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Comparison of the energy and economic feasibility of different building systems.

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Comparison of the energy and economic feasibility of different building systems.

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Mechanical Engineering

Program of Study Committee:
Gregory M Maxwell, Major Professor
Ron Nelson
Frank Peters

Iowa State University

Ames, Iowa

2009

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Chapter 1: Introduction

At no point in our history has humanity been able to make as large of an impact on our environment as we can now. Before the industrial revolution, the average atmospheric carbon dioxide (CO2) level was at 250 ppm and has risen to 379 ppm in 2005.[1] Eleven of the last 12 years have been the warmest on record.[2] There are too many studies out there that all same the same thing. We can not ignore this and we have to start doing something.

Buildings consume more than 39% of the primary energy production and account for 39% of the United States carbon dioxide (CO2) emissions. Since they consume such a large percentage of our energy use, even small improvements can amount to significant impact. Reducing building energy by 30% (which is very attainable) would eliminate 670 million metric tons of CO2 emissions. This would equate to an 11% decrease in the total US CO2 emissions[3]

There are many existing technologies available that will reduce building energy consumption. Many require little or no up front cost and most will cost less over a 20 year life span. This report analyzes the energy consumption and economic viability of five existing heating, ventilating, and air-conditioning (HVAC) technologies widely used:

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[1] Solomon, S, et al. IPCC 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press, Cambridge, UK and New York, NY, 2007) 25.

[2] Pachauri, R.K, et al. IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, Geneva, Switzerland, 2007) 2.

[3] Kelso, J., ed. 2008 Buildings Energy Data Book. (D&R International, Ltd , Silver Spring, Maryland, 2009) <http://buildingsdatabook.eren.doe.gov/>.

Single Zone Roof Top Air-conditioning Unit (RTU), Ground Source Heat Pump (GSHP), Variable Air Volume (VAV) RTU, Demand Controlled Ventilation (DCV), and Natural Daylighting.

Each system will be modeled in two different building types. The first being a standard 100 ft by 100 ft office building with a flat roof. The second building type will be two long narrow buildings with the orientation and glazing optimized to maximize daylighting.

All system models will be modeled using TRACE 700 building load and energy analysis software.

Chapter 2: Literature Review

In the past 10 years there has been a lot of talk about green buildings and energy efficiency. The latest news has been on "Net Zero Energy Buildings". According to National Renewable Energy Laboratory, the key to achieving net zero energy use is to lower building energy consumption by as much as possible before supplying the rest with onsite energy generation. By using this approach, 62% of the existing building stock could achieve net zero energy use by using existing building technologies and roof mounted solar panels to generate the rest of the building's energy needs.[4]

In a report by the National Science and Technology Council, the energy and green house gas footprint of a building can be reduced by 30 – 50% using known technologies for energy efficiency. Approaches were to increase building envelope insulation value, reduce infiltration, increasing HVAC efficiency, on site energy production and storage, and incorporating passive solar heat, daylighting, and natural ventilation in to the building design.[5] Natural daylighting it self has a large potential to reduce building energy consumption. Lighting in commercial buildings directly consumed about 26% of building energy on 2006.[6] If lighting energy were to be reduced, there would be a lot of synergies to reduce HVAC energy usage also.

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[4] Griffith,B., et al. Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector. (National Renewable Energy Laboratyory, Golden, Colorado, 2007) 38.

[5] Ritter, M., et al. Net-Zero Energy, High-Performance Green Buildings (National Science and Technology Councile, 2008) 8.

[6] Kelso, J., ed. 2008 Buildings Energy Data Book. (D&R International, Ltd , Silver Spring, Maryland, 2009) <http://buildingsdatabook.eren.doe.gov/>.

According to the US department of Energy, energy efficient office buildings will enhance the comfort and performance of workers in addition to cutting operating cost. Many of the same measures that improve a building's energy efficiency also make it a more comfortable place to work. Workers will benefit from the use of daylighting, better temperature control, ventilation and indoor air quality.[7]

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[7] "Building Technologies Program – Commercial Buildings." Energy Efficiency and Renewable Energy. (US Department of Energy, 2009) <http://www1.eere.energy.gov/buildings/commercial/offices.html>.

Chapter 3: Computer Model Description

The building energy modeling was done using the TRACE 700 software developed by the Trane Company. TRACE 700 has been tested to be in compliance with ANSI/ASHRAE Standard 140–2004, Section G2.2 for Performance Rating Method in Appendix G of ASHRAE Standard 90.1–2004, and approved by the IRS for energy-savings certification (EPAct).[8]

3.1 Building Models

Two building models were created for this study. For all models the thermal properties of all the construction materials meet the minimum requirements given in ASHREA 90.1–2004, unless otherwise specified. The building construction properties can be found in Appendix A "TRACE Inputs."

Two different building types were modeled. The first model is a standard one story office building, typical of what you would see in many cities across America. It is 100 ft by 100 ft with a flat roof. The exterior walls are 15 ft tall with a 5 ft ribbon of glass around the perimeter. The building was modeled with an acoustical ceiling mounted at 10 ft with a 5 ft plenum that serves as a return air path. The building was modeled with five different thermal zones: four 15 ft perimeter zones for each orientation and one 70 ft x 70 ft interior zone. This building model was used to model the different HVAC systems. Figure 3.1.1 shows a plan and elevation view of the building.

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[8] HVAC Design Tools, Heating And Air Conditioning, TRACE™ 700 - Analysis Software - Analysis Tools. (Trane, 2009) <http://www.trane.com/commercial/DNA/View.aspx?i=1136>

