

## Heating Ventilating and Air Conditioning Systems Tutorial

### Introduction

This Tutorial is intended to illustrate and summarize mechanical cooling systems that are commonly used in buildings. The following information is adapted from a Life Cycle Cost study conducted for the Florida Department of Education. The Tutorial outlines various mechanical cooling system types that are used in schools throughout the State of Florida which are representative of the predominant system types used nationally. System descriptions, images, schematic diagrams, first cost estimates, operating cost estimates and qualitative observations are included when applicable.

Due to the Florida climate, mechanical cooling is the largest consumer of energy in schools and second only to electrical lighting in some commercial applications subsequently contributing significantly to operating costs. Furthermore, the inherent humidity in the sub-tropical climate and the requirement for adequate fresh air to be delivered to spaces requires sophisticated equipment and strategies of implementation to achieve comfort and good indoor air quality (IAQ). Other factors such as system space requirements; mechanical system noise generated; cooling equipment noise impacting adjacent neighborhoods; rebates from electrical utilities for off-peak cooling; and the deleterious effects of excessive humidity on health, building finishes and equipment such as computers are important considerations that relate to mechanical system selection, design and operation in a hot & humid climate. Additionally, in rural areas, the availability of repair parts and factory trained repair personnel are typically limited and the use of complex systems in these areas may have long down times and increased repair costs.

### GENERAL DESCRIPTION OF MECHANICAL SYSTEMS AND COMFORT FACTORS

Elements that make up mechanical systems range from train car size chillers to sophisticated energy savings devices, from pipe insulation to digital controllers and computerized monitoring systems. This section attempts to appropriately include and discuss these elements and review the types of systems that are typically use in school buildings and other commercial applications in Florida.

Table 3.2 below provides a tabulated organization of the many elements that contribute to a complete mechanical Heating Ventilating and Air Conditioning (HVAC) system. In the following sections, specific systems are referred to by a general description and will comprise the elements listed in Table 3-2. In most cases, the systems included below will provide heating, cooling and ventilating with exceptions noted.

The Florida Department of Education has published information on educational facilities in Florida. The report includes a study of 108 facilities (36 facilities in 1992, 33 facilities in 1996 and 39 facilities in 1997). Figures 3-1 through 33 illustrate summaries of the mechanical systems. These figures show the breakdown of mechanical system types with respect to air distribution heat generation and cooling. Based on this survey, central chiller plant systems with electrical heating and variable air volume (VAV) air-side distribution are the most prevalent systems.

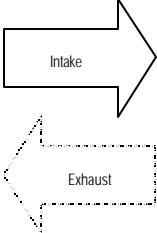



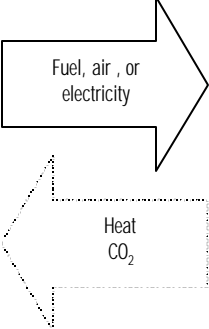
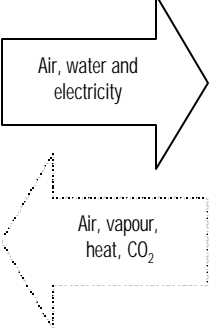
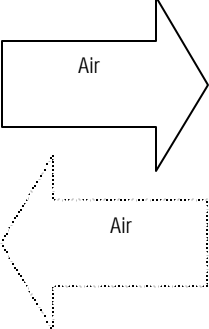
Figure 3-1 shows the percentage of refrigeration generating equipment used in the schools responding to the survey. The majority (79%) of the schools report using central systems. This could be with air-cooled or water-cooled chillers which was not clear from the survey. No split systems were reported. In actual visits to schools conducted as part of the research, the team did observe split systems in use. Interviews with Mechanical Engineers that design cooling systems in Florida indicated split systems are being installed in some schools.

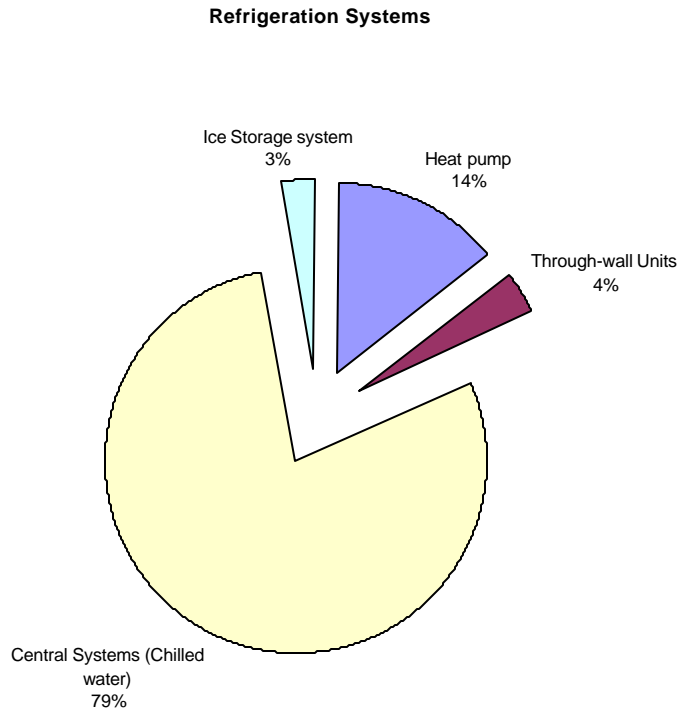
Figure 32 shows the break down of air distribution systems in the schools surveyed. Variable air volume (VAV) systems are the most commonly used (60%). The 19% air handling units may or may not serve a VAV distribution system. This issue is unclear in the survey results. The popularity of the VAV air delivery

method for central systems is likely due to its flexibility during installation, high number of zones provided and limited amount of ductwork needed. VAV systems also typically have a lower first cost than other central air distribution systems such as multi-zone or dual duct.

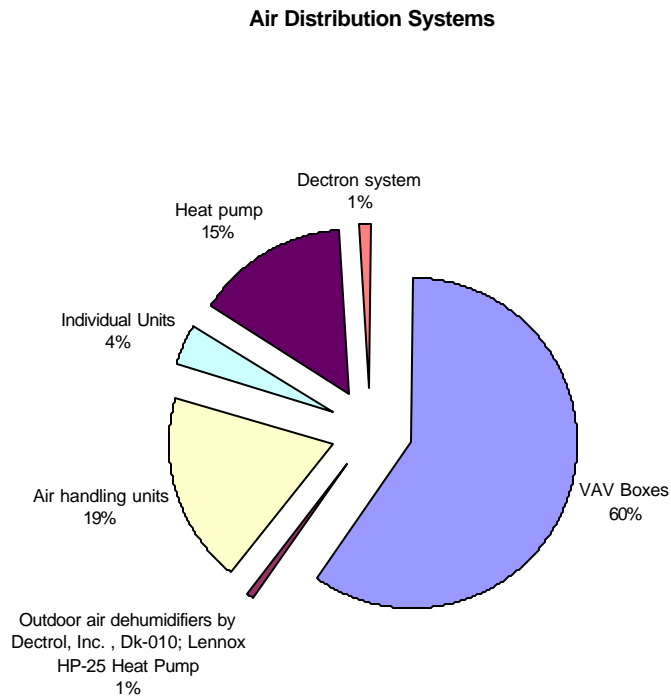
Figure 3-3 shows the breakdown of mechanical heat generation equipment in the schools surveyed. Electric resistance heat strips are the most prevalent (53%). It should be noted that most heat pump systems (35%) also have electrical heat strips for auxiliary heating that are likely not reported in the survey. In actual visits to schools for this report, the team did observe boilers with hot water distribution. In interviews with Mechanical Engineers boiler systems were noted as not often used due to high first cost and lack of need for heating during the long cooling season.

**Table 3-2 Basic HVAC Systems and Components**

<p><b>Common Tasks</b></p>	 <p><b>Intake/Exhaust</b></p>	 <p><b>Production/ Motion</b> Movers, converters and processors</p>	 <p><b>Distribution</b> Supply and return trees, delivery and control components</p>	 <p><b>Results</b> Comfort and Health in Classrooms</p>
<p><b>Heating</b></p>		<p>Boilers Furnaces Pumps</p> <p>Fans Filters Heat Strips Heat Pumps</p>	<p>Pipes Ducts Electricity conduits</p> <p>Diffusers Grilles Radiators Thermostats Valves, Dampers Controllers</p>	<p>Warm air or surfaces Air motion is often controlled</p> <p>Humidity control is sometimes needed</p>
<p><b>Cooling</b></p>		<p>Evaporative coolers Heat pumps Chillers and cooling towers Thermal Storage</p> <p>Coils Pumps Fans Filters</p>	<p>Pipes Ducts Terminal Boxes Diffusers Grilles</p> <p>Radiators Thermostats Valves Dampers Controllers</p>	<p>Cool air or surfaces Air motion is often controlled</p> <p>Humidity control is required</p>
<p><b>Ventilating</b></p>		<p>Coils Fans Filters</p>	<p>Ducts Diffusers Grilles</p> <p>Switches Dampers Controllers</p>	<p>Air motion is often controlled</p> <p>Humidity control is sometimes needed</p>

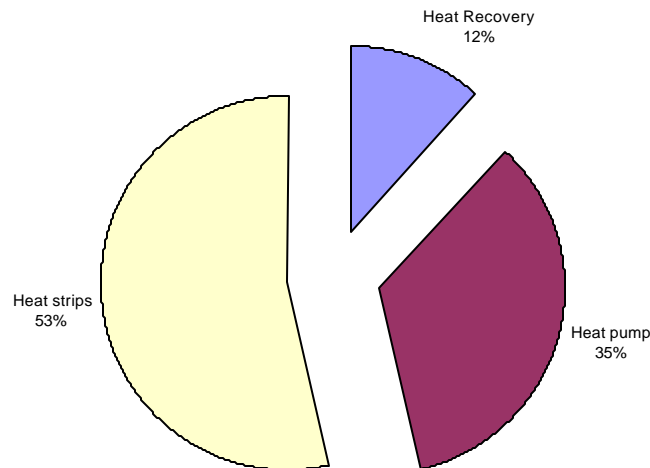


**FIGURE 3-1: Distribution of Mechanical Refrigeration Systems in Surveyed Schools**



**FIGURE 3-2: Distribution of Mechanical Air Distribution Systems in Surveyed Schools**

### Heat Generation and Recovery Systems



**FIGURE 3-3: Distribution of Mechanical Heat Generation Systems in Surveyed Schools**

#### Indoor Air Quality and Humidity Control

Providing a healthy learning environment through “Best Practices” is certainly in the best interests of promoting education in schools. Providing reliable control over Indoor Air Quality IAQ requires a sophisticated mechanical system. The basic strategy for providing good IAQ is to have well ventilated spaces that bring in large amounts of outside air while maintaining low humidity. Fresh air is required to dilute the concentration of harmful toxins such as particulate (mold spores and fungi); typical gases including CO<sub>2</sub> from occupants, and formaldehydes from off-gassing building materials; emissions from VOC’s (volatile organic compounds) used in copiers and cleaners; and naturally occurring toxins such as radon gas.

ASHRAE standard 62-1989 calls for 15 cubic feet per minute (CFM) of fresh air for each occupant of a school building. In other terms, ***the entire volume of air in an average 30 ft.x30 ft. classroom needs to be replaced with outside air every 15 minutes.*** This fresh air must be cooled and dehumidified before entering the space. This presents a difficult problem in hot humid climates such as that found in Florida. In many cases the energy required to extract humidity (latent heat) from the air exceeds that required to sensibly cool the air to achieve the desired room temperature. In Florida the ratio is approximately 7-1 (latent to sensible). Therefore, systems that will provide better humidity control will require significantly more energy than those that do not.

Controlling the humidity in classrooms is a major concern as it is a salient indicator of Indoor Air Quality (IAQ) perception. In a study conducted by the Florida Solar Energy Center in 1996, of the number of schools surveyed that had humidity problems, 86% percent also reported IAQ problems. Conversely, of the schools reporting no humidity problems only 27% reported IAQ problems.

**Table 3-3 Indoor Air Quality and Humidity in Existing Schools**

Humidity Reporting	Percent reporting IAQ problems
No humidity Problems	27.3
Humidity Problems	86.2

Data from *Energy Efficiency for Florida Educational facilities: The 1996 Energy Survey of Florida Schools*, Florida Solar Energy Center

**Temperature Control**

The comfort of individuals will be greatly determined by metabolism, activity and clothing. Since these factors likely change throughout the day, individual control of the temperature should be provided within a given range (usually between 68°F and 78°F depending on the season and other factors such as humidity, room surface temperatures, solar radiation and air movement).

The comfort of building inhabitants has been related to economic impact as a function of the ambient temperature in spaces. In a study published in the ASHRAE Journal (September, 1997) the yearly cost and Net Present Value (NPV) for loss of productivity for workers in office environments due to temperature fluctuations was estimated. Table 34 below shows the cost of decline in productivity due to temperature fluctuations beyond the comfort level for individual workers by job function.

**Table 3-4 Economic impact of temperature fluctuations.**

	Managers		Prof/tech		Clerical	
	Annual Value	NPV 5 years	Annual Value	NPV 5 years	Annual Value	NPV 5 years
Temperature fluctuation	\$692	\$2,281	\$361	\$1,367	\$189	\$716

Data from *Comfort and Control in the Workplace*, Lomonaco and Miller, ASHRAE Journal, September, 1997 pages 50-56.

These estimates, based on office worker production, illustrate the costs associated with large numbers of people inhabiting spaces that are poorly thermally controlled. One might be able to include these numbers as cost items for systems that do not provide user control in administrative areas or for teachers as they are based on loss of productivity for a base annual salary. Extended to student learning, the long term cost in reduced learning would be much more difficult to predict. Associated costs may include tutoring, remedial education and repeated grade levels.

Average cooling set point temperatures in schools surveyed by the Florida Solar Energy Center were 74.8°F. This seems a bit low based on typical comfort ranges and there is certainly a range in the data (not reported).

