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Penn State University

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Mechanical Option

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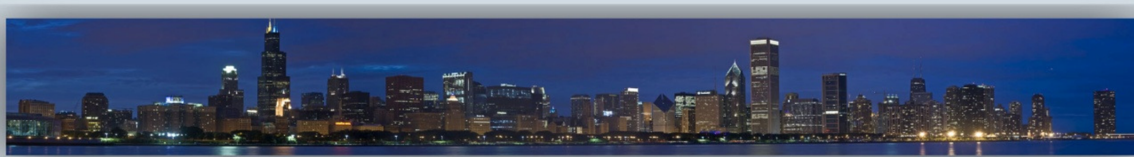
[FINAL REPORT]

Senior Thesis on Hotel Felix located in Chicago, Illinois



Hotel Felix

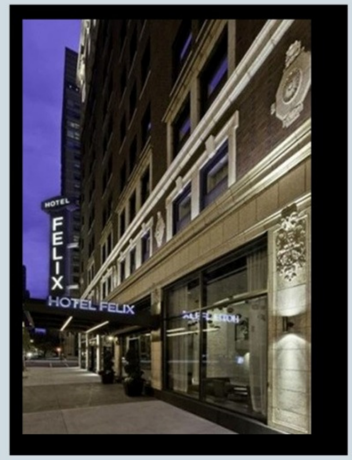
Chicago, Illinois

Cubellis: **Architect**
Gettys: **Interior Designer**
TGRWA: **Structural Consultant**
WMA Consulting Engineers: **MEP**
Schuler Shook: **Lighting Design**

BUILDING STATISTICS

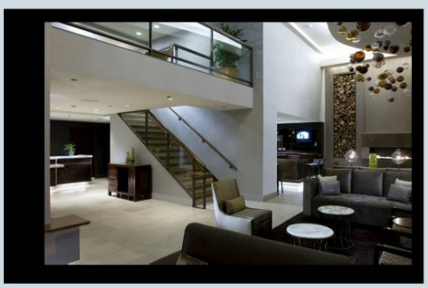
Location: Chicago, Illinois
Building Size: 85,700 SF
Building Price: $28,000,000
Stories: 12 Floors
Delivery method: Design-Bid-Build

silver certified



ARCHITECTURE

This historical was recently renovated in 2009 to become the first LEED Silver certified hotel in Chicago. Hotel Felix was able to preserve its architecturally unique and historic 1920's facade and was outfitted with sustainable eco-friendly materials for its interior such as bamboo, recycled carpet, and non-VOC paint and wallpaper. There are 225 guest rooms in total with full service-spas, business centers, meeting rooms, conference rooms, and upscale restaurants to deliver an enriching experience not only for its guests, but also for the environment.



MECHANICAL

Hotel Felix utilizes a VAV Roof Top Unit running at 7500 CFM for the hotel corridors and a self contained air handling unit located at the basement that provides air to the basement, 1st floor, and mezzanine area at 8000 CFM. Individual hotel rooms have seperate water source heat pumps ranging from 300 CFM to 400 CFM. Also, a split system AC unit with electric heat supplies air to the elevator machine room. A 160 TON cooling tower is located on the roof which supports two natural gas boilers that provide hot water to the main building.

LIGHTING / ELECTRICAL

Four service feeders provide power to the hotel. One service feeder provides power to a 4000A, 208/120V switch board. The other three provide power for elevator emergency, restaurant, and verizon service at 400A, 400A, and 200A respectively.

STRUCTURAL

A minimum 5" slab-on-grade foundation is poured over the existing subbase. To support the load, reinforced concrete columns are spaced approximately in 19'-2" x 17'-6" bays. The roof is supported with steel joists and the facade is composed of non-load-bearing masonry.

Geoffrey Kim | Mechanical Option | http://www.engr.psu.edu/ae/thesis/portfolios/2011/gjk139/index.html

ACKNOWLEDGEMENT

First of all, I would like to thank the all of the Faculty members of Architectural Engineering at The Pennsylvania State University for giving me this chance to work on thesis alongside my full time job. It would not have been possible without their continuing support for off-campus students and constant updates through e-mail that kept me up to date with the classes that I missed. Of course, I would like to name a couple of faculty members that went above and beyond in providing me with the tools to be able to complete this experience.

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Professor Jelena Srebric – Faculty Advisor

Professor Moses Ling – Mechanical Instructor

Professor James Freihaut – Mechanical Instructor

Lastly, I would like to thank Leland Curtis, Devon Lam, and Shiyun Chen for always helping me out when I was in trouble. Leland Curtis especially since he went out of his way to provide me with a contact to a new building when my first building fell apart midway through tech report 1.

Again, the completion of this course and thesis work would not have been possible without great help from my professors and friends that were always there to help me out when I was in trouble.

Thank you.

TABLE OF CONTENT

EXECUTIVE SUMMARY

Felix Hotel is a twelve story hotel with a total square footage of 85,700SF located in the heart of downtown Chicago. A total of 225 guest rooms are located from floors two through twelve with office, conference, fitness center, and a bar located in the first two floors to be used as a conference area.

There was a recent renovation in 2009 with sustainability and energy efficiency in mind to become the first LEED Silver certified Hotel. Thus, the mechanical system was designed very well to comply with many of the ASHRAE standards 62.1-2007 and 90.1-2007. An adequate quantity of outside air is introduced into the space while individual heat pump provides guests with personal control over their thermostat.

In previous technical assignments, the overall construction of the building, energy consumption and annual building utility costs, and existing mechanical equipment were investigated and analyzed. With that data, several other available mechanical systems were looked at to see if additional energy savings could be achieved. The goal of this report is to lower the annual utility cost and lower the carbon footprint of the building. Greywater Heat Recovery and Combined Heat and Power have been analyzed as alternative systems.

Greywater heat recovery system uses the waste heat that would otherwise be thrown out into the sanitary sewer to preheat cold water entering the boiler. The installation of nine greywater heat recovery system provided an energy savings of 6,177 therms per year. After considering labor of installing additional copper pipes and the heat exchangers itself, the payback period was a reasonable 6.5 years.

A micro turbine was picked as the prime mover for a combined heat and power system. Trane TRACE was mainly used to calculate the daily energy load in order to size a 30kW micro turbine that would run near max capacity all the time. The electricity load profile was never met but it would have the ability to save all thermal loads in the summer time. The payback period was 9.44 years.

Overall, the greywater heating system showed the great energy cost savings and was recommended for installation for Hotel Felix.

1. EXISTING CONDITIONS

1.1 INTRODUCTION

Situated in the heart of downtown Chicago, Hotel Felix is a historical building which was originally built in 1926. Previously known as hotel Wacker, the owner of the property made the decision to begin a green building renovation and aimed to become a LEED certified hotel. The result of this ambitious project was successful as it obtained the first LEED Silver certification for a hotel in Chicago. This was possible due to its aim to improve water efficiency, energy and atmosphere impact, materials and resources, and improved indoor environmental quality throughout the building.

Hotel Felix was able to preserve its architecturally unique and historic 1920's façade during the renovation while applying new sustainable eco-friendly materials for its interior such as bamboo, recycled carpet, and non-VOC paint and wallpaper. There are 225 Guest rooms in total with Full service spas, business centers, meeting rooms, conference rooms, and upscale restaurants.

There are many sustainability features for Felix Hotel that was incorporated during the renovation to achieve LEED Silver. Hotel Felix utilized recyclable and eco-friendly materials and products throughout the hotel. An example is the decorative wall for the lobby area is made of recycled material while the flooring is made of bamboo. The existing lights were replaced with low energy-use lighting such as compact fluorescent and LED is used throughout the building. In addition, a room was specifically designated to be used to sort recyclable waste that will otherwise be thrown out. In the hotel rooms, the carpets are made of recycled materials with a linen reuse program. The same low-energy lighting is used the room along with a water waste reduction valve. Motion sensored HVAC systems in each individual rooms allows for efficient heating and cooling according to occupation.

1.2 MECHANICAL DESIGN OBJECTIVES

All basis of design has to meet ASHRAE standards and comply with LEED requirements as to achieve LEED silver rating for the hotel. This in result will improve energy efficiency of the building and lower operating costs of the year. Also, the building will be fit with a HVAC system that will provide the guests the ability to control the temperature of the room to their own liking, while providing fresh outside air to the core of the building.

1.3 MECHANICAL EQUIPMENT SUMMARIES

The main existing mechanical HVAC system is a constant air volume heating and cooling rooftop unit with electric cooling and natural gas-fired heat (primarily for morning warm-up). The currently installed rooftop unit was installed in the renovation. The rooftop unit supply air fan delivers conditioned supply air to grilles at constant volume located in the corridors of floors 2 through 12 in location T30.The RTU intakes outside air for mechanical ventilation and has an air-side economizer feature to help utilize outside air to cool the building spaces and to reduce mechanical cooling depending on outdoor ambient air conditions. The nominal cooling capacity of the RTU is 458 MBH (38.17 tons) at 7500 CFM. The RTU is a 100% outdoor air unit with no return air.

