SOLUTIONS FOR CLASSROOMS

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OVERVIEW

With the new ANSI Standard on Classroom Acoustics (S12.60), and the updated requirements for Ventilation in accordance with ASHRAE 62.1, solving the classroom HVAC problem has never been more difficult. The tools to solve this dilemma are readily available, however. First, let's discuss the issues.

ACOUSTICS

The Architectural Transportation Barriers and Compliance Board (ATBCB) in Washington (the agency tasked with meeting the requirements of the Americans Disability Act) recently posted some guidelines for sound levels in the classroom. These were included in an ANSI Standard for determining classroom sound levels. The requirement is 35dBA. This translates to an NC <30 in most cases, often as low as NC=25. Common experience will show that an NC<35 is probably not audible in most occupied spaces, nonetheless, this is the requirement that the Acoustical Society of America recommended to the ATBCB, and included in their S12.60 Standard. There has been debate in a number of articles as to whether or not this value is too low, but it still remains the rule.

VENTILATION EFFECTIVENESS

ASHRAE Standard 62.1, 2010, Ventilation Rate Procedures (VRP), includes rules for assuring ventilation air reaches building occupants. These include requiring the addition of a per-person with a per-square-foot value (Table 6.1, ASHRAE 62.1, - see next page). In practice, the result has been to redo the outdoor air requirements in classrooms. Recently, a user's manual has been published for computing ventilation rates, which includes a calculation spreadsheet (available at the Krueger website). In addition, however, to the minimum ventilation rates, a table on Air Change Effectiveness (Table 6.2) is also required to be used (Below). The values from this table are divided into the results from Table 6.1. When heating from the ceiling, throw and delta-t must be managed to maintain comfort, avoid ventilation short circuiting, and to avoid a required increase in the ventilation rate.

TABLE 6-2
Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return.	0.8
Ceiling supply of warm air less than 15°F (8°C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level. **Note**: For lower velocity supply air, E_z= 0.8.	1.0

From Table 6.2 of the ASHRAE standard.

The effect of an 0.8 effectiveness is to require 25% more outside air. As Standard 62.1 is a prerequisite for LEED under the V2.2, meeting this requirement is often mandatory.

AIR DISTRIBUTION AND COMFORT

Acceptable air distribution is required for occupant comfort. Selection of ceiling diffusers to achieve an ADPI >80% will ensure meeting ASHRAE's Thermal Comfort Standard (55-2004) vertical temperature stratification limit of 5°F. In fact, it is the only means we know of for documenting this requirement to obtain a LEED point for Comfort. In addition, test data shows that with ceiling diffusers, if the supply air temperature to the room exceeds 90°F, the Comfort requirement will not be met.

Meeting all three of these requirements can be a daunting problem to the design engineer. Many new designs propose to use non-conventional systems, such as Displacement Ventilation (horizontally supplied air at the floor), and even Underfloor Air Distribution (UFAD) designs. Unfortunately, ADPI analysis doesn't yet cover these types of systems, so ADPI cannot be used to validate the Comfort requirement. Nonetheless, there are low cost solutions using conventional systems for which ADPI can be utilized. These types of systems can often be employed at considerably lower installed costs, with designs and equipment that the maintenance people in schools are familiar with. Improper system maintenance is probably the biggest cause of non-performance in academic environments today.

We have evaluated all the requirements above and made some preliminary calculations.

VENTILATION RATES

From the ASHRAE standard, there are several values listed for educational facilities, in table 6.1, excerpted here. Taking the most prevalent areas, Classrooms, we see that there are differences between daycare, under 8 years old (3rd grade) and the rest. These are defined for both occupant density and rate/child.

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s•person	cfm/ft²	L/s•m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Classrooms (ages 5-8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1

Looking at these levels, and doing some calculations in typical classrooms, yields some general observations about % outside air.

