Technical and Economic Assessment of a Cogeneration System in an Urban Academic Building

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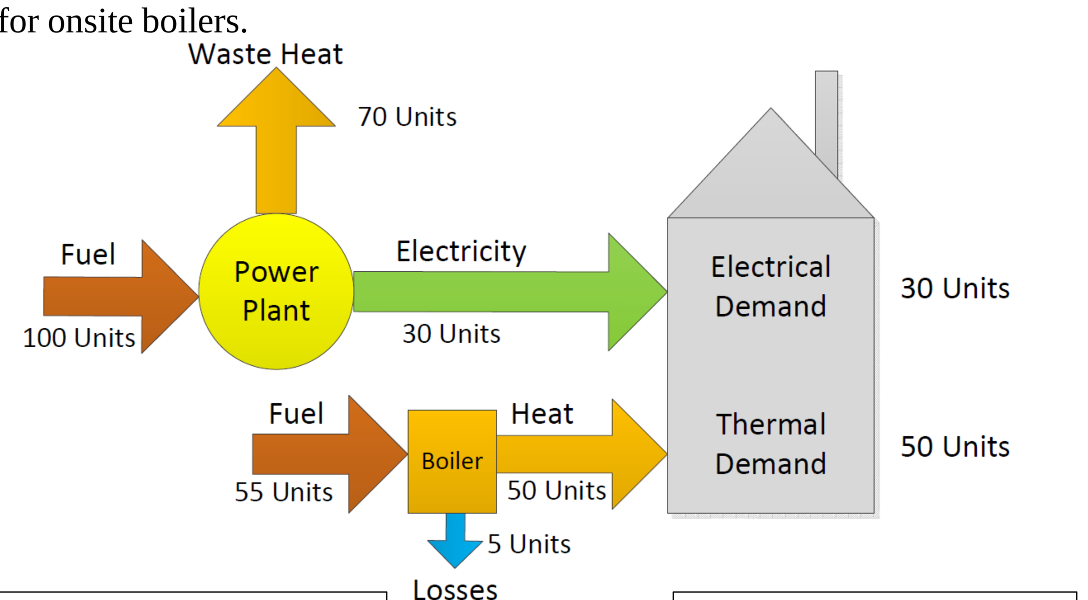
Project Overview

Buildings are subjected to two major energy demands: an electric demand and a thermal demand. Traditionally, electrical demands are met by purchasing electricity from a utility and thermal demands are met by purchasing natural gas for onsite boilers.

