ACOUSTICAL GUIDELINES FOR ORTHODOX CHURCHES

by Reader David Nelson,
St. John the Forerunner Orthodox Church, Austin, Texas
Principal Consultant, Nelson Acoustical Engineering, Inc.

Post Office Box 879, Elgin TX 78621
Telephone: 512.281.5535 Fax: 512.281.5540
e-mail: david@nelsonacoustical.com
website: www.nelsonacoustical.com

1. INTRODUCTION

What constitutes good acoustics for an Orthodox church? Opinion aside, the building can be said to have good acoustics if it assists the proclamation of the Gospel and encourages participation in the services. The building should be reflective enough to aid singing and speaking, and reverberant enough to encourage congregational singing, but not so reverberant that words become unintelligible. The room should be quiet enough that background noises do not interfere with the services. These capabilities are a direct result of the geometry of the Sanctuary and Nave, details of the construction of the building, and the design of the mechanical equipment.

Getting it right is all the more important because our services are vocal-powered: if the building works against us, it's an uphill battle every Service, every week, every year. Be forewarned that good acoustics do not occur naturally with "normal" building design and construction practices: they must be encouraged through prudent building planning and design.

The guidelines given below identify design and construction methods that tend to lead to successful worship spaces, and can be applied to both new and existing buildings. They are especially important for new construction because it is often relatively inexpensive to design for proper acoustics if it's done from the outset. By contrast, fixing a building that's already built is seldom easy or inexpensive.

The guidelines are highly generic and are intended to inform discussions and help parishes avoid the most obvious pitfalls. In this simplified form they cannot possibly account for every possible configuration or circumstance. They are not intended as a substitute for the experience and judgement of an acoustical consultant. If an acoustical consultant is to be retained, this should be done at the earliest possible stage of building design. Early design decisions can lead to success or can be all but unrecoverable. I tell my clients, "If you've drawn a diagram on the back of a napkin, it's almost too late to call...."

My personal approach in advising my clients is that operating without a sound system is

most convenient and least expensive. With strong voices and good hearing all around, rooms designed according to these guidelines will not require a sound system. However a sound system may be desired where: solo voices are insufficient to fill the room, in order to power wireless receivers for the hearing handicapped, and to allow services to be piped to other parts of the building or to be recorded. If your room has poor acoustics, a sound system may be able to help. But you should be aware that the sound system designed to patch up poor acoustics is more expensive and complicated than one designed to serve a space that possesses good acoustics. In any event, developing a good sound system requires more than simply setting up microphones and speakers at seemingly appropriate points. Professional assistance is recommended. This document does not address sound system design.

2. GUIDELINES FOR ROOM ACOUSTICS

The Sanctuary and Nave should have a volume appropriate for the number of parishioners, and should be very quiet and moderately reverberant. The following guidelines show how the design of the building influences the results.

Here are the concepts we are working with:

-- Reverberation: the persistence of sound "hanging in the air". If a room is large and/or highly reflective, reverberation is high. If small and/or absorptive, reverberation is low.

-- Projection: reflective surfaces, especially around the singer/speaker, tend to support projection of sung and spoken voice. Excessive room volume and/or excessive sound absorption hinder projection.

-- Intelligibility: The ability to understand the spoken or sung word. Low reverberation and low background noise support speech intelligibility.

-- Envelopment: the sensation of sound coming from other locations in the room and from all directions. For congregational singing, this is an important factor. If parishioners hear other people singing at least as loudly as themselves, they tend to sing with more confidence. If people only hear themselves, they generally sing more tentatively if at all. Envelopment is generally supported by a higher degree of reverberation.

2.1 Room Volume and Surfaces

Room volume and surface treatments, combined with effects of noise from inside and outside the building, determine the degree of reverberation, projection, intelligibility and envelopment.

2.1.1 Sound-reflective surfaces

For the purposes of this document, sound-reflective materials include concrete (painted or sealed), stone, masonry, wood (if greater than 1/2 inch thickness) and gypsum (if greater than 1/2 inch thickness).

2.1.2 Sound-absorptive surfaces

Sound-absorptive materials include carpeting, seat cushions and sound-absorptive ceilings. It should be noted that people are sound absorbers, sometimes collectively the most significant absorber in the room. Absorptive ceilings include commercial ceiling tile, glass fiber or mineral wool (even if vinyl-covered), Tectum(r), blown-on fireproofing or cellulose, and any other porous material[1].

