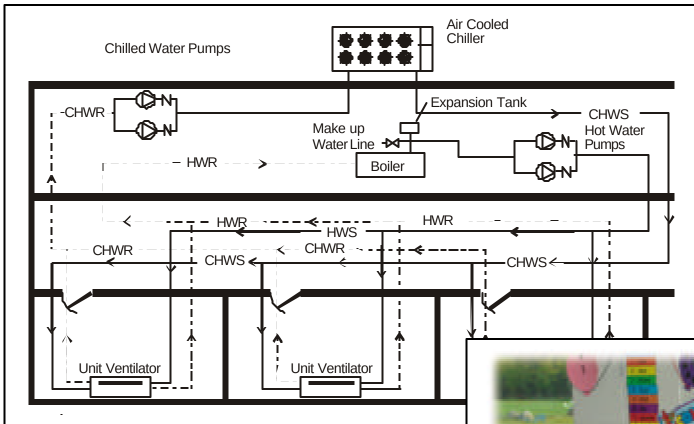
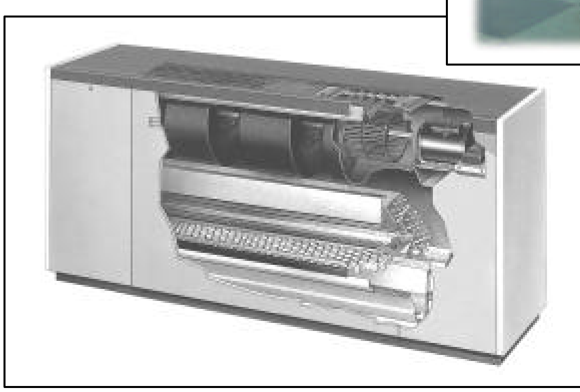
Application Guide

AG 31-004

School HVAC

Design Manual





McQuay® Air Conditioning

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Introduction

The quality of our children's education is directly connected to the quality of the classroom environment. School officials, design engineers, architects and equipment manufacturers strive to provide the best possible environment that encourages learning. Sound, temperature, humidity and Indoor Air Quality (IAQ) must all be balanced with a fiscally and environmentally responsible solution.

The purpose of this manual is to provide the design engineer with a variety of HVAC solutions for classroom environments. Issues such as IAQ, energy efficiency, sound, complexity, serviceability, first cost and operating cost will all be covered.

General Issues

In North America, the typical school system consists of elementary schools (kindergarten to grades 5 or 6), middle schools (grades 6 or 7 to 9) and high schools (grades 10 to 12). Typically, 6 to 10 elementary schools feed 2 middle schools, which in turn feed 1 high school. Population density and demographics have a large impact on school planning.

Elementary schools generally consist of approximately 10 to 15 classrooms, an administration area, a gymnasium and a library. Elementary schools are used throughout the school season (late August to June), but see little use in the summer. They are generally occupied from 7:00 am to 3:00 p.m.

A trend in elementary schools is to include science classrooms which require special consideration in design. Another popular trend is to attach a day care center to elementary schools. In most cases, the day care centers are operated as a stand-alone facility and they require their own HVAC system.

Middle schools are larger than elementary schools. In addition to the facilities found in elementary schools, middle schools also have computer classrooms and locker rooms. Middle schools are open longer during the day than elementary schools due to extracurricular activities.

High schools can also include cafeterias, natatoriums, skating rinks, industrial shops, home economics rooms, stores and auto repair shops. Like middle schools, high schools are open longer during the day. In addition, high schools are often used in the summer, either for summer school or to make use of their special facilities (gymnasiums, natatoriums, shop facilities, etc).

Colleges and technical schools are similar to high schools. They have similar facilities and are used year round. Night school programs extend the operating hours into the weekday evenings.

Many trends have emerged in recent years, including a return to neighborhood schools and longer school years. Improved building design has made modern schools more airtight. These issues affect the decision making process for HVAC design.

Room Design

Classrooms are typically 900 to 1000ft^2 (30' by 30') and hold approximately 20 to 30 students. At a minimum, the space must be heated and ventilated. Middle school and high school classrooms are often air conditioned as well. In hot or humid climates, consideration should also be given to air conditioning elementary classrooms.

The classroom heating load usually peaks early in the day when the ventilation system goes into the occupied mode. Cooling loads usually peak late in the day.

Elementary classrooms generally have at least one exterior wall with windows. While modern construction resolves most infiltration and drafting issues, buildings constructed with older materials should be carefully evaluated for infiltration concerns. In addition, a washroom may be attached to each classroom, requiring local exhaust.

Middle and high schools may have classrooms that have only interior loads. Such classrooms will require year round cooling.

Gymnasiums may be used in the evenings and on weekends. A dedicated HVAC system is recommended to deal with the range of loads and scheduling issues. If a wood floor is provided in the gymnasium, humidity control must be reviewed carefully with the flooring manufacturer to ensure the HVAC design will protect the floor.

Administrative areas are generally occupied before, during, and after school hours. To deal with the longer schedule, a dedicated HVAC system is recommended. In addition, because the occupancy level in the administrative area is lower than in classrooms, the outdoor air requirement is reduced. This should be considered in the selection of HVAC equipment to take advantage of first cost and operating cost opportunities.

Cafeterias and Auditoriums are often found in middle and high schools. Kitchens associated with the cafeterias required special ventilation and fire prevention equipment. NFPA requirements should be reviewed for such areas. Cafeteria and auditorium usage is tied to meal times and special events. Auditoriums may be required to operate in the evenings. Dedicated systems are recommended. Outdoor air ventilation systems are a special challenge because of the high population density when fully occupied. ASHRAE Standard 62.1-1999 should be consulted.

Science Classrooms can have special HVAC needs depending on the range of work performed in the space. Elementary classrooms may only need additional ventilation for experimental demonstrations performed by the teacher, or any animals kept in the room.

Middle and high school science rooms may require fume hoods and makeup air systems with materials selected to withstand the chemicals used. Higher ventilation rates are also recommended to dilute odors. Material storage and preparation areas should be ventilated continuously.

Computer classrooms have high sensible heat gains from the computers and peripherals in the room. Humidification may also need to be addressed depending upon the equipment used in the classroom. Table 1 shows heat gains from Pentium grade computers and monitors.

Table 1, Heat Gains From Computers

	Continuous (Watts)	Energy Saver (Watts)
Average Value	55	20
Conservative Value	65	25
Highly Conservative Value	75	30
Small Monitor (13"-15")	55	0
Medium Monitor(16"-18")	70	0
Large Monitor (19"-20")	80	0

Typical laser printers generate 215 watts during continuous use and 35 watts when idle.

Auto repair shops require outdoor ventilation and makeup air to dilute odors and fumes. Typically, shops are heated and ventilated but not air-conditioned. Return air from the shop should not be used in other spaces and the shop should be maintained at a negative pressure to contain odors. Because a shop can be used outside of regular school hours, a dedicated system is recommended. Special exhaust equipment to deal with welding fumes may also be required.

Ice rinks have special HVAC requirements in order to maintain a good ice surface without fogging, and to provide comfort for spectators. Ice rinks should have dedicated HVAC systems to accommodate their special requirements and extended operating hours.

School Stores are usually open for short periods of time. The HVAC system selection should accommodate the intermittent use.

Natatoriums have special HVAC needs. Humidity control from the pool surface is critical. Natatoriums should have dedicated HVAC systems designed for this application and to accommodate extended operating hours.

Industrial shops are similar to auto shops. Specialized equipment, such as dust collectors, may be required depending on the use. High sensible heat gains are possible due to machinery located in the space. A clear understanding of the machinery and its use will allow the designer to apply the proper diversity and avoid unnecessary first cost.

Locker rooms usually need to be exhausted directly to the outside if there are showers or toilets. As a result, makeup air is required to offset the exhaust. The space needs only heating and ventilation and the HVAC system be scheduled to shut down during unoccupied hours.

Home economics rooms can have high sensible heat gains from appliances. In addition, kitchen fume hoods and the appropriate makeup air may also be required. The space should be maintained at a negative pressure to contain odors.

Load Calculations

Accurate load calculations are critical to a well-designed HVAC system. Estimates for infiltration and drafting should be based on the actual school design, not on estimates from previous projects. Although some spaces will have high sensible heat gains, outdoor air will be the dominant load, particularly in modern buildings.

Figure 1, Classroom Cooling Load Components

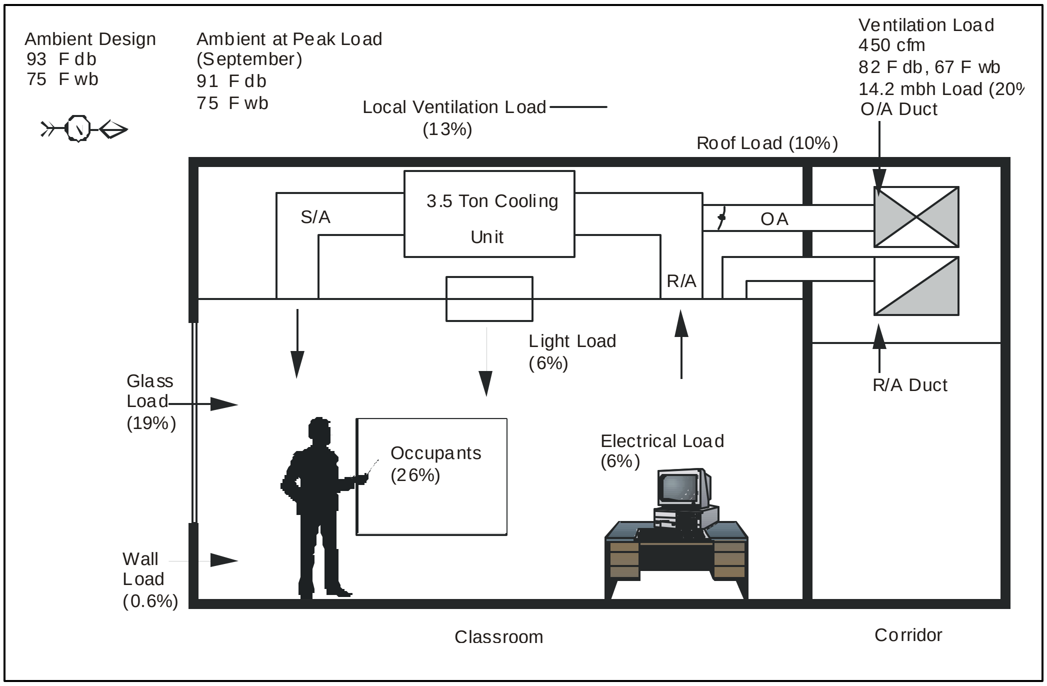


Figure 1 shows a classroom with southern exposure in the Chicago area. The classroom load peaks in September and the outdoor air load peaks in August. The HVAC system is decentralized with an energy recovery outdoor air system. Most of the outdoor air cooling occurs in the outdoor air unit (20% of the total load). Additional outdoor air cooling is required at the classroom unit (another 13%). The total outdoor air load is 33% of the classroom load.

The glass, wall and roof loads are much smaller. Even if they were larger (poor or older construction), the outdoor air load would still be the dominant parameter in the load analysis.

The high population density should also be noted. The occupants represent 26% of the total load. Like the outdoor air load, this occurs in every classroom (North side, South side or in the core).

School loads differ from office building loads because of their low sensible heat factors (sensible cooling/total cooling). In Figure 1, the sensible heat factor is 0.69. A typical sensible heat factor for offices is 0.90. Therefore, equipment designed for office environments will not be suitable for school environments.

Figure 2, Classroom Heating Load Components

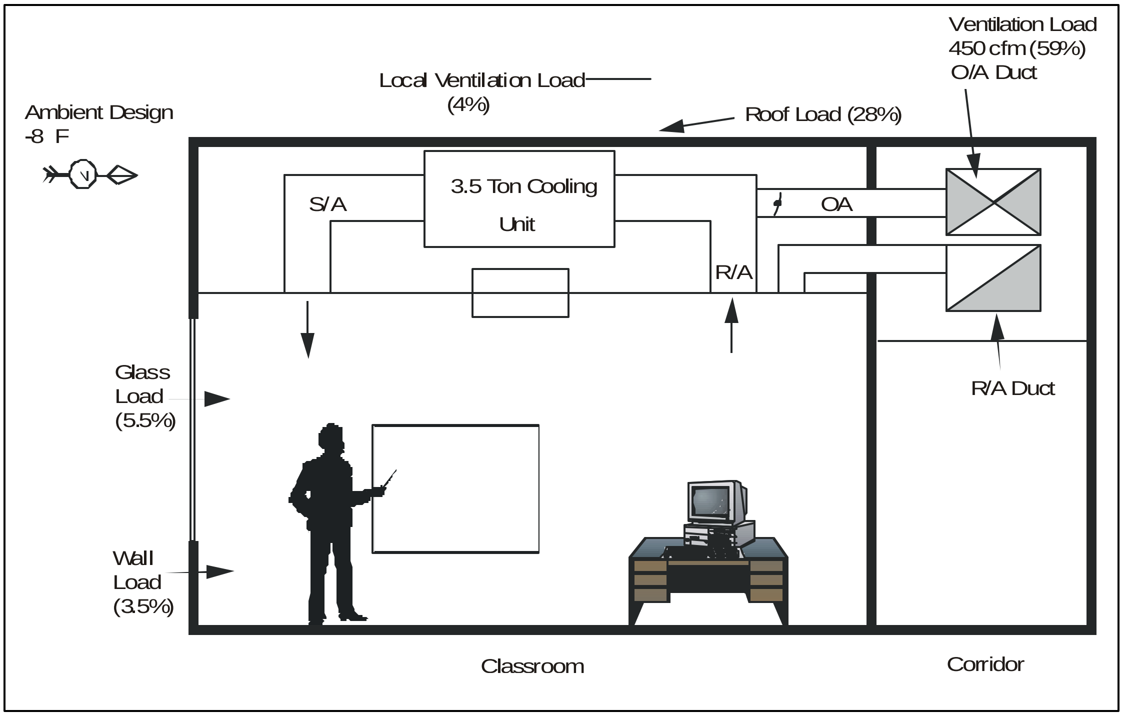


Figure 2 shows the same load breakdown but for heating. Again, the outdoor air load is dominant, representing 63% of the heat loss from the space.

An important conclusion can be drawn from these load calculations. All of the classrooms will behave approximately the same and their behavior will be dictated by the outdoor weather. Even larger schools with interior core classrooms will have similar characteristics. The details of just how the school zones will behave can only be found by performing the necessary heating and cooling load analysis.

Regional Issues

Whether the school is located in Florida or Minnesota in large part affects the HVAC design. Humidity and dehumidification concerns perhaps provide the widest range of issues. In humid climates, humidity control is critical to avoid mold growth and provide good IAQ. Both the capacity and the operating mode of the HVAC equipment must be considered. A DX cooling system that is cycling off several times an hour will allow large volumes of humid air to enter the space during the off cycles. Although the equipment may meet the design cooling and dehumidification load, it fails to maintain a proper environment because of its operating mode.

Northern climates are concerned with freezing. Great care must be taken to avoid freeze-ups and the subsequent damage they can cause.

Most schools are designed by local engineers who are familiar with local issues. When designing projects in different areas of the country, special care must be taken to understand the needs of each local area.

Sound Issues

In recent years sound has moved to the forefront as a key parameter in the quality of the learning environment. Table 2 is the recommended sound levels from the 1999 ASHRAE Handbook.

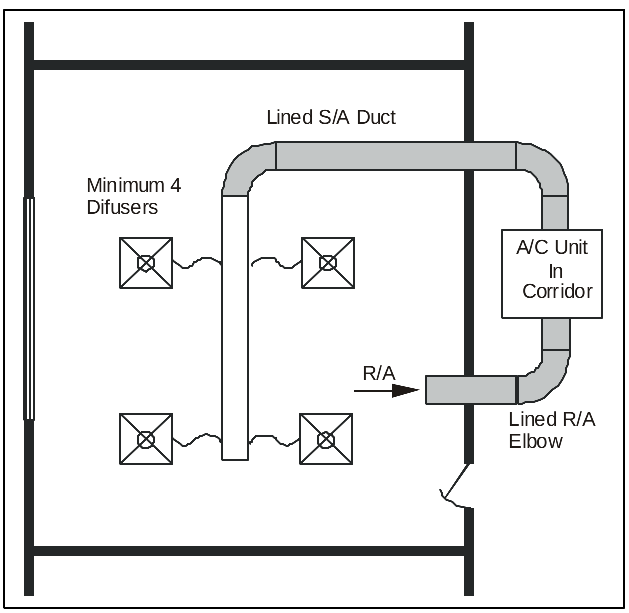
Table 2- Recommended Sound Levels

Space	A – Sound Levels dB	Desired NC (Noise Criteria)
Libraries, classrooms	35-45	30-40
Laboratories, shops	40-50	35-45
Gyms, multipurpose, corridors	40-55	35-50
Kitchens	45-55	40-55

Classroom construction makes it more difficult to achieve low sound levels than in office spaces. There is little material to absorb sound energy and the hard, dense surfaces reflect sound energy back into the room.