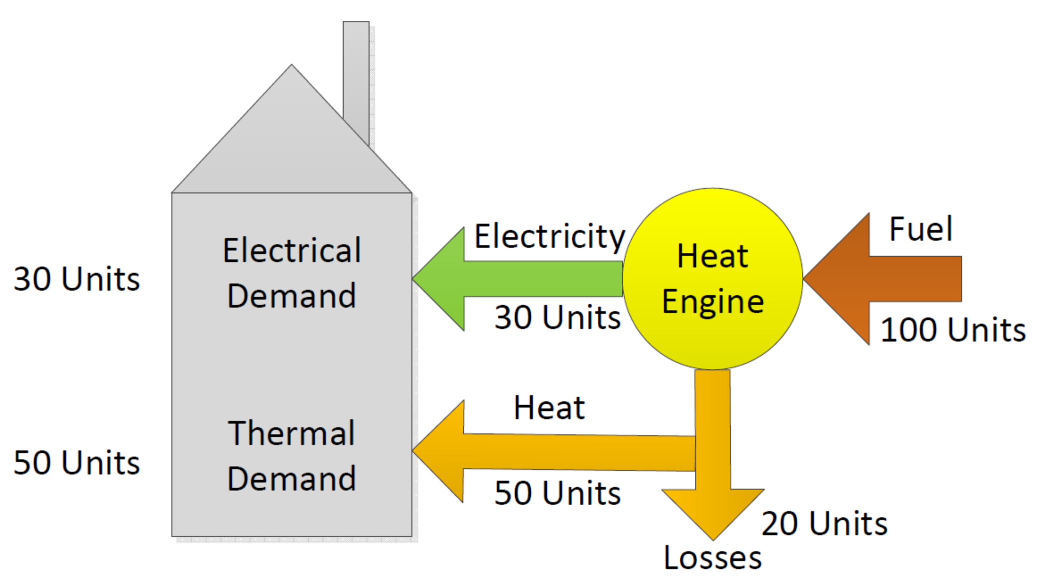


Total Energy Input: *155 units*

Efficiency: *80/155 = 52%*

The conversion of chemical energy to electrical energy results in significant waste heat. In a remote power plant, waste heat is rejected to the environment and lost. Transporting heat over large distances is impractical and difficult.

Cogeneration is the use of a heat engine to simultaneously produce electricity and useful heat. By placing the power plant onsite, the heat released by the engine can be used to meet building thermal demands. This reduces the overall energy consumption required to meet the electrical and thermals demands.



Efficiency: 80/100 = 80%

Total Energy Input: *100 units*

Cogeneration, when implemented properly, is both an energy savings and cost savings technology. By reducing the overall energy consumption of the building, lower utility bills are realized.

Applications

Cogeneration has been in use since the late 19th century when the Pearl Street Station began selling electricity and steam. Since then, the application of cogeneration has evolved from the macro scale with steam districts and industrial applications, to the small scale of large office buildings and skyscrapers, to the mini scale of small buildings like those at Cooper Union.

Heavy Industry: ~30 MW

Large Campus: ~ 10 MW

Skyscrapers: ~5 MW

41 Cooper Square: 250 kW

System Overview

In 2009, The Cooper Union opened its new academic building, 41 Cooper Square, which houses a 250 kW cogeneration unit that provides a portion of the building's electrical demand. Heat from the engine is used for hot water during the winter and for chilled water during the summer via an absorption chiller. Any excess heat is rejected to the environment to the condenser water system.

The system consists of a naturally aspirated reciprocating engine in an engine enclosure, an absorption chiller, and two plate and frame heat exchangers.

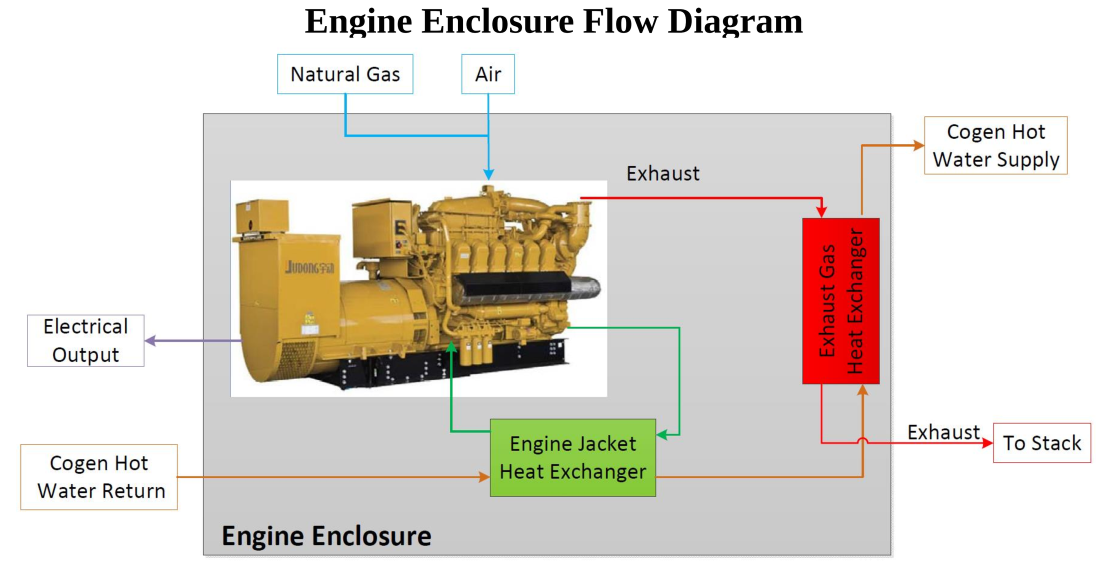
Cogeneration System Specifications

Capital Cost*	$1,200,000
Engine Size	350 hp
Engine Type	Reciprocating
Cylinder Layout	V-12
Fuel Consumption	815 kW
Fuel Type	Natural Gas

