Relocatable Classroom Acoustical Study- A Practical Application and Solution

By

Bard Manufacturing Company, Inc.

and

Geary Pacific Supply

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Irvin Derks, Vice President of Engineering, Bard Manufacturing Company, Inc.

Courtney Perkins, Laboratory Manager, Bard Manufacturing Company, Inc.

Layne Miller, Vice President, Geary Pacific Supply

Maury Tiernan, Sales Manager, Geary Pacific Supply

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I. **Introduction**

a. Background

An increased realization is developing on the importance and role of classroom acoustics for an adequate learning environment in schools. In addition to acceptable sound levels, other issues such as ventilation (as required in the ASHRAE 62.1 Standard), comfort and lighting also take a prominent role and are of equal importance to that of sound. One of these four ingredients should not be sacrificed for another.

To address the acoustical element, in 2002, the American National Standards Institute (ANSI) along with the Acoustical Society of America (ASA) published a standard titled *ANSI S12.60-2002 ACOUSTICAL PERFORMANCE CRITERIA, DESIGN REQUIREMENTS, AND GUIDELINES FOR SCHOOLS.* The purpose of this was to establish a standard for the acoustical design and performance of school classrooms. When the standard was developed, consideration was not given to Relocatable Classrooms. Some of the inherent unique challenges of relocatability and changing outdoor ambient sound levels were not considered. The feasibility of achieving the sound levels targeted by the S12.60-2002 Standard were not considered for relocatable classrooms. Those unique issues are now being addressed through a joint effort of the Modular Building Institute (MBI) and the Acoustical Society of America (ASA).

In 1997, Bard introduced a new heat pump HVAC product line called the Quiet Climate 1 Series. This was designed to improve the acoustical performance. This line has met with some market success to those users interested in its improved acoustical performance coupled with its higher energy efficiency levels, which exceeded the federal energy requirements in effect at that time by 20%. However, several classrooms continue to be built today with low cost as the primary driver. These frequently are built with lower cost construction and HVAC systems, which operate at higher sound levels than what can be achieved.

In 2003, Bard Manufacturing sought to develop an effective solution to the acoustical challenges of relocatable classrooms. Through this effort, we have successfully developed a new Quiet Climate 2 (CH Series) product line (Patent Pending) that when coupled with Bard Acoustical Accessories (Patent Pending) can be used in relocatable factory-built classrooms and meet the requirements of the S12.60-2002 standard for 35 dBA background sound levels. This product line can be used as a direct replacement for existing HVAC units to upgrade the acoustical performance without extensive construction changes. It can also be used on newly constructed classrooms. It offers the ability to meet several different sound performance levels depending on the acoustical accessories selected, the building construction and other factors. This lets the user determine the sound performance of the HVAC system based upon available budgets.

b. Sound Level Standards and Specifications

Several different standard requirements for sound levels in classrooms either have or are being established by different entities and have evolved over the past few years. A few examples of these are as follows:

1. Los Angeles Unified School District (LAUSD) – 50 dBA at 10 feet in front of the HVAC unit. This is now recently evolving to lower standards.
2. Collaborative for High Performance Schools (CHPS) – Various points are granted for 45, 40 and 35 dBA levels.
3. ANSI/ASA S12.60-2002: 35 dBA – ASA has been working aggressively to push this standard into adoption through various code and legislative paths, but with minimal success. This is likely due to the extreme low sound level incorporated into the standard and the concern of technical feasibility coupled with the cost impact.

c. Market Need

With the changing and evolving market desire for reduced sound levels in schools, Bard Manufacturing embarked on a development program to reduce the sound level as far as possible in wall mounted HVAC units. The advantages for the Relocatable Classroom industry is that with the wall mount type of design, the classroom can be truly relocatable and factory-built.

Bard Manufacturing therefore developed a new Quiet Climate 2 (CH Series) of high efficient Wall Mount Heat Pumps with many improved features. These features include the lowest sound levels ever achieved in a wall mounted heat pump system of like capacity, the highest level of energy efficiency achieved in a wall mounted heat pump and two stages of cooling and heating. It uses R-410A 'Green' refrigerant, which meets the EPA requirements which go into effect in 2010.

These new Bard models were also designed to include the capability of direct replacement for older models currently in service without requiring construction changes such as the wall openings. They are also capable of meeting the ventilation requirements for good indoor air quality of classrooms as required by the ASHRAE 62.1 Standard.

II. Purpose of this study

a. The purpose of this study was to test and evaluate the indoor acoustical background sound level in a typical unoccupied relocatable classroom using the new Bard CH Series HVAC heat pump. Testing was conducted both with and without various acoustical accessories that Bard has developed to help the modular classroom industry meet the needs and goals for improved acoustical and learning environments.
b. Another purpose of the study was to evaluate the use of improved ceiling tiles in the entire classroom and determine its impact.
c. Another objective was to test and evaluate various end wall treatments where the wall mounted HVAC is mounted, to determine their impact on sound improvements.
d. The purpose was not to:
    - Evaluate Classroom Sound Isolation from exterior sources.
    - Conduct Impact Isolation tests per the ANSI/ASA S12.60-2002 Standard.
e. What is the right sound level?
    - It is not the purpose of this study to debate what the right level of background sound level should be. It is well understood that the construction costs will increase as lower sound levels are sought.

III. The classroom

a. A previously used portable classroom was used for this study. It was a 24' wide by 40' long room with 8½' ceiling height.
b. The classroom is a typical 1992 vintage California DSA approved classroom.
c. General construction is with a metal frame, 2 x 4 wood construction, T111 exterior, R11 fiberglass insulation, ⅝" thick sheet rock covered with ⅝" vinyl covered tack board around the perimeter of the inside wall. The ceiling was a typical low cost construction grade ceiling tile of 1-inch fiberglass with a white vinyl coating on the inside. The STC of the walls were about 34 to 39 with the type of construction used. The STC rating of the ceiling/roof is not known.
d. HVAC Unit
    - This classroom was purchased with its original Bard HVAC unit installed. This was a 3.5 ton unit, model 42WH1-A08, serial number 126K920737770-1 which was produced in 1992. Production of this particular model series was discontinued in late 1992.
    - The classroom was retrofitted with a new Bard 4 ton, low sound level, high efficient two-stage, CH4S1-A series unit during the test program.

IV. **General Methodology**

a. A general acoustical survey was made and 13 acoustical measurement locations were determined. These represent a good acoustical footprint of the entire potential learning area along with a location 10 feet in front of the HVAC unit per the LAUSD and CHPS specifications. The map of the 13 locations is as shown on Figure 1 below and shown as locations 1 through 13.
b. One additional location is shown as location 18, which is exterior to the window and immediately adjacent to the side of the HVAC unit.
c. The ANSI/ASA S12.60-2002 Standard recommends various measurement heights of 20, 33, 40, 44, 54 and 60 inches dependent on grade level, sitting on the floor, seated in a chair or standing. Therefore, a general survey of the variability impact of height was made and it was determined that the measurements would be recorded at a height of 44 inches. All subsequent measurements were conducted at that height.
d. Figure 2 represents a change in the duct system put in place between Test series 1 and 2. This represents the duct system employed in these tests from test series 2 through 6.

