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Evanston Township High School

Midwest Regional Application Center
CHP for Buildings

Site Report MAC #2002-002

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1. Site Description

Figure 1: Evanston Township High School

1.1. General

Evanston Township High School (ETHS) is a 1.3 million sq. ft. high school complex located in the City of Evanston, Illinois. (Evanston borders Lake Michigan and is located just north of and adjacent to Chicago. Many know Evanston as the home of Northwestern University.)

The high school serves the entire City of Evanston and part of Skokie. With a student body of 3000 students, Evanston Township High School is a hub of activity and is known for its high academic standards. It is also a year-round operation. The academic year runs from September through the middle of June. Summer school programs run from the middle of June to mid-August.

The ETHS complex is served by a central steam boiler plant and has 2080 tons of absorption air conditioning. In the early 1990's, when the school began looking for ways to lower energy costs, ETHS discovered that the combination of a central boiler plant and central absorption cooling system made it an excellent candidate for a CHP system. A number of feasibility studies were conducted on CHP systems for the school. Different types and numbers of engines were considered.

In 1992, LaSalle Associates of Glen Ellyn, Illinois, was engaged to install a 2400 kWe CHP system at the central boiler plant. Three natural-gas-fired Caterpillar Model 3516 engine/generator sets were installed, rated at 800 kWe each. Exhaust heat recovery was employed to produce 100-110 psig steam - for hot water production year round, for heating in the winter, and for cooling in the summer. The jacket water and aftercooler heat are rejected to the atmosphere through radiators located immediately outside the engine room at the boiler plant.

The system was installed at a price of $1.5 million ($625/kWe). One of the major factors that reduced the installation cost from the more usual $800+ /kWe for a system of this size was that the engines could be placed adjacent to the existing boilers in an existing space. A new building was not required and steam piping costs were minimized. Operating savings in the first few years approached $500,000 per year. The system paid for itself in less than 4 years.

Figure 2. ETHS Complex (Boiler Stack in Distance)

Figure 3: ETHS Athletic Fields

1.2. Site Characteristics

Evanston Township High School is laid out as a college-style complex with 10 contiguous buildings. It sits on 65 acres of land that includes a track field, soccer fields, and a football/soccer stadium. The 1.3 million sq. ft. building complex includes 13 gymnasiums, 2 swimming pools, three auditoriums (one seating 1500 people), 4 cafeterias, a faculty dining room, and 330 classrooms.

The complex is heated by a central boiler plant located in its own 11,000 sq. ft. building about 600 ft. south of the school complex. The boiler plant was constructed in 1924 to serve the first high school building on the site. The plant makes 100-110 psig steam and pipes it to the school through underground steam lines. Originally coal fired, the boiler plant was served by a railroad spur that was used to deliver the coal. A portion of the boiler plant was a dedicated rail car building with a below-grade hopper.

In 1966, a major expansion of the school took place. Four building wings were added to the school. The coal-fired boilers were removed and replaced by three 50,000 lbs/hr natural gas-fired boilers, for a total capacity of 150,000 lbs/hr. Four 520-ton single-stage, steam-fired, York absorption chillers were installed (one in each of the four wings)—for a total capacity of 2080 tons. Each chiller was located in its own roof-top mechanical room. Evaporative cooling towers were located just outside the mechanical rooms. Steam-to-hot water converters and hot water storage tanks were located in each mechanical room.

In 1992, LaSalle Associates installed the 2400 kWe CHP system in the existing rail car building at the boiler plant. LaSalle designed and installed the system on a turnkey basis.

The design and operations of the new CHP system took advantage of four characteristics of the site:

1) The existing rail car building made a convenient location to house the new engines and helped minimize construction costs.

2) The year-round operation and use of absorption cooling provided an opportunity to maximize the utilization of steam produced by the engines.

3) The main electrical service for the complex came in at some distance from the boiler plant. However, there was adequate space in existing conduit runs to pull feeders necessary to interconnect the generators with the main service.

4) The electricity for the site was provided by Commonwealth Edison Company on Rate 6L, a large general service time-of-day rate. During peak hours (in 1992), from 9 am to 10 pm, Monday-Friday, the school was paying 13+¢ per kwh for electricity (including energy and demand charges and taxes). During off-peak hours, from 10 pm to 9 am Monday-Friday and all day on weekends, power from Commonwealth Edison was only costing 2-2.5¢ per kwh. By generating its own power only during the peak hours—about 3300 hours per year—the school could displace the expensive on-peak power, and continue to purchase off-peak power at 2-2.5¢ per kwh during the remainder of the year.

