DETERMINATION AND IMPLEMENTATION OF ACOUSTICAL GOALS FOR BROADCAST FACILITIES

WAYNE V. MONTONE

RICHARD K. MILLER & ASSOCIATES, INC.
ACOUSTICAL ENGINEERING GROUP

This paper addresses the acoustical environments required for good "live" and produced cable and satellite tranmissions. This information is applicable to all individuals involved with cable, television, teleconferencing and videoconferencing.

Discussions of the effects of systems typical to the industry and how the acoustical environment goals are difficult to attain, are included. Typical and common solutions will be discussed based on case histories. The terminology of noise and acoustic descriptors are defined. The basic principles involved in providing noise reduction or to reduce noise within a space are also related. Included are descriptions of how generalized acoustic data can reduce the likelihood of attaining the desired acoustical goals along with a practical acoustical checklist.

INTRODUCTION

The audio portion of broadcasting is fifty percent (50%) of the transmission. Yet the quality of the audio environment, which is affected by noise impact, is constantly overlooked. In understanding noise impact and its adverse effects, first noise itself must be understood.

Technically noise is defined as the combination of a nonharmonious group of frequencies. A more common definition is merely unwanted sound. Any sound can be considered to be noise. Music is after all, only music to the ear of the beholder. Human perception of noise is subjective; there are however analytical methods for noise assessment which remove human judgement errors.

Sound consists of very minute pressure fluctuations in the air, generated by any method that can cause these pressure fluctuations. Sound generation can be divided into three (3) broad categories.

1. **Vibrating Surfaces**
2. **Aerodynamic Turbulence**
3. **Molecular Decomposition**

Vibrating surfaces are the most common and easily understood mechanisms that generate pressure fluctuations. Some examples of vibrating surfaces are strings on guitars and pianos, drum heads, vocal chords, stereo loudspeakers, walls, windows and their support systems. As can be seen, most any solid object has the potential for generating sound. This variety of sources make detailed engineering calculations necessary to determine how noise interacts with the solid structures.

Aerodynamic turbulence is a much more complex type of noise than vibrating surfaces. When air (which may be thought of as a fluid) is moving in stable flow configurations, it does not generate any noise. When the air flow leaves its stable flow configuration and interacts with directive structures (like air changing direction in heating, ventilating and air conditioning ducts), or with ambient air (like at an air outlet grill) a turbulent mixing region is created. The volume, velocity and size of the mixing region determine the amount of turbulence and the corresponding noise generated. This can be complicated even further whenever a solid object is placed in the air flow (t-joint ducts).

The third method for generating noise is molecular decomposition. This type of noise generation is found in electric arcs from welders, furnaces, and flames. It has no architectural application.

NOISE CONTROL

There are four (4) basic concepts for reducing the noise impact architecturally. These concepts are.

1. **Sound Barriers**
2. **Sound Absorption**
3. **Vibration Damping**
4. **Vibration Isolation**

Any of these four concepts can be applied depending on the engineering analysis. It is very important to understand the difference of these noise control concepts. Typical sound barriers consist of sheet rock, gypsum board, concrete, brick, and wood. The materials' noise control quality is due primarily to their mass. They reduce sound by reflecting or resisting its transmission. The performance of the materials is measured as transmission loss, T.L.

Typical sound absorption materials are fiberglass insulation, open cell foam insulation, cloth and even people. Sound absorption theory differs widely, however what basically occurs is acoustic energy is dissipated. Because these materials have very little mass, sound is not reflected or stopped by them. The absorption materials may be used to reduce the noise within an enclosed environment. Surface treatments, such as curtains, ceiling tile, etc. to reduce typewriter or computer noises are a common example.

These first two concepts, barriers and absorbers, work extremely well together as a system in stopping and dissipating noise. The barrier reflects noise and the absorption aids in dissipating the remaining acoustical energy

Vibration damping materials are traditionally rubber or vinyl which are applied to surfaces that are radiating noise created by its own internal mechanisms. Vibration isolation materials are typically rubber or compressed fiberglass which are used to prevent vibrations from being transmitted to another surface. Their common form is machine mountings or floor isolators.

ACOUSTICAL DESCRIPTORS

Units

dB stands for decibel. A decibel is the unit of power ratio equal to one tenth a bel. A bel (named after Alexander Graham Bell) is a power ratio equal to the logarithm to the base 10 of the ratio of any two powers ($B = Log_{10}\ P_2/P_1$). The early researchers in sound and human perception found that humans perceive sound logarithmically. The bel system of measurement happened to coincide rather well with the experimental hearing data.

