Technical Assignment 2

Building and Plant Energy Analysis

Park Place Corporate Center One

Findlay Township, PA

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Executive Summary

The following technical report is intended to convey the total energy consumption of Park Place Corporate Center One (Park Place 1). Trane Trace 700, a commonly accepted energy modeling program, was used to do the analysis to most accurately represent the real performance of Park Place 1. Because the building is existing, real data does exist pertaining to the electricity and gas usage. This data was used as a comparison to the energy model with certain assumptions. Accordingly, both the design documents as well as the actual data provided by the building owner were used to analyze both the mechanical systems and the building itself. In the event that incomplete information was required for the model, conservative assumptions were made.

Part 1 of this report, titled Design Load Estimation, was aimed at determining the thermal loads of the building. The results of the energy simulation tend to agree with the design done by the mechanical engineer of the project. The load calculations done for the building by the engineer were performed by hand and therefore do not completely agree with the energy simulation program. That said however, the equipment that was selected to meet the engineers design loads agrees with the equipment that would have been selected if a modeling program were to have been used.

Part 2, Annual Energy Consumption and Costs, was a study concerning the costs associated with the loads determined in Part 1. The building systems were broken down by components, analyzed by energy source, and reconfigured to produce a total building operational energy cost.

The results found indicate a total energy cost of $1.50/SF/Year which is a reasonable figure given the age of the building. This cost per square foot implies a yearly total cost of around $150,000.00 per year for a relatively large office building—again a reasonable figure.

As a final thought, the energy model was intended to be used as a block load model. Individual spaces were not modeled and full occupancy was assumed, which is not the case as the building stands today. Also, because of the building’s age, several variables such as construction quality and building U-Values could potentially be inaccurate. This could lead to considerable deviations in building load with just minor changes to such characteristics. Nonetheless, this energy model is a good starting point into the energy analysis of Park Place 1.

Design Load Estimation

Inputs and Assumptions

Energy Simulation Program

As previously stated, Trane Trace 700 was used to evaluate the energy performance of both the building and the building's systems. Information that was entered into the modeling program was done so in accordance with the values used by the design engineer when he performed the calculations by hand. When additional information was needed for the modeling program that was not included in the hand calculation, the design drawings and specifications were used to most accurately approximate true conditions.

Two computer based models were created for this building. The first was a model that divided each floor into four corners and then each corner into three zones. Take, for example, the second floor northwest corner. That part of the building was modeled as an interior zone and two exterior zones—west and north perimeter zones. This was then repeated for all five floors and a rooftop penthouse was added. The second method was to analyze each floor as its own single zone, treating the floor as if it was one large room and then dividing it into quadrants. Once both models were complete, the existing performance of the building was compared to the results of the models and the second configuration was selected.

The second configuration was selected because the building is a tenant fit out and is relatively square. The second model provides an overall building load as opposed to loads of individual spaces. By example, this implies that interior zones were not zoned separately of perimeter spaces because the building systems analyzed are designed to suit the entire building and not individual zones. Modeling the entire floor as one space would reduce the assumptions required for diversity and would provide a more accurate representation of the equipment requirements for the building. Because the second model type more closely resembled by the engineer's load calculations and the real performance of the building, it was selected for analysis in this report.

Zone Configuration

The building floors were divided into four zones as explained previously. Each floor is relatively the same with only minor changes to the perimeter and variations in the floor to floor height. These changes were taken into account in the energy model. The first floor is shown below in Figure 1 as an example.