FIGURE 1
SOUND MEASUREMENT LOCATION MAP

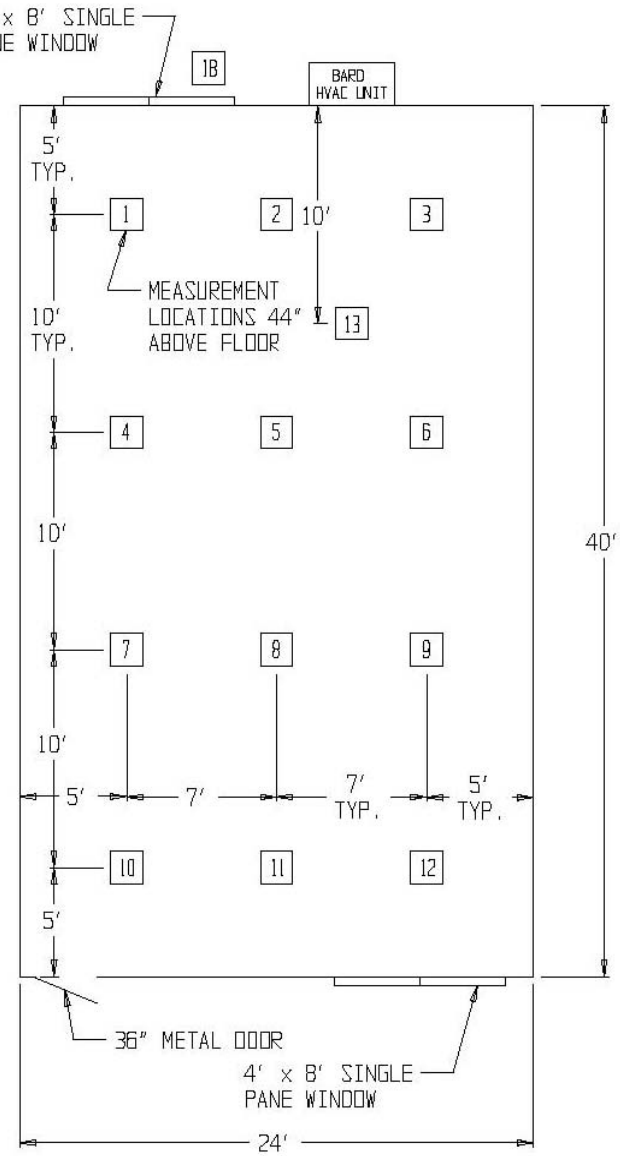
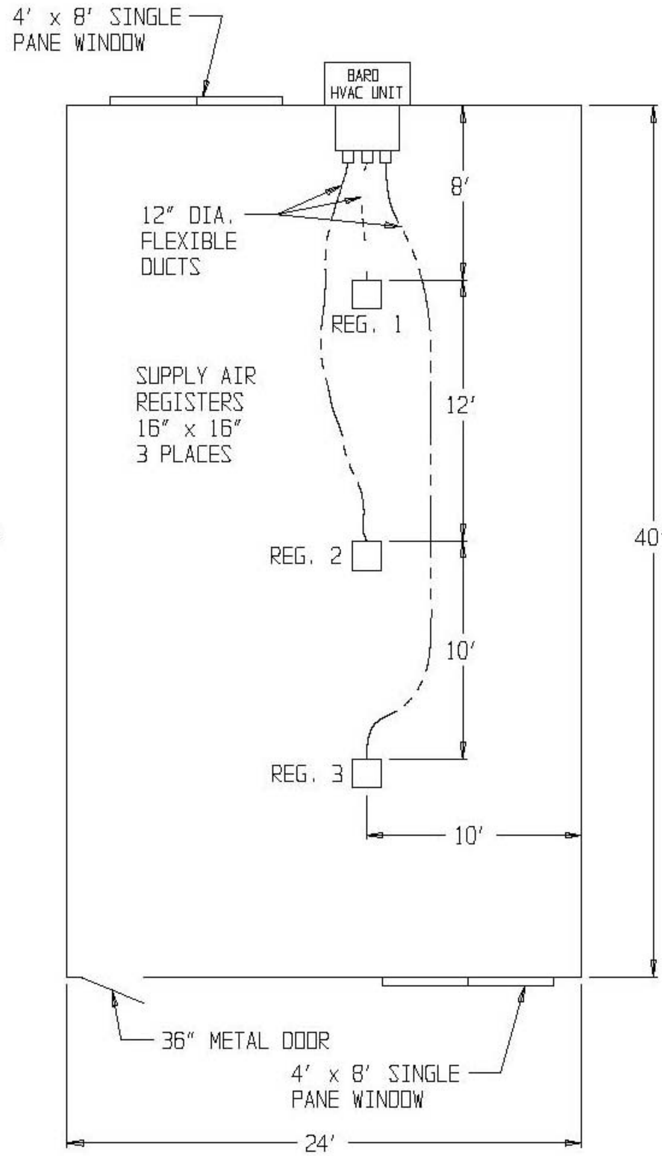


FIGURE 2
DUCT SYSTEM



V. **Instrumentation used**

a. Sound measurements were taken using an EX-IF 10 Orchestra Interface Unit with GRAS, ½" Electret Microphone and 01dB, dBRTA software. Calibration was conducted with PCB-39A40 Pistonphone. The sound measurement equipment complies with the instrumentation specifications listed in ANSI standard S12.60-2002.
b. Each reading taken was a 30 second average of 1500 individual readings.

VI. **Outdoor Ambient Sound Level**

a. Outdoor ambient background sound level tests were conducted on all four sides of the classroom
    - The outdoor ambient levels were observed on 7 separate occasions during the testing. This revealed an average of all background tests of 51dBA with a general range of 48 to 53. It must be noted however, that there were occasions during the testing that the outdoor background rose above these levels due to truck and tow motor traffic in an adjacent parking lot while semi trucks were being unloaded. In addition, the test location was near an Air Force base and we had some interference from nearby flights.
    - In addition, sound measurements were taken at approximately 1 foot from the exterior side of the window adjacent to the HVAC unit. This location (Fig. 1, location 18) was immediately adjacent to the side of the HVAC unit installed. These measurements showed that at this location, the original 42WH1 unit generated 74 dBA sound pressure while the new Bard CH4S1-A operating on stage 2 cooling generated 63 dBA sound pressure. This represents an 11-dBA reduction in outdoor sound level with the new Bard CH Series unit immediately adjacent to the end wall, reducing the ingress of outdoor sound from the HVAC unit.

VII. **Airflow balancing**

a. The airflow was tested at each of the 3 supply air outlet registers to determine if there was approximately equal airflow out of each. The measured CFM from each was 472 from register 1, 475 at register 2 and 500 at register 3 which was deemed acceptable and no damper adjustments were needed. This was conducted prior to Test series 2.

VIII. Indoor Background

The following represents the indoor background measurements with the classroom lights on and the HVAC system off.

	Test Point Location													
Test	1	2	3	4	5	6	7	8	9	10	11	12	13	Avg BG
Indoor Background HVAC OFF	33.0	31.6	34.0	31.8	31.2	33.7	34.0	31.4	32.9	33.8	32.8	32.8	31.6	32.7

This represents an indoor measured background range of 31.2 to 34 with a mathematical average of 32.7.

IX. Test Sequence and Process

a. Test series 1 – 42WH1-A original HVAC unit. This was with the original duct system in the classroom, which was with two supply air registers (16x16 inch) using two 12-inch diameter flexible ducting.
   - Tested in cooling and ventilation

b. Test series 2 – Changed HVAC unit to a Bard CH4S1-A and installed a new duct system with (three) 16 x 16 inch supply registers and (three) 12 inch diameter flexible ducts.
   - Tested in stage 2, stage 1 and ventilation mode.

c. Test series 3 – Installed Bard 'Isolation Curb' WMICT5 and Bard 'Return Air Acoustical Plenum' WAPR11 to evaluate the direct comparison from series 2 to 3.
   - Tested in stage 2, stage 1 and ventilation mode.

d. Test series 3+SP. The SP represents a change of adding the Bard WAPS51 Acoustical Supply Air Plenum to evaluate a direct comparison from series 3 to series3+SP.
   - Tested in stage 2, stage 1, and ventilation mode.

e. Test series 4 - Installed ⅝" QuietRock (QR-530) to the end wall on the inside and removed the 4' x 8' window at the end wall where the HVAC unit was installed.
   - Tested in stage 2 and stage 1.

f. Test series 5 – Installed new acoustically improved ceiling tile using Armstrong #1181 tile. This material has a Noise Reduction Criteria rating of 0.70 in accordance with ASTM C423-05.
   - Tests conducted were cooling stages 2 and 1.

g. Test series 6 – Changed the end wall covering from QuietRock QR-530 (⅝" thick) to QR-545 1⅛" thick. This was to evaluate the impact of an improved STC rated material on the HVAC mounted end wall to determine if additional blocking of low frequency sounds could be achieved.
   - Tested in stage 2, stage 1 and ventilation mode.

