Appendix E - **UNIVERSITY HONORS PROGRAM**
SENIOR PROJECT - APPROVAL

Name: Tim Thomas

College: Engineering Department: M.A.B.E

Faculty Mentor: Dr. Stan Johnson

PROJECT TITLE: Cogeneration Design Study for a Pilot Travel Center

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

Signed: [signature], Faculty Mentor

Date: 5-3-04

General Assessment - please provide a short paragraph that highlights the most significant features of the project.

Comments (Optional):

The purpose of this design study was to determine the financial feasibility of implementing a cogeneration system at a Pilot Travel Center. This paper includes yearly energy consumption calculations, energy conservation measures, and a complete cost analysis for a system utilized in Knoxville, TN and New York City, NY.

Tim Thomas

Mentor: Dr. Stan Johnson

The Feasibility of Using Microturbines for Cogeneration in a Pilot Travel Center

Abstract

Typically, commercial buildings purchase their electricity from a power company and use some combination of gas and electricity for their heating and cooling needs. The Pilot Travel Center was designed to operate with gas heat and electric cooling. There is nothing inherently wrong with this method of providing energy for a building, however, if electric rates suddenly climbed, it may be economically feasible to produce all of the electricity, heating and cooling on site. This is commonly referred to as cogeneration or the utilization of two or more kinds of energy from a single fuel source (in this case, electrical and thermal energy).

For most types of power generating applications, some machine is necessary to take the chemical energy of a fuel, burn it to produce mechanical energy, and convert it to electrical energy. Many commercial businesses produce electricity on site for emergencies and to offset the cost of high demand charges. But rarely does a company use an on-location generator to support all of its electricity needs because engines are not very efficient at producing electricity (about 30% efficient). Much of the energy is lost in the form of heat. The purpose of cogeneration is to make use of the waste heat to provide space heating directly or to provide cooling via a chiller. With a cogeneration system, efficiencies upwards of 85-90% may be achieved.

It is the goal of this project to design an appropriate cogeneration system for the Pilot Travel Center and to determine the economic feasibility of cogeneration by comparing the costs of the new system with the costs of the system for which the building was originally designed.

The Feasibility of Using Microturbines for Cogeneration in a Pilot Travel Center

Senior Honors Project

Mentor: Dr. Stan Johnson
Professor of Mechanical Engineering

Submitted by: Tim Thomas

May 3, 2004

INTRODUCTION

The purpose of this project was to perform a design study to examine the feasibility of providing space heating, cooling, and electricity to a Pilot Travel Center via a gas microturbine. This project is being performed under the supervision of Dr. Stan Johnson, Professor of Mechanical Engineering, to fulfill the senior capstone design requirement for the College of Engineering. However, as approved by the Honors Program, it will also be used as a senior honors project.

Since the College of Engineering requires the final project to be a collaborative, team assignment, while the Honors Program requires the senior to perform an individual project, an attempt will be made to separate the student's individual contribution and present it as a stand-alone project. However, it will be necessary, at times, to mention relevant results and design decisions produced by the group as a whole.

BACKGROUND

Typically, commercial buildings purchase their electricity from a power company while using some combination of gas and electricity for their heating and cooling needs. The Pilot Travel Center was designed to operate with gas heat and electric cooling. There is nothing inherently wrong with this method of providing energy for a building, but, if electric rates suddenly climbed, it may be economically feasible to produce all of the electricity, heating and cooling on site. This is commonly referred to as cogeneration or the utilization of two or more kinds of energy from a single fuel source (in this case, electrical and thermal energy).

For any power generating application, some type of machine is necessary to take the chemical energy of a fuel and burn it to produce mechanical energy. The mechanical energy is then converted to electrical energy. Many commercial businesses produce electricity on site for emergencies and to offset the cost of high demand charges. But rarely does a company use an on location generator to support all of its electricity needs because engines are not very efficient at producing electricity (about 30% efficient); much of the energy is lost in the form of heat. The purpose of cogeneration is to make use of the waste heat to provide space heating directly, to provide cooling via a chiller. With a cogeneration system, efficiencies upwards of 85-90% may be achieved.

A fairly new technology that seems to be well suited for cogeneration applications is microturbines. These operate much like the jet engines for an aircraft. Air is pressurized by a compressor and sent to a chamber where it mixes with fuel and combustion takes place. The hot combustion gases expand through a turbine to produce work. The rotation of the turbine spins an alternator which generates electricity. The turbine, compressor, and alternator are all attached to the same shaft. The exhaust gases exiting the turbine are then passed through a heat exchanger to heat up water being piped through. This hot water is then piped directly to the building for heating or to the chiller to provide cooling.

PROBLEM STATEMENT

The overall goal of this project is to determine the economic feasibility of using a microturbine as a cogeneration system for the Travel Center. This involves making fairly detailed calculations to determine the building's energy needs. These calculations will be based on weather data for Knoxville, TN and a much more economically favorable location. Following the load calculations all of the system components will be sized accordingly. Finally, a complete cost analysis will be performed to determine the economic feasibility.

The scope of this paper will include the yearly energy usage calculations, energy conservation measures, a cost analysis for a building located in Knoxville and for one located in New York City. Finally, the paper will explore options for making the system more efficient at producing electricity.

HEATING AND COOLING LOAD CALCULATIONS

In order to determine the heating and cooling needs for the building, several calculations needed to be made. For the heating loads, a certain amount of warm air must be supplied to the building to offset the heat lost by conduction through the walls, floor, and ceiling and by infiltration of cool outside air into the building. The design heating load for Knoxville, TN was determined to be approximately 350,000 Btu/h.

The cooling load calculations are very similar to the heating loads, except heat generation from internal sources (lights, appliances, people, etc.) and solar effects must be considered. The design cooling load was calculated to be about 450,000 Btu/h.