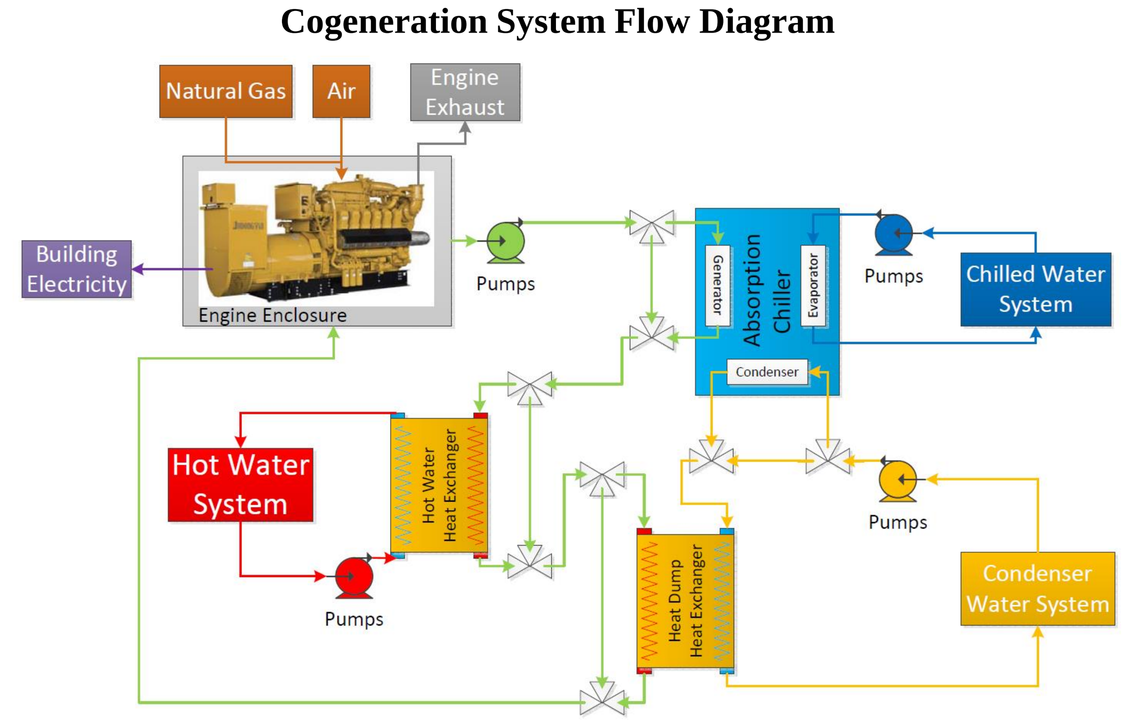
Electrical Efficiency	31%
Electrical Power	250 kW
Heat Recovered	460 kW
Heat Efficiency	56%
Absorption Chiller	80 tons
Overall Efficiency	87%

*A $400,000 grant from NYSERDA offset the capital cost.

Engine Enclosure Flow Diagram



Cogeneration System Flow Diagram



Simulations

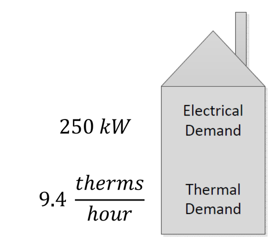
Combined Heat and Power (CHP) Economics

An estimate of the potential cogeneration savings is determined by calculating how much it would cost to purchase the same quantities of electricity and heat produced by the cogeneration system.