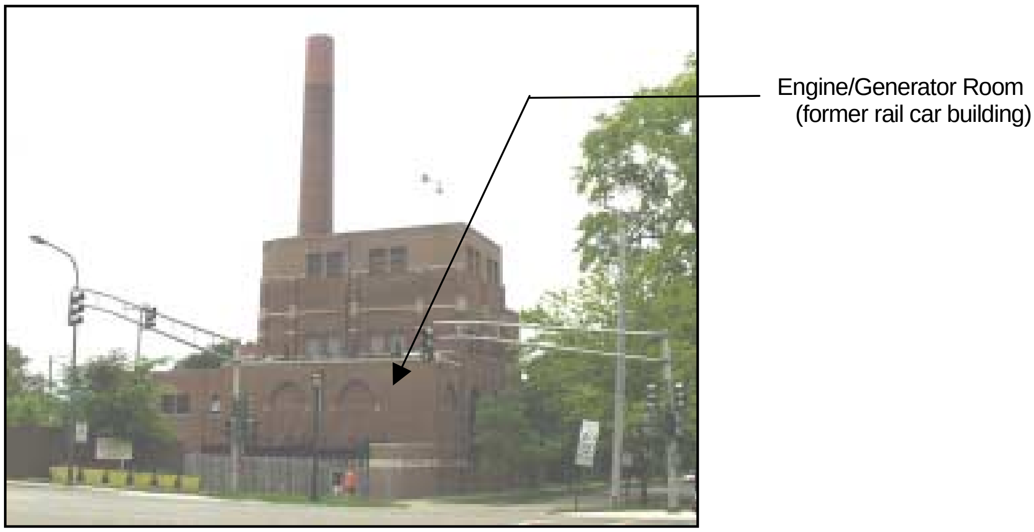


Figure 4: ETHS Boiler Plant

2. Market Segment Evaluation

Many high school complexes have characteristics similar to Evanston Township High School:

- They have central boiler plants located in separate buildings that provide steam heating.
- They are sited on large tracts of land with space for a generator building.
- They may also have central absorption cooling systems.
- They may have (or be able to negotiate) time-of-day rates with the local electric utility similar to those for ETHS.

The major considerations in determining the feasibility and need for a CHP system at such a school are the energy cost savings and the need for added reliability of power. Basic feasibility studies can be performed at little or no charge by engineering or energy firms specializing in CHP, or through the MAC.

If a first-level feasibility study shows that a project has potential, energy service companies or government agencies (such as the MAC) may be willing to fund or subsidize more detailed studies by engineering consultants or turnkey contractors.

3. Technical Description

Figure 5: ETHS Generator Room

Figure 6: Beaird Industries MFT exhaust heat recovery unit (one/engine/gen set). Each one produces 1000-1200 lb/hr of 100-110 psig steam

3.1. Equipment Overview

The major equipment for the ETHS cogeneration (CHP) system is as follows:

1) Three Caterpillar Model 3516 1200-rpm natural gas fired engine/generator sets rated at 800 kWe each. (See Figure 5.) The units are turbocharged and aftercooled. (Without turbocharging, the same units would produce only 460 kWe each.) Generator voltage is 4160V, 3-phase, 4-wire. The engines use a draw-through carburetion system in which the natural gas fuel is mixed with air before the turbocharger. The turbocharger then acts as a fuel gas compressor. The fuel gas provided by the local utility is 32-35 psig, but this is reduced to 5 psig at the fuel gas inlet to the engine.

2) Three Maxim (Beaird Industries, Inc.) exhaust heat recovery units (Figure 6). One Maxim unit is dedicated to each engine. They produce approximately 1200 lb/hr each (for a total of 3600 lb/hr) of 100-110 psig steam when the engines are running at full load. The steam is piped to the main steam header for the boiler plant. At 18 lb/hr of steam per ton of refrigeration, the engines can produce about 200 tons of steam absorption cooling.