Tag	Area Served	Type	Blower Data			Heating		Cooling	
			Total CFM	O.A. Min	Motor HP	MBH Input	MBH Output	MBH Total	Sensible MBH
RTU-13.1	Hotel Corridors	DX Rooftop	7500	7500	7.5	813	650	363	290

TABLE 1.3.1 - ROOF TOP UNIT SCHEDULE

A self contained air conditioning unit is located in the basement mechanical room with a cooling only capability using an evaporator coil and a water-cooled condenser. The unit specifically serves the basement, first floor, and mezzanine level. The self contained air conditioning unit supply air fan delivers cool air to variable air volume boxes with electrical coil to heat the supply air as needed to each zone. The self contained air conditioning unit is rated at 8,000 CFM with a 363 MBH (30 tons) cooling capacity.

Tag	Area Served	Type	Blower Data			Cooling Data		Electric
			Total	O.A. Min	Motor HP	MBH Total	Sensible MBH	
AHU-B.1	Basement/1st/mezz	Self contained VAV AHU	8000	2800	15	363	260	28

TABLE 1.3.2 - SELF CONTAINED UNIT SCHEDULE

In the recent renovation in 2009, water source heat pumps were designed to provide cooling and heating to each individual guest room in the twelve story building. Hot water for the heat pumps are provided by (2) boilers located on the roof when heating is called for the in building. Chilled water for the heat pumps is provided by the cooling tower when called for. The operator has the command to either bypass the heat exchanger or boiler whenever necessary to provide hot or chilled water to the system. Water source heat pumps have the capacity to supply 300, 400, 1600, or 2000 CFM with 0.75, 1, 3, or 5 nominal tons respectively.

Tag	Nominal Tons	CFM	Heating	Cooling			Condenser
			Total MBH	Total MBH	Sensible MBH	Rejected MBH	GPM
HP-09	0.75	300	12.1	9	6.7	10.8	2.3
HP-12	1	400	16.4	13.2	10	15.4	3
HP-48	3	1600	58.7	46.2	37.9	56.8	11.6
HP-60	5	2000	76	59.4	48.1	73.4	14.8

TABLE 1.3.3 – HEAT PUMPS SCHEDULE

A split system air conditioning unit with electric reheat is located in the elevator machine room on the roof to provide conditioned air to the elevator machine room. The air is heated using an electric heating coil at 6 KW at 2000 CFM and cooled by an auxiliary air cooled condensing unit. The air cooled condensing unit is located also on the roof outside the elevator machine room to provide cooled air to the elevator room. The heat rejection capacity for the air cooled condensing unit is 55 MBH (5 tons).

Tag	Area Served	Type	Blower Data			Heating	Cooling	
			Total CFM	O.A. Min	Motor HP	Coil KW	MBH Total	Sensible MBH
AC-13.1	Elev. Machine Room	DX Rooftop	2000	-	0.75	6	55	39.6

TABLE 1.3.4 - SPLIT SYSTEM AIR CONDITIONING UNIT W/ ELECTRIC HEAT

Along with the air handling units, numerous electric baseboard heaters, cabinet unit heaters, unit heaters are located throughout the building with heating capacities ranging from 2KW to 10 KW. Electric cabinet unit heaters are located at stairwells and electric unit heaters at electrical room, fire pump room, gas meter room, recycling, and etc.

The cooling tower for chilled water for the water source heat pumps is located on the roof. It provides cooling to the chilled water through a heat exchanger connected to the piping system. The cooling capacity for the cooling tower is 160 nominal tons.

Tag	Location	Tons	Condenser	Water		Outside Air		
			GPM	EWT (°F)	LWT (°F)	Dry Bulb (°F)	Wet Bulb (°F)	HP
CT-13.1	Roof	160	480	85	95	95	78	30

TABLE 1.3.5 - COOLING TOWER SCHEDULE

Two boilers provide hot water for the water source heat pumps located in the roof. Each boiler has the capacity of 1045 MBH.

Tag	Capacity		Max Pressure Drop (Ft.)	GPM	EWT	LWT
	Input (MBH)	Output (MBH)				
B-13.1	1100	1045	6	63	97.4	120
B-13.2	1100	1045	6	63	97.4	120

TABLE 1.3.6 - BOILER SCHEDULE

1.4 ENERGY SOURCES

Electricity and natural gas are the two primary energy sources consumed by the mechanical systems installed in Hotel Felix. Electricity will primarily be consumed by the mechanical system to produce heat and also for lighting throughout the building. Natural gas will be used by the boilers and natural gas fire heat exchanger for the roof top unit and self contained unit. The following table lists the electricity prices and natural gas price for peak, off peak, and demand for the year of 2010.

Electricity	Cost $/kWh
Off Peak Apr – May	0.0677
Off Peak June – Dec	0.0795
Off Peak Jan – may	0.0791
Peak Apr – May	0.0731
Peak June – Dec	0.0852
Peak Jan – May	0.0843
Demand Apr – May	8.452
Demand June – Dec	8.915
Demand Jan – May	8.706

TABLE 1.4.1 – ELECTRICITY PRICES

Gas	Price (cents/therm)
Off Peak	83.6
Peak	72.26

TABLE 1.4.2 - GAS PRICE

The above energy price will be used throughout this project to compare existing annual energy costs will alternate system energy costs to compare the results of the energy saving efforts.

1.5 DESIGN CONDITIONS

Design conditions will be based on data for Chicago O'Hare ITL Airport, Illinois.

Cooling Design Conditions (0.4%)		Heating Design Conditions (99.6%)
OA DB (°F)	OA WB (°F)	OA DB (°F)
91.9	74.6	-4.0

TABLE 1.5.1 - DESIGN CONDITION FOR CHICAGO OHARE ITL AIRPORT, ILLINOIS

Although block load estimation is used to simplify the process, internal loads need to be accounted for to obtain results that can represent the true energy consumption for the building. The internal loads that will be included in the model will be lighting loads, occupancy loads, and miscellaneous loads. The values that are entered for the internal loads are shown in table 2.

Room Type	Lighting Load	Occupancy Load	Misc Load
Guest Rooms	0.5 W/SF	2 people	0.5 W/SF
Corridor	0.5 W/SF	0	0 W/SF
Conference Room	1 W/SF	20 SF/person	0.5 W/SF
Office	1 W/SF	100 SF/person	1 W/SF

TABLE 1.5.2 - INTERNAL LOADS

1.6 INITIAL MECHANICAL SYSTEM COST

The approximate initial cost for the mechanical and plumbing system of the project is listed in the following table 11 according to official estimates.

	Total Cost	Cost/SF	% of Total Cost
Mechanical	$ 8,099,507	$ 94.51	28.9%
Plumbing	$ 1,081,534	$ 12.62	3.9%

TABLE 1.6.1 - MECHANICAL COST

To summarize, the mechanical system cost 28.9% of the overall project cost while the plumbing is 3.9% of the overall project cost. It is a very significant percentage of the project cost.

2. ASHRAE STANDARD AND LEED EVALUATION

2.1 DESIGN VENTILATION REQUIREMENTS

An analysis on outdoor air requirements was performed to verify the building met ASHRAE 62.1 requirements for ventilation.

	AHU-B.1	RTU-13.1
Calculated	2192 CFM	891 CFM
Designed	2800 CFM	7500 CFM

TABLE 2.1.1 – OUTSIDE AIR REQUIREMENTS

The two air handling units in the building supplying outside air to the building is sufficient enough to meet ASHRAE 62.1 requirements for minimum ventilation. The calculation process can be found on Technical Assignment 1 performed in 2010.

2.2 DESIGN LOAD ESTIMATES

A block load estimate will be performed on the building for this assignment. In order to do so, the building will be divided into 3 zones which correspond to their respective air conditioning unit. A basic model of the building was created using REVIT from the construction documents to be used by a program to analyze the building. Figure 1 below illustrates the model and the three zones that will be used to analyze the building.

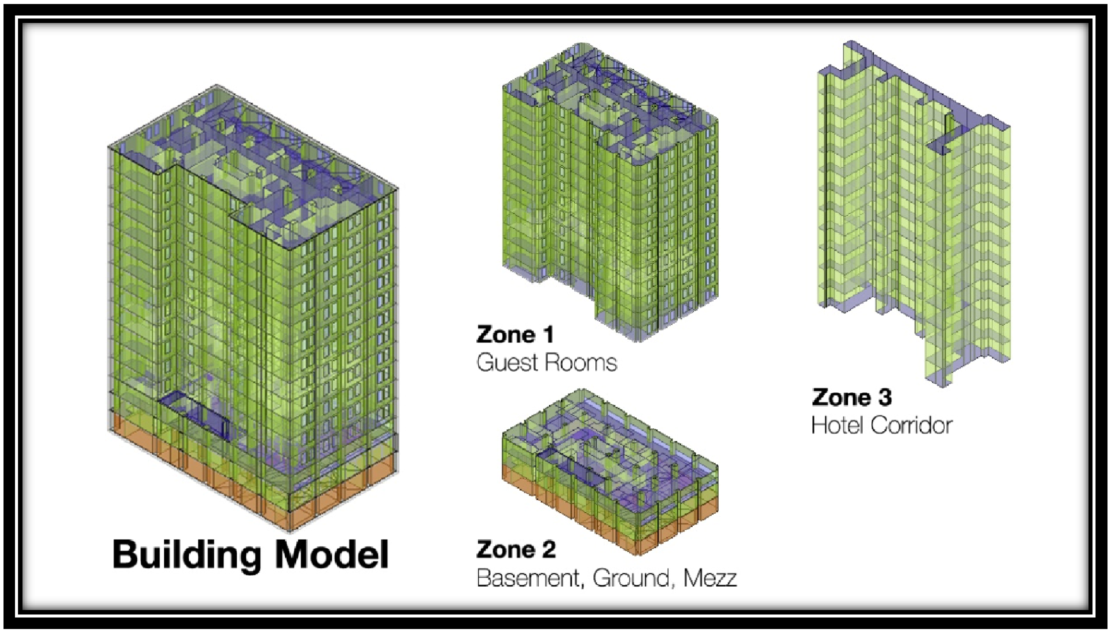


FIGURE 2.2.1 - BUILDING INFORMATION AND ZONE DIAGRAM.

