Mechanical Breadth

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The Mechanical Breadth was intended to integrate the Electrical Depth with an alternative energy source for heating the building water systems in place of steam. Based on an idea to produce electricity from the heating and cooling water loops, the generation of electricity could easily be combined with hot water generation in a combined heat and power source such as microturbines. These microturbines are the basis for the mechanical breadth design and integration to the electrical system.

Relationship with Thesis Project

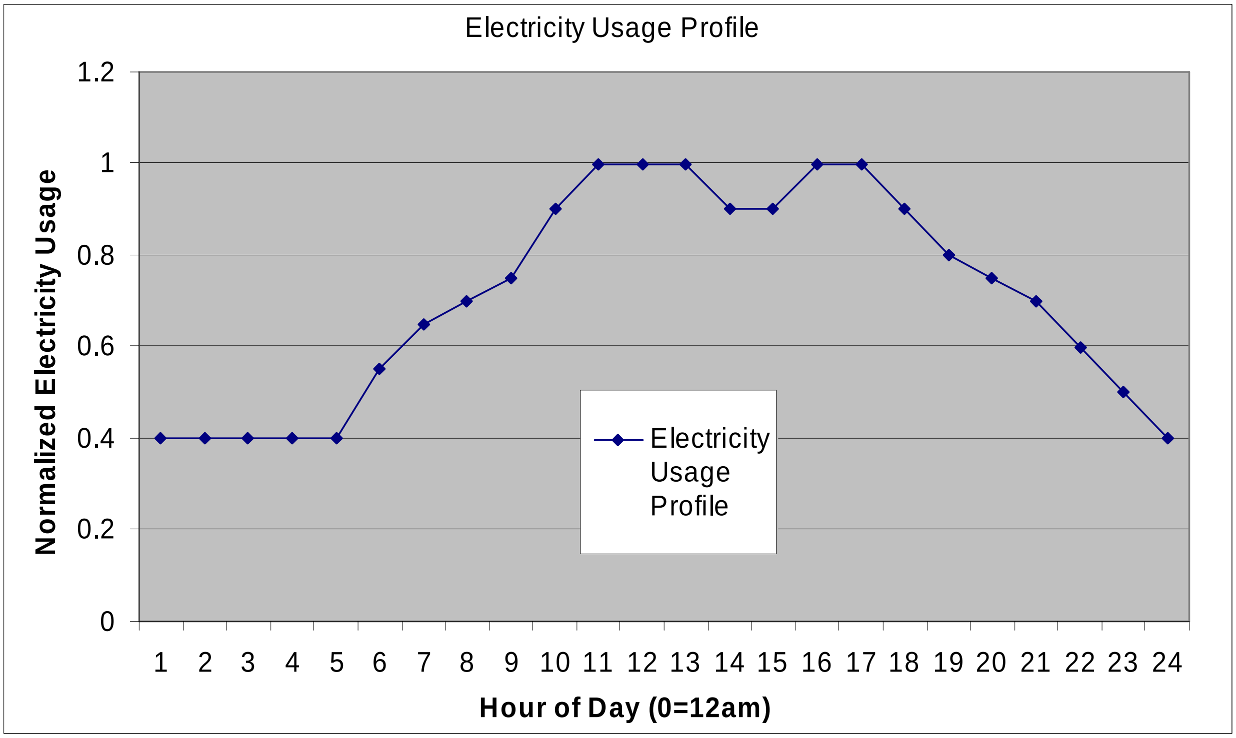
Using a combined heat and power production unit such as the microturbine with integrated heat recovery, at any given point when the building needs heating, the generation of power could offset the electrical demand put directly on the utility service. While the microturbine does not directly affect any other system in the building, it does impact the electrical design, especially considering the emphasis put on emergency power generation.