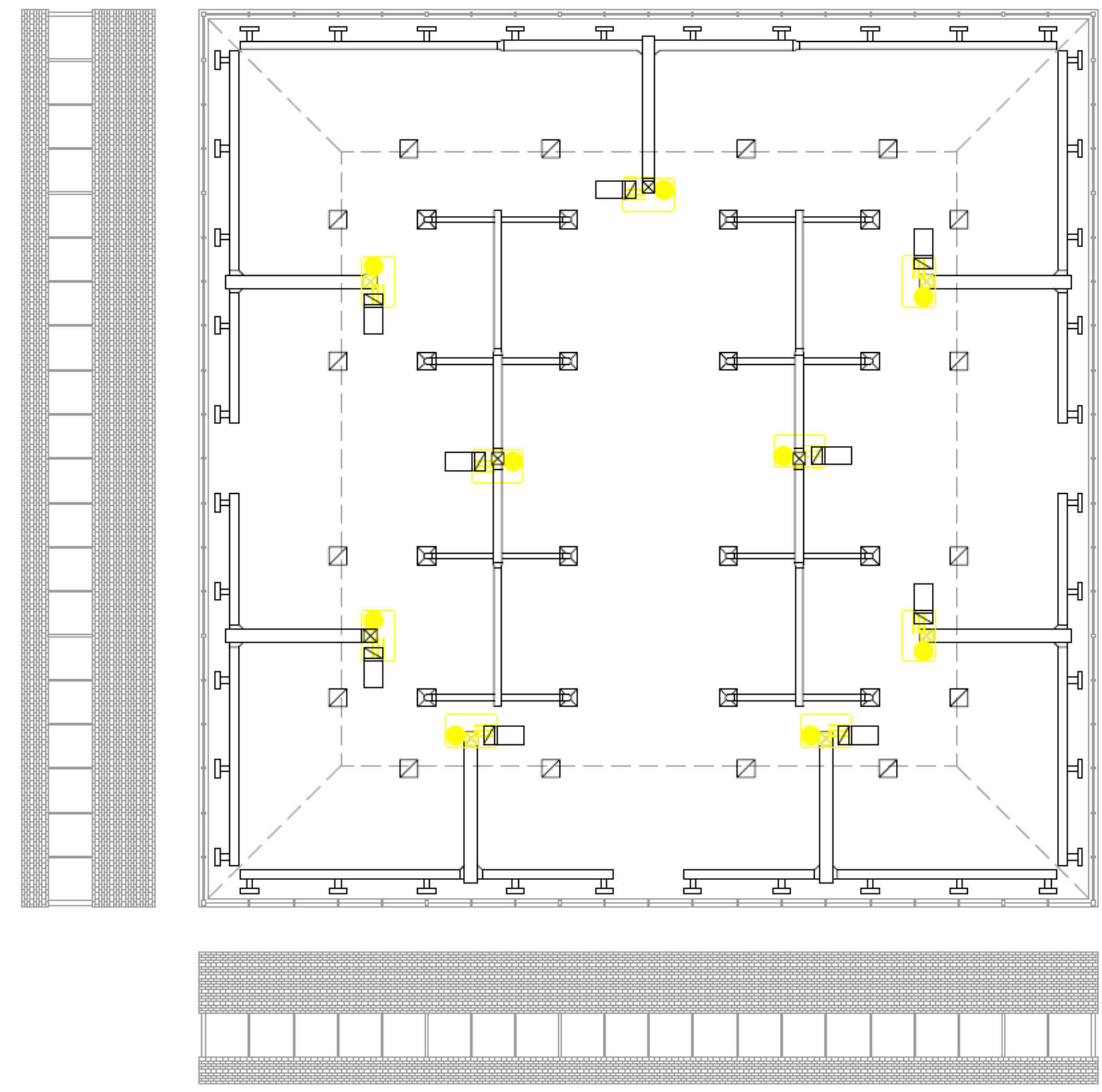

Figure 3.1.1 Standard Office Building, NTS

The second building was modeled after the Iowa Association of Municipal Utilities (IAMU) Office located in Ankeny Iowa. The building was the first LEED certified project in Iowa. All the energy saving features included in the building helped it achieve a 55% energy reduction when compared to the base line building in ASHRAE

90.1–1999.[9] The building is a good example of a daylighting design. Using the “Glazing Factor” calculation procedure in LEED NC 2.2, 100% of the building floor area has daylighting views.

The IAMU building is a combination of two different buildings with a south facing lean-to design to maximize daylight penetration into the building. Both buildings are 100 ft by 50 ft giving a total of 10,000 ft2 leasable space. The north facing wall is 11.5 ft tall and has a 4 ft strip of glazing. The south facing wall is 18.5 ft tall and has a low level strip of glazing 3.5 ft tall to daylight the south perimeter zone and a high level strip of glazing 2.5 ft tall to daylight the interior zone. There is no glazing on the east and west facing walls. Because this model was used to model the energy benefits of Natural Daylighting, the glazing for this model was changed from the code minimum requirements to a Clear Low-e glazing to increase the daylighting effectiveness. Each building was modeled with 3 thermal zones, one 15 ft x 100 ft south perimeter zone, one 15 ft x 100 ft north perimeter zone, and one 20 ft x 100 ft interior zone. Figure 3.1.2 shows a plan and elevation view of the building. Figure 3.1.3 shows a section view of the building with the solar penetration angels shown for the summer solstice, winter solstice and the equinox at 12:00 pm solar time.

Figure 3.1.2 shows that direct sunlight is allowed to penetrate the building during the fall, winter and spring months when solar heat is need. It is blocked during the summer months when cooling loads dominate and there is a large amount of indirect diffused daylight that can be used.

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[9] IAMU - Sustainable Facility - Training Facilities (Iowa Association of Municipal Utilities, 2009) <http://www.iamu.org/about/facility/performance.htm>.

Figure 3.1.2 IAMU Office Building, NTS

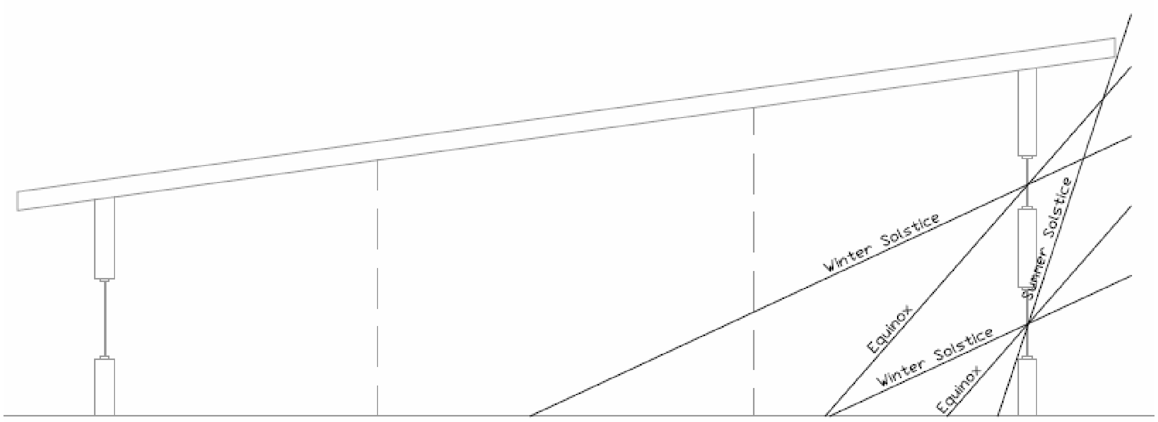

Figure 3.1.3 IAMU Office Building Daylighting Angles, NTS

For both buildings the occupancy hours were arranged around a five-day work week from 8:00 am to 5:00 pm. The schedules for People, Lights, and Miscellaneous loads can be found in Appendix A, “TRACE Inputs.” All models were simulated using the TMY3 weather data available for download at the National Renewable Energy Laboratory.

3.2 HVAC System Models

For all system types the energy load factors meet the minimum requirements given in ASHRAE 90.1–2004, unless otherwise specified. The full-load energy values of the equipment can be found in Appendix A “TRACE Inputs.”

<u>Single Zone Roof Top Air-conditioning Unit</u>:

Packaged air cooled air conditioning units with electric resistance heat were modeled for each zone. Electric resistance heat was used in this model because the utility rates in Iowa favor this. There is one RTU for each thermal zone.