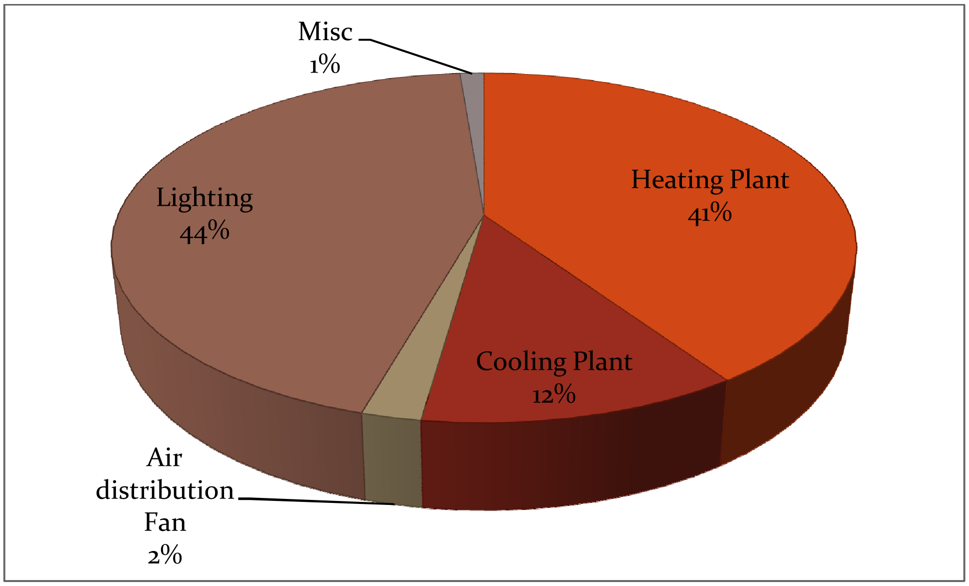


FIGURE 2.2.2 - ENERGY CONSUMPTION PER COMPONENT ANNUALLY

	Electricity (kWh)	Gas (therms)	Water (1000 gal)
Annual Consumption	759,860	11,189	411

TABLE 2.2.1 - ANNUAL ENERGY CONSUMPTION BY UTILITY

Diagram shows clearly that heating and lighting is the two major source of energy consumption for Hotel Felix. The heating plant dominates HVAC energy consumption because of its load during the cold winterer design temperatures while the cooling plant is second to cover air conditioning and cold water for the building. Here is a more detailed diagram of how the HVAC systems divide up for energy consumption.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Electric												
On-Pk (kWh)	**34,814**	**21,845**	**18,685**	**16,146**	**19,529**	**22,074**	**25,801**	**24,442**	**20,660**	**17,445**	**17,297**	**23,338**
Off-Pk (kWh)	**60,556**	41,721	30,656	16,337	18,561	18,860	22,595	22,469	18,002	17,586	24,801	42,353
On Demand (kW)	159	123	99	88	103	113	122	119	110	90	94	111
Off Demand (kW)	196	172	132	101	104	111	119	117	108	100	127	154
GAS												
On-Pk (therms)	1,053	790	692	453	300	280	310	358	436	460	464	767
Off-Pk (therms)	1,642	1,285	1,229	514	429	379	312	313	317	310	1,007	1,315
Water												
Cons. (1000gal)	1	2	7	26	53	67	80	78	58	28	6	4

TABLE 2.2.2 MONTHLY ENERGY CONSUMPTION

Figure 2: Monthly HVAC Energy Consumption

2.3 ESTIMATED ANNUAL ENERGY USE

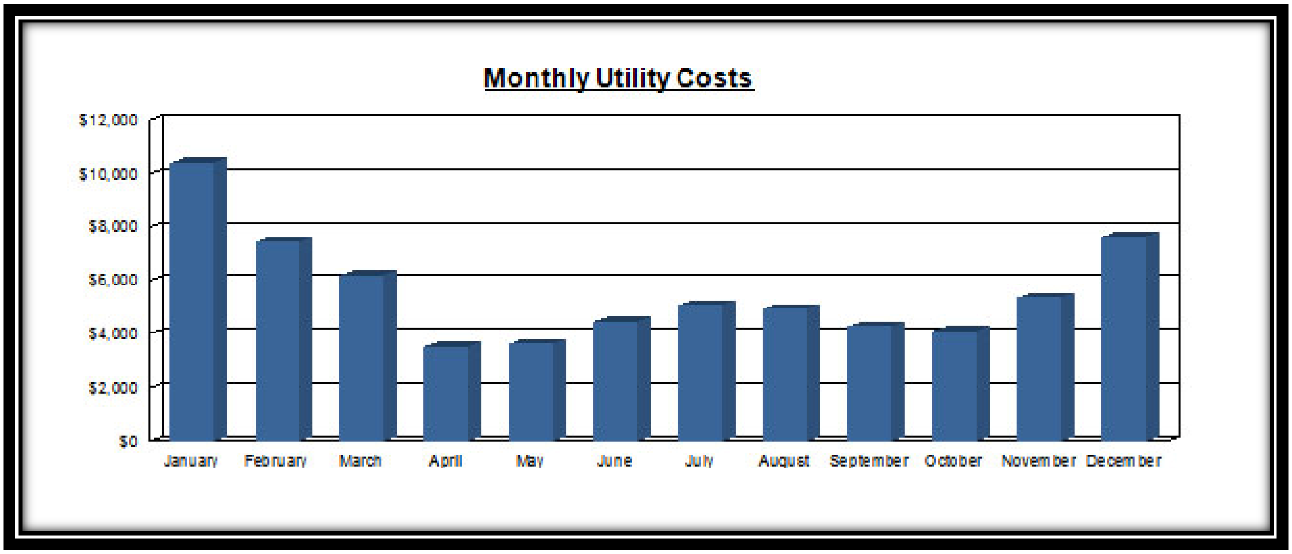


FIGURE 2.3.1 MONTHLY UTILITY COSTS

Figure 3 shows the monthly breakdown of the utility cost for the Felix Hotel. As expected, the utility cost is at its highest in the winter because of its large heating load requirements because of the cold temperature in Chicago. The monthly rises momentarily in the summer due to its cooling load but it is not very big compared to the heating bill.

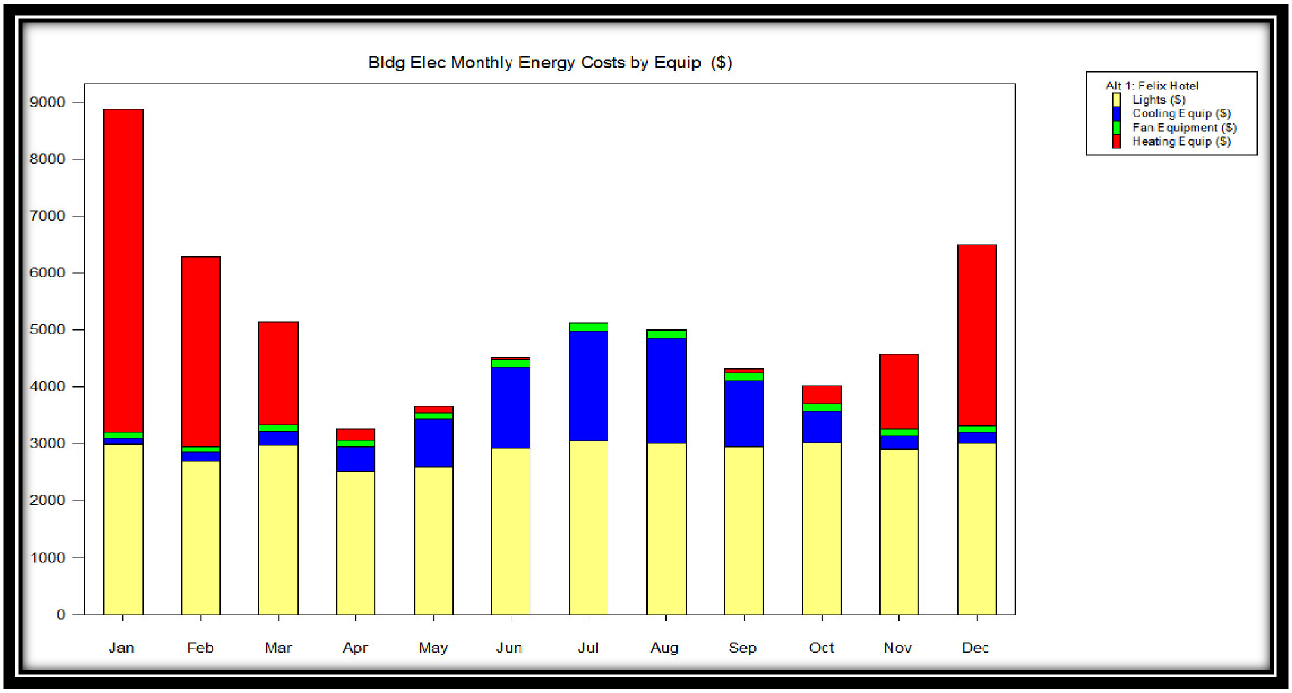


FIGURE 2.3.2 - BUILDING ELECTRIC MONTHLY ENERGY COSTS BY EQUIPMENT

Through Figure 4, the monthly energy costs can be shown in terms of equipment type. This figure is consistent with our previous results where a majority of the monthly cost will go into heating during the winter. One interesting fact is that it costs more to light the building than to cool the building in the summer time. This is something that might be needed to be addressed to decrease our monthly energy costs not only in the summer, but also in the winter.