With regard to comfort, this low set point may be due to the high humidity levels requiring lower set point temperatures to achieve a comfortable environment. If humidity is well controlled, it may be possible to have higher set point temperatures and increased IAQ. Another comfort factor is air movement. If ceiling fans were implemented to move air in classrooms, the set point temperature may be raised slightly requiring less cooling energy. Ceiling fans produce obvious disadvantages such as a strobe effect from the lights in the room if not designed to accommodate ceiling fans (fans may not be feasible in a low ceiling space). If a ceiling fan is operated at a high speed, papers will be blown around hindering the function of the classroom.

Controlling the humidity and providing adequate ventilation is an important provision of any HVAC system. In most cases, the cost impact of these benefits are not at all evident and specific estimates would be dubious at best based on current data. In choosing mechanical systems, configurations that provide good ventilation and control humidity should be considered as best practices for providing healthy environments.

**Summary of System Types for Comparison**

This section outlines mechanical system types recently used in the State of Florida and systems for potential use. Each of the system discussions includes a conceptual diagram of the system; description of the system operation; a relative first cost estimate; relative operations and maintenance cost estimate; a discussion of the expected life time; a discussion of the environmental control issues such as humidity, IAQ

and temperature control; and other general comments regarding energy and general environmental quality. Systems are given in order of general complexity with the simplest systems listed first and more complex systems later. Table 3-5 provides a tabulated summary of the relative ratings of each of the systems.

Some of the parts from some systems may be used with other parts of other systems. For example, a central system may have an air-cooled or a water-cooled chiller. A water-cooled chiller is generally more efficient. On the other hand, it has a higher first cost and slightly higher maintenance cost due to required water treatment and evaporative loss of water. The pumps required in a water cooled chiller will consume some of the potential savings in efficiency. Therefore, a detailed study must be conducted to determine which type of chiller (air cooled or water cooled) has the lowest life cycle cost (LCC) for a given school size and operating schedule. The study should evaluate the size of the school (in terms of cooling load), skill of maintenance personnel, cost of land area (cooling tower takes up more space), energy rates from the local utility, added pumps to circulate the water, scheduling of school rooms (will there be summer operation?), etc. These are important factors that will significantly impact the LCC that are difficult to accurately include in a generalized assessment.

**TABLE 3-5. Tabulated summary of systems and features.**

#	System Type	First Cost*	Operation & Maintenance	Replacement in 50 years	Energy cost**	Humidity Control
1	Package - Through-Wall	Low	Low	4	High	Poor
2	Package – Rooftop	Low/Med	low	3.3	High	Poor
3	Split System	Low/Med	Low	3.3	High	Poor
4	Heat Pump	Low/Med	Low	3.3	Medium	Poor
5	Heat Pump Water Loop	Low/Med	Medium	2.6	Medium	Poor
6	Decoupled Through-Wall	Low/med	Low	4/3.3	High	Good
7	Central – water cooled chiller with VAV	Medium	Medium	2	Low	Adequate
8	Central – air cooled chiller with VAV	Medium	Medium	2.5	Low	Adequate
9	Central – water cooled chiller with VAV and Ice Storage	High	Medium	2.5	Low***	Adequate
10	Central – Decoupled air-cooled chiller with VAV	High	Medium	2.5	Medium	Good
11	Central – Decoupled air-cooled with Fan-Coil Unit (FCU)	Medium	Medium/High	2.5	Medium	Good
12	Central – air cooled chiller with Dual Duct (CV)	High	Medium	2.5	High	Good
13	Central – Air-Cooled Multizone (CV)	Medium	Medium	2.5	High	Good
14	Central-Decoupled Low Temperature VAV with ice Storage	High	High	2.5	Low**	Good

\*First cost ratings are based on reviews of LCC analysis run on existing schools and on cost data from *Means Mechanical Cost Data 1999, 22<sup>nd</sup> Annual Edition*. Ratings refer to cost ranges in cost per ton of cooling as follows Low [up to \$800.00/ton]; Low/Med [\$800.00/ton to \$1,800/ton]; Medium [\$1,800/ton to \$2,800/ton]; and High [above 2,800/ton].

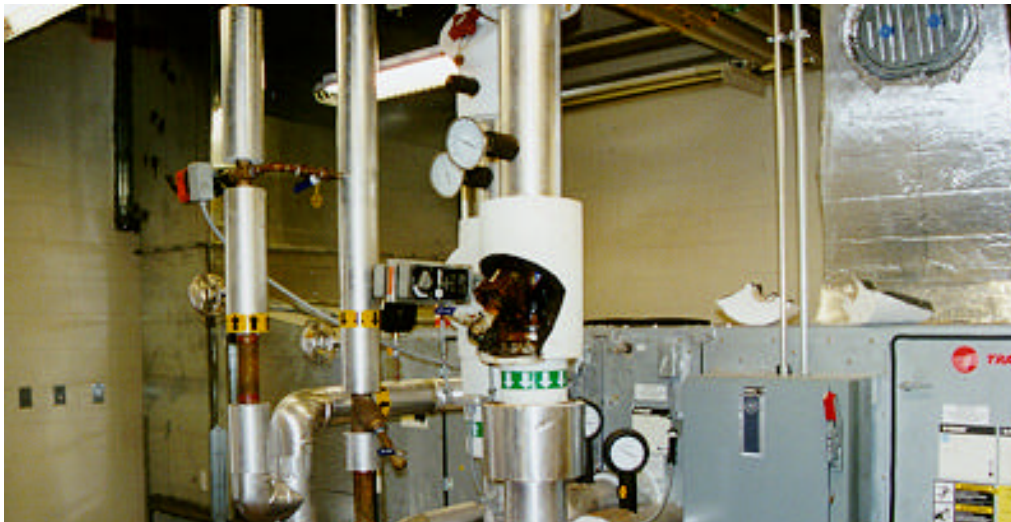
\*\*Overall energy costs are directly related to scheduling of system operation. Ratings are based on system efficiency given a similar operation schedule.

\*\*\* Rating based on utility demand charges where off-peak operation will be at a lower rate per unit of electricity.



**Table 3-6 List of systems included in summary**

System Number	System Type
1	Package - Through-Wall
2	Package - Rooftop
3	Split System
4	Heat Pump
5	Heat Pump with Water Loop
6	Decoupled Through-Wall with Split System
7	Central – water cooled chiller with VAV
8	Central – air cooled chiller with VAV
9	Central – water cooled chiller with VAV and Ice Storage
10	Central – Decoupled air-cooled chiller with VAV
11	Central – Decoupled air-cooled with Fan-Coil Unit (FCU)
12	Central – air cooled chiller with Dual Duct (CV)
13	Central – Air-Cooled Multizone (CV)
14	Central-Decoupled Low Temperature VAV with ice Storage



Typical air handling unit (AHU). In this installation the unit is providing 100% outside air as part of a central decoupled system. Chilled water and hot water coils are used to control the temperature and humidity of the air that is delivered to the space.

## **SYSTEM 1: PACKAGE**

### **Through-Wall Package Unit**



Array of Through-Wall units in elementary school

#### **Description**

Through wall package units are self-contained HVAC systems that are wall mounted in classrooms. They are typically used in portable classroom applications to provide ease in building set up and transportation. They are also used in some older facilities and are still installed in new building construction. Please refer the system diagram on the following page. This package system is considered a single zone unit and at least one is required for each space that is to be cooled. Other spaces in the school such as the Gymnasium or Auditorium or even administrative offices will need larger individual cooling systems. If corridors are to be cooled, separate systems will be required for these spaces. This type of configuration places multiple condensing units at the exterior spaces of the school. Heating is typically achieved with electrical heat strips at each unit.

#### **First Cost**

The Through-Wall system has the lowest first cost per unit however this approach requires the most number of units. There are no pumps, pipes, or other equipment that need to be provided for a complete operating system. There are a variety of features that can be added to the unit for energy savings and improved humidity control at an added cost. As noted above, other systems such as roof-top units or split system units are also required for larger building spaces. A related cost that should be considered is the added electrical service that will be required at each classroom to power the units.

#### **System Control**

Individual temperature control is provided by cycling the unit on or off as cooling is needed. When the unit is off, no air is being circulated to the classroom. In some instances when no cooling is needed, a portion of the room air is mixed with fresh air and delivered to the space without being cooled at the cooling coil.

#### **Operations and Maintenance**

Through wall package units are the simplest systems to maintain. Changing the filters on a regular basis is the primary maintenance. Most residential mechanical repair technicians can service them. In many cases if there is a breakdown the whole unit is replaced and the broken unit is taken to a shop for repair. If a unit fails it can generally be repaired or replaced quickly and while it is down it only effects one classroom.

Energy use for these systems is high. The small refrigeration system has relatively low efficiency (approximately 1.3 to 1.5 kw/ton). Some engineers have suggested that ultimately the energy use is low when compared to central systems in application because the units do not run all the time. Detailed monitoring of these systems in actual use over an extended period of time would be required to develop reliable information on actual energy use.

### Life Expectancy

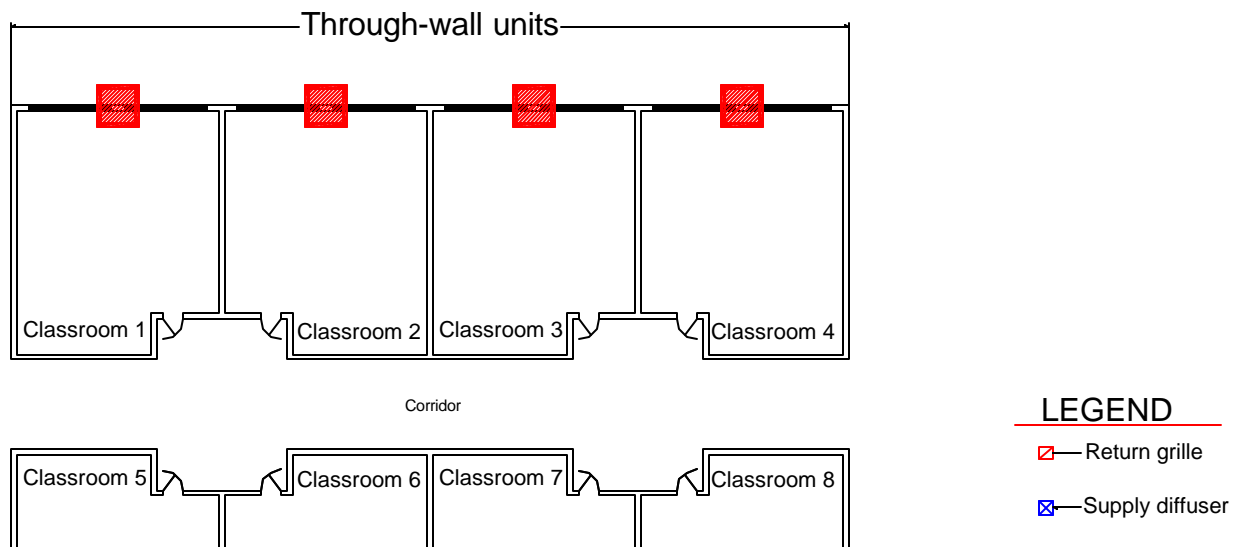
The systems are rated to last 10 years with regular maintenance. This would require 4 units in a fifty-year cycle.

### Environmental Issues

This type of system cycles on and off to provide cooling. When it is off it does not provide any cooling which would remove humidity from the air. With the need for ventilation, this system is limited in its ability to remove humidity from the fresh air needed in classrooms. The location of the units in the actual classroom wall creates a loud noise source in the rooms. Recent Studies have shown that classrooms with through wall systems have background noise levels of NC-45 to NC-50 (Siebein et al., 1999 ). Currently, the ADA Access Board is reviewing proposed standards for classroom background noise levels that establish NC-25 to NC-30 as potential values. The American Speech-Language and Hearing Association (ASHA) recommends NC-20 background noise levels.

## PACKAGE HVAC SYSTEMS

### Through-wall unit



## **SYSTEM 2: PACKAGE**

### **Rooftop system (Single or Multi-Zone)**



Rooftop unit with ducted supply and return

### **Description**

This system uses self-contained units that are located on the roof tops of buildings and they supply cooling through ducts that penetrate the roof. These units can be used to serve a single zone or to serve multiple zones. When used to serve multiple zones they are usually used with VAV boxes to control the temperature in the individual zones. The multi-zone system would typically serve 2 to 4 classrooms. Heating is typically provided by using electrical resistance heat strips that are located inside the air handler.

### **First Cost**

This system has a low first cost depending on the number of zones provided and whether or not each unit will have multiple zones. Ducts are required to move air to and from the classroom and VAV boxes are required if multiple zones will be incorporated. There are no pumps, pipes, or other equipment that need to be provided for a complete operating system. Another cost that should be considered is the added electrical service that will be run to each rooftop unit (single zone) to power the system.

### **System Control**

Individual temperature control is provided by cycling the unit on or off as cooling is needed in the single zone system. In this case, when the unit is off, no air is circulated to the classroom. In some instances when no cooling is needed, a portion of the room air is mixed with fresh air and delivered to the space without being cooled at the cooling coil. In the multi-zone system, air-flow is reduced at the VAV box to meet the cooling needs and the rooftop unit runs constantly or over specified periods of time (weekdays for example).

### **Operations and Maintenance**

Rooftop package units are simple systems to maintain. Changing the filters on a regular basis is the primary maintenance. Most residential mechanical repair technicians can service them. If a unit fails it can generally be repaired quickly and while it is down it only effects one classroom or a small number of classrooms. The roof location allows easy access for maintenance and/or repair.

Energy use for these systems is high. The small refrigeration system has relatively low efficiency (approximately 1.3 to 1.5 kw/ton). Some engineers have suggested that ultimately the energy use is low when compared to central systems in application because the units do not run all the time. Detailed monitoring of these systems in actual use over an extended period of time would be required to develop reliable information on actual energy use.

