

## Net Zero Private Residence Case Study

DMA Engineering is a Mechanical, Electrical, and Plumbing engineering firm based in the Denver Metro area. Our main clientele is the million dollar residential and light commercial. We were recently contracted by Harrison Custom Builders Ltd. to design a ground source heat pump system and solar thermal system for a private residence in Denver, Colorado. The residence also has a solar photo voltaic (PV) system that was a design-build. The results of our analysis show that the home will be net zero or fairly close to net zero depending on the final usage. We have performed an energy analysis between our systems and more conventional systems to develop energy usage and payback schedules.

The home being highly efficient has short payback periods but also attractive internal rate of returns. Not only is the home environmentally friendly it is also financially attractive.

The parameters of the home are:

- Approximately 6143 square feet with three floors including basement. The home has 5 bedrooms with 5 ½ baths. The maximum heating load is 57,900 Btu/h and the maximum cooling load is 47,200 Btu/h.
- The home is heated using a radiant floor system and cooled with hydronic fan coils.
- 3 Adult occupants and one child with 120 gallons of domestic hot water usage per day.
- One 2000 gallon outdoor pool on a May 15<sup>th</sup> to September 15<sup>th</sup> Schedule. Pool set point is 85°F.
- One 300 gallon outdoor spa on yearly schedule. Spa set point is 104°F.
- LED lighting, 1 Watt per square foot lighting density.

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Based upon these parameters we designed a system with the following:

- ✓ 8-ton ground source heat pump (GSHP)
- ✓ Ground loop heat exchanger with six 300 foot boreholes.
- ✓ 3 solar thermal panels
- ✓ 18 radiant zones, with one radiant wall
- ✓ 2 energy recovery ventilators, (ERV's)

The Solar PV contractor installed a 9.9 KW system.

### **Building Heating and Cooling Energy Analysis**

We ran two competing energy models through Trane's TRACE 700 design software to develop the energy usage of the home excluding hot water usage, pool and spa heating.

We did not perform a HERS rating as the customer isn't concerned with a LEED or Energy Star rating. They were only concerned with having the highest efficiency home along with the lowest possible energy bill. This is typical of our clientele.

The model included the electrical usage of appliances including lighting, computers and televisions.

One model was for a condensing boiler with an efficiency of 93% and DX split system with an EER of 11. The second was for the ground source heat pump system with a COP of 3.5 and an EER of 19. The results of the analysis are given below:

## MONTHLY ENERGY CONSUMPTION

By DMA Engineering

21,776 KWh

—— Monthly Energy Consumption ——

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
<b>Alternative: 1 Harrison Geothermal</b>													
<b>Electric</b>													
On-Pk Cons. (kWh)	1,628	1,489	1,513	1,569	1,951	2,058	2,545	2,288	1,972	1,692	1,479	1,592	21,776
On-Pk Demand (kW)	4	3	3	3	4	5	5	5	4	3	3	3	5

Energy Consumption	
Building	12,099 Btu/(ft <sup>2</sup> -year)
Source	36,300 Btu/(ft <sup>2</sup> -year)
Floor Area	6,143 ft <sup>2</sup>

Environmental Impact Analysis	
CO2	43,249 lbm/year
SO2	58 gm/year
NOX	65 gm/year

30,109 KWh

<b>Alternative: 2 HARRISION BOILER</b>													
<b>Electric</b>													
On-Pk Cons. (kWh)	2,127	1,918	2,089	2,008	2,743	2,954	3,754	3,328	2,802	2,253	1,946	2,186	30,108
On-Pk Demand (kW)	4	4	4	4	7	8	8	8	7	5	4	4	8
<b>Gas</b>													
On-Pk Cons. (therms)	23	24	6	0	0	0	0	0	0	0	1	14	69
On-Pk Demand (therms/hr)	0	0	0	0	0	0	0	0	0	0	0	0	0

Energy Consumption	
Building	17,858 Btu/(ft <sup>2</sup> -year)
Source	51,379 Btu/(ft <sup>2</sup> -year)
Floor Area	6,143 ft <sup>2</sup>