	Annual Cost
Total Building Operation Cost ($)	63,237
Annual Building operation cost ($/SF)	0.86

TABLE 2.3.1 - TOTAL BUILDING OPERATIONAL COST

2.4 LEED NC ANALYSIS

Felix Hotel was designed to obtain LEED Silver in mind from design phase, so it strictly adhered to certain requirements and procedures that the U.S. Green Building Council had setup as prerequisites to obtain credits necessary to earn a LEED Silver Certification. By earning LEED certification, the project was to minimize impact on the natural environment in the choice of building materials, during construction and during building use. Also, provide a high level of indoor air quality for building occupants and use water and energy efficiently so that the new hotel can be designed to be a sustainable or "green" building.

For the purpose of LEED analysis for this project, we will only look at the section Energy and Atmosphere and Indoor Environmental Quality. These two sections will affect how the mechanical system is sized and installed.

ENERGY AND ATMOSPHERE

There are three prerequisites that are required for this section. The three are fundamental commissioning, minimum energy performance, and CFC reduction in HVAC&R equipment. The three were met by properly installing, calibrating, and performing according to the owner's project requirements, establishing the minimum level of energy efficiency for the proposed building and system, and to reduce ozone depletion by eliminating and chlorofluorocarbon-based refrigerants for the HVAC&R equipment.

Another big area where credit was earned was "Optimize Energy Performance" for HVAC and equipment and appliances. This credit shows that the building was able to achieve an "increase level of energy performance above baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use." This done by comparing an energy calculation using ASHRAE Standard 90.1 with the installed HVAC equipment and achieving better energy performance records.

The building was also able to earn a point in Enhance Commissioning. This meant the commissioning process was introduced early into the design phase and also extended to after the design is complete so it can do a performance verification test. The commissioning process was developed and led by an independent commissioning agent and started as early as pre-functional procedures where a series of field observations were conducted during the installation of commissioned equipment to verify that equipment is installed per the contract documents and is ready for startup.

The point total can be seen in Figure 2.

2	4		Energy & Atmosphere		12 Points
Y			Prereq 1	Fundamental Commissioning	Required
Y			Prereq 2	Minimum Energy Performance	Required
Y			Prereq 3	CFC Reduction in HVAC&R Equipment	Required
	?		Credit 1.1	Optimize Energy Performance - Lighting Power	3
	?		Credit 1.2	Optimize Energy Performance - Lighting Controls	1
Y			Credit 1.3	Optimize Energy Performance - HVAC	2
Y			Credit 1.4	Optimize Energy Performance - Equipment and Appliances	2
Y			Credit 2	Enhanced Commissioning	1
	?		Credit 3	Energy Use, Measurement & Payment Accountability	2
	?		Credit 4	Green Power	1

FIGURE 2.4.1 - ENERGY AND ATMOSPHERE LEED CREDITS

INDOOR ENVIRONMENTAL QUALITY

The indoor environmental quality category of the LEED rating system can be shown in the figure 3 below. The prerequisites for minimum IAQ performance and environmental tobacco smoke control were met by making the hotel a smoke free building and establishing a minimum indoor air quality performance.

Low-emitting materials were purchased for adhesives and sealants, paints and coatings, carpet systems, composite wood and laminate adhesives, and systems furniture and seating. This was done by establishing a VOC limit of the South Coast Air Quality Management District (SCAQMD) rule #1168 to make sure low-emitting material is used for adhesives and sealants. Paints and coats also comply with VOC limits established by Green Seal Standard GS-11 to use low-emitting materials.

11	2	4	Indoor Environmental Quality		17 Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
		N	Credit 1	**Outdoor Delivery Monitoring**	1
		N	Credit 2	**Increased Ventilation**	1
Y			Credit 3	**Construction IAQ Management Plan**, During Construction	1
		N	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
Y			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
Y			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
Y			Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
Y			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Laminate Adhesives	1
Y			Credit 4.5	**Low-Emitting Materials**, Systems Furniture and Seating	1
Y			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
Y			Credit 6.1	**Controllability of Systems**, Lighting	1
Y			Credit 6.2	**Controllability of Systems**, Temperature and Ventilation	1
Y			Credit 7.1	**Thermal Comfort**, Compliance	1
		N	Credit 7.2	**Thermal Comfort**, Monitoring	1
	?		Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
	?		Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1
Y			Credit 8.2	**Daylight & Views**, Views for 90% of Seated Spaces	1

FIGURE 2.4.2 - INDOOR EIVNROMENTAL QUALITY LEED CREDITS

3. OVERALL SYSTEM EVALUATION

Overall, all the mechanical systems in the building are efficient and sized to comply with ASHRAE standards 62.1-2007 and 90.1-2007. Because the building earned a LEED Silver, most of the mechanical system was designed to perform better than a baseline building in performance and energy utilization.

4. MECHANICAL SYSTEM REDESIGN PROPOSAL

The current mechanical system design complies with ASHRAE standards and was able to obtain a LEED Silver certification with points from "Optimize Energy Performance – HVAC". This shows that the current system has already been designed to be efficient and meet the needs of the building.

However, other systems will be explored to help reduce overall energy usage throughout the building and lower utility costs and make the building more efficient. Payback periods for these systems will be also explored to conclude if the system is really viable or not in Chicago, Illinois.

4.1 COMBINED HEAT AND POWER (CHP)

Combined Heat and Power (CHP) is an alternative system that will be explored for possible energy reduction, utility cost reduction, and low payback period. CHP is a method of generating both electricity and thermal energy at the site instead of buying electricity from the grid. Originally, separate heat and power (SHP) is the main scheme where electricity is bought from the power company to provide the necessary energy to run the mechanical systems, boilers, and cooling tower.

Felix hotel can be a good candidate for CHP technology because it has a high electrical demand as well as thermal demand all around the year. From technical assignment 2, we saw that the boiler was the biggest energy consumer in the mechanical system and we can potentially produce all the thermal energy required through one single prime mover that produces both electricity and thermal.

A combined heat and power plant could potentially have many benefits over a separate heating and power. One major benefit of combined heat and power is that the system will use much less fuel overall. CHP systems have one prime mover that produces electricity and the waste heat is then captured to be used for thermal load using a heat exchanger or a steam turbine. Because we take the boiler out of the equation compared to a SHP system, less fuel is utilized. Also, there is no loss in electricity transmission through power lines to the building because we don't have to buy the electricity from the grid.

However, adding a CHP system will result in a high initial cost because the prime mover must be purchased on site and the accessories involved in the system. Also, maintenance cost must not be forgotten in keeping the CHP system operable. Additional work is required that would not be needed in a conventional SHP system.

This could also mean that we could get rid of certain mechanical equipments. The gas fired unit heat for basement laundry can be removed along with downsizing water heaters and boilers for domestic water and water source heat pumps because the thermal energy from the prime mover can cover the system.

By doing a CHP analysis, the feasibility of the system will be found by choosing the correct type of prime mover and comparing the spark gap between the fuel that would be used for the system and electricity. There are many prime movers that could work but reciprocating internal combustion engine and natural gas micro turbine will be considered for this building.

4.2 GREYWATER HEAT RECOVERY

Greywater heat recovery is a very interesting topic because not many applications of this system exist today in the United States. Greywater is any household wastewater such as kitchen sinks, showers, bathroom tubs, and bathroom sinks. Blackwater such as toilets and sewage are not part of the recovery process because of health concerns.

Greywater heat recovery uses the principle of capturing some of the heat in drain-water, allowing it to be reused by incoming water. This can be done because 80-90 percent of energy used to heat water for domestic use goes down the drain.

A high rise hotel with many shower heads in the building can be a very good candidate for this system as it can reduce energy costs of water heating because the water heater can be sized significantly smaller. Another benefit of this system is it can increase the effective availability of hot water when it is needed the most, such as in the morning or night.

4.3TOOLS FOR ANALYSIS

COMBINED HEAT AND POWER

Trane TRACE is the primary load simulator that will be used for the analysis of the mechanical systems for Hotel Felix. TRACE has the capability to model various types of systems and configure them to be a fairly accurate representation of the existing mechanical systems present in the hotel. Obtaining an accurate energy model for the hotel will be crucial as it can be the deciding factor if the proposed alternate system is feasible for the building.

Trane TRACE at its current state does not have the capability to choose CHP as one of the systems for analysis. However, the hourly energy model generated from the base building is important in choosing the correct capacity for optimization.