Sound generating mechanical equipment (fancoils, watersource heat pumps, and fan powered VAV) should be located in the corridor where possible. Figure 3 shows the recommended duct design for a classroom. A return air elbow is recommended for all systems when a corridor ceiling plenum is used for the return air path. Fire dampers may be required in both the supply and return ducting, depending on the rating of the wall between the classroom and the corridor.

Figure 3, Classroom Duct Design for Good Acoustics



Special care should be taken in selecting diffusers. For a standard classroom of 1000ft², four - diffusers are recommended. If less than four diffusers are used, the required throw may make them too noisy. Most diffuser catalogs are based on only one diffuser in the space and a room absorption of 10dB re 10-12 watts. While these are acceptable assumptions for an office, they may be insufficient for a classroom. As a rule of thumb, for each additional diffuser, subtract 3 dB from the cataloged NC rating (i.e., for 4 diffusers, subtract 9 dB from the cataloged performance). Volume control dampers should be located between the flex duct and the main duct, away from the diffuser.

Duct velocities should be limited to 800-1000 fpm to minimize sound issues. The supply duct should be acoustically lined for the first 10 ft. The return air elbow should also be lined. If duct lining is not acceptable, a sound attenuator with an insertion loss of 10 dB at 125 Hz is recommended.

Discharge and radiated sound from terminal equipment must also be carefully considered. Using cataloged NC levels for various terminal equipment is not recommended. The assumptions made to derive NC levels are may be inaccurate for classroom applications. Instead, use sound power ratings. Most terminal equipment manufacturers can provide both radiated and discharge sound power levels. For discharge sound power levels, 75 dB at 125 Hz and 72 dB at 250 Hz are recommended.

Design Conditions

Table 3 lists recommended drybulb temperatures from the 1999 ASHRAE handbook. For highly populated spaces, where the sensible heat factor is less than 0.75, lower drybulb temperatures will result in less latent heat from the occupants. This may reduce the overall cooling and /or reheat requirement for the school. The actual drybulb design condition should be carefully reviewed.

Table 3 – Recommended Winter and Summer Design Drybulb Temperatures for School Spaces

Space	Winter Design (°F)	Summer Design (°F)
Laboratories	72	78 d
Auditoriums, Libraries administrative areas etc.	72	78
Classrooms (Pre-K through 3rd)	75	78
Classrooms (4^{th} through 12th)	72	78
Shops	72	78b
Locker, shower rooms	75 d	c,d
Toilets	72	c
Storage	65	c,d
Mechanical rooms	60	c
Corridors	68	80^{d}

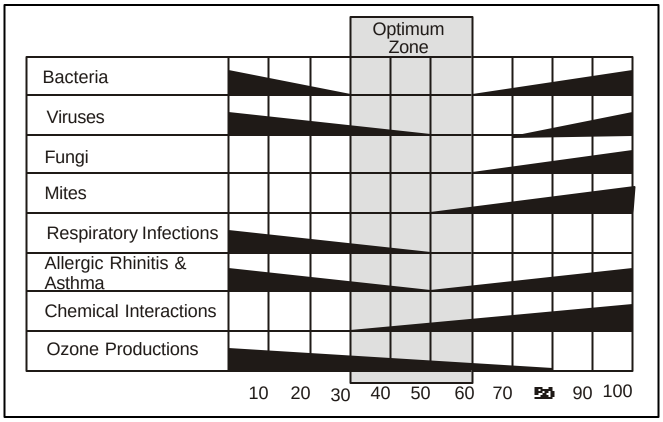
Notes:

a Frequently not air conditioned.

b Usually not air conditioned

c Provide ventilation for odor control

Figure 4, Sterling Bar Graph



As mentioned previously, the humidity level in schools is a key issue. Both low and high humidity levels are concerns. Figure 4 shows the Sterling bar graph from the 2000 ASHRAE handbook indicating how high and low humidity levels affect key health factors.

Humidification in dry climates is not mandatory, but it will improve the environment for the occupants. Dehumidification in humid climates is a larger concern because undesirable microbial can grow in damp locations. The HVAC system should be designed to maintain the relative humidity between 40 and 60% throughout its entire operating range.

System Complexity

The requirements of good indoor air quality, comfort, energy efficiency and acoustics can lead the designer to some very complex HVAC solutions. Because school districts represent owner occupied customers, the school district's ability to support the system must be considered in the design of the HVAC system. If the system becomes so complicated that only specially trained personnel can operate and maintain it, then the designer's efforts may have been in vain.

The designer should understand and appreciate the skills and limitations of the school district that will operate the system, and this should be taken into account when selecting the HVAC system.

Serviceability

In addition to operating the HVAC system, the school district will also have to maintain it. They are acutely aware of the maintenance costs associated with operating schools and will highly value serviceability.

Indoor Air Quality (IAQ)

Schools present unique challenges for achieving good IAQ. For example, the population density of an average classroom (900ft² classroom with thirty students) is three times that of a typical office.

ASHRAE has developed Standard 62.1-1999, Ventilation for Acceptable Indoor Air Quality. It is in normative (code enforceable) language and has become the minimum standard of care in most building codes.

Std 62.1-1999 provides two procedures to obtain acceptable indoor air quality. Table 4 represents the ventilation rate procedure, which is the most popular. There is also the Indoor Air Quality Procedure. The later requires identifying and controlling known and specifiable contaminants.

Table 4 – Outdoor Air Requirements for ventilation From ASHRAE Std 62.1-1999

Application	**Estimated Maximum occupancy**	**Outdoor Air Requirements**				**Comments**
	P/1000 ft² or100 m²	**Cfm/ person**	**L/s person**	**Cfm/ ft²**	**L/s m²**	
Education						Special contaminant control systems may be required for processes or function including laboratory animal occupancy
Classroom	50	15	8			
Laboratories	30	20	10			
Training Shop	30	20	10			
Music Rooms	50	15	8			
Libraries	20	15	8			
Locker Rooms				0.50	2.50	Normally supplied by transfer air. Local mechanical exhaust with no recirculation recommended.
Corridors				0.10	0.50	
Auditoriums	150	15	8			
Smoking Lounges	70	60	30			

The minimum outdoor air rates listed in STD 62.1-1999 represent the minimum supply air volume to the space. The total supply air can be made up of the minimum outdoor air and acceptable recirculated air. It is acceptable to supply more air to meet the heating or cooling loads.

The HVAC system design must be able to maintain space temperature and humidity conditions at the minimum outdoor air rate. For example, with a VAV system, the minimum airflow rate for the VAV box must be the minimum outdoor air rate for the classroom. During certain periods, this may be too much air and the classroom will be over cooled. In this case, some form of reheat would be required rather than reducing the airflow.

Ensuring the proper amount of outdoor air is brought into the school is only the first step. It is essential that the correct amount of outdoor air be delivered to each space. Dedicated makeup air systems can be ducted directly to the terminal unit (fancoils, WSHPs) and an air balance performed to ensure proper distribution.

Where a single mechanical system serves multiple spaces, more care must be taken. ASHRAE Std 62.1-1999 includes the equation:

$$Y = X/[1+X-Z]$$

Where;

Y = Corrected fraction of outdoor air in total supply.

X = Sum of all outdoor airflows divided by the total supply

Z = Outdoor air fraction required in supply to critical space

Critical space = The space with the greatest required fraction of outdoor air in the supply air

Figure 5, STD 62.1-1999 Ventilation Reduction Graph For Multiple Spaces From A Common Source

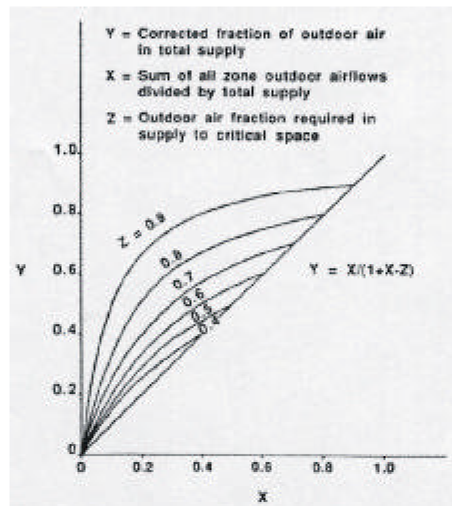


Figure 5 shows this equation as a graph. For example assume a central air handling unit will serve the following;

Space	Total Outdoor Air (cfm)	Total Supply Air (cfm)
5 Classrooms	450 x 5	1200 x 5
1 Lab	600	1200
Corridor	50	300
Total	2900	7500

The quick assumption would be that the minimum outdoor air ventilation setpoint for the air handling unit is 2900 cfm/7500 cfm or 39%. However, this is not correct because the critical space is the lab. It requires 50% outdoor air. Using the equation from STD 62.1-1999:

$X = 2900/7500 = 0.40$

$Z = 600/1200 = 0.50$

$Y = 0.4/[1+0.4-0.6]=0.44$

The minimum outdoor setting for the air handling unit is 44%.

Demand Control Ventilation (DCV) allows the amount of outdoor air to modulate to meet the needs of the space. Typically they are used in spaces where the population density varies significantly. Carbon Dioxide (CO_2) is an excellent measure of the amount bioeffluents in the space. People give off CO_2 and bioeffluents at a rate proportional to their activity.

To design a DCV system, determine the design outdoor air rate without any diversity. Locate CO_2 sensors in the space or the return air duct for single zone systems. For multiple zone systems, CO_2 sensors must be in every zone, or at least those zones considered critical.

Calculate the maximum CO_2 concentration level allowed. Typically this is around 1000 ppm with ambient CO_2 concentrations around 300 ppm. An outdoor CO_2 sensor is not required if a conservative ambient level is used.

The minimum ventilation rate must be maintained regardless of CO_2 levels. This rate is meant to account for contaminants from building materials, carpeting, etc. The current Standard 62.1-1999 does not provide this minimum level. It is proposed in an upcoming addendum.

A thorough explanation of the Standard is beyond the scope of this manual. It is recommended that the designer have access to the Standard and a complete understanding of its contents. ASHRAE considers Standard 62.1-1999 a high profile standard and has it on continuous maintenance, meaning it is constantly improved rather than being reissued every 5 years.

Energy Efficiency

After payroll, the utility bill is the next largest expense for a school district. Modern construction materials and techniques help reduce the energy bill. High efficiency lighting also has a large impact on reducing the utility bill. The last big opportunity for savings is the HVAC system – particularly the outdoor air system.

ASHRAE Standard 90.1-1999, Energy Standard for Buildings Except Low Rise Residential Buildings is a normative (code enforceable) Standard endorsed by the Department of Energy (DOE). It has become the minimum standard of care for most building codes.

The standard was updated in October 1999. The new version represents a significant energy improvement from the previous standard. Improvements to mechanical systems represent a major portion of the improvement.

Standard 90.1 - 1999 offers two approaches to the school designer. There is also a third approach for small buildings that is generally not applicable to schools. The more popular approach for schools is the Prescriptive Method. This method provides procedures for designing the building envelope, HVAC, service water heating, electrical power, lighting and electrical motors. The standard requires all the general and mandatory provisions are met.

The other approach is the Energy Cost Budget (ECB) method. This method allows the designer to make tradeoffs. For example, the ECB method would allow the savings from more efficient lighting be used to offset a building envelope that does not meet the prescriptive method.

The following is an abbreviated list of requirements for the prescriptive method outlined in Standard 90.1 - 1999. The numbers in brackets refer to the Standard section.

1. Standard 90.1-1999 includes energy efficiency tables for a wide range of HVAC equipment. Several tables have two columns. One column is effective now. The second column goes into effect Oct 28, 2001(6.2.1).
2. Schools are ideal candidates to schedule the HVAC equipment to be off during unoccupied hours. Standard 90.1 mandates that this process be automated (6.2.3.1).
3. Demand Controlled Ventilation is required for systems with at least 3,000 cfm of outdoor air and occupant density greater than 100 people per 1,000 ft^2 (6.2.3.9).
4. Air or water side economizers are required. There are several exceptions to this rule, particularly when dealing with heat recovery (6.3.1).
5. Simultaneous heating and cooling systems such as constant volume terminal reheat, some perimeter induction systems, constant volume dual duct or multizone systems are not permitted. These systems, while offering good space temperature control, are too inefficient (6.3.2.1).
6. VAV reheat is allowed if the minimum air volume meet the ventilation requirements prescribed by ASHRAE Standard 62.1 - 1999.
7. Reheat is also allowed if at least 75% of the energy for reheat comes from on-site energy recovery (Templifiers).
8. WSHP systems must have either a bypass line around the cooler or low leakage positive closure dampers on either the cooler inlet or discharge (6.3.2).

9. Where humidification is required to maintain humidity above 35°F dewpoint, waterside economizers must be used when economizers are required. Introducing large amounts of cool, dry air - while meeting the sensible cooling load - adds significantly to the humidifier load. Process loads, including hospitals are exempt (6.3.2.4).
10. Small fan (fancoils, WSHPs, Fan powered VAV) power consumption is not regulated. For systems under 20,000 cfm, constant volume is limited to 1.2hp/1,000 cfm and VAV is limited to 1.7 hp/1,000 cfm. For systems over 20,000 cfm, constant volume systems are limited to 1.1 hp/1,000 cfm and VAV systems are limited to 1.5 hp/1,000 cfm (6.3.3.1).
11. Hydronic systems with a system pump power that exceeds 10 hp must employ variable flow and isolation valves at each terminal device. The system must be able to operate down to at least 50% of design flow. Individual pumps over 50 hp and 100 ft head must have VFDs and consume no more than 30% design power at 50% design flow (6.3.4.1).
12. Supply temperature reset is required for hydronic systems larger than 300 mbh. Temperature reset is not required if it interferes with the proper operation of the system i.e. dehumidification (6.3.4.3).
13. Fan motors on cooling towers larger than 7½hp must either have VFDs or be two speed. A control system is required to minimize power usage (6.3.5).
14. Energy recovery is required for systems with at least 5,000 cfm supply air and a minimum of 70% outdoor air. This is specifically aimed at schools and labs (6.3.6.1).
15. Hot Gas Bypass for refrigeration systems is permitted, but has strict limitations (6.3.9).

A thorough explanation of the Standard is beyond the scope of this manual. It is recommended that the designer have access to the Standard and a complete understanding of its contents. The ASHRAE 90.1- 1999 Users Manual is also very helpful. ASHRAE considers Standard 90.1-1999 a high profile standard and has it on continuous maintenance, meaning it is constantly improved rather than being reissued every 5 years.

Decentralized Systems

General

Decentralized systems include Unit Ventilators, WSHPs and fancoils. Each zone is typically handled by a dedicated unit, allowing one zone to be in heating while another is in cooling. Equipment malfunctions affect only one zone. Scheduling can be zone-specific allowing for increased operating savings.

Decentralized equipment is generally straightforward to service and can be a major advantage in rural areas. Some decentralized equipment can rival the most advanced built up systems for energy efficiency.

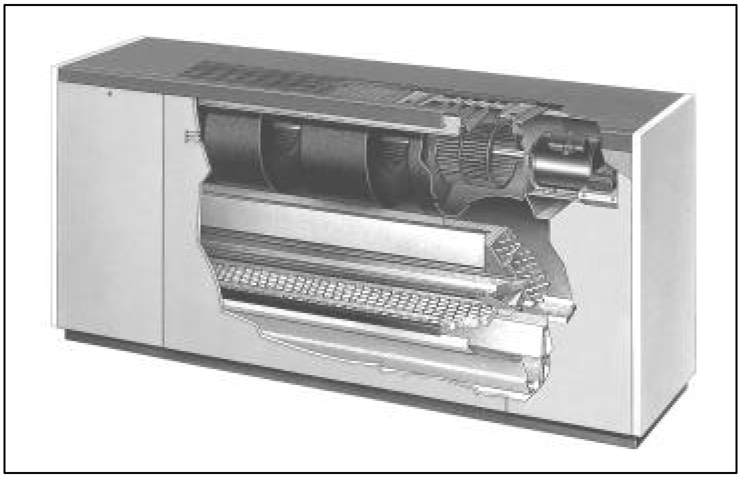
Disadvantages to decentralized systems include maintaining equipment spread throughout the building, often in occupied spaces. Equipment life is generally shorter and locating mechanical equipment at or near the occupied space can make sound an issue that must be dealt with.

Unit Ventilators

General

Unit ventilators are the only HVAC system specifically designed for schools, and they condition more classrooms than any other HVAC system. The inclusion of an airside economizer, introduces proper ventilation directly into the classroom. The four pipe version is one of the most energy cost effective systems because the fan power is very small.

Figure 6, Unit Ventilator



Unit ventilators that are robust enough for the classroom environment come in a wide variety of configurations. They have integral airside economizers that allow the unit to provide up to 100% outdoor air directly into the space. They can be horizontal or vertical, and they can have steam, hot water or electric heating plus chilled water integral or remote DX cooling. There are also airside heatpump and WSHP versions. Modern unit ventilators come with sophisticated DDC controls that can maintain space conditions, operate the outdoor air/economizer section and schedule operation. With this capability, they can be integrated into a building automation system (BAS).