Standard 62.1 2004 requirements.
Assumes Air Change Effectiveness of 1.0

Standard Case (1)			Larger Classroom (2)			High Density (3)		
# Students	25		# Students	30		# Students	35	
Ventilation CFM =	375	CFM @ 15cfm/ student	Ventilation CFM =	450	CFM @ 15cfm/ student	Ventilation CFM =	455	CFM @ 13cfm/ student
Area =	1000	SqFt @ 25/1000sf	Area =	1200	SqFt @ 25/1000sf	Area =	1000	SqFt @ 35/1000sf
Student Load =	2500	Watts @ 100W/Student	Student Load =	3000	Watts @ 100W/Student	Student Load =	3500	Watts @ 100W/Student
Lighting load =	1700	Watts @ 1.7 w/sqft	Lighting load =	2040	Watts @ 1.7 w/sqft	Lighting load =	1700	Watts @ 1.7 w/sqft
Room BTUH =	14322		Room BTUH =	17186.4		Room BTUH =	17732	
CFM =	663	@ 55F	CFM =	796	@ 55F	CFM =	821	@ 55F
%outside air =	56.6%	O.A.	%outside air =	56.6%		%outside air =	55.4%	

These calculations ignore perimeter loads, however. Almost all classrooms today are in a perimeter zone. Assuming overhead air distribution, when typical design cooling and heating loads are included, the % required outside air drops in half:

Perimeter loads			Perimeter loads			Perimeter loads		
Cooling:								
Room Width =	33	Ft	Room Width =	33	Ft	Room Width =	33	Ft
Room Length =	30	Ft (perimeter)	Room Length =	36	Ft (perimeter)	Room Length =	30	Ft (perimeter)
Cooling Load =	600	BTUH/Lin Ft	Cooling Load =	600	BTUH/Lin Ft	Cooling Load =	600	BTUH/Lin Ft
Cooling Flow =	842	CFM	Cooling Flow =	1010	CFM	Cooling Flow =	842	CFM
Total flow rate	1505	CFM @ 20 Derg Delta-t	Total flow rate	1806	CFM @ 20 Derg Delta-t	Total flow rate	1663	CFM @ 20 Derg Delta-t
%outside air	24.9%	O.A.	%outside air	24.9%	O.A.	%outside air	27.4%	O.A.
	1.50	CFM/SF						
Heating:								
Room Width =	33	Ft	Room Width =	33	Ft	Room Width =	33	Ft
Room Length =	30	Ft (perimeter)	Room Length =	36	Ft (perimeter)	Room Length =	30	Ft (perimeter)
Heating Load =	400	BTUH/Lin Ft	Heating Load =	400	BTUH/Lin Ft	Heating Load =	400	BTUH/Lin Ft
Heating Flow =	748	CFM @ 15Deg Delta-t	Heating Flow =	898	CFM @ 15Deg Delta-t	Heating Flow =	748	CFM @ 15Deg Delta-t
Total flow rate	1411	CFM	Total flow rate	1694	CFM	Total flow rate	1569	CFM
%outside air	26.6%	O.A.	%outside air	26.6%	O.A.	%outside air	29.0%	O.A.

This looks good, until one looks at situations other than design loads. At part load, especially when the exterior load offsets the interior heat gain, the BTUH requirement becomes secondary to the ventilation requirement, and either 100% outside air at reheated minimum VAV airflow, or isothermal air at a design constant volume air flow, is required. This situation pretty much precludes using a single duct VAV box to supply a classroom, unless significant reheat is allowed (and ASHRAE Standard 90.1, and title 24 in California, don't).

So, it seems that either fan powered boxes (Series or Parallel), or a Dual Duct design will be required for overhead well mixed systems. The acoustical requirements of the ATBCB / ANSI 12.60 preclude any fan powered devices (or any other mechanical equipment, in most cases) in or above the classroom. Fan boxes may be located in the hallway, ducted into the classroom, but fire dampers required by some codes add complexity to this option. Dual Duct units, located over the classroom, can meet the 35dBA requirement, however. If 100% outside air, tempered to near room temperature is supplied through one duct, and cooled recirculated through the other, ventilation and thermal needs may be handled separately through one diffuser. To provide winter heating, the ventilation air is heated a few degrees above average room temperature, based on outside air temperatures.