3) Three Amercool Mfg. Inc. single fan, two-speed radiators (Figure 7). One radiator is dedicated to each engine. Each radiator has two circuits. The larger circuit is for jacket water (2,142 MBH, design temp. in = 200° F, design temp. out = 190° F). The smaller circuit is for aftercooler water (610 MBH, design temp. in = 130° F in, design temp. out = 120° F). Both circuits use a 50/50 mixture of water and propylene glycol for freeze protection.

4) Zenith Controls (now GE Zenith Controls) 4160 V switchgear (Figure 8). Included are three generator breakers, Woodward paralleling controls, and a main breaker. The design of the operation is such that the main breaker closes first. Then the generator breakers close one-by-one as each generator set parallels with the main bus.

5) Three (existing) Babcock& Wilcox built-in-place natural gas fired boilers designed by Perkins & Will and installed in 1966 (Figure 9). Normally, one boiler can carry the load year round. Only on the rare occasion when temperatures drop to –10° F with a -30° F wind chill, is a second boiler required. Winter loads approach 35-40,000 lbs/hr. Summer air conditioning loads are about the same. Fuel gas pressure to the boilers is 2.5-3 psig. Condensate return to the boilers is >90%, due to an ongoing and very aggressive steam trap replacement program.

6) Four (existing) 520-Ton York single stage low-pressure steam fired absorption chillers (Figure 10). They take 8-9000 lbs/hr of steam (approximately 18 lbs/hr per ton) each—for a total of 36,000 lbs/hr at full load. They are supplied from the 100-110 psig main steam system (Figure 10). The steam pressure is reduced to 15 psig through pressure-reducing valves (PRV's) before it enters the chillers. Originally, the four chillers served four individual chiller loops. In 1997, however, the loops were interconnected.

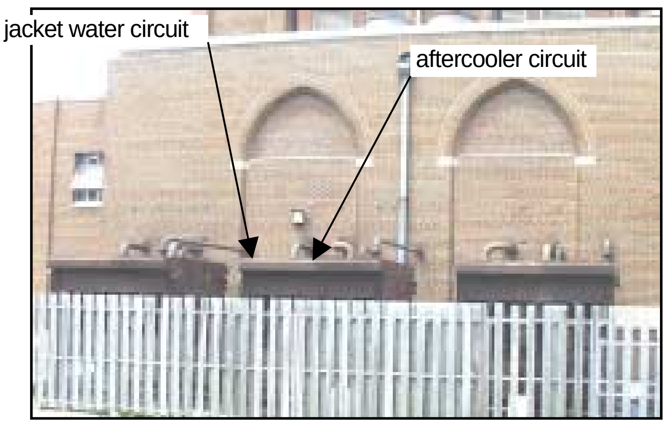


Figure 7: Engine Radiators (Amercool Mfg., Inc.) (one per engine)

Figure 8: Zenith Controls Switchgear (showing main tie line breaker)

Figure 9: One of Three Existing Steam Boilers (Babcock & Wilcox 50,000 lb/hr design output)

Figure 10: One of Four Existing York 520-Ton Single-Stage Steam-Fired Absorption Chillers

3.2. Operations

The system operates Monday through Friday all year long, with the exception of about 10 holidays each year that are designated by ComEd in their time of use (TOU) tariffs. From 1992 to 1994, the system was operated from 8:45 am to 10:15 pm to bracket ComEd's peak hours for energy (kwh) and demand (kWe) (9 am to 10 pm Monday – Friday). In January 1995, the on-peak period for demand was reduced to 9 am to 6 pm, Monday – Friday. The on-peak period for energy remained at 9 am – 10 pm Monday – Friday. The system currently follows the on-peak hours for demand, and is started at 8:45 am and is shut down at 6:15 pm every operating day. The system takes standby power on ComEd's Standby Rate 18 and takes supplemental power on ComEd's Rate 6L.