### **Life Expectancy**

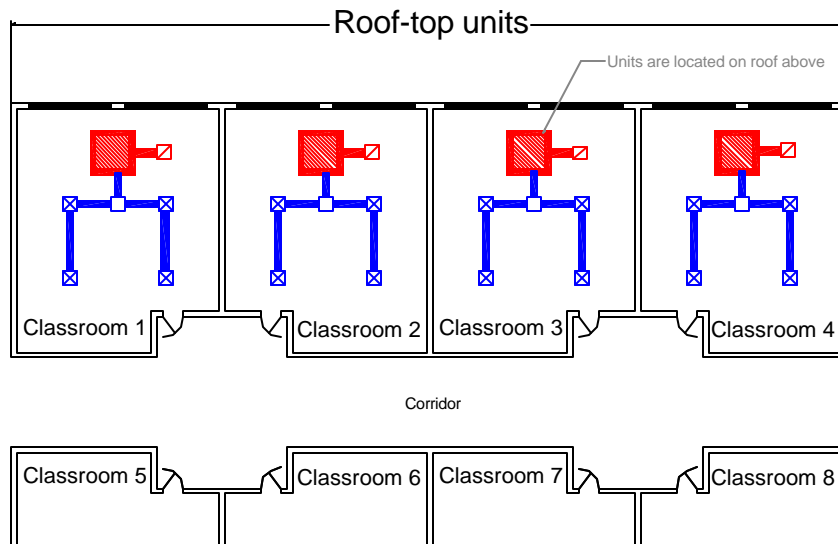
The systems are rated to last 15 years with regular maintenance. This would require 4 units in a fifty-year cycle.

### Environmental Issues

This type of system cycles on and off to provide cooling (single zone). When it is off it does not provide any cooling which would remove humidity from the air. With the need for ventilation, this system is limited in its ability to remove humidity from the fresh air needed in classrooms. The location of the units in close proximity to the actual classroom creates a loud noise source near the rooms. Recent Studies have shown that classrooms with roof top systems have background noise levels of NC-35 to NC-45 (Siebein et al., 1999). Currently, the ADA Access Board is reviewing proposed standards for classroom background noise levels that establish NC-25 to NC-30 as potential values. The American Speech-Language and Hearing Association (ASHA) recommends NC-20 background noise levels.

### PACKAGE HVAC SYSTEMS

#### Roof-top unit



#### LEGEND

- Return grille
- Supply diffuser



## **SYSTEM 3: SPLIT SYSTEM**

### **Split Dx Coil system for each zone**



Condensing units for Split System

### **Description**

This system uses a combination of individual elements to provide cooling including an air handler and a condensing unit. The air handler is typically located adjacent to (in a closet) or above the space that it is cooling. The condensing unit is located outside near the classroom or on the roof. Heat is removed from the air at the air handler and sent to the condensing unit via refrigerant. This is considered a single zone unit and can serve one or more individual spaces depending on the desired control. Heating is typically provided by electrical resistance heat strips that are located inside the air handler.

### **First Cost**

This system has a low to moderate first cost depending on the amount of zones provided and flexibility of control provided.

### **System Control**

Individual temperature control is provided by cycling the unit on or off as cooling is needed. When the unit is off, no air is circulated to the classroom. In some instances when no cooling is needed, a portion of the room air is mixed with fresh air and delivered to the space without being cooled at the cooling coil.

### **Operations and Maintenance**

Split system units are relatively easy to maintain. Changing the filters on a regular basis is the primary maintenance. Most commercial mechanical repair technicians can service them. In many cases if there is a breakdown the system can be repaired quickly as parts are commonly stocked in all but the most remote areas of the state. If a unit fails all spaces in the zone will be without cooling, typically one classroom.

Energy use for these systems is high. The small refrigeration system has relatively low efficiency (approximately 1.3 to 1.5 kw/ton).

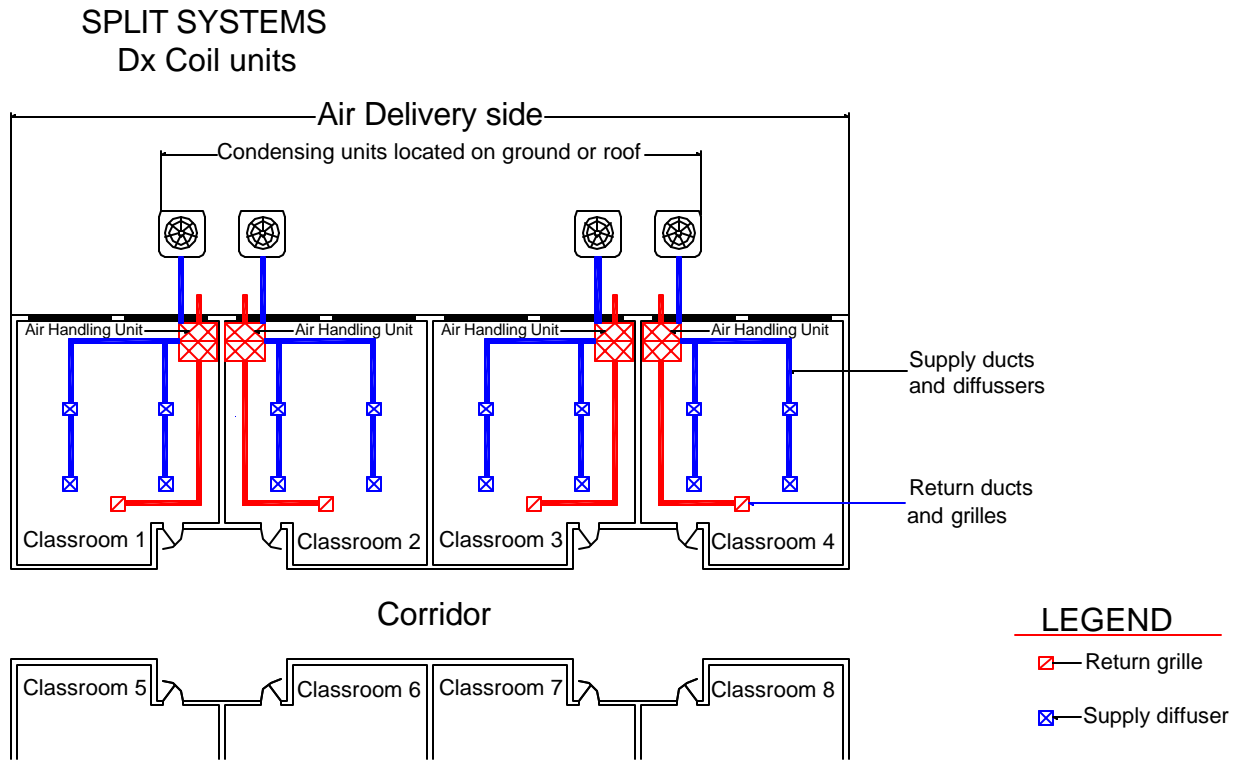
### **Life Expectancy**

With proper maintenance, the systems can be expected to last up to 15 years. This would require 4 units in 50 years.

### **Environmental Issues**

This type of system cycles on and off to provide cooling. When it is off it does not provide any cooling which would remove humidity from the air. With the need for ventilation, this system is limited in its ability to remove humidity from the fresh air needed in classrooms. Typically, these units are located in close

proximity to the classrooms they serve either in a closet, located in a ceiling plenum, or in a mechanical mezzanine above the space. Recent Studies have shown that classrooms with split systems have background noise levels of NC-40 to NC-45 (Siebein et al.,1999 ). Currently, the ADA Access Board is reviewing proposed standards for classroom background noise levels that establish NC-25 to NC-30 as potential values. The American Speech-Language and Hearing Association (ASHA) recommends NC-20 background noise levels. Furthermore, when the condensing units are located near the classroom, noise comes in through windows. In some cases when they are located on the roof, noise can be spread throughout the building.



## **SYSTEM 4: HEAT PUMP**

### **Individual Heat Pump unit for each Zone**

#### **Description**

In most applications the heat pump system works much like the split system (see System 3 above). What distinguishes it as a different system is that the refrigerant loop has the ability switch the direction of flow. This allows the unit to perform two functions. It can move heat from inside to outside (provide cooling in summer) or move heat from outside to inside (provide heating in winter). The efficiency of the system allows it to heat spaces until the outside air temperature drops below 40° F. Electric heat strips are usually used to provide auxiliary heating when needed. In the Florida climate, temperatures only occasionally drop below 40°F and then usually during the late-night/early-morning hours and are not sustained for long periods of time.

Therefore, these heat pump systems are used extensively in residential and small commercial applications as they can provide cooling and heating during most of the year.

#### **First Cost**

This system has a relatively low first cost which is similar to that of the split system.

#### **System Control**

Individual temperature control is provided by cycling the unit on or off as cooling is need. When the unit is off, no air is being circulated to the classroom. In some instances when no cooling is needed, a portion of the room air is mixed with fresh air and delivered to the space without being cooled at the cooling coil.

#### **Operations and Maintenance**

Heat pump systems are relatively easy to maintain. Changing the filters on a regular basis is the primary maintenance. Most commercial mechanical repair technicians can service them. In many cases if there is a breakdown the system can be repaired quickly as parts are commonly stocked in all but the most remote areas of the state. If a unit fails all spaces in the zone will be without cooling/heating, typically one classroom.

#### **Life Expectancy**

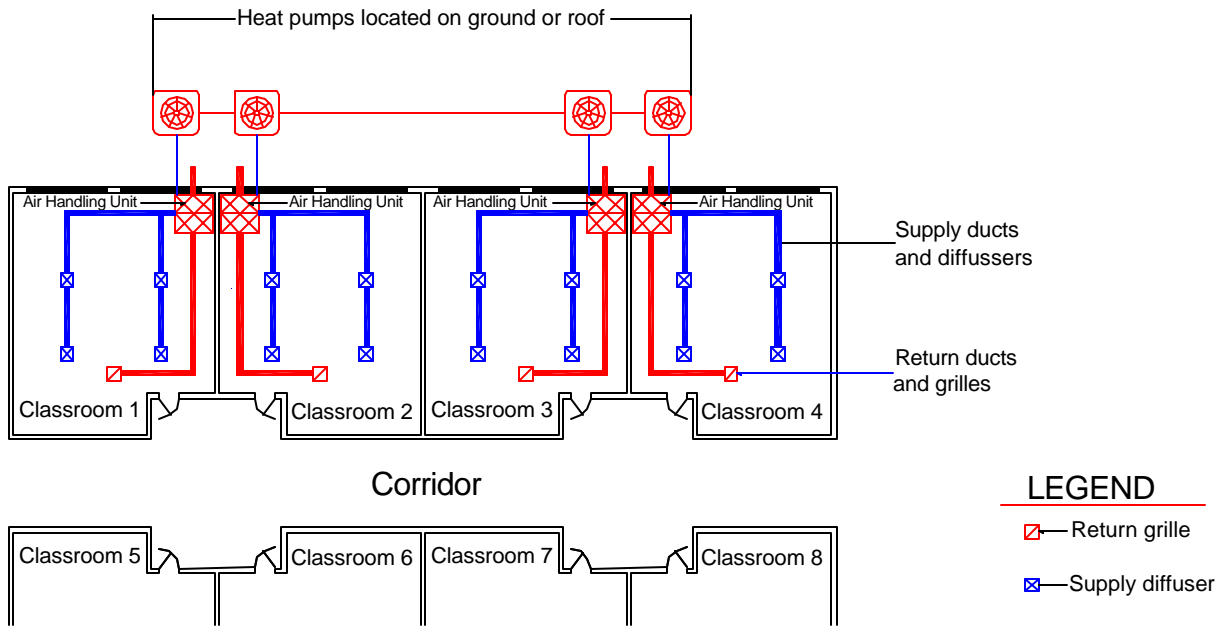
With proper maintenance, the systems can be expected to last up to 15 years.

#### **Environmental Issues**

This type of system cycles on and off to provide cooling. When it is off it does not provide any cooling which would remove humidity from the air. With the need for ventilation, this system is limited in it's ability to remove humidity from the fresh air needed in classrooms. Typically, these units are located in close proximity to the classrooms they serve either in a closet, located in a ceiling plenum, or in a mechanical mezzanine above the space. Recent Studies have shown that classrooms with split/heat pump systems have background noise levels of NC-40 to NC-45 (Siebein et al.,1999 ). Currently, the ADA Access Board is reviewing proposed standards for classroom background noise levels that establish NC-25 to NC-30 as potential values. The American Speech-Language and Hearing Association (ASHA) recommends NC-20 background noise levels. Furthermore, when the condensing units (cooling mode) are located near the classroom, noise comes in through windows. In some cases when they are located on the roof, noise can be spread throughout the building.



## HEAT PUMP SYSTEMS



## **SYSTEM 5: HEAT PUMP**

### **Individual Heat Pump with Water Loop**

#### **Description**

The water loop heat pump system functions the same as a regular heat pump (see System 4 above) with the added feature of using water as a heat sink rather than the outside air. For heating, the heat is extracted from the water loop. Since the water temperature (70° F to 80° F) is usually more stable than the outside air temperature (30° F to 98°F) there is a great efficiency with this system.

#### **First Cost**

The first costs are low to moderate. The added cost of the pumps and pipes for the water system significantly increases the cost above an air-to-air heat pump system. The improved efficiency may make up for the added first cost depending on the school size and occupancy schedule.

#### **System Control**

Individual temperature control is provided by cycling the unit on or off as cooling is needed. When the unit is off, no air is being circulated to the classroom. In some instances when no cooling is needed, a portion of the room air is mixed with fresh air and delivered to the space without being cooled at the cooling coil. If a unit goes down all spaces in the zone will be without cooling/heating, typically one classroom.

#### **Operations and Maintenance**

Water loop heat pump systems are more difficult to maintain than air-to-air heat pumps due to the maintenance of the water system. Water may need periodic treatment and additional pipes, pumps and valves are required. Changing the filters on a regular basis is also required. Most commercial mechanical repair technicians can service them. In many cases if there is a breakdown the system can be repaired quickly as parts are commonly stocked in all but the most remote areas of the state. If a unit fails all spaces in the zone will be without cooling/heating.