The air handler options are highly dependent on the climate where the school is located. There are successful dual duct designs in the Midwest utilizing 100% outside air and avoiding reheat. In humid climates, the quantity of outside air should probably be minimized, but will still be a high percentage of the total under certain conditions. It is unlikely that "off the shelf" air handlers will meet any of the requirements in most classroom situations.

ACOUSTICS PLUS AIR DISTRIBUTION, PLAN A

The next problem is providing an air distribution system that will provide a draft free environment, and still meet the acoustical requirements of the ANSI requirement. Calculation of the acoustical requirement, for just the HVAC components, requires including both the VAV terminal's sound with the diffuser generated sound levels, by octave band. These values must be logarithmically added (not arithmetically). If the system is VAV, the air distribution over a range of airflows must be considered as well. Determination of minimum airflows are quite complex in a perimeter zone (as most classrooms are).

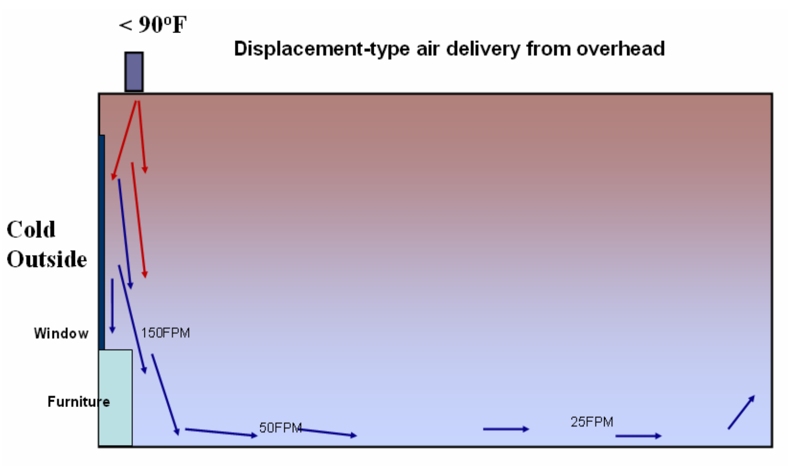
The air distribution design must offset both the perimeter skin loads as well at interior occupant loads. Displacement ventilation is defined as floor located, horizontally supplied low velocity air. Typically supplied through low velocity diffusers located at the floor (and usually ducted from the ceiling), there is a comfort limitation of about 65°F minimum discharge temperature. And these floor mounted diffusers cannot normally take care of heating demand / perimeter skin loads so a perimeter baseboard or radiant system is often required, adding cost and reducing some furniture/cabinet options along the perimeter of the classroom.

Displacement Ventilation does, however, offer a reduced outdoor air requirement through ASHRAE 62.1:

From Table 6.2, ASHRAE 62.1 2004, Air Change Effectiveness:

Floor supply of cool air and ceiling return, provided low- velocity displacement ventilation achieves unidirectional flow and thermal stratification	1.2

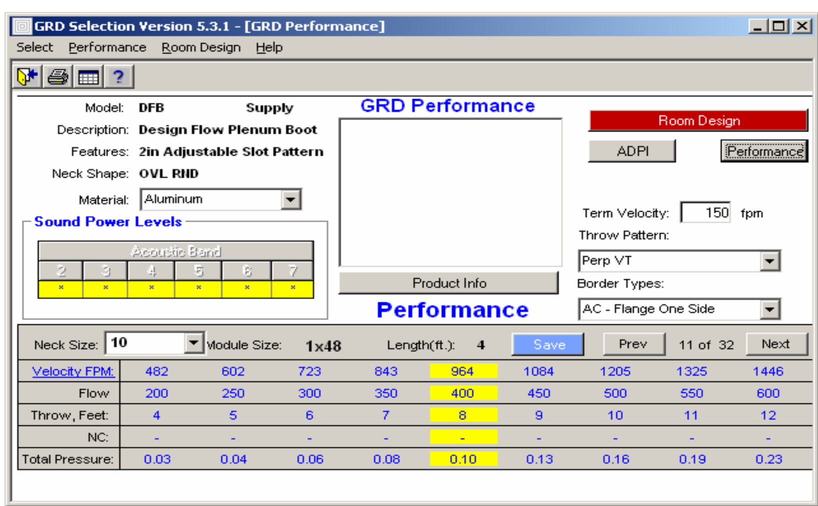
As the ACE number is divided into the required ventilation rate, this is a 25% reduction in required outside air. Perimeter heating, however, cannot be accomplished with floor located displacement diffusers. What can work, however, is a vertical pattern linear slot in the ceiling, located at the exterior wall. The downward jet will enter the occupied zone at the floor, horizontally, below the window/wall, and qualifies as a "displacement Ventilation" system.