X. **Indoor Test Results**

Test series 1 - *Base line with 42WH1-A, 2 Supply Air Outlet Ducts*

	Test Point Location													
Test series 1	1	2	3	4	5	6	7	8	9	10	11	12	13	Avg.
Cooling–Single stage unit dBA	49.7	52.0	51.7	50.0	48.9	48.7	46.9	47.0	46.8	45.2	45.3	46.4	50.8	48.5
Ventilation only dBA	44.7	47.8	46.4	43.8	44.5	44.7	42.0	43.1	42.3	41.3	41.9	42.2	47.2	44.0

The following is a linear third octave band graph from position 13 while operating in the cooling mode so the specific frequencies can be evaluated for analytical purposes. It must be noted that these third octave band graphs are NOT ‘A’ weighted to enable better and more detailed analysis.

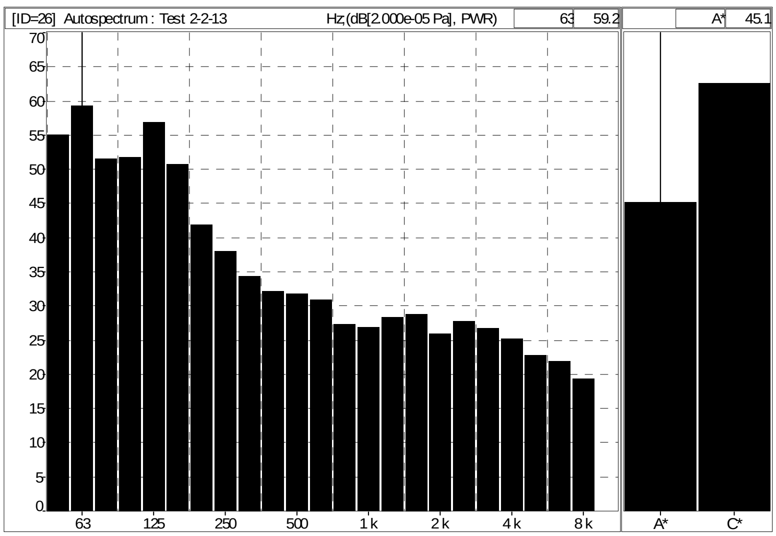
Comments: This base line test is representative of the acoustical characteristics of a classroom, with this HVAC system, when installed using a dual supply outlet duct and no additional acoustical treatment. Using position 13 as a reference, it shows 50.8-dBA sound pressure in cooling and 47.2 during the ventilation mode.

Test series 2 – *CH, Direct Mount, 3 Supply Air Ducts and Registers*

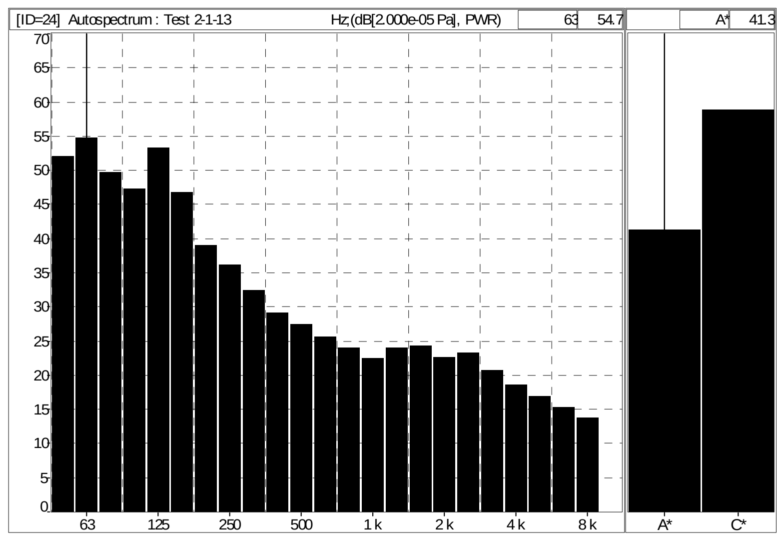
	Test Point Location													
Test series 2	1	2	3	4	5	6	7	8	9	10	11	12	13	Avg.
Cooling Stage 2	43.2	44.7	45.9	43.4	42.3	43.4	40.5	44.4	42.9	39.2	40.6	42.5	45.1	42.9
Cooling Stage 1	40.0	40.6	41.5	39.8	39.3	41.1	38.0	39.3	39.3	35.6	38.0	40.5	41.3	39.6
Ventilation	33.4	34.9	34.5	32.9	32.7	33.5	31.2	31.8	32.2	32.6	31.6	32.0	33.9	32.8

The following are linear third octave band graphs from position 13 while operating in stage 2 and stage 1 cooling.

Stage 2 Cooling



Stage 1 Cooling



Comments: When compared to test series #1, this demonstrates a real and significant reduction in sound level. At position 13, stage 2 was reduced from 50.8 to 45.1 or a 5.7 dBA reduction and stage 1 offering an additional reduction to 41.3 or a total of 9.5 dBA. In the ventilation mode, the reduction was from 47.2 on the baseline test to 33.9 or a reduction of 13.3 dBA.

It must also be noted that in the ventilation mode, the room average is 32.8 while the previous background testing revealed that with the HVAC system completely off it was 32.7. This means that there is NO measurable acoustical noise from the HVAC unit in the ventilation mode.

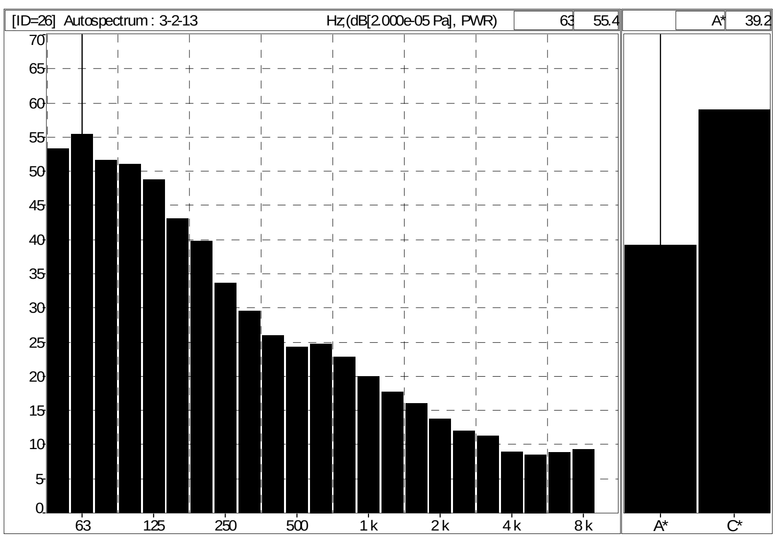
The third octave band data shows significant reductions from the baseline unit in the low frequency spectrums, which are very difficult to reduce. It also shows very significant reductions in the 250 to 2000 Hz. ranges, which represent a large spectrum of what is the very audible frequency spectrum. This represents the significant acoustical improvement of the CH Series design when installed with a three-outlet supply duct.