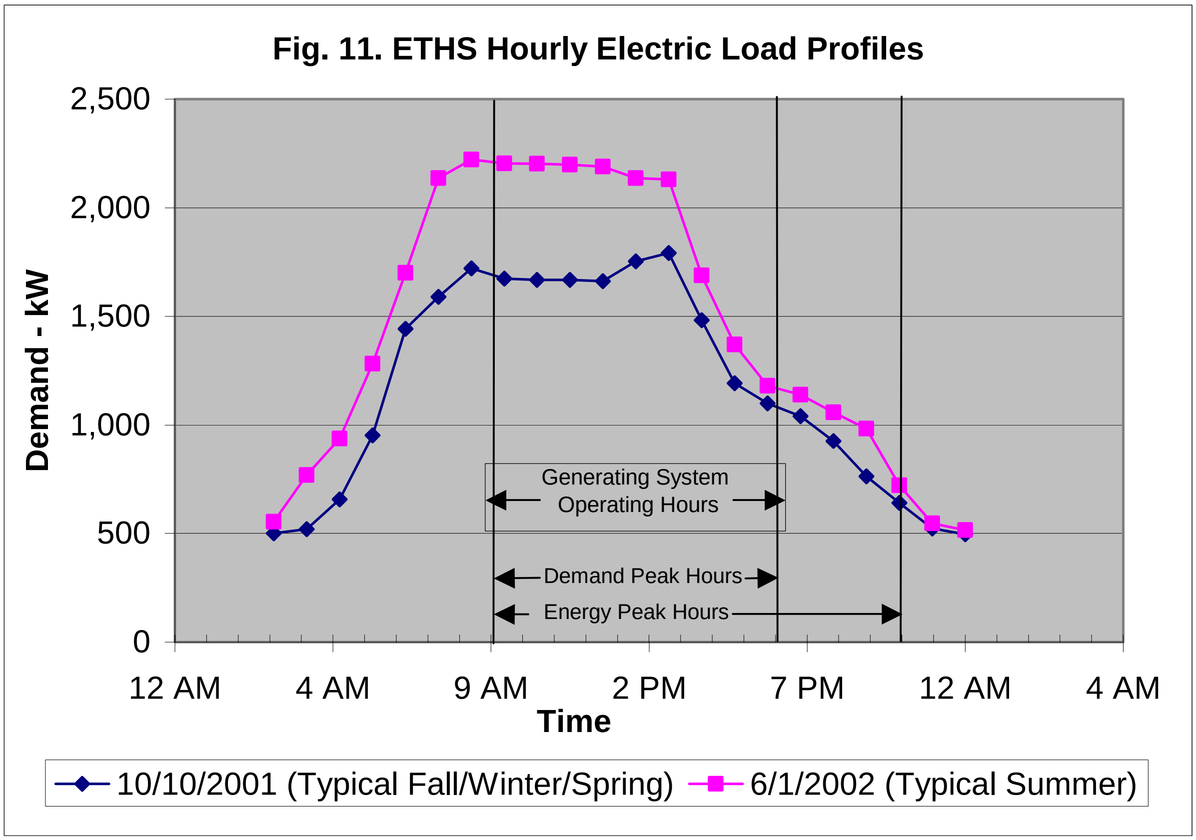
Routine maintenance is done by in-house staff, and is scheduled as weekend work, when the units are not operating. Non-routine work is conducted under contract with Patten Industries in Elmhurst, Illinois. When possible, non-routine work is also performed on weekends. Major overhauls are scheduled ahead of time and are coordinated with ComEd. ComEd allows a reduction in standby demand charges for what is considered scheduled "maintenance power" in their Standby Rate 18.

4. Energy Analysis

4.1. ETHS Electric Load Profiles

The actual electric load for ETHS varies substantially over the course of the day. Hourly electric profiles for a typical fall/winter/spring day and for a typical summer day are shown in Figure 11. The nighttime base load, mostly due to emergency lighting, is 500 kWe (0.38W/sq. ft. for 1.3 million sq. ft.). This base load is reached at midnight and continues until approximately 4 a.m. At 4 a.m., loads begin to steadily increase, reaching a crest at 8 a.m., of about 1700 kWe in the fall and winter and 2200 kWe in the summer. At 3 p.m., the load begins to drop steadily, until it reaches 500 kWe again at midnight.

Also shown in Figure 11 are ComEd's on-peak periods for demand and energy. Demand charges apply during the hours of 9 am to 6 pm, Monday – Friday. On-peak energy charges apply from 9 am until 10 pm, Monday – Friday. Also shown in Figure 11 are the operating hours of the generating system. The high school is currently operating the units from 8:45 am to 6:15 pm to recover both demand and energy charges during the system operation.



