Fast-Track School Construction

Engineers must provide the best mechanical systems that budget and construction time allow. This school construction project not only successfully balanced these concerns but also addressed indoor air quality issues.

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The 175,000 sq ft Westfield Community School in Community Unit School District 300, Kane County, Ill., was built following a fast-track schedule. Construction began in January 1994 and was completed in August 1996. The building steel and the site utilities were bid and under construction approximately two months before the mechanical, electrical, plumbing, and fire protection work. Westfield Community School houses kindergarten through eighth grade classes. It is an elementary school and middle school that share the same offices, cafeteria, library, multipurpose room, and building services.

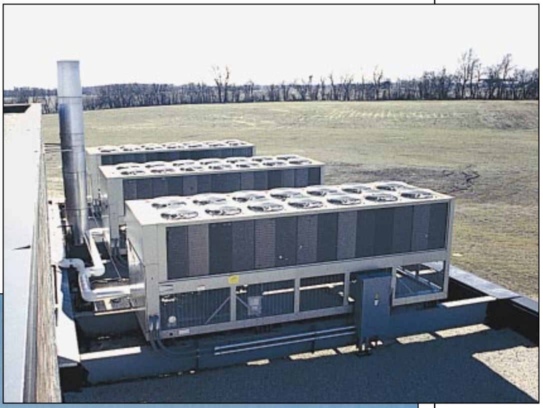
Three alternatives for the mechanical systems were examined in the initial phase of design for cost and operating characteristics. These were:

▲ A central boiler and chiller plant with variable air volume (VAV) distribution and perimeter baseboard radiation.

▲ A central boiler and chiller plant with four-pipe distribution supplying hot and chilled water to four-pipe classroom unit ventilators.

▲ Packaged VAV rooftop HVAC units with gas heating and electric cooling.

Table 1 summarizes these options and shows the cost of each. The school district chose to have VAV air conditioning with perimeter baseboard radiation for heat in lieu of the other options be-



Air-cooled chillers on roof.

cause of the better performance and reduced operating and maintenance costs. Air conditioning would be provided using air-cooled chillers in lieu of a cooling tower and one or more centrifugal chillers to save initial cost and maintenance expenses. The building has a central chiller plant, a central boiler plant, and two central mechanical rooms that house the air handling equipment. Locating all of the air handling equipment in two central fan rooms reduced the chilled water and hot water piping on the project substantially. This allowed the design to beat the initial budget of $3,038,000 by $398,000, resulting in a mechanical system cost of approximately $15.09 per sq ft.

Table 1—Mechanical systems options.

Option	Estimated cost, $
VAV with baseboard heat, fan rooms	3,038,000*
VAV with baseboard heat, packaged rooftop units	2,573,000
Four-pipe unit ventilators	2,655,000

*Actual cost for this system was $2,640,000

Chiller system

The entire building is air conditioned. The air handling equipment is provided with a 20 percent ethylene glycol solution from a central chilled water plant. This provides freeze burst protection so that the system does not have to be drained in the winter.

The chilled water plant consists of three 190 nominal ton air-cooled chillers that are mounted on steel above the boiler room. Each chiller has a dedicated pump to maintain a constant flow through the chiller when it is activated. Each chiller also operates on its own controls to provide 45 F chilled water. Chilled water is pumped to the air handling equipment by a secondary loop served by two pumps. Two pumps were provided so that some cooling could occur if one of the pumps were to break.

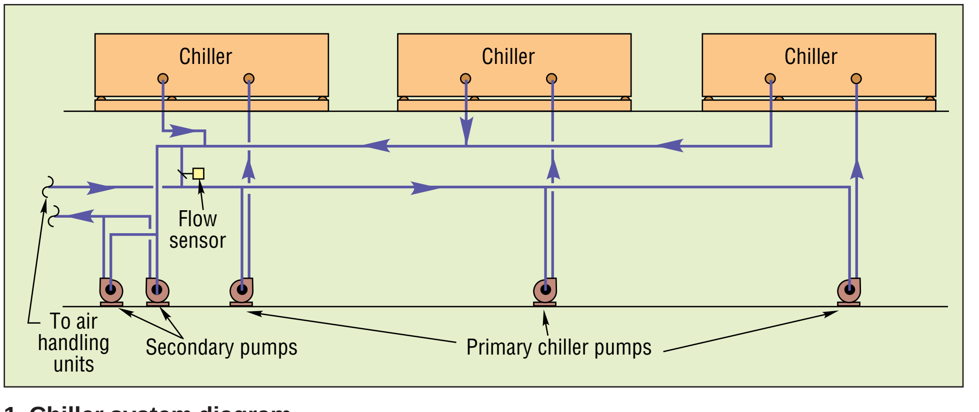
The chiller plant is piped for primary-secondary pumping. The primary loop consists of the three chillers and their pumps piped in parallel with each other. This loop is constant volume in stepped increments of 370 gpm. For instance, if only one chiller is initiated, then the primary loop is 370 gpm; if two are initiated, the primary loop is 740 gpm; and if three are initiated, the primary loop is 1110 gpm.