The RTU supply fan runs continuously when the building is occupied and cycles on and off with the cooling/heating demand when the building is unoccupied. When zone temperature rises above 75°F the RTU compressor runs and rejects heat though an air cooled condenser until the zone drops below 75°F. When zone temperature falls below 70°F the electric heating coil runs until the zone rises above 70°F. The outdoor air section of the RTU was modeled with a dry-bulb economizer to mix outdoor air with return air for free cooling when the out side air temperature is below 55°F. The RTU compressors are off in economizer mode.

The supply fan, compressors, condenser fan, electric heating coil, and misc accessories were all modeled separately.

Ground Source Heat Pump:

Packaged water cooled heat pumps with a ground water storage loop for a heat sink were modeled for each zone. In cooling mode the compressor runs and pulls heat from the zone and rejects it into the ground loop. In heating mode the refrigerant reversing valve switches and the compressor pulls heat from the ground water loop and rejects it into the space. The ground loop was oversized to keep the loop water temperature below 80°F eliminating the need for a cooling tower. Each GSHP was modeled with an electric heating coil that would run when the ground loop temperature fell below 40°F. There is one GSHP for each thermal zone.

The GSHP supply fan runs continuously when the building is occupied and cycles on and off with the cooling/heating demand when the building is unoccupied. When zone temperature rises above 75°F the GSHP compressor runs and rejects heat to the ground water storage loop until the zone drops below 75°F. When zone temperature falls below 70°F the compressor runs and rejects heat in to the zone until the zone rises above 70°F. If the ground loop temperature falls below 40°F the compressor shuts off and the electric heater on the discharge of the GSHP runs. The ground water loop pump runs continuously at a constant speed.

The supply fan, compressors, electric heating coil, ground water loop pump and misc accessories were all modeled separately.

VAV Roof Top Air Conditioning Unit:

A packaged air cooled air conditioning unit with a variable speed supply fan was modeled to supply cooling air to variable air volume terminal units. The VAV RTU stages its compressors on and off to maintain a constant 55°F discharge air temperature. A variable frequency drive varies the supply fan speed to match the cooling load in the building. The outdoor air section of the RTU was modeled with a dry-bulb economizer to mix outdoor air with return air for free cooling when the out side air temperature is below 55°F. The RTU compressors are off in economizer mode.

A parallel fan powered terminal unit at each zone varies the supply air to maintain the zone at 75°F. There is a minimum air flow of 30% for ventilation air. If the space temperature falls below 70°F a supply fan and electric heating coil in the terminal unit cycle on. Plenum air is mixed with the minimum primary air and heated to 100°F. The terminal unit supply fan and electric coil run until the zone temperature rises above 70°F.

The supply fan, compressors, condenser fan, electric heating coil, and misc accessories were all modeled separately.

Demand Controlled Ventilation:

The ventilation was scheduled to match the occupancy schedule in the building to mimic the action of a carbon dioxide sensor in the return air duct of the air handling units. The amount of out side air from the air handling unit was modulated to provide 20 cubic feet per minute (CFM) of out side air per person.

In practice the CO2 sensor would be set at 700 ppm to ensure that the air being supplied to each zone is below the levels recommended in ASHRAE 62.4-2004. While this system does not meet the requirements of ASHRAE 62.4-2004, it is a generally accepted way to modulate the ventilation air to match building occupancy. An HVAC system without DCV would leave the outside air damper minimum position constant at the ventilation rate for maximum building occupancy. This would force the HVAC system to heat and cool the outside air when the building has a low occupancy or is unoccupied.

Natural Daylighting:

Continuously dimmable ballasts on florescent lights were modeled for six lighting zones in the IAMU building model. A photo sensor located in the center of the lighting zone at the ceiling measures the lighting level of a point located directly below and 2.5 feet above the finished floor. The program calculates the lighting level and modulates the lighting power to maintain a constant 50 foot candle at the reference point. The light output is directly proportional to the energy input to the light fixture. TRACE 700 uses the same calculation algorithm as DOE-2

3.3 Energy Models

Eight different energy models were built to analyze the effects of different design features on the building performance. Table 3.3.1 lists the design features analyzed.

Table 3.3.1 Building Model Matrix

Building Alternative	Building Type	Lighting	HVAC
1	Standard Office Building	Standard	CV RTU
2	Standard Office Building	Standard	CV RTU with DCV.
3	Standard Office Building	Standard	VAV RTU with DCV
4	Standard Office Building	Standard	GSHP with DCV
5	IAMU Office Building	Natural Daylighting	CV RTU
6	IAMU Office Building	Natural Daylighting	CV RTU with DCV.
7	IAMU Office Building	Natural Daylighting	VAV RTU with DCV
8	IAMU Office Building	Natural Daylighting	GSHP with DCV

Building Alternative 1 was used as the base line to compare all the other models to.

3.4 Economic Models

In addition to the energy models done on the buildings, economic models were created to provide another reference on the buildings performance. In the eyes of a building owner this is one of the most important factors for them to make a decision.

The building fabric construction, mechanical installation, electrical installation, and yearly maintenance costs were estimated by a couple Des Moines area contractors and are with in plus or minus 10% of actual costs. See Appendix B for the budget quotes. The yearly utilities were calculated using the Mid American Energy “General Service, Electric Heat, Demand Metered - GHS” electrical rate. The rate structure can also be found in Appendix A.

To realize the full benefits of the energy efficiency of the models the maintenance and utility costs were summed up over a 20 year period. Equations 1 and 2 below were used to adjust for inflation and cost of capital. Cost of capital is the factor that all future cash flows are discounted by to bring them back to present day dollars. Inflation was set at 3% for utility rates and maintenance costs. Cost of capital was set at 10%.

$$Inflation = Cost \times 1.03^{n} \tag{1}$$

$$Cost.of.Capital = Cost \div 1.10^{n} \tag{2}$$

Where n = year number

Chapter 4: Analysis

4.1 Energy Usage

The annual energy usages for each building model are shown in Figure 4.1.1.