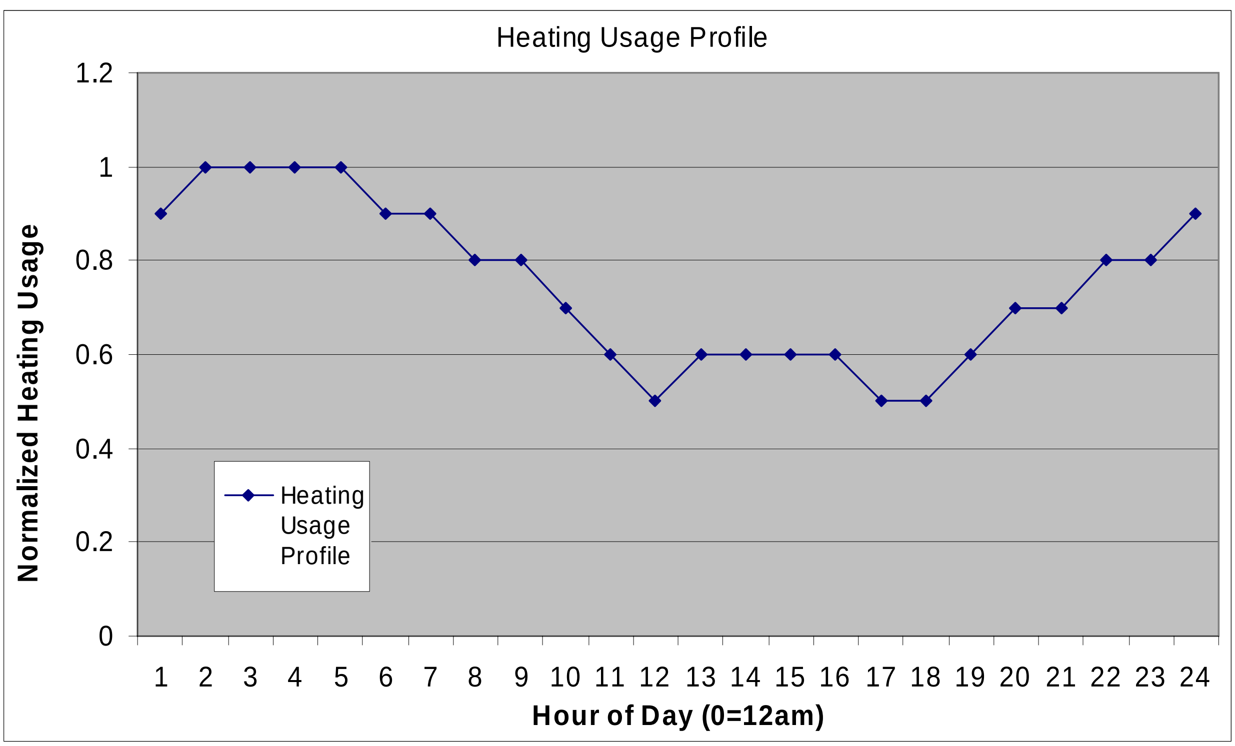
Proposal

The proposed system is to replace the condominium heat exchangers entirely and replace them with Capstone C65 Microturbines running on natural gas. In addition to this complete replacement, the new system will replace the current office heat exchangers with 7 Capstone C65 Microturbines. This will not completely replace the steam service to the building as will be described, but will attempt to produce as much heating power for the building's water systems as possible using the Microturbines up to the point of over-generation at full running capacity. This should effectively reduce the steam demand as close to zero as possible. The offset to be compared is the cost of natural gas for running each of these microturbines.

Load Modeling

The energy records for the past 16 months were obtained from WE Energies for natural gas, electricity, and steam service to Cathedral Place. The natural gas was all but non-existent for the office tower, very low for the condominium section, and not present for the parking garage. Steam consumption was provided in Mlbs for each of the preceding months separately for the Condominiums and Office Tower. Since the Microturbines would be replacing the steam as a heat source, it was necessary to model the steam usage for each day of a given month. The steam usage for the month was divided by the supplied number of days between meter readings to obtain a daily steam usage profile. A load profile for both electricity usage and heating usage was developed as a part of the design, normalized to a maximum value of 1 (equivalent to 100% heating usage). The profiles for Electrical usage and Heating usage can be seen below.


Electricity Usage Profile
Normalized Electricity Usage
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (0=12am)
Electricity Usage Profile


Heating Usage Profile
Normalized Heating Usage
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (0=12am)
Heating Usage Profile

Using these profiles and dividing by their respective areas, the fraction of the total steam usage in a day was calculated to obtain consumption per hour. This puts the most steam and electricity consumed when the profile is the greatest, and the least consumed when the profile is the lowest. This profiling technique well-approximates the steam usage throughout the day and allows the comparison to get much more detailed. While introducing some inaccuracies, the method improves the accuracy of the calculations by using realistic, and in the case of the steam consumption, actual statistics.

Once the steam usage per hour per month for an entire year was tabulated, (as seen in Appendix E) the number of Btus was calculated based on the enthalpy of the entering steam, magnified by a factor 1.25 as a "safety factor", and also tabulated. Thus the heat required per hour per month for an entire year was charted for comparison with the Btu input and output requirements of the microturbines.