2.2 Categories of Construction and Recommended Volumes

Typical categories of construction are defined in Table 1 below. Identify the type of construction that applies to your Sanctuary and Nave. Then find the corresponding range of recommended per-person room volumes (see Table 2). For each category a maximum total volume is given that can typically be filled by one strong voice. The room volume here refers to the combined Nave and Sanctuary, and can be estimated as the floor area times the average height. The lower value is the minimum volume per person necessary to adequately support congregational singing. The upper value is the maximum volume per person for which speech intelligibility is expected to be just acceptable.

Table 1: Simplfied Categories of Construction

Category	Floor	Walls	Ceiling
A	Solid (concrete, stone)	Masonry	Solid (wood, concrete)
B	Solid (concrete, stone)	Gypsum	Solid (wood, concrete)
C	Solid (concrete, stone)	Gypsum	Gypsum
D	Thin, Loop-pile Glue-down Carpet throughout, or Seat Cushions	Gypsum	Gypsum
E1	Solid (concrete, stone)	Gypsum	Absorptive
E2	Cut-pile Carpet and Seat Cushions	Gypsum	Gypsum

F	Thin, Loop-pile Glue-down Carpet throughout, or Seat Cushions	Gypsum	Absorptive

Table 2: Recommended Room Volumes by Category

Category	Min Vol./Person	Max. Vol./Person	Max. Volume
A	105 ft^3	170 ft^3	185,000 ft^3
B	120 ft^3	200 ft^3	145,000 ft^3
C	135 ft^3	215 ft^3	115,000 ft^3
D	185 ft^3	300 ft^3	50,000 ft^3
E1 or E2	240 ft^3	380 ft^3	30,000 ft^3
F	300 ft^3	480 ft^3	15,000 ft^3

If the room's volume per person ratio is lower than given above, poor envelopment is anticipated that could discourage congregational singing. If the room's Volume/Person is higher than given above, poor intelligibility should be expected. Finally, if the maximum volume is exceeded, Clergy and Chanters (even those with strong voices) will have difficulty projecting adequately without the aid of a sound system.

Category D is very commonly used but discourages congregational singing and, in larger rooms, hinders projection. Categories E1, E2 and F should generally be avoided. Notice that Categories E1 and F differ from Categories C and D, respectively, only by the properties of the ceiling. Thus if you presently have a building in Category E1 or F, it may be possible to modify the ceiling to improve the situation.

Example 1

A parish desires to build a stone basilica with marble floors, solid wood planking ceiling, and unpadded wooden benches around the perimeter for 300 parishioners. What size should the room be?

This is a Category A construction type. Appropriate room volumes are between 31,500 ft3 (105 x 300) to

51,000 ft3 (170 x 300). Since the appropriate volumes are less than the maximum allowable limit, one strong voice ought to be able to fill the room.

Example 2

A small parish desires to lease a building from a protestant congregation. The worship space is 20 ft. x 40 ft. x 12 ft. high (average height). It currently has wall-to-wall cut-pile carpeting, a gypsum board ceiling and walls, and pews with cloth-covered seat and back cushions. This parish typically has 50 in attendance. Does this room work?

This room corresponds to Category E2 construction. The volume per person will be 192 ft3 (20 x 40 x 12 (50), which is way too low to encourage congregational singing. The room volume (9,600 ft3) is much less than the maximum allowable, so one voice ought to be able to project adequately.

Options? Converting to Category D would provide adequate envelopment for congregational singing. The carpet and seating need to be changed.

Example 3

A large parish has an existing building for 500 parishioners that is 95,000 ft3 and corresponds to Category D. There are complaints that the homily is not intelligible at the back of the room. Someone has suggested that the room acoustics are bad. What do the guidelines suggest?

The volume per person (95,000 (500 = 190) is in the acceptable range, and tends towards the small side which favors intelligibility. However, the room exceeds the maximum volume (50,000 ft3) that one strong voice can fill for this construction type. Two options are available: 1) a sound system may be added to enhance projection, or 2) the construction type could be changed to Category C by removing carpet or eliminating padded seating. In either event, the background noise levels should also be checked (see Section 4.2).

Example 4

A parish considers purchasing an old Episcopalian church for services which fits Category B. A parishioner has recently passed away and lovingly bequeathed money to the parish "for carpeting in the church". The room volume is 30,000 ft3 and there are typically 200

parishioners in attendance. Is the carpet beneficial?