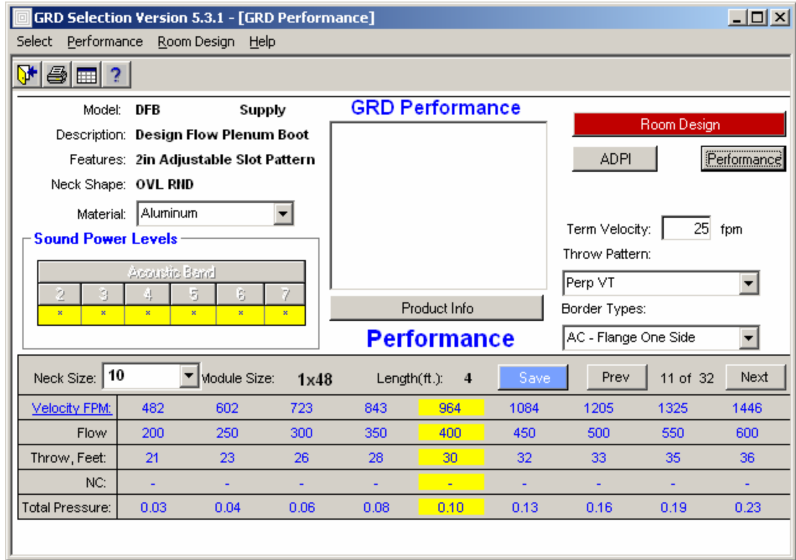
Using the Krueger selection program KSelect for boxes and diffusers, as well as the acoustical calculation spreadsheets located on the Krueger website several performance parameters for a linear diffuser and Dual Duct boxes are investigated.

DIFFUSER PERFORMANCE

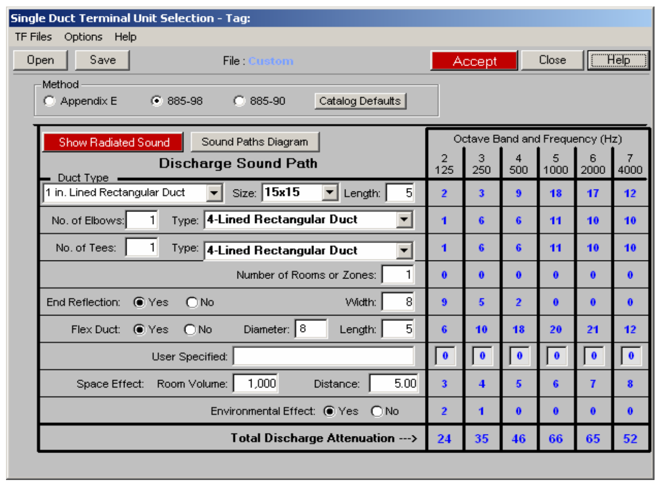
Using a 4' Design Flow, 2" single slot, 10" inlet, located at the perimeter of the room, and assuming 4 diffusers with 400 cfm each, we find that the octave band sound generated is <20 in all bands. The throw to 150 fpm is 8 feet. This means the jet will be entering the occupied zone at less than 150 fpm, at the floor.