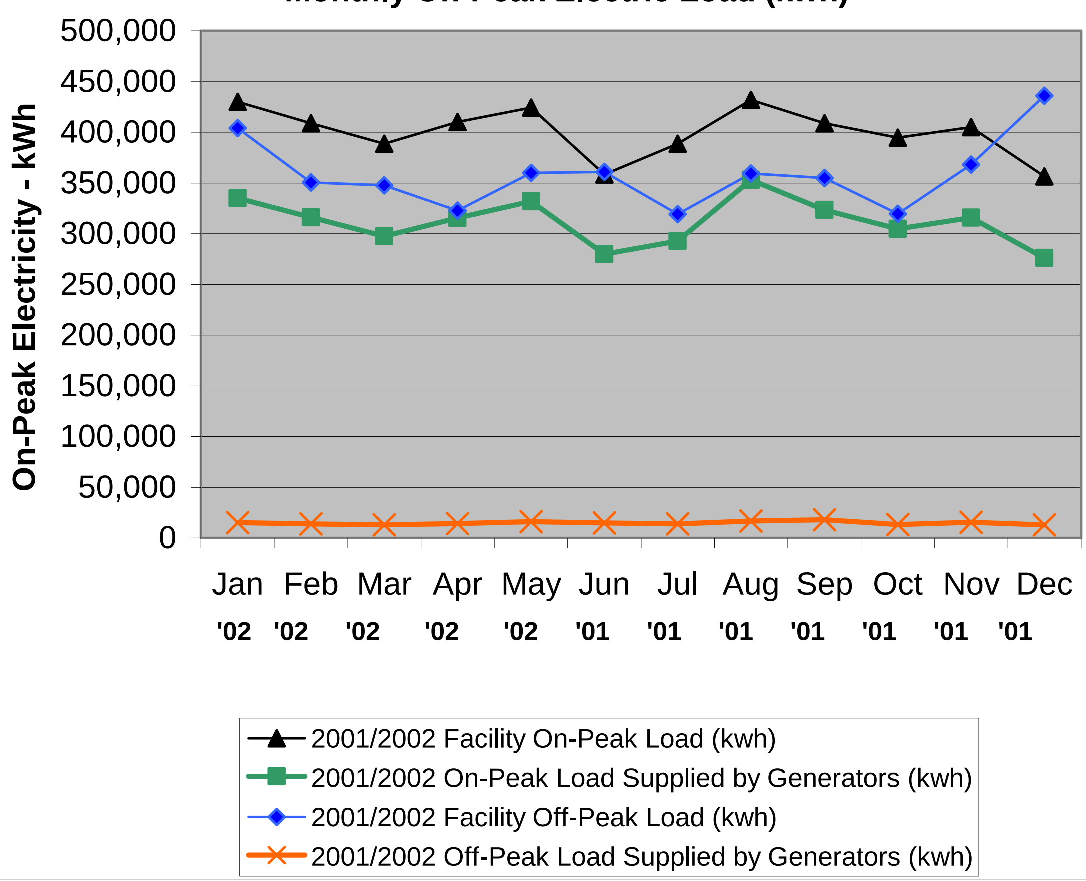
4.2. Electric Energy Profile

On an annual basis, Evanston Township High School currently uses about 9.1 million kwh of electricity per year, of which 4.8 million is used during ComEd's energy on-peak hours. The generators provide virtually all the schools power while they run—about 3.7 million on-peak kwh per year, or 77% of ETHS's on-peak energy. Most of the remaining 23% of on-peak energy is purchased from 6 pm to 10 pm, when the engines do not run.

The school's current monthly on-peak and off-peak electric loads are shown in Figure 12.—as well as the on-peak and off-peak amounts that are provided by the generators.

The generators produce about 177,000 kwh per year of off-peak electricity (about 4% of the total off-peak load). This amount is generated as a result of the school providing some overlap into the off-peak hours to insure that the units are on line during ComEd's peak hour periods.