At 30,000 ft3 and 150 ft3 per person, the room is currently within the guidelines for Category B. Addition of thin carpet would make the room Category D and the room volume per person would be inadequate to support congregational singing. If the as yet unspecified carpeting turns out to be thick, padded, cut-pile, and wall-to-wall the room might also be too sound-absorptive for the Clergy and Chanters to fill (Category E2 maximum volume = 30,000 ft3).

3. GUIDELINES FOR NOISE CONTROL

Unwanted noises compete with the Services. Reducing these noises is primarily a function of proper design of the building structure and mechanical systems.

The most significant culprit is typically the air handling system because it discharges directly into the Sanctuary and Nave. Note that the air handling system does not have to sound particularly noisy to be a problem: the requirements for quiet in a church are much more aggressive than in other spaces. Believe me, you won't be happy with an air handling system design that "sounds acceptable" at the local supermarket[2]. However, this may be what you get if you don't insist on something better.

Any noise source within the building that is not part of the service can also cause problems. These include plumbing, cry rooms, nursery, kitchen, and other tenants in a shared building (e.g., a kennel). First and foremost, prudent planning keeps high noise areas away from the Nave and Sanctuary. When they must be near one another, proper sound isolation must be designed into the building.

The building envelope should also isolate noise from highways and busy streets, aircraft overflights, emergency services, rainfall on lightweight roofs, barking dogs, etc.

3.1 Air Handling Noise

Noise from the air handling system has three primary origins: air movement through the blower, turbulence at grilles, registers, dampers, and fittings, and structure-borne vibration from motors, blowers and compressors.

A. For new construction, air handler sound levels no greater than RC-30 or alternatively, NC-30[3], are recommended. These are the standard requirements for churches.

B. HVAC blowers and compressors should be in a separate space, not in or directly above the Nave or Sanctuary. About 20 feet of internally lined duct is usually necessary between the fan and the first outlet and inlet. It is advantageous if the duct includes an internally-lined 90-degree elbow. Motors, blowers and

compressors should be resiliently supported on vibration isolators and have flexible service and ductwork connections. And don't fall for the myth that sound only travels downstream and thus won't come out of the air return: it travels happily upstream and the inlet typically needs a similar treatment as the discharge. An untreated return is the most common, and hardest to fix, defect in an air handling system.

C. Common ductwork between loud and quiet spaces should be avoided. For instance, the Nave and Sanctuary, and in some circumstances including the Narthex as well, should be served by a dedicated air handling system. The Cry Room, Kitchen and other potentially noisy spaces should be served by a separate system. If the system must be shared, a sound-absorbing trap is required.

D. Keep airflow rates low within the ductwork and at discharge and inlet grilles. Prefer grilles with large gaps between vanes (e.g., 1 inch). Avoid using grilles with integrated variable dampers.

3.2 Other sources within the Building

A. Effective sound-isolating walls and ceilings are heavy (e.g., brick or multiple layers of gypsum board) and minimize penetrations and gaps. Walls must be carried from floor to deck and sealed with non-hardening caulk. Thick, dense sound-absorbing batts should be used in cavities. Sound isolation performance of wall, door and window constrictions is commonly rated by "Sound Transmission Class" (STC[4]): the weakest wall surrounding the Nave and Sanctuary should have a Field STC rating of 50 or greater.

B. Sound isolating doors should be solid-core with continuous weatherstripping around the entire perimeter, including jambs, header and sill. Gaps in the weatherstripping should be minimized. All seals should be flush to one face of the door (it's common to find jamb and header seals on the "exterior" side and a bottom seal mounted ineffectively on the interior face). The bottom seal is also usually more effective when it contacts a smooth surface: consider cutting away the carpet under the entire door swing. To increase longevity of the seals, an automatic door bottom or cam-lift hinges may be used.

C. Return-Air Openings in Doors should be avoided: they are acoustically transparent.

D. Sound-isolating windows are typically of the "fixed" type, with dual glazing and a separating airspace greater than 2 inches. If neither of the panes is laminated glass, then the glass panes must have dissimilar thickness. Such windows usually have STC ratings greater than 40. In extreme cases, even higher ratings may be required.

E. Metal chairs should be padded on seat and back to reduce noise when they are shifted. Vinyl-covered padding is less sound-absorptive than fabric-covered padding and is therefore usually preferred. Note that the padded seating is sound absorptive.

