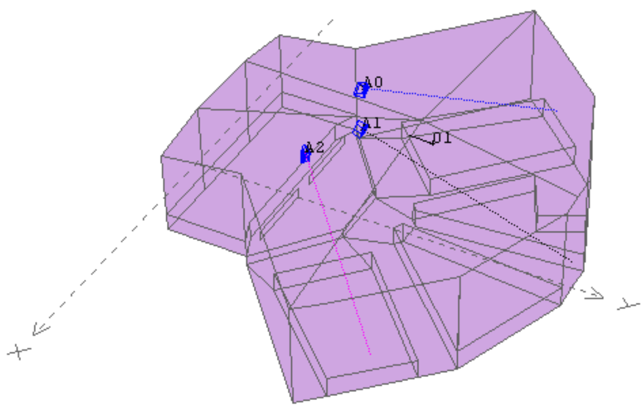
ACOUSTICAL ANALYSIS
FOR
“SAMPLE CHURCH”



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FOR
"SAMPLE CHURCH"

I. SANCTUARY

The acoustical environment of a church sanctuary involves numerous aspects. Most obvious is the ability of congregation members to hear sounds at an adequate level. In a contemporary worship setting, this aspect is largely a function of sound-system design. Other areas of concern include naturalness of the sound and intelligibility of the spoken word. Certain measures used in concert-hall acoustics also apply to the congregation's sense of involvement with the music and with hymn singing. The development of analytical architectural acoustics in the 20th and early 21st centuries has involved the acceptance of a number of predictable parameters that can be used to determine listeners' subjective response to the acoustics of a room. These will be discussed one at a time.

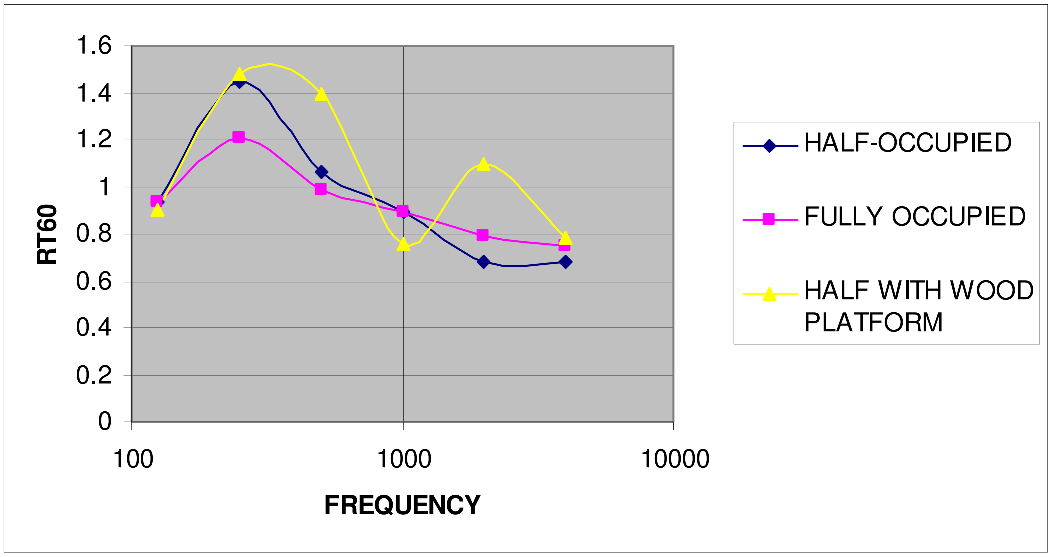
REVERBERATION TIME

The oldest, and probably the best known predictable acoustical parameter of a listening room is the **reverberation time**, the time required for a normal speech sound to decay to inaudibility. While a completely non-reverberant room (an anechoic chamber) and an empty untreated coliseum are both very unpleasant acoustically, determining an ideal reverberation time between these two extremes is not generally possible. Careful listener studies have shown that the preferred reverberation time depends heavily upon the type of program material and the cubic volume of the room.