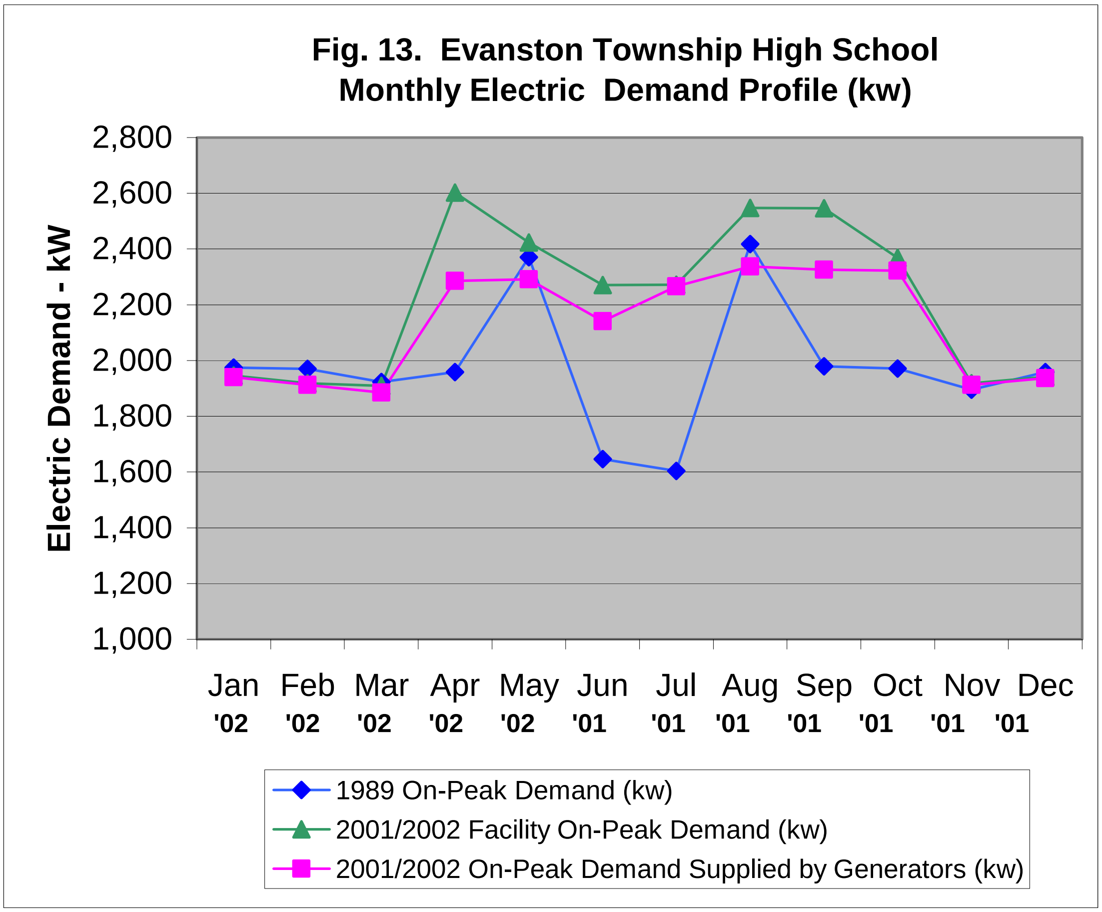
Fig. 12. Evanston Township High School Monthly On-Peak Electric Load (kwh)



4.3. Electric Demand Profile

The current monthly peak electric demand profile for ETHS is shown in Figure 13 below. The current monthly peak demands are running between 1900 kWe and 2600 kWe. Generator system output is in the range of 1900 kWe to 2350 kWe. Six months of the year, the generators can meet 100% of the demand load of the high school. From April through September, when electric loads associated with the air conditioning system are present (chilled water pumps, cooling tower fans, and ventilation fans), supplemental power must be purchased form ComEd.

The 1989 demand profile is shown for comparison. The current profile reflects an increase in the school's summer programs.



