Gas Heat Conversion and Cogeneration Save High School Money

By BRIAN M. BERG, JR., PE,
Project Engineer,
Brian Berg & Associates, Ltd.,
Schaumburg, Ill.

Building program leads to significant energy cost savings from a unified mechanical system for the old and new

The 1993 building program of Lincoln-Way Community High School District 210, Frankfort, Ill., included additions to the East and Central Campuses. The additions to the East Campus consisted of an 84,000 sq ft academic wing, an 86,000 sq ft fieldhouse, a 51,000 sq ft auditorium and performing arts wing, and a 45,000 sq ft addition to the offices. It also consisted of some remodeling in the core of the existing academic wing. The existing facility was approximately 138,000 sq ft. The enlarged structure totals approximately 368,000 sq ft.

The academic wing addition is attached to the west side, and the fieldhouse addition is attached to part of the north side of the existing building. The auditorium and performing arts addition is attached to the east side of the existing building (Fig. 1).

As part of this project, the original building was converted from all-electric space and domestic water heating to natural gas-fired boilers and water heaters. A cogeneration plant was also added to reduce the electrical demand charges and save the school district additional money. This article focuses on the heating conversions and cogeneration installation. The cost of increasing the new building services to accommodate the existing building was much less than if this work had been completed for each building separately. This made the payback time of these items more acceptable.

Space heat conversion

New boiler, electrical, and cogeneration rooms were attached to the new fieldhouse to accomplish the conversion. This was located in the back at the center of the entire facility to reduce the size and length of pipe runs of the heating hot water, domestic hot water, and electrical systems.

The heating hot water mains to the new academic wing penthouses would run above the ceiling of the existing second floor. These heating mains just happen to run by all but two of the existing penthouses and fan rooms. This made it apparent that the removal of the existing electric heating coils and the installation of hot water heating coils in the existing air handling units would be cost effective. Of the two fan rooms that the new mains did not run by, one was immediately next to the performing arts wing addition, and the mains for that wing were also nearby. This left only one penthouse that required any significant amount of piping to obtain heating hot water.

The new boiler plant consists of three 250 hp wetback scotch marine-type water boilers. Each boiler can supply one-half of the maximum heating load, as required by the Illinois School Code, so one boiler is standby. The boilers are piped in series with two constant volume circulating pumps and are controlled in a lead-lag fashion to maintain 200 F in the header after the last boiler

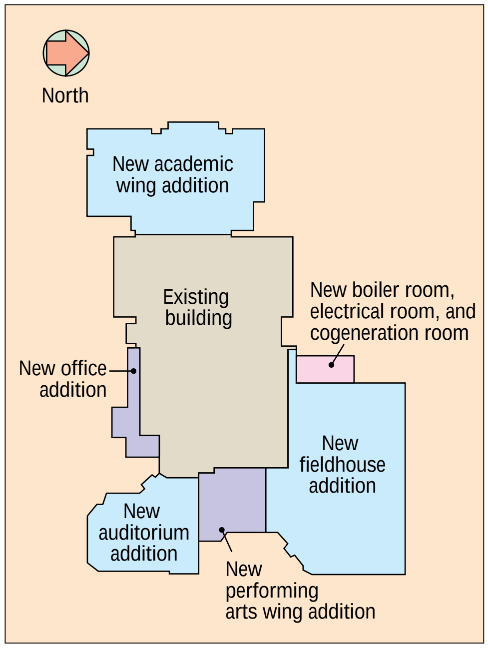
(Fig. 2). Because the boilers are piped in series, they are always hot, and the digital control system can start and stop them at will without additional thermal stress. The high temperature drop (50 F) is not seen by only one boiler.

The building is supplied with heating hot water by four pumps that run together in parallel through modulating butterfly valves. This enables the hot water supplied to the building to be reset from 200 to 100 F to provide better temperature control at the heating equipment. If one of the pumps should fail, the remaining three would follow their pump curve and provide more than 90 percent of the original flow.