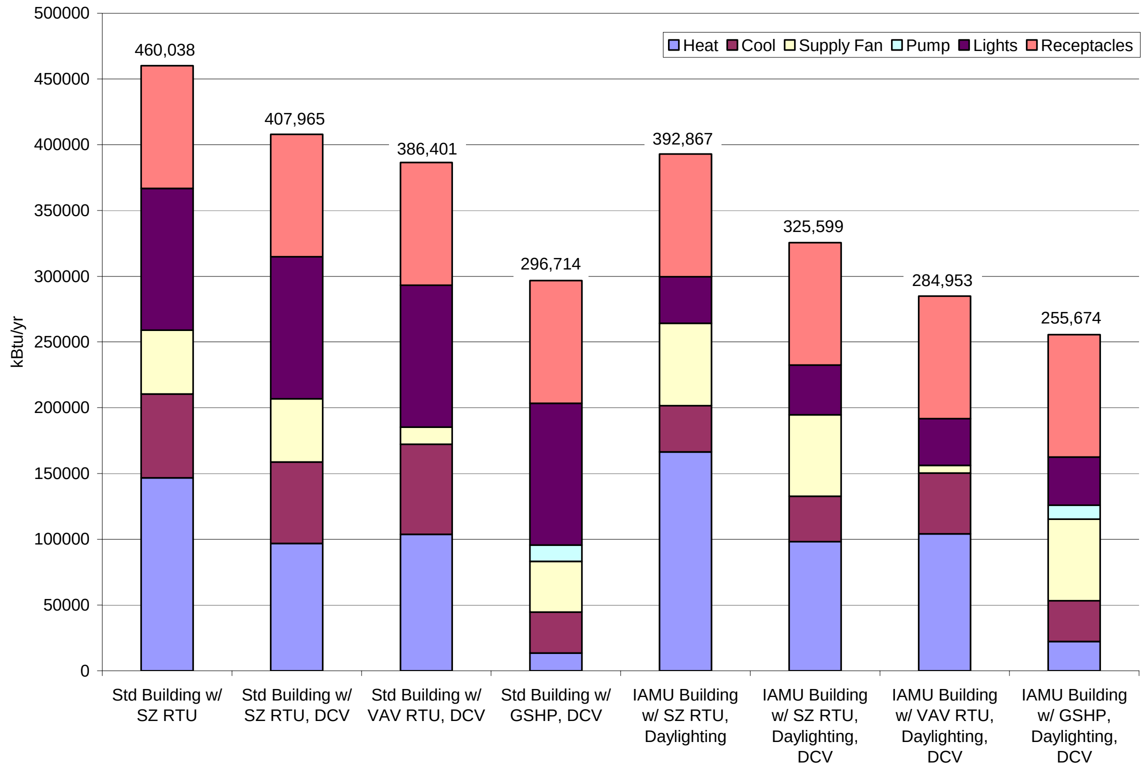

Figure 4.1.1 Annual Energy Usage

The standard office building with single zone roof top air-conditioning units uses 460,036 kBtu per year. It will be used as the base building to compare all energy saving features to. By adding CO2 sensors and matching the ventilation airflow to the actual building occupancy the building energy usage dropped 11% below the base. The addition of a variable speed supply fan dropped the energy usage to 16% below the base building. As expected the GSHP system with DCV had the lowest energy usage for the standard office building. It used 34% less energy than the base building.

From Figure 4.1.1 you can see that for the standard office building the largest constant energy user is the lights. By reconfiguring the building layout to maximize the daylighting in the building and adding a control system to dim the office lights to maintain an average lighting level of 50 foot candles, the building energy usage is significantly reduced. The single zone RTU model used 15% less energy. Adding CO2 sensors reduced the energy usage to 29% below the base. The VAV system used 38% less energy and the GSHP system used 45% less energy than the base building.

4.2 Life Cycle Cost

A cost of ownership analysis was preformed on all the building models to compare long term cost of ownership of each building model. The cost analysis includes the building construction (general, HVAC, and electrical), utility and yearly maintenance.

The building construction costs for each model are shown in figure 4.2.1.

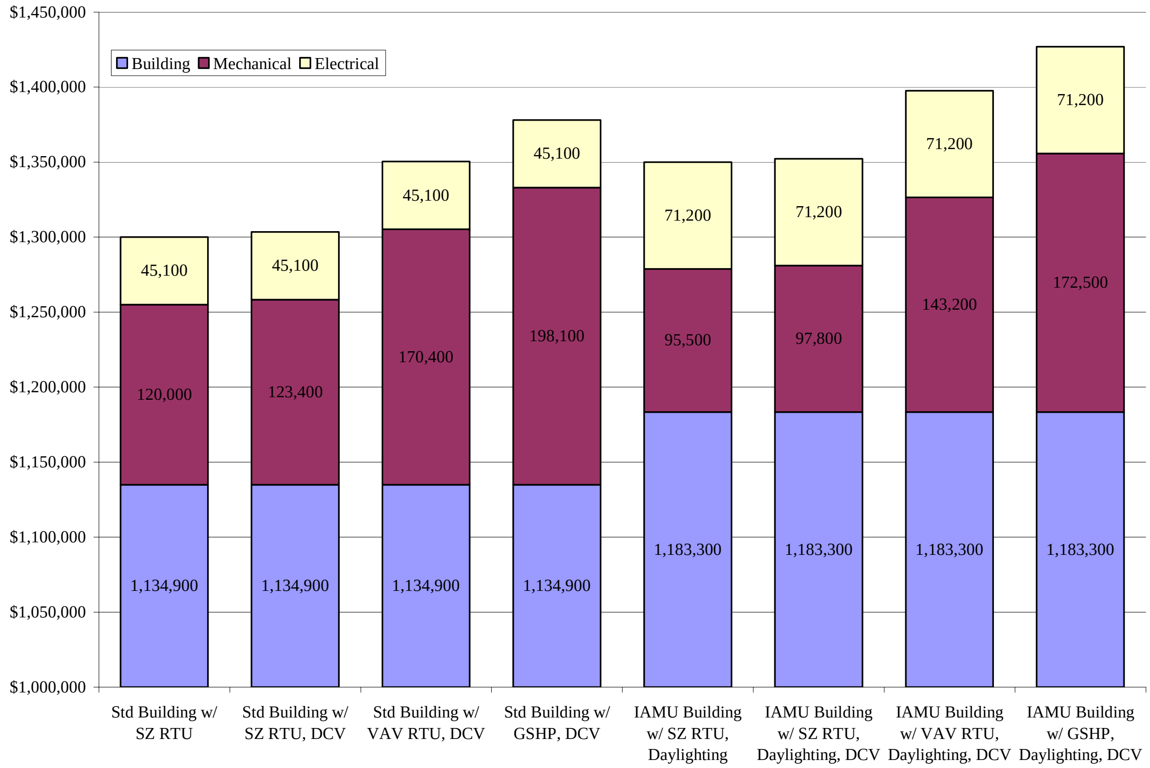

Figure 4.2.1 Building Construction Costs

The first year utility costs for each model are shown in Figure 4.2.2. As expected the trends mimic the building energy usage. They also have an exact opposite trend to the building construction costs.