YEARLY ENERGY CONSUMPTION

With the heating and cooling loads determined, the next step was to calculate the total yearly energy consumption, broken down by heating energy, cooling energy, and electrical energy. While trying to configure the solution of the yearly energy consumption, the concept of leaving room for error was essential. The data going into the calculations for the energy consumption was an assimilation of previous calculations, and therefore a method of approximating the energy consumption was needed. Three main methods of estimating energy consumption were considered. One method was the single measure method, which was theoretically excellent for obtaining quick estimations. However, the disadvantage was that the single measure method used a surplus of assumptions, which had a tendency to produce less-than-reliable results. On the other hand, detailed simulation procedures were a possibility, as they could obtain approximations that were a whole lot more accurate than those obtained from the single measure methods. Yet, the detailed simulation procedures were thought to be more complex in terms of the data input, typically requiring the use of a computer, and were found to be more expensive. A method was desired that could produce inexpensive and quick results that were also fairly accurate, and it was discovered that multiple measure methods fit those qualifications. Therefore, a multiple measure method was used to estimate the yearly energy consumption.

A bin method was chosen and is advantageous in the fact that it could be applied for both heating and cooling loads. It entailed the use of instantaneous energy calculations at several different outdoor dry-bulb temperatures and weighting each by the number of hours of temperature occurrence within each bin. The bins typically were in 5°F sizes and were collected in three daily 8-hr. shifts.

The classical bin method was employed for the calculations and it uses peak load values, so that quicker estimations can be obtained that are within a reasonable scope of accuracy. Furthermore, to determine the building balance point, factors that needed to be considered were the indoor temperature, internal heat generation, and the thermal properties. The balance point was calculated to be 59°F based on the amount of internal heat generation and the building heat transfer characteristics.

Using the classical bin method, factors such as weather data bin hours, heating capacity, and operating time fraction played key contributions to the energy calculations. The energy consumption due to heating was calculated to be 108,000 kWh, while that due to cooling was found to be 239,000 kWh. The choice of kWh for units is used in order to facilitate comparisons between the heating and cooling energy needs and the electricity requirements. Table 3 and Figure 5 below show the yearly energy consumption and percentage distribution. Since the cooling loads had earlier been found to be greater than the heating loads, these calculations made sense for Knoxville. Subsequently, the energy consumption from the electricity was significantly larger, as it was 2,410,000 kWh. This accounts for 87% of the total yearly energy consumption.

TABLE 3: YEARLY ENERGY CONSUMPTION BY TYPE

Heating	108,000	kWh
Cooling	239,000	kWh
Electric	2,410,000	kWh
TOTAL	**2,760,000**	**kWh**

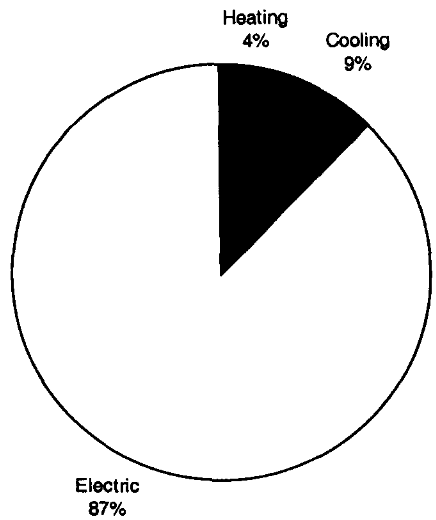

Figure 5: Distribution of Yearly Energy Consumption

DESIGN CONSIDERATIONS

To meet the electrical demands of the building four microturbine units are required: one 250 kW unit and three 70 kW units. Obviously, there will be a tremendous amount of waste energy due to the poor electrical efficiency of microturbines. With all four units operating, there will be approximately 1500 MBH of energy to be used for either heating or cooling, which is significantly more than necessary for the Travel Center (the max cooling load is 460 MBH).

In heating mode, the hot water leaving the microturbine will be sent directly to a large heating coil. When operating in cooling mode, the hot water leaving the microturbine will be sent to two 20-ton chillers. Cool water leaving the chillers will then be piped to the building's cooling coil.

COST ANALYSIS

Baseline—Knoxville, TN

The baseline case used to compare and evaluate the feasibility of cogeneration will be the system that was originally designed for the Pilot Travel Center. Under this system, all of the electricity and natural gas would have been purchased from the utilities. Seven rooftop air-conditioning units would have been used to provide gas heating and electric cooling.

The electricity and natural gas rates are those quoted by the Knoxville Utilities Board and are summarized in the appendix.

The baseline case will also include capital and maintenance costs for the system. Since both systems will require similar ductwork, heat exchangers, and air-moving devices, the costs for such components will be neglected. It should be noted that for the cost comparison model used, it was assumed that over a 10-year period, the relative increase of natural gas and electricity prices will be approximately the same. Also, an opportunity interest rate of about 6% will be used and all costs are determined on a present value basis. The following tables should be used for the purpose of comparison only and do not reflect the total costs for implementing either the baseline or cogeneration system; only the costs that varied based on the system being analyzed were considered. Table 4 presents a summary of costs considered for the baseline system.

TABLE 4: FINANCIAL SUMMARY FOR BASELINE SYSTEM

Electricity	**$1,248,435.93**
Fuel	**$43,481.88**
Maintenance	**$66,240.78**
Capital	**$280,000.00**
TOTAL	**$1,638,158.59**

Obviously, electricity costs would make up the bulk of the system as it were initially designed by Pilot.

Cogeneration—Knoxville, TN

Since all electricity is produced on site for this scenario, the only money spent on utilities is for the fuel (natural gas). The same natural gas rates apply for the cogeneration system as the baseline. Table 5 shows the breakdown of costs for the cogeneration system.