For your sanctuary of about 100,000 cubic feet, a good reverberation time for speech would be about 0.9 second. For contemporary music, a slightly longer time would be preferred – about 1.1 – 1.2 seconds. For traditional worship, the optimum for a 100,000 cubic foot room would be nearer 1.5 seconds. Thus for your worship style, a compromise value between 0.9 and 1.2 seconds would seem to be ideal.

Reverberation time varies with frequency. Listening tests in concert halls have shown that the less the variation with frequency, the better. However, most construction materials, as well as most seating, absorb reverberation more effectively at high frequencies, making the reverberation time longer at lower frequencies. Tests have shown that a slight increase starting at the frequency of middle C, rising to 75% two octaves below middle C, is acceptable.

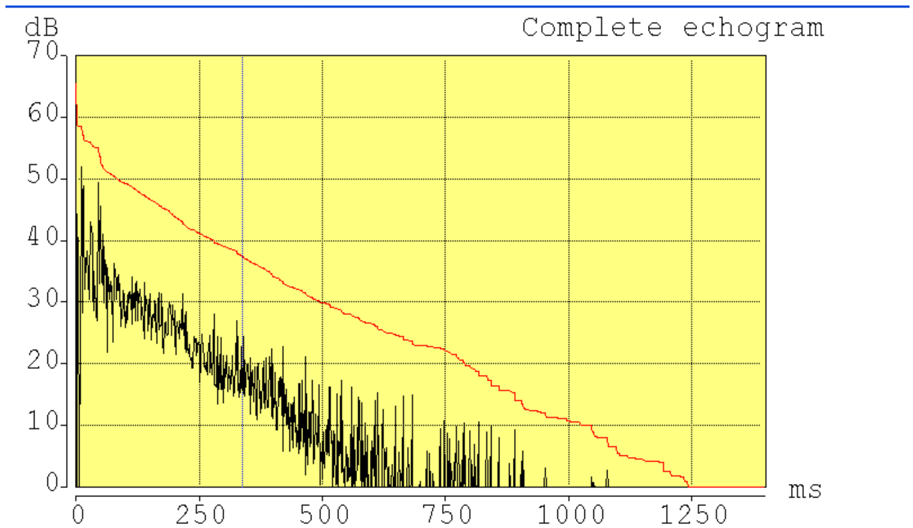
Modeling indicates predicted reverberation times as indicated in the graph on the following page. The magenta curve shows the behavior of the room when half-occupied; the yellow curve, when completely occupied; the blue, when half-occupied; and the yellow; half-occupied and with a wooden platform floor rather than carpeted. In all cases, the ceiling material is Armstrong Graphis, which is a fairly reflective lay-in ceiling having a noise-reduction coefficient (NRC) of about 0.1. **NOTE: Armstrong Graphis is the recommended ceiling material for your sanctuary.**



Notice that in all three cases, the reverberation time is close to the target value of 1.1 to 1.2 seconds at 2 kHz, which is the most important band for speech intelligibility. The increase in reverberation time at low frequencies is no more than 66% in any case. This sanctuary will have a pleasant sound for your worship style. The use of a more absorptive ceiling material is not recommended, as it would make the room too acoustically dead.

