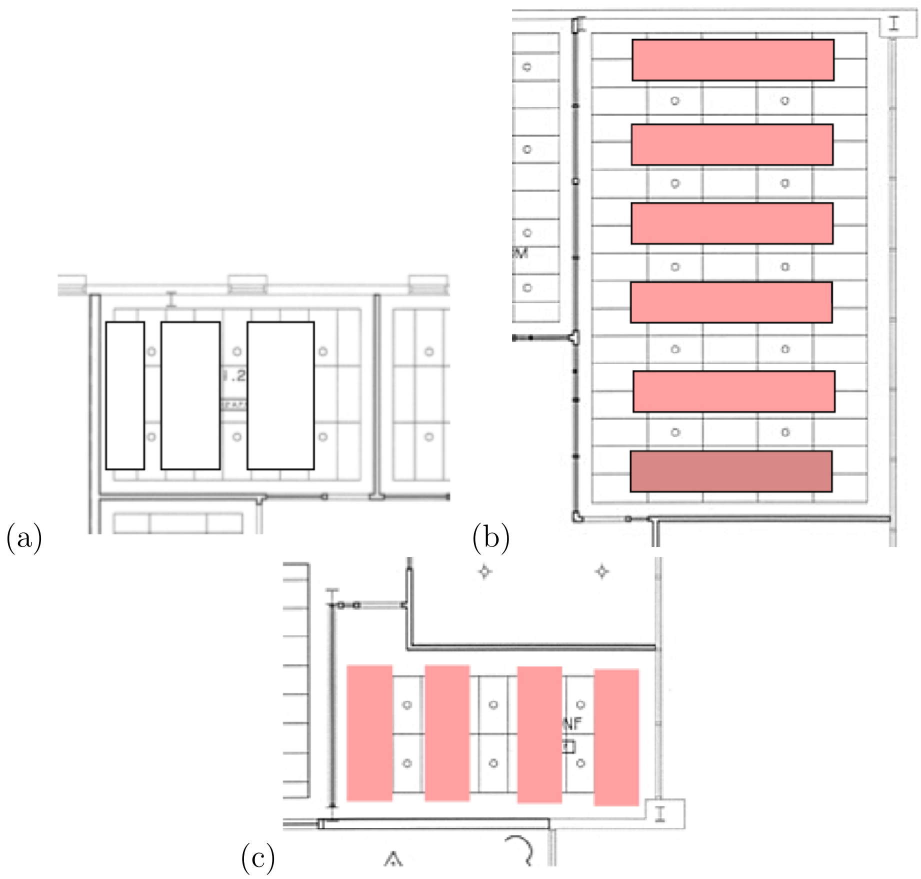


Figure 15: *Schematic: locations for whisper clouds or hanging baffles. These are installed above the metal grid. It might be necessary to relocate the sprinklers. (a) Executive office; (b) conference room; c) meeting room.*

8.7 Executive Office Wall Treatments

For noise control and privacy: All walls except for the West Wall should be lined with 5/8" Quiet Rock sheets (see `www.quietrock.com`). The sheets should be placed over a coating of Green Glue (see `www.greengluecompany.com/`), fastened lightly using long sheet rock screws.

To lower the reverberation time: The South and East Walls are then treated with Bekesy screening. See Figure 16. The screens need to extend over the entire walls, including the space above the metal grid. A commercial version of these is available at `www.walltechnology.com/products/pages/wallpanels/metrorebound.aspx`.

A possible objection with Bekesy screening (other than possible aesthetic objections) is that it complicates fixing frames and pictures to the wall. An alternative plan is to put the Bekesy screening on the East wall, and the South Wall can be treated using Whisper Walls (see `www.whisperwalls.com`), or wood panels (`www.acousticalsolutions.com/woodtrends-wall-panels`).