TABLE 5: FINANCIAL SUMMARY FOR COGENERATION SYSTEM

Electricity	**$0.00**
Fuel	**$1,463,802.38**
Maintenance	**$47,840.57**
Capital	**$649,000.00**
TOTAL	**$2,160,642.95**

Financial Conclusions—Knoxville, TN

Based on the above analysis, the described cogeneration system does not appear to be economically feasible. The main reason being the large amount of money spent on fuel as a result of the building's electricity demands. The Travel Center's heating and cooling requirements hardly need to be considered since they are easily met by the system's large amount of waste energy. This type of application would be better suited and economically worthwhile at a location that required significantly more heating and cooling and at the same time had much higher electricity rates than Knoxville.

Baseline-NYC

After researching a number of cities throughout the United States, New York City, NY seemed like an attractive location due to its high electric rates. The heating and cooling loads were recalculated for New York City and were found to be not much different than those for Knoxville. The maximum heating load was calculated to be 375 MBH and the maximum cooling load was computed as 453 MBH.

Applying the bin method for calculating yearly energy consumption, a Pilot Travel Center in NYC would use almost the same amount of total energy as the Knoxville location, about 2.8 million kWh. Even though both locations were found to have the same energy usage, the electricity prices are high enough in New York that cogeneration will be cost effective. Table 6 outlines the major costs for a Pilot Travel Center operating under the baseline system in New York City while table 7 shows the financial summary for the cogeneration system.

TABLE 6: BASELINE COSTS FOR NEW YORK CITY

Electricity	**$2,612,127.44**
Fuel	**$27,115.61**
Maintenance	**$66,240.78**
Capital	**$280,000.00**
TOTAL	**$2,985,483.83**

TABLE 7: COGENERATION COSTS FOR NEW YORK CITY

Electricity	**$0.00**
Fuel	**$1,376,947.17**
Maintenance	**$47,840.57**
Capital	**$649,000.00**
TOTAL	**$2,073,787.73**

It appears that implementing the cogeneration system will be cost effective. On the other hand, this is still not the ideal cogeneration application because the heating and cooling loads are small enough that there will still be a tremendous of waste heat. Rather than investing so much on the latest microturbine and cogeneration technology, it would probably be less expensive to purchase a proven, tried and true electricity generator and a separate heating and cooling system for this particular location.

It was the recommendation of the design team that a cogeneration system not be employed in Knoxville, TN at this time. Until electricity rates are high enough and natural gas prices are low enough, it will not be economically feasible. The situation in which cogeneration would be ideal would be one where electricity prices are relatively high and at the same time would demand a large heating or cooling load so the use of waste heat can be optimized and, therefore, more money saved.

SYSTEM IMPROVEMENTS

In an effort to reduce costs of the cogeneration system, several possibilities will be considered. First of all, this analysis will explore several energy conservation measures that will improve the building's heating and cooling requirements. Also, a few ways to improve on the system's efficiency and produce more electricity will be evaluated.

Conservation Measures—Energy Savings

The first conservation measure considered was an exhaust air heat exchanger. A certain amount of air must be ventilated from the building as it becomes stale. With that exhausted air goes a wasted amount of energy. Depending on whether the system is in heating or cooling mode, with an air to air heat exchanger the exhaust air can preheat or precool the ambient outdoor air as it is introduced to the system. This will significantly cut back on the energy wasted as stale air is ventilated from the building.

To determine the energy savings for this device the ventilation rate had to be determined. A value of about 8000 cfm was settled upon after reviewing the building's HVAC schedule and speaking with the local Pilot engineers. This number would include exhaust air from the kitchen, bathrooms, showers and other miscellaneous locations. After subtracting the air flow entering by infiltration from the amount of air exiting via exhaust, the amount of fresh air needed to be supplied to the building could be determined. Then using the design indoor and outdoor air temperatures the maximum possible heat transfer to the outdoor air could be calculated.

Using a cross flow, air-to-air heat exchanger with an effectiveness of approximately 30%, about 125 MBH of heat can be recovered at the outdoor design temperature of 19°F in the winter and about 40 MBH of heat can be removed from the outside air at the summer design temperature of 92°F. Figure 6 is a plot showing the energy recovery/removal accomplished by the exhaust air heat exchanger for a range of outdoor temperatures.