Test series 3 - CH, 3 SA outlet ducts, *Isolation Curb, Return Air Acoustical Plenum*

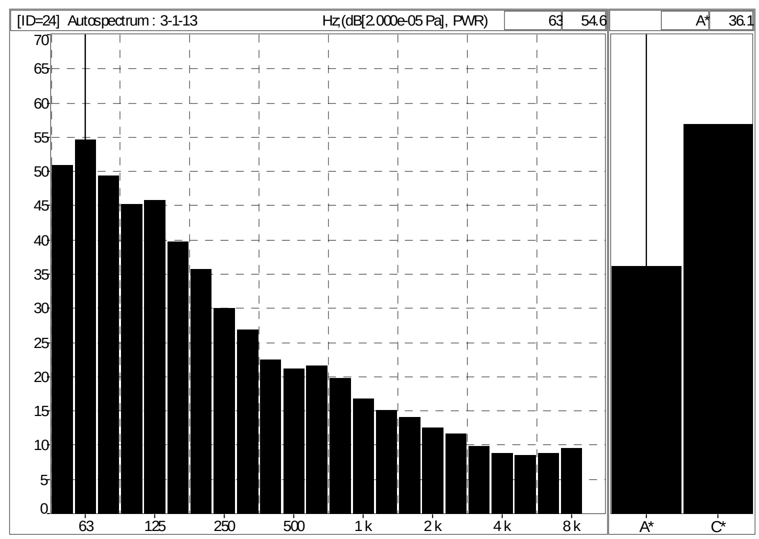
						Test Point Location							
Test series 3	1	2	3	4	5	6	7	8	9	10	11	12	13	Avg.
Cooling Stage 2	38.2	42.4	40.6	36.9	38.0	36.8	33.9	35.4	35.1	32.7	34.0	34.2	39.2	36.7
Cooling Stage 1	34.1	37.6	37.0	34.0	36.3	35.3	31.8	33.5	33.9	32.2	32.6	32.9	36.1	34.4
Ventilation	31.9	32.1	31.7	32.0	31.8	30.6	29.4	30.8	30.8	31.6	32.0	31.6	31.8	31.4

The following are linear third octave band graphs from position 13 while operating in stage 2 and stage 1 cooling.

Stage 2 Cooling



Stage 1 Cooling



Comments: This demonstrates an additional real and significant reduction in sound level. At position 13, stage 2 was reduced from a baseline of 50.8 to 39.2 or an 11.6 dBA reduction and stage 1 offering an additional reduction to 36.1 or a total of 14.7 dBA. In the ventilation mode, the reduction was from 47.2 on the baseline test to 31.8 providing a reduction of 15.4 dBA. This again is comparable to the room with the HVAC system completely off.

When comparing to test series 2, this also represents a reduction of 5.9 dBA on the stage 2 mode of and a 5.2-dBA reduction on stage 1 that can be attributed strictly to the Isolation Curb and Return Air Acoustical Plenum.

The significant improvement in the low frequency range of 63 to 250 Hz. demonstrates the improvement obtained with the use of the Bard Isolation Curb.

The improvements in the 500 to 4000 Hz. shows great reduction in that very audible range. This improvement is credited to the Return Air Acoustical Plenum.

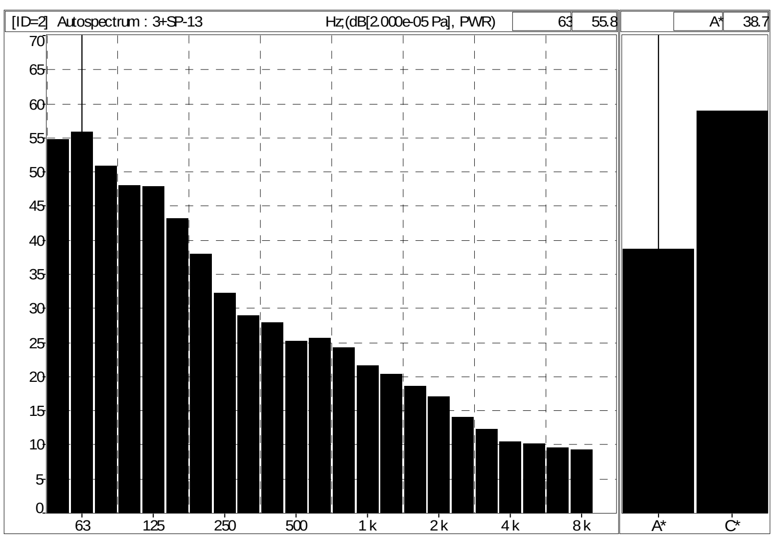
This demonstrates the added acoustical value of each of these two acoustical accessories, as each are designed to work on different portion of the acoustical signature.

<u>Test series 3+SP –</u> <u>CH, Isolation Curb, 3 SA outlet ducts, RA Acoustical Plenum</u>**<u>,</u>**
<u>Supply Air Acoustical Plenum</u>

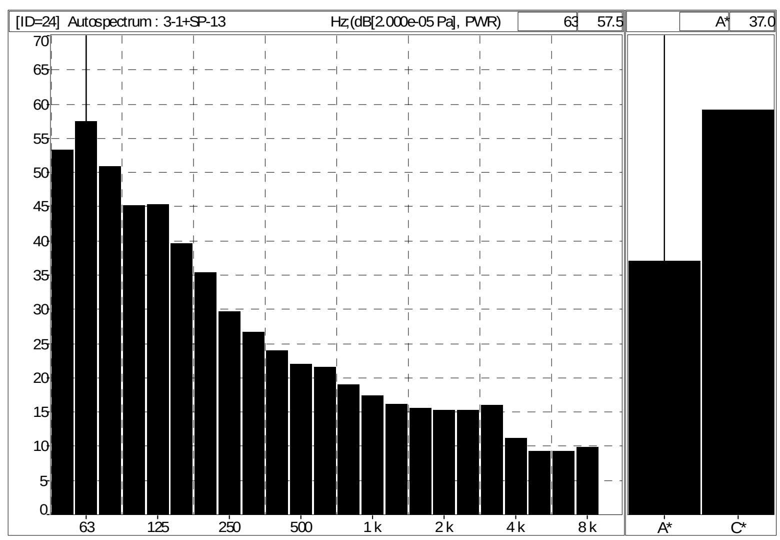
							Test Point Location							
Test series 3+SP	1	2	3	4	5	6	7	8	9	10	11	12	13	Avg.
Cooling Stage 2	37.6	41.0	40.0	37.2	37.8	36.6	33.2	34.4	34.3	31.9	34.6	33.5	38.7	36.2
Cooling Stage 1	34.7	37.5	35.9	34.1	35.5	34.7	32.9	34.6	34.0	31.8	32.9	33.7	37.0	34.6

The following are linear third octave band graphs from position 13 while operating in stage 2 and stage 1 cooling.

Stage 2 Cooling



Stage 1 Cooling



Comments: This test series demonstrates that a small gain can be made from the use of the Acoustical Supply Plenum particularly when there is breakout noise at the supply plenum. It must be reported, however, that this test series was difficult to measure in that there was a large increase in outdoor sound interference caused by the unloading of lumber from an adjacent facility and forklift truck noise was very audible. Because of this outside interference, this data may not be 100% representative of the actual improvement gained from the Supply Acoustical Plenum.