The conversion of the existing air handling units (AHUs) was accomplished by removing the existing electric heating coils and controls and replacing them with new hot water heating coils and controls. These AHUs were of three different types. The first type were multizone units. Each of these seven units was given a new hot water heating coil and a coil circulating pump. The coil circulating pump provides a constant flow of water through the heating coil to maintain a consistent hot deck temperature from one side of the unit to the other. This also enables the building hot water system to be variable volume with a 50 F temperature drop, reducing the size of the building hot water mains (Fig. 3).

The second type of unit included 12 constant volume, single-zone units. There were 12 of these units. The existing electric heating coils were removed, and new hot water heating coils and controls were provided. These units take in 20 to 25 percent outside air and are provided with two pumps in parallel. These pumps maintain a water velocity in the tubes of the coil greater than 3 fps, which protects the coils from freezing (Fig. 4). The primary/secondary pumping system of these units enables the building hot water system to be variable volume and maintain the 50 F temperature drop as noted above.

Because the existing school was all-electric heat and was designed for the lowest initial cost, six of the 12 single zone AHUs provided 50 percent or more outside air. These existing systems were reviewed to see if there was any way of getting makeup air from other areas of the building instead of heating outside air. The ductwork to the units that supplied air to the ex-



1 Building key plan.

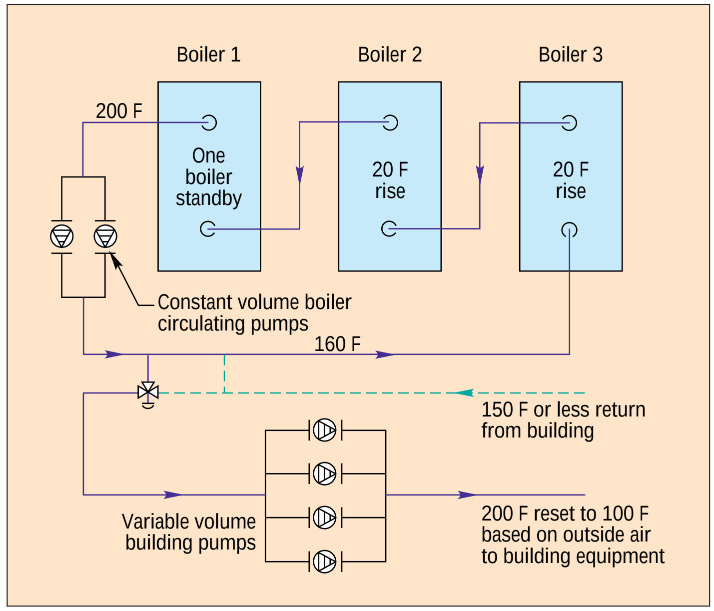
760-KW engine-generator set. The heat recovery silencer is the vertical unit in line at the far end of the engine.

isting gym locker rooms was changed so that they could take air from the gymnasium. Originally, these units provided 100 percent heated outside air to the locker rooms. This air was then exhausted. The new coils for these units were sized to take in 25 percent outside air. In addition, the new heating coils for the gymnasium units were also sized so that they can take in 25 percent outside air. This provides more than enough outside air for locker room exhaust, code required ventilation, and space pressurization.