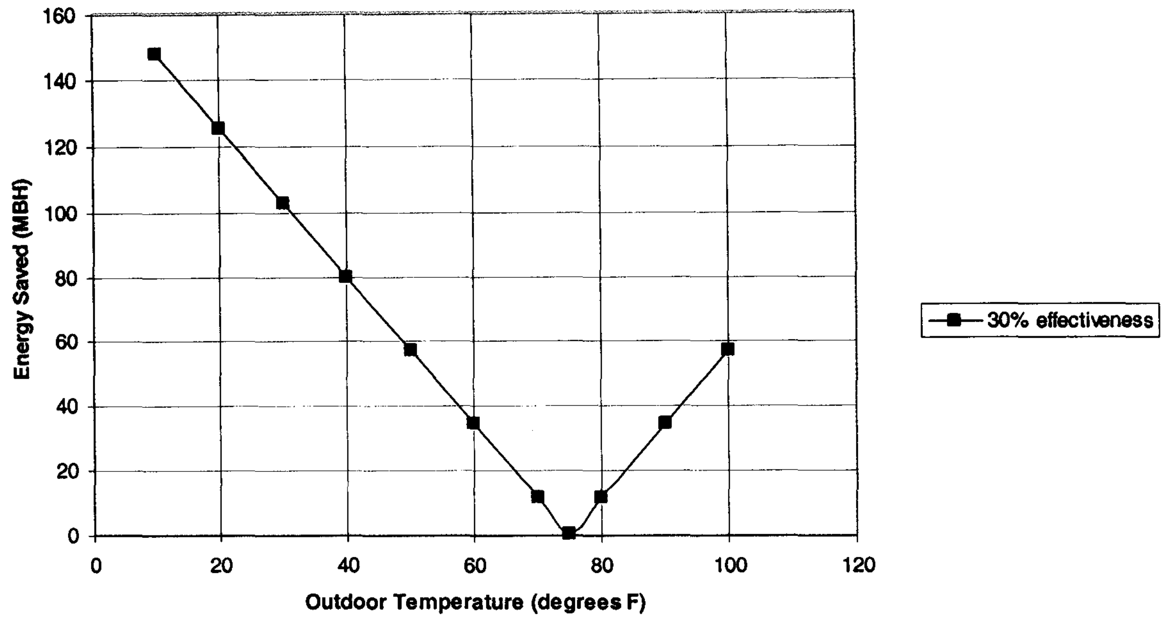

Figure 6: Energy Savings Using an Exhaust Air Heat Exchanger

The next conservation measure considered was an improvement on the largest area of heat loss/gain. This happened to be the roof and ceiling. Nearly 50% of the heat loss occurs through the roof in the winter and a large amount enters through the roof in the summer. By adding an extra three inches of insulation throughout the roof, approximately 50MBH of heat can be saved based on a 19 degree outdoor temperature.

It was also of interest to determine how the heating and cooling loads would change for different indoor thermostat settings. Figure 7 illustrates the effect a range of indoor temperatures would have on the overall heating and cooling loads.

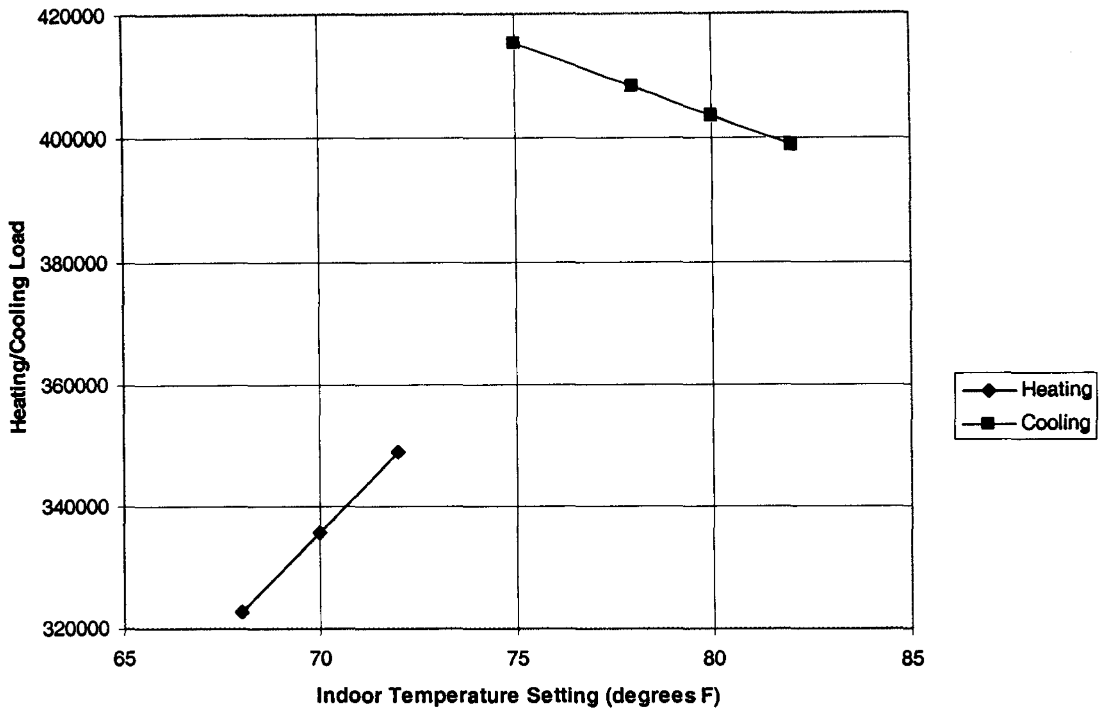

Figure 7: Energy Savings For Various Indoor Temperature Settings

It appears that adjusting the thermostat 3 degrees cooler in the winter will lower the maximum design heating load by about 20 MBH or about 6%, while 3 degrees warmer in the summer will save about 7 MBH or about 2% of the maximum cooling load. Therefore, it may be slightly advantageous to go from the 72°F design temperature to somewhere between 66-69°F in the winter months, but it is probably best to maintain a temperature no higher than 78°F in the summer months to insure human comfort and because very little energy is saved otherwise.

Conservation Measures—Cost Savings

Upon analyzing the integration of the above conservation measures into a cogeneration system for the Pilot Travel Center, it appears that the cost savings would be minimal. The reason is that in order to meet the building's electricity requirements, the system will have to be run near capacity much of the time, and will produce more waste energy that the Travel Center would ever need to meet its heating and cooling needs. Therefore, additional money spent on the above conservation measures would be impractical.

Wave Rotor Topping Cycle

One way to improve on the efficiency of the microturbines would be to add a wave rotor topping cycle. Wave rotors are unsteady-flow devices that use compression waves to pressurize a fluid. As opposed to steady-flow devices, such as compressors, unsteady-flow devices can produce a much higher pressure rise.

A wave rotor uses the hot exhaust gas from the combustion chamber to further compress the air exiting the compressor. This compressed air is then sent to the combustion chamber. The pre-expanded exhaust gas then passes through and spins the turbine. The reason wave rotors are so effective is that they are capable of producing a much higher turbine inlet pressure than a conventional system while maintaining the same temperature.

Akbari and Müller found that a 30 kW microturbine topped with a wave rotor can have efficiency improvements up to 33%. However, the costs associated with such an implementation are unknown due to the relative newness of the technology.

BIBLIOGRAPHY

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3. *Fundamentals, 1989 ASHRAE Handbook I-P Edition.* American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. Atlanta, GA. 1989.