The secondary pumping loop is variable flow utilizing two-way control valves on all of the air handling unit coils. The flow varies in this loop from 1250 down to 250 gpm. There is approximately 140 gpm of diversity because the gymnasiums and the multipurpose rooms will not be fully loaded at the same time as the academic wings and vice versa. There is not much diversity due to environmental conditions since this building does not have a significant amount of west-facing glass. The pumps ride up and down their pump curves to achieve the variable flow, and the chilled water control valve actuators are sized to close against the block tight head of the pumps. If additional money had been available, this loop would have had variable-speed pumping (Fig. 1).

The chillers are initiated in a lead/lag, first-on/first-off sequence by measuring the flow in the common pipe of the primary loop and the secondary loop. After the lead chiller has been operating for at least 30 min and a reverse flow is sensed in the common pipe, which means that the system flow exceeds the chiller flow, then the next chiller and its respective pump are initiated on. Each chiller then runs on its own controls to maintain 45 F chilled water. The third chiller is started the same way.

The first chiller is initiated off when the last chiller has been operating for over 20 min and the chiller or primary loop flow has exceeded the system flow by 400 gpm for 10 min. This control resets itself if the flow drops below the 400 gpm rate.

The switchover flow and time delays are field adjusted or tuned to match the actual operating characteristics of the building. At times, the building will operate with two or more chillers partially unloaded. This is unavoidable. Each chiller has two separate screw compressors and refrigerant circuits, and each can unload in four steps of 25 percent. This helps the system match the building load since there are three chillers with four steps each for a total of 12 steps of control. The chillers actually perform better when partially loaded, as shown in Table 2. The air handling unit coils were selected to perform with 47 F chilled water so that



1 Chiller system diagram.

Table 2—Chiller performance
(taken from chiller manufacturer's literature).

Load, percent	Capacity, tons	Power, KW	*EER*
100	189.3	214.5	9.6
75	142.0	131.0	11.2
50	94.7	72.1	12.2
25	47.3	30.0	14.0

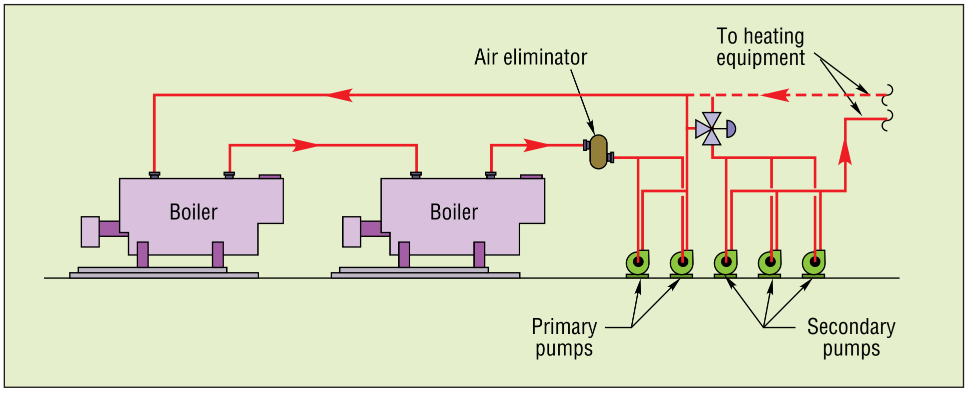
during the time that chillers are being added to the system, humidity control will not be lost. They were also chosen for a 12 F rise at design conditions.

Boiler system

The air handling equipment, finned tube radiation, and unit heaters are provided heating hot water from a central boiler plant. The central boiler plant consists of two 150 bhp scotch marine, natural gas-fired boilers piped in series with dual constant-flow pumps (Fig. 2). If one pump fails, then the second pump rides out on its pump curve to provide approximately 75 percent of the total flow that they provided together. The boilers are sized for two-thirds of the building load as required by the Illinois State School Code Part 175. The flow through the boilers was selected for a 25 F maximum temperature rise through the boiler system, which equals 800 gpm. The maximum temperature drop when two boilers are operating is 12.5 F.

The boiler system is operated whenever the outside air temperature is below 70 F, and the lag boiler is started whenever the outside air temperature is below 30 F. This can be adjusted lower if necessary.

Each boiler was provided with modulating burners. The modulating operating controls were removed from each boiler and reinstalled in the common header after the last boiler in the pumping loop so that when two boilers are initiated, they both fire at approximately the same rate. The operating high limit controls remain on each boiler to insure that they do not over fire.