ECHOES

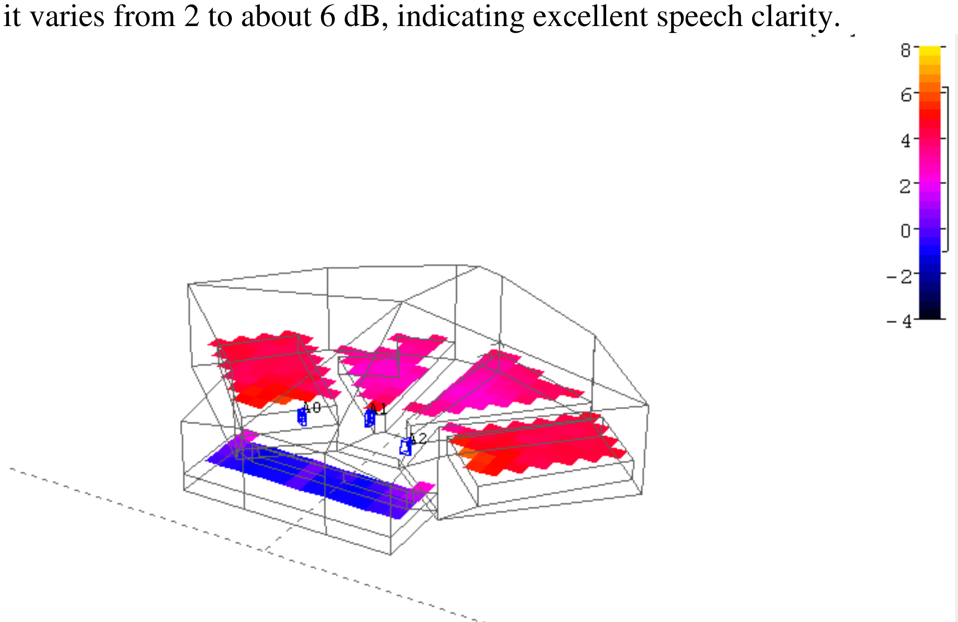
Echoes are different from reverberation, although both are caused by reflected sound. An echo is a discrete reflection whose sound level exceeds that of the reverberant sound, the latter having a very slowly varying level. In order for an echo to be perceptible, it has to occur more than 65 milliseconds after the initial sound. The effect of echoes on listener satisfaction is also complex, depending both upon the time delay between the original sound and the echo, and the loudness of the echo compared to the original sound. The graph below shows the expected sound level in the sanctuary immediately after an impulsive sound, such as a single syllable, with the sound source being the sound system designed by Church Interiors Audio and Video, Inc.



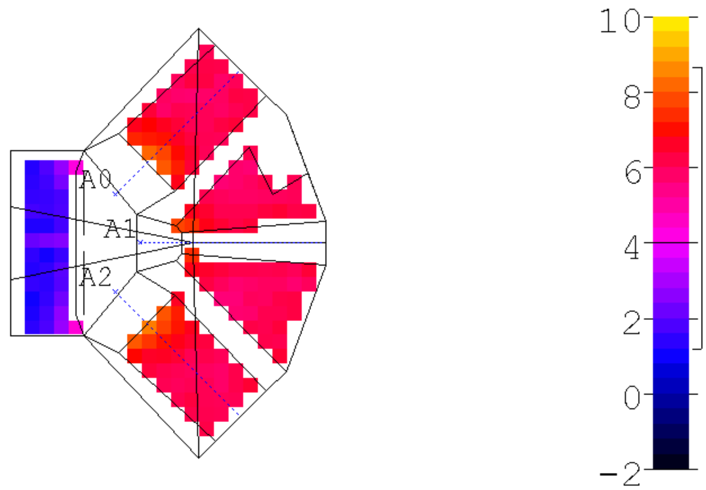
The continuous curve represents the reverberant sound level as it decays. Any humps in that curve might represent echoes, if they occurred after 65 milliseconds and were sufficiently loud compared to the original sound. Notice that there is over 38 dB between the original sound and the first bumps in the curve after 65 milliseconds, indicating that echoes will not be a problem for any program material.

OTHER ACOUSTIC CRITERA

There are two related criteria: **C50** and **C80**. C50 relates to the intelligibility of speech in the room, and is a measure of the level of early-arriving (first 50 milliseconds) sound (which contributes to intelligibility) compared to the total sound level. C50 is expressed in dB. For good speech intelligibility, C50 should be some positive dB value: the higher, the better. The graph below shows the value of C50 in the seating areas of your sanctuary: it varies from 2 to about 6 dB, indicating excellent speech clarity.



C80 relates to the clarity of music, and should be at least 6 dB or more for contemporary music. The calculated C80 values are shown below: they are in the range of 6 to 8 dB, indicating good clarity of music.