Economizer Operation

There are two key properties of unit ventilators: institutional quality construction and an integrated economizer. The institutional quality construction is aimed at withstanding use and abuse in the classroom environment. The economizer allows the unit ventilator to locally accommodate the IAQ needs of the classroom by introducing the necessary outdoor air.

Figure 7, Recirculation Mode

Figure 7 shows the unit during full recirculation. This is the unoccupied mode. Only return air passes through the unit. The classroom can be maintained at either classroom conditions or unoccupied (setback) conditions without the expense of conditioning any outdoor air.

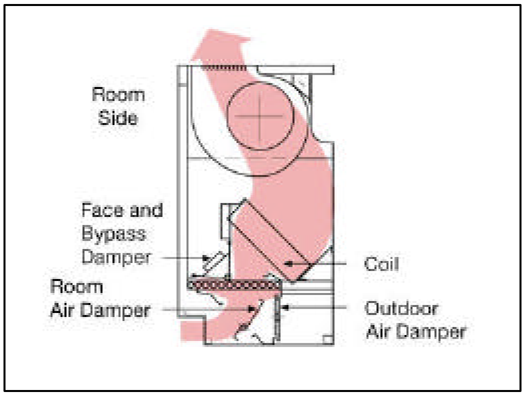


Figure 8, Face and Bypass Mode

Figure 8 shows a draw through fan arrangement unit ventilator with Face and Bypass temperature control during the economizer mode. In this arrangement, the outdoor air and return air are mixed and then flowed around and through the coil(s) to maintain the proper room setpoint. The conditioned air is then delivered into the classroom.

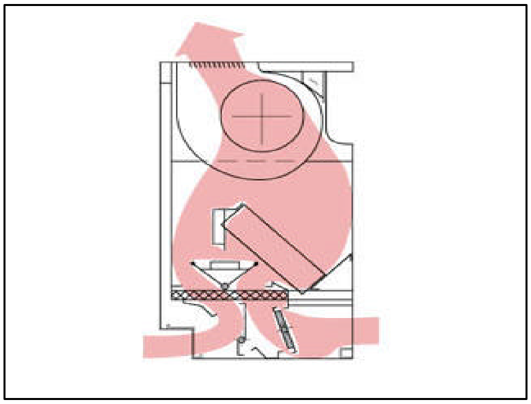


Figure 9, Full Heating or Cooling Mode

Figure 9 shows the same unit in full cooling or heating. During full heating or cooling, the outdoor air drops to the minimum design level (typical to around 450 cfm). Here again, the outside air and return air are mixed and then flowed around and through the coil and into the space.

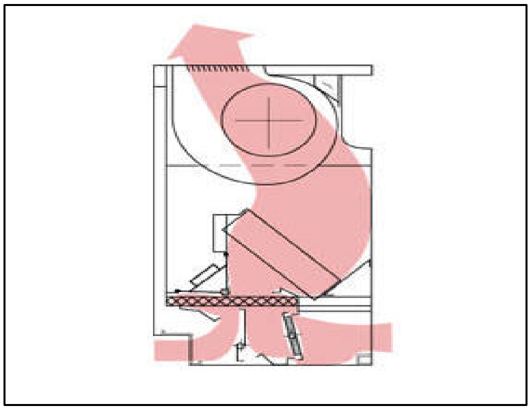
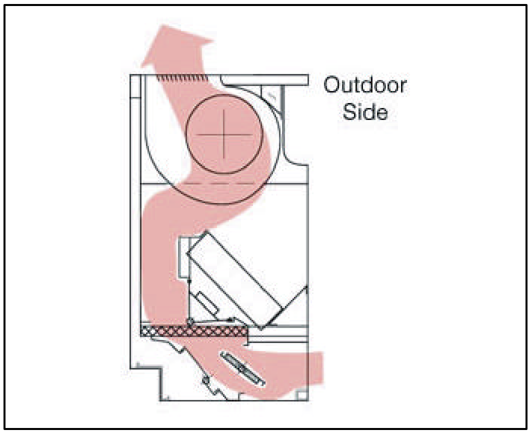


Figure 10, Economizer Mode

Figure 10 shows the unit ventilator during full economizer mode. The economizer mode allows the unit ventilator to take advantage of favorable (moderate) outdoor conditions for "free" cooling. In this mode, the unit ventilator can condition the classroom with up to 100% outside air without mechanical heating or cooling. This arrangement provides the best IAQ and the lowest operating cost.



If the classroom temperature is set back or up, the recirculation mode can be used to quickly get the room to occupied conditions by cooling or heating 100% of the recirculated air.

Face and Bypass vs. Valve Control

The above examples use the preferred method of face and bypass control. The other common control strategy is valve control. In unit ventilators with valve control, the space temperature is maintained by modulating a control valve. While valve control does maintain the drybulb setpoint and is a necessary building block for variable flow systems, it is not as effective as face and bypass control in humid or cold climates.

Figure 11, Face and Bypass vs. Control Valve

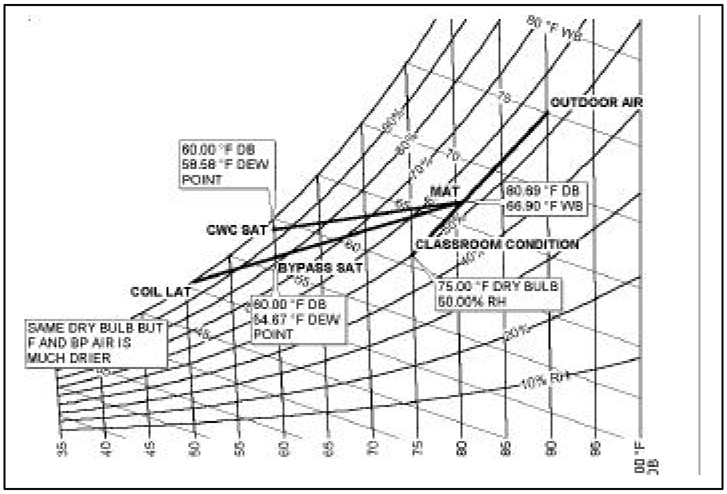


Figure 11 demonstrates the difference between valve control and face and bypass control on a psychometric chart. At part load operating conditions, the valve control approach provides the same dry bulb conditions, but not the same level of dehumidification. With the face and bypass arrangement, the air that passes through the cooling coil is significantly dehumidified. When this air mixes with the bypassed air, the dry bulb setpoint is met and the wet bulb is lower than the control valve arrangement.

Cold weather climates also benefit from the face and bypass approach. The high percentage of outdoor air can make coil freezeups a concern. Valve control lowers the water velocity in the tube, which can lead to coil freezeups. This can be further exacerbated by poor control valve selection. If the valves are incorrectly sized, they may not modulate the fluid flow, but cycle like an on-off valve. The face and bypass arrangement maintains full flow through the coil to protect it from freezing. When valve control is used, correct valve selection is critical for proper unit operation.

While AAF-McQuay Unit Ventilators are offered with both control options, face and bypass is strongly recommended. End-of-cycle isolation valves are available to automatically close off flow to the coil when it is no longer required.

Draw Through vs. Blow Through

The draw through fan arrangement in unit ventilators offers two key advantages. The first is even air flow across the coils. This is important because the unit ventilator cabinet is more confined than a central station air handling unit, making airflow transitions difficult. The second advantage is that the fan motor heat is added after the cooling coil. The high latent load found in classrooms makes adding the motor heat as reheat more attractive.

Draftstop

Classrooms with exterior exposures typically have large windows. This can cause drafting in cold climates, especially for students located near the windows. Older schools with less efficient glass are also a concern. A draftstop system can be used to reduce drafting.

Figure 12, Draftstop

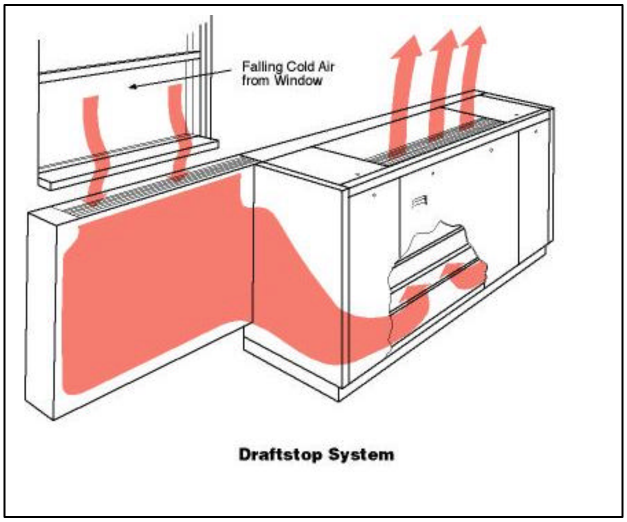


Figure 12 shows how Draftstop collects the air from around the window and delivers it to the unit ventilator. The air is then conditioned and returned to the classroom.

Classroom Exhaust

A typical occupied classroom needs to exhaust a minimum of 450 cfm to offset the 450 cfm of outdoor air. There must be a way to remove the exhaust air from the classroom or the required ventilation will not be met.

Figure 13, Ventimatic Shutter

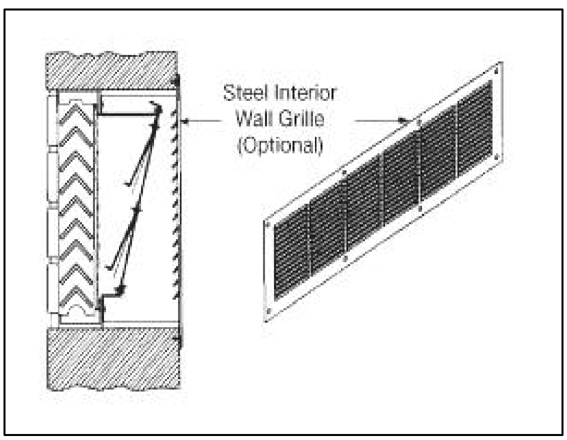


Figure 13 shows a Ventimatic shutter, which can provide local relief for a classroom. Another possibility is to have central exhaust fan ducted to four to six classrooms. During occupied hours, the fan operates and removes the required exhaust from each classroom If a classroom is used after regular hours, the exhaust fan can be left off to allow the exhaust air to vent into the corridor. The exhaust fan can also be interlocked with the unit ventilators and operated when any of them require exhaust air.

Unit Ventilators with Chillers and Boilers

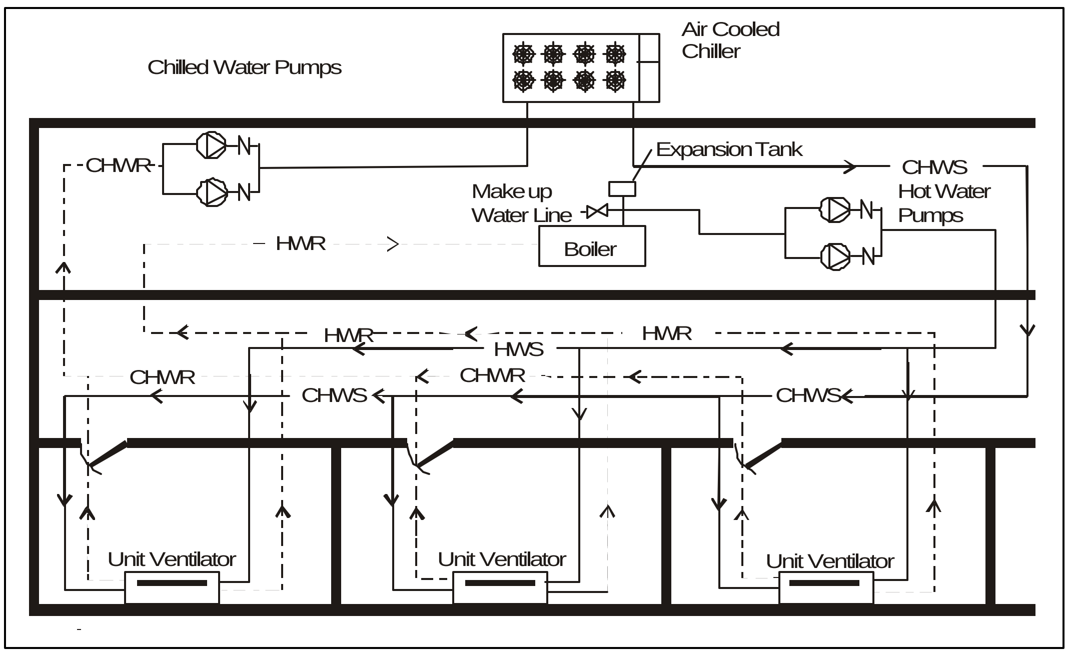
Using a central chiller plant and boilers in combination with unit ventilators can be more energy efficient than self-contained dx systems. Unit ventilators with one or two water coils are the most common arrangement. Single coil (2 pipe) units can provide heating and ventilating only, or heating with a changeover to cooling. Units with dedicated heating and cooling coils (4 pipe) offer excellent performance.

Using a central chiller and boilers offers many advantages. The chiller and the boilers can be sized for the school block load rather than the connected load. Taking diversity into account allows smaller chiller/ boiler plants. The piping and pump horsepower required to heat and cool the school is significantly smaller than the equivalent air duct and fan horsepower. Finally, chilled water and hot water offer accurate control with either face and bypass or valve control. Sound issues are also simplified with chiller and boiler plants.

Either air-cooled or water-cooled chiller plants can be used.

A central boiler plant can operate on natural gas or other primary energy source and modern condensing boilers with efficiencies over 90% can be used. The hydronic heating loop can be used in entrances with convectors and cabinet heaters rather than electric heaters. The boiler plant can be located in a safe remote mechanical room.

Figure 14, Four Pipe System



With a four-pipe system the classroom unit control is an airside economizer with either valve control or face and bypass. Two pipe heating and ventilating units have been an excellent choice for elementary schools in moderate climates. The schools have traditionally seen little occupancy during the summer, so cooling was not mandatory. The shoulder seasons can usually be handled by the economizer operation inherent in a unit ventilator. The current trend is towards longer school seasons and air conditioning even in elementary schools.

Four pipe units allow some classrooms to be in cooling mode while other classrooms are in heating. This is especially advantageous for schools with core area classrooms that require cooling while perimeter classrooms need heating. Four pipe systems require an additional set of insulated piping, another set of pumps and a second coil in the unit ventilators.

Two-Pipe Changeover System

Two-pipe changeover systems reduce the first cost of the system by deleting one set of insulated pipes and one set of pumps. The unit ventilator price is also reduced, as there is only one coil required. This can reduce the construction cost by 25% over the four-pipe arrangement.

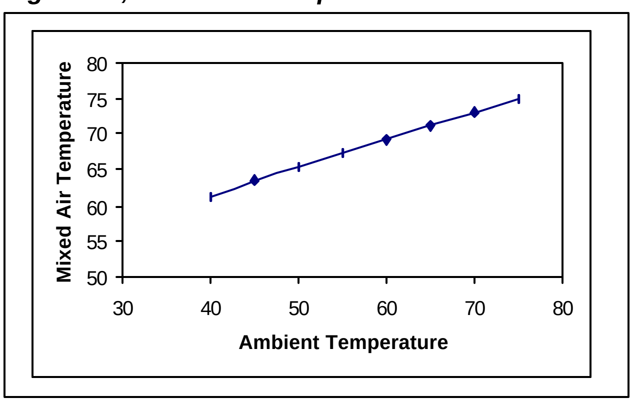
The first cost and operating cost savings are desirable but some performance benefits are lost with the two-pipe concept. It is no longer possible to have one unit ventilator in cooling while another is in heating. In addition, dehumidification by means of reheat is not possible. With proper design, these issues can be minimized.

Simultaneous heating and cooling cannot occur in a two-pipe system which is energy efficient. However, during changeover, the hydronic system must be either heating or cooling which is not energy efficient. To deal with this issue, ASHRAE Standard 90.1-1999 has specific requirements for changeover systems (6.3.2.2.2). These are:

- There must be a deadband in the changeover of at least 15°F outdoor air temperature.
- The system must be designed and installed with controls that allow operation in one mode for at least 4 hours before changing back to the other mode.
- Reset controls are provided that allow the hot water and chilled water setpoints to be no more than 30°F apart at changeover.

In addition to energy concerns, the changeover period raises comfort concerns. What if the classroom on the north side requires heating while the classroom on the south side requires cooling? The main HVAC loads in a modern classroom are outdoor air (33%) and internal heat gains (38%). These two factors are constant in all classrooms throughout the school regardless of the shoulder weather-delete. The remaining load from the roof, walls and glass represents 29% and can vary depending on the zone. With only these loads as variable and the economizers in unit ventilators, dealing with the transition is possible.