Environmental Impact Analysis	
CO2	63,837 lbm/year
SO2	86 gm/year
NOX	96 gm/year

69 Therms

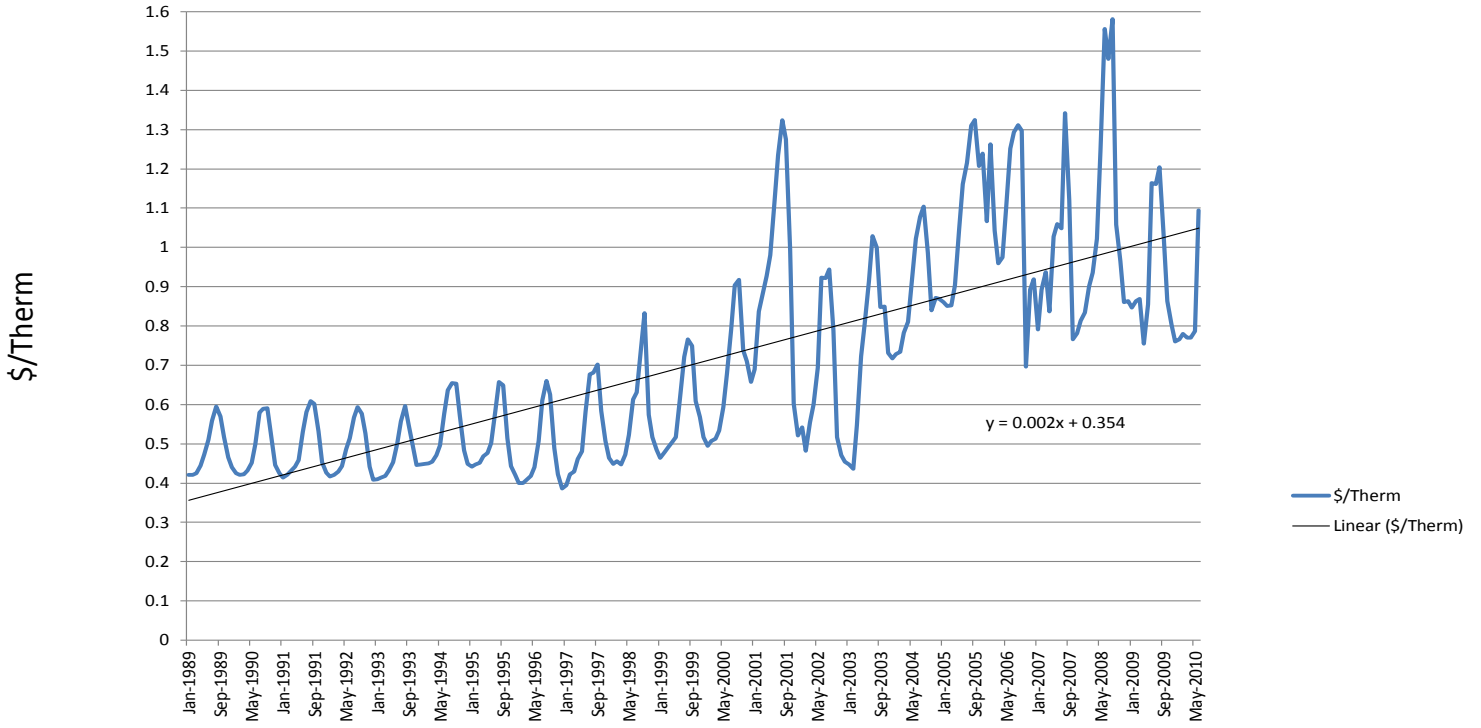
Project Name: Harrison  
Dataset Name: HARRISION FOR PAY BACKS.trc

TRACE® 700 v6.2.5 calculated at 10:51 AM on 10/24/2010  
Alternative - 2 Monthly Energy Consumption report Page 1 of 1