The **lateral fraction (LF)** is the proportion of early sound that reaches the listener from the sides, compared to the total sound, and relates to the sense of spaciousness in the room. To avoid having a cramped, one-dimensional sound, LF should be about 20%-40%. The average calculated LF value for your sanctuary when half-occupied is about 35%.

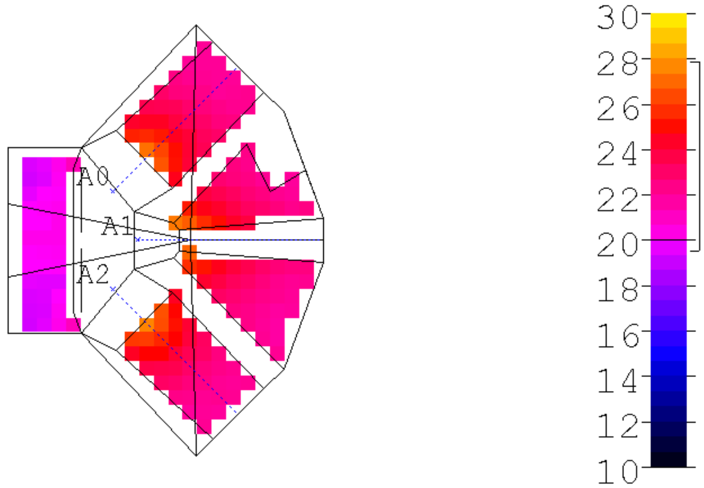
WORSHIPPER INVOLVEMENT

One concern that sets church acoustics apart from concert-hall acoustics relates to the singing of hymns. It has been observed that when worshippers can not easily hear those near them singing, they themselves will not sing as loudly, because it sounds as if they were singing alone. The primary variable in this effect is the absorption *vs* reflection of sound near in the congregation seating area. A reflective ceiling, as I have recommended, helps in this regard; however, upholstered chairs and carpeted floors add absorption that tends to reduce worshipper involvement. Modeling your new sanctuary shows that each worshipper should be able to hear nearby worshippers singing reasonably well.

ACOUSTICAL PROJECTION FROM PLATFORM

Even in churches in which most worship events are amplified, acoustical projection from the platform is still important. Perhaps the most common instance in which it matters is dramatic presentations, especially those involving children, in which not all performers can be miked. Acoustical projection from the platform is enhanced by adjacent reflecting surfaces such as back walls, ceilings, and floors. Your back walls and ceiling are reflective, but your floor is carpeted. The parameter that shows the effectiveness of acoustical projection is **G**, the “room gain,” which expresses how much louder the sound is at a given listener position due to a person speaking from the platform, compared to the loudness at the same talker-to-listener separation out-of-doors. The calculated values for your present platform design, for typical listener locations, are shown below.

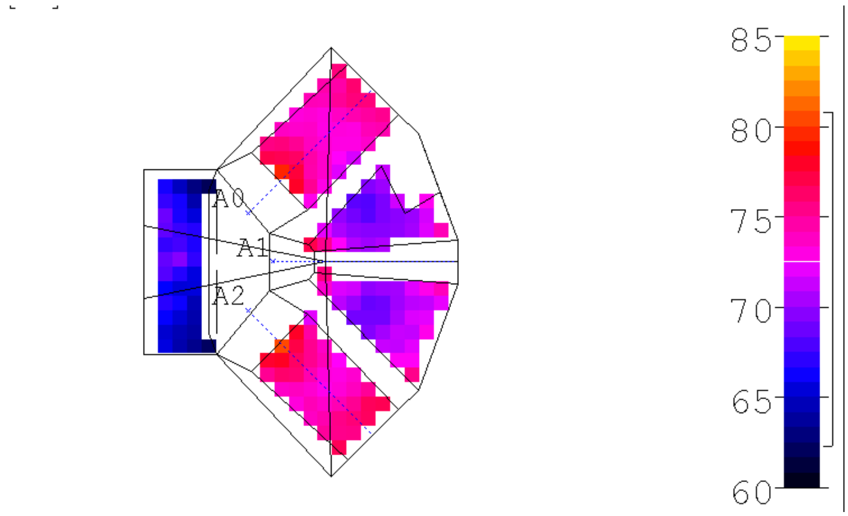
Note that the average value is about 24 dB. If you use a wooden platform floor rather than a carpeted floor, the values increase as shown below, to an average of about 26 dB.