4.4. Thermal Profiles

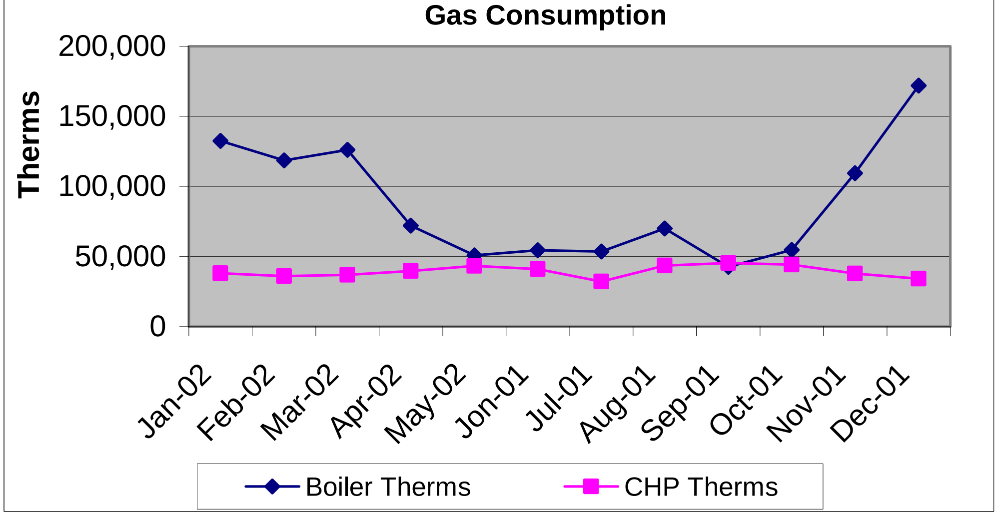
Evanston Township High School takes delivery of transportation gas from Nicor Gas. Table 1 and Figure 14 below show the boiler and cogen system fuel gas consumption. Studies of the heat recovery system show that approximately 12.5% of the input energy to the engines is recovered as steam. The heat recovery provides approximately 7.1% of the high school's steam load.

Table 1. Evanston Township High School
Boiler and Generation Natural Gas Consumption, Heat Recovery Credit,

Month	Boiler Therms	Generated kwh	Generator Therms	Heat Recovery Credit (15.6% of CHP Therms)[1]	Heat Rate (Btu/kwh) (HHV)
Jan-'02	132,449	349,956	38,076	5978	10,880
Feb-'02	118,359	330,253	36,063	5662	10,920
Mar-'02	126,014	310,550	36,804	5778	11,851
Apr-'02	72,013	329,589	39,581	6214	12,009
May-'02	50,904	347,938	43,362	6808	12,463
Jun-'01	54,435	294,635	40,913	6423	13,886
Jul-'01	59,522	306,638	36,007	5653	11,743
Aug-'01	64,226	369,703	45,169	7092	12,218
Sep-'01	33,327	341,217	38,107	5983	11,168
Oct-'01	56,596	317,930	43,019	6754	13,531
Nov-'01	71,648	331,381	37,653	5912	11,362
Dec-'01	120,105	289,020	31,891	5007	11,034
Totals:	959,598	3,918,810	466,645	73,265	11,908

[1] Based on (a) 3.6 million Btuh recovered at 2400 kWe = 1500 Btu/kwh, and .
(b) 1500 Btu/kwh recovered with 11,908 Btu/kwh input = 12.5%, and
(c) accounting for 80% boiler efficiency = 12.5%/0.8 = 15.6%

Figure 14. ETHS Boiler and Generating System Natural Gas Consumption



The heat recovery system contributes a credit of about 73,000 therms towards the natural gas that would be required to satisfy the steam load without the CHP system. At $4.00 per MMBtu (40¢ per therm), this is a savings of $29,200 per year due to the heat recovery system.