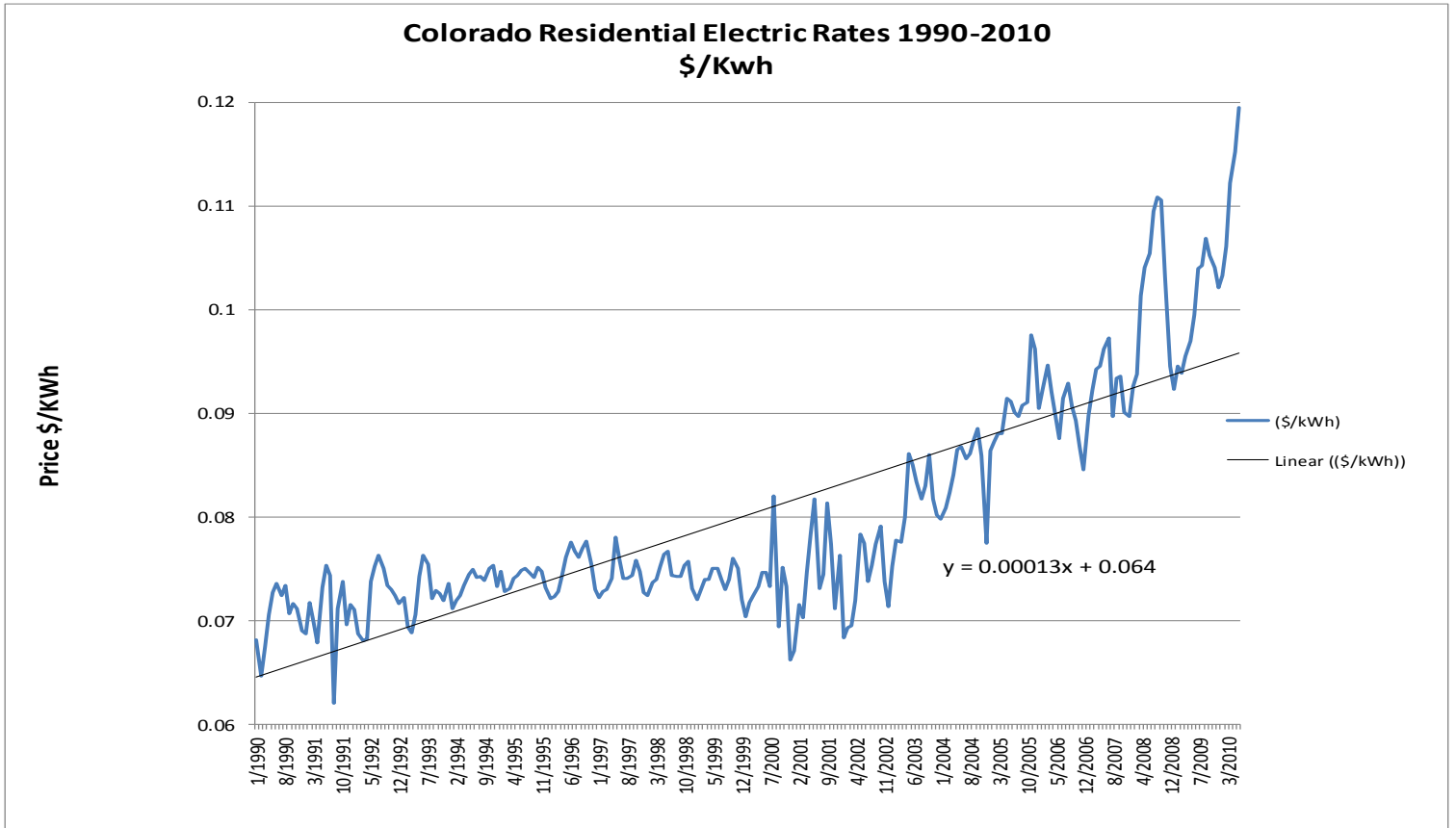
## Energy Costs

All energy costs are evaluated on annual average utility costs for the Denver area. Due to the highly fluctuating energy prices a 4 year average is used, see graphs 1 and 2.

**Colorado Residential Natural Gas Prices 1989-2010**  
**\$/Therm**



Graph 1



Graph 2

The 4 year monthly average values are:

Colorado Average Utility Costs													
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Average
Natural Gas Prices (\$/Therm)	\$ 0.81	\$ 0.86	\$ 0.88	\$ 0.85	\$ 0.98	\$ 1.26	\$ 1.25	\$ 1.36	\$ 1.13	\$ 0.82	\$ 0.83	\$ 0.84	\$ 0.84
Electricity Cost (\$/KWh)	\$ 0.09	\$ 0.10	\$ 0.10	\$ 0.10	\$ 0.10	\$ 0.10	\$ 0.10	\$ 0.10	\$ 0.10	\$ 0.10	\$ 0.10	\$ 0.10	\$ 0.10

The annual energy cost for each system is given in the cart below:

Boiler A/C system Utility Usage and Costs														
Boiler/AC (KWh)	2,127	1,918	2,089	2,008	2,743	2,954	3,754	3,328	2,802	2,253	1,946	2,186	30,108	
Boiler/AC Electrical Cost	\$199.99	\$182.38	\$203.03	\$201.77	\$281.82	\$309.47	\$373.72	\$341.94	\$288.00	\$225.44	\$187.76	\$210.51	\$3,005.82	
Boiler/AC (Therms)	24	24	6	0	0	0	0	0	0	0	1	14	69	
Boiler/AC Gas Cost	\$19.44	\$20.62	\$5.27	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.83	\$11.75	\$57.91	
													Total=	\$3,063.73

Geothermal System Utility Usage and Costs														
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Totals	
GSHP (KWh)	1,628	1,489	1,514	1,571	1,957	2,066	2,560	2,299	2,066	1,724	1,479	1,592	21,945	
GSHP Electrical Cost	\$153.07	\$141.59	\$147.15	\$157.86	\$201.06	\$216.44	\$254.85	\$236.22	\$212.35	\$172.51	\$142.70	\$153.31	\$2,189.10	
													Total=	\$2,189.10

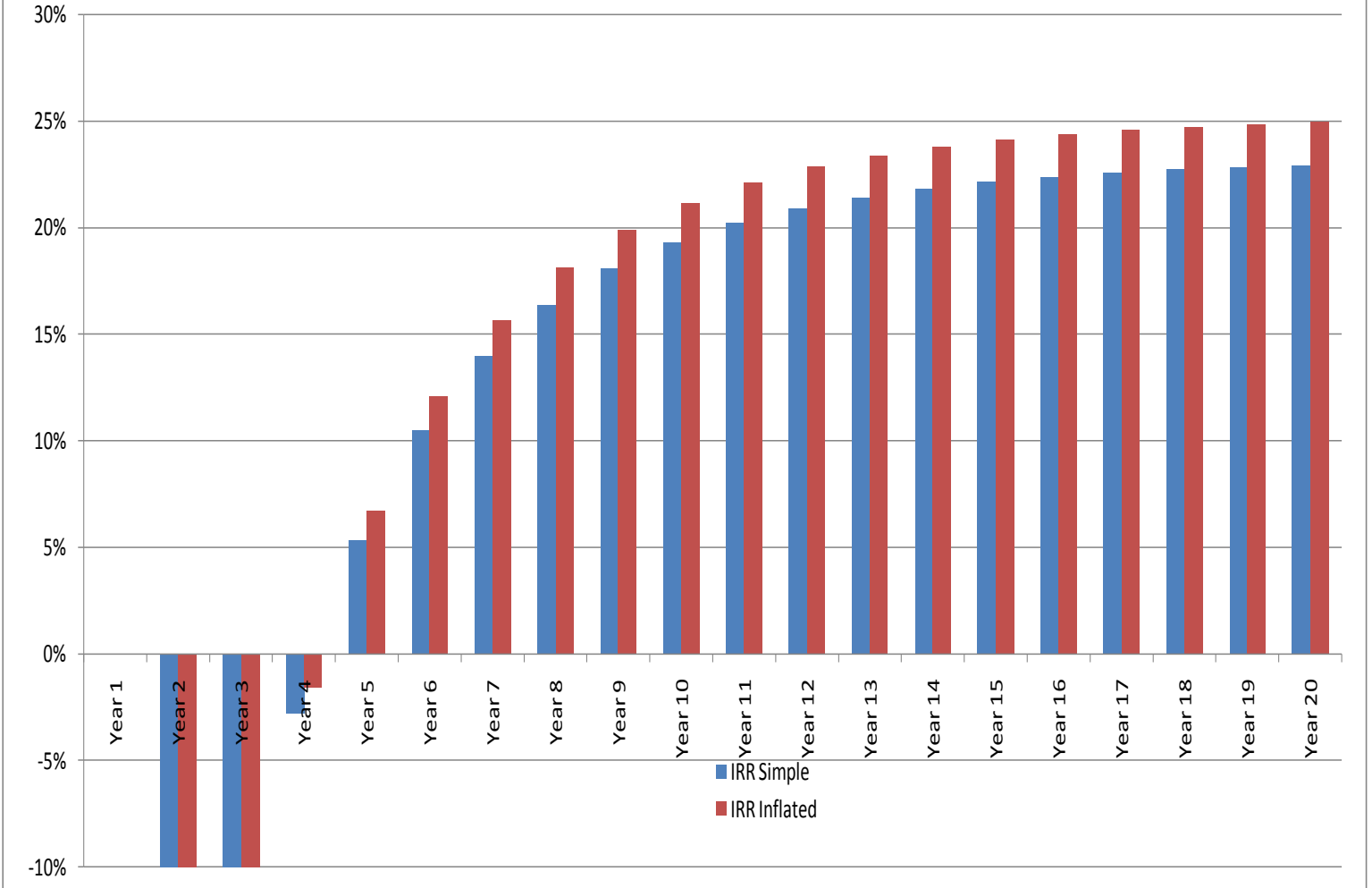
The installed cost of the geothermal system and the boiler system are:

GSHP	
Annual Electrical Usage (KWh)=	21,945
Annual Energy Cost=	\$ 2,189.10
Cost of Geothermal System Installed=	\$ 142,650.00
Federal Tax Credit=	\$ (42,795.00)
Cost of Geothermal System Installed with 30% Tax Credit=	\$ 99,855.00
Difference in Cost of Systems=	\$3,755.00
Annual Energy Savings=	\$874.63
Natural Gas Inflation Rate=	3.0%
Electricity Inflation Rate=	2.0%

BOILER / AC UNIT	
Annual Natural Gas Usage (Therms)=	69.00
Annual Energy Cost of Natural Gas=	\$ 57.91
Annual Electricity Usage (KWh)=	30108.00
Annual Energy Cost of Electricity=	\$ 3,005.82
Cost of System Installed=	\$96,100.00
Annual Energy Cost=	\$3,063.73

The payback and the internal rate of return of the geothermal system are given in the chart below:

## Internal Rate of Return For Geothermal



## Domestic Hot Water

The federal tax credit only applies to domestic hot water for solar thermal heating. The solar thermal system was designed using T\*SOL to provide the majority of the domestic hot water heating all year round and about 10% of the space heating in the winter. The geothermal system is considered as the backup system for the solar thermal system.

We added the energy costs and installation costs into the geothermal system and developed installation costs and pay back schedule. The solar thermal consists of two panels, one 120 gallon tank and 2 pumps. The installed costs are given in the table below:

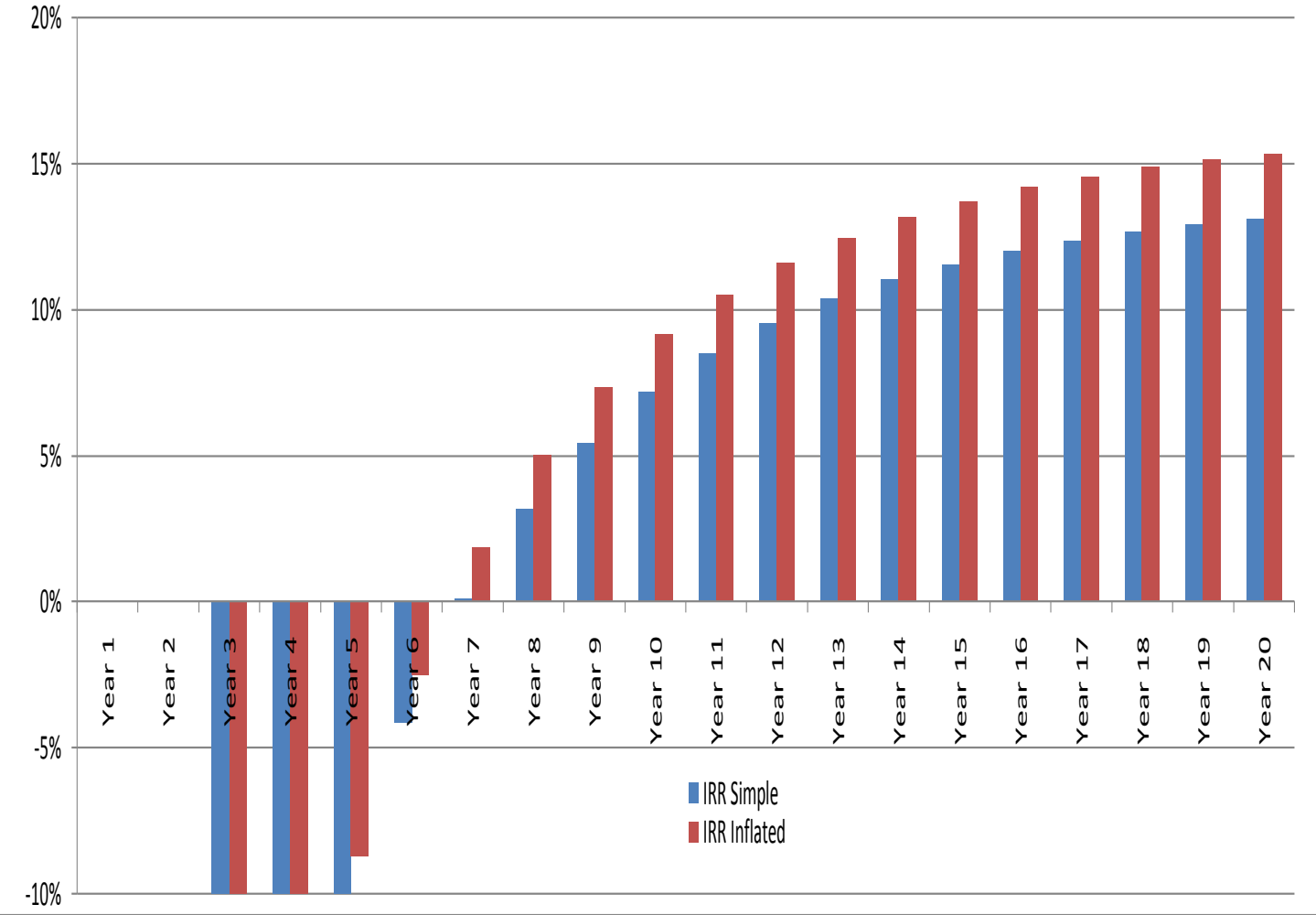
<b>GSHP/Solar Thermal</b>	
Annual Electrical Usage (KWh)=	21,972
Annual Energy Cost=	\$ 2,215.93
Cost of Geothermal/Solar Thermal System Installed=	\$ 150,300.00
Federal Tax Credit=	\$ (45,090.00)
Cost of Geothermal/Solar Thermal System Installed with 30% Tax Credit=	\$ 105,210.00
Difference in Cost of Systems=	\$7,960.00
Annual Energy Savings=	\$1,141.96
Natural Gas Inflation Rate=	3.0%
Electricity Inflation Rate=	2.0%

<b>BOILER / AC UNIT</b>	
Annual Natrual Gas Usage (Therms)=	366.48
Annual Energy Cost of Natural Gas=	\$ 352.07
Annual Electricity Usage (KWh)=	30108.00
Annual Energy Cost of Electricity=	\$ 3,005.82
Cost of System Installed=	\$97,250.00
Annual Energy Cost=	\$3,357.89

The payback and the internal rate of return of the geothermal and solar thermal system are given in the chart below:



# Internal Rate of Return For Geothermal/Solar Thermal DHW



## Spa and Pool

Again we used T\*SOL and in house spreadsheets to model the spa and pool energy requirements. The pool and spa's heating requirements are to be met mainly with the solar thermal. The pool schedule provides additional summer hot water storage that allows a better yearly solar fraction. With the addition of one panel to the existing solar thermal system we are able to meet the pool and spa heating requirements. The geothermal system will be the backup to the solar thermal system and we have added one additional bore hole to the geothermal system to allow for this.

The spa and pool energy requirements are given in the table below:

Boiler													
Spa, Pool Heating (Therms)	64.111	56.477	60.398	53.976	95.36	102.799	73.9104	85.8526	78.161	53.1365	58.168	64.415	847
Spa, Pool Heating Gas Cost=	\$58.67	\$54.82	\$59.92	\$51.60	\$105.56	\$146.06	\$104.01	\$131.90	\$99.45	\$49.37	\$54.86	\$61.10	\$977.32
Geothermal/Solar Thermal System Utility Usage and Costs													
Spa, Pool Heating Solar Thermal (KWh)	75.546	75.546	75.546	75.546	75.546	75.546	75.546	75.546	75.546	75.546	75.546	75.546	907
Spa, Pool Heating Solar Thermal Cost=	\$7.10	\$7.18	\$7.34	\$7.59	\$7.76	\$7.91	\$7.52	\$7.76	\$7.76	\$7.56	\$7.29	\$7.28	\$90.07