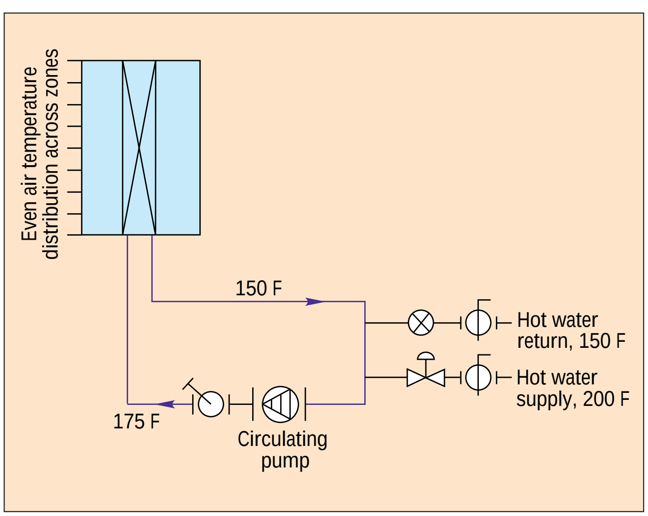
The conversion of the locker room AHUs from 100 to 25 percent outside air will save 4000 therms per year in energy or approximately $1200 (Table 1). This work cost approximately $4000 for a simple payback of 3.3 years. If the building remained all-electric heat, this change would have saved $4500 per year for less than a one-year payback.

It was not possible to change the ducting of four of the existing single-zone units to reduce the quantity of outside air that they provide. This is the third type of air handling unit in the building. These units supply makeup air to the kitchen and shop areas of the building. To protect the new heating coils from freezing, a water-to-glycol heat exchanger and pumps were provided. The heating coils

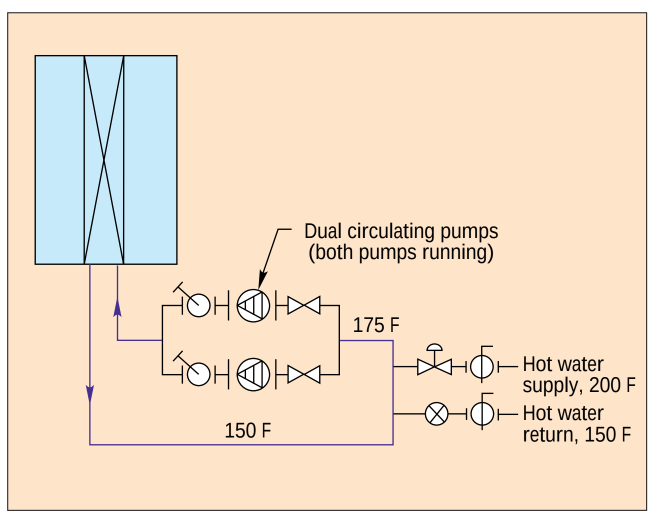
2 Boiler plant piping.



New gas-fired boiler plant. The new gas-fired domestic water heaters and storage tanks are shown at the left rear.



3 Multizone air handling unit piping.



4 Single-zone air handling unit piping.

were sized for the heating load, including outside air with 150 F 40 percent high-temperature ethylene glycol.

The increase in cost of the boiler plant attributable to the existing building was about $188,000. The estimated cost of the removal of the electric heating coils, installation of new hot water heating coils and pumps, and increasing piping size was $170,000. The total cost of the conversion was approximately $358,000. The projected yearly energy cost saving is the difference between the electric heating cost and the projected gas cost as noted in Table 2 and is $36,400. This works out to a simple payback of 9.8 years. If a new boiler plant was not being provided to supply the new additions, the cost to change the existing building to gas heating would have been significantly higher and would certainly push the payback to the 15-year mark. A 15-year payback would have been unacceptable. Table 3 shows the lighting and power costs for the original building.

Domestic hot water

The existing domestic hot water heating system was also all-electric. The new additions required additional water heating. The existing electric domestic water heater was over 20 years old and in need of repair. Obviously, a new domestic water heating system or at the least significant maintenance would be required sometime soon. A new gas-fired domestic water heating system was provided in the new boiler room. This system consists of three 250-gal forced draft gas-fired storage-type water heaters and three 865-gal storage tanks. The estimated incremental cost of the new system sized to handle the entire building vs. one that would have been sized just for the additions was $27,500. The projected saving of $5000 per year as shown in Table 4 works out to a simple payback of 5.5 years.