<u>Without Cogeneration</u>

(per hour in Winter Mode)

Electricity	
250 kW	44.25 $/hr
Natural Gas	
10.4 therms/hr	10.70 $/hr
Total	
54.95 $/hr	



<u>With Cogeneration</u>

(per hour in Winter Mode)

Natural Gas	
27.8 therms/hr	28.61 $/hr
Maintenance	
7.99 $/hr	
Total	
36.60 $/hr	

<u>CHP saves:</u> $18.35/hour
$440/day
$13,200/month

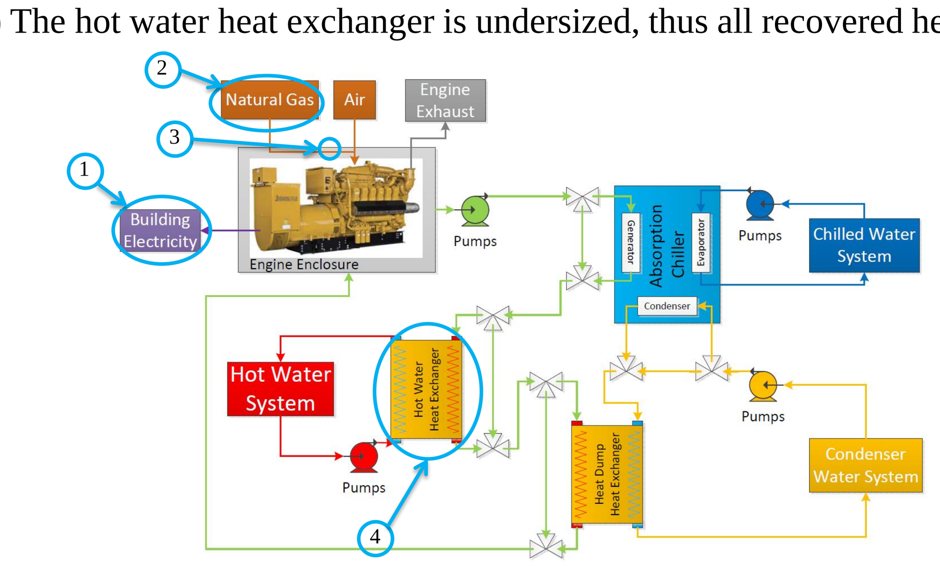
On a per energy basis, electrical prices are 5 times more expensive than natural gas prices. This is because electricity is a secondary form of energy. The use of a cogeneration system shifts the utility energy consumption to natural gas, which is inherently cheaper.

	Electricity	Natural Gas
HESS Energy Supplier	0.081 $/kWh	0.541 $/therm
conEdison Distributor	0.096 $/kWh	0.488 $/therm
Total Price	*0.177 $/kWh (49.17 $/GJ)*	*1.029 $/therm (9.76 $/GJ)*

System Limitations

The best economics for a cogeneration are achieved when the system can run at full capacity, operate 24 hours a day, 7 days a week continuously, and make full use of the engine heat. Unfortunately, four key limitations prevent this.