GREY WATER REHEAT

Grey water reheat analysis will be done in similar format to Combined Heat and Power. Trane TRACE will produce the necessary energy consumption by the building. There is no program available made specifically for Grey Water Reheat analysis so it will be done using Microsoft Excel with the correct formulas and values to get the results.

5. GREYWATER HEAT RECOVERY

5.1 INTRODUCTION

A significant amount of heat still remains in hot water that goes down the drain to a sanitary sewer. An astonishing 80% of the heat from a shower remains in the water that gets drained out. The idea behind a greywater heat recovery system is to capture the leftover heat through a heat exchanger made specifically to preheat cold water entering the water heater. This effectively reduces the amount of energy needed to produce hot water.

The heat exchanger consists of copper coils wound around the central pipe. The hot drain water enters the central pipe from the top and as it flows down through the pipe it transfers the heat to the cold water that is moving through the copper coils wound around the central pipe. When the hot drain water flows through the central pipe, it slows down due to the water clinging onto the inner walls of the vertical drain pipes. This effectively increases the area of heat exchange for a high rate of heat transfer. The pipes are designed so the water does not just fall through, but slowly climbs down the inner walls of the pipe to get the necessary surface area for heat exchange.

FIGURE 6.1.1 GREYWATER HEAT RECOVERY

5.2 INSTALLATION AND APPLICATION

Two applications of greywater heat exchange are explored.

Showers are a great source of greywater with regular flow so it is a very good candidate for installation. Also, the heat exchanger needs to be installed vertically in order to get the necessary surface tension required for high rate of heat exchange, and this can be accomplished since sanitary pipeline for showers extend from the top floor to the basement.

Another location is the laundry wastewater. Since a laundry washer uses hot water for wash and rinse with no addition of cold water, it contains a high amount of energy. The problem is that wastewater is not available readily from washing machines and the slab-on-grade location for the laundry makes it very tough to install the heat exchangers so that a vertical drop of water is available for heat transfer. Additional pipe rerouting would be required to achieve the desired setup. It did not seem feasible to install greywater heat exchange for a laundry wastewater.

5.3 ASSUMPTIONS AND CURRENT ENERGY USE

Since the necessary data on water flow is not available for the hotel, assumptions need to be made on the water usage and heat available in the shower heads.

	Hotel Room Showers
Cold Water Supply (°F)	54
Hot Water Leaving Boiler (°F)	140
Temperature of Shower (°F)	110
Efficiency of Boiler + Hot Water Pipes	80 %
Thermal Capacity of Water (btu/ft^3 °F)	62.4
Energy to heat one gallon of shower water (Btu/gallon)	**585**

TABLE 5.3.1 - ENERGY REQUIRED FOR SHOWER WATER (HOTEL ROOMS)

The cold water supply temperature and the hot water temperature leaving the boiler are 54 degrees in and 140 degrees Fahrenheit out. The boiler from the building, according to the plumbing schedule, is 84% efficient. The heat loss through the piping was also considered in the calculation for the total efficiency. Assuming a heat loss of 5% through the pipes, the overall efficiency came out to be 80%.

The energy to heat one gallon of shower water was then calculated using the thermal capacity of water and the efficiency of the boilers. The results of this calculation will be required later to compare the energy savings for installing a greywater heat recovery unit.

	Hotel Room Showers
Typical Shower Flow Rate (GPM)	2.5
Average Length of Shower (Min)	5
Number of Showers (225)	225
Number of Showers per Day per Room	2
Daily Shower Water Usage (gallons/day)	6875
Estimated Hotel Occupancy	70%
Estimated Daily Shower Water Usage	4812

TABLE 5.3.2 - DAILY SHOWER WATER USAGE (HOTEL ROOMS)

In Table 5.3.2, the daily shower water usage was calculated. It is important to get the quantity of water that is used daily since it is what sets the energy savings for the greywater heat recovery unit. A total of 225 guest rooms exist in the hotel with 1 shower in each room. A safe assumption of a 5 minute shower at a rate of 2.5 GPM was chosen. The actual energy savings will most likely be higher than the set calculations if the duration of the shower increases.

However, an additional step was taken to account for hotel occupancy levels. The hotel will not always be fully occupied in the building. With an assumption of 70% average occupancy throughout the year, the daily shower water usage decreased to 4812. It is still important to size the heat recovery system at the worst case scenario, at full hotel occupancy, regardless of estimate hotel occupancy.

	Hotel Room Showers
Energy required to heat water per day (btu/day)	4,0240,20
Natural Gas Price ($/therm)	0.836
Annual cost (per year)	**12,279**

TABLE 5.3.3 - ANNUAL COST TO HEAT HOT WATER (HOTEL ROOMS)

The annual cost to heat hot water for the showers is $12,279 through a set of simple calculations. In actuality, this cost will be lower since the hotel is not always one hundred percent occupied all the time.

5.4BASE BUILDING CONDITIONS

Pipe Stack #	# of shower heads	Existing Sanitary Pipe Size
1	21	4”
2	21	4”
3	11	4”
4	21	4”
5	21	4”
6	11	4”
7	11	4”
8	11	4”
9	97	6”
TOTAL	225	

TABLE 5.4.1 – EXISTING PIPE STACK

There are 15 pipe stacks that are relevant to the installation of heat exchangers. As they pipe down to the basement, they converge near the electrical room as it is discharged through the sanitary sewer. The existing GPM of these sanitary pipe stacks will provide the information needed to calculate the number of heat exchangers required for the building.

5.5 ENERGY SAVINGS

	Hotel Shower Rooms
Energy Use (therms/day)	46.0
Water Flow (gallons/day)	4812
Cold Water Temperature (°F)	54
Heat Exchanger Efficiency (64%)	64
Usable Thermal Energy (therms/day)	16.9
Annual Energy Savings (therms/year)	4,324
Annual Energy Cost Savings ($/year)	5,188

TABLE 5.5.1. - ANNUAL ENERGY SAVINGS POTENTIAL

There are 15 pipe stacks that are relevant to the installation of heat exchangers. As they pipe down to the basement, they converge near the electrical room as it is discharged through the sanitary sewer. The existing GPM of these sanitary pipe stacks will provide the information needed to calculate the number of heat exchangers required for the building.

5.6 EQUIPMENT COST

	Central Drain Size (in.)	Cold Water Pipe Size (in.)	Length (in.)	Efficiency	Price ($)
P2S3-40	Two pairs of 4”	¾”	80	64%	3060

TABLE 5.6.1 – EQUIPMENT SPECIFICATIONS

The building requires a total of nine grey water heat recovery systems attached to each pipe stack. The price of a grey water heat recovery unit was obtained from a manufacturer. The manufacturer is GFX Technologies that provide the cost and specifications for the heat exchangers.

	Quantity	Total Price ($)
P2S3049	9	27,540

TABLE 5.6.2 – TOTAL EQUIPMENT COST FOR HEAT EXCHANGER

In addition to the greywater heat exchanger, additional pipes need to be installed to connect the cold water pipe back to the water heater. Labor cost is also considered for the cost of piping.

	Total Length	Copper Installation Price ($/ft)	Total Piping Cost w/ Installation
Copper Pipe (3/4")	800	9.00	6400

TABLE 5.6.3 – TOTAL EQUIPMENT COST FOR PIPING

5.7 RESULTS AND CONCLUSION

The comparison between the energy savings and the equipment cost can be seen below.

	Price
Total Equipment ($)	33940
Annual Cost Savings ($)	5188
Payback Period (yrs.)	6.5
Annual Energy Consumption (Shower Hot Water) (therm)	14,673
Annual Energy Savings (Shower Hot Water) (therm)	6,177
Percentage Saving	58%

TABLE 5.7.1 – RESULT SUMMARY WITH PAYBACK PERIOD

The potential for energy savings is great can be seen after a basic set of calculations. The total equipment cost for the heat exchangers and piping is $33,940. The labor cost was added for the piping but not for the heat exchangers, so the actual price will be higher depending on the contractor cost. But overall, without labor costs for the heat exchangers, the payback period is a reasonable 7 years.

6. COMBINE HEAT AND POWER ANALYSIS

Many calculations and assumptions will need to be made in order to figure out if combine heat and power is feasible for Hotel Felix in Chicago. Some of the information will be modeled using TRACE for accurate representation of real time load profiles. Using a load profile graph is one indication to know if CHP can be used for a specific building. Another big factor is the spark gap, which is the price difference between electricity and fuel used by the CHP system. The spark gap is the easiest way to know if CHP will be feasible at a certain location.

6.1 SPARK GAP

The spark gap for Chicago can be calculated using the data found on the Bureau of Labor Statistic with the average energy prices in the Chicago Area taken at December 2010. The U.S. Energy Information Administration (EIA) is a better source for prices but the latest electricity price update was done in 2008. The electricity price given by the Bureau of Labor Statistic was $0.83/kWh for the month of December. One thing to note here is that the electricity price is never static and will change from month to month and also will vary according to peak time and off-peak times. A more detailed calculation will be done later together with the cost analysis for the CHP system. The natural gas price was listed at $0.832/therm for Chicago. After both the values are converted into MMBTU, the result was 23.4 MMBTU for electricity and 8.32 MMBTU for natural gas. A general rule is if the spark gap is greater than 12 MMBTU a CHP system could be viable for the given location. With a 15.13 MMBTU spark gap for the Chicago area, the first test of feasibility was proven favorable to continue on with the next step of CHP calculation.