Table 1—Energy savings due to reduction of outside air heating.

Modified bin method				
Temperature range	Average temperature	Heating load, Btuh	Bin #1 9 to 16 hr	Energy usage, MBtu
65/69	67	17,697	220	3893
60/64	62	47,193	176	8306
55/59	57	76,689	160	12,270
50/54	52	106,185	163	17,308
45/49	47	135,680	164	22,252
40/44	42	165,176	181	29,897
35/39	37	194,672	237	46,137
30/34	32	224,168	251	56,266
25/29	27	253,663	160	40,586
20/24	22	283,159	100	28,316
15/19	17	312,655	60	18,759
10/14	12	342,150	43	14,712
5/9	7	371,646	30	11,149
0/4	2	401,142	18	7221
–5/–1	–3	430,638	9	3876
–10/–6	–8	460,133	3	1380
–15/–11	–13	489,629	1	490
			Total	**322,819**

Total air quality of 100 percent outside air air handling units—3530 + 3720 = 7250 cfm
Total quantity of outside air that will not be heated—7250 3 0.75 = 5437 cfm
Bin data is taken from "Engineering Weather Data" 1978, Dept. of Air Force, the Army and the Navy.
Heating load = cfm 3 1.085 3 (70 F, average bin temperature)
Total energy saved = 322,819 31.25 (gas utilization) = 403,524 or 4035 therms

Table 2—Electric heat vs. gas heat for the original building.

Month	Actual electric heat used, KWH	Actual electric heat cost	Estimated gas usage, therms	Estimated gas cost, $
Jan	212,800	$9553	8171	$2576
Feb	196,800	$8834	7556	$2382
Mar	166,400	$7470	6389	$2014
Apr	94,400	$4238	3625	$1143
May	38,400	$1724	1474	$465
Jun	16,000	$0	0	$0
Jul	26,400	$0	0	$0
Aug	27,200	$0	0	$0
Sep	28,000	$0	0	$0
Oct	44,800	$2011	1720	$542
Nov	169,600	$7613	6512	$2053
Dec	188,000	$8439	7218	$2276
Totals	**1,208,800**	**$49,882**		**$13,452**

Note: The electric usage and cost is taken from actual electric heating bills for 1991. 1991 was chosen as a representative year for simplicity of calculations.

The cogeneration plant

There was no more room in the existing electrical room for any additional switchgear, and the existing switchgear was too small to feed both the new additions and the existing building. A new electrical service would be required to feed the new additions. The new electrical service could easily be designed to include the connections required for the cogeneration plant, and the cost of adding cogeneration would consist of only the cost of the cogeneration equipment.

The cogeneration system con-

Table 3—Lighting and power cost, existing building.

	Demand, KW	Consumption, KW	Demand cost	Consumption cost
Jan	378	117,120	$4298	$4417
Feb	345	127,920	$3923	$4798
Mar	353	104,760	$4014	$3982
Apr	346	98,400	$3934	$3758
May	321	91,320	$3650	$3508
Jun	264	45,840	$5394	$2470
Jul	186	49,800	$4260	$2976
Aug	307	60,240	$6005	$3372
Sep	321	103,200	$10,251	$4913
Oct	383	113,760	$4355	$4299
Nov	382	128,520	$4343	$4819
Dec	391	106,320	$4446	$4037
			$58,873	$47,349
			Total electric cost	**$106,222**

Note: The electric usage and cost is taken from actual electric bills for 1991. 1991 was chosen as a representative year for simplicity of calculations.

Table 4—Electric domestic water heating vs. gas heating, existing building.