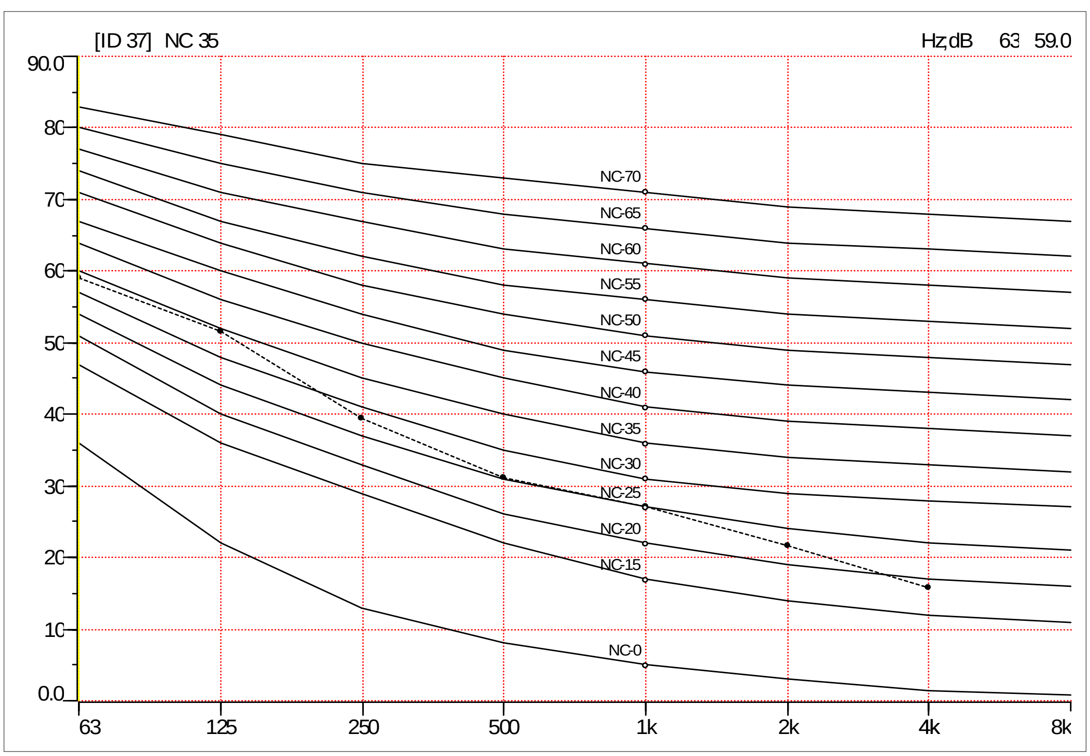
An additional measurement observation was made here. Direct comparison measurements were taken 12 inches below all three supply registers and without the supply air acoustical plenum the measurements in dBA were 44, 39 and 38 from register 1 –2 –3. With the supply air acoustical plenum installed, these measurements were reduced to 42.5, 38.3 and 37.1 respectively.

However, if one looks at the location most impacted by this acoustical accessory, by comparing positions 1, 2 and 3, it becomes evident that there was improvement. The average reduction from integrating those 3 measurement positions was a reduction of 0.9 dBA even with the disturbing outdoor background sound levels.

In general, one can also conclude that at this point in the test program, the Bard CH series has already provided significant acoustical improvements. The outdoor background sound begins to have a greater influence over the indoor sound level than the HVAC system and becomes a more significant factor.

Noise Criteria (NC)
Sometimes, a single numerical value is used to describe a sound that has a spectrum over a wide frequency range, and is quite useful because of their simplicity. This single numerical value is known as NC (Noise Criteria) curves.

Below is the NC curve for "Test series 3+SP with the Bard Quiet Climate2 series model CH4S1-A installed with an Isolation Curb, Supply and Return Air Acoustical Plenums.

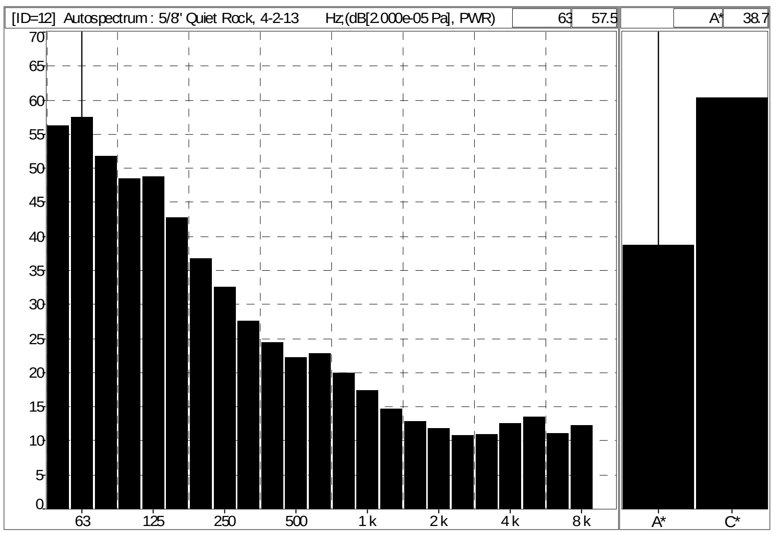


Test series 4 – CH, Isolation Curb, 3 SA outlet ducts, RA Acoustical Plenum, Supply Air Acoustical Plenum***, Added QR-530 and eliminated the end wall 4' x 8' single pane window.***

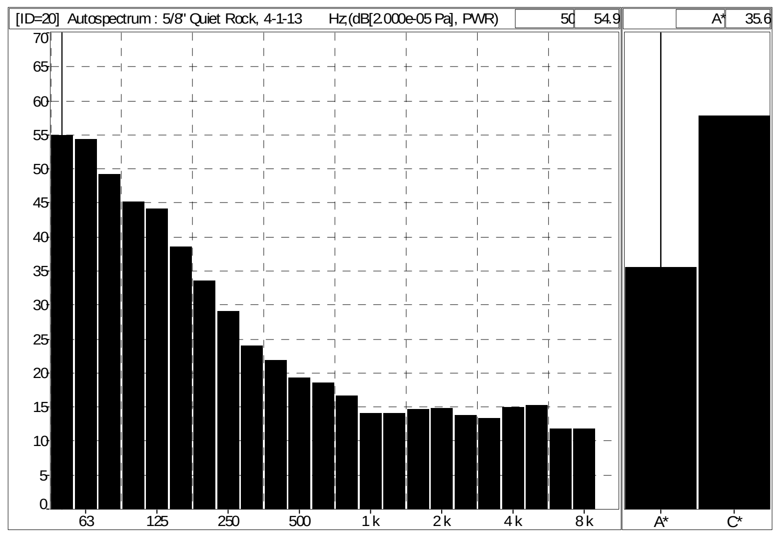
						Test Point Location							
Test series 4	1	2	3	4	5	6	7	8	9	10	11	12	13	Avg.
Cooling Stage 2	36.9	41.6	39.5	36.1	37.3	36.4	33.0	34.1	33.7	32.5	34.1	34.4	38.7	36.0
Cooling Stage 1	34.2	37.1	37.2	33.8	35.6	34.2	33.3	33.5	33.8	33.2	31.8	30.7	35.6	34.1

The following are linear third octave band graphs from position 13 while operating in stage 2 and stage 1 cooling.

Stage 2 Cooling



Stage 1 Cooling



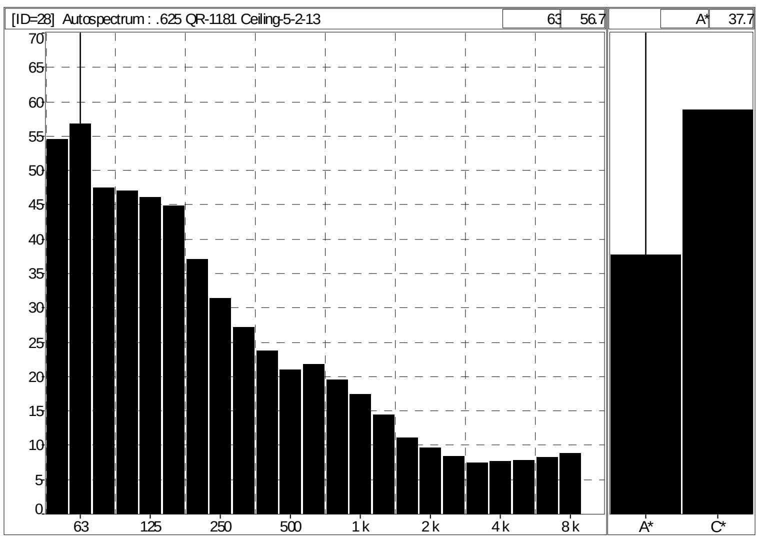
Comments: When comparing these results to test series 3 or 3+SP, we did not see the improvement in low frequency sound in the range of 63 to 250 Hz. that we had expected from the addition of the QuietRock. We believe the potential gains have already been obtained with the Bard HVAC unit and acoustical accessories. Additional improvements are now harder to realize. Another factor is that the outdoor background is now having a larger influence on the net result. When looking at the comparison to test series 3+SP as an average at positions 1, 2 and 3 there is a reduction of 0.2 dBA.