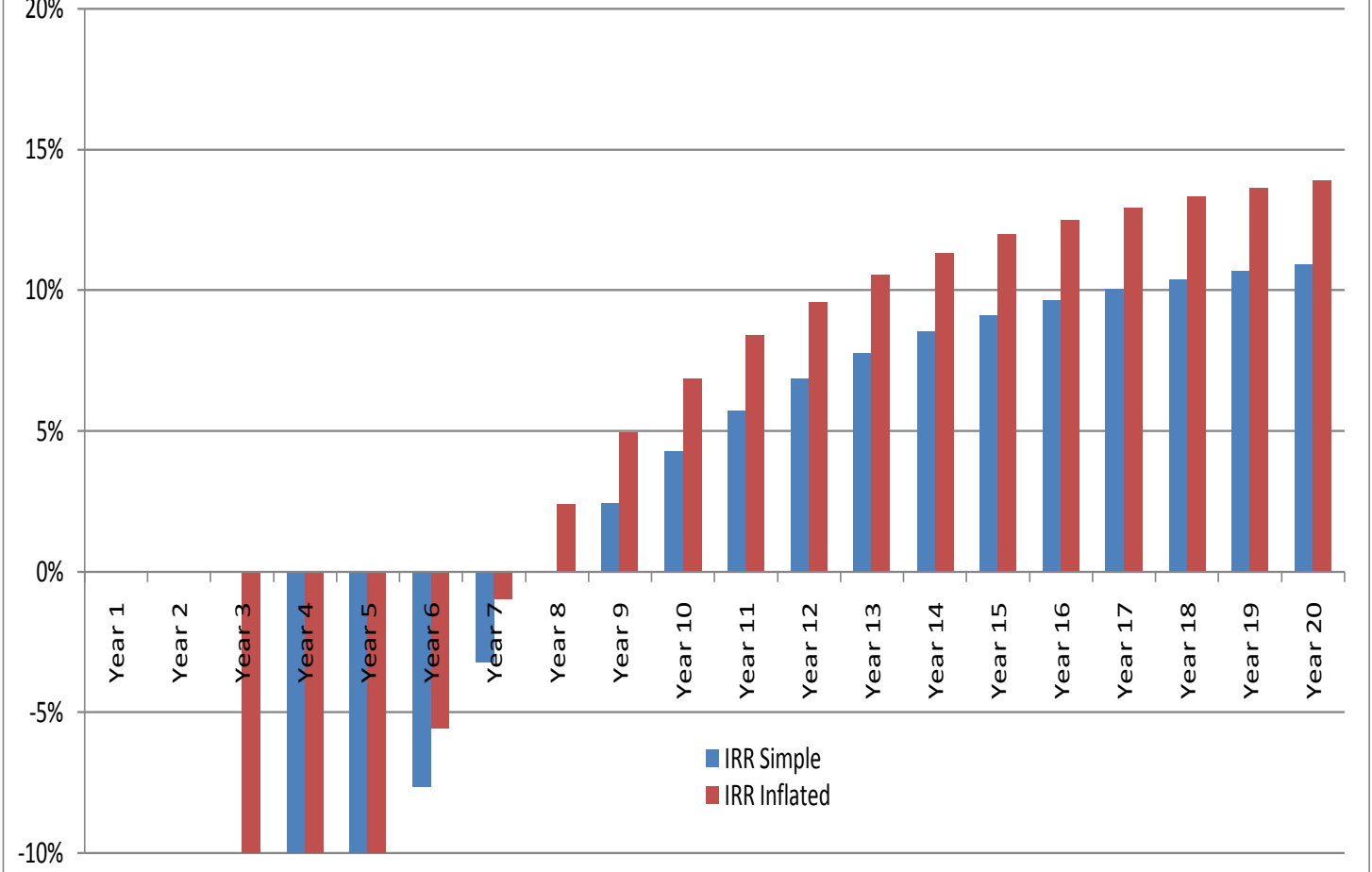
Since the geothermal and solar thermal systems are already designed to be in place we are only considering the incremental cost for the pay back schedule. We are not applying the federal tax credit to the system because it doesn't apply to solar thermal pool heating. The installed costs are given in the chart below:

GSHP/Solar Thermal	
Annual Electrical Usage (KWh)=	907
Annual Energy Cost=	\$ 90.07
Cost of Geothermal System Installed=	\$ 10,250.00
Federal Tax Credit=	\$ -
Cost of Geothermal System Installed with 30% Tax Credit=	\$ 10,250.00
Difference in Cost of Systems=	\$7,100.00
Annual Energy Savings=	\$887.26
Natural Gas Inflation Rate=	3.0%
Electricity Inflation Rate=	2.0%

BOILER / AC UNIT	
Annual Natural Gas Usage (Therms)=	846.76
Annual Energy Cost of Natural Gas=	\$ 977.32
Annual Electricity Usage (KWh)=	0.00
Annual Energy Cost of Electricity=	\$ -
Cost of System Installed=	\$3,150.00
Annual Energy Cost=	\$977.32

The payback and the internal rate of return of the geothermal and solar thermal system are given in the chart below:

## Internal Rate of Return For Geothermal/Solar Thermal for Spa and Pool Heating



### Solar Photo Voltaic System

The solar PV system is 9.9KW of dc power with an AC output of 9.4 KW. Based upon an average solar day of 6 hours the PV plant will produce annually 20,597 KWh of electricity. This is less than 21,776 KWh of energy the TRACE model predicted. The TRACE model isn't modeling the solar thermal system. When the pool is out of season the solar thermal system will have extra capacity that

can contribute to the heating of the home, approximately 2,420 KWh. This will reduce the heating requirement of the ground source heat pump system and thus reduces the electrical requirement making the home net zero or very nearly net zero.