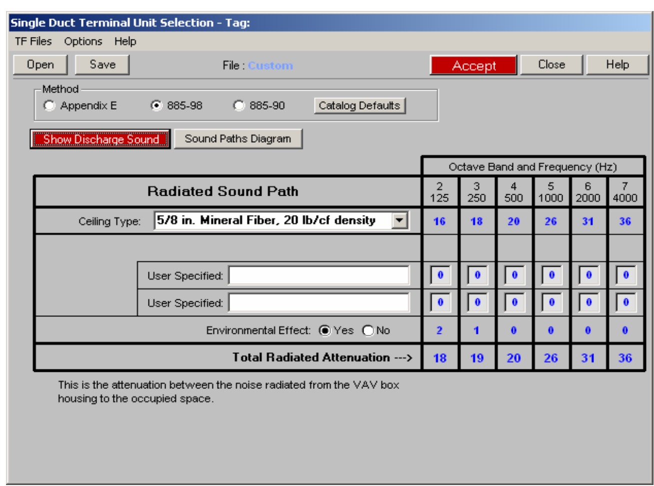
The throw to 25 fpm is 30 feet, meaning the air will make it across the floor, nearly to the far wall. This should provide the necessary comfort using displacement ventilation concepts, at the reduced ventilation rates. Note: ADPI cannot be determined for this application (See Plan B, below). ADPI is a ceiling diffuser analysis not really suited for this type of application.



Next, we look at the sound levels from the dual duct unit, using the KSelect/Terminal program. The calculated Discharge values use assumptions from ARI 885 as shown below:



The Radiated sound assumes a mineral tile ceiling, with the unit located above the room:



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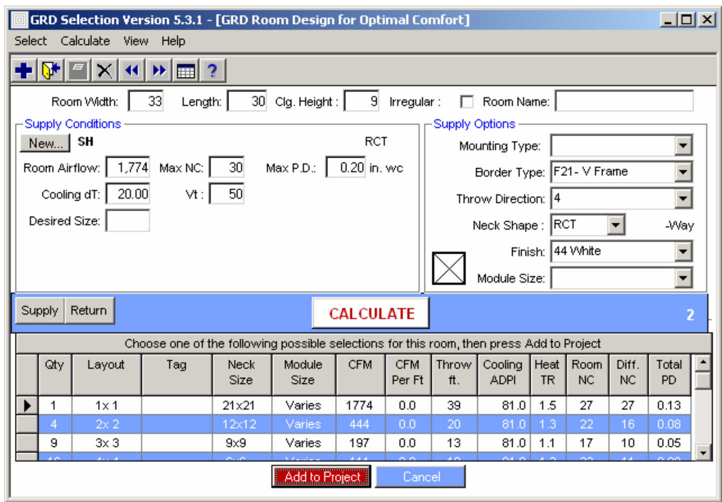
Taking the radiated Discharge and Radiated sound, and assuming 20dB / band for the diffuser (data indicates <20), we calculate the room sound level for a classroom with the dual duct above, and 4 4ft. diffusers, and get a room dBA of 32 dBA, meeting the classroom sound requirement:

Project	Classroom / DF, LMHDT					
Octave Band	2	3	4	5	6	7
Mid Frequency, Hz	125	250	500	1000	2000	4000
VAV Box Discharge Sound Pressure	31	24	10	-5	-8	-3
VAV Box Radiated Sound Pressure	45	30	23	13	6	-11
Diffuser Sound Power	20	20	20	20	20	20
# of Diffusers	4					
Room Attenuation	3	4	5	6	7	8
Other (Custom)	0	0	0	0	0	0
Environmental Adjustment Factor	2	1	0	0	0	0
Diffuser Sound Pressure	21	21	21	20	19	18
Total Room Sound Pressure	45	31	25	21	19	18
Output NC	26					
		R?	H?			
Output RC, Letters	22	R	H			
DbA	32					