Test series 5 - CH, Isolation Curb, 3 SA outlet ducts, Return Air Acoustical Plenum, Supply Air Acoustical Plenum, QR-530***, changed to Armstrong 1181 Ceiling Tiles***

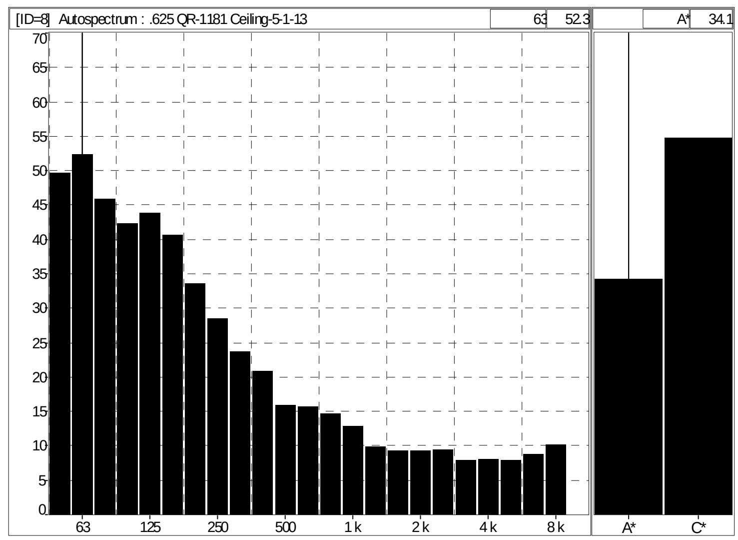
	Test Point Location													
Test series 5	1	2	3	4	5	6	7	8	9	10	11	12	13	Avg.
Cooling Stage 2	35.9	40.8	39.7	36.5	37.4	36.8	33.7	35.6	35.3	33.3	34.4	33.5	37.7	36.2
Cooling Stage 1	33.8	37.1	36.6	33.0	33.8	34.0	31.7	32.2	33.0	30.5	30.5	31.4	34.1	33.2

The following are linear third octave band graphs from position 13 while operating in stage 2 and stage 1 cooling.

Stage 2 Cooling



Stage 1 Cooling



Comments: The purpose of this test series was to evaluate the impact of changing from a low cost construction grade fiberglass-ceiling tile to an improved Armstrong #1181 ceiling tile. When comparing to test series 4, it shows at position 13 a 1-dBA reduction on stage 2 and a 1.4-dBA reduction on stage 1. In looking at the linear third octave charts, it illustrates a reduction on stage 2 in the 2000 to 8000 Hz. frequency range and on stage 1 a general reduction in the 500 to 8000 Hz. ranges.

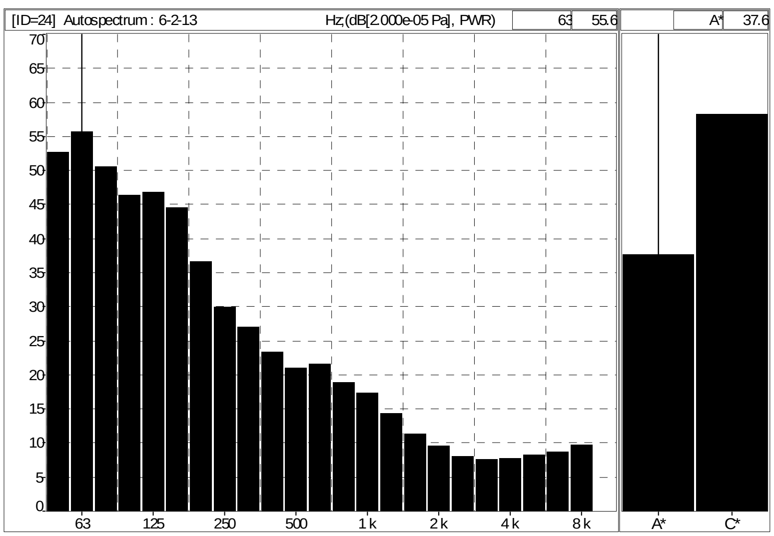
Again, the sound level was so low that it was difficult to make any accurate determination of specific improvements as the outdoor variances were having an impact. However, a general observation to those present in the room was that it was generally felt that the sound characteristics were improved. This was likely due to the improvements observed in the 500 to 8000 Hz. frequency ranges discussed earlier.

Test series 6 - CH, Isolation Curb, 3 SA outlet ducts, RA Acoustical Plenum, Supply Air Acoustical Plenum, QR-530, Armstrong 1181 Ceiling Tiles, ***changed QR-530 to QR-545 on end wall.***

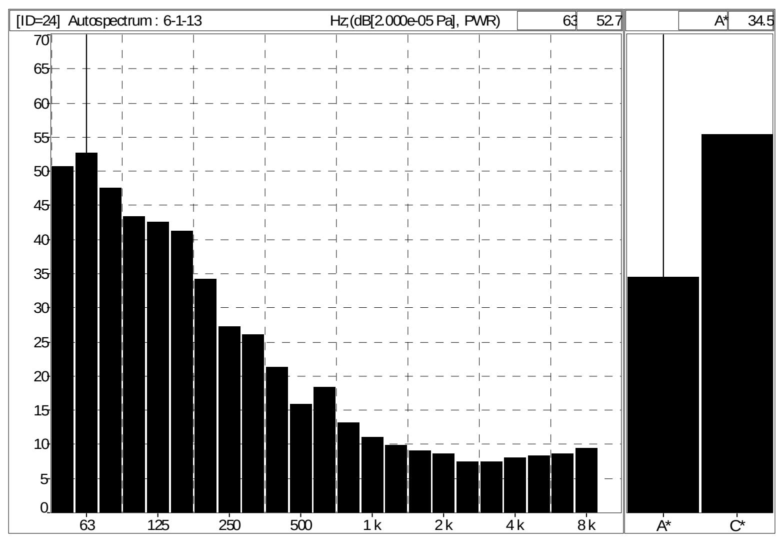
	Test Point Location													
Test series 6	1	2	3	4	5	6	7	8	9	10	11	12	13	Avg.
Cooling Stage 2	36.1	41.1	40.0	35.0	35.3	36.2	33.4	34.7	35.1	31.2	32.5	32.2	37.6	35.4
Cooling Stage 1	33.6	37.2	36.7	32.3	33.4	35.1	30.6	32.2	33.4	30.5	31.4	31.1	34.5	33.2
Ventilation only	28.6	31.4	30.1	28.1	28.7	29.7	29.5	30.5	30.5	29.6	29.8	29.2	29.7	30

The following are linear third octave band graphs from position 13 while operating in stage 2 and stage 1 cooling.

Stage 2 Cooling



Stage 1 Cooling



Comment: This is a direct comparison to test series 5 with a change from QR-530 to QR-545 QuietRock on the end wall. The data did not reveal any measurable improvement in the acoustical profile of the room and the added cost could not be justified based on this test series.