Month	Actual electric heat used, KWH	Actual electric heat cost	Estimated gas usage, therms	Estimated gas cost, $
Jan	9000	$565	384	$121
Feb	11,280	$709	481	$152
Mar	10,200	$641	435	$137
Apr	8640	$543	369	$116
May	10,200	$641	435	$137
Jun	2520	$158	108	$34
Jul	2160	$136	92	$29
Aug	2880	$181	123	$39
Sep	10,560	$663	451	$142
Oct	11,160	$701	476	$150
Nov	11,640	$731	497	$157
Dec	10,080	$633	430	$136
Totals	**100,320**	**$6302**		**$1349**

Note: The electric usage and cost is taken from actual electric bills for 1991. 1991 was chosen as a representative year for simplicity of calculations.

New space mechanical systems

Space heating in the new additions is accomplished by means of air handling units (AHUs) incorporating hot water coils. The offices and auditorium are also mechanically cooled via chilled water coils in the AHUs serving these spaces. A summary of the systems employed follows.

- Seven multizone units serve the 84,000 sq ft academic (classroom) wing addition. The new 17,000 sq ft auditorium and performing arts wing is heated by means of a single multizone unit.
- Constant volume, single-zone AHUs supply the main areas of both the fieldhouse and the auditorium. The large, open area of the 86,000 sq ft fieldhouse is heated and ventilated by two large, single-zone constant volume units. The locker area, showers, weight room, and other ancillary areas are served by two multizone units.

The auditorium proper is served by two constant volume AHUs. These are fitted with both preheat and reheat coils and with chilled water coils. The lobby areas are heated and cooled by means of a single multizone unit.

- Office space was enlarged from 4500 sq ft to 9000 sq ft. This area is served by a VAV air handler having both hot water and chilled water coils.

Prior to remodeling, the original offices were heated and cooled with a multizone unit having an electric resistance coil and a DX cooling coil.

- Chilled water for the office and auditorium space cooling is provided by three 75-ton packaged air-cooled chillers.
- The original electric control system was retired. The HVAC in both the original building and the new additions is controlled by a modern DDC energy management system.

sists of a 760-KW natural gas-fired engine-driven cogenerator, an automatic paralleling system, and load-shed breakers. This system combined with the load-shed breakers also functions as a standby generator. It is estimated that during the winter or low-load months, the cogenerator will provide 65 percent of the total electrical demand of the building. At all of the other times, it will provide approximately 50 percent. The engine is turbocharged and operates at 1200 rpm.

The cogenerator cooling system consists of two water-to-water heat exchangers and a roof-mounted radiator. The engine jacket water is passed through a heat-recovery silencer before dissipating the heat in the heat exchangers. The system is piped so that the cooling fluid heats boiler water, then domestic water. This allows more heat to be removed from the fluid because the temperature difference between the boiler water and the jacket water is only 10 F. The roof-mounted radiator is used to reject the heat if the heat exchangers are not able to cool the jacket water sufficiently. It was not economically feasible to recover the after-cooler heat, so a separate roof-mounted radiator was provided.

The projected cost of electricity without cogeneration as shown in Table 5 was approximately $427,000. The actual cost of electricity with cogeneration as shown in Table 6 was nearly $213,500. The projected electric-

Table 5—Projected electrical costs without cogeneration, entire complex.

	Demand, KW	Consumption, KW	Demand cost	Consumption cost
Mar	974	259,362	$11,015	$15,291
Apr	1222	355,229	$13,595	$21,256
May	1240	365,995	$13,803	$23,143
Jun	946	275,631	$13,472	$16,848
Jul	918	275,634	$13,071	$16,112
Aug	1163	309,646	$16,563	$21,002
Sep	1192	359,637	$16,974	$24,614
Oct	1266	361,563	$14,092	$22,578
Nov	1323	433,160	$14,725	$25,228
Dec	1201	448,110	$13,363	$24,738
Jan	1172	423,039	$13,047	$23,783
Feb	1182	483,039	$13,153	$25,929
			$166,873	$260,524
			Total energy cost	**$427,397**

Note: Electrical consumption was projected using the actual use for a period beginning March 1995 and ending February 1996 (see Table 6).

Table 6—Actual electical energy costs with cogeneration, entire complex.