Figure 15, Mixed Air Temperature



The first requirement of STD 90.1-1999 is a 15°F ambient deadband. Providing stable space conditions while maintaining the deadband can be accomplished with economizers. For example, a deadband of 15°F from 50°F ambient to 65°F ambient meets the requirement. Figure 15 shows the mixed air temperature as the ambient temperature drops. At 65°F ambient, the economizer can supply air from 65°F (100% outdoor air) to 71.2°F (minimum outdoor air). At 50°F ambient, the economizer can supply air from 55°F to 65.4°F at minimum outdoor air. The actual deadband setpoints will depend on the specific site conditions.

The second requirement of STD 90.1-1999 is the 4 hour deadband. Since two thirds of the load is ambient and internal heat gains, all the classrooms will behave approximately the same. Swings from heating to cooling or visa-versa are not likely unless there are radical changes in the weather.

The last issue is the 30°F deadband. Resetting the chilled water up to 50°F and the hot water down to 80°F will meet the requirement. Resetting the hot water also resolves an issue with the coil, which has to be selected to meet the more demanding role of cooling and will be oversized for heating. An oversized coil will lead to control problems and poor space temperature control. By using a condensing boiler, the heating loop can be operated at 80°F and modulated up with an outdoor air reset controller. The lower temperature will allow good space temperature control.

School layout and orientation also play a key role in assessing how the school will perform during the transition period. The school layout may be such that one block or wing of classrooms will behave differently than another block of classrooms. This can be resolved by having two loops, one serving each block of classrooms.

Piping Design

Piping design for unit ventilators is straightforward as long as good piping practice is followed. For chilled water and hot water systems, ASHRAE Standard 90.1-1999 has specific pipe insulation requirements (6.2.4.5). Reverse return piping is favorable due to its inherent self balancing. However, direct return piping is possible. Proper balancing valves should be installed to allow the system to be balanced.

Traditional operating conditions are 44°F EWT/ 54°F LWT for chilled water and 180°F EWT/160°F LWT for boiler loops. For chilled water, these temperatures result in 2.4 USgpm/ton. For heating, the result is 1 mbh per USgpm. Using larger delta T's for the water loops reduces first cost (smaller piping and pumps) and operating cost (lowers horsepower). However, it usually hurts equipment performance by lowering the LMTD (Log Mean Temperature Difference). Careful evaluation is required to determine the best operating temperatures and flow rates.

In the case of two pipe changeover systems, the flow should be based on the chilled water flow rate. Variable flow design can lower the flow rate for heating.

Central chilled water and boiler plants allow the designer to apply diversity to the load. Whether the diversity is applied to flow or temperature range will depend on the plant design and valve selection. For more details on diversity and chiller plant piping, refer to *McQuay's Multiple Chiller Plant Design Manual (AG-31-003).*

For boilers, a high efficiency, condensing boiler is the best choice. The condensing boiler efficiency is over 90%, which can lower the school operating cost. They can be selected in modules to provide staging and redundancy. In addition, condensing boilers require no circulating boiler pumps and they have a very small footprint. This allows the mechanical room size to be reduced as an added benefit to school administrators.

Proper flushing of the piping system is critical to the correct operation of the system. If the system is not properly flushed, the contaminants can lodge in the small heat exchangers used in decentralized equipment, which can be extremely difficult to resolve.

Pumping Design

In most cases, some form of redundant pumps is preferred. This can include two pumps, each sized for the load with one as a standby. It can also include three pumps, each sized for half the load, with two operating and one as a standby. All pumps should have a check valve on their discharge line and strainers on their suction lines.

ASHRAE Standard 90.1-1999 requires hydronic systems with system pump power exceeding 10 hp to employ variable flow and isolation valves at each terminal device. The system must be able to operate down to at least 50% of design flow. Individual pumps over

50 hp and 100 ft head must have VFDs and consume no more than 30% design power at 50% design flow (6.3.4.1). The Standard has several exceptions to this requirement.

For variable flow, two-way control valves are required. Three-way valves are not acceptable. A bypass will also be required to maintain minimum flow. Minimum flow will be dictated by the requirements of the chiller or boiler plant, and will likely be 33% or more. For a variable frequency drive, horsepower savings are minimal below 20Hz due to motor inefficiencies.

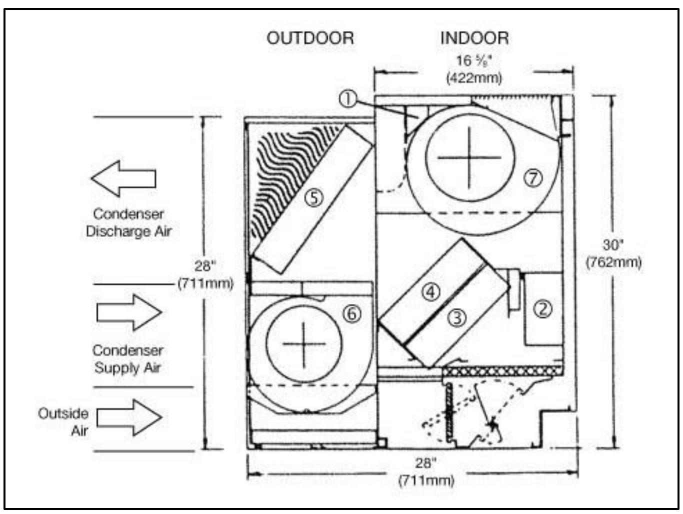
Face and bypass systems should be installed with end-of-cycle shutoff valves so that variable flow can be accomplished.

Varying the system flow can be accomplished several ways. If the three pump approach is used (two operating, one as a standby), then one of the pumps can be turned off at reduced demand. Two speed pumps or variable frequency drives can also be used. Standard 90.1-1999 does allow the option of "riding" the pump curve. However, the pressure differential at low flow may not allow the valves to set properly and negate the power savings.

Self-Contained Unit Ventilators

Self-contained unit ventilators do not require chilled water plants. They include DX cooling, either completely integrated into the unit or as a split system with an air-cooled condenser nearby. The advantage of this approach is overall first cost, reduced complexity and no requirement for a chiller mechanical room.

Figure 16, Self-Contained Unit Ventilator



Disadvantages of self-contained units are lower energy efficiency, poorer space control (particularly dehumidification) and no way to take into account cooling diversity. More tons of cooling will have to be purchased for a school using the self-contained approach than for a school based on a central chiller plant. In addition, sound can be a concern because the units may have compressors and are-delete located in the classroom.

Heating can be hot water, steam or electric. Integrated self-contained units can also be air-to-air heat pumps, greatly improving their energy efficiency but also requiring more operating hours for the refrigeration circuit. Air-to-air heat pumps are popular in warmer climates where the heating requirements are less. Supplemental heating may be required if the ambient conditions stay below freezing for any length of time.

Self-contained unit ventilators are an excellent choice for small to medium size elementary schools where cooling is required. Electric heat self contained units are well suited for portable classroom applications as well.

WSHP Unit Ventilators

Unit ventilators can also be supplied as a water source heat pump (WSHP) or as a ground source heat pump. This approach allows the designer to have WSHPs with built in airside economizers. Further energy savings can be realized by using ground source to eliminate the need for a boiler and closed circuit cooler.

The next section describes the WSHP design concept in detail. However, WSHP unit ventilators have some unique properties. Since the coil is refrigerant-cooled and heated, face and bypass is not possible. There are also limits on the heating capacity of WSHP unit ventilators. As a rule of thumb, the unit ventilator can work down to about 15°F ambient. Further care must be taken to protect the heatpump water loop from freezing.

Ground source heatpump unit ventilators do not have loop freezing issues, as the loop will have some form of antifreeze. The designer should discuss what kind of antifreeze to use with the school board. Concerns about toxicity, performance and environmental issues will need to be reviewed.

Ambient conditions that exceed the heating capacity of the unit ventilator will require either supplemental heating (a small electric heater) or a central system to deal with outdoor air. If a central system is used, it does not have to be sized for all of the outdoor air. Depending on the site conditions, it may only need to be sized for half of the outdoor air with the WSHP unit handling the balance of the outdoor air requirement.

WSHPs

General

The WSHP concept is very versatile. As a decentralized system, it takes advantage of moving energy around the school in water rather than air. It also has the advantage of not relying on a central chiller plant for cooling. The main advantage of the WSHP concept is its ability to add and subtract energy from a common loop. By doing this, the heat collected from zones that require cooling are used to heat the zones that require heating. The WSHP loop is a single loop that does not require insulation, which significantly reduces first cost. WSHPs are an excellent choice for medium to large schools, schools with larger internal zones and retrofit applications.

Figure 17, Various WSHP Units

The *McQuay Water Source Heat Pump Design Manual CAT C:330-1* is an excellent reference for designing WSHP systems. This manual will discuss details related to school design. WSHP systems require outdoor air systems, which are discussed in the next section.

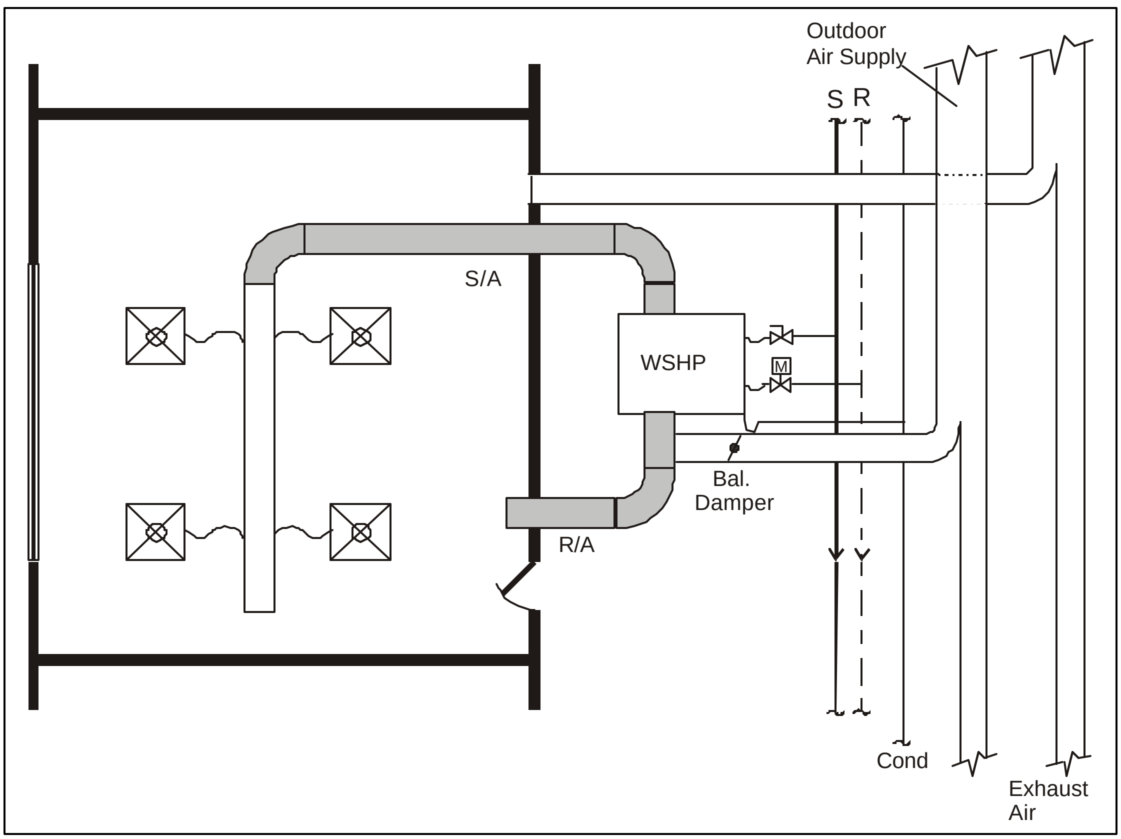
WSHPs for Classrooms

WSHPs come in various shapes and sizes as shown in Figure 17. The most common style used for classrooms is a ceiling concealed version. Figure 18 shows the typical layout with the heat pump in the corridor, ducted into the classroom. The return air is also ducted. A dedicated outdoor air ventilation system supplies outdoor air to each heat pump.

Using vertical units in a closet beside the classroom improves the serviceability of the heat pump but uses floor space. The supply air can be ducted above the ceiling and the closet can be used as a return air plenum. The outdoor air can also be delivered to the closet.

Since the heat pump is a compressorized unit, extra care has to be taken regarding acoustics. The discharge sound from the fan can be treated following the practices outlined in the "Sound Issues" section of this manual. The radiated sound mostly comes from the compressor. Units with extra quiet construction should be used. Locating the unit in the corridor will maintain acceptable sound levels in the classroom.

Figure 18, Classroom with WSHP System



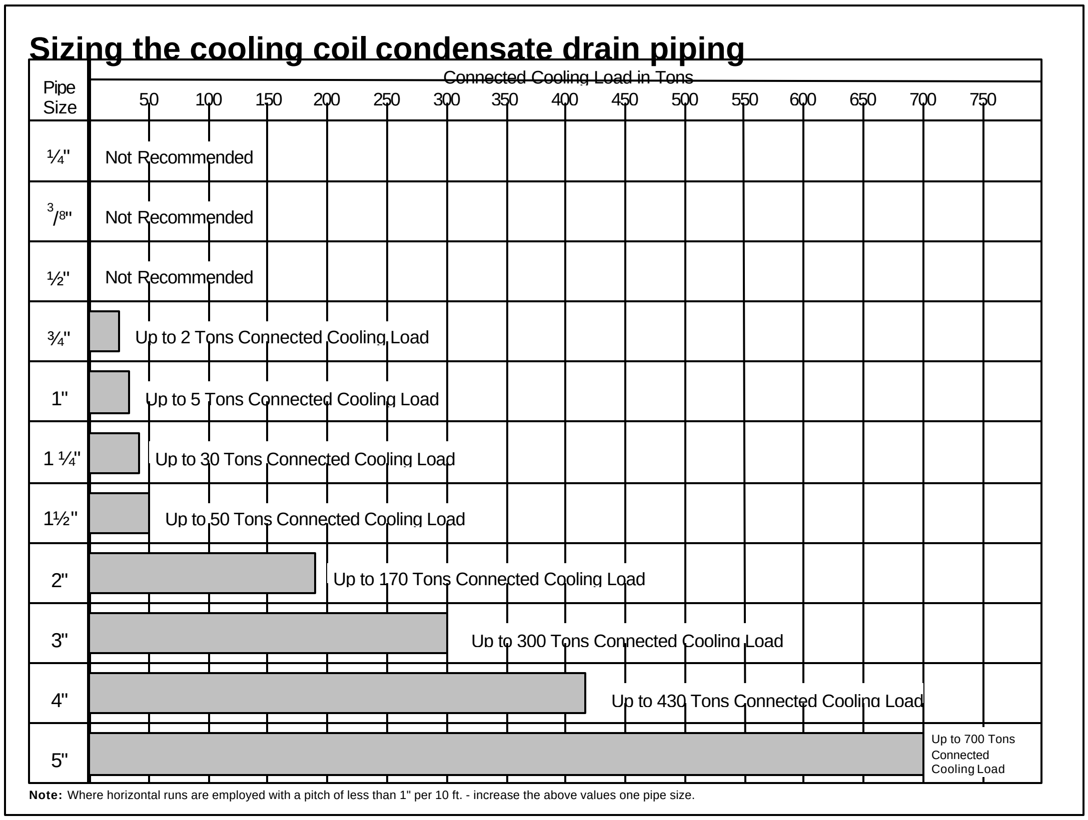
WSHPs for Other Areas

Areas such as libraries, gyms and administration can all be handled with heatpumps. Libraries and administration areas can use ceiling concealed units. Gyms often use large vertical heat pumps.

Condensate Issues

WSHPs will generate condensate while cooling in most climates. The units have drain pans that need to be field trapped and drained. Both the trap and the slope required for draining must be taken into consideration. Ceiling units will require condensate lines above the ceiling. Closet units will need drains in the closet or some other system to deal with the condensate. Figure 19 is a condensate sizing chart.

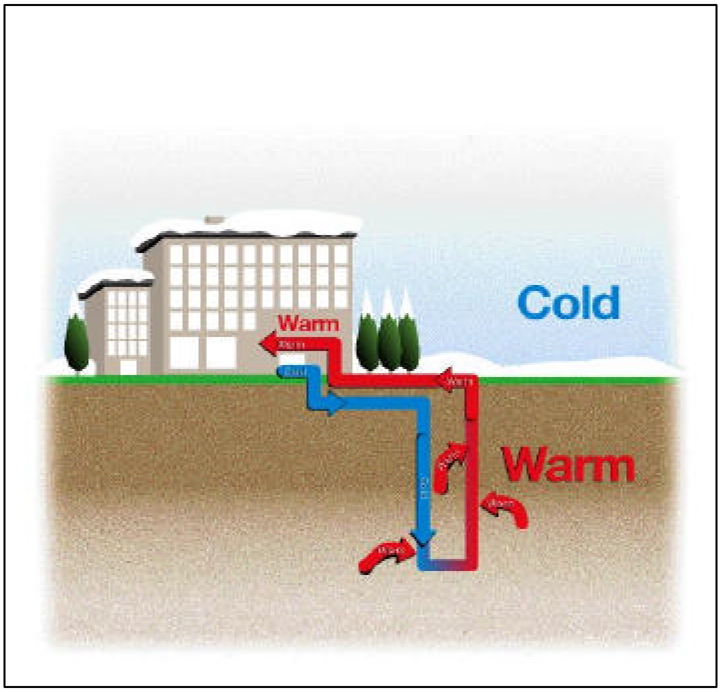
Figure 19, Condensate Line Sizing Chart



Ground Source Heatpumps

Ground source heat pumps are similar to water source heat pumps with the exception that they are designed to operate with colder water. Standard water source heat pumps cannot be used in ground source applications. Ground source systems have a high first cost due to the ground loop. However, they can be economical to operate because no boiler or coolers are required. Incentives are usually available for ground source systems and it is a good idea to check with the local utility about these programs.