NOTE: The use of a wooden platform floor is recommended in this sanctuary.

SPEECH INTELLIGIBILITY

Numerous methods have been developed to measure and/or predict speech intelligibility. One of the best-documented ones is the **speech-intelligibility index**, or STI. An STI value above 66% is considered to represent good intelligibility; above 88% is excellent. The graph below shows the predicted speech intelligibility for your new sanctuary.



Notice that the intelligibility in all seating areas is in at least the “good” range, and in much of the room, it approaches the “excellent” range. The platform monitors were not modeled in this simulation; hence, the lower STI levels shown on the platform.

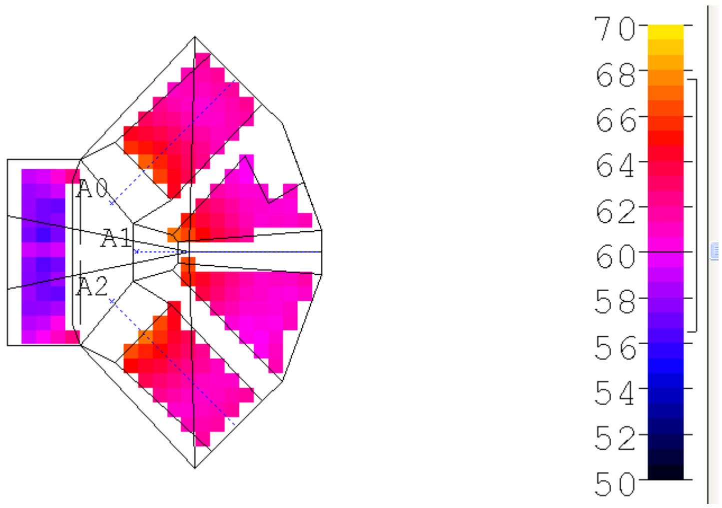
ABILITY OF PERFORMERS TO HEAR EACH OTHER

In churches using traditional worship, often two or more instrumentalists or vocalists perform together, and the ability of the performers to hear each other is critical. This ability is affected by the same parameters that control acoustical projection from the platform.

In churches using primarily amplified music, this is not as great a concern if a good monitoring system is included in the sound system. If any use is made of acoustic instruments or unamplified singing groups, the acoustical environment of the platform does become more important to the performers. However, since your platform is flanked by hard walls and if you choose a reflective ceiling and a wooden platform floor, you should have good reflections to enhance performers’ ability to hear each other.

SOUND LEVEL EVENNESS

The graphs below show the evenness or sound level in the sanctuary using the proposed loudspeaker design. The graphs are for the level in to 500-Hz octave band, which is the frequency range containing the greatest amount of energy for most contemporary music. The maximum variation in sound level from the loudest to the softest positions is 6.6 dB, which represents excellent uniformity of coverage from the system designed by Church Interiors Audio and Video, Inc.



Sound Levels: Room Half-Occupied

The sound-level map for the fully-occupied condition is almost identical with the one shown above.

BACKGROUND NOISE

One of the most common causes of congregation complaints about not being able to hear, or to understand what is heard, is background noise. In some church locations, external (traffic) noise is the major problem, but with a relatively isolated location, heating/air conditioning (HVAC) noise is likely to be the worst culprit. The recommended maximum noise level for churches is defined as the “room criterion” curve RC25 or RC30. Higher levels have been shown to cause problems for listeners, especially those with hearing aids. Under optimum conditions, churches using primarily amplified music can stand slightly higher levels of background noise, since the program is louder. However, as any experienced sound technician an attest, optimum conditions do not always exist.