6.2 PRIME MOVER OPTIONS

The prime mover is what identifies the CHP system. It is the equipment that produces the electrical energy that is utilized in combined heat and power systems. There are various types of prime movers available for CHP application. Internal combustion engine and micro turbine are two types of prime movers that will be explored for the purpose of this analysis.

	Internal Combustion Engine	Micro turbine
Electrical Efficiency	22-40%	20-30%
Capacity	500kW – 7MW	30kW – 500 kW
Power to Heat Ratio	0.5-1	0.4-0.7
Fuels	Natural Gas, Biogas, Propane, Landfill Gas	Natural Gas, Biogas, Propane, Oil
Noise	High	Moderate

Thermal Output	Hot water, Low Pressure Steam	Heat, Hot water, Low Pressure Steam
Overall Efficiency	70-80%	65-85%
Cost ($/kW$_e$)	1,100-2,200	700-1,100
O&M Cost ($/kW)	0.009-0.022	0.005-0.016

TABLE 6.2.1 – PRIME MOVER COMPARISON

An internal combustion engine is widely used not only in the building industry but can be seen used daily in automobiles. The internal combustion engines run well at part load conditions and have a low installation cost like micro turbines making it an attractive choice for a prime mover. Internal combustion engines have the capability to produce electricity at a very high efficiency of up to 40%. This means the internal combustion engine is capable of higher efficiency than micro turbines for electricity generation. The downside is the exhaust thermal heat will be low because more of the energy was converted into electricity.

In a CHP application, the thermal energy from the exhaust gas, engine jacket cooling water, lube oil cooling water, and turbocharger cooling can be captured for space heating and hot water requirements. The overall efficiency of the engine will increase up to 80% with heat recovery, although the useful heat from the exhaust is not very high.

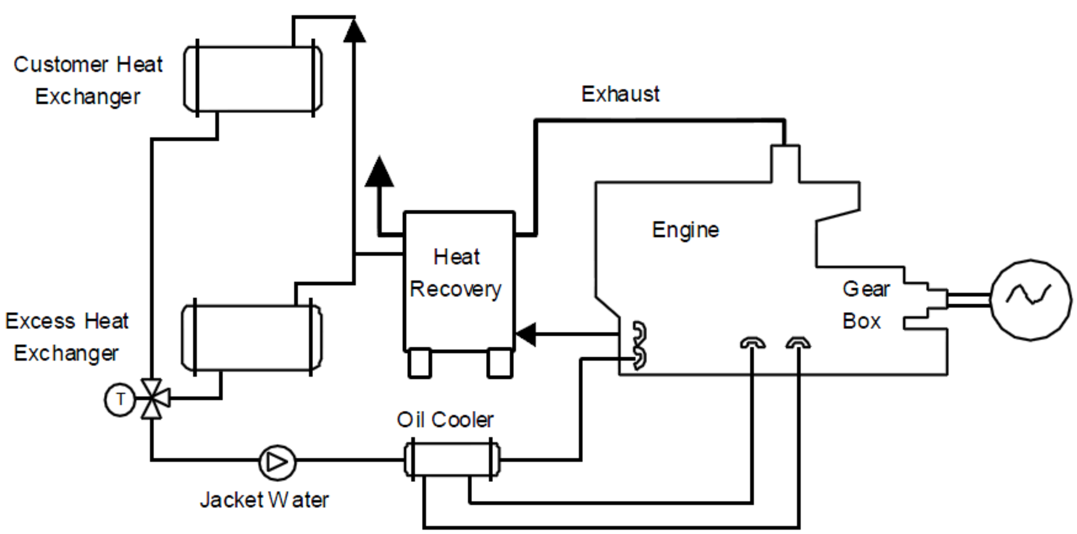
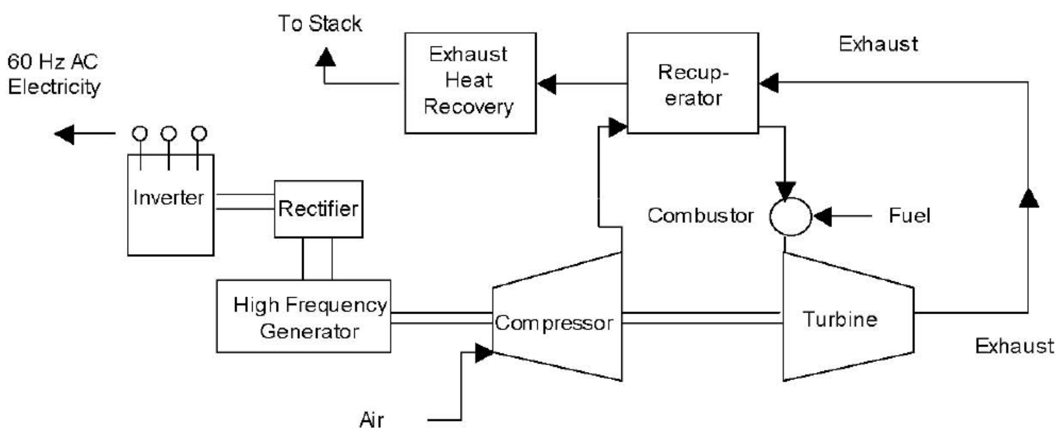


FIGURE 6.2.1 – GAS TURBINE SCHEMATIC DESIGN

The micro turbine is a smaller version of the gas turbine. They are built in modular units so they are very flexible to connect and they are easy to install. Since they have less moving parts, maintenance is easy and the emission is very low as a byproduct of generating electricity. Reusable energy can be used as a source of fuel such as biogas from landfills and treatment plants.

The electrical efficiency of a micro turbine ranges from 20 to 30% when a recuperator is added to the system. A recuperator is a heat exchanger which uses the hot turbine exhaust gas to preheat the air going into the combustor, thereby reducing the fuel needed to heat the compressed air to turbine inlet temperature. However, this process lowers the temperature of the usable thermal exhaust so the usable thermal load is used for heat, hot water, or low pressure steam. In a typical CHP operation, a second heat exchanger transfers the remaining energy from the micro turbine exhaust to a hot water system or it can also utilize the lower pressure steam to heat the building through convectors. Overall, the efficiency of a micro turbine with heat recovery will increase up to 85% in some applications, but the usable heat is very little.



6.2.2 – MICROTURBINE SCHEMATIC DESIGN

5.3 PRIME MOVER SELECTION

It is important to select a prime mover that will fit the system in order save annual energy consumption and to decrease the carbon footprint of the building. A CHP system that is sized too big could result in wasted energy and a system sized too small could result in a long payback period and make it less attractive to the owner.

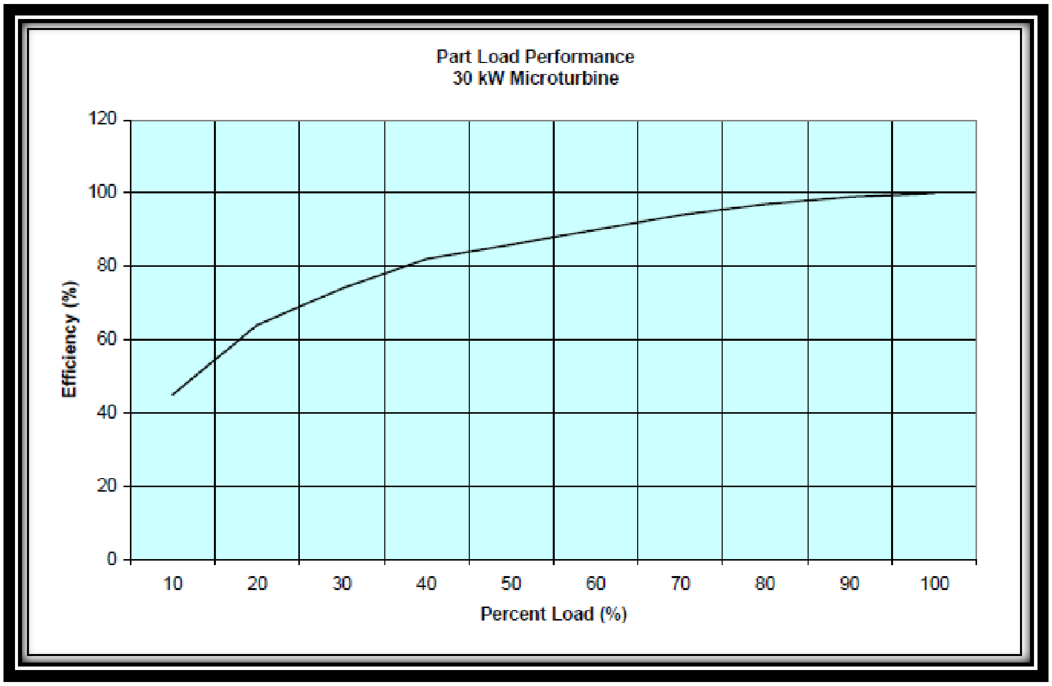


FIGURE 5.2.1 - MICROTURBINE PART LOAD POWER PERFORMANCE.

Having the prime mover operating near maximum capacity is also a great way to increase the efficiency of the system. As seen in the graph above, the efficiency of a micro turbine steadily decreases as the system operates at a lower load.