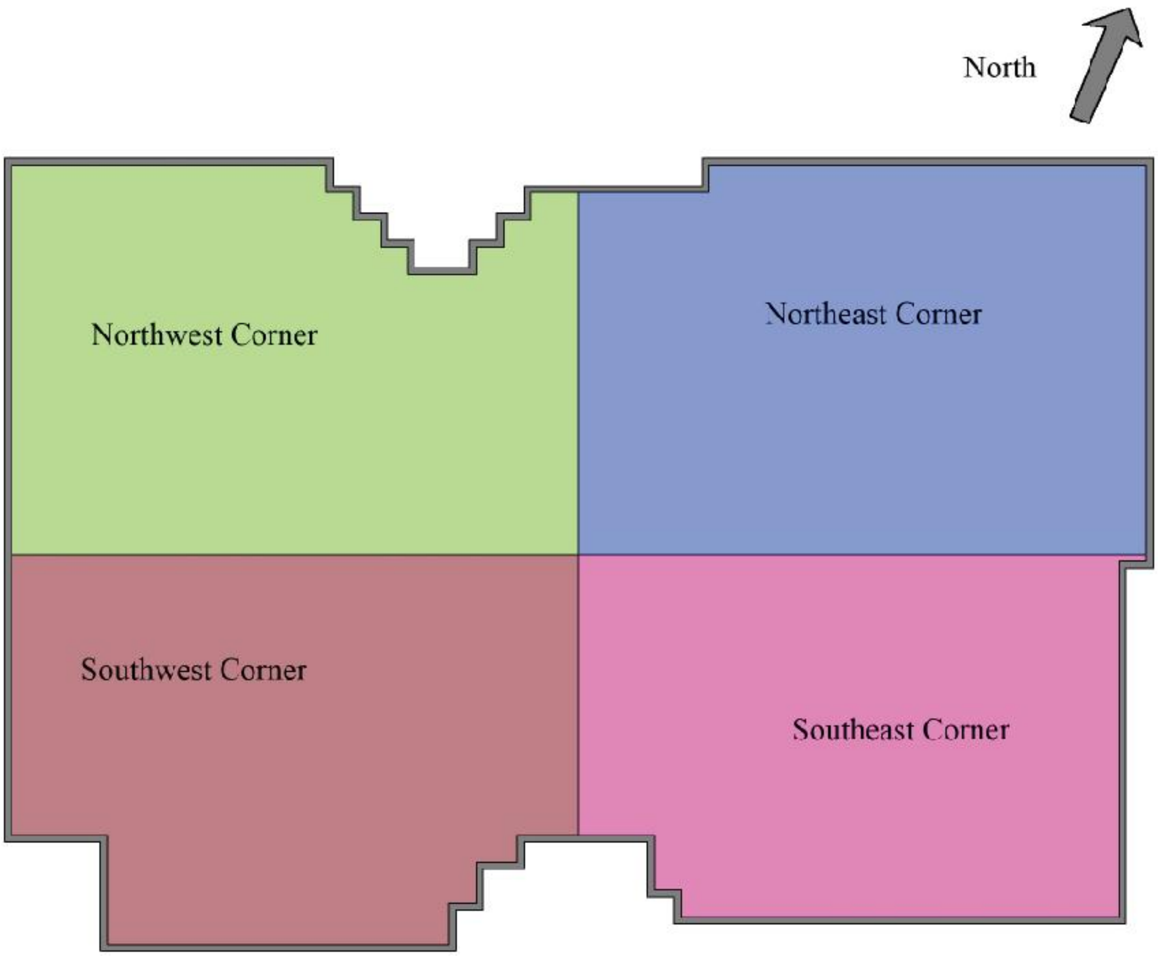


Figure 1 – Zone Breakdown for Typical Floor

Outdoor and Indoor Design Conditions

The design conditions for Park Place 1 were based on TMY2 weather data for the Pittsburgh area and ASHRAE Standard 55 which dictates appropriate conditions for thermal comfort.

Thermostat Settings	
Cooling Dry Bulb (°F)	75
Heating Dry Bulb (°F)	70
Relative Humidity (Cooling Only) (%)	50
Cooling Driftpoint (°F)	81
Heating Driftpoint (°F)	64

Table 1- Indoor Design Conditions

All thermostats either are or will be located in occupied zones to ensure that control occurs at the point of interaction between the occupant and mechanical system. Humidity will be controlled in RTU-1 and 2. Additional humidistats may be provided during tenant fit out but no additional humidity control is provided in the base building system.

Outdoor Design Conditions		
	Summer (0.4 %)	Winter (99.6 %)
Dry Bulb (°F)	89.1	1.8
Wet Bulb (°F)	72.5	-
Dew Point (°F)	65.6	-
Clearness	0.97	0.97
Ground Reflectance	0.2	0.2
Wind Velocity	11.7	15

Table 2- Outdoor Design Conditions

Airflow

The energy model for Park Place 1 has two different airflow templates, both in accordance with ASHRAE Standard 62.1-2007. The first is for general office space, the second for the rooftop penthouse. Spaces such as corridors, conference rooms, and other spaces taken into account in Technical Report 1 were neglected because office space airflow requirements are, in almost all cases, conservative with respect to the other spaces. Also, because it is the largest percentage of the occupied space and therefore the energy model zones, it was selected as the design airflow condition for the entire floor. Air distribution was selected as a VAV minimum 30% Clg Airflow.

Infiltration

Due to the age of Park Place 1, an assumed infiltration input into Trace was used. The “Neutral, Poor Const.” option was selected by recommendation of the design engineer as a conservative assumption of what the true performance of the building is. This implied one air change per hour for both heating and cooling.

Building Construction

Building construction properties for walls, floor slabs, roofs, and glass can be seen in Table 3 below. Floor elevations can be seen in Table 4 below as well.

Building Construction		
Element	Type	U-Value (Btu/h·ft^2·°F)
Slab	4" LW Concrete	0.213
Roof	4" LW Concrete	0.213
Wall	8" LW Block, 2" Insulation	0.110

Table 3 – Building Construction Properties

Glass Type			
Element	Type	U-Value (Btu/h·ft^2·°F)	Shading Coefficient
Window	Coated 1/4"	0.5	0.5

Table 4 – Glass Type Properties

Floor Heights			
Floor	FLR to FLR (ft)	Plenum Depth (ft)	Ceiling Height (ft)
1	15.5	3	12.5
2	15	3	12
3	12	3	9
4	15	3	12
5	12	3	9
Penthouse	15	3	12

Table 5 – Floor Heights

Schedules

An example schedule can be found in Figure 2 below. All schedules follow a typical office building work week, dominated by full load occupancy from Monday through Friday, 8 A.M. to 5 P.M. with moderate occupancy during other hours.