2 Boiler system diagram.

Heating hot water is supplied to the air handling equipment, finned tube radiation, and unit heaters by a secondary pumping loop that is served by three pumps. This pumping loop provides 555 gpm of heating water to the heating equipment. Most of the equipment is piped with two-way control valves so that this system is variable volume, with the pumps riding up and down their pump curves and providing the reduced flow. The water temperature in this loop is also reset based on outdoor air temperature, from 200 F when the outdoor air is -10 F to 120 F when the outdoor air is 70 F. This provides better heating control and reduces the heat loss of the piping system. The heating equipment in the building was sized for 200 F entering water and a 50 F drop. This reduced the size of the heating piping.

Just like the primary pumping circuit, if one of the pumps fails, then the other two follow their pump curves to provide almost as much flow as all three provided. Three pumps were chosen because two pumps could not be adequately selected and would have actually cost more than the three pumps.

Piping the boilers in series allows them to be started and stopped by the control system at will. It can do this because every boiler is hot—even the boilers that are off. There is no way to shock a boiler with cold water. This also allows the use of large temperature drops in the building piping and a much lower reset schedule for better control.

Air handling systems

The classrooms, library, and offices are heated and air conditioned by variable volume air handling units and perimeter baseboard radiation. Each room has its own VAV box and control of its finned tube radiation if located on the perimeter. There are five VAV air handling systems—a 36,000 cfm unit for the grade school classroom wing, a 43,000 cfm unit for the middle school classroom wing, an 11,000 cfm unit for the offices, an 18,000 cfm unit for the library and learning resources areas, and a 21,500 cfm unit for the performing arts wing.

Each air handling system consists of a draw-through air handling unit with a chilled water cooling coil, two-row preheat coil, 30 and 65 percent efficient filters, mixing dampers, and a return fan. Schools often only have 20 to 30 percent efficient filters with no capability to provide better filtration because no space is provided for better filters and the fans cannot provide the additional pres-

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Boiler installation.

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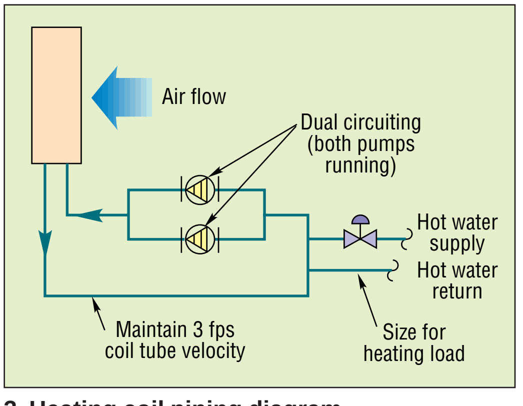
sure drop. To provide better indoor air quality (IAQ), we decided that this building should have better filters right from the start. Each air handling unit has 30 percent efficient prefilters and 65 percent efficient final filters.

IAQ is also enhanced by the variable volume air handling systems, which have fan-tracking control to insure that the minimum quantity of outside air is provided at all times. Each air handling system also has a 100 percent outside air return/exhaust fan economizer to use outside air for cooling when the outside air temperature is below 55 F. The control system also brings in 100 percent outside air and uses the chilled water to cool it down to 55 F when the outside air temperature is between 65 and 55 F.

Fan volume is adjusted with inlet guide vanes. The supply fan inlet vanes are controlled by a duct static pressure transmitter to maintain 1.25 in. WG. This sensor is located two-thirds of the way downstream in the supply main. There is an air measuring station in the supply main and the return main to measure air velocity. The control system computes the air flows and modulates the return fan inlet vanes to maintain a set differential between the supply and return fans equal to the minimum outdoor air required for the system.

When the system is throttled back during low load, it provides 100 percent outdoor air. This air then requires preheating because it would be objectionable to supply -10 F air into the spaces. The preheat coils are piped with two pumps in parallel to provide a constant flow through the coil. These pumps are sized to provide a flow that equals a minimum of 3 fps velocity in the tubes of the coil. This will keep the coils from freezing. This flow is much greater than the flow required to heat the air, and during operation, the temperature of this loop approaches the temperature of the discharge air plus a few degrees. This loop is supplied hot water from the secondary heating piping system by a two way valve (Fig. 3). The actual amount of 200 F water required to heat the ventilation air is quite small compared to the flow required to keep the coil from freezing. It is not uncommon to see a 4 in. coil loop served by a 1 in. hot water line and 3/4 or 1/2 in. heating valve. The air handling units are for air conditioning and ventilation, not heating. The pumps operate whenever the outside air is 50 F or below regardless of whether the air handling unit is operating or not.