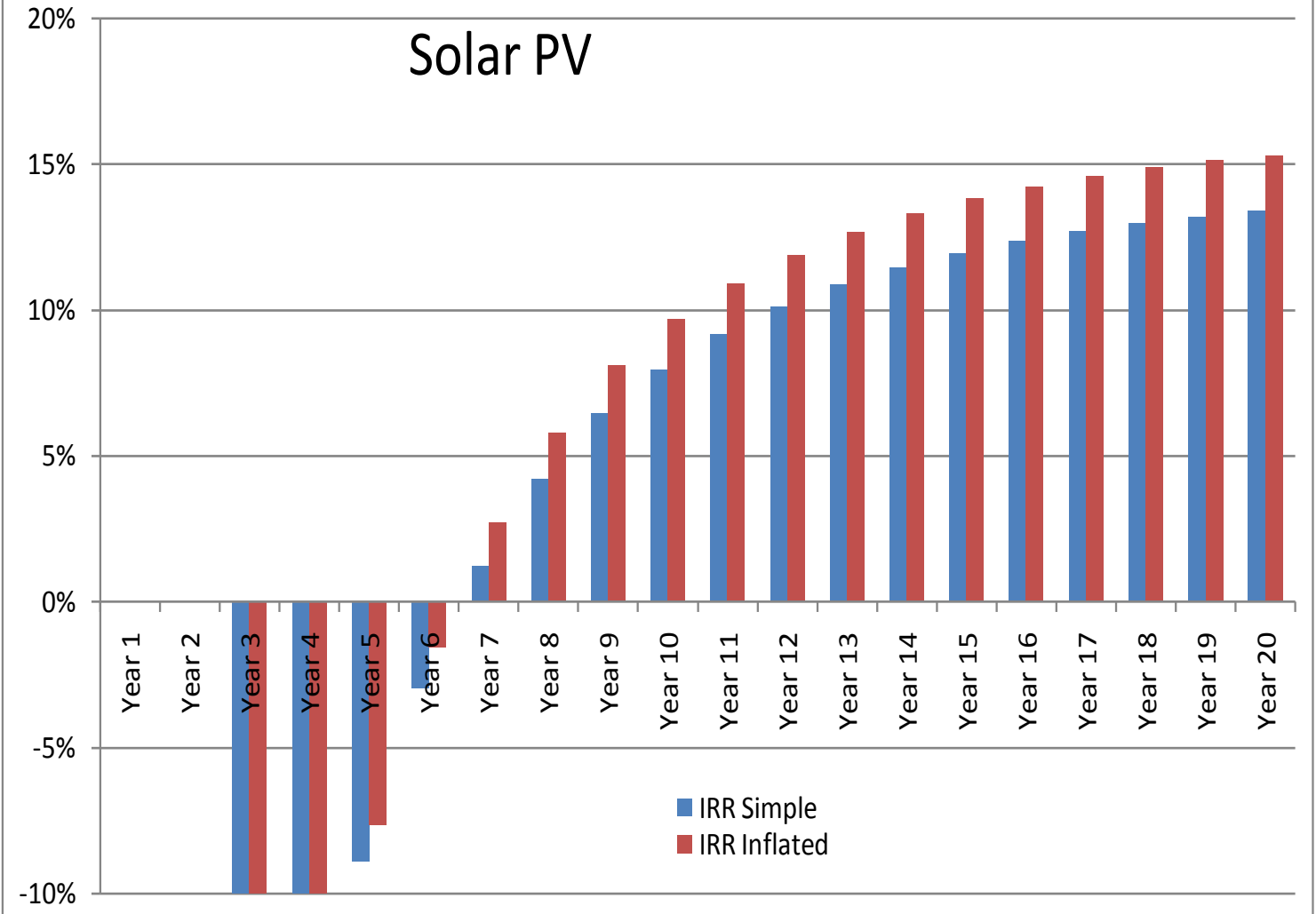
The cost for the solar photo voltaic system is given in the table below:

<b>Solar PV</b>	
Array Size (KW)=	10
Cost Per Watt=	\$ 4.75
Solar Cost=	\$ 47,500.00
Xcel Rebate Per Watt=	\$ 2.00
XCel Rebate=	\$ (20,000.00)
Installed Cost With Rebate=	\$ 27,500.00
Federal Tax Credit=	\$ (14,250.00)
Installed Cost With Tax Credit=	\$ 13,250.00
Cost of Systems=	\$13,250.00
Annual Energy Production (Kwh)=	20,075
REC (\$/KWh)=	\$ 0.045
Annual Energy Savings=	\$1,985.09

10 Year Efficiency=	90%
20 Year Efficiency=	80%
Electricity Inflation Rate=	2.0%

The payback and the internal rate of return of the solar photo voltaic system are given in the chart below:

# Internal Rate of Return For Solar PV



**Whole System**

Combining all the costs of every system and comparing them to a conventional system we have the costs given below:

<b>GSHP/Solar Thermal</b>	
Annual Electrical Usage (KWh)=	23,122
Annual Energy Cost=	\$ 2,306.00
Cost of Geothermal/Solar Thermal System Installed=	\$ 160,550.00
Federal Tax Credit=	\$ (45,090.00)
Cost of Geothermal/Solar Thermal System Installed with 30% Tax Credit=	\$ 115,460.00
Difference in Cost of Systems=	\$15,060.00
Annual Energy Savings=	\$2,029.21
Natural Gas Inflation Rate=	3.00%
Electricity Inflation Rate=	2.00%