4. Mcquiston and Spitler. *Cooling and Heating Load Calculation Manual, Second Edition.* ASHRAE 1992.

5. Pilot Travel Center Blueprints. Provided by Pilot Corp.

6. "Turbine Cogeneration" Global Energy Capstone. www.globalmicroturbine.com

7. Yazaki Energy Systems, Inc. website. www.yazakienergy.com

APPENDIX

Knoxville Utility Board Electricity/Natural Gas Rates

Electric Rates

- Customer Charge: $15.00 per month
- Demand Charge: First 50 kW of billing demand per month, no demand charge. Excess over 50 kW of billing demand per month, at $10.96 per kW.
- Energy Charge: First 15,000 kWh per month at 7.196¢ per kWh
  Additional kWh per month at 3.537¢ per kWh

Gas Rates

- Customer Charge: $100 per month
- Demand Charge: $1.60 per therm of demand
- Commodity Charge: First 30,000 therms per month at 79.22¢ per therm
  Additional therms per month at 71.20¢ per therm

Consolidated Edison (NYC) Electricity/Natural Gas Rates

Electric Rates

- Demand Charge: $16/kW of billing demand per month
- Energy Charge: $0.09/kWh per month

Gas Rates

- Transportation: $0.1241 per therm
- Commodity Charge: $0.67551 per therm

NYC, NY

BIN METHOD, HEATING--MICROTURBINE

Temp Bin F)	Temp. Diff	Weather Data Bin Hours	Heat Loss Rate (Btu/hr)	Heat Pump Integrated Heating Capacity (Btu/hr)	Cyclnig Capacity Adjustment Factor	Adjusted Heat Pump Capacity (Btu/hr)	Rated Electric Input (kW)	Operating Time Fraction	Heat Pump Supplied Heating (Btu)	Seasonal Heat Pump Electric Consumption (kWh)	Space Load (Btu)	Supplemental Heating Required (kWh)	Total Electric Energy Consumption
57	3	715	18750	415000	0.761295181	315937.5	100	0.059347181	13406250	4243.323442	13406250	0	4243.323442
52	8	644	50000	390000	0.782051282	305000	100	0.163934426	32200000	10557.37705	32200000	0	10557.37705
47	13	624	81250	365000	0.805650685	294062.5	100	0.276301807	50700000	17241.23273	50700000	0	17241.23273
42	18	664	112500	340000	0.832720588	283125	100	0.397350993	74700000	26384.10596	74700000	0	26384.10596
37	23	780	143750	315000	0.864087302	272187.5	100	1	212306250	78000	112125000	-100181250	78000
32	28	792	175000	290000	0.900862069	261250	100	1	206910000	79200	138600000	-68310000	79200
27	33	522	206250	265000	0.944575472	250312.5	100	1	130663125	52200	107662500	-23000625	52200
22	38	359	237500	240000	0.997395833	239375	100	1	85935625	35900	85262500	-673125	35900
17	43	246	268750	215000	1	215000	100	1	52890000	24600	66112500	13222500	24600
12	48	164	300000	190000	1	190000	100	1	31160000	16400	49200000	18040000	16400
7	53	91	331250	165000	1	165000	100	1	15015000	9100	30143750	15128750	9100
2	58	39	362500	140000	1	140000	100	1	5460000	3900	14137500	8677500	3900
								TOTALS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

BIN METHOD, COOLING--ABSOPRTION CHILLER

Temp Bin F)	Temp. Diff	Weather Data Bin Hours	Heat Gain Rate (Btu/hr)	Chiller Integrated Cooling Capacity (Btu/hr)	Cyclnig Capacity Adjustment Factor	Adjusted Chiller Capacity (Btu/hr)	Rated Electric Input (kW)	Operating Time Fraction	Chiller Supplied Cooling (Btu)	Seasonal Chiller Electric Consumption (kWh)	Space Load (Btu)	Supplemental Cooling Required (kWh)	Total Electric Energy Consumption
102	-42	0	504000	640000	0.946875	606000	100	0.831683168	0	0	0	0	0
97	-37	6	444000	615000	0.930487805	572250	100	0.775884666	2664000	465.5307995	2664000	0	465.5307995
92	-32	33	384000	590000	0.912711864	538500	100	0.713091922	12672000	2353.203343	12672000	0	2353.203343
87	-27	137	324000	565000	0.893362832	504750	100	0.641901932	44388000	8794.056464	44388000	0	8794.056464
82	-22	291	264000	540000	0.872222222	471000	100	0.560509554	76824000	16310.82803	76824000	0	16310.82803
77	-17	456	204000	515000	0.849029126	437250	100	0.466552316	93024000	21274.78559	93024000	0	21274.78559
72	-12	668	144000	490000	0.823469388	403500	100	0.356877323	96192000	23839.4052	96192000	0	23839.4052
67	-7	759	84000	465000	0.79516129	369750	100	0.227180527	63756000	17243.00203	63756000	0	17243.00203
62	-2	740	24000	440000	0.763636364	336000	100	0.071428571	17760000	5285.714286	17760000	0	5285.714286
								TOTALS	407280000	[illegible]	407280000	[illegible]	[illegible]

YEARLY TOTALS

Heating	267024	kWh
Cooling	119333	kWh
Electric	2409000	kWh
TOTAL =	**2795357**	**kWh**