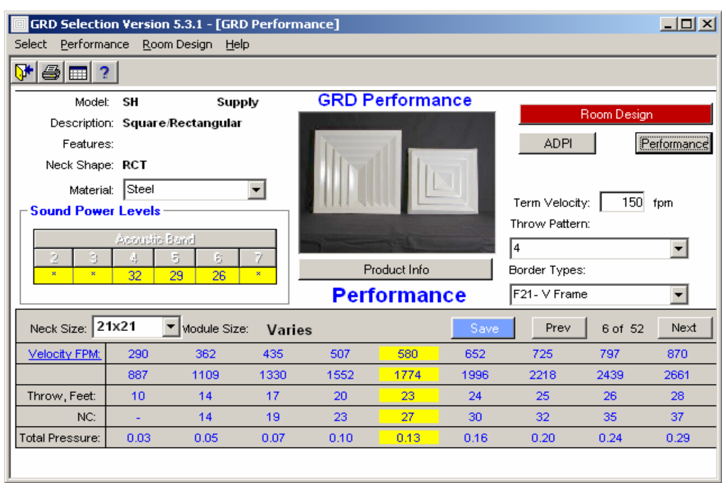
This arrangement of a Dual Duct and perimeter located downblow linear slots has some limitations. This includes assuring that the minimum airflow setting of the dual duct terminal will provide sufficient airflow to maintain the jet all the way to the floor.

CONVENTIONAL OVERHEAD AIR DISTRIBUTION, PLAN B

Should we decide to use a traditional ceiling diffuser, instead of the linear slots at the perimeter, the best choice for both acoustics and room air distribution using ADPI analysis, is a single diffuser in the room, a 21x21 SH (Flush Louver Face) diffuser. A number of arrangements of other diffusers were evaluated and rejected as either not meeting the ADPI>80 or room dBA<36 requirements. The Room Design ADPI calculator for the SH diffuser yields the following:



The selected diffuser octave band can be determined at the same time:



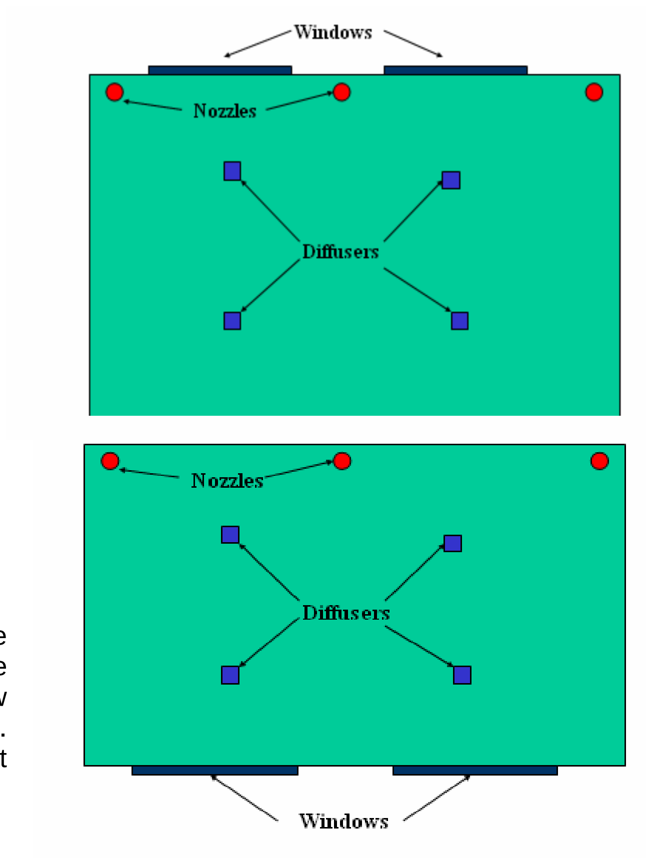
Combining the octave band for that diffuser with the Dual Duct unit above also yields a 32 dBA in the room. This diffuser should be located 1/3 of the way from the window to the opposite wall to ensure the window is washed by heating air in the winter.

Project	Classroom / SH, LMHDT					
Octave Band	2	3	4	5	6	7
Mid Frequency, Hz	125	250	500	1000	2000	4000
VAV Box Discharge Sound Pressure	31	24	10	-5	-8	-3
VAV Box Radiated Sound Pressure	45	30	23	13	6	-11
Diffuser Sound Power	28	30	32	29	26	20
# of Diffusers	1					
Room Attenuation	3	4	5	6	7	8
Other (Custom)	0	0	0	0	0	0
Environmental Adjustment Factor	2	1	0	0	0	0
Diffuser Sound Pressure	23	25	27	23	19	12
Total Room Sound Pressure	45	32	28	23	19	12
Output NC	26					
		R?	H?			
Output RC, Letters	24	R	N			
DbA	32					

This solution does not provide displacement airflow, so will require the higher minimum ventilation rate. It will still require a Dual Duct supply in order to avoid the reheat issues discussed previously. The 21x21 diffuser will not fit in a standard 2'x2' ceiling tile, but requires a modified ceiling cutout, with a 27"x27" lay-in t-bar arrangement. (Surface mount frame for a plastered ceiling is also available).