High HVAC noise levels are caused by a number of design defects, including:

- The selection of noisy air-handling equipment
- Improper or absent vibration-isolating equipment mounts
- High air velocity at registers and/or return air ducts
- Rumble generated in ducts being conducted into wall or ceiling surfaces
- Improper design of turns and bends in ducts
- Over-or under-sized equipment for the heat load
- Air-volume dampers located in or near registers

There are four ways in which HVAC units radiate noise into a room:

- From the vents, including fan noise conducted through the ducts and turbulence noise created at the vents
- From the air handler, through the duct walls and the ceiling

- From vibrations mechanically coupled to the building and being radiated as noise
- From the return inlet.

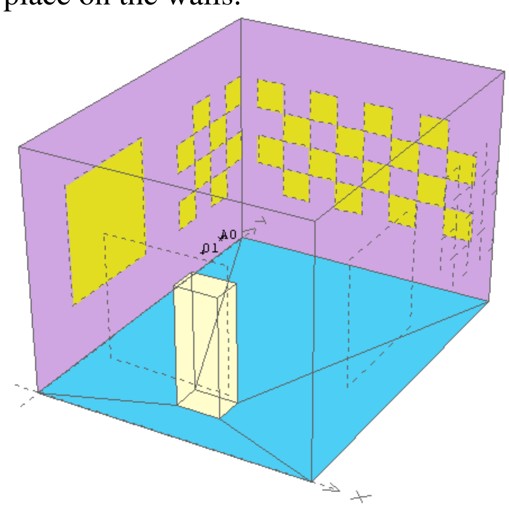
Your mechanical contractor has assured me that, although he does not have acoustical performance numbers yet, the HVAC system will be designed to meet an RC20 or 25 noise criterion, which is very good.

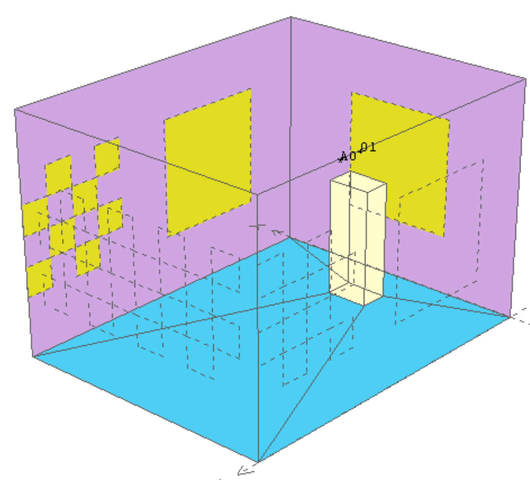
AURALIZATION

By tracing the behavior of sound waves as they crisscross the room, being reflected and absorbed on their way, it is possible to create a recording representing the sound of program material in the room at the design stage. The specific program material available is limited to that which has been recorded in an anechoic environment: mainly speech, choral music, and unaccompanied acoustic instruments. I have included a CD containing examples of various program materials as they will sound in your new sanctuary. The selections include bongos (track 1), speech (track 2), xylophone (track 3), and the St. Olaf College Choir performing Randall Thompson's *Alleluia* (track 4). The latter selection demonstrates the short reverberation time of your sanctuary – good for your worship style, but well below optimum for this particular choral selection. **NOTE: The auralizations will only be accurate if heard on a set of studio-quality headphones; they are of little value if heard on speakers, as the sound of the room in which they are heard will cover the characteristics of the room that was auralized.**

II. PRODUCTION ROOM

The acoustical characteristics of a good production room are different from those for a good sanctuary. Ideally, a production room should add no sound of its own – especially not a small-room "boxy" sound to the spoken word when it is recorded in the room. This necessitates a very absorptive ceiling and specifically-placed sound-absorbing material on the walls. **A material called ProFoam has been selected for the wall treatment, and Armstrong Pebble is to be used for the ceiling.** Because of the limited reflections of sound in the room, reverberation time as classically defined does not apply to such a room; nor do most of the other acoustic parameters usually used in auditorium design. The figures below show two views of the production room with the acoustical absorption in place on the walls.