Using the water loop as a heat sink allows the system to be more efficient. This saves energy in the cooling season and in most cases in Florida, eliminates the need to use auxiliary heat strips

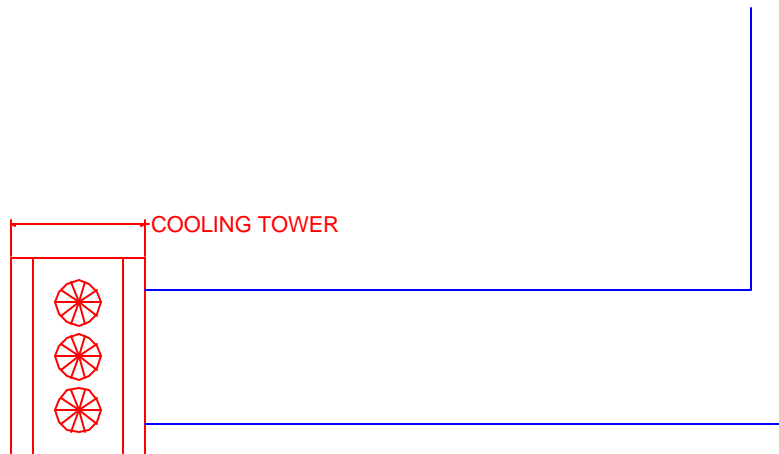
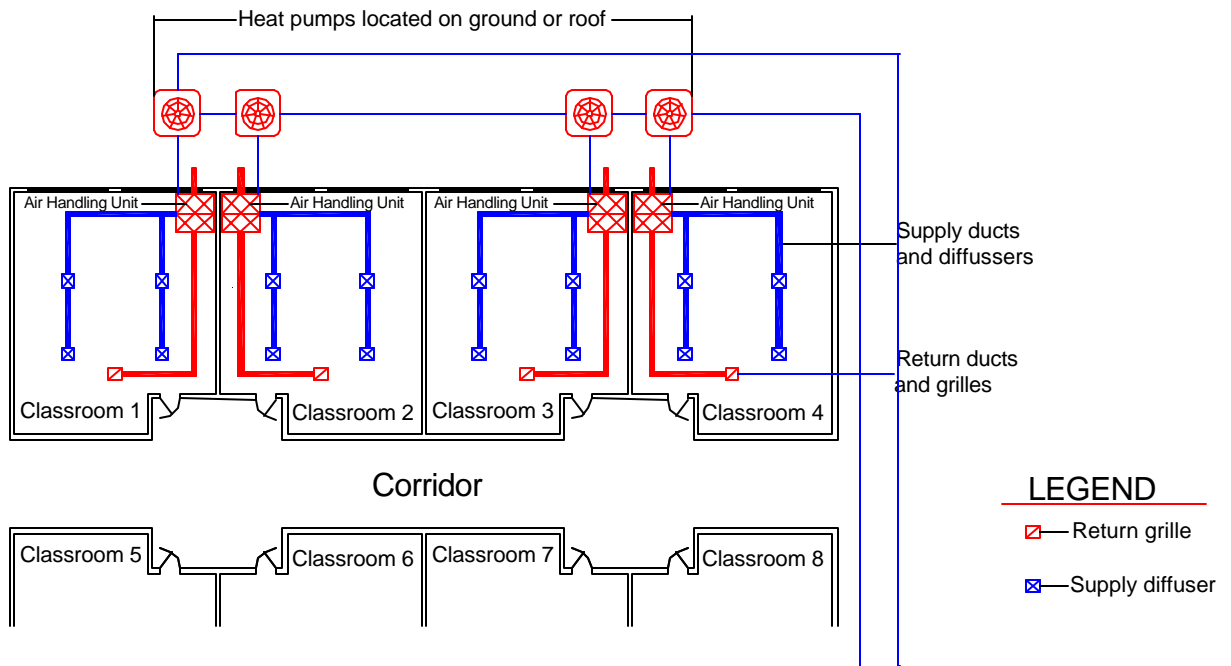
#### **Life Expectancy**

With proper maintenance, the systems can be expected to last up to 19 years.

#### **Environmental Issues**

This type of system cycles on and off to provide cooling which does not provide any cooling to remove humidity when no space cooling is needed. With the need for ventilation, this system is limited in its ability to remove humidity from the air in classrooms. Typically, these units are located in close proximity to the classrooms they serve either in a closet, located in a ceiling plenum, or in a mechanical mezzanine above the space. Recent Studies have shown that classrooms with split/heat pump systems have background noise levels of NC-40 to NC-45 (Siebein et al., 1999). Currently, the ADA Access Board is reviewing proposed standards for classroom background noise levels that establish NC-25 to NC-30 as potential values. The American Speech-Language and Hearing Association (ASHA) recommends NC-20 background noise levels. With this system pumps should be located remotely from occupied spaces.

## HEAT PUMP SYSTEMS With water-loop



## **SYSTEM 6: DECOUPLED PACKAGE**

### **Through wall units with decoupled split system**

#### **Description**

This system combines the Through Wall Package Unit and the Split System to provide separate ventilation and space cooling systems. The Through Wall Units are self-contained HVAC systems that are typically wall mounted in classrooms (please refer to System 1). This is considered a single zone unit and at least one is required for each space that is to be cooled. In this configuration the Through Wall Unit provides the space cooling by being cycled on or off as required. A Split System (please refer to System 2) is used to cool and dehumidify 100% outside air to provide ventilation at a neutral temperature and humidity (75° F and 50% rh). This second (decoupled) system would operate as long as the classrooms are occupied. The Split System would serve multiple classrooms (3 to 6). An air discharge system is also required to allow the ventilation air to escape to the exterior. Additional systems are required for the support spaces in the building.

#### **First Cost**

Typically this type of system has a low first cost compared to centralized decoupled systems. There are no pumps, pipes, or water distribution systems. Another cost that should be considered is the added electrical service that will be run to each classroom to power the units.

#### **System Control**

Individual temperature control is provided by cycling the through Wall Unit on or off as cooling is needed. The Split system provides fresh ventilation air.

#### **Operations and Maintenance**

Through wall package units are the simplest systems to maintain. Changing the filters on a regular basis is the primary maintenance. Most residential mechanical repair technicians can service them. In many cases if there is a breakdown the whole system is replaced and the broken unit is taken to a shop for repair. If a cooling unit fails it can generally be repaired or replaced quickly and while it is down it only effects one classroom. If the ventilation unit fails, more spaces are effected however cooling is still provided.

Energy use for these systems is high. The small refrigeration system has relatively low efficiency (approximately 1.3 to 1.5 kw/ton). Some engineers have suggested that ultimately the energy use is low in application because the units do not run all the time. Detailed monitoring of these systems in actual use over an extended period of time would be required to develop reliable information on energy use.

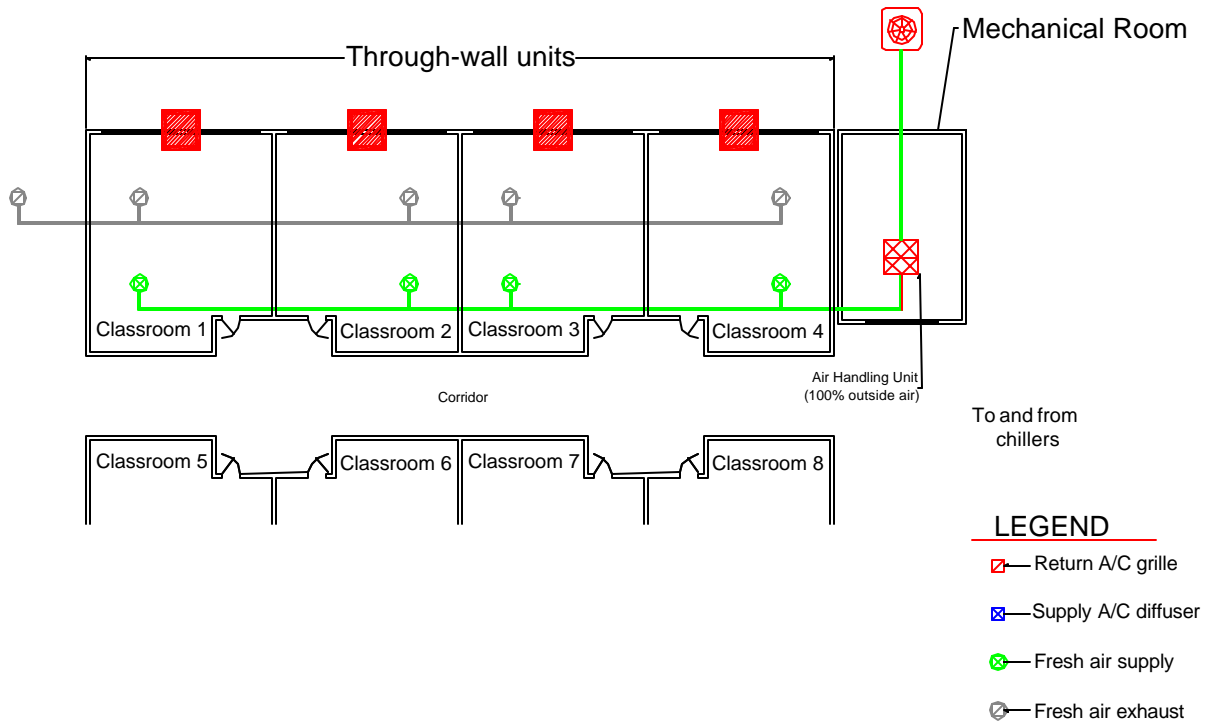
#### **Life Expectancy**

The Through Wall units are rated to last 10 years with regular maintenance. This would require 4 units in a fifty-year cycle. The Split Systems will last 15 years with regular maintenance.

#### **Environmental Issues**

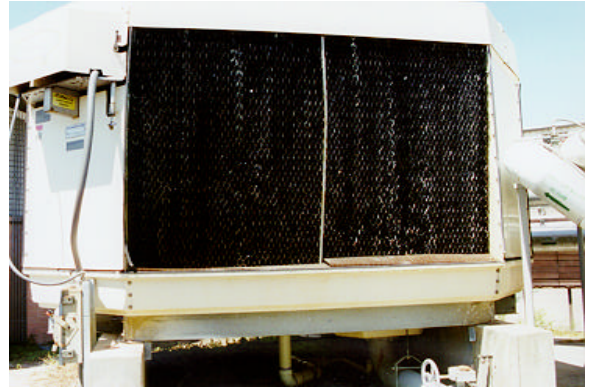
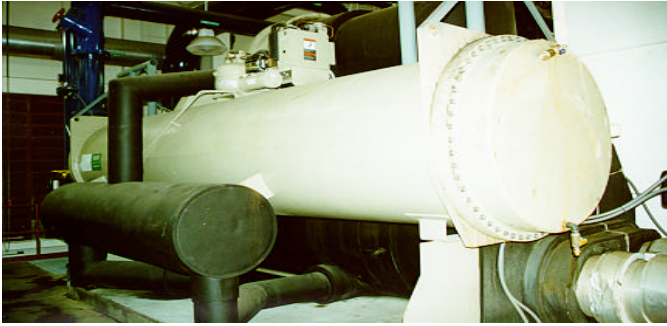
This type of system cycles on and off to provide cooling. The location of the Through Wall Units in the actual classroom wall creates a loud noise source in the rooms. It is important to locate the Split System remotely from the classroom to reduce the noise impact as it could add to the noise from the Through Wall Unit. Recent Studies have shown that classrooms with through wall systems have background noise levels of NC-45 to NC-50 (Siebein et al., 1999). Currently, the ADA Access Board is reviewing proposed standards for classroom background noise levels that establish NC-25 to NC-30 as potential values. The American Speech-Language and Hearing Association (ASHA) recommends NC-20 background noise levels.

### DE-COUPLED SYSTEM Through-wall with split system



## SYSTEM 7: CENTRAL-VAV

### Water Cooled Chiller with VAV Air Delivery System



Centrifugal chiller (Above). Small cooling tower (Right).

#### Description

This system uses a combination of individual elements to provide cooling including a cooling tower, chiller, water loops, pumps, air handlers, VAV boxes and air ducts as the major elements. Cool air is supplied to the classroom via ducts and a *variable air volume* (VAV) box. The VAV box adjusts the amount of cool air that will be sent to the space to maintain the set temperature. The air from the space is then removed via the return air duct. At the air handler the heat is transferred to water (cooling the air) and then piped to the chiller (chilled water loop). In the chiller, the heat is removed from the water via refrigerant. In this system with the water-cooled chiller, the heat is transferred to another water loop (condenser water loop) which carries the heat to the cooling tower. At the cooling tower the water is sprinkled over a matrix of tiles while air is blown past to extract the heat from the water releasing it to the outside environment. Heating may be provided through the existing water loop (heating or cooling only), an additional water loop 4 pipe system, or electrical resistance heat strips.

#### First Cost

Typically this type of system has a high first cost due to the amount of equipment, distribution systems, control network and building space that is required.

#### System Control

Individual temperature control can be provided by supplying a VAV box and thermostat in each of the classrooms. In this system some amount of air must constantly be delivered to the classroom to provide fresh air. If a VAV unit fails, all spaces in the zone will be without cooling/heating, typically one classroom. If an air handler fails a group of zones will be affected, typically 8 to 16 classrooms. If the central refrigeration system fails, the school will operate under partial cooling at some reduced level.

#### Operations and Maintenance

Due to the complexity of the equipment and the control systems to regulate and monitor performance, trained personnel are needed to supervise the system operation. Water treatment and cleaning of the cooling towers is also a maintenance concern that will add to the cost. In the event of a major system failure, specialized personnel and equipment will be required. The larger refrigeration plant and cooling tower provide a high efficiency with regard to cooling per unit of energy expended (0.6 to 0.8 kw/ton). Therefore long-term energy savings may offset the increased first cost depending on school size and scheduling. It is important to note that additional pumps used to move condenser water will somewhat reduce this efficiency rating.