OTHER ALTERNATIVES

If one were to disconnect either the perimeter conditioning, or the ventilation system, from the interior comfort zone conditioning, there are opportunities using a series of small ceiling nozzles to supply either hot and cold air to the perimeter, or tempered ventilation air along the interior wall. Both these technologies have been used successfully in the past, and may offer an affordable alternative. The nozzles do not add to the room sound levels. If the loads are low enough, it may be possible to use a single diffuser that fits into a 2x2 ceiling, and still meet sound requirements.



Option A: Separate Perimeter Conditioning with Nozzles:

In this configuration, heating and cooling of the perimeter skin is provided with a system which is separate from the ceiling diffusers. This may be a convenient option if a dedicated outside air unit is providing ventilation, and a separate conventional air handler is providing cooling to the ceiling through a dual duct unit, and a heating only fan coil, or a separate ducted heating system, is providing perimeter heating.

Option B: Separate Ventilation to the Interior with Nozzles:

A dedicated outside air unit may provide ventilation air to the nozzles located along the interior wall, and a conventional system can now provide heating and cooling from ceiling diffusers. This system may allow for conventional comfort conditioning equipment, including the air handler.

Option C, Displacement Air Delivery

Krueger offers a complete line of Displacement Air Delivery outlets (DV). These units can supply quiet (typically) <20NC to classrooms, and reduce the OA requirement by 25%. Often a couple units are located on either side of the white boards in the front of the classroom, with a couple more in the rear corners of the classroom. Of course, a separate heating system should be supplied for the perimeter. DV systems should never be designed for discharge temperatures below 65F to avoid uncomfortable feet by the classroom occupants. The key in selecting Displacement systems is to ensure that there is sufficient clearance in front of the units to allow the discharge air to settle to the floor. This limits the amount of air that can be delivered to the units. It should also be noted that the challenge for the mechanical system with DV is to provide 65F air with a 55F dewpoint, without using reheat. A new addendum to ASHRAE 62.1 2010 now gives displacement ventilation to low velocity UFAD systems. The challenge with UFAD in the classroom is to find diffuser locations that don't conflict with occupant locations. Often, a combination of UFAD and DV is utilized, as both have similar air temperature/humidity requirements. Both are also very quiet, but both have the perimeter heating and cooling challenge.

Option D: Chilled Beams

Finally, we are seeing Chilled Beams being specified for classrooms. While they do not have the lowered ventilation requirement, Beams are seldom noisy, and offer some opportunities for energy savings. Perimeter skin loads may also be a challenge. Krueger offers a complete line of Chilled Beams.

SUMMARY

The requirements of LEED, ASHRAE Standards 62.1 and 55 and ANSI S12.60 all combine to limit the air distribution element choices in a classroom environment. Using available selection tools, several scenarios have been determined that meet all of the above requirements. The use of a linear downblow slot at the glass, as shown in Plan A, to provide displacement-type air delivery from overhead has the advantage of reducing the required amount of outside ventilation air, per ASHRAE 62.1. A more conventional air distribution design (Plan B) can be provided with a single diffuser, but requires greater ventilation air quantities.

Both designs will employ a Dual Duct system, and likely a custom air handler. This is the only air supply system which we have found will meet all the requirements, at all load conditions. In addition, it may be possible to decouple the ventilation and comfort systems, for a lower cost solution.

Displacement, UFAD and chilled beams also offer opportunities for innovative designs in the classroom of the future. LEED for schools, 2012, is likely to have a mandatory sound limit in the classroom, so all designs will need to be considered.