By definition a decibel (dB) is a power ratio, but because it is a ratio it can be converted to other ratios. What is normally referred to as a dB in noise work is the sound pressure level (Lp). The sound pressure level is defined as.

$$Lp = 20 \log P/0.0002 \text{ microbars} \qquad (1)$$

Where Lp = Sound Pressure Level in dB
P = Sound Pressure (rms) in Microbars

Since decibels are logarithmic, they cannot be added together like normal numbers. 50 dB + 50 dB DOES NOT equal 100 dB. The long method to add decibels is to work Equation (1) backwards through the antilogs, arrive at the original pressures, add them together and recalculate the Lp dB.
There is however a short cut. If the difference between decibels is known, then Table I can be used to add decibels.

TABLE I

Decibel Addition

Correction Factor to dB Difference Between Sound Levels	Added to the Higher Sound Level
0 to 1 dB	3 dB
2 to 3 dB	2 dB
4 to 8 dB	1 dB
9 dB or more	0 dB

Example. 50 dB + 51 dB = 54 dB

(51 dB - 50 dB = 1 dB, the 1 dB difference is equal to an addition factor of 3 dB. Make this addition to the highest level, 51 dB + 3 dB = 54 dB)

Frequencies

Humans can perceive a large range of discrete frequencies. Normal human hearing has a range from 20 Hz to 20,000 Hz (Hz = Hertz = cycles per second). The lower frequencies are commonly called bass tones and the higher frequencies are called treble tones. For technical analysis it is necessary to consider all the frequencies of the noise impact or sources.

Discrete frequency analyzers are expensive and difficult to use. To simplify frequency analysis octave bands have been developed. Octave bands divide the frequencies into groups. The standard octave bands are listed in Table II.

TABLE II

Center Frequency, Hz	Octave Band Range, Hz
31.5	22-44
63	44-89
125	89-177
250	177-354
500	354-707
1000	707-1414
2000	1414-2828
4000	2828-5657
8000	5657-11313

Because people do not, however, perceive all frequencies with equal acuity, a single number evaluation was created. Humans hear the middle frequencies, around 500 - 4000 Hz, easier than the high or low frequencies. This explains why it is so easy to hear a baby cry. Babies cry at the frequencies that are the easiest to perceive.

To mimic the way a human ear actually hears sound, a system of "weightings" have been developed for sound level meters. A-weighting (dBA) mimics human hearing at low intensity sound levels, B-weighting (dBB) duplicates human hearing at middle intensity sound levels and C-weighting (dBC) is for analyzing the sound at high intensity sound levels to human standards. The weightings to be applied to sound levels for the octave bands are presented in Table III.

TABLE III

	A, B & C Weightings		
Center Frequency, Hz	dBA	dBB	dBC
31.5	-39.5	-17.1	-3.0
63	-26.2	-9.3	-0.8
250	-8.6	-1.3	0
500	-3.2	-0.3	0
1000	0	0	0
2000	+1.2	-0.1	-0.2
4000	+1.0	-0.7	-0.8
8000	-1.1	-2.9	-3.0
16000	-6.6	-8.4	-8.5

The dBA weighting is most commonly used because of its similarity to human hearing. However, engineering analysis does not require this weighting. This and other systems are used for generalized comparisons or discussion only. The difficulties of using dBA data, or any other single number rating system for engineering analysis will be discussed later in the paper.

Barrier Performance

A noise reducing system, such as an architectural wall, performance is measured in dB and the measurement is referred to as sound transmission loss, T.L. The sound transmission loss class, STC, is a single-number rating of a wall's sound transmission loss performance. The sound transmission loss class rating method procedures are specified in the American Society for Testing Materials (ASTM) annual book of standards. The sound transmission loss of a wall is measured or calculated at 16 third-octave bands with center frequencies from 125 to 4000 Hz. To determine the standard transmission loss class the transmission loss values are plotted and compared with a reference contour. The rating is easily determined by using a transparent overlay on which the contour is drawn. The contour is shifted vertically relative to the test data curve to as high position as possible according to the following conditions:

1. The maximum deviation of the test curve below the contour at any single angle shall not exceed 8 dB.
2. The sum of the deviations at all 16 frequencies of the test curve below the contour shall not exceed 32 dB - an average of 2 dB.