#### Life Expectancy

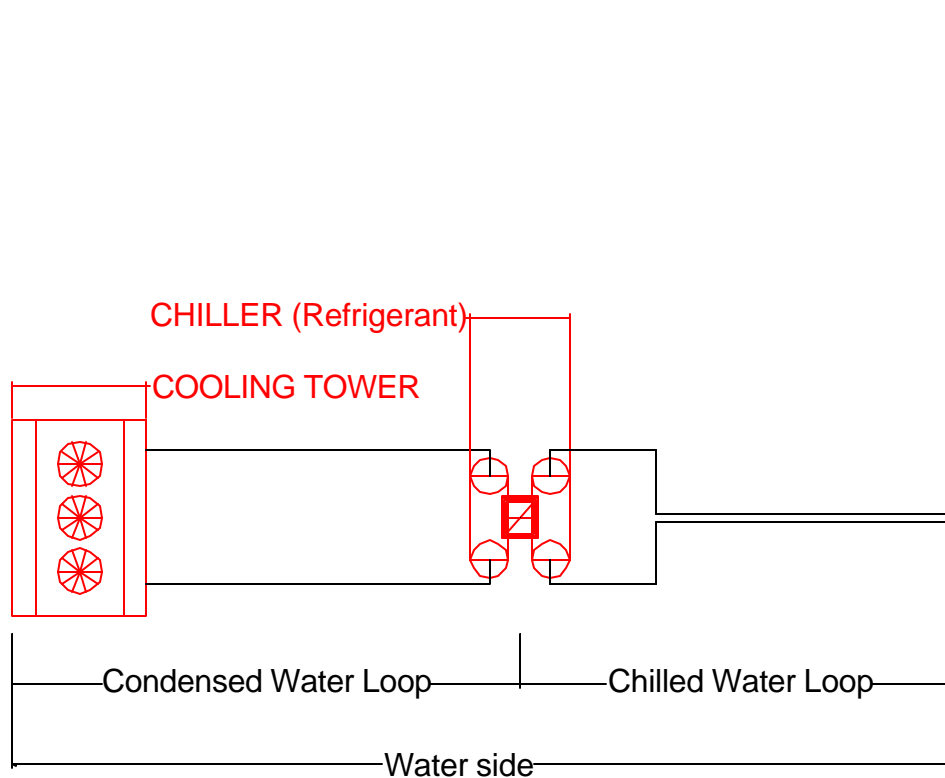
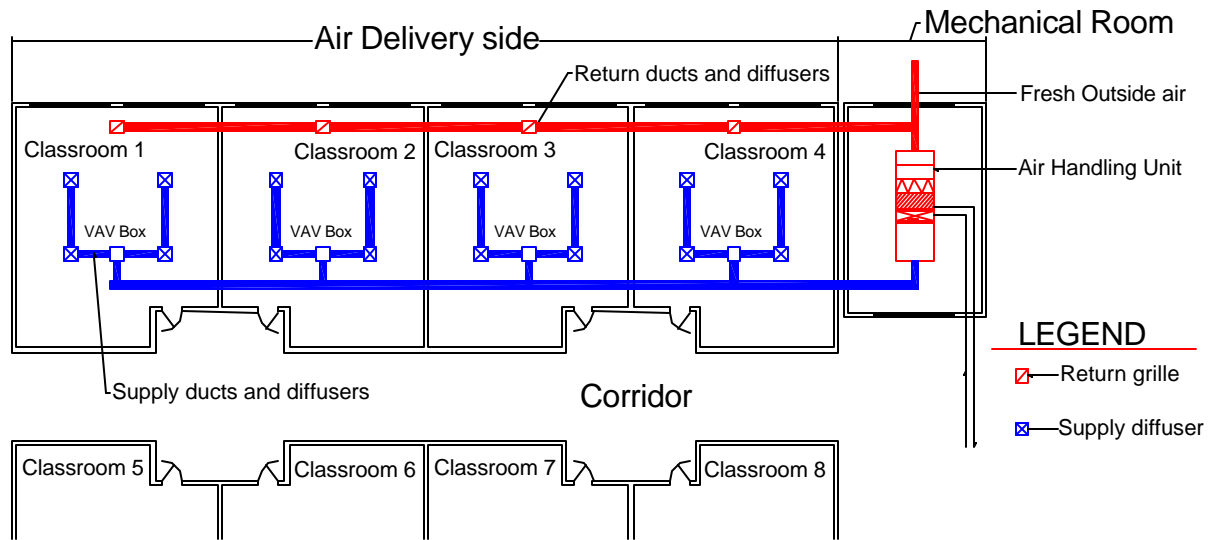
The systems are rated to last 25 years with regular maintenance.

#### Environmental Issues

Because the VAV delivery system throttles back the air when little cooling is needed it also throttles back the amount of fresh air that enters the space. This can only be done to the point of minimum ventilation air flow. In some cases, overcooling may occur which can cause humidity problems. This is a function of all VAV

delivery systems regardless of the refrigeration mechanism. The primary cooling equipment is located away from the classroom allowing low background noise levels to be achieved in the classroom spaces. This also concentrates the noise generating equipment into contained zones which can be strategically located in a facility to reduce interference with student spaces and/or adjacent neighborhoods.

### CENTRAL HVAC SYSTEMS Water-cooled chiller/VAV Distribution



## **SYSTEM 8: CENTRAL VAV**

### **Air Cooled Chiller with VAV Air Delivery System**



Air cooled chiller in equipment yard

#### **Description**

This system uses a combination of individual elements to provide cooling including a chiller, chilled water loop, pumps, air handlers, VAV boxes, and air ducts as the major elements. Cool air is supplied to the classroom via ducts and a variable air volume (VAV) box. The VAV box adjusts the amount of cool air that will be sent to the space to maintain the set temperature. At the air handler the heat is transferred to water (cooling the air) and then piped to the chiller (chilled water loop). In the chiller, the heat is removed from the water via refrigerant. In this system with the air-cooled chiller, the heat is transferred directly to the outside environment at the chiller. This eliminates the need for a cooling tower, condenser water loop and pumps.

#### **First Cost**

Typically this type of system has a high first cost due to the amount of equipment and building space that is required for the equipment.

#### **System Control**

Individual temperature control can be provided by supplying a VAV box and thermostat in each of the classrooms. If a VAV unit fails, all spaces in the zone will be without cooling/heating, typically one classroom. If an air handler fails a group of zones will be affected, typically 8 to 16 classrooms. If the central refrigeration system fails, the school will operate under partial cooling at some reduced level.

#### **Operations and Maintenance**

Due to the complexity of the equipment and the control systems to regulate and monitor performance, trained personnel are needed to supervise the system operation. In the event of a major system failure, specialized personnel and equipment will be required.

The larger refrigeration plant provides high efficiency with regard to cooling per unit of energy expended (0.7 to 0.9 kw/ton). Therefore long-term energy savings may offset the increased first cost depending on school size and scheduling.

#### **Life Expectancy**

The systems are rated to last 20+ years with regular maintenance.

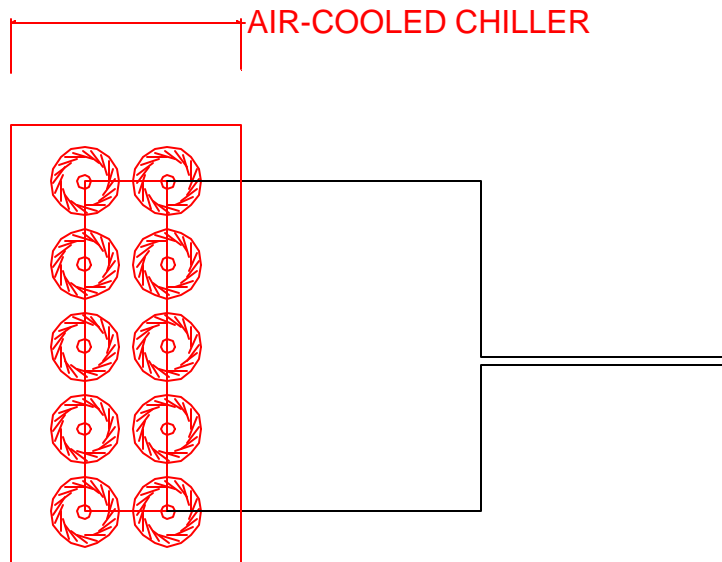
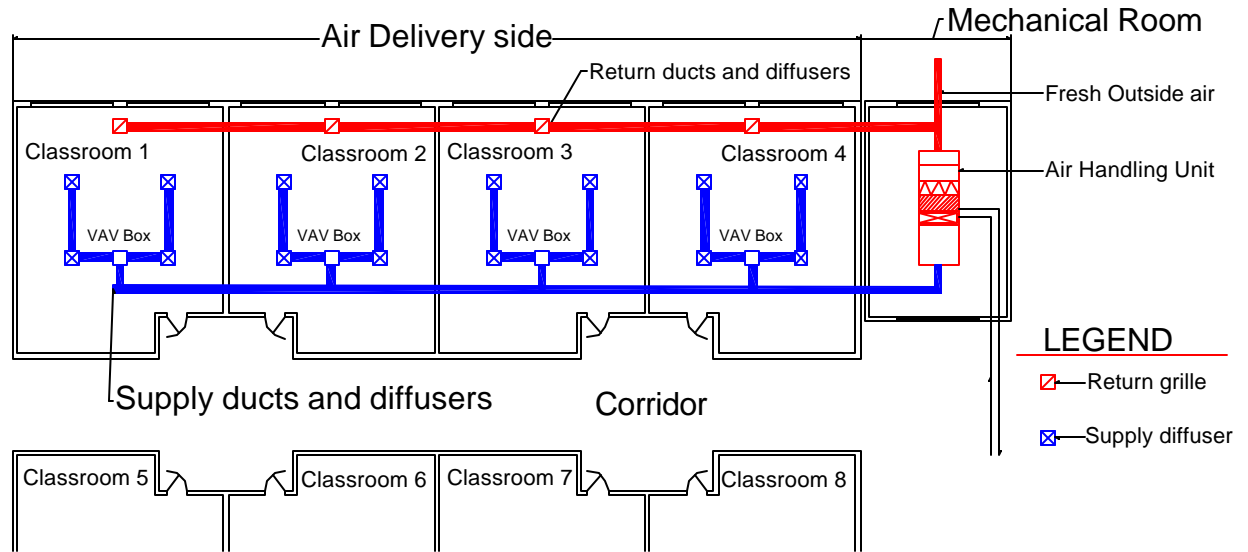
#### **Environmental Issues**

Because the system throttles back the air when little cooling is needed it also throttles back the amount of fresh air that enters the space. In some cases, overcooling may occur which can cause humidity problems. The primary cooling equipment is located away from the classroom allowing low background noise levels to be achieved in the classroom spaces. The air-cooled chillers are typically located outside and are quite noisy. Care should be taken to locate this equipment in a location that will not cause a noise disturbance.



# CENTRAL HVAC SYSTEMS

## Air-cooled chiller/VAV Distribution



## SYSTEM 9: CENTRAL-VAV

### Water Cooled Chiller with VAV Air Delivery System and Ice Storage



Ice storage tanks partially embedded in the ground.

#### Description

This system uses a combination of individual elements to provide cooling including a chiller, chilled water loop, pumps, Ice storage tanks, air handlers, VAV boxes and air ducts as the major elements. It is identical to System 7 above with the addition of ice storage tanks. This feature allows cooling to be generated at any time and then used at another time. This advantage allows the chillers to run at night during periods when electric companies do not have demand charges (higher rates for electricity). This can have a substantial long term savings in energy costs. It does not necessarily reduce the amount of energy consumed and requires additional pumps and control equipment that may increase the total energy consumed. An Ice storage system can be incorporated as a part of any of the central cooling systems such as the Decoupled, Dual-duct, or Multi-zone.

#### First Cost

Typically this type of system has a high first cost due to the amount of equipment and building space that is required for the equipment which is typical of central systems. The actual cost will vary significantly depending on the actual configuration of the system. The Ice storage system will contribute a significant amount to the first cost of a mechanical system. Some utilities in Florida such as Florida Power & Light will give subsidies of up to \$100,000 to offset the first cost of the ice storage equipment.

#### System Control

Individual temperature control can be provided by supplying a VAV box and thermostat in each of the classrooms. If a VAV unit fails, all spaces in the zone will be without cooling/heating, typically one classroom. If an air handler fails a group of zones will be affected, typically 8 to 16 classrooms. If the central refrigeration system fails, the school will operate under partial cooling at some reduced level.

#### Operations and Maintenance

Due to the complexity of the equipment and the control systems to regulate and monitor performance, trained personnel are needed to supervise the system operation. In the event of a major system failure, specialized personnel and equipment will be required. Some additional training in the operation and maintenance of the systems is required. Periodic scheduled maintenance specific to the ice storage equipment is also required.

The larger refrigeration plant provides high efficiency with regard to cooling per unit of energy expended (0.7 to 0.9 kw/ton). Therefore long-term energy savings may offset the increased first cost depending on school size and operation scheduling.