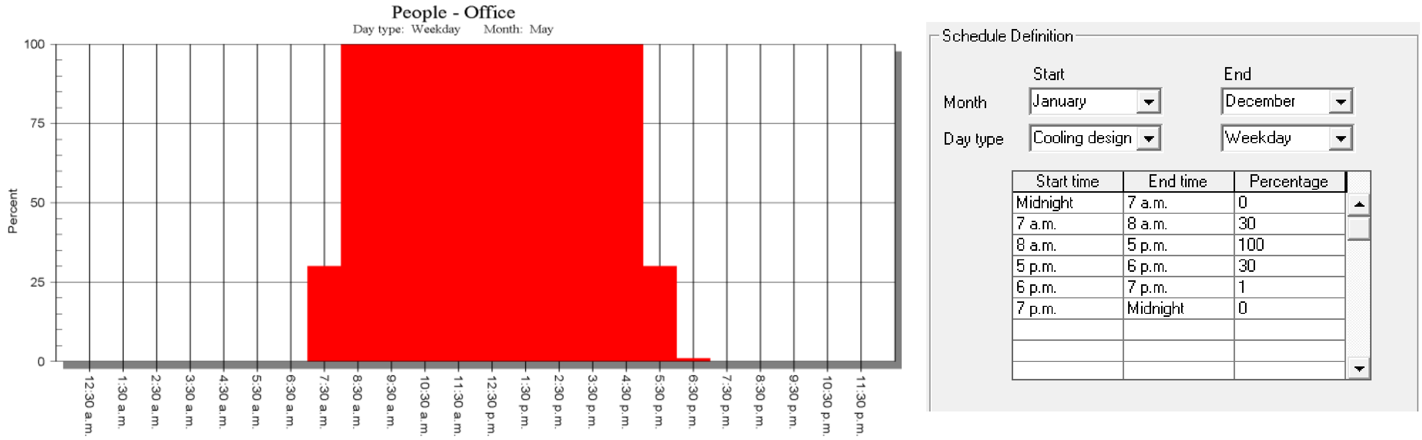


Figure 2 – Example Occupancy Schedule

Internal Loads

Internal loads for the office spaces can be seen below in Table 6. People are assumed to be doing light office work. The lighting density for the space is slightly higher than most modern office buildings and the miscellaneous loads account for computers and other light office equipment. The value taken for this equipment is the default value provided by Trace 700.

Internal Office Loads		
Load	Sensible	Latent
People (Btu/h)	250	200
Lighting (W/ft^2)	1.2	
Misc. (W/ft^2)	0.5	

Table 6 – Internal Office Loads

Block Load Approximation Results

Once the above information was entered into Trane Trace 700, results were compiled and are reported in this section.

The total building load summary can be seen below in Figure 3 as an output of Trace 700. From this figure, it can be seen that the total cooling load required is about 225 Tons.

	COOLING COIL PEAK				CLG SPACE PEAK	
Peaked at Time:	Mo/Hr: 7 / 15				Mo/Hr: 7 / 15	
Outside Air:	OADB/WB/HR: 86 / 71 / 95				OADB: 86	
	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	294,375	294,375	11	0	0
Glass Solar	343,786	0	343,786	13	343,786	24
Glass/Door Cond	101,024	0	101,024	4	101,024	7
Wall Cond	22,291	5,844	28,135	1	22,291	2
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	630,643		630,643	23	239,298	17
Sub Total ==>	1,097,744	300,218	1,397,962	52	706,399	50
Internal Loads						
Lights	279,353	69,838	349,191	13	279,353	20
People	306,629	0	306,629	11	170,350	12
Misc	166,281	0	166,281	6	166,281	12
Sub Total ==>	752,263	69,838	822,102	30	615,984	43
Ceiling Load	95,733	-95,733	0	0	95,733	7
Ventilation Load	0	0	304,412	11	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-95,252	-95,252	-4		
Sup. Fan Heat			275,562	10		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	1,945,740	179,073	2,704,787	100.00	1,418,116	100.00

Figure 3 – Cooling Requirement Breakdown and Total

The percentage breakdown of the origin of the loads can be seen in Figure 3 above. Important observations can be made based off of this data. First, the building is approximately 52% envelope load which means it is an envelope dominated building. The internal loads in the building are around 30% which leaves the remaining 20% accounted for in fan heat and ventilation load to the interior.

The heating load is usually easier to calculate than the cooling load to due the fact that less variables need to be taken into account. The heating requirement can be seen below in Figure 4.

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 5

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	-254,353	17.94
Glass Solar	0	0	0.00
Glass/Door Cond	-651,402	-651,402	45.95
Wall Cond	-123,223	-164,747	11.62
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	-1,414,035	-1,414,035	99.74
Sub Total ==>	-2,188,661	-2,484,538	175.24
Internal Loads			
Lights	13,303	16,628	-1.17
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	13,303	16,628	-1.17
Ceiling Load	-125,709	0	0.00
Ventilation Load	0	-678,912	47.89
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	1,769,274	1,769,274	-124.79
Exhaust Heat		124,859	-8.81
OA Preheat Diff.		-2,586	0.18
RA Preheat Diff.		-162,497	11.46
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-531,793	-1,417,772	100.00

Figure 4 – Heating Requirement Breakdown and Total

Because the load calculations done by the design engineer were by hand, it is difficult to compare either for accuracy. In order to determine the quality of the energy model, existing records of energy consumption and equipment selections will be used. Both topics will be addressed in later sections of this report.