Microturbine Usage and Parallelizing

For the condominium steam usage, the number of microturbines required to produce enough steam to over-generate for every hour of every month was determined and tabulated. The resulting over-generation of steam would be used in parallel with the office microturbines to preheat the inlet water. Using the office steam usage in Btu per hour per month tabulation, the number of over-generated Btus was subtracted from the office required Btus, and the remaining quantity divided by the thermal output of the microturbine. Unlike the condominium setup, the largest number of turbines not exceeding 7 was determined such that no over-generation occurred. The remainder of the Btu requirement would be fulfilled by the steam utility and thus, the total steam required for the month based on this "deficit" was calculated.

For every microturbine that was used, the number of therms of natural gas consumed was tabulated per hour and summed per month. Also based on the number of microturbines used, the electricity generation was tabulated. This quantity was subtracted from the tabulated electricity usage with the same method as described earlier. When the generation exceeded the demand, the value was placed at 0. When the demand exceeded the generation, the value was tabulated and summed across a month to get the overall resultant kWh usage for a given month.

These values were then put into an equation to calculate the monthly energy bill based on the current energy prices. The yearly cost of the system was then calculated and compared to the current energy bill's consumption multiplied by the same utility rates used to compute the cost of the new system (apples to apples).

There are a few assumptions that should be addressed immediately. First, the assumption is made that the hot water exchange of heat between the Condominium unit and the Office units is perfect. While this would not be the case, it is used for simplification of calculation, but without neglecting its contribution. Second, the load profile developed is an accurate representation of the energy usage with respect to each utility. While this was developed independently, the error in the profile should be relatively marginal. Third, the variance in steam usage for a given day of the month is offset both positively and negatively throughout the month to average within marginal error to the "average day" tabulated in these calculations. Fourth, the enthalpy of the steam entering the heat exchangers and resulting Btu consumption of the building is based on the inlet pressure of 2 psig as noted for the heat exchangers in the drawings. Even if the steam was superheated it will not have an enthalpy much greater than the value used. Fifth, the cost of natural gas varies considerably throughout the year and the cost calculated used a standard rate for natural gas consumption. The cost used was obtained from the utility company for the month of April, a cooler, but closer to average heating month for price comparison.

Integration with Electrical System and Emergency Distribution

The initial intention of the microturbine was its ability to generate electricity. The number of microturbines specified in this design breadth was relative to the amount of electricity it could produce and deliver to the emergency power distribution system. 9 microturbines have the ability to generate 585kW of electricity and when considering the loss in efficiency due to ambient temperatures, in excess of 525kW. This amount of electricity was taken from the emergency system demand in the new Electrical Depth distribution design.

In the case where the microturbines are connected at the emergency throw of the ATS (and not putting electricity directly into the Main switchboard), transfer of power would be instantaneous if the units were running, and power would be uninterrupted the necessary emergency equipment based on a logical emergency loading profile (condominium tenants needing to plug in their heat pumps and refrigerators minutes after the initial loss of power) and microturbine startup lag. In the case when all of the turbines are not connected and running simultaneously, the emergency condition would dictate, through any basic controller, that the microturbines must all start up and run until the emergency condition is cleared.

In addition to the electrical benefits of having instant energy, the microturbines are also producing heat for both the entire condominium section and the entire office section because of their electrical inefficiency. This added bonus would allow the office tenants to possibly wait out the emergency condition of electricity were to be restored within a few hours.

Combined Heat and Power Yearly Analysis

The combined heat and power analysis hinges on a variety of initial conditions and assumptions that cannot be immediately accounted for. A set of assumptions was used to calculate a few example conditions where the system design either benefits or hinders the project. The largest obstacle in this design is the initial cost of the microturbines, as can be seen in the payback periods and differences in cost. The detailed analyses are listed below.