The electrical load requirement of the building is much higher than the thermal load of the building. Therefore, the CHP system will be sized to produce the required thermal load and the resulting electricity output will be added back into the building. Electricity will be sold back to the grid in a case where there is more electricity output than needed, while additional electricity will be purchased from the grid in the case more electricity is needed from the building in addition to the CHP system.

After comparing the advantages and disadvantages of a micro turbine and an internal combustion engine, a micro turbine will be selected for analysis. One major reason for this selection was the noise level of the equipment. The CHP equipment will most likely be installed on the roof level of the building since there is no free space in the basement mechanical room. Since the hotel is situated in downtown Chicago, it is very important to keep the noise level as to avoid complaints from neighboring buildings. Also, the number of components to a micro turbine is less than an internal combustion engine and less complicated since it comes in factory installed modular units, therefore putting less burden on a building engineer without great CHP knowledge.

6.3 RESULTS

	SHP	30kW Micro turbine
Annual Electric Cost ($)	52,558	29,396
Annual Natural Gas Cost ($)	10,680	27,719
Annual Cost ($)	63,237	57,115
Difference ($)		6,355

6.3.1 – SHP AND CHP COST COMPARISON

The SHP annual electric cost and natural gas cost is the result of the calculations from the building energy load from technical assignment 2. In the case of SHP, the electricity price is high since it is bought from the power company in order to power the air handling units and lights.

The SHP system is sized so that the thermal can be met during the summer and partially during the winter time. The bi-product of the thermal load is the electricity that was generated and this lessens the need for the hotel to rely on the grid for electricity purchase.

Equipment Cost ($2000/Kw)	60,000
Savings from Energy Annually ($)	6,355
Payback Period	9.44

6.3.2 – PAYBACK PERIOD CALCULATION

The information that was required for a micro turbine was hard to obtain in terms of pricing. Competition for micro turbine is fierce and companies are doing their best to lure investors for their future developments. As a result, the pricing information is not given out easily so one can only assume the price per kilowatt of energy. Generally, a micro turbine costs around $1,100 to $1,500 per kilowatt. Once installation, labor, and equipment testing is testing the price could easily increase to $2,000 per kilowatt.

A payback period of 9.5 years was the result for the given conditions of the building. 9.5 years is not including the price of the piping and connections for natural gas and the thermal exhaust that would be connected to a heat exchanges to heat water for the boiler.

6.4 CONSIDERATIONS

The efficiency of a micro turbine is at a modest 30% at the 30kW range. One factor that was not considered in the above calculations was the temperature effect on the efficiency of the micro turbine engine.

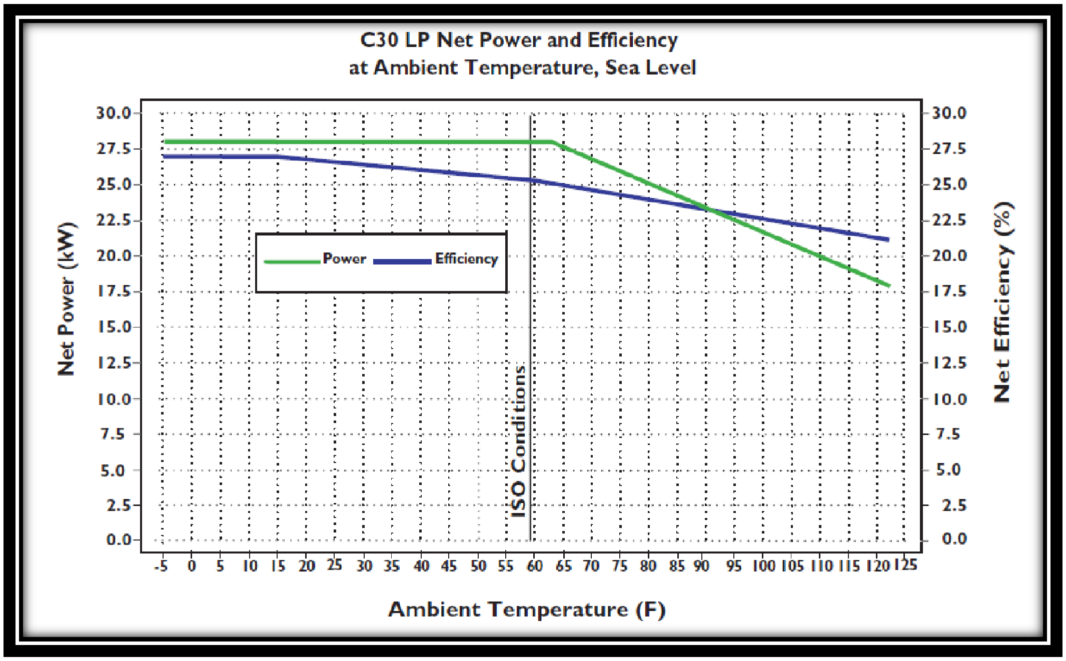


FIGURE 6.4.1 - CHP EFFICIENCY VS. AMBIENT TEMPERATURE

Figure 6.4.1 shows the effect of ambient temperature on the overall efficiency of the micro turbine and the resulting loss of net power generation. The net power generation of a CHP system decreases drastically once it pasts 64 degrees Fahrenheit, a temperature that is easily reached in spring and fall. The decrease in the power generation will result in loss of efficiency and the payback period will increase.

7. ACOUSTICAL ANALYSIS

7.1 OVERVIEW

The sound level of the micro turbine needs to be examined to see if it meets ordinance codes. A building exists on two sides of the building so any power generating unit could cause unwanted noise coming from the micro turbine, especially since the unit will be located on the roof.

First, we will examine if the noise level is acceptable without any acoustic enclosures around the micro turbine. If it is found that noise will have an impact on the surroundings, a further step needs to be taken to remedy the noise problem. Second, a study will be done on the roof to see the impact of noise on the 12th floor hotel guest rooms.

7.2 CHICAGO NOISE ORDINANCE CODE

Section 11-4-2810 of the Chicago Environmental Noise Ordinance code states that the sound pressure level must not be greater than 55 dB when measured from a distance of 100 feet or more from the source, or 70 dB when measured from a distance of 10 feet or more from the source.

The 30KW micro turbine unit emits a sound pressure level of 65dBA at a distance of 10 meters according to product specifications. This is well below the requirements so no additional construction is needed to lower the sound level through the air to other buildings.

7.3 ACOUSTIAL ANALYSIS TO ADJACENT SPACES

The acoustical data for the micro turbine is given below.

	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Micro turbine db	45	51	56	59	59	63	61

TABLE 7.3.1 – ACOUSTICAL DATA OF MICROTURBINE

The Transmission loss data for the roof was obtained with the following information.

	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Roof	24	25	34	40	47	50	56

TABLE 7.3.2 – TL DATA FOR ROOF

	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz

Micro turbine	45	51	56	59	59	63	61
A Weighting	-26	-16	-9	-3	0	1	1
Adjusted	81	67	65	62	59	64	62
Roof TL	29	31	34	40	47	50	56
Hotel room dB	52	36	31	22	12	0	0

TABLE 7.3.3. – RESULTING NOISE LEVEL IN HOTEL ROOM

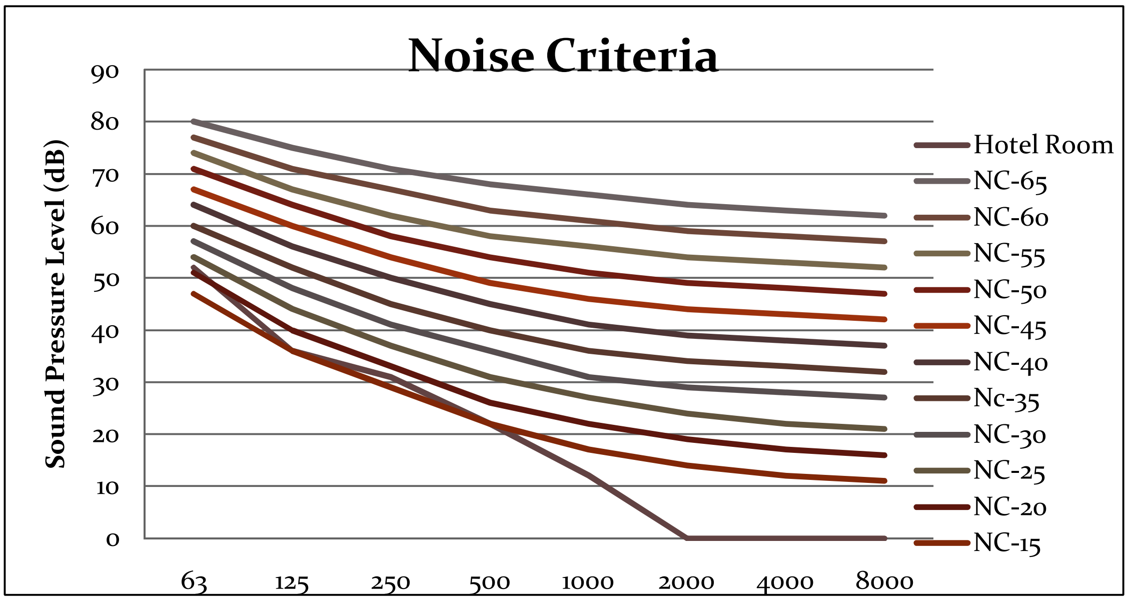


FIGURE 7.3.1 – NOISE CRITERA LEVEL OF HOTEL

The noise criteria in the hotel room are NC-30, well within the limits of max NC level of 3-40 for hotel rooms. The resulting level of the micro turbine is not a big concern.