XI. **Using the S12.60-2002 Standard**

About the standard:

We want to acknowledge that while there are certainly a lot of good elements to the standard, there are some portions that are not clear and leave a lot to interpretation by the user.

To meet the requirements of the S12.60-2002 standard, the indoor sound level must meet the requirement of Table 1 requiring 35 dBA indoor background level with a tolerance of + 2 dBA (or a maximum of 37 dBA) per Section 4.7 of the standard.

Paragraph 4.3.1 of the standard states that the limits on the A-weighted background noise levels in Table 1 shall be increased by 5 dB when the noisiest hour is dominated by transportation noise.

Paragraph E3.7.1 references a one-hour average steady state background level in a 'typical' hour usage. To properly interpret paragraph E3.7.1, the issue was discussed on multiple occasions with an ASA consultant along with other members of ASA, who are knowledgeable on the S12.60-2002 Standard. One consultant discussed his findings on an installation in Riverside, California in which he measured the sound level on a two stage HVAC machine and then integrated the sound levels measured, assuming 50% run time on stage 1 and 50% run time on stage 2. This was discussed at a meeting between MBI and ASA members in Minneapolis and again in a later meeting in Los Angeles. The continued feedback is that the measured acoustical results can be integrated between different stages of operation based on 'typical' operating schedules as stated in the standard paragraph E3.7.1. At the time that the S12.60-2002 Standard was developed, this type of multi-stage HVAC equipment had not been considered for use in the standard and the integration was not specifically spelled out.

We therefore, made what we believed to be a fair and honest assessment on how to best do that. This was done with input from an acoustical engineer familiar with the S12.60-2002 Standard. In general, there is no known source to gather the integration ratios between stages 2, stage 1 and ventilation modes of operation. To determine what integration schedule should be used, we used field test data available supplied to Bard that was developed through an extensive 1-year field test program conducted by Lawrence Berkley National Labs (LBNL) on the Bard CH4S1-A system. That integration time was recorded on 8 units, with 4 operating in southern California and 4 operating in northern California for 1 year each. Analysis of that revealed the following:

Location / school duration Average of Four classrooms per location shown	**% Run time in each mode**		
	Vent Mode	Cooling/Heating stage 1	Cooling/Heating stage 2
Northern Ca. / 12 months	51%	26%	23%
Southern Ca. / Off June 13 – July 21	65%	24%	11%
Average Occupied % run time	**58%**	**25%**	**17%**

To obtain the integration time for integrating the sound level during the occupied periods over the full year, we used the average % run time in each mode of operation as monitored in 8 classrooms shown above.

XII. Compliance with and meeting the S12.60-2002 35 dBA Sound Level

a. We found that section E3.6 of the S12.60-2002 Standard to be confusing. It guides the user to a 'key' location and 5 other measurement locations in the 'customary listening area'. However after discussing this point with the acoustical consultant we used only the measurements from the 'key' location, throwing out all of the other 5 measurements. By using measurement location 2 as the key position, the entire area in the acoustical map can be used as a customary listening area and there are no portions of the classroom that would be restricted from any use.

b. The following is the integrated result of test series 3 and series 3+SP.

	Test Series 3	Test Series 3	Test Series 3+SP	Test Series 3+SP	
Key Location	1	2	1	2	Integration %
Stage 2	38.2	42.4	37.6	41	17%
Stage 1	34.1	37.6	34.7	37.5	25%
Ventilation	31.9	32.1	31.9	32.1	58%
Integrated dBA	**33.5**	**35.2**	**33.6**	**35.0**	100%

As shown above, this classroom does meet the ANSI S12.60-2002 Standard when using either test location 1 or 2 in test series 3 and 3+SP. Using location 2 as the 'Key' location, the entire room can be used as a customary listening area.

Reference is made to Annex E of the standard, "**Good architectural practices" and procedures to verify conformance to this standard.**

> The integrated values above represent the sound level measured in accordance with our understanding of the S12.60-2002 Standard paragraph E3.7.1 Steady background noise. "The one-hour average steady background level for the typical usage hour may be obtained from measurements of one 30-second sound level…"

It must be noted that the above demonstrates compliance with the 35-dBA requirement is achievable in an older retrofitted classroom, provided it is located in an area with an acceptable OD sound level of about 50 dBA.

XIII. Special Tests to evaluate the impact of the removal of the end wall window and revisions to the wall construction to a higher STC levels.

We wanted to conduct a special experiment to help evaluate the impact of the removal of the 4 x 8 foot single pane window at the end wall where the HVAC system is mounted. That area is the most susceptible to the ingress of noise generated by the HVAC system itself. To do this, we used an outdoor noise source immediately adjacent to the window and generated 75 dBA adjacent to the outside of the wall at the window area. This was done in various modes as summarized in the following table.

Construction /test description	OD Sound level dBA	Indoor Sound Level dBA at position 1, 5 feet in front of window
Base Line – with window and standard wall construction –	51.1 dBA Natural OD Sound Level	29.5dBA
Same as above	75 dBA	41.3 dBA
Removed window, framed in opening, insulate R13 fiberglass	75 dBA	36.6 dBA
Installed QuietRock QR-530	75 dBA	32.3 dBA

Normal operation of the CH4S1-A directly adjacent to the compressor and OD fan discharge is 63 dBA.

In summary, the removal of the window reduced the sound transmission through that end wall sufficient to reduce the indoor sound level by 4.7 dBA at measurement position 1. The addition of QR-530 reduced the sound level by an additional 4.3 or a total of 9 dBA at position 1. The addition of QR-545 in place of QR-530 also resulted in 32.3 dBA at position 1, which was no measured improvement.

XIV. A to C Weighted Limits

The S12.60-2002 Standard specifies in paragraph 4.3.2.1 that the limit of a steady C weighted background noise level shall not exceed the A weighted level by more than 20 dB with a 2 dB tolerance per paragraph 4.7 (1) thus a maximum difference of 22 dB from A to C weighted dB.

The following shows the results of the A – C weighted difference in the measurement position 13, which is 10 feet directly in front of the HVAC unit and position #1 (Fig 1) which is used as the 'key' position.

		A - C weighted difference	
	Stage 2	Position 13	**Position 1**
Test series 1	42WH1 Base line	18.4	**14.9**
Test series 2	**CH Direct Mount & 3 Supply Air Ducts**	17.4	**16**
Test series 3	CH - added **ISO & RA Acoustical Plenum**	19.8	**18.4**
Test series 3+SP	CH - added **SA Acoustical Plenum**	20.3	**19.2**
Test series 4	Above - **removed window & added QR 530** to end wall	21.6	**21.7**
Test series 5	Above - **Ceiling Armstrong 1181**	21.1	**21.2**
Test series 6	Above - changed to **QR 545 on end wall**	20.6	**19.8**
	Stage 1		
Test series 2	**CH Direct Mount & 3 Supply Air Ducts**	17.5	**15.8**
Test series 3	CH - added **ISO & RA Acoustical Plenum**	20.8	**18**
Test series 3+SP	CH - added **SA Acoustical Plenum**	22	**18.8**
Test series 4	Above - **removed window & added QR 530** to end wall	22.1	**21.3**
Test series 5	Above - **Ceiling Armstrong 1181**	20.1	**20.5**
Test series 6	Above - changed to **QR 545 on end wall**	20.9	**19.7**

Analysis of the above A-C difference illustrates that in position 1 and 13 on stage 2 operating mode, the upper limits of 22 were not exceeded. During stage one, that limit was exceeded only in test series 4 and by a mere 0.1 dB, which the writer believes is inconsequential.

XV. **Summary**

In summary, the new Bard Quiet Climate 2 (CH Series) HVAC unit with optional acoustical accessory items can be selected to meet various targeted sound levels in a classroom. Each application can be tailored to meet the users goals and budget. The following is a combined summary of the direct comparisons of stage 1 and stage 2 results for each tested scenario showing both the spatial average and the measurement position 13 at 10 feet in front of the HVAC unit.