#### Life Expectancy

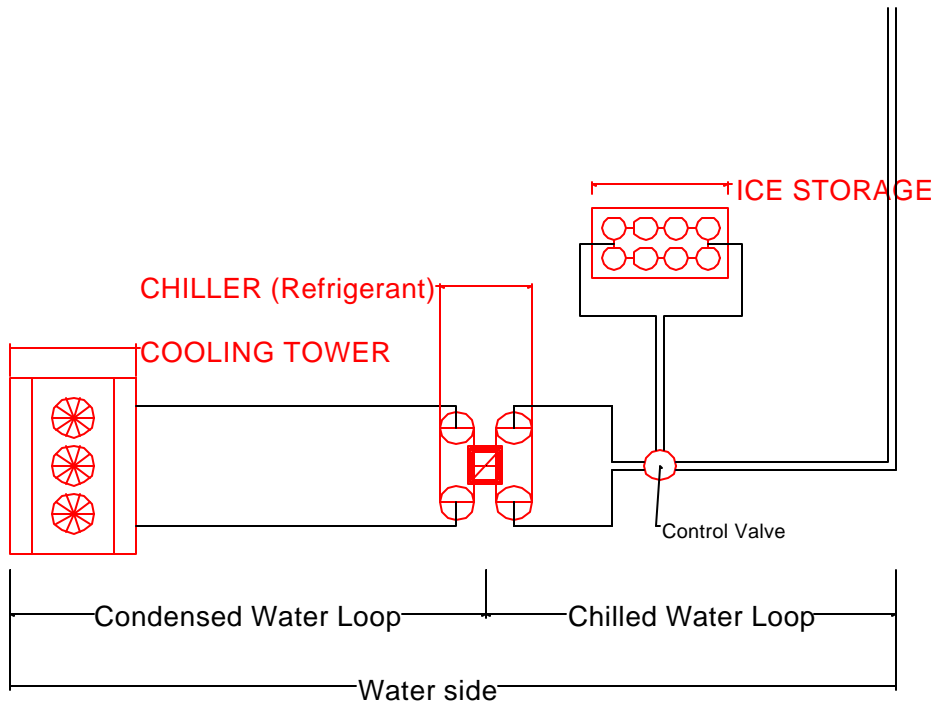
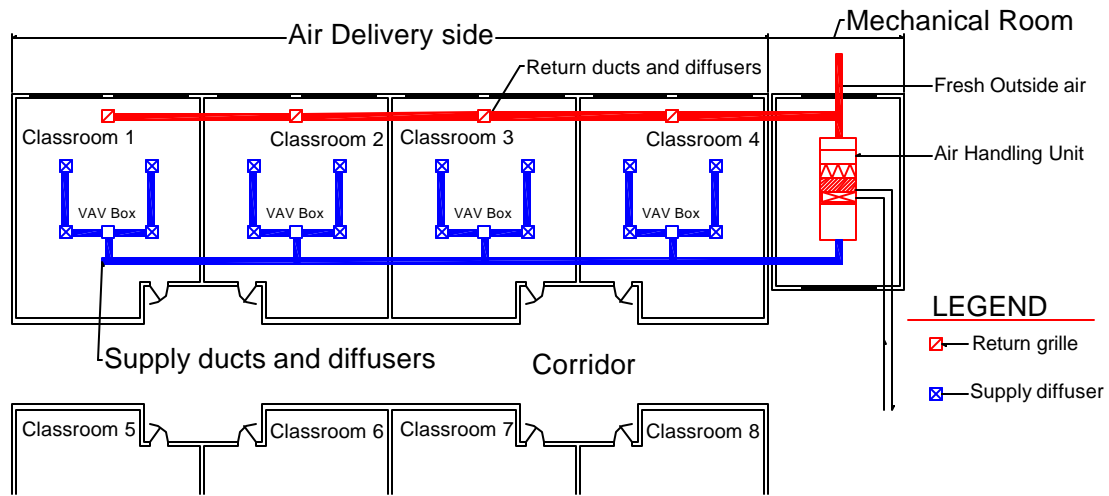
The systems are rated to last 20+ years with regular maintenance.

### Environmental Issues

Because the system throttles back the air when little cooling is needed it also throttles back the amount of fresh air that enters the space. In some cases, overcooling may occur which can cause humidity problems. The primary cooling equipment is located away from the classroom allowing low background noise levels to be achieved in the classroom spaces. The cooling tower is typically located outside and can be noisy. Care should be taken to locate cooling tower in a location that will not cause a noise disturbance to students or neighbors.

### CENTRAL HVAC SYSTEMS

Water-cooled chiller and Ice Storage  
 Storage/VAV Distribution



## **SYSTEM 10: CENTRAL-DECOUPLED**

### **Air Cooled Chiller with Separate Ventilation Air and Space Cooling VAV Air Delivery System**

#### **Description**

This system uses a combination of individual elements to provide cooling including a chiller, pumps, air handlers, VAV boxes and air ducts as the major elements. Decoupled systems have recently been installed in some new schools and are at the forefront of providing good humidity control and space cooling. In general, these systems separate the ventilation requirement from the space-cooling requirement resulting in two different air deliver systems to each classroom. This allows the space to be cooled as needed to meet the loads from the building and people, while maintaining independent temperature and humidity control over the fresh air required. This system is typically used with a central chiller plant (air-cooled or water-cooled) with a VAV air distribution system to cool multiple zones. The ventilation air would also service multiple zones providing air at the ambient room temperature (" 75EF, 50% rh). Other combinations of mechanical systems are also possible. Heating could be supplied by a central system or by electrical heat strips.

#### **First Cost**

Typically this type of system has a high first cost due to the amount of equipment and building space that is required for the equipment. This is a result of using two air handlers to supply air to each classroom which results in additional duct runs and space in the building. The actual cost will vary significantly depending on the actual configuration of the system and the scheduling of operation.

#### **System Control**

Individual temperature control can be easily achieved in each of the classrooms. In this system fresh air is always provided at room temperature so if no cooling is needed then no air-flow will be provided from the space cooling system. This system allows for very good humidity control as the fresh air is dehumidified and will supply air to the space even when no cooling or heating is not needed. If a VAV unit fails, all spaces in the zone will be without cooling/heating, typically one classroom. If an air handler fails a group of zones will be affected, typically 8 to 16 classrooms. In some cases the fresh air system may be able to partially compensate for the cooling load if the main air-handler fails. If the central refrigeration system fails, the school will operate under partial cooling at some reduced level.

#### **Operations and Maintenance**

Due to the complexity of the equipment and the control systems to regulate and monitor performance, trained personnel are needed to supervise the system operation. However, in the event of a breakdown, specialized personnel and equipment will be required.

The larger refrigeration plant provides high efficiency with regard to cooling per unit of energy expended (0.7 to 0.9 kw/ton). Therefore long-term energy savings may offset the increased first cost depending on school size and scheduling.

#### **Life Expectancy**

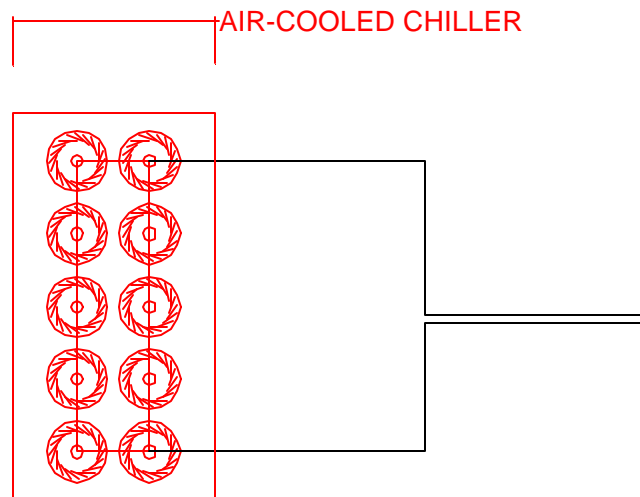
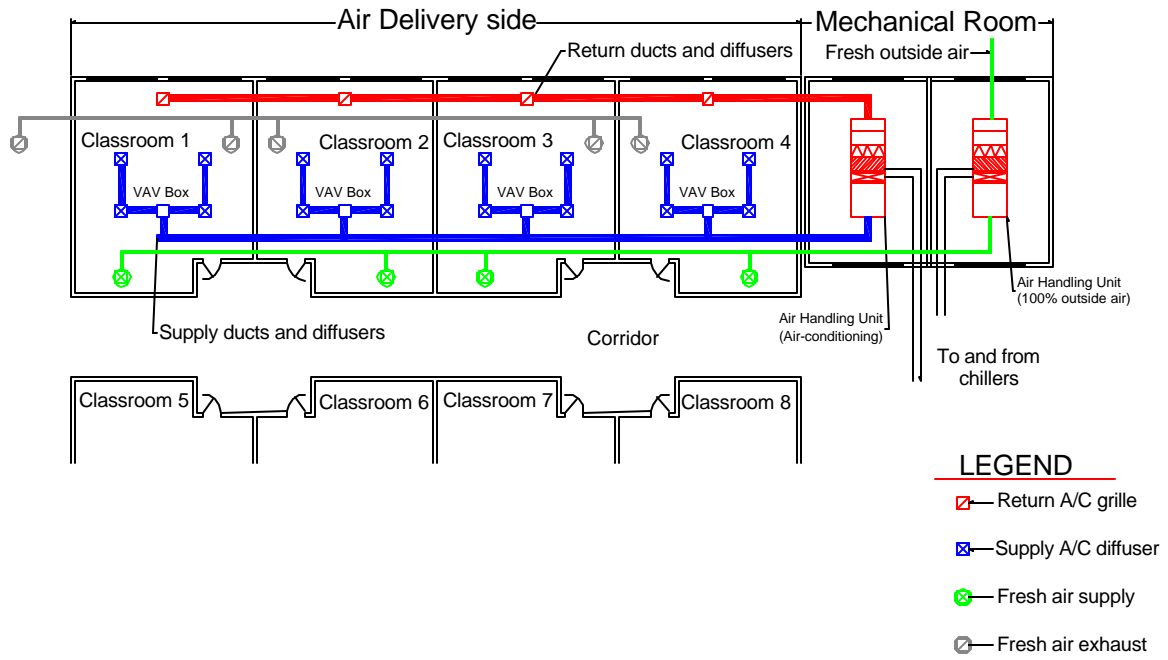
The systems are rated to last 20+ years with regular maintenance.

#### **Environmental Issues**

Separating the space cooling load and the ventilation load allows very good control over the humidity and temperature of the classroom. This provides good thermal comfort and contributes to good IAQ. The primary cooling equipment is located away from the classroom allowing low background noise levels to be achieved in the classroom spaces. This also concentrates the noise generating equipment into contained zones which can be strategically located in a facility to reduce interference with student spaces or adjacent neighborhoods.

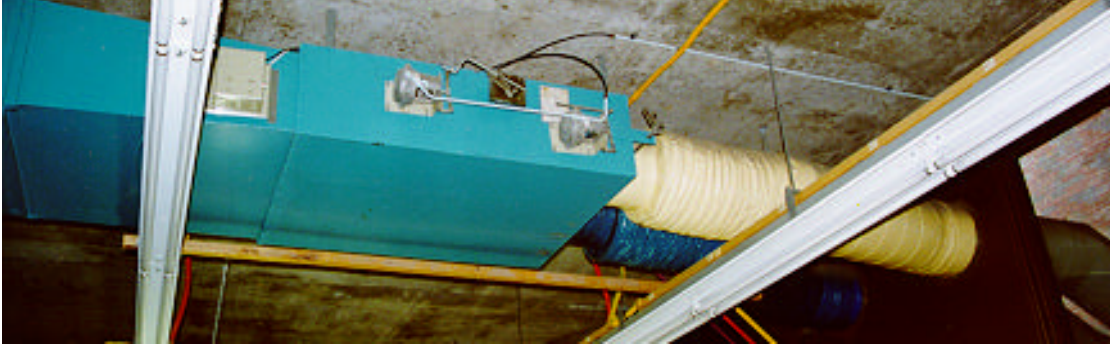
# CENTRAL HVAC SYSTEMS

## De-coupled with air-cooled chiller



## **SYSTEM 11: CENTRAL – DUAL DUCT**

### **Air Cooled Chiller with Dual Duct Air Distribution**



Constant volume mixing box for Dual Duct air delivery system. Receives hot and cold air.

#### **Description**

This system uses a combination of individual elements to provide cooling including a chiller, pumps, air handlers, mixing boxes and air ducts as the major elements. Dual (two) air supply ducts (one with hot air and one with cold air) deliver a constant volume of air to the space. The temperature of the room supply air is varied as needed to meet the cooling load in the space by a mixing box located near the space. This system allows great flexibility for expansion and renovation as mixing boxes may be added or removed as needed to accommodate a variety of zones.

#### **First Cost**

This system has a high first cost. This is due to the central refrigeration plant and the two duct supply system. Furthermore, a central heating system is required that will operate simultaneously with the cooling system to provide suitable temperatures.

#### **System Control**

The temperature in the classroom would be controlled by balancing hot and cold air to provide a constant volume of air at the appropriate temperature. The ventilation air would be through the air handler. If mixing box fails, all spaces in the zone will be without cooling/heating, typically one classroom. If the central refrigeration system fails, the school will operate under partial cooling at some reduced level.

#### **Operations and Maintenance**

Due to the complexity of the equipment and the control systems to regulate and monitor performance, trained personnel are needed to supervise the system operation. In the event of a major system failure, specialized personnel and equipment will be required.

The larger refrigeration plant provides high efficiency with regard to cooling per unit of energy expended (0.7 to 0.9 kw/ton). Therefore long-term energy savings may offset the increased first cost depending on school size and scheduling. Simultaneous heating and cooling are generated for the entire building resulting in added energy costs. Even if no heating or cooling is needed in a classroom, hot and cold air are mixed to provide neutral temperature air to maintain the constant volume of air. There are opportunities for cost savings through economizers to use outside air if it is hot or cold enough so heating costs can be reduced in summer and cooling costs can be reduced in winter but it adds costs to the air handler units.