8.8 Meeting Room Wall Treatments

We suggest treating, fully, either the West or East walls, with RPG Absorbor 3" (see www.rpginc.com/products/absorbor/index.htm). An incremental noise isolation from the kitchen area is achieved if the panels are added to the West wall. These panels are expensive. A viable alternative is to make the panels in-house. See Figure 17. Mineral wool or Quiet-batt is recommended for a filler, which should be 4" thick. The panels shown in Figure 17 can be disguised using wooden slats, as in `http://9wood.com/series/index/1000`,

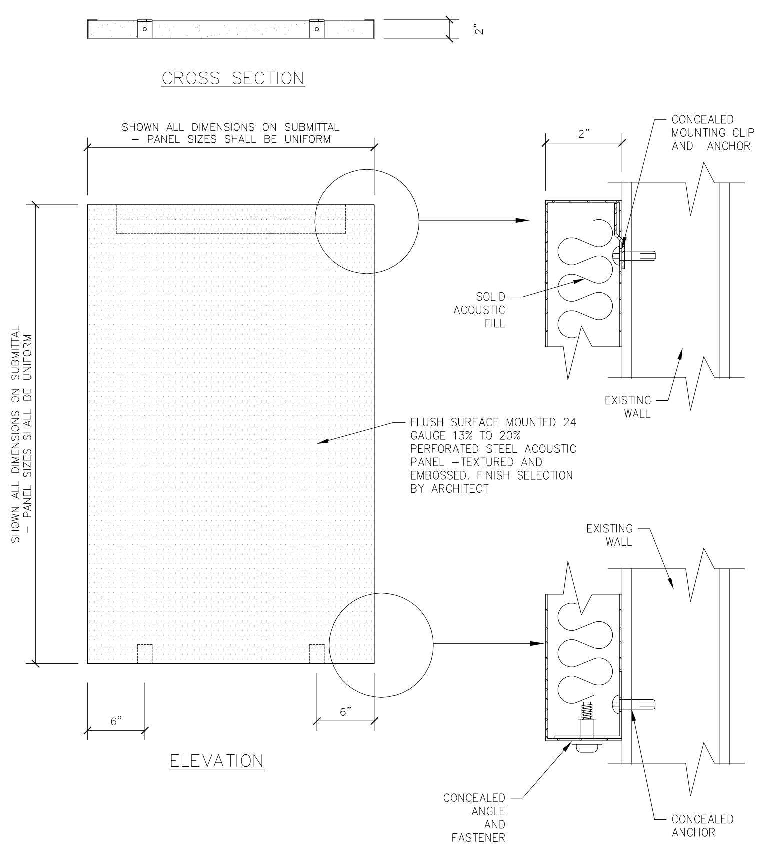


Figure 16: *Schematic of Bekesy screen, which treats the South and East Walls of the executive office.*