Mechanical System Simulation

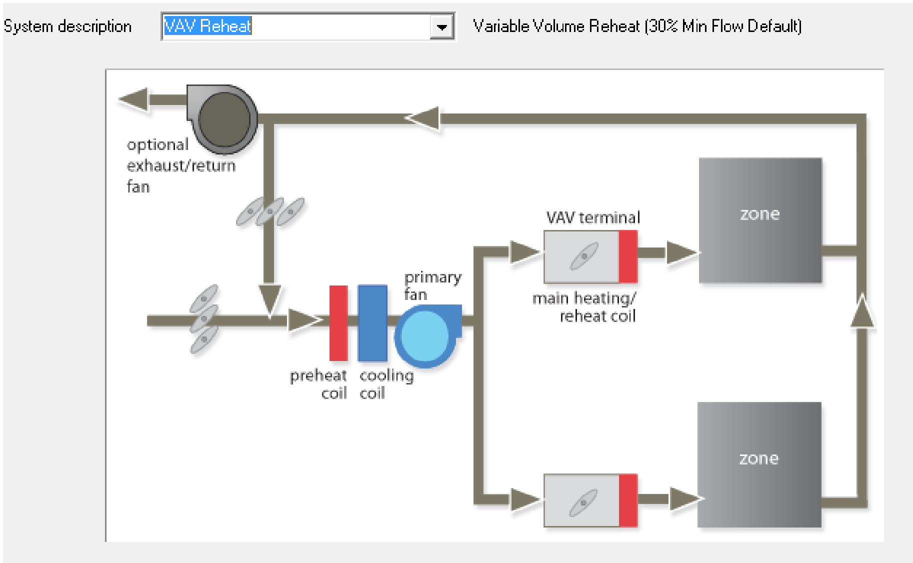
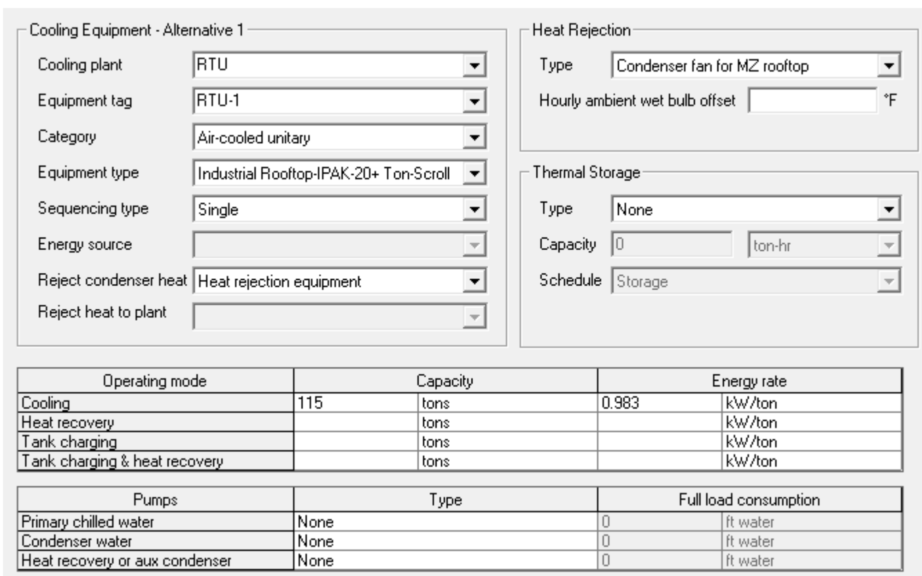


Figure 5 – Mechanical System Schematic



Cooling Equipment - Alternative 1

Cooling plant	RTU
Equipment tag	RTU-1
Category	Air-cooled unitary
Equipment type	Industrial Rooftop-IPAK-20+ Ton-Scroll
Sequencing type	Single
Energy source	
Reject condenser heat	Heat rejection equipment
Reject heat to plant	

Heat Rejection

Type	Condenser fan for MZ rooftop
Hourly ambient wet bulb offset	°F

Thermal Storage

Type	None	
Capacity	0	ton-hr
Schedule	Storage	

Operating mode	Capacity		Energy rate	
Cooling	115	tons	0.983	kW/ton
Heat recovery		tons		kW/ton
Tank charging		tons		kW/ton
Tank charging & heat recovery		tons		kW/ton

Pumps	Type	Full load consumption	
Primary chilled water	None	0	ft water
Condenser water	None	0	ft water
Heat recovery or aux condenser	None	0	ft water

Figure 6 – Rooftop Unit Trace Selection

Seen above in Figures 4 and 5 are the selections that were made in Trace 700 to most closely resemble the mechanical systems in Park Place 1. Figure 4 shows a variable air volume distribution system with reheat (hot water reheat provided by boilers). Supply air in the system is supplied by the two RTU's in the penthouse which have both a supply and return fan. Figure 5 shows the capacity and energy efficiency of the RTU's which is based on TOPSS, Trane's equipment selection program. The efficiency is based on outdoor ambient air conditions, air quantity, and the rated capacity of the equipment.

Simulated Loads vs. Designed Equipment Capacity

Described in more detail as a part of Technical Report 1, the mechanical systems of Park Place 1 are comprised of two Rooftop Air Handling Units (RTU-1,2) which each serve half of the building. The RTU's are sized to meet up to 115 Tons of cooling load each for a total of 230 Tons. Table 7 below compares the required load based on the energy model produced by Trace 700 and the equipment that is to be installed per the design of the engineer.