Test Series	Description	dBA Spatial avg.	dBA. 10 ft.
	Stage 2		
Test series 1	42WH1 Base line	48.4	50.8
Test series 2	**CH Direct Mount & 3 Supply Air Ducts**	42.9	45.1
Test series 3	CH - added **ISO & RA Acoustical Plenum**	36.7	39.2
Test series 3+SP	CH - added **SA Acoustical Plenum**	36.2	38.7
Test series 4	Above - **removed window & added QR 530** to end wall	36	38.7
Test series 5	Above - **Ceiling Armstrong 1181**	36.2	37.7
Test series 6	Above - changed to **QR 545 on end wall**	35.4	37.6
	Stage 1		
Test series 2	**CH Direct Mount & 3 Supply Air Ducts**	39.6	41.3
Test series 3	CH - added **ISO & RA Acoustical Plenum**	34.4	36.1
Test series 3+SP	CH - added **SA Acoustical Plenum**	34.6	37
Test series 4	Above - **removed window & added QR 530** to end wall	34.2	35.5
Test series 5	Above - **Ceiling Armstrong 1181**	33.2	36.6
Test series 6	Above - changed to **QR 545 on end wall**	33.2	34.5

XVI. **Conclusions**

The Bard CH4S1-A system, when installed with an adequate low velocity duct system and various acoustical accessories, can meet the 35-dBA requirements as specified in the ANSI/ASA S12.60-2002 Standard. Other levels of acoustical results can be obtained at different cost impacts depending on the goals and objectives of the end user.

Tests conducted by LBNL indicated that in a direct comparison test to a standard 10 SEER HVAC unit at the same ventilation rate, the unit operated at a reduction in energy consumption of 44% in cooling and 38% in the heating mode. This reduced energy consumption will provide a payback, offsetting the added cost for the acoustically improved HVAC system and accessories.

The acoustical performance required in the S12.60-2002 Standard can be met with minimal building construction modifications for both new construction and retrofit application if the classroom is located in an area with an acceptable outdoor ambient noise level [about 50 dBA]. If higher outdoor ambient noise levels were present, the building would have to be constructed with improved acoustical treatment such as higher Sound Transmission Coefficient [STC] levels for walls, ceilings, windows and doors. This report does not evaluate those construction options beyond the removal of the end wall window, a ceiling change and the use of alternate end wall sound treatment as illustrated in the report. The wall construction used for this classroom has an STC level of about 34 – 39. For new construction, changing the wall and ceiling to achieve higher STC levels would likely provide significant improvement and make the location of the classroom into noisier outdoor ambient areas less critical. By way of example, this could be adding 2 layers of 5/8 Gyp which would raise the STC to 43-45, using staggered studs with two layers of insulation would raise the STC to 46-47. Any increase of 5 or more in the STC rating would be clearly noticeable. There are many other options available to increase the STC and the acoustical performance of the building envelope.

It is noted that in this study, changes to the end wall construction, had little impact with the exception of the removal of the window adjacent to the HVAC system. This is attributed to the Bard CH unit and the various acoustical accessories that have been used in this study. The HVAC unit itself was designed to significantly reduce wall vibration along with other acoustical improvements. In addition, the Isolation Curb further reduced wall resonance when used on end walls that are prone to vibration. The acoustical plenums are designed to further reduce high frequency noises and the study validated those designs.

It is recognized that the S12.60-2002 Standard did not consider multi-stage HVAC units when the standard was developed. We believe the standard needs to be upgraded to have that technology addressed, clearly spelled out and included. The results in this study are based on interpretation of the standard as outlined in the report above.

We are confident that with the very significant reduction in sound levels achieved by Bard and proven in this study, we can supply HVAC systems to the modular classroom industry and the users of them, that will be acoustically acceptable to school administrators and parents alike.

References: 1.ANSI.2002.ANSIS12.60-2002, *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools,* American National Standards Institute. N.Y. Acoustical Society of America.

XVII. **Photos**

Building with original HVAC system 42WH1

CH4S1-A with Top Plenum being installed

Installation of 3 outlet supply ducts

Installation of CH4S1-A

Installation of CH4S1-A

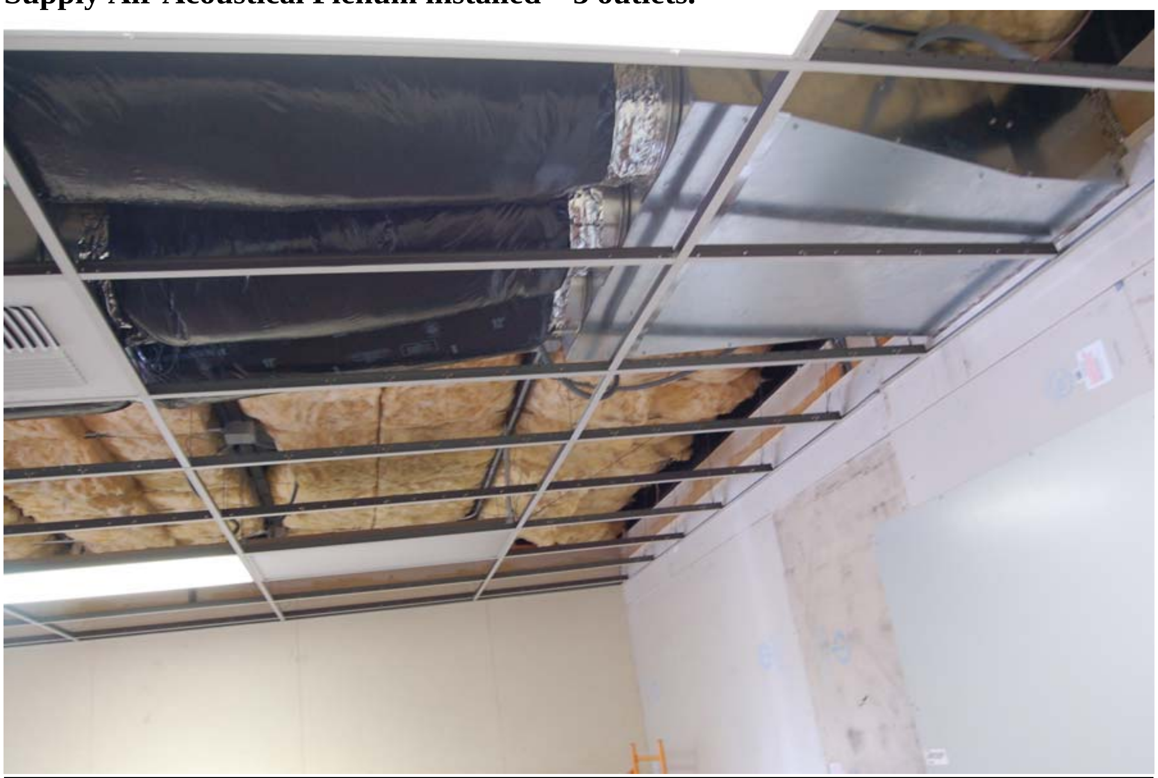
Interior with Return Air Acoustical Plenum installed.

Interior with end wall window removed and return air acoustical plenum in place.

Interior with QR530 installed

Interior with the ceiling tile being replaced.

Supply Air Acoustical Plenum installed – 3 outlets.



Interior with QR530 replaced with QR545.

Outside area of classroom showing commercial enterprises in the area.

Outside area of classroom showing commercial enterprises in the area.

California sunset with 35 dBA or less recorded in a modular relocatable classroom.

Modular relocatable classroom.

Modular relocatable classroom.

Indoor modular relocatable classroom view of Return Air Acoustical Plenum.