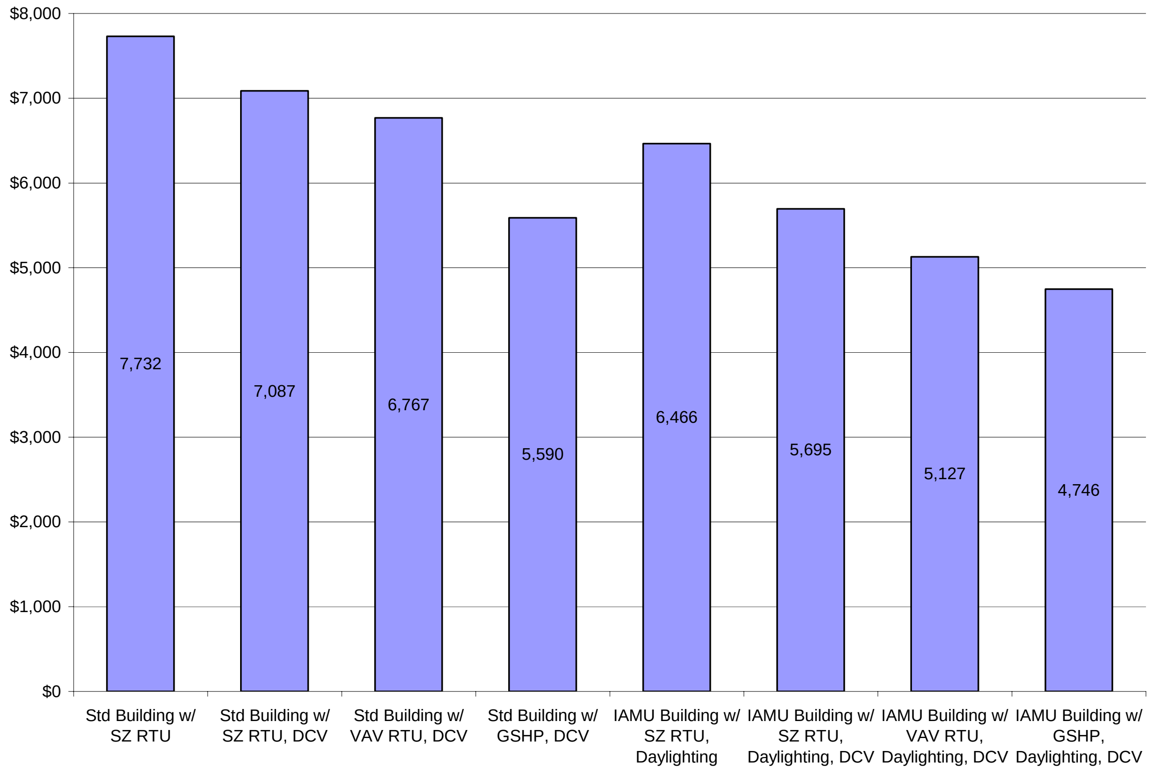

Figure 4.2.2 First Year Utility Costs

One way of looking at the total cost of ownership is to do simple payback analysis. This applies the cost of inflation (3%) to future energy, maintenance, and repair bills. Figure 4.2.3 shows the simple payback for all buildings over a 20 year period. 20 years was used because it is the average life expectancy of the major HVAC equipment and is the time when the building would most likely need to be remodeled. Around year eight the more expensive buildings to construct become cheaper to own. The winner is the standard office building with the VAV roof top air conditioning unit followed closely by the IAMU VAV system with daylighting controls.

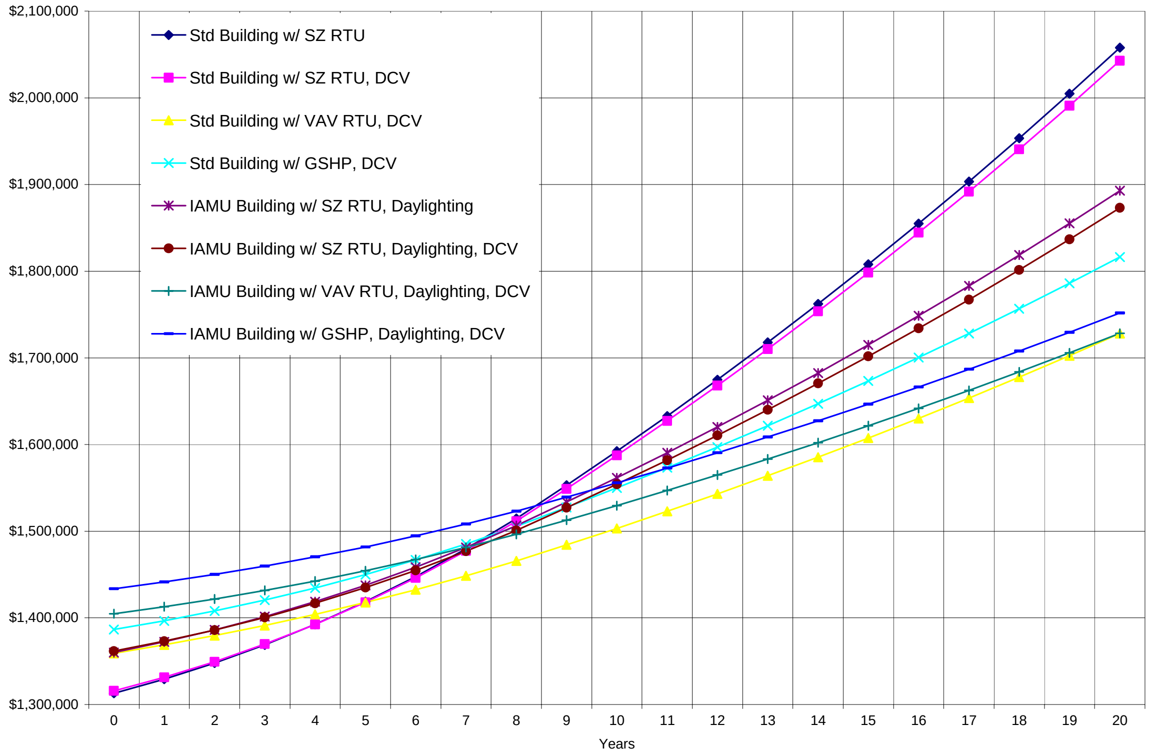

Figure 4.2.3 Simple Payback Analysis

Another way to look at the cost of ownership is convert all future payments back to today's value by calculating the cost of capital. It can be thought of as the value of money you would need today to cover all the future cost of ownership. This analysis applies a 10% cost discount for each year in the future the payment is made. Figure 4.2.3 shows the present day value of the cost of ownership.