Figure 20, Ground Source System



In cooler climates, heating for entrances and outdoor air must be considered. If natural gas is available, a boiler can be used, but this will increase the installation cost.

Another alternative is to use a McQuay Templifier™ to make hot water from the ground loop that can be used for outdoor air and entrance heating.

Ground source systems use extract or reject heat from the ground using a series of underground pipes. The pipes can be looped horizontally or vertically in deep holes depending upon which is more advantageous. Vertical holes are more common. Approximately 150 to 200 ft holes per ton are required. A school with a 250 ton design cooling load will require 250 holes 200 feet deep on 15 ft centers. The loops are typically in parallel to minimize the fluid pressure drop. The holes are backfilled with a special material to enhance energy transfer and protect the piping.

Ground source loops operate near freezing temperatures so some form of antifreeze is required. Several solutions are available however, school boards are sensitive to toxicity issues, so they type of antifreeze should be discussed with the school board prior to design.

The outdoor air load represents 1/3 of the system load. To take full advantage of the ground loop, the HVAC design should address how to tie in the outdoor air load to the ground loop. One option is to use water to water GSHPs and use the heated/cooled water in an air handling unit. Another solution is to use a McQuay Templifier™ to produce up to 140F hot water for heating the outdoor air and the entrance heaters and an enthalpy wheel to reduce the cooling load. The latter solution resolves supplemental heating issues and is more energy efficient than even a GSHP.

Fan Coil Units

General

Like WSHPs, fan coils allow cooling and heating to be distributed through piping rather than ducting. Fan coils require a chiller and boiler plant as well as a dedicated outside air system (discussed in the next section). Diversity can be taken into account in sizing the chiller plant. Fan coils do not have radiated sound issues because there are no compressors. They are an excellent solution for medium to large schools and retrofits.

Figure 21, Various Fan Coils

Fan coils can have a single coil (two-pipe) or two coils (four-pipe). Two-pipe systems require changeover and are not a good solution for schools. Four-pipe systems have dedicated cooling and heating coils and are recommended for school applications. The four-pipe system allows some fan coils to be in heating while others are in cooling. The system does, however, require two insulated hydronic loops within the school, which can raise installation costs.

Fan Coils for Classrooms

Figure 21 shows several different fan coil styles. McQuay Horizontal Thinline™ units are designed for offices with short supply duct runs and no return ducts. Vertical wall mounted Thinline fan coils are also designed for offices and will not stand up well to the classroom environment. McQuay Large Capacity™ fan coils have the configuration flexibility, static rating and robustness for school applications.

Large capacity units can use a direct drive or belt drive. Direct drive units offer the advantage of having no belts to service. However, they are more limited in their static rating and air balancing flexibility than belt drive units. To compensate, McQuay direct drive large capacity fan coils are three-speed to help with balancing. Direct drive units only come in 120/1/60 power.

Belt drive units offer the best range of static capabilities and air balancing. They can also be supplied with a wide range of voltages with single or three phase motors.

Figure 22, Classroom with Fan Coil System

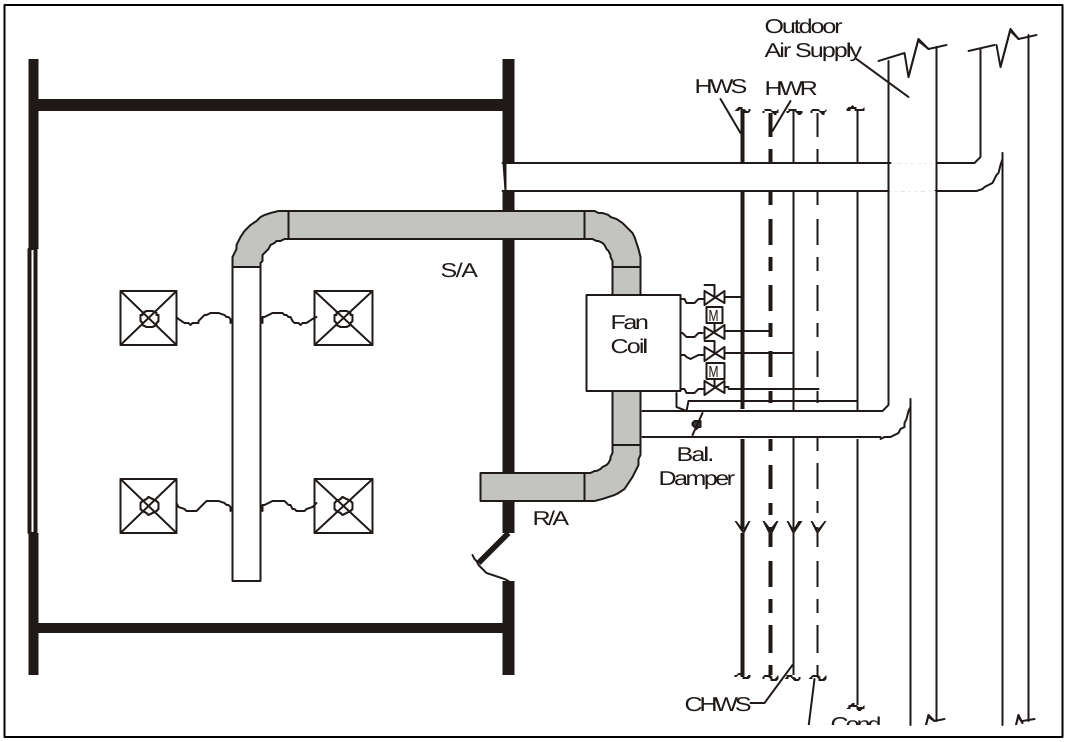


Figure 22 shows a typical classroom layout with a large capacity fan coil in the corridor. The ducting is similar to a ceiling concealed heat pump. The ducting provides good air distribution and absorbs discharge sound from the fan coil. Radiated sound is generally not an issue since there is no compressor.

Fan Coil Units for Other Areas

The administrative areas can be handled with Thinline type fan coils mounted in the ceiling plenum or on the wall. Fan coils or small air handling units can service gyms, libraries and other large areas.

Condensate Issues

Fan coils will generate condensate while cooling in most climates. The units have drain pans that need to be field trapped and drained. Both the trap and the slope required for draining must be taken into consideration. Ceiling units will require condensate lines above the ceiling. Refer to Figure 19 for a condensate sizing chart.

Central Outdoor Air Ventilation Systems

General

Several HVAC systems such as WSHPs and fan coils require dedicated outdoor air systems to meet the classroom ventilation requirements (typically 450 cfm per classroom). Large schools can require significant systems. A 200,000ft² high school can require 28,000 cfm of ventilation air. These systems are expensive to operate and special care should be taken in their design and selection. A basic gas heat, DX cooling system can cost over $30,000/yr to operate. This cost can almost be cut in half with a good design and the proper equipment.

ASHRAE Standard 90.1-1999 requires energy recovery for systems with at least 5,000 cfm supply air and a minimum 70% outdoor air (6.3.6.1). This is specifically aimed at schools and labs.

Where required, energy recovery systems must be at least 50% efficient. In Addition, energy recovery systems must include an economizer and bypass if economizers are required by the Standard 90.1-1999 (6.3.1.1).

Outdoor Air Psychrometrics

Since the outdoor air load represents a large portion of the school heating and cooling load, and it has the potential to introduce large amounts of moisture into the school, the psychrometrics must be clearly understood. For example consider a schoolroom located in Miami, Florida. The ASHRAE design conditions are 90°F db and 79°F wb. The indoor design condition is 75°F db and 62.5°F wb (50% RH).

Figure 23, Outdoor Air Example

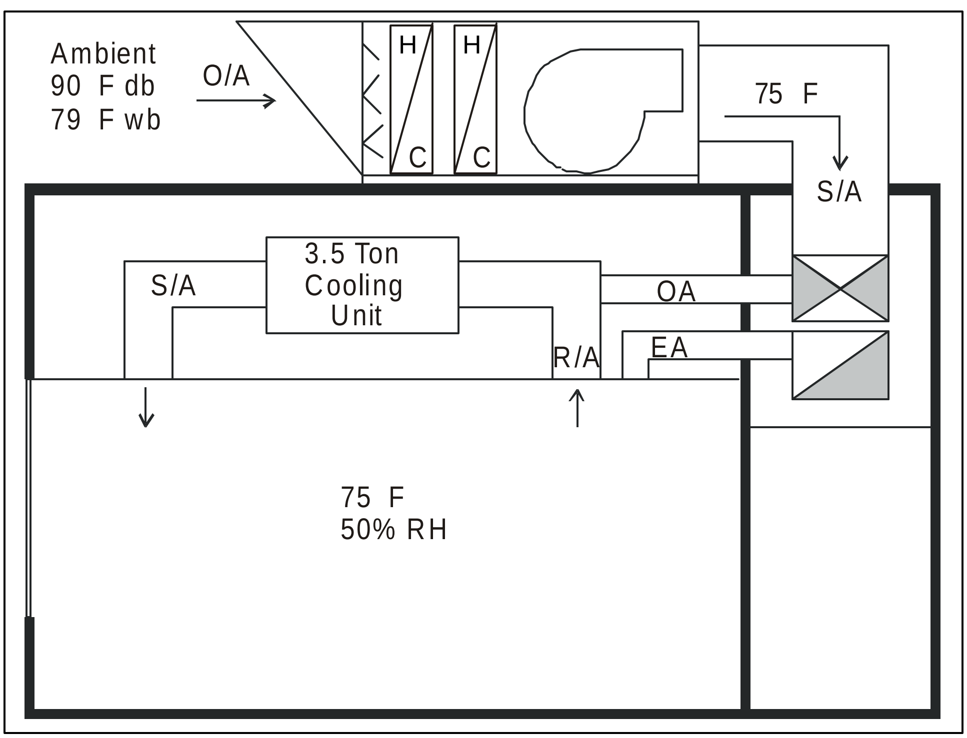
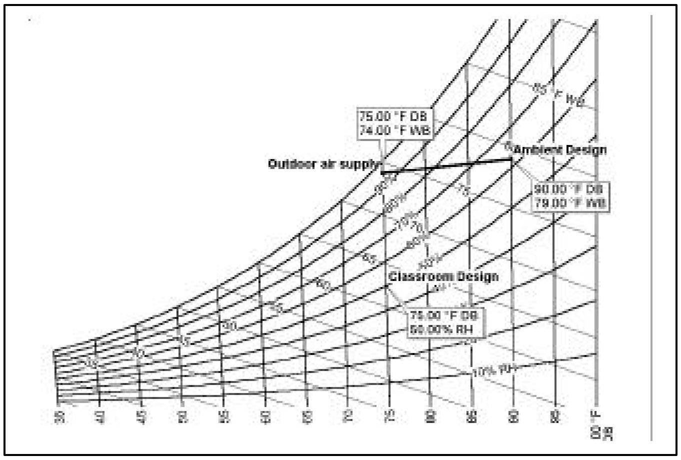


Figure 24, Outdoor Air Supplied at 75°F db



One way to achieve the design conditions is to cool the outdoor air to 75°F db with either DX or chilled water coils. If this is done the outdoor supply air will be over 90% RH. Return air from the classroom will mix with the outdoor air and the additional cooling load from the outdoor air will be placed on the fan coil or WSHP. In this case the load is all latent and is 19,000 btu/hr. Most terminal systems are not designed for such a high amount of latent cooling. The unit will have to be oversized which can add to noise concerns.

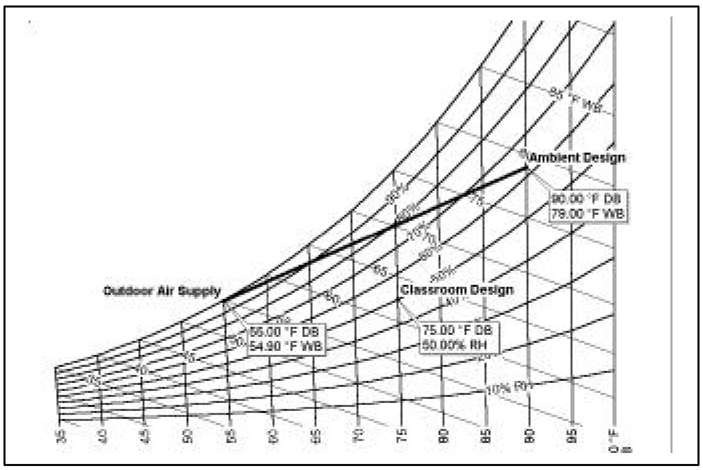
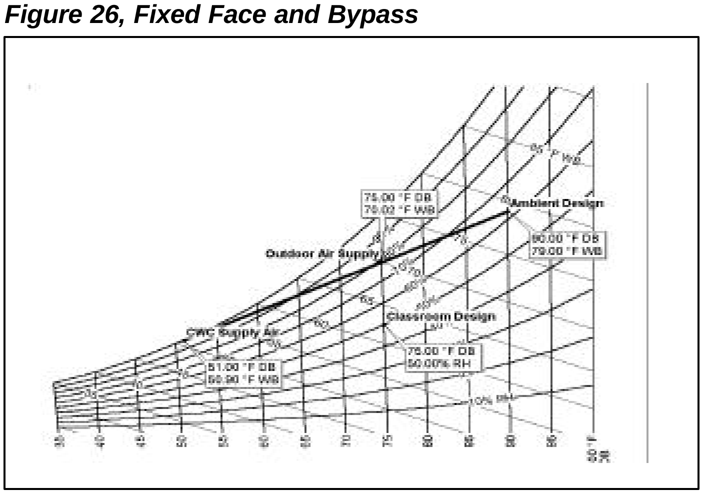


Figure 25, Outdoor Air supplied At 55°F db

Figure 25 shows another approach. The outdoor air is cooled to 55°F, which is the dewpoint for the classroom design to deal with the latent portion of the ambient air. However, the supply air could actually over-cool the classroom in shoulder weather, so a reset schedule is needed to raise the supply air temperature as the ambient temperature drops. While this would resolve most issues about over cooling, little or no cooling would occur and the classroom RH would climb when the design conditions are 75°F db and high humidity.

Figure 26, Fixed Face and Bypass



A better solution is to use a fixed face and bypass arrangement. Some of the outdoor air passes through the cooling coil and is cooled to 51°F or 52°F. The balance of the air bypasses the coil and mixes with the cooled air. The result is 75°F supply air with only 2/3 the moisture found in the first example.

There are several items to note in the above example. First, the outdoor air cooling load is large. For a typical Miami classroom, the outdoor load is 29 mbh. Second, it is not easy to cool ambient air to classroom design conditions with either chilled water or DX cooling. It is possible to cool the air to the classroom dewpoint (55°F) and reheat it to 75°F. However, this is an expensive approach and not very energy efficient.

How well the outdoor air ventilation unit operates will have a huge impact on the selection of the classroom terminal units. Most building load calculation programs allow the engineer to enter the amount and conditions of ventilation air supplied to the return of a classroom HVAC unit. The program can then calculate the mixed air condition and provide the additional outdoor air cooling load that must be handled by the classroom unit. Accurate conditions must be used. If the estimate used in calculating cooling loads is different from the real performance of the outdoor air unit, the loads will have to be recalculated.

Evaluating outdoor air units based on nominal tonnage is also not effective. Assume the Miami school has 10 classrooms. The outdoor air cooling load is then 10 times 29 mbh or 290 mbh (24.2 tons). While this load could be used to calculate the school block load and to size a chiller, it cannot be used to describe the outdoor unit. A nominal "24-ton" outdoor air unit could supply air anywhere from 63°F and 100% RH to 75°F and 50% RH. Therefore, outdoor air units need to be evaluated by the entering and leaving air conditions.