The sound transmission loss class will "hide" deficiencies, therefore full frequency sound transmission loss data should be used for engineering analysis. A wall or building membrane's sound transmission loss characteristics are affected by its coincidence effects (resonance), mass (pounds per square foot) and leaks (perforations or openings). The coincidence effects describes the frequency at which a material resonates. This effect greatly reduces a material's ability to stop sound at that particular frequency. The material's mass in part defines its ability to prevent sound from being transmitted through its body.

Before complex or double wall constructions can be evaluated, each layer of the wall must be examined for its own coincidence effects and mass characteristics. Double walls with layers of different materials will perform superior to those walls with layers of similar materials because the coincidence effects (frequency at which the noise reduction capabilities will be less than expected) will not occur in the same frequency. The air space within a double wall provides a decoupling effect between the two layers in a wall. This air space effect is also reduced at its natural resonant frequency which is a function of air space thickness (inches). The addition of sound absorption materials that do not cancel the decoupling effect will enhance the noise reducing qualities even further.

It should be realized that detailed composite sound transmission loss calculations must be performed if the membranes of a room do not have similar characteristics. This is because weaker wall membranes sound transmission loss performance will cancel out superior qualities that may be present.

Sound Absorption

Sound indoors is affected by the room shape, volume, and the interior surfaces. In most cases the room shape and volume are fixed by other design criteria and processes. Except in the case of special facilities where speech projection is the focal point of the design, the surface treatments are the controlling factor of the interior environment. The sound absorption qualities of surface treatments are delineated by their sound absorption coefficients.

Sound absorption values vary with frequency, and are dependent upon porosity and thickness. Material facings, have a large effect on the sound absorption values. Where two or more materials are considered within a room, all surface treatments or the lack of it must be used when determining the interior effects. The room's sound absorption characteristics affect the amount of time sound will be reflected about in the closed space. The reflected sound is called reverberation.

CRITERIAS

Recommended acceptable interior noise levels, or as they are more commonly known "Noise Criteria Curves," have been compiled for a large scope of interior uses. The noise criteria values are presented in dB and octave band sound pressure levels. The various interior uses (speech, working, reading, etc.) and their corresponding noise criteria level goals are presented in Table IV.

The octave band sound pressure levels of the Noise Criteria Curves are shown in Table V. They are used to establish the background or ambient noise levels in a given environment. The ambient noise level is the sound present in a facility when it is not in use and only the support systems are in use. By designing a room to particular Noise Criteria Curve levels excellent signal to noise ratios and proper microphone keying may be achieved for appropriate broadcasting conditions. The recommended Noise Criteria Curve levels should not be exceeded. If the recommended Noise Criteria Curve levels are exceeded, the ambient levels may mask or drown out the intended activities, by being within in ten dB of the broadcast signal. This can manifest itself as a problem in speech intelligibility. Any noise sources whether from inside the facility itself or external sources (intrusive noise) must comply with the Noise Criteria Curve guidelines.

Normally a NC 15 is desired for a broadcasting facility whether for cable, television, telecommunication or vidoecommunications. It would be necessary to reduce any potential intrusive noises to approximately 10 dB below Noise Criteria Curve 15 values, while the interior sources should not exceed Noise Criteria Curve 15. This will avoid the decibel addition factor of 1-3 dB, raising the noise level above the Noise Criteria Curve goals.

Reverberation from sound buildup within the facility is measured as a function of time. Reverberation time is the time that would be required for the mean-square sound pressure level to decrease to 60 dB after the noise source has stopped.