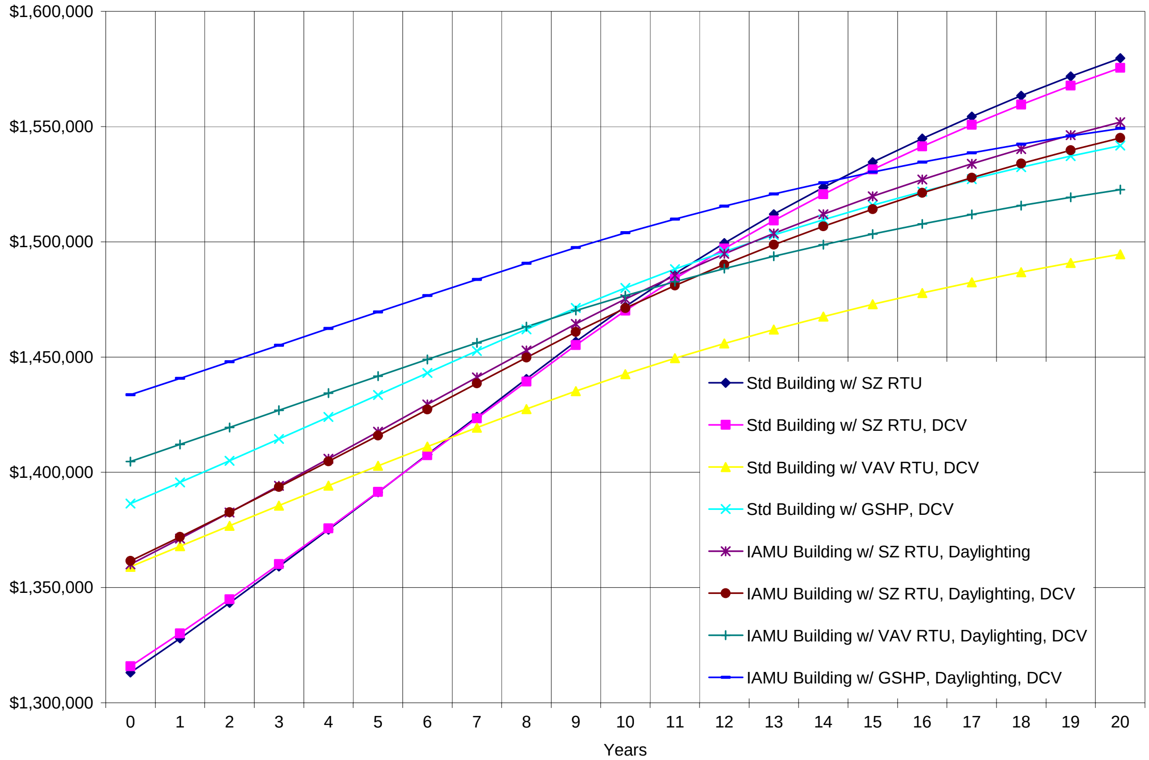

Figure 4.2.4 Present Day Value Analysis

This analysis put larger emphasis on first cost and depreciating value on future costs. Because of this, the buildings with daylighting and ground source heat pumps cost more to own even though they have lower energy usages. The clear winner with this analysis is the standard office building with VAV rooftop air conditioning. It benefits from an optimal balance between first costs and annual energy, maintenance and repair costs.

Both Simple Payback and Present Day Value analysis are often used to help a building owner decided which system is the best value for there dollar. The problem with both of these analyses is they assume the building owner has an unlimited amount of money to pay for upgrades to the base system. A better analysis is a Simple Financed

Payback analysis. This analysis assumes the building owner has a fixed amount of money that they can spend on their new building. Any system upgrade would then need to be financed and paid for by the reduced energy, maintenance and repair costs. Figure 4.2.5 shows the Simple Financed Payback analysis**.**

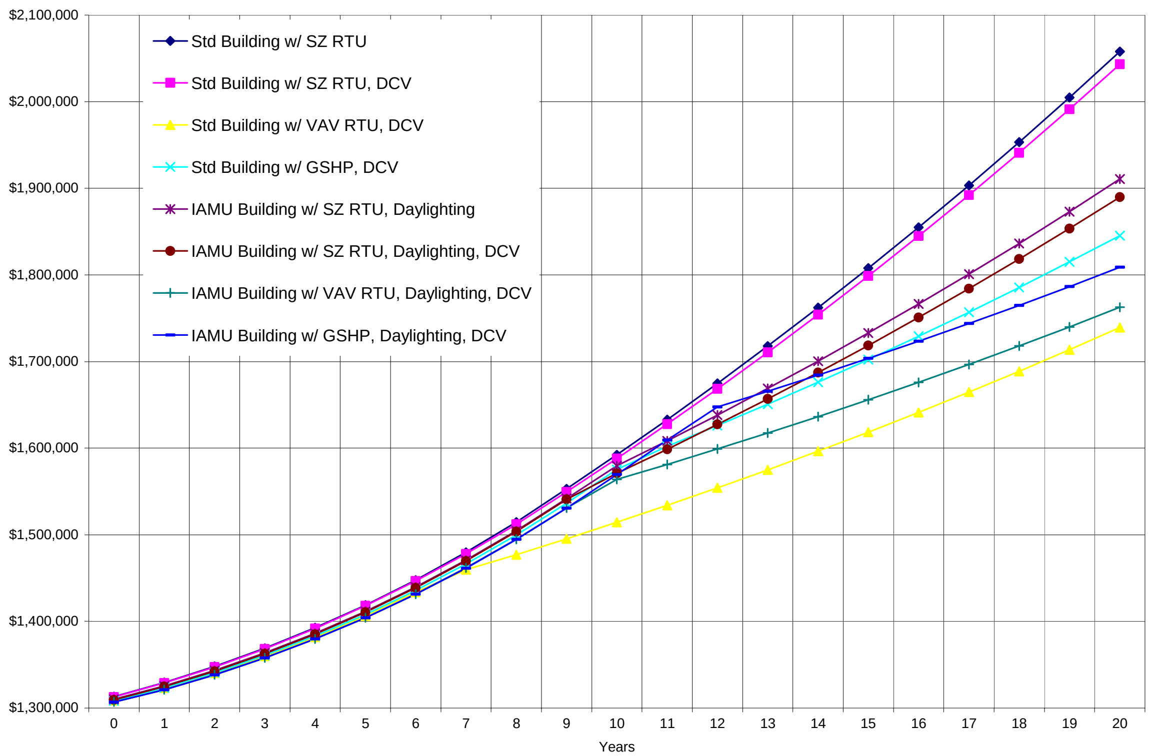

Figure 4.2.5 Simple Financed Payback Analysis

All the buildings start off at the same first costs. As the years go by all systems follow the same cash flow line. After year 7 the increased cost for the standard office building with VAV air-conditioning is paid off and diverges from the base building curve. IAMU building with VAV air-conditioning is paid off after year 10. By year 12 all of the upgrades could be paid off. This analysis shows that all buildings could be built with the same first cost.

Chapter 5: Conclusions and Recommendations

There are many factors that a building owner will have to look at to determine which type of building he should build. In the past first cost and architectural look have been the dominating factors in building choice. As the costs of energy continue to rise building owners will need to put more emphasis on energy efficiency and occupant comfort while keeping with in their budget.

There are a lot of synergies with building an energy efficient building. Energy efficient buildings usually have better indoor air quality, occupant comfort and are easier to maintain (as seen in Appendix B “Budget Quotes”). Good indoor air quality leads to less employee sick leave. High occupant comfort leads to improved worker performance. These combined with low maintenance cost will lower the long term cost of ownership of a high performing building.

The key to designing an energy efficient building is integrated design. The architect, design engineers and contractors need to be involved in all the steps of the construction process. By optimizing only the HVAC system we were able to increase the standard office building efficiency to 34% over the base building. When the building layout was optimized with the HVAC system and lighting design the IAMU building was able to increase its efficiency to 45% over the base system.