Current System

Equipment		Cost
HX-0.1,0.2	2	$ 4,600.00
P-0.7,0.8	2	$ 10,400.00
HX-0.3,0.4	2	$ 15,600.00
P-0.1,0.2	2	$ 5,800.00
P-0.3,0.4	2	$ 17,400.00
350kw GenSet		$ 76,550.00
TOTAL		$ 130,350.00
To get same redundancy in new system		
TOTAL		$ 245,200.00

New System

Equipment		Cost
P-0.7,0.8	2	$ 10,400.00
HX-0.3,0.4	2	$ 15,600.00
P-0.1,0.2	2	$ 5,800.00
P-0.3,0.4	2	$ 17,400.00
C65	9	$ 1,260,000.00
TOTAL		$ 1,309,200.00

Current System Yearly Utility Cost

	CONDO			OFFICE				
	Energy			Energy				Total Cost
	Steam	Electric	Gas	Steam	Electric	Gas		
Month	Mlbs	kWh	therms	Mlbs	kWh	therms		
03/29/06	86	10,880	4	775	366,966	0		$ 43,840.18
02/27/06	112	10,240	4	1,024	389,779	0		$ 48,044.62
01/30/06	95	11,840	4	871	383,628	0		$ 46,348.93
12/29/05	128	10,080	6	1,112	359,923	0		$ 45,847.71
11/29/05	87	11,840	8	681	405,047	0		$ 47,014.60
10/27/05	42	11,520	6	341	396,403	0		$ 43,304.73
09/28/05	34	23,760	6	231	526,654	0		$ 56,499.00
08/29/05	35	25,280	6	344	479,409	0		$ 52,823.30
07/29/05	34	25,840	4	364	497,050	0		$ 54,756.40
06/29/05	34	17,360	6	244	448,960	0		$ 48,296.77
05/31/05	42	13,680	8	365	346,209	0		$ 38,743.33
04/29/05	44	12,240	7	464	355,141	0		$ 40,222.16
							TOTAL	$ 565,741.73

New System Yearly Utility Cost – 1.25 Safety Factor, $1.05 per therm – Payback NEVER

GENERATED				MAIN				Difference
	Energy			Energy			Total Cost	
	Steam	Electric	Gas	Steam	Electric	Gas		
Month	Mlbs	kWh	therms	Mlbs	kWh	therms		
03/29/06	0	971	0	236	239279	20469.5	$ 47,111.99	$ (3,271.81)
02/27/06	0	19526	0	318	191917	29817.9	$ 52,654.45	$ (4,609.83)
01/30/06	0	6159	0	226	197510	21985.4	$ 44,446.76	$ 1,902.17
12/29/05	0	29642	0	309	162457	30577.9	$ 50,338.40	$ (4,490.69)
11/29/05	0	0	0	200	248338	16178.2	$ 43,219.96	$ 3,794.64
10/27/05	0	0	0	148	359589	7585.8	$ 44,724.26	$ (1,419.53)
09/28/05	0	0	0	67	441655	5817.2	$ 50,355.45	$ 6,143.54
08/29/05	0	0	0	111	475717	7585.8	$ 55,908.61	$ (3,085.31)
07/29/05	0	0	0	150	444456	7583.8	$ 53,108.27	$ 1,648.14
06/29/05	0	0	0	91	392059	5817.2	$ 45,637.31	$ 2,659.47
05/31/05	0	0	0	130	308572	7587.8	$ 39,556.51	$ (813.18)
04/29/05	0	0	0	207	283953	10366.1	$ 40,634.21	$ (412.06)
						TOTAL	$ 567,696.18	$ (1,954.45)

**Does not include 10% tax credit
**Assumes 1.5 cents buyback for generated electricity

New System Yearly Utility Cost – 1.0 Safety Factor, $1.05 per therm – Payback in 89.9 years

GENERATED				MAIN					Difference
	Energy			Energy				Total Cost	
	Steam	Electric	Gas	Steam	Electric	Gas			
Month	Mlbs	kWh	therms	Mlbs	kWh	therms			
03/29/06	0	0	0	188	273408	16174.2		$ 45,598.86	$ (1,758.68)
02/27/06	0	7826	0	246	228967	23754.0		$ 49,543.69	$ (1,499.07)
01/30/06	0	0	0	195	232301	16932.2		$ 42,398.62	$ 3,950.31
12/29/05	0	12312	0	232	193876	24766.7		$ 46,981.31	$ (1,133.60)
11/29/05	0	0	0	156	275638	12641.0		$ 41,844.98	$ 5,169.63
10/27/05	0	0	0	125	375189	5817.2		$ 44,219.51	$ (914.78)
09/28/05	0	0	0	23	441655	5817.2		$ 50,028.82	$ 6,470.18
08/29/05	0	0	0	97	491317	5817.2		$ 55,476.92	$ (2,653.62)
07/29/05	0	0	0	126	460056	5815.2		$ 52,600.23	$ 2,156.17
06/29/05	0	0	0	36	392059	5817.2		$ 45,234.80	$ 3,061.97
05/31/05	0	0	0	111	324172	5819.2		$ 39,088.03	$ (344.70)
04/29/05	0	0	0	141	297603	8597.4		$ 39,622.76	$ 599.40
							TOTAL	$ 552,638.52	$ 13,103.21