F. In many churches the Sanctuary and Solea are constructed as a raised wooden platform. In order to minimize squeaking, screws instead of nails should be used to assemble the platform and sound absorbing batts should be added in the subfloor cavities.

G. If you rent your space and the building has other tenants, be informed about what possible noise events could take place in their spaces and provide adequate sound isolation. And not just for Sunday morning, but at other potential Service times as well. Realize also that the current tenants could be replaced by noisier ones at some point in the future. Be aware that even though fire codes typically require a floor to deck wall between the spaces, the least expensive wall that meets the fire code is typically not adequate for sound isolation. Also be aware that large amounts of vibration and sound can be transmitted through a common floor slab.

3.3 Sources outside the building

A. Windows and doors are the main path of noise into the building from the exterior. If the building is located near an obvious source of noise such as a highway, busy street, fire station, airport or heliport, sound isolating windows are probably required.

Sound-isolating windows are typically of the "fixed" type, with dual glazing and a separating airspace greater than 2 inches. If neither of the panes is laminated, then the glass panes must have dissimilar thickness. Typically these will have STC[5] ratings greater than 40. In extreme cases, even higher ratings may be required, which typically runs into extra expense.

B. Locate air conditioner compressors away from the sanctuary and nave, preferably around a building

corner.

C. Rain Noise on light-weight sheet metal roofs can be surprisingly loud. A heavier or more complex roof construction is required to adequately shield the space from rain impact. A noticeable improvement can be obtained by affixing a gypsum board ceiling from the underside of the roof structure and filling the resulting cavity 75% with sound-absorbing batts. More reduction can be obtained by resiliently supporting the gypsum board ceiling. A structural engineer should be consulted regarding the extra weight.

D. Aircraft Noise: Heavy roof and window construction is required to adequately shield the space from aircraft flyovers.

4. TROUBLESHOOTING

4.1 Room Acoustics

A. Determine the category of construction using Table I above. Determine the corresponding volume range per person and the maximum volume. If outside of the acceptable range, consider modifying the materials applied to the floor and ceiling. Failing this, addition of a sound system may help the Priest and Chanters project, but it won't encourage the congregation to sing.

B. Turn off all building HVAC systems such that the room is "silent" to the greatest extent possible. Ask Priests and Chanters to read from the Sanctuary and from the Chanters' stand. Is their speech intelligible at the back of the room (whichever is farther)? If not, the space may be too reverberant. Or, there may be too much interfering noise from outside the building.

C. Turn off all building HVAC systems such that the room is "silent" to the greatest extent possible. Have Priests and Chanters sing from the Sanctuary and from the Chanters' stand. Do they have to exert noticeable effort to fill the building to an acceptable level? If so, either the room volume or the sound absorption is excessive. If the room geometry and treatments cannot be addressed, a sound system may be required.

D. For existing buildings that are too sound-absorptive:

-- consider replacing acoustical ceiling tile with 1/2-inch gypsum board panels cut to fit

the T-grid. In many cases an existing light-duty grid system can be beefed up[6] by adding hanger wires to carry the extra weight (consult a ceiling contractor!). Material cost estimates for the gypsum tiles typically run $0.50 per square foot, installed cost estimates for new typically construction run $1.50 per square foot.

-- consider covering exposed (or vinyl-covered) glass- or mineral-fiber insulation with at least one layer of 1/2-inch gypsum board. In many cases the roof structure can bear the extra weight, but a structural engineer should be consulted to be sure.

-- if thin wood paneling (e.g., 1/8-inch) is applied directly to studs, consider removing the veneer from the studs, affix gypsum board to the studs, and then affix the veneer to the gypsum board if desired.

-- consider replacing thick, padded, cut-pile carpet with thin, glue-down, loop-pile carpet. Consider using it only in the aisles of the Nave.

-- consider replacing thick, cloth-covered seat cushions applied to both seat and back with thinner, vinyl-covered cushions applied to the seat only.

-- carpet should ideally not be used in the Sanctuary, on the Solea, around the Chanter's stand or in the Choir area.

4.2 Air Handler Noise

A. To evaluate air handler noise in an existing building:

-- Run the intelligibility check given above in 4.1.B. If successful, then do the following.

-- Turn on all air conditioning systems, including those that serve other parts of the building.