3 Heating coil piping diagram.

The control valve is controlled by a low limit temperature sensor located downstream of the preheat coil. This valve remains under control regardless of whether the air handling unit is operating or not. This eliminates nuisance trips of the low limit manual reset control during startup. If the valve did not remain under control, the air in the air handling unit would rise to above 100 F when the unit is off. When the unit is started up, the outside air damper and exhaust damper open 100 percent and the control valve closes. This trips the low limit manual reset.

The grade school gymnasium, middle school gymnasium, and the shared multipurpose room are too large to be supplied air from the variable volume air handling systems. These spaces are also used at times when the VAV systems are off. Each of these spaces is heated and air conditioned with its own constant-volume draw-through air handling unit with return fan economizer. The grade school unit is 8100 cfm, the middle school unit is 19,000 cfm, and the multipurpose room unit is 12,500 cfm. The heating coils are piped the same as the VAV units discussed above, but because they also heat the space, the supply water flow from the hot water mains is closer to the flow circulated through the unit. The heating coils were selected for 150 F entering water and 125 F leaving water.

Kitchen HVAC

The school has a complete commercial kitchen that provides meals to the students of this school and other schools in the district. Because of this, the kitchen is much larger than would normally be found in a school this size. The kitchen is air conditioned and heated by a 7800 cfm draw-through air handler with a chilled water coil and a glycol heating coil. This unit is ducted to take 3900 cfm of air from the middle school gymnasium and provide 3900 cfm of outside air. The fan has a two-speed motor and operates at low speed whenever the main hood exhaust fan is off. This coil is supplied with 175 F, 20 percent ethylene glycol from a water-to-glycol heat exchanger.

The total installed kitchen exhaust is 22,375 cfm, and maximum simultaneous exhaust is 18,475 cfm. The main kitchen exhaust is provided by a 16,000 cfm makeup type hood; the makeup air volume is 9600 cfm. This makeup air is heated by a constant-volume air handling unit fitted with a glycol heating coil. In addition to the main exhaust hood, the kitchen also has a dishwasher exhaust of 1275 cfm and two 600 cfm oven exhausts, providing the design exhaust volume of 18,475 cfm.

There is also a general kitchen exhaust fan sized for 3900 cfm. This runs whenever the main supply air system is operating and the main exhaust fan is off.

The kitchen is positively pressurized if the main hood exhaust, dishwasher exhaust, and oven exhausts are off. If any of these fans are on, the kitchen is at a negative pressure relative to the rest of the building. This pressurization strategy helps control moisture, odor, and smoke. There is a large serving opening that opens up into the multipurpose room. This is utilized to transfer air to and from the kitchen.

Temperature controls

The temperature control system was bid to be pneumatic, with an alternate design to provide direct digital controls with pneumatic actuation of valves and dampers and digital VAV boxes also bid. The digital control system would have cost $40,000 more than the all-pneumatic system. The school district decided not to spend the additional money, and the all-pneumatic temperature control system was installed.

Conclusion

It is the engineer's responsibility to provide the best system that the budget and the construction time allow. This building balances these issues and provides a building with a mechanical infrastructure that can be upgraded in the future, as money allows, to provide additional operating cost savings.

The performance of both the boiler and chilled water variable volume pumping loops will be reviewed to see if it is possible to save any pump energy. The VAV systems' performance will also be reviewed to see if they turn down more than 50 percent for any significant amount of time. If they do, then there is a possibility to use variable-speed drives instead of the variable inlet guide vanes, which would save additional energy and money. HPAC

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single-speed condenser fan will, when started, want to continue in the direction it was free-wheeling. If this is the wrong direction, it will block air movement through the condenser. A three-phase motor will spin in only one direction; if free-wheeling in the wrong direction, the starting torque (backward spinning fan inertia) could damage the motor or fan blade connection. Proper shielding of the fans or rotation direction control will prevent this.

Installation of units on large roofs can be a challenge. The capacity of most job cranes is limited as the reach (horizontal roof distance from the crane at grade) is increased. Unit placement by helicopter is limited to 3500 lb for most services. Higher capacity lift helicopters are available at greatly increased cost. This comes into play most often when RTUs are replaced. The original RTUs were placed during the construction of the structure with better accessibility. Additionally, the weight of the original units may be less than the replacement units. These weights should be verified prior to installation.

Maintenance

All mechanical equipment requires periodic maintenance. Access to rooftop equipment should be considered in the design by the architect, roofing consultant, and engineer. Wear or walk pads to each unit will minimize future damage to the roof by individuals and service equipment. Access to the roof should be considered relative to future component replacement—*e.g.,* moving the heaviest replacement component, usually a compressor, up to and across the roof to the unit. HPAC