**Does not include 10% tax credit
**Assumes 1.5 cents buyback for generated electricity

New System Yearly Utility Cost – 1.25 Safety Factor, $0.955 per therm – Payback in 74.9 Years

GENERATED				MAIN					Difference
	Energy			Energy				Total Cost	
	Steam	Electric	Gas	Steam	Electric	Gas			
Month	Mlbs	kWh	therms	Mlbs	kWh	therms			
03/29/06	0	971	0	236	239279	20469.5		$ 44,999.55	$ (1,159.36)
02/27/06	0	19526	0	318	191917	29817.9		$ 49,577.25	$ (1,532.63)
01/30/06	0	6159	0	226	197510	21985.4		$ 42,177.86	$ 4,171.07
12/29/05	0	29642	0	309	162457	30577.9		$ 47,182.77	$ (1,335.05)
11/29/05	0	0	0	200	248338	16178.2		$ 41,550.36	$ 5,464.24
10/27/05	0	0	0	148	359589	7585.8		$ 43,941.41	$ (636.68)
09/28/05	0	0	0	67	441655	5817.2		$ 49,755.12	$ 6,743.88
08/29/05	0	0	0	111	475717	7585.8		$ 55,125.75	$ (2,302.46)
07/29/05	0	0	0	150	444456	7583.8		$ 52,325.62	$ 2,430.78
06/29/05	0	0	0	91	392059	5817.2		$ 45,036.97	$ 3,259.80
05/31/05	0	0	0	130	308572	7587.8		$ 38,773.45	$ (30.12)
04/29/05	0	0	0	207	283953	10366.1		$ 39,564.44	$ 657.72
							TOTAL	$ 550,010.54	$ 15,731.19

**Does not include 10% tax credit
**Assumes 1.5 cents buyback for generated electricity

New System Yearly Utility Cost – 1.0 Safety Factor, $0.955 per therm – Payback in 43.1 Years

GENERATED				MAIN					Difference
	Energy			Energy				Total Cost	
	Steam	Electric	Gas	Steam	Electric	Gas			
Month	Mlbs	kWh	therms	Mlbs	kWh	therms			
03/29/06	0	0	0	188	273408	16174.2		$ 43,929.68	$ (89.50)
02/27/06	0	7826	0	246	228967	23754.0		$ 47,092.27	$ 952.35
01/30/06	0	0	0	195	232301	16932.2		$ 40,651.21	$ 5,697.72
12/29/05	0	12312	0	232	193876	24766.7		$ 44,425.39	$ 1,422.32
11/29/05	0	0	0	156	275638	12641.0		$ 40,540.42	$ 6,474.18
10/27/05	0	0	0	125	375189	5817.2		$ 43,619.18	$ (314.45)
09/28/05	0	0	0	23	441655	5817.2		$ 49,428.49	$ 7,070.51
08/29/05	0	0	0	97	491317	5817.2		$ 54,876.58	$ (2,053.29)
07/29/05	0	0	0	126	460056	5815.2		$ 52,000.10	$ 2,756.30
06/29/05	0	0	0	36	392059	5817.2		$ 44,634.47	$ 3,662.31
05/31/05	0	0	0	111	324172	5819.2		$ 38,487.49	$ 255.84
04/29/05	0	0	0	141	297603	8597.4		$ 38,735.50	$ 1,486.65
		**Does not include 10% tax credit					TOTAL	$ 538,420.79	$ 27,320.94
		**Assumes 1.5 cents buyback for generated electricity							

Conclusion

The general conclusion for this mechanical breadth is that it is a terrible idea. While the redundancy exists and is better than the Generator Set and the microturbines have an infinite utility downtime supply, the cost is extremely prohibitive. The utility cost does not seem to be very large when comparing the two systems and their relative heat contributions per dollar are very similar. Even with the variations in the calculations, the difference in the cost per year does not increase quickly enough to offset the initial cost. Sadly, this very redundant system is not useful as an installation in Cathedral Place. If the building was located in a much colder climate (somewhere described as "arctic tundra") where heating was necessary all year long, the initial cost might be offset by the difference in utility. Regardless, it is not a viable solution for Cathedral Place.