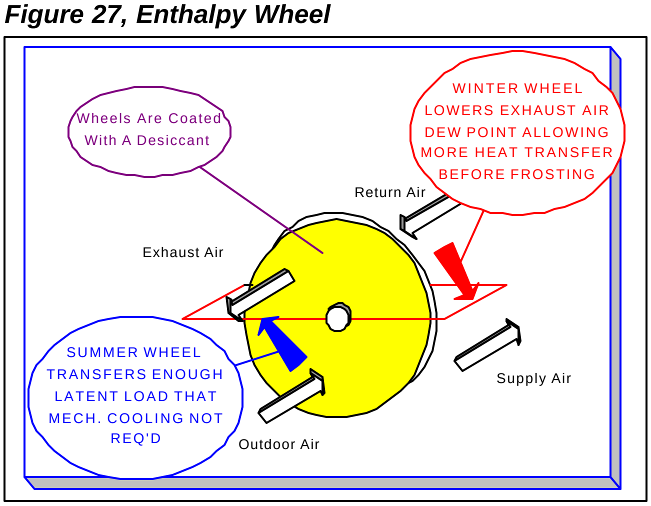
Energy Recovery Systems

There are several popular energy recovery devices available in the market today. Common systems include enthalpy wheels, heat pipes, plate-to-plate heat exchangers and run around loops. Most require that the return air and the supply air be connected to a common unit. This requires that the return air be ducted back to a mechanical room or rooftop unit. Several smaller energy recovery devices located nearer to the classrooms may be easier to install and less costly. They also provide redundancy.

An in depth study of each of the energy recovery systems is beyond the scope of this manual. However, two systems will be discussed as they have special merit for schools.

Enthalpy Wheels

Figure 27, Enthalpy Wheel

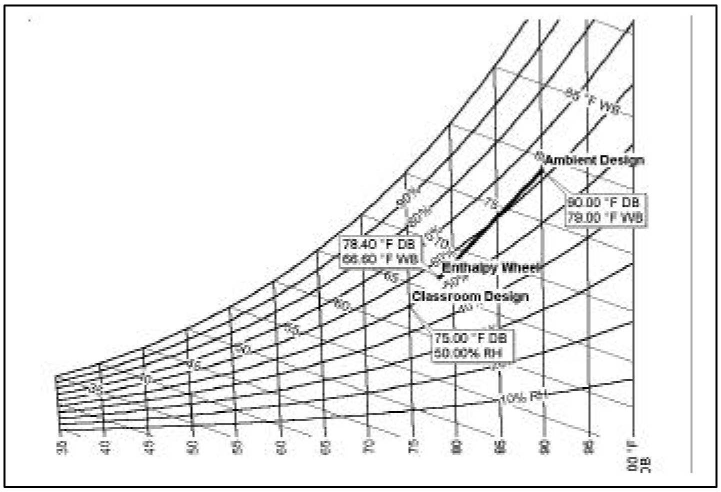


Enthalpy wheels are coated with a desiccant that absorbs moisture in one air stream and releases it to another. This allows an enthalpy wheel to dehumidify air without having to cool it to the dewpoint as in the case with cooling coils. An enthalpy wheel selected for Miami conditions would supply air at 78.4°F db and 66.6°F wb.

The enthalpy wheel provides 23 mbh of the 29 mbh required cooling in each classroom. Moreover, the outdoor air is dehumidified enough so that no further conditioning is required at the outdoor air unit. Therefore, the enthalpy wheel does not require any mechanical cooling. The terminal units can easily handle the small remaining load. Enthalpy Wheels can provided in McQuay Vision™ Air Handling Units and McQuay RPS™ rooftop units.

Enthalpy wheels also perform very well in cooler climates. Similar to plate-to-plate heat exchangers and heat pipes, enthalpy wheels can sensibly heat outdoor air. However, enthalpy wheels have the added advantage of transferring moisture from the return air stream to the supply air. This has two positive affects. First, the dew point of the exhaust air stream is lowered, allowing the wheel to continue to transfer sensible heat before some form of defrosting is required. Most other devices will need to defrost at around 32°F, which inhibits their ability to transfer energy.

Figure 28, Enthalpy Wheel Performance



The second advantage is the humidity of the supply air is increased significantly in cold weather. An enthalpy wheel can raise the RH of the outdoor air from essentially 0% to around 20% RH in winter climates.

Enthalpy wheels differentiate themselves from all other devices in their ability to transfer moisture. Heat pipes, plate-type heat exchangers and runaround loops can transfer sensible energy reasonably well, which can save on operating costs during the winter months in colder climates. However, sensible cooling in the summer has only a minimal impact and the outdoor air would still require further mechanical cooling. Sensible energy transfer devices provide no help with humidity loads in the winter months.

Run-around Loops.

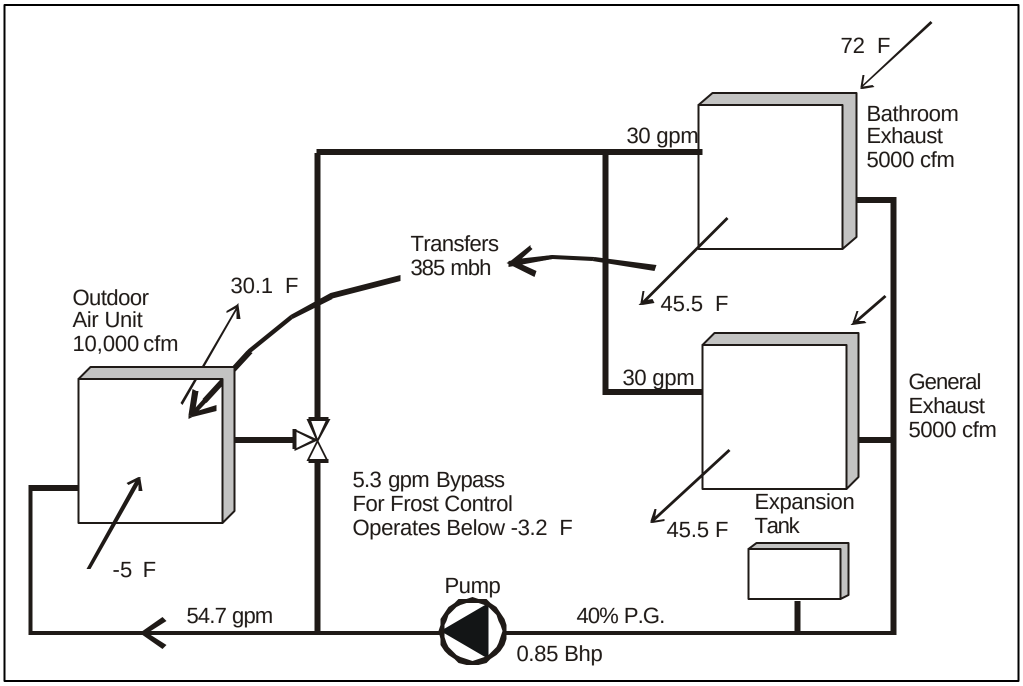
Run-around loops circulate a fluid (usually a water/glycol solution) through coils located in the return air (where heat is added to the loop) to coils located in the outdoor air (where heat is rejected from the loop).

The main advantage to run-around loops is the return air and the outdoor air do not have to be near each other. The fluid can be pumped from one mechanical room to another. In addition, several exhaust air streams (For example the bathroom exhaust and return air) can service one outdoor air unit.

Figure 29 shows a typical McQuay Run Around Loop™ design for a 10,000 cfm outdoor air unit and two 5,000 cfm exhaust air units. A 1 hp pump is required to circulate the 40% propylene glycol solution during energy recovery. The system can transfer 385 mbh at -5°F. At 32°F ambient, the run around loop transfers 214 mbh.

In most cases a three-way valve is required during cold weather as frost control. When the exhaust air temperature approaches 32°F, some fluid is bypassed around the outdoor air coil to avoid freezing the exhaust air coils. Another key design issue is the exhaust air coils will usually form condensate. They are “cooling coils” and as such require a drain pan piped to drain. A good solution is to use a McQuay Vision™ cooling coil section with integral drain pan. As with any closed loop system, an expansion tank is required.

Figure 29, Run Around Loop



In assessing their value the designer must consider the pump brake horsepower and coil air pressure drop penalties. Including bypasses around the coils for periods when the energy recovery is not possible or required can minimize the coil air pressure drop penalty. Standard 90.1-1999 may require bypasses if an economizer is necessary (6.3.6.1).

Central Systems

General

Central systems are all-air systems that condition air in a remote location (i.e. a mechanical room or on a roof) and then distribute it through ductwork to the occupied spaces. The centralized approach has the advantage of distancing the mechanical equipment from the occupants, thereby reducing sound issues. Locating the equipment remotely also allows service to be performed without interfering with the occupants.

Central systems generally allow airside economizers to be integrated into the design. The economizers allow the equipment to supply the high amounts of outdoor air needed in school designs. A separate, standalone outdoor air system is usually not required. Diversity can also be built into the central system to reduce operating costs.

Some disadvantages of central systems are they are more complicated to design, install, commission and operate. The ductwork can be very large and difficult to fit in the ceiling plenum. To work properly, central systems require a reasonable sophisticated Building Automation System (BAS). The energy disadvantage of central systems is the large amount of fan power required to distribute the air.

Multiple Zones

Central systems differentiate themselves from decentralized systems in that one system serves many zones (classrooms). Because the needs of each classroom will not always be the same, some manner of adjustment must be built into the central system.

The two parameters that can be varied in a central system are supply air temperature and/or supply air volume. Examples of variable air temperature are terminal reheat induction and fan powered VAV. Variable supply air volume systems are more commonly known as VAV systems.

Restricted Systems

Several central systems offer excellent space control but are very inefficient. ASHRAE Standard 90.1-1999 restricts the use of systems that have simultaneous cooling and heating (6.3.2). These systems can include:

- Constant volume reheat
- Perimeter induction
- Multizone
- Constant volume, dual duct

Constant volume reheat and perimeter induction systems typically cool the supply air to 55°F and then reheat it at each zone to maintain space conditions. Some Multizone systems simultaneously mix cooled air and heated air to meet the requirements of the zone. While they were very popular in schools during the 1970s, many systems have reached the end of their useful life and needed to be replaced. Standard 90.1-1999 covers additions (4.1.2.1) and alterations (4.1.2.2) to existing buildings. When reviewing options for replacing systems such as multizone, Standard 90.1-1999 compliance should be taken into consideration.

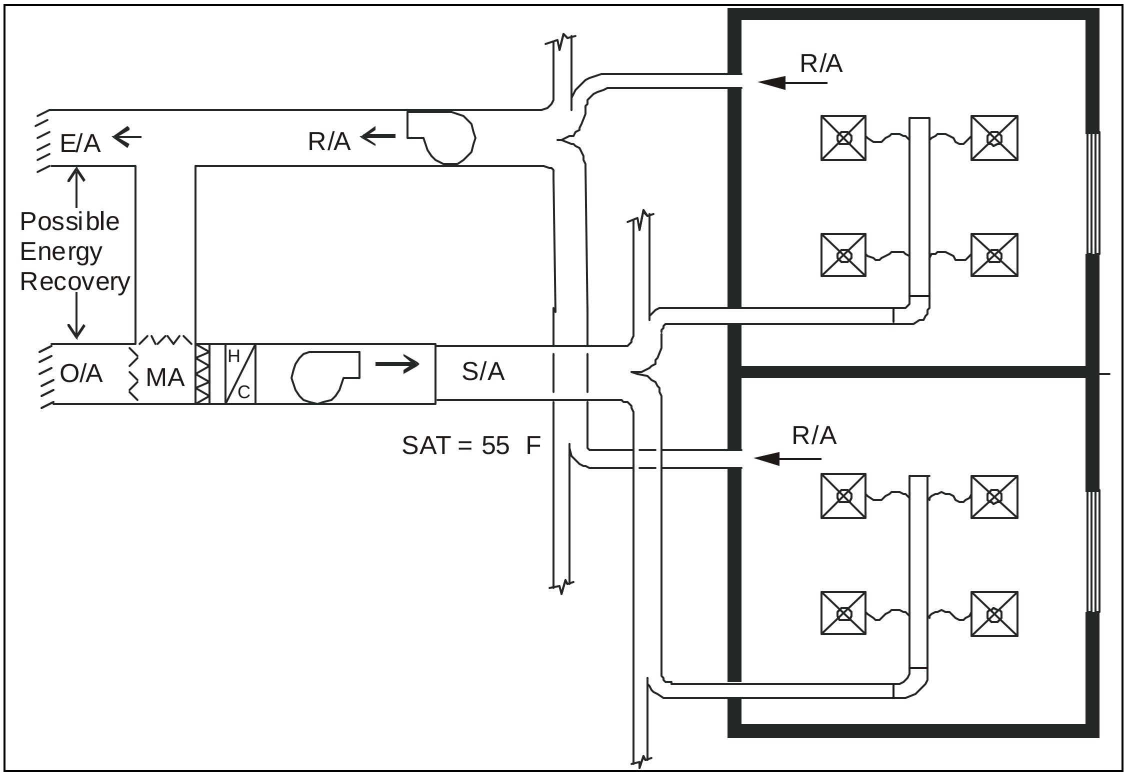
There several exceptions allowed by the Standard. It is recommended that the readers familiarize themselves with this section of the Standard.

Heating and Ventilating Systems

Heating and ventilating systems are the most basic central system. They can heat the space and provide the necessary outdoor air, but they are not equipped with cooling. However, they can cool the space by means of an airside economizer when weather permits. The air handling units can be located in a mechanical room or on the roof.

If an air handling unit services a single zone, such as a gym, then the unit controller can vary the supply air temperature to maintain proper space conditions. In most cases, however, several zones will be serviced from one unit. Therefore, it is a good idea to have reheat coils for each zone as shown in Figure 30. The heating and ventilating unit typically supplies 55°F air to all the zones. If a particular zone is being overcooled, the local zone temperature controller raises the supply air temperature by means of a reheat coil. However, this system does comply with ASHRAE Standard 90.1-1999 because the air is not mechanically cooled.

Figure 30, Heating and Ventilating System



Heating and ventilating systems are popular is smaller schools where cooling is not required. A central boiler can be used for preheating the supply air and the reheat coils. Energy recovery is possible as shown in Figure 30.

When air handling units are selected for heating-only applications, the coil face velocity can be much higher than is permissible with cooling coils. In addition, no condensate drain pans are required. If future cooling is considered, the coil face velocities should be selected based on cooling coil parameters with a drain pan added to the unit. Note that adding cooling to this system would create a constant volume terminal reheat system, which is restricted by Standard 90.1. Further changes, such as switching to VAV would also be required.

Variable Temperature, Constant Volume Systems

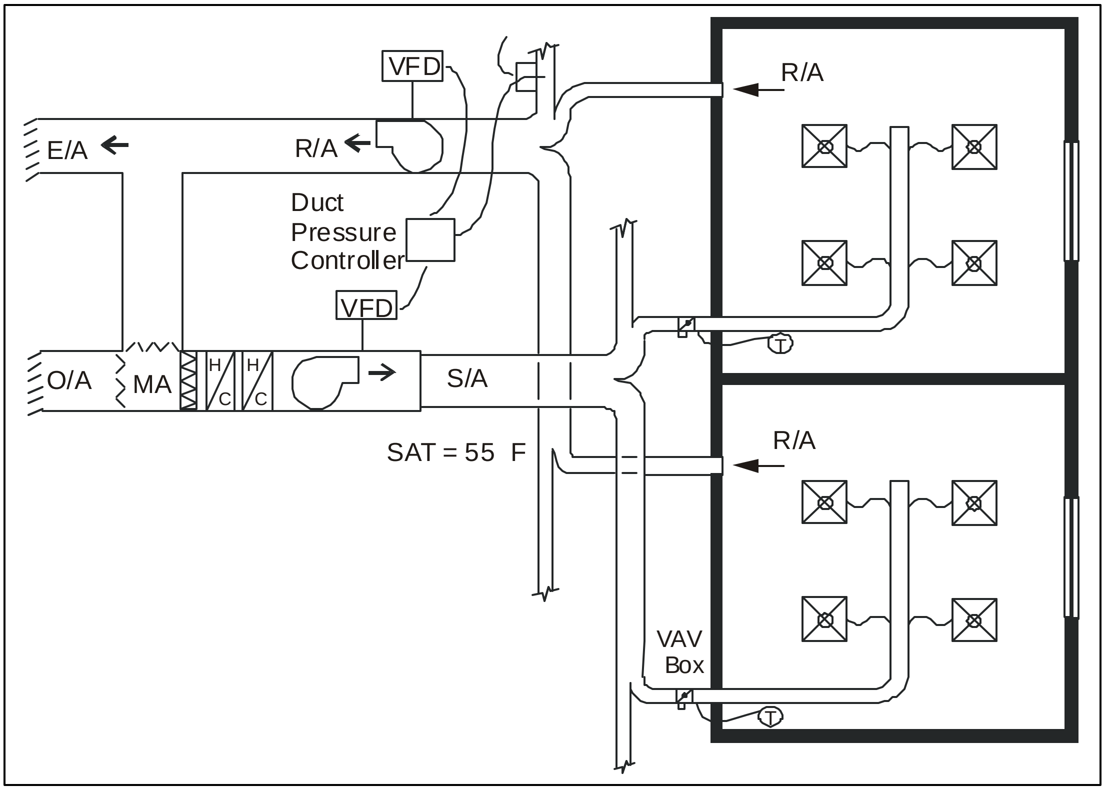
Variable temperature, constant volume systems serve only one zone (e.g., a gym). They are similar to heating and ventilating systems except a cooling coil is included in the unit to cool air as necessary. Since only one zone is served, the unit never heats and cools at the same time and complies with Standard 90.1-1999.