5. Financial Analysis

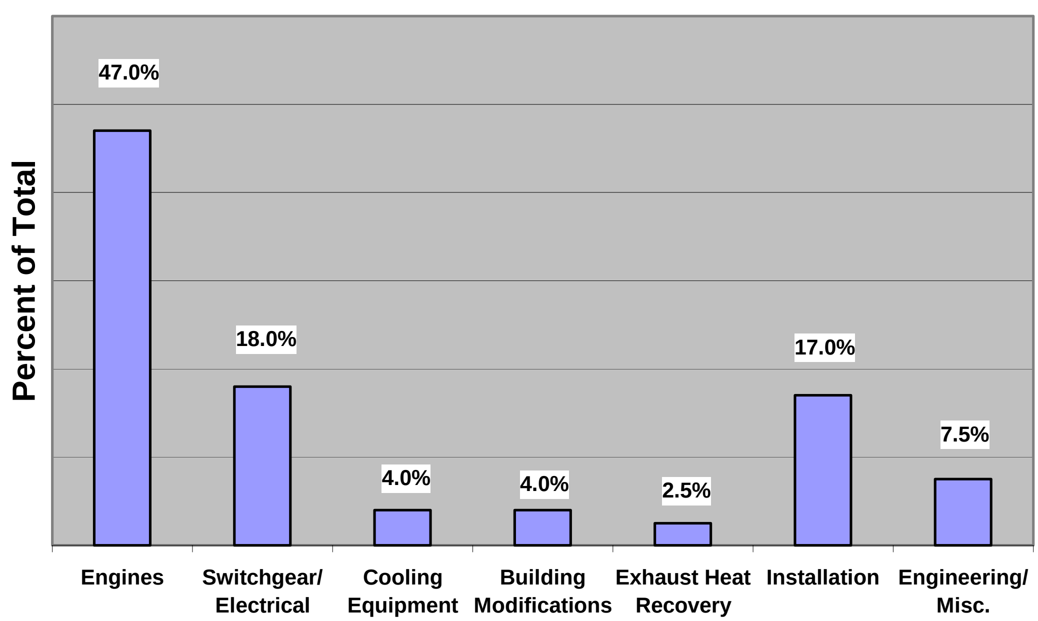
5.1. Project Cost

The total cost to install the project was $1.5 million (in 1991). Table 2 and Figure 15 show an itemization and breakdown of the construction cost. Note that the major equipment (designated by *) accounts for 71% of the total installed cost.

Table 2. Evanston Township High School Installation Cost Summary

No.	Item:	Percent of Total	Amount
1.	Engines *	47.0%	$705,000
2.	Switchgear/ Electrical*	18.0%	$270,000
3.	Cooling Equipment*	4.0%	$60,000
4.	Building Modifications	4.0%	$60,000
5.	Exhaust Heat Recovery*	2.5%	$37,500
6.	Installation	17.0%	$255,000
7.	Engineering/ Misc.	7.5%	$112,500
	Totals:	100.0%	$1,500,000

Fig. 15. CHP System Installation Cost Summary



5.2. Project Operating Economics

With the current rate structure for ComEd and the current pricing structure for natural gas, the comparative economics of the project are summarized in Table 3. Without the CHP system, utility costs would be about $1.197 million per year. With the CHP system, utility costs are reduced to about $843,000 per year. Annual savings are approximately $354,000 per year (30%) with CHP.

Table 3. Operating Savings With CHP

	Utility and O&M Costs		Annual Energy Consumption	
Item	**Without CHP System**	**With CHP System**	**Without CHP System**	**With CHP System**
Utility Electricity:	$800,300	$261,000	9,107,939 kwh	5,189,129 kwh
Generated Electricity:	---	---	---	3,918,810 kwh
			Total	9,107,939 kwh
Natural Gas				
Boilers	$397,360	$369,174	1,032,861 therms	959,598 therms
Engines	----	$165,957	----	466,645 therms
Total	$397,360	$535,132	1,032,861 therms	1,426,243 therms
Maintenance (1.2¢/kwh)	---	$47,026		
Total	$1,197,360	$843,158		
Annual Savings:		**$354,202**		

5.3. ETHS Cost of Electricity

As shown in Table 4, the cost of electricity for the high school would be approximately 8.79¢ per kwh without the CHP system. With the system, the net cost of power is approximately 4.9 ¢ per kwh—a savings of 44%.

Table 4. ETHS Unit Cost of Electricity

Item	**Without CHP System**	**With CHP System**
Purchased Power	$800,300	$261,000
Incremental Cost of Fuel		$137,772
Maintenance		$47,026
Total (for 9,107,939 kwh)	**$800,300**	**$445,798**
Unit Cost of Power:	**8.79¢**	**4.90¢**
Savings With CHP		**44%**

6. Project Schedule

The project feasibility studies were completed in January of 1991. It took a year to obtain the necessary approvals and financing.

Design started:	January
Construction began:	May 1992
Project Completion:	October 1992.

The six month construction schedule was somewhat short because of the relatively little work required to put the units into the existing building. A more typical construction period is 9-10 months, to allow for the construction of a new building for the generating system.

7. Environmental Considerations

The Caterpillar engines that were used in this project have lean-burn combustion systems with NOx emissions of 2 grams per brake horsepower. Because these units are dedicated natural gas engines below 1500 hp, they were exempt from an air permit for construction under Illinois Administrative Code (35IAC 201.146 (i).

8. Lessons Learned

(1) There are large economic benefits to using existing building space, if possible.

(2) Periodic review of the CHP plant operations is advised to insure that savings are maximized.

(3) Ongoing discussions with both electric and gas utilities can keep staff current on rate changes and incentives that may affect the economics and hours of operation of a CHP system.