TABLE IV

Designs Goals For Indoor NC Levels in rooms with various uses

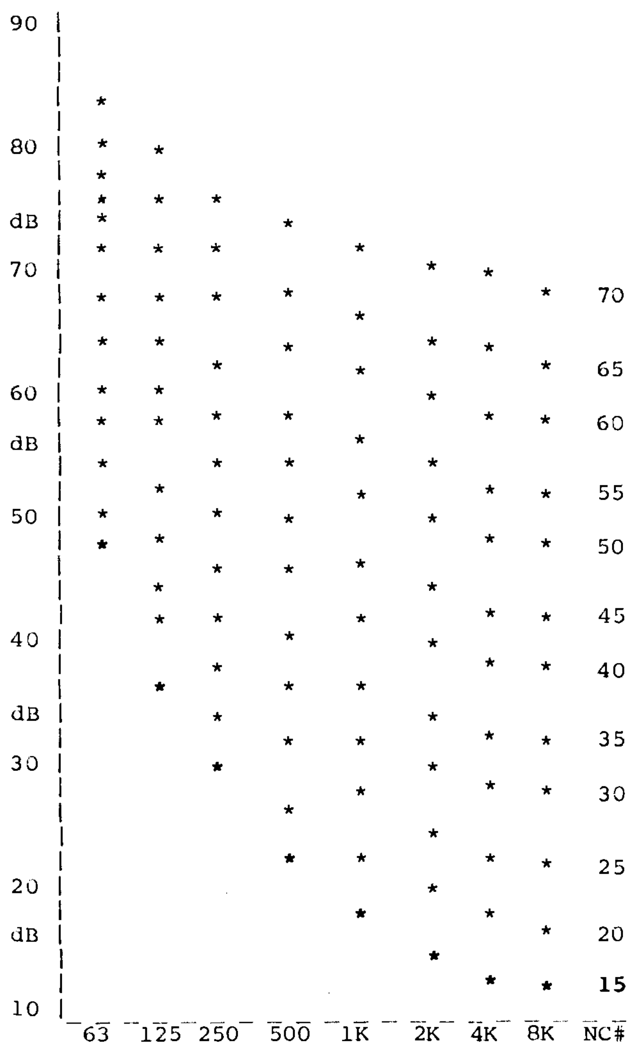
Type or use of space	Noise Criteria Level
Concert halls, opera houses, recital halls, drama theaters, **broadcast**, television and recording studios (excellent listening conditions)	**15 - 20**
Bedrooms, sleeping quarters, hospitals, residences, apartments, hotels, motels (for sleeping, resting, relaxing)	20 - 30
Small auditoriums, small theaters, small churches, music rehearsal rooms, large meeting and conference rooms (for very good listening)	20 - 30
Private or semiprivate offices, small conference rooms, classrooms, libraries, living rooms and similar spaces in dwellings (for good listening conditions)	30 - 35
Large offices, reception areas, retail shops and stores cafeterias, restaurants, etc. (for fair listening)	35 - 40
Lobbies, corridors,	

laboratory, work spaces, drafting and engineering rooms, general secretarial areas, maintenance shops (moderately fair listening conditions) 40 - 45

Speech intelligibility has a direct correlation with the time it takes the sound to decrease. If a lecturer's first spoken word continues to travel within a room even after he has spoken his fifth word, the audience will not be able to understand what is being said. This affects speech intelligibility. Table VI presents building uses and ideal design reverberation times. Extremely low design goals are used for broadcasting uses. This minimizes activity noises of the room and allows for clear understanding of the spoken word at relatively close distances.

TABLE V

Noise Criteria Curves
Level, dB v.s. Frequency, Hz



PROBLEMS IN PRACTICE

Single Number Rating Systems

As previously presented single number rating systems such as dBA and STC attempt to average or generalize the sound spectrum so the information can be easily handled. Unfortunately this causes design deficiencies where weighting factors or performance dips are disguised and the full impact is not realized. For example, the speech range is considered to be 500 HZ to 2000 HZ with the peak frequency at 1000 HZ. This is true when considering only speech intelligibility, but the normal human being is capable of producing sound levels as low 125 HZ. A voice outside a facility may intrude at low frequencies if the dBA weighting was used.

TABLE VI

OPTIMUM REVERBERATION TIME at 500/1000Hz

Use versus Time, seconds
(building size range = xxXXxx)

Use	Time, seconds (0.2 – 3.0)
Liturgical	XXXXXXXXXXX>
Symphonic	xxXXXXxx
Secular	xxXXXxxx
Opera	xxXXxx
Orchestra	xxXXxx
Classical	xXXXXxx
Musicals	xxXXxx
Bands	xxXXxx
Churchs	xxXXXXXXXXXXXXXXX>
General	xXXx
Theater	xxXXxx
Cinema	xxXXXXxx
Lectures	xxxXxxx
Drama	xxXxx
Classrooms	xxXXxx
Recording	xxXXXxx
Broadcast	**xxXXXxx**
Nightclub	xxxXXXXxxx
	0.2 0.5 1.0 1.5 2.0 2.5 3.0

Without that information the

engineered wall would not be sufficient to stop or reduce the noise impact at that frequency. In addtion, the lower frequencies are much more difficult to stop and would require elaborate high mass walls.

When designing a telecommunications facility that uses microphones with actuation levels, which would include all the frequencies from 31.5 - 8000 Hz, a wall with certain a standard transmission loss class value may provide a corresponding Noise Criteria Level that appears satisfactory. However, the sound transmission loss value at 125 HZ would be significantly less than expected and would not provide the proper environment. This would cause the microphone to activate and be continuously "open" or on.