Load Comparison vs. Designed Equipment Capacity			
Modeled		Designed	
Season	Load	Equipment Name	Equipment Capacity
Cooling	225.4 Tons	RTU-1,2	230 Tons
Heating	-1417.8 MBh	RTU-1,2	1,100 MBh
		Boiler 1,2	970 MBh

Table 7 – Load Comparison vs. Designed Equipment Capacity

Air Flow Comparison		
	Estimated	Designed
Floor Area	102,312	99,281
cfm	66,430	90,000
Tons	225.4	230
cfm/ft^2	0.65	0.91
cfm/Ton	294.72	391.30
ft^2/Ton	453.91	431.66

Table 8 – Air Flow Comparison

In Table 8 above there are clearly differences between the design and the estimated loads. This is especially obvious in the divergence between the amount of supply air required to the space. Because the RTU's are variable air flow, they will almost never certainly be pushing 90,000 cfm's of supply air at any single time. In reality, they will most likely be supplying an amount of air similar to that of the modeled amount. The modeled amount is simply indicating that at 55 degrees Fahrenheit, the amount of supply air required is around 66,000 cfm's to meet the load. If, for example, the unit wanted to use the economizer and provide warmer air to the space, it would reduce the temperature difference between the supply air and the ambient air temperature of the space which would require a larger amount of supply air to sufficiently cool the space. The extra supply air capacity would allow for this to happen.

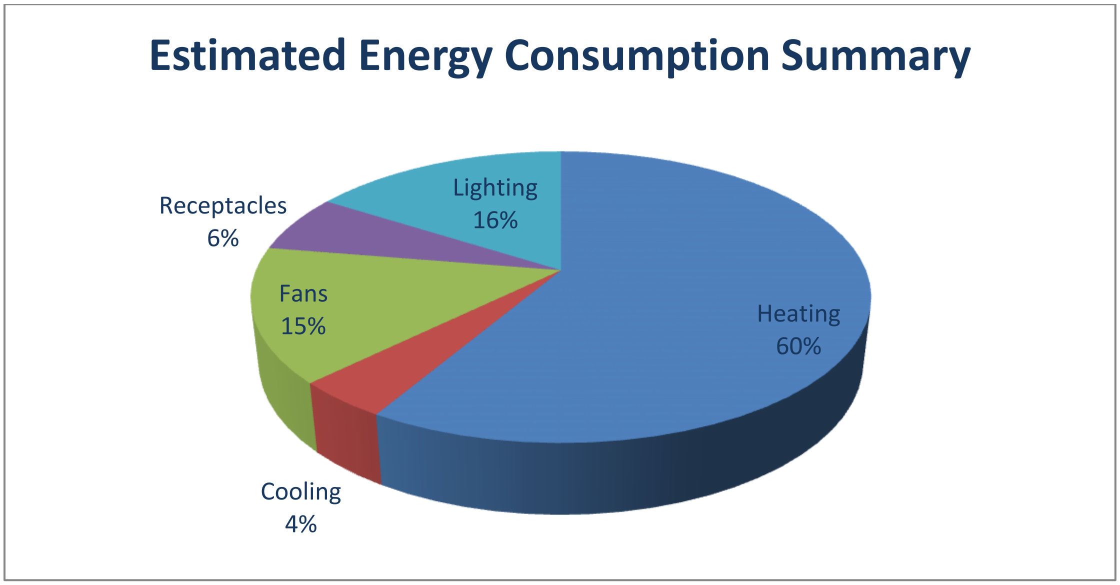


Figure 7 – Estimated Energy Consumption Summary

Figure 6 above shows the breakdown in energy consumption of the estimated building model. The model shows that the building is dominated by its heating load, which makes sense because the winter in Pittsburgh is cold and the summers are generally milder when cooling would be required. The fan energy takes into account both heating and cooling seasons which explains why it is fairly large. The receptacle and lighting consumption is reasonable for an office building.

An important piece of information in the study of this building is the use of existing records of energy consumption and how they relate to the energy model output. The difficulty is that the building is not totally occupied in real life, yet it has been modeled as though it is. According to the owner, the building is about one-half occupied. As an assumption, increasing the heating requirement by a factor of two should represent a fully occupied building. Based on February of 2010 records for heating energy consumption and assuming full building occupancy, the model is only 3.5% different from the actual records. The calculation is shown below in Table 9.

Reported Energy Consumption	Estimated Energy Consumption	% Difference
7130 therms	7389 therms	3.50%

Table 9 – Estimated vs. Actual Energy Consumption for February 2010

Annual Energy Consumption and Costs

Annual Energy Consumption

The annual energy consumption was calculated by Trace 700 as a part of the energy model for the entire building. The annual energy consumption of the building is divided into electricity which is used by the RTU's, fans, pumps, receptacles, and lights. The other source of energy is gas which is consumed entirely for heating purposes. Shown below in Table 10 and Figures 8 through 10 are the output reports from Trace 700 providing numerical outputs and their corresponding graphs respectively.