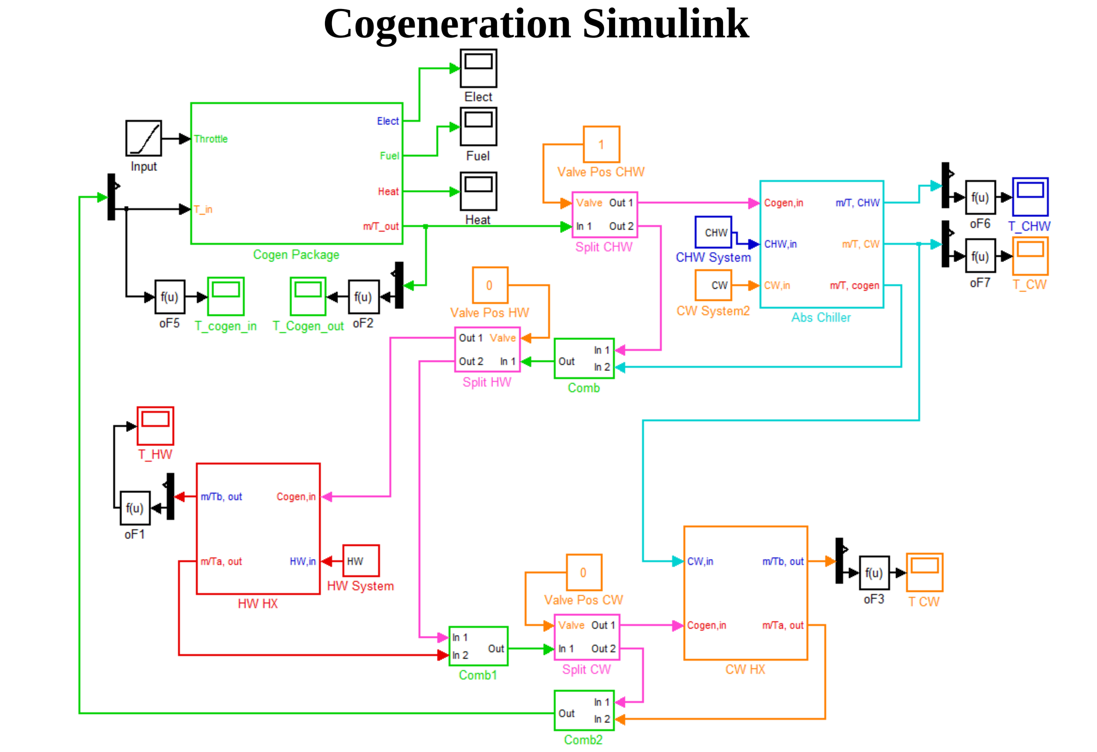
1) Overnight the system operates at 175 kW due to insufficient electrical demand.
2) During shoulder seasons the system operates at 200 kW due boiler/gas line issues.
3) The gas meter on the system cannot be commissioned for lower natural gas rate.
4) The hot water heat exchanger is undersized, thus all recovered heat is not utilized.



MATLAB Modeling

Using data provided by Elite Energy and thermodynamic, heat transfer, and fluid mechanics first principles, a Simulink model of the cogeneration system was developed.