#### **Life Expectancy**

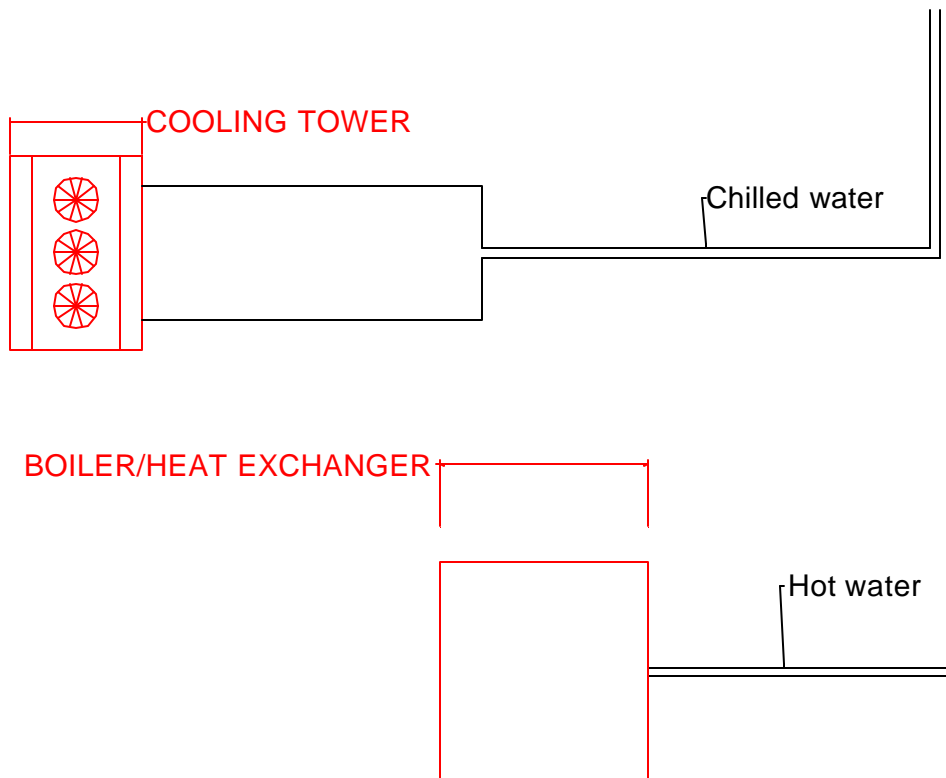
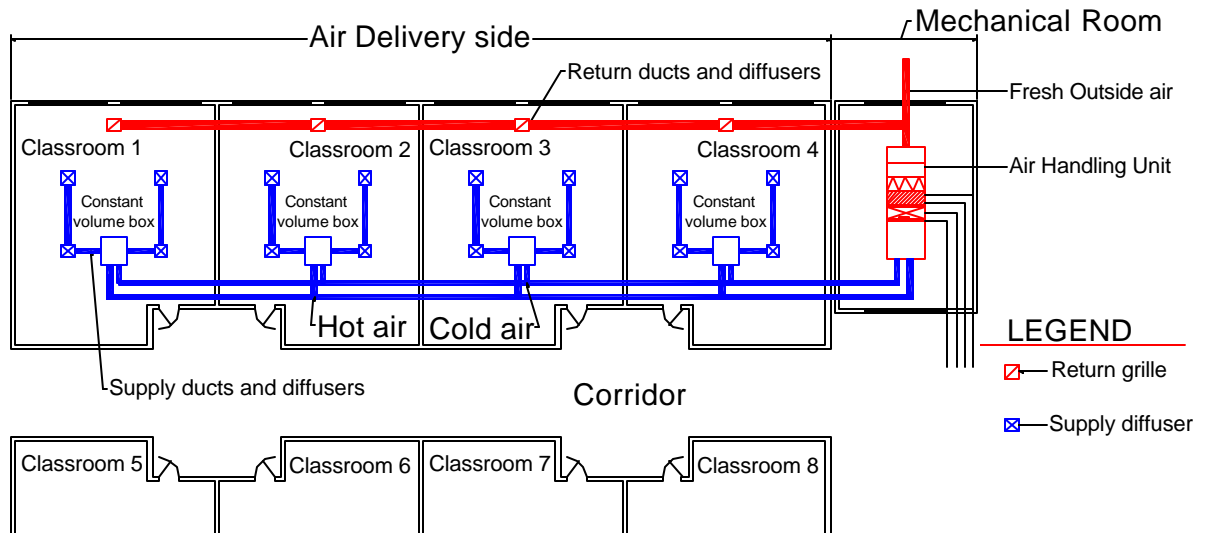
The systems are rated to last 20+ years with regular maintenance.

#### **Environmental Issues**

Providing the ability to mix warm and cold air as needed to provide cooling allows good control over humidity. This provides good thermal comfort and contributes to good IAQ. The constant volume delivery system allows ventilation rates to be maintained even when space cooling or heating is not needed. Careful installation of mixing box units requiring a significant length of duct between the units and the classrooms are required to achieve background noise levels of NC-30.

## CENTRAL HVAC SYSTEMS

### Air-cooled chiller with dual duct



## **SYSTEM 12: CENTRAL-DECOUPLED**

### **Air Cooled Chiller with Separate Ventilation air and Fan-Coil units in rooms**

#### **Description**

Decoupled systems have recently been installed in some new schools and are at the forefront of providing good humidity control and space cooling. In general, these systems separate the ventilation requirement from the space cooling requirement resulting in two different air deliver systems to each classroom. This allows the space to be cooled as needed to meet the loads from the building and people while maintaining independent temperature and humidity control over the fresh air required. This system is typically used with a central chiller plant (air-cooled or water-cooled) to generate refrigeration. In this system, air handling units would be used to provide ventilation air at a neutral temperature (75° F and 50% rh) to each classroom. In each classroom a fan-coil unit would provide cooling as need in the room by recirculating air in the space over a chilled water coil. Chilled water from the central plant would be piped to each classroom and to the ventilation air handlers.

#### **First Cost**

This system has a high first cost. This is due to the central refrigeration plant and the amount of pumps and chilled water pipes that would be run to each classroom. The amount of duct work required would be reduced.

#### **System Control**

The temperature in the classroom would be controlled by cycling the fan-coil unit on and off as cooling was needed. The ventilation air would constantly be supplied to the space during scheduled periods. If a fan-coil fails, all spaces in the zone will be without cooling/heating, typically one classroom. If the central refrigeration system fails, the school will operate under partial cooling at some reduced level. In some instances the ventilation air system may be able to compensate for a failed fan-coil unit.

#### **Operations and Maintenance**

Due to the complexity of the equipment and the control systems to regulate and monitor performance, trained personnel are needed to supervise the system operation. In the event of a major system failure, specialized personnel and equipment will be required.

The larger refrigeration plant provides high efficiency with regard to cooling per unit of energy expended (0.7 to 0.9 kw/ton). Therefore long-term energy savings may offset the increased first cost depending on school size and scheduling.

#### **Life Expectancy**

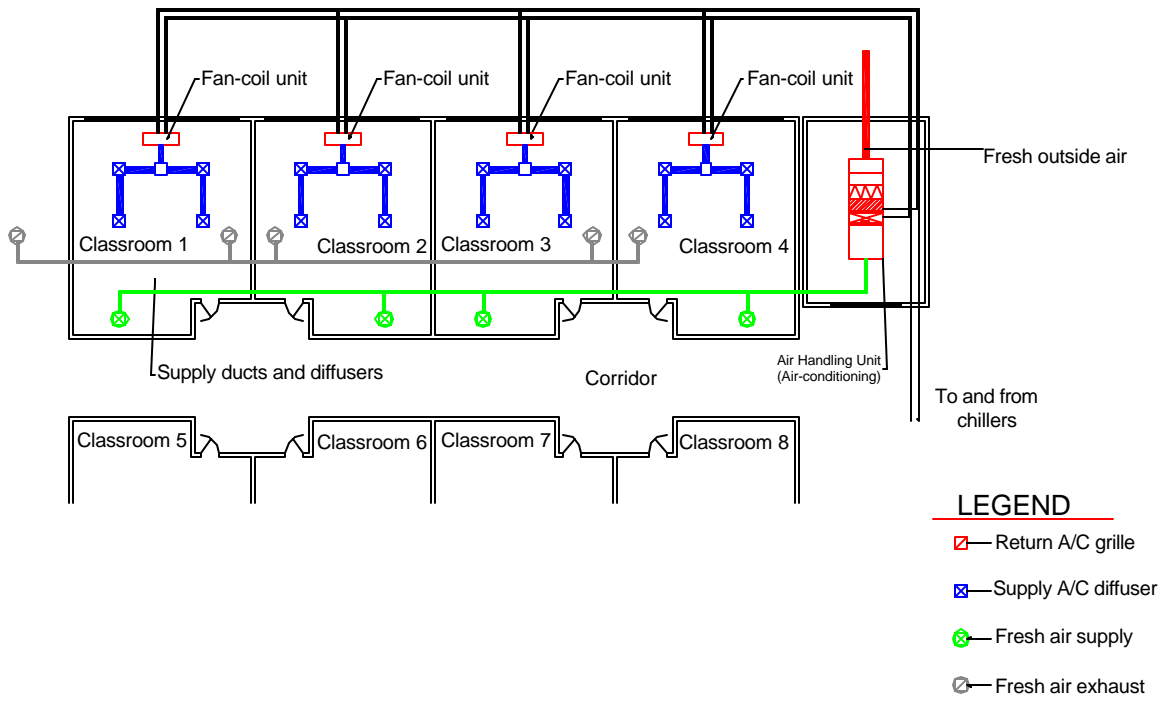
The systems are rated to last 20+ years with regular maintenance.

#### **Environmental Issues**

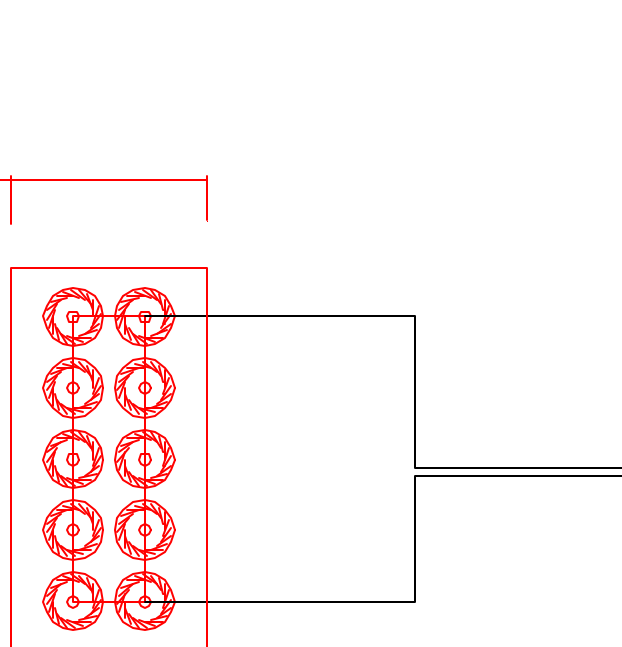
Separating the space cooling load and the ventilation load allows very good control over the humidity and temperature of the classroom. This provides good thermal comfort and contributes to good IAQ. As the fan-coil unit in this system is typically located directly in or adjacent to the classroom, high noise levels in the classroom from the fan are likely. Careful installation of these units requiring a significant length of duct between the units and the classroom are required to achieve background noise levels of NC-30.



## CENTRAL HVAC SYSTEMS De-coupled with fan-coil system



AIR-COOLED CHILLER



## **SYSTEM 13: CENTRAL-MULTIZONE**

### **Air Cooled Chiller with Multi-zone Air Delivery System**

#### **Description**

A multi-zone system incorporates the basic refrigeration plant as described in the central systems above. The major difference is in the air distribution system. In this system a constant amount of air (Constant Volume) is delivered to each space and the temperature of the air is varied to provide the amount of cooling (or heating) needed. This requires providing hot and cold air simultaneously, which is then blended to provide the appropriate temperature air in the classroom. The air (hot and cold) is mixed at the air handler and then distributed to the spaces or zones. Typically a Multi-zone system can provide cooling to 5 to 7 zones.

#### **First Cost**

The first cost is high as it requires a central refrigeration plant and heating plant. Even if no heating or cooling is needed in a classroom, hot and cold air are mixed to provide neutral temperature air to maintain the constant volume of air. There are opportunities for cost savings through economizers to use outside air if it is hot or cold enough so heating costs can be reduced in summer and cooling costs can be reduced in winter but it adds costs to the air handler units. Furthermore, the ducts that carry the cool air to the classrooms all must run from the air handler (home-run) rather than tap-off from a main supply line. This results in the use of more duct and requires more air distribution space than some other systems such as the VAV or non-ducted systems.

#### **System Control**

The temperature in the classroom would be controlled varying the temperature of the air at the air handling unit which would supply a constant volume of air. Ventilation air would be added at the air handler. If the air handler fails, all zones would be without cooling (5 to 7 classrooms). If the central refrigeration system fails, the school will operate under partial cooling at some reduced level.

#### **Operations and Maintenance**

Due to the complexity of the equipment and the control systems to regulate and monitor performance, trained personnel are needed to supervise the system operation. A centralized heating system will need to be maintained during most of the year.

As both heating and cooling is provided, operations costs, primarily for energy will be high. This can be somewhat off-set with energy savings devices. However it will increase the first cost.

The larger refrigeration plant provides high efficiency with regard to cooling per unit of energy expended (0.7 to 0.9 kw/ton). Therefore long-term energy savings may offset the increased first cost depending on school size and scheduling.