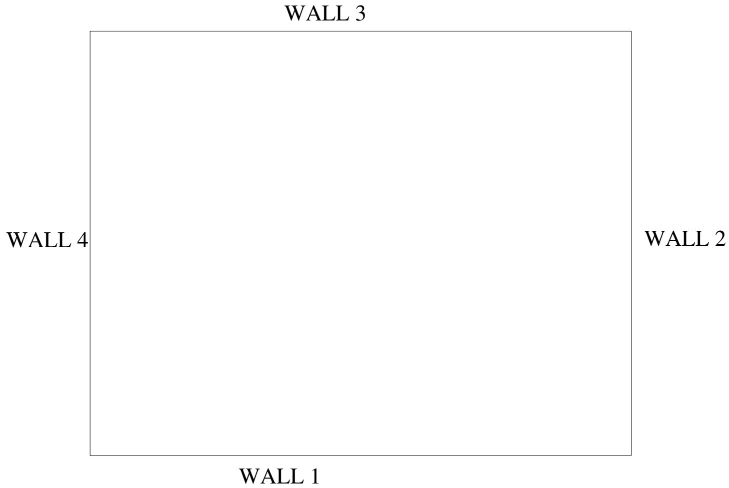


The white block in the room is an artifact of the modeling needed to designate a listener location. It has no acoustical properties.

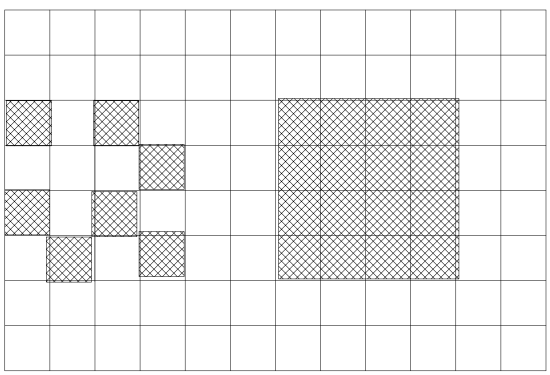
The drawing on the next page shows how the ProFoam blocks are to be attached to the walls in order to provide optimum absorption and diffusion of sound in the production room.

The CD includes auralizations of several sources in the production room:
The bongos (track 5) and xylophone (track 6) demonstrate the lack of noticeable reflections in the room, while the speech (track 7) shows the lack of coloration of the sound in the room.

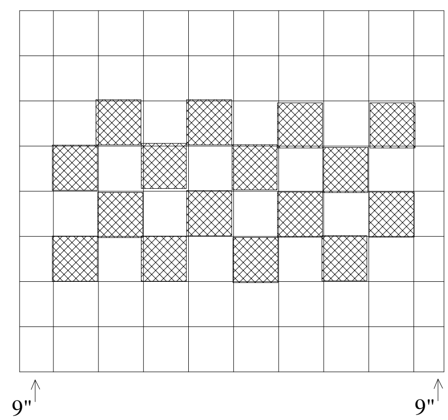
VIEW FROM TOP OF PRODUCTION ROOM



WALL 1 VIEWED FROM INSIDE

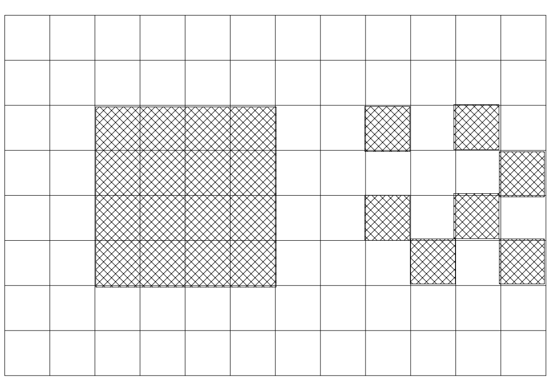


WALL 2 VIEWED FROM INSIDE



NOTE: ALL GRID SPACINGS ARE 1 FOOT UNLESS OTHERWISE INDICATED.

WALL 3 VIEWED FROM INSIDE



WALL 4 VIEWED FROM INSIDE