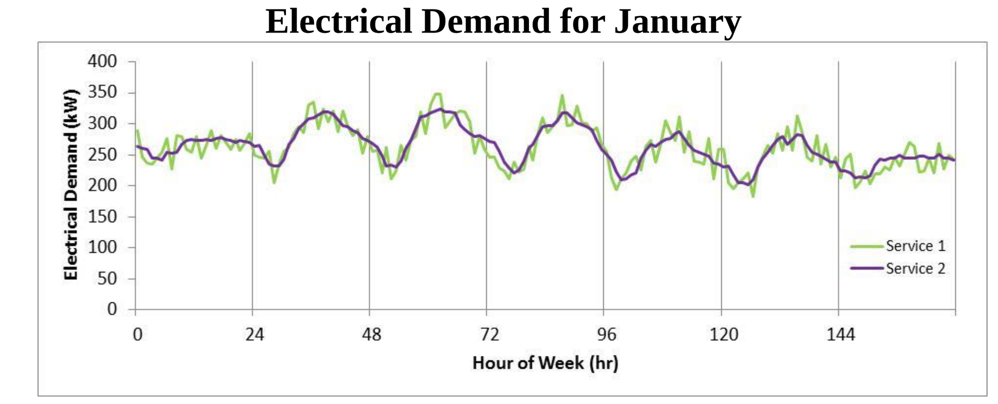
Cogeneration Simulink



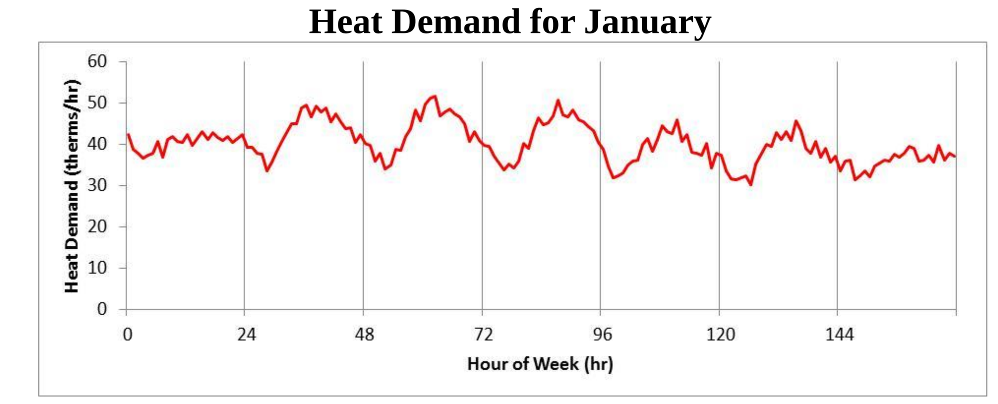
Electrical and Heat Load Profiles

Load profiles for 41 Cooper Square were developed using a combination of utility bills and Building Management System data. These load profiles provide hourly demands for a typical week in a given month. The profiles serve as the input to the Simulink model.

Electrical Demand for January

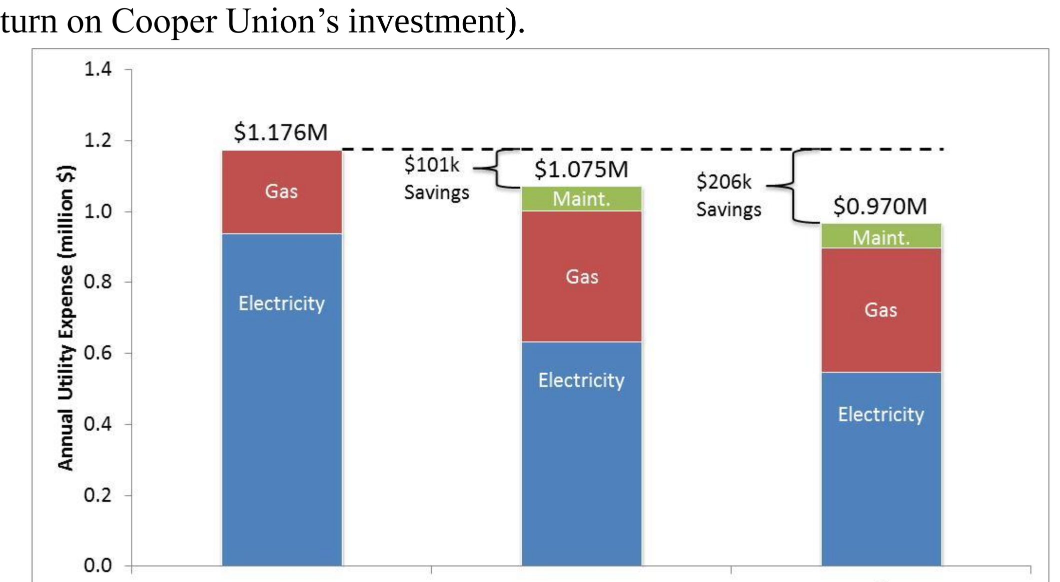


Heat Demand for January



Results

The use of the cogeneration system reduces 41 Cooper Square's annual utility expenses by an estimated $101,000 per year. A grant from NYSERDA reduced Cooper Union's investment into the cogeneration system to $800,000. Given these annual savings, the system will be paid for in 8 years (equivalently a 13% return on Cooper Union's investment).



By implementing modest retrofits to resolve the system's limitations, additional savings can be achieved. These retrofits result in an additional $105,000 in annual savings, effectively doubling the savings. The retrofits to resolve these four deficiencies are estimated to cost about $75,000; given the increase in savings this investment would be paid off within the first year.

Future Work

Future projects should look for opportunities to minimize energy consumption and minimize operating expenses.
The absorption chiller on the cogeneration system can be leveraged to reduced operating expenses. Operating the large chiller units requires an engineer to be present at all times. If the absorption can meet the entire cooling load when the building is closed, then the salary cost of the engineer can be eliminated.
Additional mathematical models of the building's chilled water and condenser water system should be developed and integrated with the mathematical model of the cogeneration system to develop a set of operating guidelines that minimize energy consumption and operating expenses.
Lastly, this methodology should be applied to analyze Cooper 150 kW Foundation Building Cogeneration Plant.

Acknowledgments

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