Knoxville, TN

BIN METHOD, HEATING--MICROTURBINE

Temp Bin F)	Temp. Diff	Weather Data Bin Hours	Heat Loss Rate (Btu/hr)	Heat Pump Integrated Heating Capacity (Btu/hr)	Cyclnig Capacity Adjustment Factor	Adjusted Heat Pump Capacity (Btu/hr)	Rated Electric Input (kW)	Operating Time Fraction	Heat Pump Supplied Heating (Btu)	Seasonal Heat Pump Electric Consumption (kWh)	Space Load (Btu)	Supplemental Heating Required (kWh)	Total Electric Energy Consumption
57	2	684	12500	415000	0.75753012	314375	100	0.03976143	8550000	2719.68191	8550000	0	2719.68191
52	7	689	43750	390000	0.77804487	303437.5	100	0.14418126	30143750	9934.08857	30143750	0	9934.08857
47	12	690	75000	365000	0.80136986	292500	100	0.25641026	51750000	17692.3077	51750000	0	17692.3077
42	17	642	106250	340000	0.828125	281562.5	100	0.37735849	68212500	24226.4151	68212500	0	24226.4151
37	22	585	137500	315000	0.85912698	270625	100	1	158315625	58500	80437500	-77878125	58500
32	27	440	168750	290000	0.89547414	259687.5	100	1	114262500	44000	74250000	-40012500	44000
27	32	220	200000	265000	0.93867925	248750	100	1	54725000	22000	44000000	-10725000	22000
22	37	97	231250	240000	0.99088542	237812.5	100	1	23067812.5	9700	22431250	-636562.5	9700
17	42	40	262500	215000	1	215000	100	1	8600000	4000	10500000	1900000	4000
12	47	21	293750	190000	1	190000	100	1	3990000	2100	6168750	2178750	2100
7	52	6	325000	165000	1	165000	100	1	990000	600	1950000	960000	600
2	57	2	356250	140000	1	140000	100	1	280000	200	712500	432500	200
								TOTALS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

BIN METHOD, COOLING--ABSOPRTION CHILLER

Temp Bin F)	Temp. Diff	Weather Data Bin Hours	Heat Gain Rate (Btu/hr)	Chiller Integrated Cooling Capacity (Btu/hr)	Cyclnig Capacity Adjustment Factor	Adjusted Chiller Capacity (Btu/hr)	Rated Electric Input (kW)	Operating Time Fraction	Chiller Supplied Cooling (Btu)	Seasonal Chiller Electric Consumption (kWh)	Space Load (Btu)	Supplemental Cooling Required (kWh)	Total Electric Energy Consumption
102	-43	1	531635	640000	0.95766984	612908.7	100	0.8673964	531634.8	86.73964	531634.8	0	86.73964
97	-38	21	469817	615000	0.94098244	578704.2	100	0.81184273	9866152.8	1704.86974	9866152.8	0	1704.86974
92	-33	129	407999	590000	0.92288085	544499.7	100	0.7493095	52631845.2	9666.0926	52631845.2	0	9666.0926
87	-28	358	346181	565000	0.90317735	510295.2	100	0.67839321	123932726	24286.477	123932726	0	24286.477
82	-23	573	284363	540000	0.88164944	476090.7	100	0.59728703	162939884	34224.5468	162939884	0	34224.5468
77	-18	785	222545	515000	0.85803146	441886.2	100	0.50362469	174697668	39534.5381	174697668	0	39534.5381
72	-13	1058	160727	490000	0.83200347	407681.7	100	0.3942458	170048954	41711.2062	170048954	0	41711.2062
67	-8	928	98909	465000	0.80317677	373477.2	100	0.26483223	91787366.4	24576.431	91787366.4	0	24576.431
62	-3	782	37091	440000	0.77107432	339272.7	100	0.10932445	29005005.6	8549.17168	29005005.6	0	8549.17168
								TOTALS	815441238	184340.073	815441238		184340.073

YEARLY TOTALS

Heating	153206	kWh
Cooling	238924	kWh
Electric	2409000	kWh
TOTAL =	**2801130**	**kWh**

SAMPLE SPREADSHEET--COOLING LOADS

Cooling Load Calculations (CLTD Method)

Input Temperatures

Building Temp (F)	78
Ambient Temp (F)	92

Window & Door Perimeter (ft)	629.57
Window Perimeter (ft)	309.63

Input Material Properties/Output Heat Transfer Properties and Heat Transfer

Front of Building (Entrance)

Bldg. Feature	# of Feature	Section Length (ft)	Section Height (ft)	Area, A (ft2)	Material Thickness (in)	Material Thickness (ft)	Thermal Resistance, R (F*ft²*hr/Btu)	Overall Heat Transfer Coefficient, U (Btu/hr*ft²*F)	Heat Transfer (Btu/hr)
Wall Section #1 (Arby's Front)	1								
Window Glass	5	5.77	5.75	33.18	NA	NA	NA	1.1	
CLTD Calculation									
Time of Day		CLTD (WindowConduction)	LM Correction	$CLTD_{corr}$	Conduction Hourly Total	SCLsh	SC	Solar Hourly Total	Hourly HT
1.00 AM		1.00	1.00	9.00	328.50	2	0.9	59.73	388.23
2.00 AM		0.00	Indoor Temp. Correction	8.00	292.00	2	0.9	59.73	351.73
3.00 AM		-1.00	0.00	7.00	255.50	1	0.9	29.86	285.37
4.00 AM		-2.00	Outdoor Temp. Correction	6.00	219.00	1	0.9	29.86	248.87
5.00 AM		-2.00	7.000	6.00	219.00	1	0.9	29.86	248.87
6.00 AM		-2.00		6.00	219.00	21	0.9	627.15	846.15
7.00 AM		-2.00		6.00	219.00	25	0.9	746.60	965.60
8.00 AM		0.00		8.00	292.00	25	0.9	746.60	1038.61
9.00 AM		-2.00		6.00	219.00	29	0.9	866.06	1085.06
10.00 AM		4.00		12.00	438.01	33	0.9	985.51	1423.52
11.00 AM		7.00		15.00	547.51	36	0.9	1075.11	1622.61
12.00 PM		9.00		17.00	620.51	38	0.9	1134.83	1755.34
1.00 PM		12.00		20.00	730.01	38	0.9	1134.83	1864.84
2.00 PM		13.00		21.00	766.51	38	0.9	1134.83	1901.35
3.00 PM		14.00		22.00	803.01	35	0.9	1045.24	1848.25
4.00 PM		14.00		22.00	803.01	32	0.9	955.65	1758.66
5.00 PM		13.00		21.00	766.51	33	0.9	985.51	1752.03
6.00 PM		12.00		20.00	730.01	35	0.9	1045.24	1775.25
7.00 PM		10.00		18.00	657.01	15	0.9	447.96	1104.97
8.00 PM		8.00		16.00	584.01	10	0.9	298.64	882.65
9.00 PM		6.00		14.00	511.01	7	0.9	209.05	720.06
10.00 PM		4.00		12.00	438.01	5	0.9	149.32	587.33
11.00 PM		3.00		11.00	401.51	4	0.9	119.46	520.96
12.00 PM		2.00		10.00	365.01	3	0.9	89.59	454.60
								Max Window Cooling Load	1901.35
Stucco		52.04	3.58	186.48	0.375	0.03125	0.075	13.33333333	
Stud Buildout (Air Gap)		52.04	3.58	186.48	3.625	0.302083333	0.91	1.098901099	
Inner Wall Board		52.04	3.58	186.48	0.625	0.052083333	0.56	1.785714286	
Batt Insulation		52.04	3.58	186.48	6	0.5	19	0.052631579	
Outer Wall Board		52.04	3.58	186.48	0.500	0.041666667	0.45	2.222222222	
							Lower Wall Total "U"	0.047630366	