	Monthly Energy Consumption													
	Month	January	February	March	April	May	June	July	August	September	October	November	December	Total
Electric	Consumption (kWh)	65,948	59,327	66,822	54,480	60,542	77,314	83,072	70,180	53,789	59,651	59,721	62,901	773,746
	Demand (kW)	199	198	215	219	387	500	541	452	351	216	215	199	541
Gas	Consumption (therms)	7,887	7,389	5,870	1,914	153	0	0	0	268	2,487	3,739	6,650	36,357

Table 10 – Monthly Energy Consumption

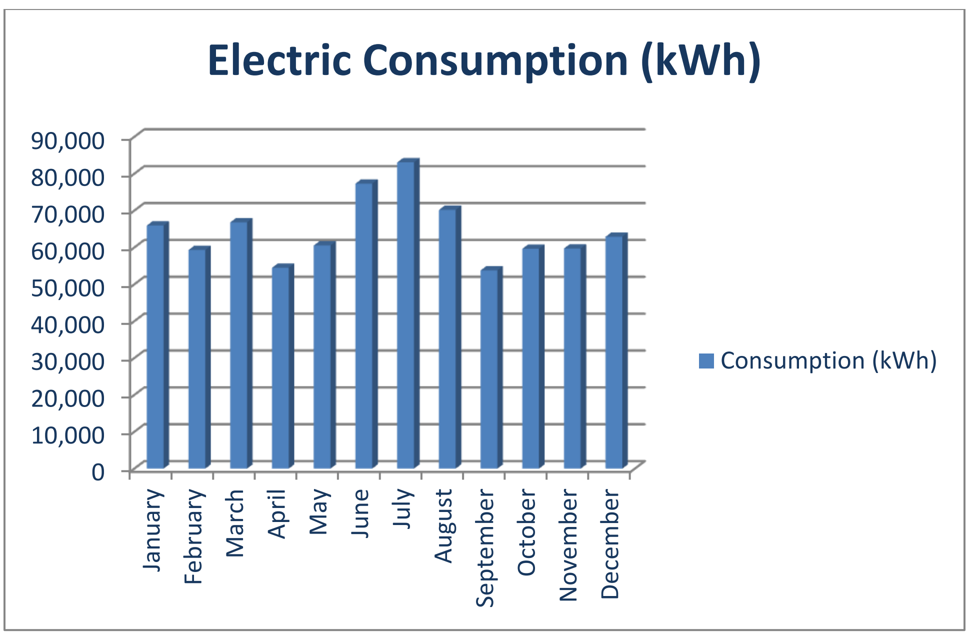


Figure 8 – Electric Consumption

Shown above in Figure 8 is the electricity consumption expressed in kWh's. The graph demonstrates that electricity will be used throughout the entire year, with the peak occurring during the summer months when the cooling load is at its maximum. The electricity demand shown below in Figure 8 demonstrates a similar concept of maximum load occurring during July, usually the warmest month.