Each efficiency upgrade over the base system increased the building initial construction costs. When the reduced utility and maintenance cost were analyzed over a 20 year period, the long term cost of ownership was lower for the high performing buildings.

Appendix A: TRACE 700 Input

Table A.1 Building Construction Properties – Standard Office Building

Type	Description	U-value (Btu / hr-ft2-F)	Shading Coefficient
Roof	Metal Deck, 3” Isocaynate Insulation, 3/8” Felt Membrane, ½” Gravel Ballast	0.0555	N/A
Wall	4” Brick, 3/4” Wood Sheathing, 4” Metal Stud with Insulation, 5/8” Gypsum Board	0.0436	N/A
Window	1/4” Gray Tint, 1/2” Air Space, 1/4” Low-E	0.34	0.46

Table A.2 Building Construction Properties – IAMU Building

Type	Description	U-value (Btu / hr-ft2-F)	Shading Coefficient
Roof	Metal Deck, 3” Isocaynate Insulation, 3/8” Felt Membrane, ½” Gravel Ballast	0.0555	N/A
Wall	4” Brick, 3/4” Wood Sheathing, 4” Metal Stud with Insulation, 5/8” Gypsum Board	0.0436	N/A
Window	1/4” Clear, 1/2” Air Space, 1/4” Low-E	0.34	0.77

Table A.3 Building Internal Loads

Type	Density
People	143 ft2 / person
Lights	1.1 W / ft2
Computer	1.5 W / ft2
Ventilation	20 cfm / person

Table A.4 HVAC System Fan Energy

Type	Main Fan (kW / cfm - inwg)	Secondary Fan (kW / cfm - inwg)	Exhaust Fan (kW / cfm - inwg)
CV RTU	0.000357 @ 1 inwg	N/A	N/A
VAV RTU	0.000390 @ 1.5 inwg	.000378 @ 0.375 inwg	0.000390 @ 0.1 inwg
GSHP	0.000357 @ 1 inwg	N/A	N/A

Table A.5 HVAC Plant Energy

Type	Cooling	Heating
CV RTU	12 SEER	100 %
VAV RTU	9.5 EER, 9.7 IPLV	100%
GSHP	13.4 EER	Heat Pump 3.1 COP Electric Backup 100%

Table A.6 Mid American Energy GHS Utility Rate

	June - September	October - May
Service Charge	$80.00	$80.00
First 250 hours x kW of demand	$0.07207 / kWh	$0.04107 / kWh
Next 150 hours x kW of demand	$0.02907 / kWh	$0.02527 / kWh
Additional kWh	$0.01957 / kWh	$0.01957 / kWh

Appendix B: Budget Quotes

Construction Services, Inc.
Consulting • Construction Management

February 27, 2008

Alan Gudenkauf
The Waldinger Corporation
2601 Bell Avenue
Des Moines, Iowa 50321

Dear Alan,

In response to your request, we did a comparison of similar building types.

The parameters of each building were as follows: single story office building, with brick veneer and a strip of windows 5' tall around the perimeter. Balance of construction was of a typical office construction, somewhat like the R&R facilities in which our office is presently located.

One building is to be 100' x 100' while the other consists of two 100' x 50'.

Below is the analysis:

1. Single story 100' x 100' office building with typical finishes, with 5' band of glass: 10,000 SF @ $130/SF = $1,300,000.
2. Single story 100' x 50' office building with typical finishes, with 5' band of glass: 2 x 5,000 SF @ $135/SF = $1,350,000.

Each price is approximate in nature and includes MEP work in its totals.

If you have any questions, please do not hesitate to call.

Sincerely,
Construction Services, Inc.

Steve Bennett
President

1225 Jordan Creek Parkway • Suite 200 • West Des Moines, IA 50266 • 515.223.4518 • Fax: 515.223.7235 • Web: csiresults.com

THE WALDINGER CORPORATION

2601 BELL AVENUE / P.O. BOX 1612 / DES MOINES, IOWA 50306 / PHONE 515-284-1911 / FAX 515-323-5150

February 11, 2008

(To) Adam Gudenkauf

Reference: Thesis
Mechanical Proposal

Gentlemen:

Thank you for the opportunity to submit this budget to perform the mechanical installation for the referenced project. Our proposal includes the HVAC and plumbing work as described on your drawings, with the following clarifications.

<u>Alternate 1: Standard Light Commercial Office Building</u>

1. Purchase and install Nine (9) roof top air conditioning units with electric heat.
2. Purchase and install all supply and return air grilles.
3. Manufacture and install supply and return ductwork. All ductwork will be lined with one inch insulation.
4. Purchase and install programmable thermostats and control wiring for all roof top air conditioning units.

<u>Alternate 2: Standard Light Commercial Office Building with CO2 Monitoring</u>

1. Purchase and install Nine (9) roof top air conditioning units with electric heat.
2. Purchase and install all supply and return air grilles.
3. Manufacture and install supply and return ductwork. All ductwork will be lined with one inch insulation.
4. Purchase and install programmable thermostats and control wiring for all roof top air conditioning units.
5. Purchase and install wall mounted carbon dioxide sensors and control wiring for all roof top air conditioning units.

Alternate 3: Standard Light Commercial Office Building with Fan Powered VAV System and CO_2 Monitoring

1. Purchase and install one (1) VAV roof top air conditioning unit.
2. Purchase and install twelve (12) fan powered VAV terminal units with electric heat.
3. Purchase and install all supply and return air grilles.
4. Manufacture and install supply and return ductwork. All ductwork will be lined with one inch insulation.
5. Purchase and install DDC system and control wiring for the VAV roof top air conditioning unit and terminal units.
6. Purchase and install duct mounted carbon dioxide sensors and control wiring for the roof top air conditioning unit.

Alternate 4: Standard Light Commercial Office Building with GSHP and CO_2 Monitoring

1. Purchase and install Nine (9) ground source heat pumps with electric heat.
2. Purchase and install all supply and return air grilles.
3. Manufacture and install supply and return ductwork. All ductwork will be lined with one inch insulation.
4. Purchase and install programmable thermostats and control wiring for all heat pumps.
5. Purchase and install wall mounted carbon dioxide sensors and control wiring for all heat pumps.
6. Purchase and install one (1) ground loop distribution pump.
7. Hire subcontractor to drill twenty five (25) 200 foot closed loop heat pump wells.
8. Purchase and install 30% ethylene glycol solution for ground loop.

Alternate 5: IAMU Office Building with Daylighting Control

1. Purchase and install six (6) roof top air conditioning units with electric heat.
2. Purchase and install all supply and return air grilles.