Dehumidification can be an issue with variable temperature, constant volume systems. During periods of mild but humid weather, the system will raise the supply air temperature to maintain the space drybulb temperature. Since the air is no longer being cooled to approximately 55°F, the moisture is no longer removed and the space humidity will climb.

VAV Systems

To avoid simultaneous heating and cooling and to minimize fan brake horsepower, VAV systems are often employed. In VAV systems, the supply air temperature is held constant (typically around 55°F) and the amount of air supplied to the space is changed to meet the cooling or heating load.

Figure 31, VAV System



To modulate the airflow into a zone (classroom), some form of damper is used. The most common method is to use a pre-manufactured VAV box. A temperature sensor, located in the space modulates the damper to maintain the room setpoint.

As more and more boxes close, the duct system static pressure increases. The supply fan is then modulated to maintain duct static pressure either by discharge dampers (FC fans only), inlet guide vanes or Variable Frequency Drives (VFDs).

The difficulty with VAV systems is maintaining outdoor air levels. As the supply air volume to the zone (classroom) is reduced to maintain space temperature, there is a risk that the amount of outdoor air entering the space will fall below minimum ventilation requirements. The solution is to maintain the net amount of outdoor air and reduce the amount of recirculated air. Consider a system serving 10 classrooms with the following design conditions:

Supply Air volume	12,000 cfm
Supply air temperature	55°F
Outdoor air Required	4,500 cfm

If we assume that each classroom has the same outdoor air requirement, then outdoor air represents about 38% of the total supply air volume at design conditions. As the supply air volume decreases in response to more moderate weather, the percentage of outdoor air will increase. For example, if the cooling load can be met with 9,000 cfm of supply air, then the 4,500 cfm of outside air will represent 50% of the total supply air volume.

The above example has been used for illustration only. In most schools, the outdoor air requirements vary from zone to zone. ASHRAE Standard 62.1-1999 has a method of calculating the correct percentage of outdoor air to ensure all zones receive the correct amount. This is also covered in the IAQ section of this manual.

In addition, the example illustrates that the ability to maintain minimum ventilation requirements with VAV systems hinges on the system consistently bringing in the minimum outdoor air requirement. To do this, some form of direct airflow measurement is required, particularly with rooftop VAV systems, The dynamics of the rooftop environment (wind, heat, humidity) can cause turbulence, pressure variations and uneven flow patterns that make accurate, repeatable measurement very difficult. McQuay's answer is the patent pending DesignFlow™ Precision Outdoor Air Measurement system, which responds directly to the total mass volume of air flowing through the outdoor air intake area and automatically corrects to terms of standard air. In doing so, it is indifferent to uneven flow profiles, air turbulence, and pressure variations.

Dependant vs. Independent Systems

VAV systems can be either dependent or independent. The difference is mostly in the VAV box design. Dependent VAV boxes modulate the *damper position* in proportion to the cooling load. Independent VAV boxes modulate the *air volume* in proportion to the cooling load. Independent VAV boxes can measure the amount of air passing through them while dependent VAV boxes cannot. A good example of an independent box is a constant volume box. As the supply duct pressure fluctuates, the box's damper modulates to maintain a fixed airflow rate.

Independent systems are more desirable because they offer better control. Dependent systems cost less and are generally limited to Variable Volume, Variable Temperature (VVT) systems. They are not commonly used in school applications.

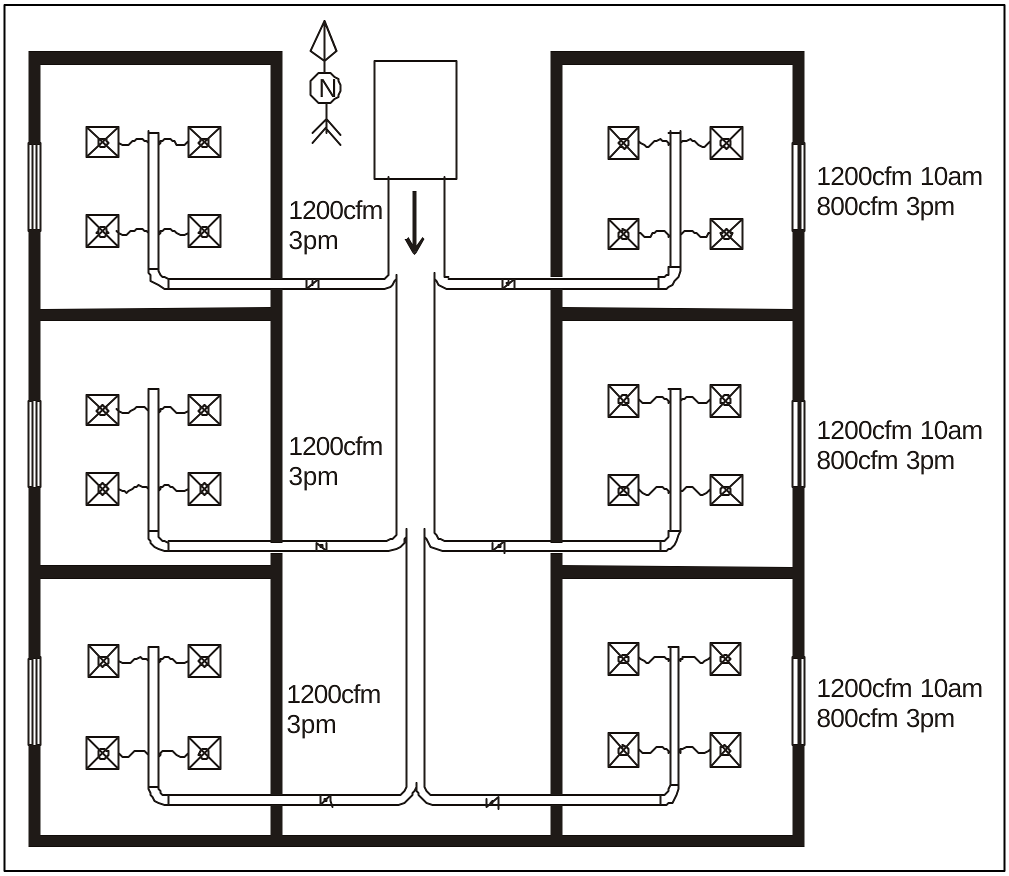
VAV and Diversity

VAV systems allow the option of diversity. The cooling load for each zone (classroom) is calculated individually. However, not all the zones will peak at the same time. Figure 31 shows a system with 6 classrooms. The three classrooms facing East peak in the morning. In the afternoon, the classrooms facing West peak while the east classrooms are heavily loaded. The maximum load occurs at 3 p.m. and the total required supply air is 6,000 cfm.

The actual connected load is 6 times 1200 cfm or 7,200 cfm. The air-handling unit should be selected and the ductwork designed for 6,000 cfm with a diversity of 83%.

It is not an uncommon practice to "default" to a minimum cfm/ft2 and design the air system based on this airflow while applying diversity to the cooling plant (chiller) size. This practice should be discouraged, as it will result in an oversized air handler and ducting. Even worse, the cooling load calculated from the air handling unit psychrometrics and the cooling load from the load estimation won't match. The potential for a fundamental design calculation error is very high.

Figure 32, VAV and Diversity



VAV with Reheat

Standard 62.1-1999 requires that the minimum airflow for a VAV zone be no less than the minimum outdoor air requirement. On a moderate day, this can supply more air than is required to meet the cooling load. As a result, the classroom temperature will drop below the design condition.

In this case, reheat is allowed by Standard 90.1-1999 (6.3.2.1).

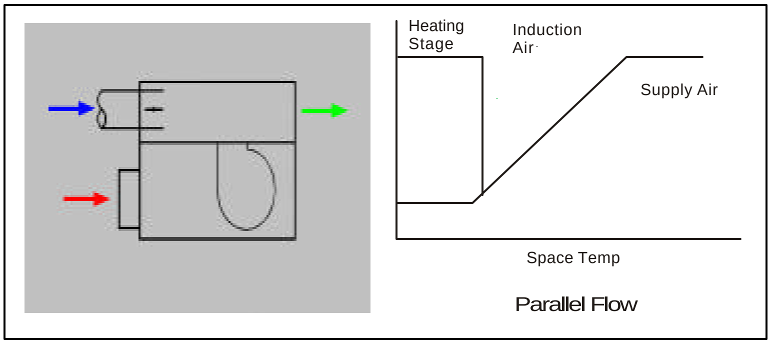
The reheat can take the form of a reheat coil in the ductwork or some form of parameter radiation (wall fin, radiant panels). In the case of parameter radiation, Standard 90.1-1999 has certain requirements for zone control (6.2.3.1).

Standard 90.1-1999 does allow reheat for other situations and it is recommended that you familiarize yourself with the Standard. The requirements are significantly more strict than the previous Standard 90.1-1989.

Fan Assisted VAV

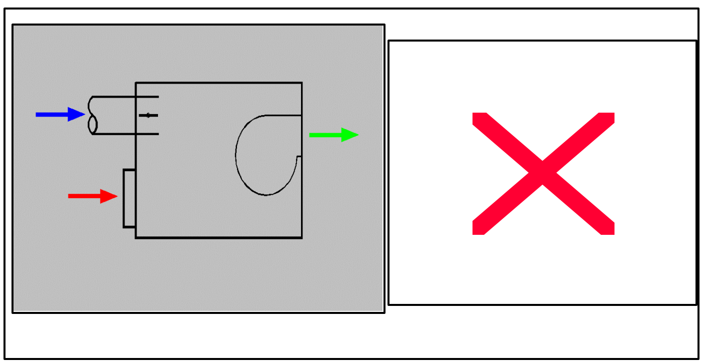
A modification to the standard VAV system is to use fan assisted VAV boxes. These boxes include a small fan which can draw in return (induction) air and mix it with the supply air (sometimes called primary air). The boxes come in two forms, parallel and series flow.

Figure 33, Parallel Flow Box



Parallel flow systems provide constant temperature, VAV when cooling and variable temperature, constant volume when heating. As the space load drops, the supply air is reduced from maximum flow to minimum flow. As the load drops further, the fan in the box is started, mixing warm return air with the minimum supply air volume. Reheat can be added if further heating is required.

Figure 34, Series Flow Box



Series flow systems provide variable temperature, constant flow. The fan operates all the time the space is occupied. As the supply air is reduced to minimum flow, the fan draws in more and more induction air raising the supply air temperature. Further heat can be added by staging on reheat.

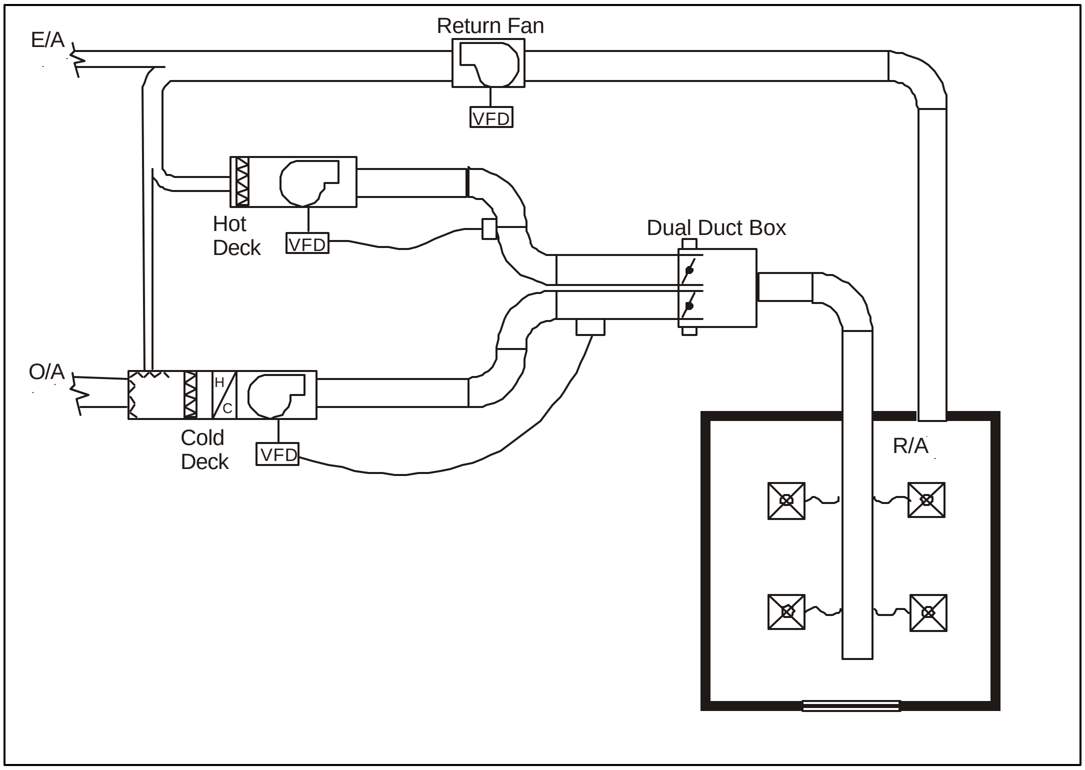
Both systems use heat in the ceiling plenum for reheat, which is very energy efficient. However, both operate a small fan which uses power and adds to the sound issue. Parallel boxes do not operate the fan all the time. While this saves power, the cycling of the fan can be a bigger sound issue than a constant sound source.

If the boxes are equipped with reheat coils, they can be used for maintaining space setback during unoccupied hours in lieu of starting up the main air-handling unit.

Dual Duct Applications

Traditional dual duct systems supply each zone with hot air in one duct and cold air in another. A dual duct box then mixes the two supply air streams to meet the required space load. Because this system involves simultaneous heating and cooling, Standard 90.1-1999 restricts it.

Figure 35, Dual Duct, Dual Fan System



A variation of the dual duct concept is dual fan, dual duct arrangement shown in Figure 35. This system delivers neutral return air (around 75°F) and cold air (around 55°F) to each dual duct box. The box can modulate the volume of each supply air source. As the space cools off, the cold primary air is reduced to minimum flow. With a further drop in load, the neutral air damper opens raising the air temperature supplied to the space.

Fan brake horsepower is reduced since both systems are VAV. Reheat is accomplished by means of plenum air, which is also efficient. The small fan motors used in fan assisted VAV boxes are not as efficient as the hot deck fan arrangement. Sound issues are also reduced because the fans are located away from the occupied spaces. However, installing two duct systems will cost more than a single duct system.

Fan Brake Horsepower Considerations

Fans are generally the largest energy consumers in an HVAC system. ASHRAE Standard 90.1-1999 has fan power limitations for all air systems with a fan nameplate horsepower over 5 hp (6.3.3.1).

Table 5, STD 90.1-1999 Fan Horsepower Requirements

	Under 20,000 cfm	Over 20,000 cfm
Constant Volume Systems	1.2 hp/1000cfm	1.1 hp/1000cfm
VAV Systems	1.7hp/1000cfm	1.5hp/1000cfm

The Standard allows credits for special filters, process devices and certain applications of relief fans. It is recommended that you thoroughly review this part of the standard.

Duct Design Basics

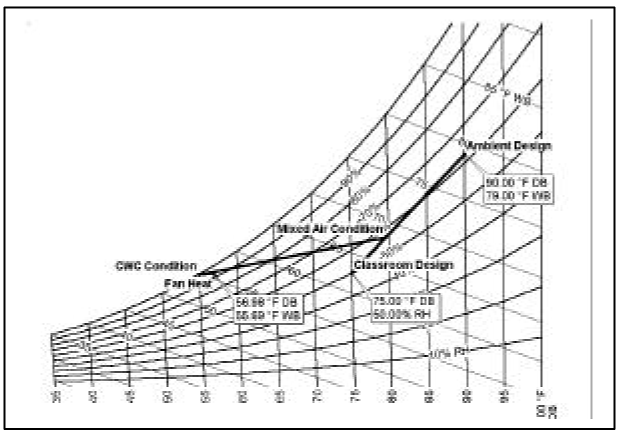
Good duct design is critical to the success of a central system design. Most school design is based on low to medium pressure systems. Often, duct systems must be located in the corridor ceiling plenum along with other equipment. Careful layout is required. The designer should refer to SMACNA and ASHRAE guidelines for duct design.

Most schools are under 3 stories, so long duct runs are an issue. The ducts become large and the fan power to distribute air rises. This can be reduced by breaking down the school into smaller sections and having each section serviced by an air handling unit located within the section.

ASHRAE Standard 90.1 has requirements for duct leakage (6.2.4.3) and insulation (6.2.4) which must be met.

Air distribution within the space is critical to maintaining space conditions and minimizing sound concerns. Refer to the Sound Issues section of this manual for quiet duct design. VAV systems complicate matters because the terminal devices must work over a wide range of airflows without dumping. Be careful not to oversize the terminal device with VAV systems.

Figure 36, Central System Psychrometrics



To calculate the required supply air in the space, the internal heat gain must first be calculated. Figure 36 shows the psychrometric process for a typical classroom. Although the supply air is cooled to 55°F off the coil, the fan work (assuming a draw-through unit) will raise the supply air temperature delivered to the classroom to about 57°F. This leaves an 18°F delta T to absorb the sensible heat in the classroom.