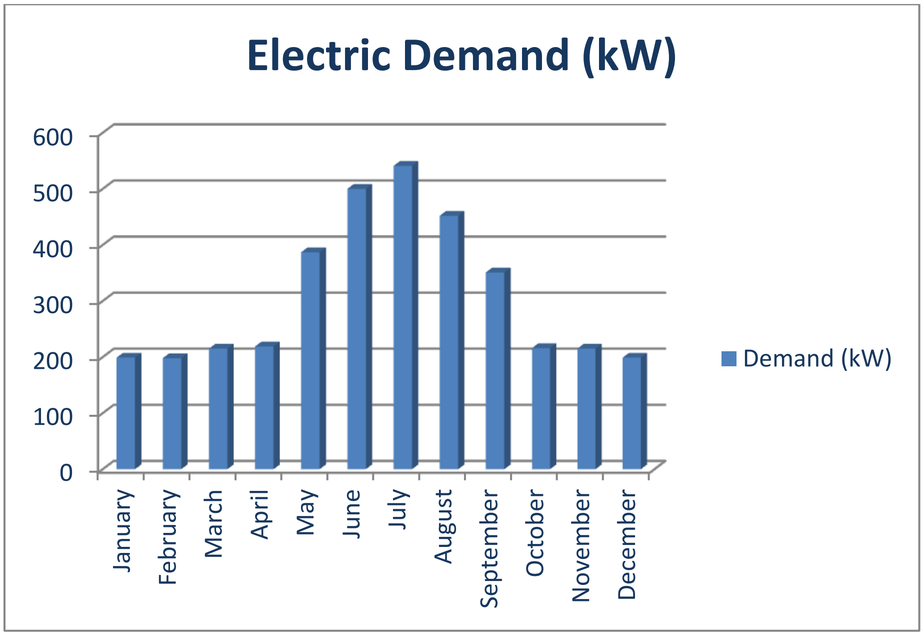


Figure 9 – Electric Demand

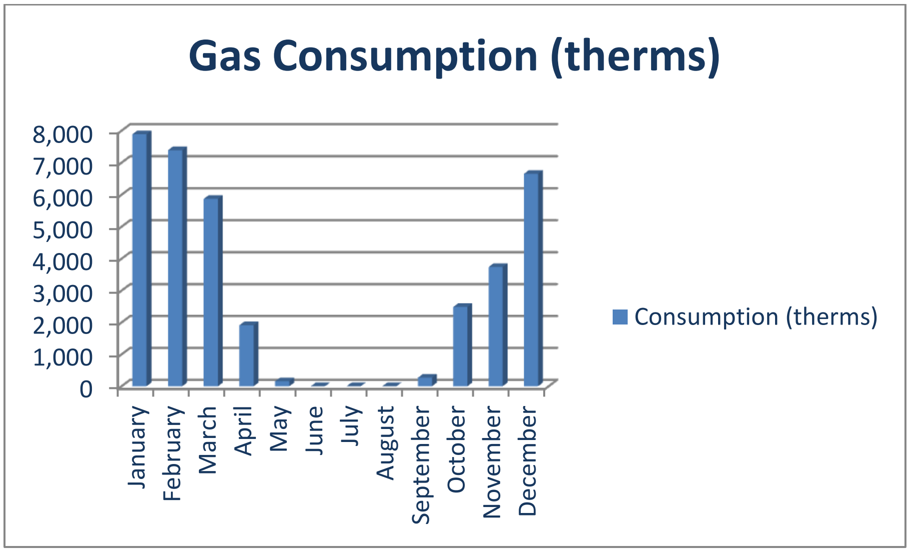


Figure 10 – Gas Consumptions

It is evident that from the charts and figures above, the predominant consumption of energy will be in the form of electricity. Electricity is used in the building throughout the entire year as compared to gas which is used just during the heating months. Figure 9 shows that a peak shaving strategy during the summer months could be an excellent way to reduce cost by reducing the electricity demand on the building.

Another important observation is that there is no water use for the building other than domestic use in restrooms, cleaning facilities, or drinking fountains. This is due to the fact that the RTU's are air cooled and do not require a cooling tower. This is important in assessing the operating costs of the building in the future.

Energy Costs

The energy costs for the building are determined by the resource providers which in this case are Duquesne Light and Columbia Gas. Shown below in Figure 11 is the distribution map of electricity providers for Pennsylvania. Findlay Township is located in the region shaded by orange.

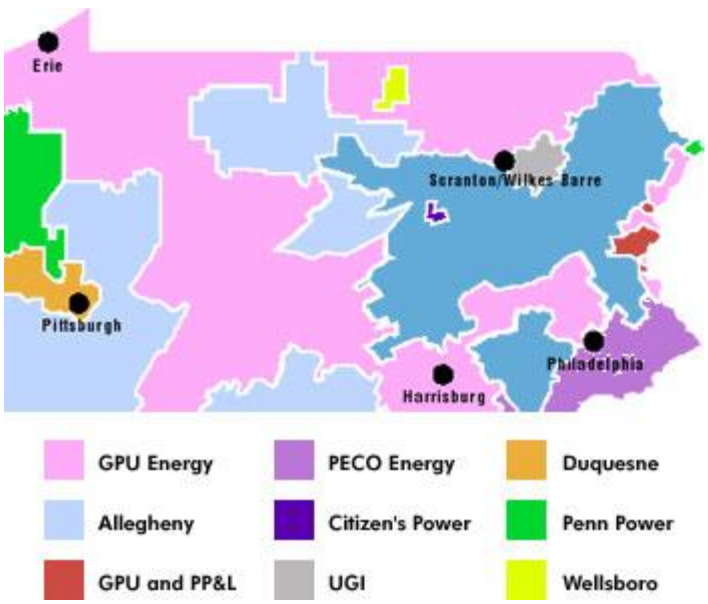


Figure 11 – Pennsylvania Power Distribution

Duquesne Light Electricity Rates	
Demand	Usage
7.07 $/kW	0.1236 cents/kWh

Table 11 – Electricity Rates

Table 11 above shows the cost for both electric demand and usage of Duquesne Light. The demand is broken down into two subdivisions. The first stipulation is that if the demand is less than 300 kW, then the cost per kW is 7.07 $/kW. If the demand exceeds 300 kW, then the cost is reduced to 6.45 $/kW. These values are based on the assumption that Park Place 1 falls into the category of General Service Large. Table 12 provides the cost of natural gas for Park Place 1.

Pennsylvania Natural Gas Rate
8.9 $/MCF

Table 12 – Natural Gas Rates

The following graphs display the monthly as well as overall energy costs for Park Place 1. The analysis is separated by energy type.

Electricity Cost				
	Consumption (kWh)	$	Demand (kW)	$
January	65,948	8,151.17	199	1,406.93
February	59,327	7,332.82	198	1,399.86
March	66,822	8,259.20	215	1,520.05
April	54,480	6,733.73	219	1,548.33
May	60,542	7,482.99	387	2,682.15
June	77,314	9,556.01	500	3,411.00
July	83,072	10,267.70	541	3,675.45
August	70,180	8,674.25	452	3,101.40
September	53,789	6,648.32	351	2,449.95
October	59,651	7,372.86	216	1,527.12
November	59,721	7,381.52	215	1,520.05
December	62,901	7,774.56	199	1,406.93
	Total	95,635.13	Total	25,649.22

Total Cost/Year	$121,284.35

Table 13 – Electricity Cost

The total energy cost for the building will be the sum of the electric energy cost from Table 13 above and the total natural gas cost from Table 14 below. When added together, this figure comes out to be $153,642.09 for the entire year. This number seems reasonable for a building of such size and occupancy.