3. Manufacture and install supply and return ductwork. All ductwork will be lined with one inch insulation.

4. Purchase and install programmable thermostats and control wiring for all roof top air conditioning units.

Alternate 6: IAMU Office Building with Daylighting Control and CO2 Monitoring

1. Purchase and install six (6) roof top air conditioning units with electric heat.

2. Purchase and install all supply and return air grilles.

3. Manufacture and install supply and return ductwork. All ductwork will be lined with one inch insulation.

4. Purchase and install programmable thermostats and control wiring for all roof top air conditioning units.

Alternate 7: IAMU Office Building with Daylighting Control, Fan Powered VAV System and CO2 Monitoring

1. Purchase and install one (1) VAV roof top air conditioning unit.

2. Purchase and install six (6) fan powered VAV terminal units with electric heat.

3. Purchase and install all supply and return air grilles.

4. Manufacture and install supply and return ductwork. All ductwork will be lined with one inch insulation.

5. Purchase and install DDC system and control wiring for the VAV roof top air conditioning unit and terminal units.

6. Purchase and install duct mounted carbon dioxide sensors and control wiring for the roof top air conditioning unit.

Alternate 4: IAMU Office Building with Daylighting Control, GSHP and CO2 Monitoring

1. Purchase and install six (6) ground source heat pumps with electric heat.

2. Purchase and install all supply and return air grilles.

3. Manufacture and install supply and return ductwork. All ductwork will be lined with one inch insulation.

4. Purchase and install programmable thermostats and control wiring for all heat pumps.
5. Purchase and install wall mounted carbon dioxide sensors and control wiring for all heat pumps.
6. Purchase and install one (1) ground loop distribution pump.
7. Hire subcontractor to drill twenty five (25) 200 foot closed loop heat pump wells.
8. Purchase and install 30% ethylene glycol solution for ground loop.

Your cost for this work is:

Alternate 1: One Hundred Twenty Thousand Dollars ($ 120,000.00).

Alternate 2: One Hundred Twenty Three Thousand Dollars ($ 123,000.00).

Alternate 3: One Hundred Seventy Thousand, Four Hundred Dollars ($ 170,400.00).

Alternate 4: One Hundred Ninety Eight Thousand, One Hundred Dollars ($ 198,100.00).

Alternate 5: Ninety Five Thousand, Five Hundred Dollars ($ 95,500.00).

Alternate 6: Ninety Seven Thousand, Eight Hundred Dollars ($ 97,800.00).

Alternate 7: One Hundred Forty Three Thousand, Two Hundred Dollars ($ 143,200.00).

Alternate 8: One Hundred Seventy Two Thousand, Five Hundred Dollars ($ 172,500.00).

We appreciate your considering this proposal and look forward to the opportunity to work with you. If you need additional information, please call.

Sincerely,

Jeff Johnson
Project Manager

THE WALDINGER CORPORATION

2601 BELL AVENUE / P.O. BOX 1612 / DES MOINES, IOWA 50306 / PHONE 515-284-1911 / FAX 515-323-5150

February 11, 2008

(To) Adam Gudenkauf

Reference: Thesis
Electrical Proposal

Gentlemen:

We're pleased to submit this proposal to budget the electrical installation for the referenced project. We include work described on your drawings, with the following clarifications.

<u>Standard Light Commercial Office Building</u>

1. Purchase and install one hundred twenty (120) three bulb lamps with dimmable ballasts to provide an average of 50 foot candles.
2. Purchase one (1) 460 volt 3 phase electrical panel.
3. Purchase and install electrical wiring and conduit to one hundred twenty (120) lamps.
4. Purchase and install electrical wiring and conduit to all HVAC equipment.

<u>IAMU Office Building</u>

1. Purchase and install one hundred twenty (120) three bulb lamps with dimmable ballasts to provide an average of 50 foot candles.
2. Purchase and install six (6) photo sensors.
3. Purchase and install daylighting control system with six (6) lighting zones.
4. Purchase and install control wiring for lighting control system.
5. Purchase one (1) 460 volt 3 phase electrical panel.
6. Purchase and install electrical wiring and conduit to one hundred twenty (120) lamps.
7. Purchase and install electrical wiring and conduit to all HVAC equipment.

THE WALDINGER CORPORATION

Your cost for this work is:

Standard Light Commercial Office Building: Seventy One Thousand, Two Hundred Dollars ($ 71,200.00).

IAMU Office Building: Forty Five Thousand, One Hundred Dollars ($ 45,100.00).

We appreciate your considering this proposal and look forward to the opportunity to work with you. If you need additional information, please call.

Sincerely,

Joe Ingersoll
Project Manger

THE WALDINGER CORPORATION

2601 BELL AVENUE / P.O. BOX 1612 / DES MOINES, IOWA 50306 / PHONE 515-284-1911 / FAX 515-323-5150

February 11, 2008

(To) Adam Gudenkauf

Reference: Thesis
Maintenance Proposal

Gentlemen:

Thank you for the opportunity to submit this budget to perform the preventative maintenance for the referenced project. Our proposal includes the HVAC and plumbing equipment as described on your drawings, with the following clarifications.

The preventive maintenance annual budget numbers below reflect quarterly inspections, quarterly filter changes, annual belt change, and annual condenser cleaning.

<u>Alternate 1 & 2: Standard Light Commercial Office</u>

1. Qty(9) all electric roof top air conditioning units.

<u>Alternate 3: Standard Light Commercial Office with Fan Powered VAV System</u>

1. Qty(1) cooling only VAV roof top air conditioning unit.

<u>Alternate 4: Standard Light Commercial Office with GSHP</u>

1. Qty(9) all electric ground source heat pumps.
2. Quarterly inspection of ground loop pump.

<u>Alternate 5 & 6: IAMU Office Building with Daylighting Control</u>

1. Qty(6) all electric roof top air conditioning units.

<u>Alternate 7: IAMU Office Building with Fan Powered VAV System and Daylighting Control</u>

1. Qty(1) cooling only VAV roof top air conditioning unit.

THE WALDINGER CORPORATION

Alternate 8: IAMU Office Building with GSHP and Daylighting Control

1. Qty(6) all electric ground source heat pumps.
2. Quarterly inspection of ground loop pump.

Your cost for this work is:

Alternate 1 & 2: Five Thousand, Four Hundred Dollars ($ 5,400.00).

Alternate 3: One Thousand, Eight Hundred Fifty Dollars ($ 1,850.00).

Alternate 4: Two Thousand, Eight Hundred Dollars ($ 2,800.00).

Alternate 5 & 6: Three Thousand, Six Hundred Dollars ($ 3,600.00).

Alternate 7: One Thousand, Eight Hundred Fifty Dollars ($ 1,850.00).

Alternate 8: One Thousand, Nine Hundred Dollars ($ 1,900.00).

Any repair cost for the first year will be covered under the equipments warranty agreement. For budgetary purposes your average repair costs for the second through tenth year will vary proportionally from one half to three times the yearly maintenance cost. The average repair cost for the remaining years will be three times the maintenance cost.

We appreciate your considering this proposal and look forward to the opportunity to work with you. If you need additional information, please call.

Sincerely,

Matt Larsen
Maintenance Project Manager

References

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