-- Speak in a *raised* voice (as if reading scripture) and have a listener positioned at a distance of 50 ft. or at the back of the room, whichever is nearer. "Just Acceptable" ambient noise conditions are characterized

by the raised voice being readily intelligible at 50 ft. If the reading is not readily intelligible at 50 ft. or at the furthest point in the room, ambient noise is too high and remedial action should be taken.

Good ambient noise conditions are characterized by a *normal* speaking voice being readily intelligible at 50 ft.

Excellent ambient noise conditions are characterized by a quiet or relaxed voice being readily intelligible at 50 ft.

B. If ambient noise is too high, try removing the supply and return grilles. If this reduces air handler noise to acceptable levels, you are fortunate: grilles with larger vane spacing should be substituted, or the grilles can sometimes be left off altogether. If not, the noise is emanating from either the fan itself or from fittings within the ductwork. In the latter case, significant work may be required to mitigate the situation. If multiple systems are in service, turn all systems off and then on one at a time to try to identify individual noise sources.

4.3 Isolation from interior noise

A. Close all doors and windows separating the Sanctuary and Nave from other portions of the building. Have someone sing or play a loud portable stereo at various locations (e.g., cry rooms, nursery, kitchen) in the building while another listens in the Nave. Check doors seals by temporarily sealing with masking tape: if this helps, door seals need improvement. Close off communicating ductwork with gypsum board: if this helps, air handling systems need to be separated or a sound-absorbing trap needs to be inserted in the line.

B. Operate all plumbing and listen in the Sanctuary and Nave. Avoid plumbing in the Sanctuary and Nave walls. If this can't be avoided, plumbing should be resiliently mounted to reduce noise transmission. Operate all plumbing and listen in the Nave.

4.4 Isolation from Exterior Noise

A. Invest some time listening inside and outside of the building at all reasonable service times. Note airport flight patterns, especially low-level departure patterns. Be aware of the location and proximity of nearby fire stations, ambulance services, etc. Be aware of automobile traffic, especially on highways. When inside, listen close to doors, windows and any other penetrations. Let your ears guide you to hotspots that correspond to weaknesses in the building envelope. Any improvements in the exterior noise isolation almost certainly have to begin there.

5. SELECTING A CONSULTANT

Finding the right acoustical consultant can be challenging because good acoustics and noise control capability is a matter of experience and education, but everybody and anybody can legally call themselves a consultant. There are a few bodies that give their "seal of approval" to people in the acoustics and noise control fields. Members of these groups should be preferred. Because of varied experience the specific capabilities of individual consultants or firms should be considered.

-- Members of The National Council of Acoustical Consultants are listed according to their areas of expertise. Some member firms provide comprehensive services for all types of church sound issues (room acoustics, noise control and sound system design). www.ncac.com

-- Full Members (that is, Board Certified) of the Institute of Noise Control Engineering typically have their primary expertise in the area of noise and vibration control, and can handle room acoustics issues. http://users.aol.com/inceusa/ince.html

-- Oregon is the only state in the USA that licenses Professional Engineers in the field of Acoustics. No list is currently available.

-- Syn-Aud-Con provides training to its members that cover sound system design and room acoustics. www.synaudcon.com

6. CONCLUSION

In conclusion it can be said that obtaining good acoustics in Orthodox churches is not a matter of either blind luck or Divine intervention (although a little of either never hurts). It is a matter of intentionally designing the worship space to do what it is supposed to do: help us worship. In order to be successful this design should be based on the laws of physics and the observed principles of human perception.

The guidelines provided above hit the highlights: there are a great many other fine points that could be discussed. Nevertheless, it is my hope that the distillation provided here will be helpful to Orthodox parishes, to the glory of God.

Pray for me, a sinner.

Reader David Nelson

1 However, porous materials above or behind sound reflective surfaces (as defined above, e.g., gypsum board) do not add sound absorption to the space.

2 Indeed, you tolerate it at the supermarket because you usually have no reason to communicate important information across the entire store.

3 Room Criterion and Noise Criterion, respectively, which refer to levels of background noise in the building. Your architect and HVAC contractor should know what these indicators mean.

4 Sound Transmission Class, defined in ASTM E413, a measure of the degree of sound isolation from speech and other high-frequency sounds.

5 Sound Transmission Class, defined in ASTM E413, a measure of the degree of sound isolation from speech and other high-frequency sounds.

6 Normally, an intermediate duty grid is used to support the gypsum board ceiling. Please consult a ceiling contractor to be sure this is done correctly.