SAMPLE SPREADSHEET--HEATING LOADS

Input Temperatures

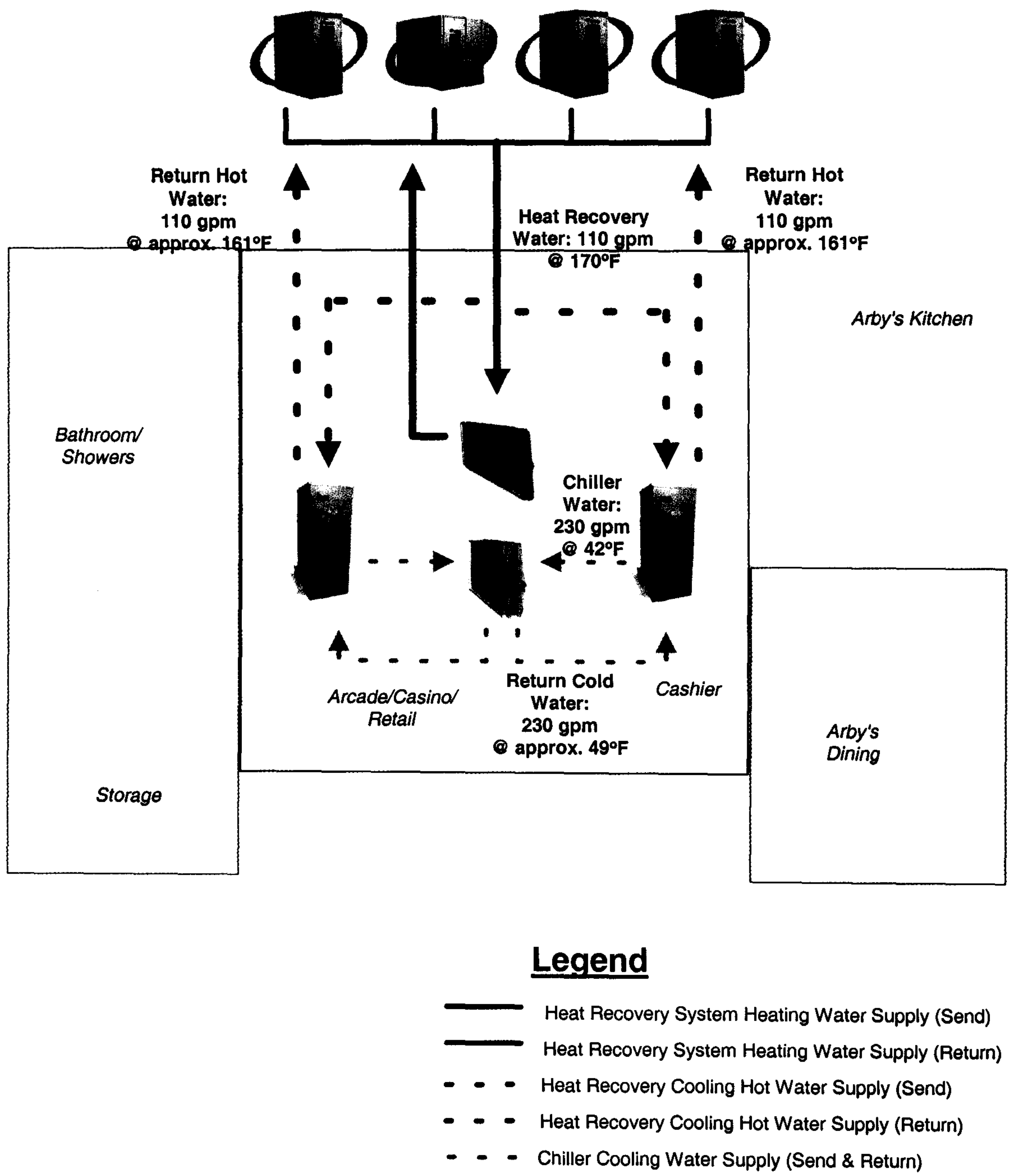
Building Temp (F)	72
Ambient Temp (F)	2

Window & Door Perimeter (ft)
629.57

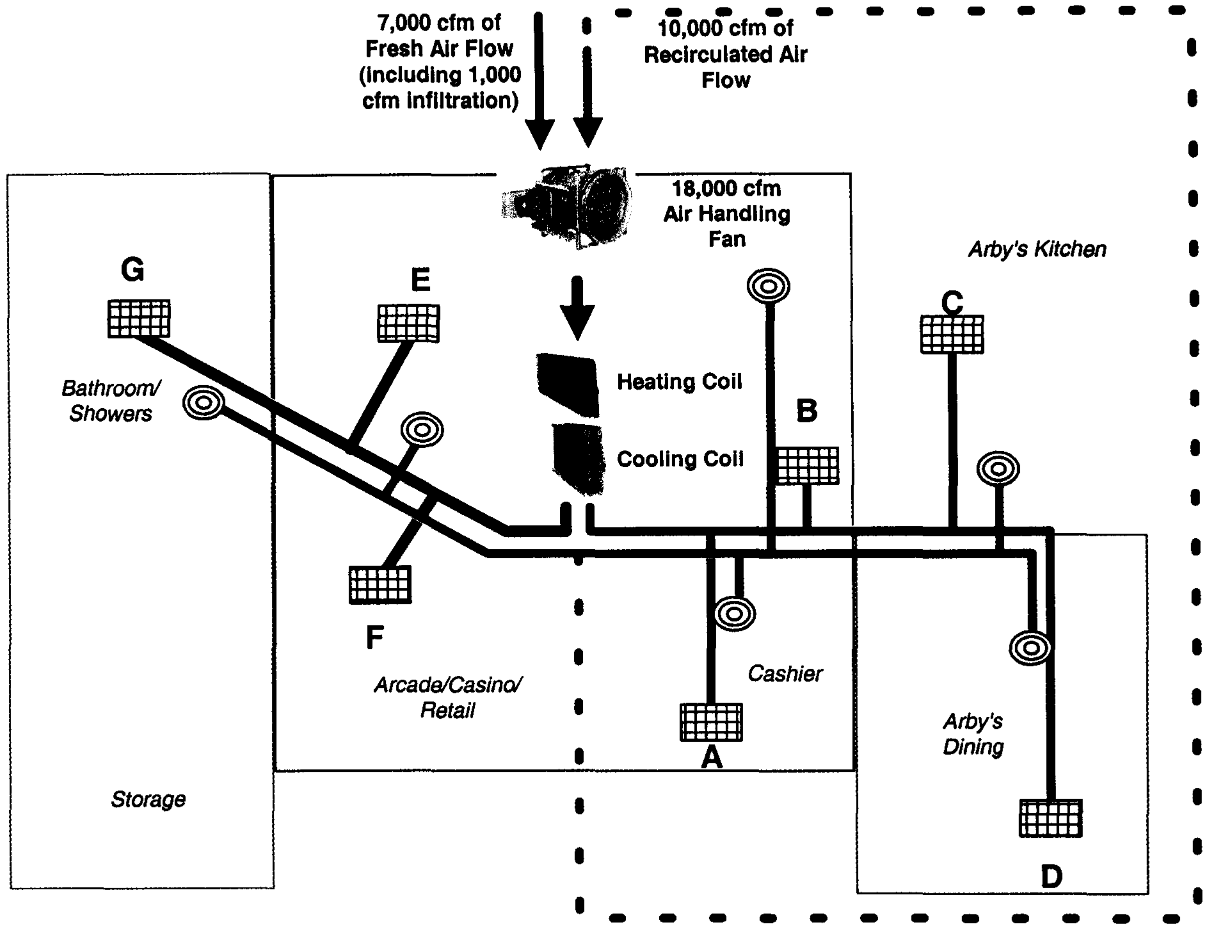
Window Perimeter (ft)
309.63

rties and Heat Transfer

# of Feature	Thermal Conductivity, K	Section Length (ft)	Section Height (ft)	Area, A (ft2)	Material Thickness (in)	Material Thickness (ft)	Thermal Resistance, R ($F*ft^2*hr/Btu$)	Overall Heat Transfer Coefficient, U ($Btu/hr*ft^2*F$)	Heat Transfer (Btu/hr)
1									
5	NA	5.77	5.75	33.18	NA	NA	NA	1.1	
								Window Heat Transfer	12775.18
	NA	52.04	3.58	186.48	0.375	0.03125	0.075	13.33333333	
	NA	52.04	3.58	186.48	3.625	0.302083333	0.91	1.098901099	
	NA	52.04	3.58	186.48	0.625	0.052083333	0.56	1.785714286	
	NA	52.04	3.58	186.48	6	0.5	19	0.052631579	
	NA	52.04	3.58	186.48	0.500	0.041666667	0.45	2.222222222	
							Lower Wall Totals	0.047630388	621.76
	NA	52.04	5.92	274.73	0.375	0.03125	0.075	13.33333333	
	NA	52.04	5.92	274.73	0.625	0.052083333	0.56	1.785714286	
	NA	52.04	5.92	274.73	6	0.5	19	0.052631579	
	NA	52.04	5.92	274.73	0.500	0.041666667	0.45	2.222222222	
							Upper Wall Totals	0.049788399	957.49
	Section Totals	52.04	9.50	494.40				Total Heat Transfer	14354.43
1									
	NA	NA	NA	343.38	0.375	0.03125	0.075	13.33333333	
	NA	NA	NA	343.38	0.625	0.052083333	0.56	1.785714286	
	NA	NA	NA	343.38	6	0.5	19	0.052631579	
	NA	NA	NA	343.38	0.500	0.041666667	0.45	2.222222222	
							Wall Totals	0.049788399	1196.73
	Section Totals	33.50	10.25	343.38				Total Heat Transfer	1196.73



Schematic of System Components



Legend

- Air Damper
- Air Ventilation Vent
- Air Inlet Ventilation Duct
- Air Oulet Ventilation Duct

Schematic of Air Handling System