Natural Gas Cost			
	therms	MCF	$
January	7,887	788.7	7019.43
February	7,389	738.9	6576.21
March	5,870	587	5224.3
April	1,914	191.4	1703.46
May	153	15.3	136.17
June	0	0	0
July	0	0	0
August	0	0	0
September	268	26.8	238.52
October	2,487	248.7	2213.43
November	3,739	373.9	3327.71
December	6,650	665	5918.5
		Total	32,358

Total Cost/Year	$32,357.73

Table 14 – Natural Gas Cost

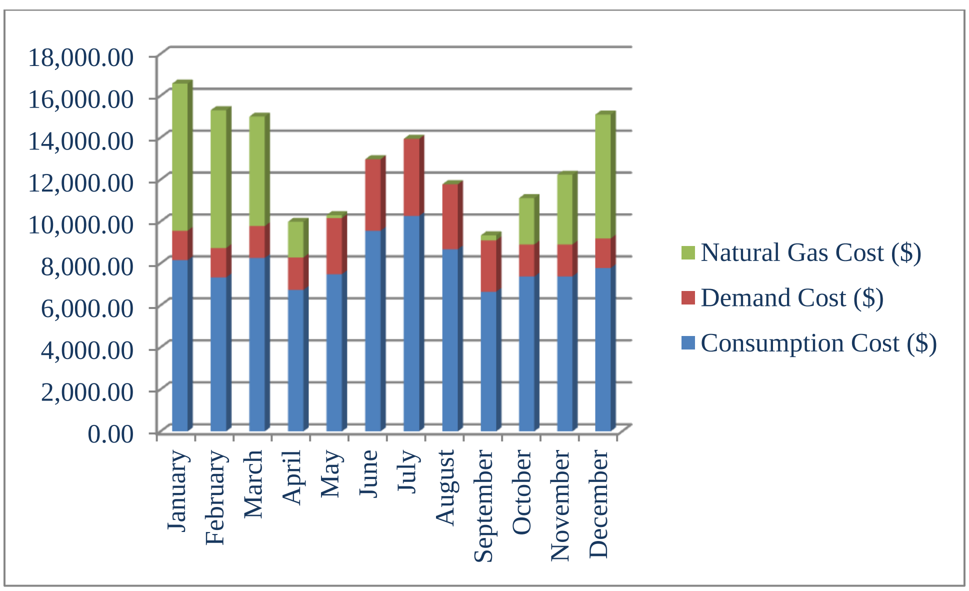


Figure 12 – Comparative Total Costs of Utilities

Figure 12 above expresses the relationship between each of the utility costs. It is very clear to see that the electrical consumption cost (shown in blue) accounts for the majority of the total energy cost of the building. This is to be expected. As a reference for the future, if the electricity consumption of the building could be reduced, the largest cost savings would most likely coincide.

Energy Cost Breakdown			
Element	Yearly Cost of Operation	$/SF	% of Total
Heating	$32,357.73	$0.32	21.0%
Lighting	$47,300.90	$0.46	30.8%
Receptacles	$17,707.51	$0.17	11.5%
Fans	$44,268.79	$0.43	28.8%
Cooling	$12,128.43	$0.12	7.9%
Total	$153,763.36	$1.50	100.0%

Table 15 – Energy Cost Breakdown by Element

From Table 15 above, lighting and fan energy are the greatest consumers in terms of both energy and dollars. What is surprising is that the cooling energy is the lowest, and simultaneously the cheapest of the elements in the table above.

Emissions

Pollutant (lb) Generated During On-Site Combustion		
Commercial Boiler (Natural Gas)		
Pollutant (lb)	1 MCF	lb Pollutant
CO_{2e}	1.23E+02	4.47E+05
CO_2	1.22E+02	4.44E+05
CH_4	2.50E-03	9.09E+00
N_2O	2.50E-03	9.09E+00
NO_X	1.11E-01	4.04E+02
SO_X	6.32E-04	2.30E+00
CO	9.33E-02	3.39E+02
VOC	6.13E-03	2.23E+01
Lead	5.00E-07	1.82E-03
Mercury	2.60E-07	9.45E-04
PM10	8.40E-03	3.05E+01

Table 16 – Pollutant Generated During On-Site Combustion

Table 16 expresses the amount of pollutant, in pounds, of building emissions according to data provided by *Source Energy and Emission Factors for Energy Use in Buildings*. The data provided pounds of pollutant per 1000 ft^3 of natural gas.

Summary

The above analysis is an estimate of the energy consumption of Park Place 1. While it is always difficult to determine accuracy in a computer generated model, in this case, there is no basis of comparison. The design engineer did not create a computer model simply due to the scale of the building project. Because the building was a renovation, the owner did not request a model in the interest of saving money. If the building had been constructed recently, an energy model would surely have been constructed. However, because this is not the case, the hand calculations from the design engineer have been compared to those of the computer output. Needless to say, the two pieces of information are difficult to compare.

To determine accuracy, the equipment capacities from the design as well as the existing building records of energy consumption have been compared to the energy model. In general, the model tends to reflect both pieces of information. The output of the energy model also seems to be reasonable based on rule-of thumb calculations.

References

ASHRAE Handbook of Fundamentals 2005

CJL Engineering, Park Place Corporate Center One Renovation Mechanical, Electrical, and Plumbing Drawings and Specifications

DiCicco Development

Past Thesis Technical Reports, e-Studio Archives, 2009-2010

Source Energy and Emission Factors for Energy Use in Buildings

WTW Architects, Park Place Corporate Center One Drawings

APPENDIX A

List of Figures and Tables

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