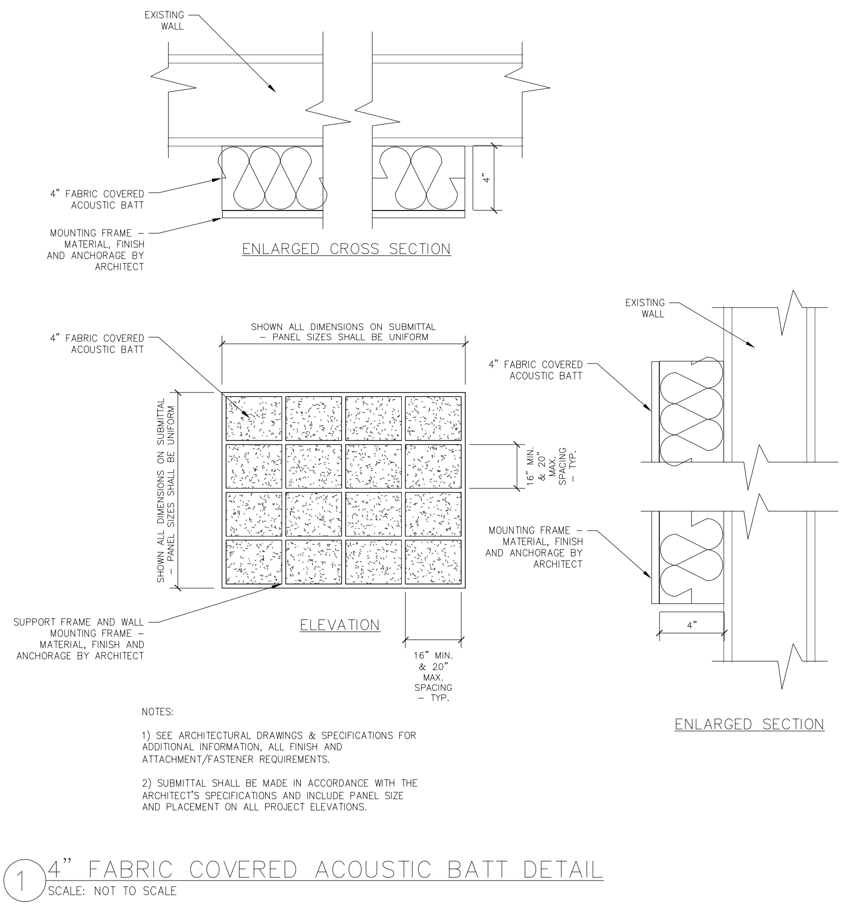


Figure 17: *Schematic of fabric-covered batt panels.*

leaving 37-40% of the face exposed to the underlying fabric-covered cotton batt. The wooden sections should be 1.5” high and 3.4” wide. The wooden slats need to be cross-braced every 18”.

8.9 Conference Room Wall Treatments

- Save for the glass, the whole South wall should be treated with Bekesy panels (the commercial ones are `www.walltechnology.com/products/pages/wallpanels/metrorebound.aspx` and the screens made in-house appear in Figure 16).

- The East wall should be fully covered with either RPG Absorbor 3” (see www.rpginc.com/products/absorbor/index.htm) or the far less expensive alternative shown in Figure 17. The latter is to be built in-house.

8.10 Meeting Room Ceiling Treatments

Whisper Clouds (see `www.whisperwalls.com`) should be added, above the metal grill. See Figure 15 for a sketch.

8.11 Hallway Carpeting

The hallways will be considerably quieter if the carpeting is extended to the hallway and reception areas. This will bring down the overall noise level in the whole suite considerably, at a nominal cost.

8.12 Doors

Door drops and gasketing should be installed on all of the office and conference room doors. The doors are custom built. Door drops and floor hardware can be found at PEMKO (see `www.pemko.com`). Gasketing the doors will prove challenging since there is no room for a rubber gasket internal to the door frame. There is no point to doing one or the other: it is essential that both door frame gasketing as well as door drop hardware be incorporated into each door in the facility, including exit doors of the suite.

Appendix

A MEASUREMENTS

A.1 Methodology and Equipment

Noise measurements were performed on August 15, 2011, and August 28, 2011, and Oct 12, 2011.

- The sound level meter SPER Scientific Datalogger, calibrated using SPER Scientific 2-point acoustical calibrator 840031. Sound level meter was used also as a condenser microphone source for sound and noise capture for post-processing. Calibrated to 94 dB SPL (calibration record available on request). Meter conforms to IEC651 type2, ANSI S1.4 Type 2 for sound level meters.
- SE322 Testlink noise level meter software
- TrueRTA Spectrum analysis software.
- ECM8000 condenser microphone with parabolic adaptor was used in the STC measurements.
- Audacity, Spectrum Labs, matlab, comsol, and proprietary software is used in the analysis of the data.

Measurement uncertainty was estimated at approximately 5 dB SPL for frequencies below 500 Hz and 7 dB SPL for measurements above this frequency. These uncertainty estimates were computed from the statistics of approximately 40 samples, taken using slow averaging, from samples taken at a rate of 0.2 sec intervals. Measurements were taken at a height of 4.5 ft above ground level. Reverberation measurements were obtained by extrapolating the decay rate of a signal captured at 44000 samples per second, above the noise floor (we did not turn off the HVAC system and thus did not have a required 60 dB SNR to find the reverberation time without extrapolation).