Either the fan, motor, ducts or the supply grills can be the source of the problem. All parts of the systems must be considered, especially the supply grills which can create high frequency "whistling" noises.

The vibration levels within modern buildings are another source of the designer's concern. Structure borne vibrations have several sources, the primary ones are fixed machinery and foot falls of the building's occupants. Here we see the heating, ventilating and air conditioning system hardware come into play. Its location and mounting techniques can directly effect any critical facility within the building.

The vibration levels are transmitted to all rigidly attached membranes which all have the possibility of becoming acoustical radiators or "speakers". This effect can cancel out the effort of stopping the airborne intrusive noise by allowing the vibrations to pass through the very systems themselves. The noise from footfalls (peoples foot steps) from floors above in an average slab building can reach levels above the Noise Criteria Curve of 35. This prevents reaching the extremely low Noise Criteria Curve goals required for cable or broadcast facilities. There can also be undocumented effects on camera optics and picture quality.

In combating the noise and vibration levels typical solutions used for large on-grade studios are just not applicable. The solutions usually involve massive walls and doors which are not feasible in multi-level structures that many teleconferencing, videoconferencing and cable facilities are being installed in today. The point source building loads typically are in the range of 8 - 10 pounds per square foot. At these low levels high mass wall solutions can not be used and radical acoustical wall membrane design is necessary.

SOLUTION SYSTEMS

Detailed Research and Measurements

It is extremely important to have fully researched the peak (maximum) noise levels, as well as the ambient levels, that exist in the building. This must include the variety of building modes the building is used in, such as lunch hour, high load air conditioning demand and late night operation. The potential impacts that can happen any time must be considered. This includes employee disagreements, high traffic conditions, such as building tours and uncontrolled wall impacts from doors. Every second your broadcast facility is in operation it should not be interrupted.

When considering the ability to hear clearly, the signal-to-noise ratio is critical. Signal-to-noise ratio is the difference between the ambient noise levels as compared to the speaker's voice level. If the ambient noise level is high due to design deficiencies, the speaker may have to speak abnormally loud to be heard properly, or not heard well at all.

Impact Determination

A very common problem is underestimating the impact of the intrusive noise (exterior noise) that will be affecting the facility. The origin of this problem lies in accurately determining the type of activities that will be present. The noise levels of raised speech or yelling can be very loud and be surprising low in frequency. The designer may use the generalizing dBA equivalent of the expected noise level for an activity outside the facility. This will invalidate all further goal calculations. It is essential that the maximum level that may occur, within reason, be used in computing the sound transmission loss necessary to provide the desired acoustical environment.

Typical Building Construction

The typical or average building provides a multitude of problems for the acoustical designer of a broadcast facility. Making use of every square foot of building space does not sound like a problem, but this usually leads to having many types of spaces with different acoustical goals improperly placed. Careful planning or space zoning is necessary and can save a multitude of problems and dollars in the future.

The heating, ventilating and air conditioning system is a cronic problem because of the various types that can be used. Open plenum return systems render a facility acoustically useless without expensive return air silencers and ceiling treatments. The sound produced in one area of the floor can travel to any facility area where the air flows to. Many systems utilize unlined trunk lines that link facilities together in very short distances. This allows sound to reflect in the ducting directly into the next facility. The heating, ventilating and air conditioning system hardware itself leads to the next building concern.

When the noise from the heating, ventilating and air conditioning system itself is too loud, it too can be broadcasted along with the speakers voice. In addition the signal-to-noise ratio may be improper and the audience will not be able to distinguish between the two sounds, therefore masking the message.

Having to stop production or retape in your facility is defeating its special purpose. These costly "down times" are often accepted as the cost of doing business or passed along to the production staff as their problem to overcome.

Full Frequency Analysis

When making the base line building surveys include measurements throughout the octave band sound pressure levels of 31.5 to 8000 Hz. Any predictions of potential noise sources or impacts should be calculated throughout the same frequency range. This data should be used to determine the acoustical design goals. No single number rating systems or evaluations should be used, especially with the sound transmission loss class. This will prevent an unforseen deficiency in the designed wall at any particular frequency resulting in an improper acoustical environment.

Multiple Building Membranes

The determined sound transmission loss goals must apply equally to all membranes that are part of the facility. This includes walls, floors, ceilings, windows and doors. The composite or overall sound transmission loss will only be as good as the weakest membrane. This weakness is proportional with the entire surface area.