Internal sensible gains 29,400 btu/h
CFM = 29,400/(18°F*1.085)
CFM = 1500

The latent cooling should also be reviewed. In office buildings, the latent load from the space is minimal, so most effort goes to resolving the high sensible heat gains. School classrooms have higher latent gains due to the student count. Thirty students can provide 6,000 Btu/h of latent load. This will have the affect of raising the RH in the classroom about 5%. If 50% RH must be maintained, then the supply air will have to be 6 gr/lb drier or have a dew point of 52.5°F.

For most engineers, the process of calculating zone air volumes is computerized. However it is important to understand the process and to understand how data input into the program will affect the output.

Optimal Air Temperature Design

Typical central system design is based on cooling the air to 55°F leaving the cooling coil. This is arrived at because 55°F is the dewpoint for the space design condition of 75°F and 50% RH. Air cooled to this point will have the correct humidity ratio for the typical design condition. In a draw through unit, fan heat is added after the coil so the supply air ends up around 57°F delivered to the space.

The result is an 18°F delta T to absorb the sensible heat gain in the space. However, lowering the supply air temperature to 50°F off the coil and 52°F to the space results in a 23°F delta T. This will require 20% less air than the typical design which represents a significant first cost savings in ductwork. The fan horsepower saving usually offsets any additional cooling work.

Optimal air temperature design avoids the complications associated with low temperature air designs while still providing smaller ductwork in the ceiling, better humidification control and a lower first cost. Refer to the McQuay Optimal Air Design Manual, 31-AG005 for further information.

Central System Equipment

Air Handling Units

Air handling units typically consist of mixing box, filter bank, heating coil, cooling coil and fan section. They can be either indoor such as the McQuay Vision™ unit or outdoor such as the McQuay RAH™ units. The trademark of air handling units is a very flexible layout.

Air handling units typically have hot water and chilled water coils. They require some form of chilled water plant and boiler system. In smaller systems, DX coils can be used along with remote air-cooled condensing units. Many local codes have special requirements to isolate the air handling units from the boiler and chiller.

Figure 37, McQuay Vision Air Handling Unit

Features that should be considered for schools are double wall construction, isolated efficient fans, access to all components (coils especially) and sloped drain pans. The goal here is to select a quiet, serviceable, IAQ-ready air-handling unit. Selection of air-handling units is usually done in computer programs such as McQuay SelectTools™.

Air handling units take up a significant portion of the mechanical room. The designer must address many issues. The outdoor air and exhaust air openings must be far enough apart to avoid recirculation. Avoid using the same wall for both openings. Consider a mushroom cap for the exhaust air if the ceiling is the roof. Coil removal is another concern. Normally coils do not have to be removed for service such as cleaning. However if a coil is badly damaged (e.g., frozen) it may need to be replaced. It is essential that the coils can be removed some how. Some air handling units like the McQuay Vision™ unit will allow the coil to be removed vertically.

Low wide units provide more head room for running ducting above while narrow tall units require less floor space and less room for coil removal. The McQuay Vision™ and other custom air handling units can vary the cross sectional area of the unit to best fit the mechanical room.

The condensate trapping height must be correct or the unit will flood. Concrete house keeping pads are common but expensive. In addition, the higher the pad, the heavier it will be. Consider using high base rails supplied with the air-handling unit to get the necessary trapping height.

VAV systems require special attention. The fans must be selected with enough turndown to meet the requirements of the design and still offer stable operation. Acoustics is also an issue. Careful selection of the fans can greatly reduce the sound energy. Any savings found selecting forward curved fans over airfoil fans could be lost when the additional acoustics treatments are included.

VFDs provide the most efficient and quietest solution to varying air volumes. Inlet guide vanes are basic mechanical devices well understood by a broad range of technicians and operators. If a school district is comfortable with the technology, VFDs are recommended. ASHRAE Standard 90.1-1999 requires that 30 hp and larger fan motors must use no more than 30% of design power at 50% airflow (6.3.3.2). Typically, only VFDs and vane axial type fans can meet this requirement.

As the supply air volume is reduced, the outdoor air volume should remain constant. In cold weather applications the mixed air temperature can get very low. For an ambient design condition of -10°F and a 50% airflow rate, the mixed air temperature is below freezing. Although a VAV air-handling unit supplies only cold air, it may need a heating coil. Alternatively, reheat coils at the VAV boxes can be used. Care should be take to ensure condensation along the ductwork won't occur if the supply air is not heated until the VAV boxes.

In colder climates, coil freeze-ups are another issue, particularly with rooftop equipment. Antifreeze, pumped coils and face and bypass coils are options that can be considered to protect the coils from freezing.

Larger air handling systems will require a return fan to maintain proper building pressurization. For rooftop equipment, the return fan should be integral to the unit. For indoor units, the designer will usually have more design flexibility if the return fan is separate from the supply air unit. Hanging the return fan from the ceiling makes good use of the mechanical room space.

Tubular centrifugal inline fans or cabinet fans are good options for return fans. Cabinet fans are an excellent choice if a runaround system is to be used. A coil section can be added to the fan cabinet for the run around loop. Ensure the coil section has a drain pan, as the coil will probably form condensation.

Long supply air ducts provide a significant amount of sound attenuation. Return fans can cause more sound issues because of short duct runs even though the supply air fan operates at higher static pressures releases more sound energy. Units used in applications such as gyms, with no return fans, can still have return duct sound issues. The designer is cautioned to always review the return duct sound path.

Chillers

Chiller plants are required for several HVAC systems used in schools. These include unit ventilators, fan coils and air handling units. Using chilled water for cooling provides excellent control high efficiency and the equipment can be located away from the students. Chillers can be either air or water cooled. A wide range of compressors is used for chillers, each which has strengths and weaknesses.

Figure 38, McQuay Distinctionä Chiller

Since the chiller plant represents a major power consumer in the school, special care should be taken in selection and design. Performance must be balanced with first cost and serviceability. For a basic understanding of how centrifugal chillers operate, refer to McQuay's *Centrifugal Chiller Fundamentals, 31-AG002*. McQuay's *Chiller Plant Design, 31-AG002* explains various chiller plants systems such as primary/secondary, variable flow and parallel chiller systems.

Rooftop Systems

Rooftop equipment comes in two distinct forms - unitary and applied. Unitary equipment is designed for light commercial applications and is not suited for school applications. It has limited outdoor air capability, lighter construction and more basic operation.

Applied equipment is more robust and distinguished by its configuration flexibility. The basic unit has an economizer section, filters, supply fan, integral DX cooling advanced controls and modulating gas heat. Return fans, other forms of heat (hot water, steam, electric) and energy recovery are also available.

Figure 39, McQuay RPSä Unit

Applied systems have a wide operating range. Typically there are multiple DX circuits with several stages of unloading. The DX coils can be selected with various numbers of rows and fins/inch to meet the design conditions and to allow the units to be configured for optimal air temperature applications. Gas furnaces with McQuay's Super Mod™ burner can have up to

20:1 turndown. This is particularly important in VAV applications where preheat is required. The combination of small temperature rises and low air volume necessitates high turndown for controllability. This type of flexibility makes applied equipment a good choice for school applications.

Rooftop equipment does not require a mechanical room, which improves the useable floor area to total floor area ratio. Servicing rooftop equipment has to be done from outdoors and the school board should be involved in the decision to locate equipment on the roof. Multiple units can be used reducing long duct runs, which saves fan horsepower and reduces duct sizes. It also provides some redundancy.

Many of the air handling unit issues discussed earlier apply to rooftop units. For VAV systems, high turndown burners allow gas heat to be used to raise the supply air temperature during reduced supply air volumes. If the design calls for a boiler plant, hot water coils can be supplied in the rooftop unit. To avoid freezing concerns, hot water coils can be installed in the supply air ductwork with in the building envelope. The rooftop unit controller can operate the hot water control valve.

In addition the previously discussed sound issues, rooftop refrigeration equipment creates sound issues. The McQuay RPS™ unit has a cantilevered condensing section that resolves compressor noise in the space. However environmental sound must be checked with all roof mounted equipment. Most local codes have requirements that certain sound levels be met at the property line. This is especially true for schools, which are built in residential neighborhoods. Radiated sound from the unit, particularly compressor sound, can be an issue at the property line. The designer should obtain the sound power levels and confirm the overall sound levels at the property line meet local codes. A method for this is described in McQuay *SED 7512* and *9001*.

Vertical Self-Contained Systems

Vertical self-contained units are institutional grade air conditioning units with water-cooled condensers. They are installed indoors in small mechanical rooms. The vertical layout has a small footprint, so the mechanical rooms can be small. The units can be constant volume or VAV. Their DX system has multiple circuits, compressors and variable row and fin coil selections, which allows the unit to service a wide range of operating conditions. Vertical self-contained units come complete with full DDC controls that can be programmed for a wide range of applications.

Figure 40, McQuay, SWP Unit

Vertical self-contained units are located in small mechanical rooms throughout the school. They are cooled by a cooling tower water loop. The loop does not need to be insulated. Both airside and water-side economizers are available. With water-side economizers, the units can simultaneously use waterside free cooling with supplemental mechanical cooling. This extends the free cooling season considerably and reduces the operating cost. While this is popular in office applications, it requires a large outdoor air ventilation system for schools. Airside economizers avoid the outdoor air ventilation unit and allow the cooling tower to be shutdown during periods when mechanical cooling is not required.

Vertical self-contained units provide a self-contained solution with the equipment located indoors. No chiller plant is required and the equipment is easily accessed for service without disrupting the students. Property sound issues are avoided for the most part with the exception that the cooling tower should be reviewed.

Vertical self-contained units do require mechanical rooms. Because they are compressorized, they can create sound issues around the mechanical room. The McQuay application Guide *AG31-001, Achieving a Quiet Environment with McQuay Indoor Vertical Self-Contained Systems* can assist the designer in resolving any sound issues.

Templifiers ã

The McQuay Templifier™ is a unique product that can let a designer take advantage of low grade heat in fluids. A Templifier™ can produce up to 160°F hot water from waste heat such as Chiller condenser water. A Templifier™ is a much more efficient way to produce hot water for VAV reheat than heat recovery chillers. The higher water temperature will work with standard 1 or 2 row reheat coils rather than requiring 3 or 4 row coils common with the lower temperature (105°F) water produced by heat recovery chillers.

Figure 41, McQuay Templifier ã

Templifiers™ can also be used with ground source heatpump loops to produce hot water to treat outdoor air. They can even be used with WSHP loops to extract heat from the closed loop and use it for treating the outdoor air. This is very useful where natural gas is not available. On occasions when the WSHP loop closed circuit cooler is rejecting heat, the Templifier™ can use that heat to condition the outdoor air rather than heating the air with boiler hot water or natural gas. Refer to McQuay *Catalog MP Templifier* for further information.

HVAC Controls

HVAC controls are a critical component to the success of the school design. Even the most basic HVAC design requires controls to operate properly. Most school districts require the ability to monitor and adjust HVAC systems remotely, typically from a district office or administrative building. This can be a difficult issue if a school district with 50 schools ends up with a dozen different controls systems. The potential for this is very real with the differing requirements and systems used in elementary, middle and high schools.

The solution is interoperability. Industry standard Protocols such as BACnet™ and LonMark™ allow the school board to accept systems from a wide range of controls vendors and still access them from a common front end.

Interoperability also improves integration within the school HVAC system itself. Mechanical equipment that has interoperability features such as McQuay's Open Protocol or Protocol Selectablity™ can communicate directly with the school building automation system (BAS). It allows the designer and the school board to select the equipment they want and know that it will function seamlessly with the BAS they want.

Most mechanical equipment can be supplied with or without factory-mounted controls. Unit ventilators, WSHPs, fan coils, chillers, air handling units, vertical self-contained and rooftop equipment all can be supplied with controls. In the past, integrating them into BAS has been a problem. Interoperability now allows easy integration. Factory supplied equipment controls offer:

- A controller specifically designed and programmed for the particular piece of equipment and the application.
- A full run factory test to demonstrate that the unit and controls are functioning properly.
- Single source responsibility with equipment issues.
- No conflicts about warranty responsibility.
- Smoother commissioning. The technician commissioning the equipment can also commission the controls.

The designer should familiarize themselves with controls capabilities and develop a controls strategy that will integrate new equipment and controls with the school with the school district's existing infrastructure. Even if the school district does not currently have an interoperable front end, it is wise to have all new projects built with interoperability included.

System Economics

After functionality, system economics is perhaps the most important issue. The utility costs for a school district are often second only to payroll. However, capital to purchase more efficient systems is rarely readily available. School districts own their facilities and should consider life cycle analysis as the main primary mechanism for evaluating HVAC systems.

The wide range of HVAC systems, climates, school sizes and types makes any simple economic evaluation unrealistic, if not counterproductive. This is best accomplished with computer modeling to derive the operating and life-cycle costs for a system, and to determine the value added by one system versus another.

System Comparison

Table 6 compares HVAC systems for a school in the Chicago area. It is based on a large high school, 200,000 ft2, 3 stories and new construction. This comparison should by no means be considered a ranking of the various HVAC systems. Simply relocating the school to Phoenix or Miami would change the order. This is a large school. A smaller school would favor different HVAC systems.

Systems 1 through 4 compare different terminal air systems using the same 2 chiller primary/secondary chilled water plant. These systems are penalized because of supply and return fan work. This shows up both in the power to operate the fans and the additional cooling required to remove the fan heat.

Systems 4 through 6 compare the same terminal air system (VAV with reheat) with different primary supply air sources. As expected, moving away from a chiller plant to self-contained DX systems improves the first cost but penalizes the school board in operating cost.

Systems 7 through 9 show decentralized systems with a DX cool, gas heat, make up air unit. These offer the lowest cost and the worst performance. Although ground source heatpumps are very efficient, the poor performance of the make up air unit hurts the overall performance. Treating the outdoor air with the ground loop and a Templifier™ would greatly improve the system performance.

System 10 is 4 pipe unit ventilators. Unit ventilators utilizing chillers and boilers perform very well. They take advantage of an efficient boiler chiller and boiler plant and there is little fan power or fan heat involved. In a sense, they offer the performance of a central system without the penalty of fan work.

Systems 11 through 13 are the same decentralized systems but with an efficient energy recovery system. Reducing the cost to treat outdoor air made the decentralized systems perform better than the central systems. Adding energy recovery to central systems would change the order again.

What can be concluded from the analysis is that there is no clear-cut winner. The systems are relatively close in cost and performance. The only way to choose a system is to do the evaluation based on the information for the specific project.

Table 6, Comparison of Various HVAC Systems for a Large High School

System	Max Cooling Load Tons	Max. Heating Load Mbh	First Cost $/ft^2	Total First Cost $	Utility Cost $/yr	Maint. Cost $/yr	Building Energy Usage Btu/(ft^2-yr)	Building Energy Cost Btu/(ft^2-yr)
Chiller/AHU/FPVAV Series	470	4965	$8.30	$1,642,447	$169,119	$19,735	46189	0.8541
Chiller/AHU/FPVAV Parallel	470	4965	$8.31	$1,644,622	$159,844	$19,735	44295	0.8073
Chiller/AHU/Dual Duct Dual Fan	470	4965	$8.91	$1,764,270	$161,156	$18,499	44303	0.8139
Chiller/AHU/VAV Reheat	470	4965	$8.19	$1,620,692	$159,040	$18,777	43728	0.8032
Applied Rooftop/VAV Reheat	470	4965	$6.08	$1,203,011	$162,861	$20,459	43889	0.8225
Vertical Self-Contained/VAV Reheat	470	4965	$6.34	$1,255,221	$160,773	$20,177	43868	0.8120
WSHP/MUA	430	4615	$5.38	$1,065,240	$180,841	$24,493	41449	0.9133
GSHP/MUA	430	4615	$7.10	$1,405,800	$175,759	$24,493	39671	0.8877
Chiller/Fan Coil/MUA	430	4615	$8.60	$1,702,800	$172,903	$17,204	41154	0.8732
Unit Ventilator	441	4615	$5.77	$1,142,460	$161,159	$20,434	40707	0.8139
WSHP/MUA w/ Enthalpy Wheel	348	4615	$5.53	$1,094,940	$163,844	$24,493	31934	0.8275
GSHP/MUA w/ Ehthalpy Wheel	348	4615	$7.25	$1,435,500	$156,762	$24,493	30156	0.8018
Chiller/Fan Coil/MUA w/ Enthalpy Wheel	348	4615	$8.74	$1,730,520	$155,906	$17,204	31639	0.7874

Notes:

1. School located in Chicago area, 200,000 square feet, 3 floors, new construction
2. Equipment Code
   a) AHU = Air handling unit
   b) VAV = Variable air volume
   c) MUA = Makeup air unit

Conclusion

School HVAC design, while drawing on the basics, has very specific needs that must be addressed. Many stem from the relatively high amount of outdoor air required in schools. However, energy conservation, serviceability, location etc all come into play.

This manual provides some insights into the various solutions available in the market today. Further assistance in school HVAC design is available from your McQuay Representative.

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