8. FINAL RECOMMENDATIONS

After running through all the calculations for a greywater heating system and combined heating and power system, the greywater heating system looked favorable over the combined heating and power system. The payback period is nearly 3 years shorter than the CHP system and has many advantageous.

The installation would be minimal compared to a combined and heating power plant since all it requires is additional copper piping in the basement with heat exchangers installed near the walls. A significant percentage of the electrical load depends on the CHP so in the case of emergency, a redundant system would most likely have to be considered.

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Appendix A. Greywater Heat Recovery Calculations.

Shower Energy Use and Potential Recovery

		Hotel Room
Cold Water Temperature		54
Hot Water (boiler)		140
Temperature of Shower		110
Hot water/Total flow of shower		0.65
Efficiency of Boiler/hot water pipes		80
Thermal capacity of water		62.4
Gallons to Ft^3 Conversion		0.134
Energy to heat one gallon of shower water		**585**
Shower flow rate (GPM)		2.5
Average length of shower		5
Estimated Number of showers		550
Daily shower water usage		**6,875**
Energy used to heat shower water		4,024,020
Therms used per day (100,000 Btu)		40.2
Therms used per year		14,688
Cost of one therm	$	0.84
Estimated cost of heating shower water	**$**	**34**
	$	**12,279**

Potential Greywater Heat Recovery		
		Basement Locker Room Showers
Energy Usage		46.0
		16,790
Daily Flow		6,875
Temperature of water reaching drain		100
Cold Water Temp		54
Efficiency of Exchanger[1]		64
Actual Therms recovered		16.9
		6,177
Annual energy consumption avoided[2]		**8,825**
Annual energy costs avoided[2]	$	7,413

Combined Heat and Power Spreadsheet
CHP Efficiency : 30%
Electricity Price : 0.83 cents / kWh
electricy Buy Back : 0.008 cents/ kWH

Month	Hour	Electric Consumption kWh	Electrical Output kWh	Electrical from Grid kWh	Electricity back to grid kWh	Thermal Generation kWh	Electric Cost $	Electric Paid Back $	Total Electric Paid Back $	Natural Gas Consumption Therms	Natural Gas Price $	Total Cost $
Jan	1	11.07	30	0.00	18.93	49.95	0.000	0.151	-0.131	3.072	2.55	2.42
Jan	2	13.60	30	0.00	16.40	49.95	0.000	0.131	-0.127	3.072	2.55	2.42
Jan	3	14.16	30	0.00	15.84	49.95	0.000	0.127	-0.128	3.072	2.55	2.42
Jan	4	14.02	30	0.00	15.98	49.95	0.000	0.128	-0.129	3.072	2.55	2.42
Jan	5	13.88	30	0.00	16.12	49.95	0.000	0.129	-0.131	3.072	2.55	2.42
Jan	6	13.65	30	0.00	16.35	49.95	0.000	0.131	-0.111	3.072	2.55	2.44
Jan	7	16.13	30	0.00	13.87	49.95	0.000	0.111	-0.035	3.072	2.55	2.51
Jan	8	25.60	30	0.00	4.40	49.95	0.000	0.035	3.146	3.072	2.55	5.70
Jan	9	67.01	30	37.01	0.00	49.95	3.146	0.000	2.568	3.072	2.55	5.12
Jan	10	60.21	30	30.21	0.00	49.95	2.568	0.000	2.536	3.072	2.55	5.09
Jan	11	59.84	30	29.84	0.00	49.95	2.536	0.000	2.827	3.072	2.55	5.38
Jan	12	63.26	30	33.26	0.00	49.95	2.827	0.000	2.967	3.072	2.55	5.52
Jan	13	64.90	30	34.90	0.00	49.95	2.967	0.000	4.154	3.072	2.55	6.70
Jan	14	78.87	30	48.87	0.00	49.95	4.154	0.000	5.494	3.072	2.55	8.04
Jan	15	94.63	30	64.63	0.00	49.95	5.494	0.000	4.242	3.072	2.55	6.79
Jan	16	79.91	30	49.91	0.00	49.95	4.242	0.000	2.963	3.072	2.55	5.51
Jan	17	64.85	30	34.85	0.00	49.95	2.963	0.000	5.717	3.072	2.55	8.27
Jan	18	97.26	30	67.26	0.00	49.95	5.717	0.000	1.552	3.072	2.55	4.10
Jan	19	48.25	30	18.25	0.00	49.95	1.552	0.000	1.512	3.072	2.55	4.06
Jan	20	47.78	30	17.78	0.00	49.95	1.512	0.000	1.548	3.072	2.55	4.10
Jan	21	48.21	30	18.21	0.00	49.95	1.548	0.000	1.261	3.072	2.55	3.81
Jan	22	44.83	30	14.83	0.00	49.95	1.261	0.000	-0.155	3.072	2.55	2.39
Jan	23	10.60	30	0.00	19.40	49.95	0.000	0.155	-0.156	3.072	2.55	2.39
Jan	24	10.46	30	0.00	19.54	49.95	0.000	0.156	-0.135	3.072	2.55	2.41

Nov	17	80.19	30	50.19	-50.19	49.95	4.266	-0.402	12.600	3.072	2.55	15.15
Nov	18	165.49	30	135.49	-135.49	49.95	11.516	-1.084	2.949	3.072	2.55	5.50
Nov	19	61.71	30	31.71	-31.71	49.95	2.695	-0.254	2.888	3.072	2.55	5.44
Nov	20	61.06	30	31.06	-31.06	49.95	2.640	-0.248	2.888	3.072	2.55	5.44
Nov	21	61.06	30	31.06	-31.06	49.95	2.640	-0.248	2.531	3.072	2.55	5.08
Nov	22	57.21	30	27.21	-27.21	49.95	2.313	-0.218	-0.967	3.072	2.55	1.58
Nov	23	19.60	30	-10.40	10.40	49.95	-0.884	0.083	-0.915	3.072	2.55	1.63
Nov	24	20.16	30	-9.84	9.84	49.95	-0.836	0.079	-1.503	3.072	2.55	1.05
Dec	1	13.83	30	-16.17	16.17	49.95	-1.374	0.129	-1.150	3.072	2.55	1.40
Dec	2	17.63	30	-12.37	12.37	49.95	-1.051	0.099	-1.159	3.072	2.55	1.39
Dec	3	17.54	30	-12.46	12.46	49.95	-1.059	0.100	-1.159	3.072	2.55	1.39
Dec	4	17.54	30	-12.46	12.46	49.95	-1.059	0.100	-1.168	3.072	2.55	1.38
Dec	5	17.44	30	-12.56	12.56	49.95	-1.067	0.100	-1.168	3.072	2.55	1.38
Dec	6	17.44	30	-12.56	12.56	49.95	-1.067	0.100	-0.954	3.072	2.55	1.60
Dec	7	19.74	30	-10.26	10.26	49.95	-0.872	0.082	-0.008	3.072	2.55	2.54
Dec	8	29.92	30	-0.08	0.08	49.95	-0.007	0.001	3.970	3.072	2.55	6.52
Dec	9	72.68	30	42.68	-42.68	49.95	3.628	-0.341	3.193	3.072	2.55	5.74
Dec	10	64.34	30	34.34	-34.34	49.95	2.919	-0.275	3.093	3.072	2.55	5.64
Dec	11	63.26	30	33.26	-33.26	49.95	2.827	-0.266	3.355	3.072	2.55	5.90
Dec	12	66.07	30	36.07	-36.07	49.95	3.066	-0.289	3.516	3.072	2.55	6.07
Dec	13	67.81	30	37.81	-37.81	49.95	3.214	-0.302	3.547	3.072	2.55	6.10
Dec	14	68.14	30	38.14	-38.14	49.95	3.242	-0.305	4.955	3.072	2.55	7.50
Dec	15	83.28	30	53.28	-53.28	49.95	4.529	-0.426	3.573	3.072	2.55	6.12
Dec	16	68.42	30	38.42	-38.42	49.95	3.265	-0.307	3.438	3.072	2.55	5.99
Dec	17	66.96	30	36.96	-36.96	49.95	3.142	-0.296	5.570	3.072	2.55	8.12
Dec	18	89.89	30	59.89	-59.89	49.95	5.091	-0.479	1.998	3.072	2.55	4.55
Dec	19	51.49	30	21.49	-21.49	49.95	1.827	-0.172	1.950	3.072	2.55	4.50
Dec	20	50.97	30	20.97	-20.97	49.95	1.783	-0.168	1.977	3.072	2.55	4.53
Dec	21	51.25	30	21.25	-21.25	49.95	1.807	-0.170	1.654	3.072	2.55	4.20
Dec	22	47.78	30	17.78	-17.78	49.95	1.512	-0.142	-1.608	3.072	2.55	0.94
Dec	23	12.71	30	-17.29	17.29	49.95	-1.470	0.138	-1.595	3.072	2.55	0.95
Dec	24	12.85	30	-17.15	17.15	49.95	-1.458	0.137	0.000	3.072	2.55	2.55