#### **Life Expectancy**

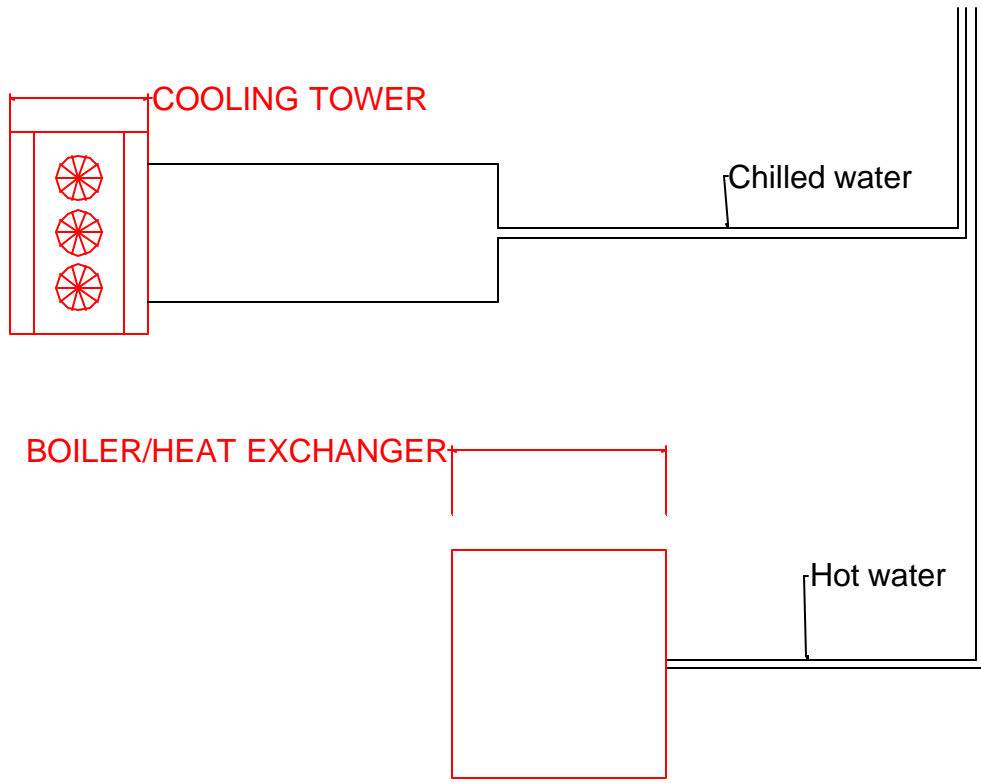
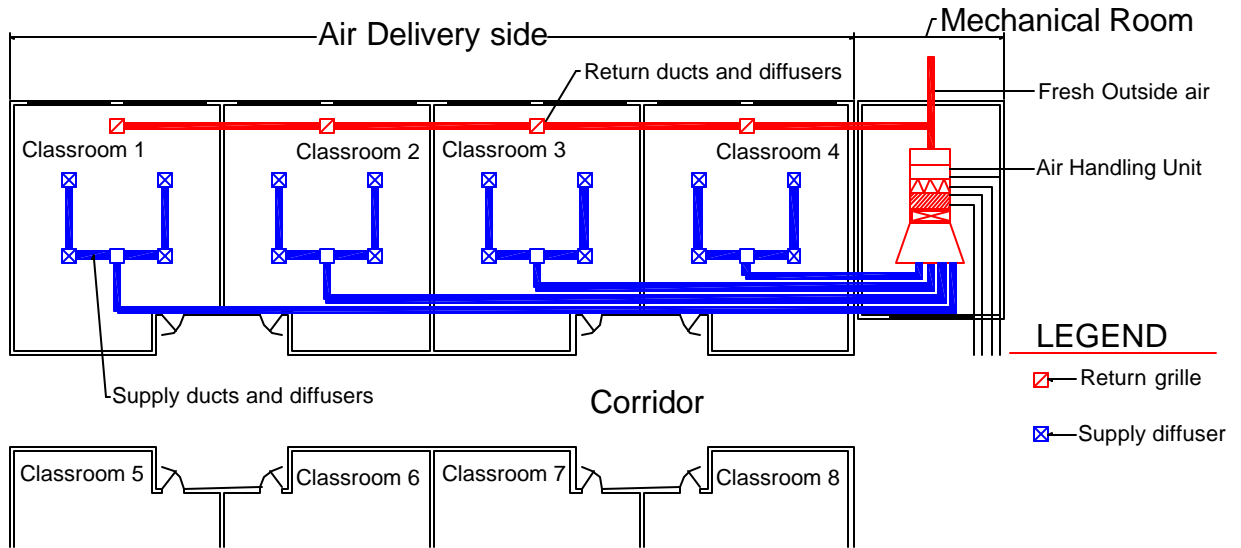
The systems are rated to last 20+ years with regular maintenance.

#### **Environmental Issues**

Because the system provides both heating and cooling, very good control over humidity in the spaces can be achieved. The potential for overcooling is reduced. Since a constant volume of air is provided the amount of fresh air delivered remains constant even when no heating or cooling is needed. This allows for very good control over the indoor air quality. The primary cooling equipment is located away from the classroom allowing low background noise levels to be achieved in the classroom spaces. The air-cooled chillers are typically located outside and are quite noisy. Care should be taken to locate this equipment in a location that will not cause a noise disturbance.

# CENTRAL HVAC SYSTEMS

## Multi-zone/Air-cooled Chiller



## **SYSTEM 14: CENTRAL-LOW TEMPERATURE DECOUPLED Air Cooled Chiller with Ice Storage and VAV Air Delivery System**

### **Description**

The low temperature system delivers cooling air at temperatures of approximately 42° F rather than the typical 55° F that is most commonly used. This allows for smaller air distribution ducts, pipes fans and pumps and ultimately less space is required for these systems. A separate fresh air delivery system is provide to meet the fresh air requirements. Fresh air would be delivered at a space neutral temperature (75° F, 50% rh). This low temperature distribution system could be used in conjunction with an ice storage system if desired.

### **First Cost**

This type of system has a high first cost due to the amount of equipment and building space that is required for the equipment which is typical of central systems. The first cost of equipment and space may be slightly lower than typical systems due to the smaller size. However, the labor costs will be higher as all of the ducts need to thermally insulated to prevent condensation from forming on them in the plenum spaces and then dripping to the classrooms below. The actual system cost will vary greatly depending on the actual configuration of the system. An Ice storage system if included, may contribute a significant amount to the first cost of the system depending on the availability of subsidies from local power utilities.

### **System Control**

Individual temperature control can be provided by supplying a terminal box and thermostat in each of the classrooms. In this case the terminal box would have control over the volume of air (VAV) to meet cooling needs.

### **Operations and Maintenance**

Due to the complexity of the equipment and the control systems to regulate and monitor performance, trained personnel are needed to supervise the system operation. These system are very new at the time of this writing and have been implemented in only a couple schools therefore reliable information on the long term maintenance costs are not available.

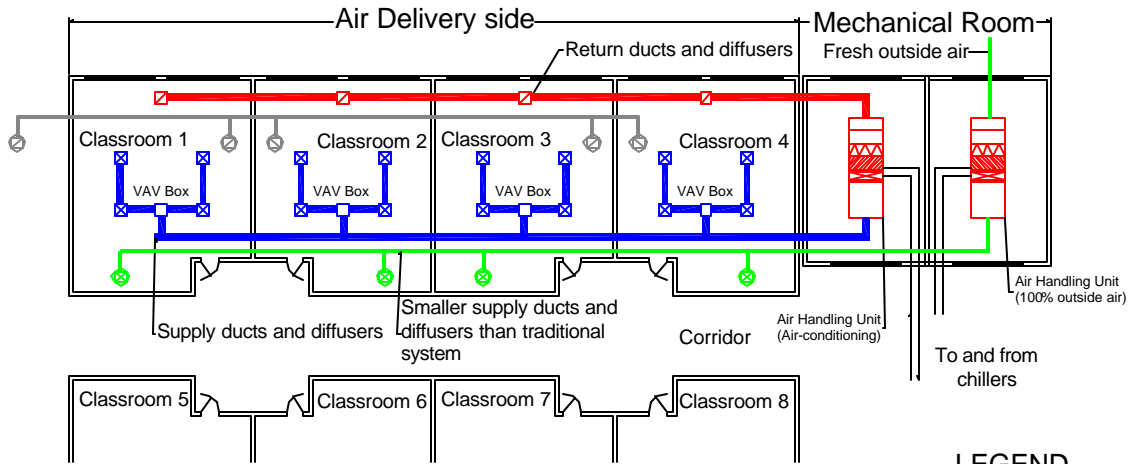
### **Life Expectancy**

The systems are rated to last 20+ years with regular maintenance.

### **Environmental Issues**

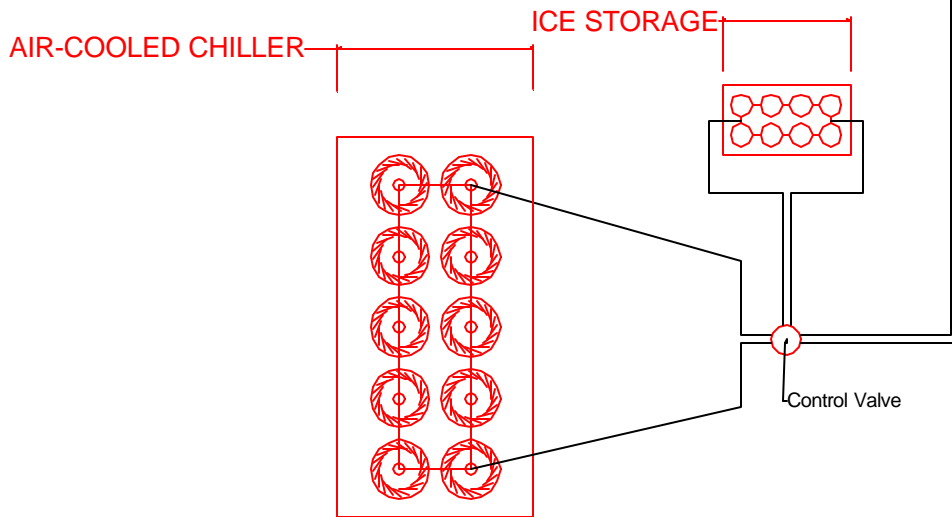
This system provides good IAQ and humidity control. The primary cooling equipment is located away from the classroom allowing low background noise levels to be achieved in the classroom spaces. The air-cooled chillers are typically located outside and are quite noisy. Care should be taken to place this equipment in a location that will not cause a noise disturbance.

### CENTRAL HVAC SYSTEMS Low temperature, de-coupled with ice storage system



#### LEGEND

- Return A/C grille
- Supply A/C diffuser
- Fresh air supply
- Fresh air exhaust



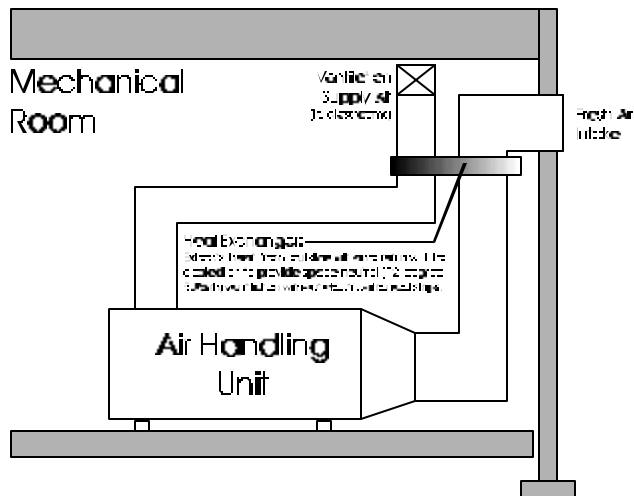
## Energy Savings Strategies

There is a high potential to use the existing LCC analysis of schools to model more aspects of the building than just the cost of the mechanical systems. Building elements such as window glazing, thickness of insulation (for walls and/or roofs), building orientation, building scheduling, and zoning for reduced occupancy (summers) operation. All of these factors could be modeled using the existing software typically used to conduct HVAC LCC analysis. It would require that this be done on an individual building basis. Guidelines should be developed for some of the assumptions that are required for the detailed LCC. Such as: Maintenance costs for appropriately skilled personnel required to maintain systems of different levels of complexity; cost of power distribution to remotely located individual units; cost of building space considering weather it is finished or unfinished space; and cost in acquiring parts for repairs over a given period.

Other issues include the possible use of ceiling fans in conjunction with mechanical systems to allow room set point temperatures to be slightly higher. A feasibility study of this strategy could be conducted in a couple of schools to better evaluate potential energy savings.

Good control of the humidity in classrooms generally requires cooling and in some cases re-heating to avoid overcooling while maintaining required ventilation rates. Current trends favor de-coupled with separate ventilation cooling and dehumidification. There are some passive techniques to reduce the energy costs in this system type such as ventilation re-heat extraction systems that extract the sensible heat from the outside air to reheat the ventilation supply air after it has been cooled for dehumidification. The re-heating is required to prevent overcooling in the classroom. Please refer to figure 34 below. Other techniques might include using waste heat from other systems such as condenser water that may be run through reheat coils in air handling units to regain heat after dehumidification.

**Figure 3-4. Ventilation Re-heat Extraction schematic diagram**



Economizer cycle cooling may be beneficial in northern Florida. This is a technique that uses outside air directly during the winter (cold air) to cool spaces in the building rather than by mechanical cooling. This is typically used in internally load dominated buildings which would typically not include single or two story school buildings. It would include mid-rise schools.

Opening windows is also an option for cooling during many portions of the year in Florida. There are periods during the regular school year (Fall and Spring) when the outside air is at a comfortable temperature and relative humidity. It is important to note that if this strategy is to be utilized, cross ventilation should be included in the design of classrooms to accommodate this strategy. Noisy equipment and outside play areas should be located away from classrooms to avoid disturbances during times of the year when window can be opened. Some discussion of how this option could be implemented with the faculty of the school and the potential for savings and improved school efficiency should also be part of this strategy.

## Qualitative Issues

Building systems, especially HVAC have a tremendous effect on the environmental well being of spaces in schools. Environmental factors such as temperature, humidity, acoustics, and illumination play an important role in the process of learning. In order for students and faculty to concentrate and focus on the daily tasks at hand, they must be housed in a healthful and comfortable environment. Mechanical systems should provide appropriate temperatures with a range of individual adjustment. The system should have good control over humidity levels to promote good IAQ. It is part of the role of the professionals involved in the design and construction process to qualitatively weigh these complex and often contradictory issues. The value of that expertise as manifest in school buildings is usually reflected in the approved scope of services. In many cases, providing reliable LCC savings recommendations while maintaining high quality environments requires complex detailed individual studies that should be supported in the school design budget.

**Humidity:** Humidity in classrooms is a salient indicator of IAQ. If the humidity is controlled (low) then IAQ is usually good. Therefore, mechanical systems that provide better humidity control will typically provide environments with good IAQ. High humidity also reduces the life of building materials such as ceiling tile, carpet and draperies. This is hard to quantify as these items are typically not readily replaced even though there is a need. Many of the sophisticated electronic equipment that are used in schools today such as televisions and computers have a reduced lifetimes in humid environments.

**Moisture:** Infiltration of moisture to the interior spaces of the building can cause mildew and IAQ problems in a similar manner as humidity that is brought in through the ventilation system. A centralized mechanical system can provide a steady positive pressure in the building to prevent moisture from seeping in at porous materials or through cracks in the construction. Furthermore, if run at some reduced capacity in the evenings and weekends, the occupied spaces can remain humidity free through this period. This is especially important in the early morning hours when the outside humidity is at or near 100% and water condenses on the building surfaces.

**Noise:** Building mechanical systems should not interfere with other environmental aspects such as the sonic environment. In many cases, existing mechanical systems in schools produce background noise levels well above those recommended by ASHA. Although the presence of noise in classrooms has been well documented, there is no definitive standard for appropriate noise, nor is there definitive data available to quantitatively relate the acoustic quality of school environments with learning. At the time of this writing the Access Board is currently working to establish a nation wide classroom noise standard under the Americans with Disabilities Act (ADA). It is estimated that NC-30 to NC-35 will be the adopted standard based on existing information. This will have a significant impact on the types of, and installation techniques of mechanical systems in schools favoring systems that locate noisy equipment away from the classroom spaces.