Sealing

An illogically large deficiency in the sound transmission loss can result from very small areas, including miniscule gaps. The sound transmission loss of a wall system with air gaps in and around receptacles and doors equal to 1% of the total surface area will be limited to just 10 dB.

This limitation results from poor sealing. The need of designing the facility to be "airtight" is essential. Anywhere air or light can travel so can sound. This basic principle must be translated into practical construction practices. The sealing of all perforations through the acoustical membranes that surround the facility must be carried out by the installation crew. A quality control system with caulking examples and check points in the process should be created for the contractor or the subs. To be most effective the system is to have the acoustical designer carry out the quality. However, a sealing quality control system can be designed and construction or building owner employees can be trained for implementation.

CONCLUSIONS

To provide a superior acoustical environment the common problems presented in this paper must be dealt with. The following Table VII presents a suggested check list that you or your acoustical designer should always take into consideration.

With is practical checklist of critical points in the acoustical design process of a critical space the common pitfalls can be avoided. For complete design services rely on a qualified acoustical consulting firm.

TABLE VII

Acoustical Design Checklist

I MEASUREMENT

1. Ambient Levels
   - Morning [ ]
   - Lunch [ ]
   - Afternoon [ ]
   - Night [ ]
2. Peak Levels
   - Voices [ ]
   - Cleaning [ ]
   - Walking [ ]
   - Impacts [ ]
   - Office Equip [ ]
   - External [ ]
3. Flanking Paths
   - Electrical [ ]
   - Phone Lines [ ]
   - HVAC [ ]
   - Chases [ ]
   - Construction [ ]
   - Other [ ]

II ASSESSMENT

4. Zoning
   - Traffic Pattern [ ]
   - HVAC [ ]
   - Usability [ ]
   - Noise [ ]
   - Other [ ]
5. Full Frequency Data [ ]
6. Microphone Cutoffs
   - Overall Level [ ]
   - Frequency [ ]
7. Signal to Noise Ratio Goal [ ]
8. Noise Criteria Levels
   - NC-15 [ ]
   - NC-20 [ ]
   - NC-25 [ ]
9. Acoustical Environment Goals
   - Ambient [ ]
   - Privacy [ ]

TABLE VII (cont)

Acoustical Design Checklist

III ANALYSIS

10. Transmission Loss Goals [ ]
11. Transmission Loss Data
    - Floor [ ]
    - Ceiling [ ]
    - Walls [ ]
    - Doors [ ]
    - Windows [ ]
12. Transmission Loss Calculations
    - Mass Law [ ]
    - Coincidence [ ]
    - Air Resonance [ ]
    - Double Wall [ ]
13. Surface Areas
    - Floor [ ]
    - Ceiling [ ]
    - Walls [ ]
    - Doors [ ]
    - Windows [ ]
14. Reverberation Time Calculations [ ]
15. Composite Transmission Loss [ ]

IV SPECIFICATIONS

16. Wall Schedule
    - Thicknesses [ ]
    - Air Spaces [ ]
    - Insulation [ ]
    - Stud Distances [ ]
    - Stud Type [ ]
    - Isolation [ ]
    - Membrane Number [ ]
17. Door Schedule
    - Weight [ ]
    - Frame [ ]
    - Seals [ ]
    - Number [ ]
18. Finish Schedule
    - Product [ ]
    - Amount [ ]
    - Thickness [ ]
    - Nightime [ ]

TABLE VII (cont)

Acoustical Design Checklist

IV SPECIFICATIONS (cont)

19. HVAC

System Type	[ ]
Lining	[ ]
Duct Size	[ ]
FPM	[ ]
CFM	[ ]
Grill Type	[ ]
Grill FPM	[ ]
Silencer	[ ]

20. Installation

Methods	[ ]
Sealing	[ ]
Perforations	[ ]

V CONSTRUCTION

21. Materials Checks

Membranes	[ ]
Insulation	[ ]
Isolation	[ ]
Studs	[ ]
Doors	[ ]
Windows	[ ]
Ducting	[ ]
Gaskets	[ ]
Caulking	[ ]
Glue	[ ]

22. Sealing

Caulk Location	[ ]
Caulk Width	[ ]
Glueing Locat.	[ ]
Glueing Width	[ ]
Perforations	[ ]

23. Transmission Loss Testing

Walls	[ ]
Walls & Doors	[ ]
Windows	[ ]
Complete	[ ]

24. Reverberation Testing

Surface	[ ]
Furnished	[ ]