	Demand, KW	Consumption, KW	Purchased electricity cost	Cost of cogeneration gas
Mar	240	122,104	$7275	$4434
Apr	478	207,684	$12,774	$4172
May	500	225,025	$15,039	$3608
Jun	219	138,209	$8948	$3045
Jul	198	147,185	$8727	$3010
Aug	431	171,260	$13,046	$3339
Sep	459	217,474	$16,441	$3668
Oct	529	228,795	$14,946	$3093
Nov	558	288,537	$16,914	$4422
Dec	460	307,007	$16,626	$5780
Jan	426	283,388	$15,714	$6589
Feb	440	329,878	$17,123	$4731
			$163,574	$49,892
Total cost of electricity with cogeneration				**$213,465**

Note: Electrical consumption and costs were for a period beginning March 1995 and ending February 1996. The ogeneration system operates Monday through Friday from 9 AM to 10 PM 52 weeks per year.

Table 7—Yearly energy and cost savings summary.

Item	Energy saved, therms	Cost of energy saved	Energy cost savings	Total savings
Reduction of outside air	4000	$1200		$1200
Gas space heating[1]			36,400	$36,400
Gas domestic water heating[1]			$5000	
Cogeneration system [2]			$237,900	$237,900
			Total	**$280,500**

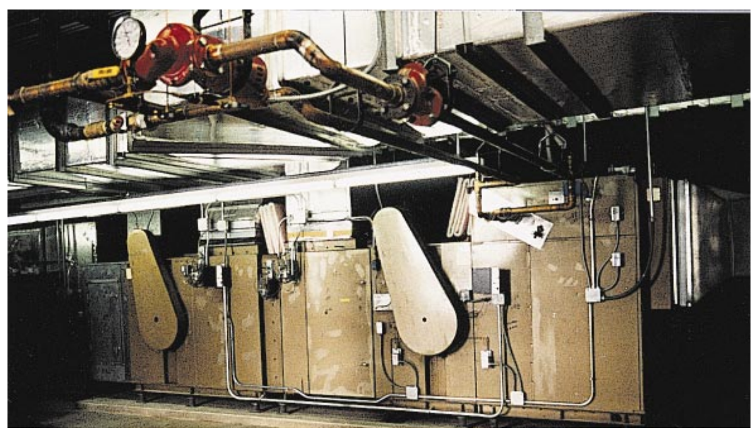
[1]Savings from converting building to gas space heating and domestic water heating.
[2]Table 6 minus, Table 5 plus value of recovered heat.

ity cost savings for the cogeneration system was approximately $213,900 per year.

Both the boiler water heat exchanger and the domestic water heat exchanger can recover all of the heat from the cogeneration system. For these calculations, we will assume that between the two of them, all the available heat will be recovered during all of the months except June, July, and August. The recovered heat equals about 7000 therms per month, making the projected yearly saving $24,000. This saving added to the electricity saving totals $237,900 annually. The total cost of the cogeneration system was approximately $750,000 for a simple payback of 3.2 years. The actual value of the heat recovery probably will be more because the auditorium system is a constant volume reheat system and will use the recovered heat during the summer months. In addition, we have assumed that no domestic water heating will be required during the summer months. The absence of both conditions is highly unlikely.

The total estimated cost of construction of the changes noted in Table 7 was $1,140,000. This works out to a simple payback of 4.1 years. The cost of electricity and gas for the completed building for the year beginning March 1995 and ending February 1996 was $295,000. The total of the electric bills

Existing multizone unit and hot water circulating pumps after the electric heating coils were replaced with hot water coils.



for 1991 was $162,000 (from Tables 2, 3, and 4). The energy cost of the building increased by 82 percent although the school is 166 percent larger in area. When making significant additions to an existing building, one must review the existing building services to see if it is possible to save energy or the cost of energy. Many energy or cost savings that would not be feasible may look more attractive.

HPAC