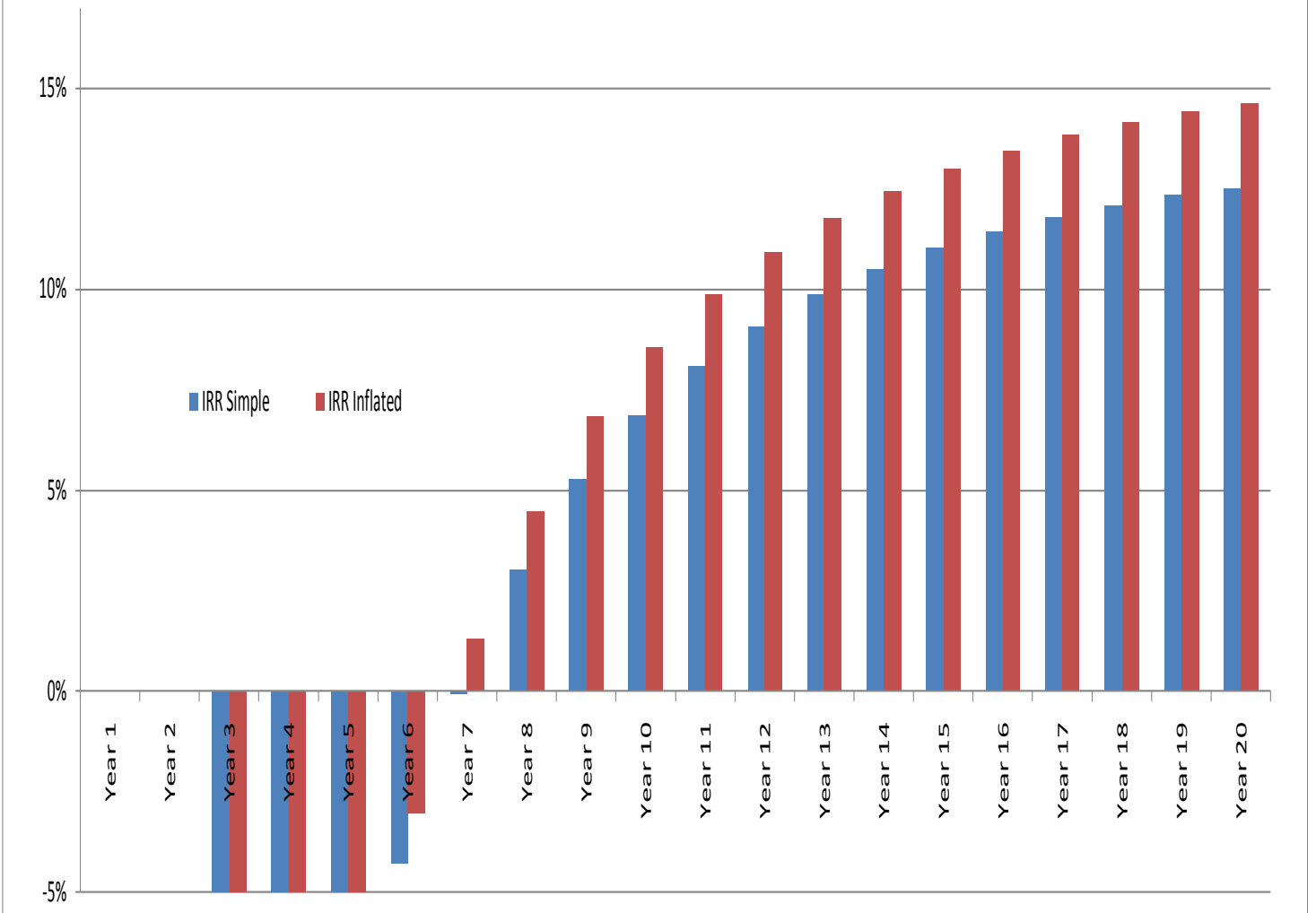
Annual Electrical Usage (KWh)=	3047
Annual Energy Cost=	\$ 302.69
Installed System cost with Rebates and Tax Credit	\$ 128,710.00
Difference in Cost of Systems=	\$28,310.00
Annual Energy Savings=	\$ 4,032.53

<b>Solar PV</b>	
Array Size (KW)=	10
Cost Per Watt=	\$ 4.75
Solar Cost=	\$ 47,500.00
Xcel Rebate Per Watt=	\$ 2.00
XCel Rebate=	\$ (20,000.00)
Installed Cost With Rebate=	\$ 27,500.00
Federal Tax Credit=	\$ (14,250.00)
Installed Cost With Tax Credit=	\$ 13,250.00
Cost of Systems=	\$13,250.00
REC (\$/KWh)=	\$ 0.045
Annual Energy Production (KWh)=	20,075
Annual Energy Savings=	\$1,985.09
10 Year Efficiency=	90%
20 Year Efficiency=	80%

<b>BOILER / AC UNIT</b>	
Annual Natrual Gas Usage (Therms)=	1,213.24
Annual Energy Cost of Natural Gas=	\$ 1,329.39
Annual Electricity Usage (KWh)=	30,108.00
Annual Energy Cost of Electricity=	\$ 3,005.82
Cost of System Installed=	\$100,400.00
Annual Energy Cost=	\$4,335.21

The payback and the internal rate of return are given in the chart below:

# Internal Rate of Return For Entire System



## **Conclusion**

The residence does have a higher initial capital cost. Taking advantage of the available tax credits and rebates the system is marginally more expensive. Neglecting the benefits to the environment and society as whole, the building will actually pay for itself in 7 years, resulting in a positive cash flow for the home owner.

The home is a private residence but the owner's have graciously allowed for us to model the home. If you would like to visit the residence please contact us to set up an appointment.

Regards,



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Steven Forrester, PE CGD