THERMAL STORAGE SOLUTIONS WHITEPAPER

Contact Information

Ed Whitaker: 802.584.4615
ewhitaker@thermalstoragesolutions.com
Bruce McGeoch: 802.651.0571
bmcgeoch@thermalstoragesolutions.com

Solar Thermal Space Heating For New Construction Utilizing Thermal Storage

A Cost Benefit Analysis using an example structure

Purpose:

To provide a decision support tool for selecting and specifying the optimum space (and domestic hot water) heating system for new construction based on a rigorous 30 year cost analysis. We will show that a solar thermal system utilizing TSS thermal storage is a cost effective alternative to traditional fossil fuel burning systems while providing all the benefits of renewable energy. TSS plans to make an Excel tool available on its website that incorporates the methodology described in this paper.

Overview:

This analysis will highlight the benefits of utilizing thermal storage in combination with solar thermal collectors to:

1) Provide cost effective space heating and domestic hot water (DHW),
2) Reduce the consumption of non-renewable energy,
3) Decrease the cost of ownership / operating cost of the heating system,
4) Improve the environment by reducing emissions of Green House Gases.

The core benefits of utilizing TSS thermal storage are a 50% to 80% reduction in operating costs and the lowest overall cost of ownership versus the best fossil fuel systems available while providing protection against unpredictable fossil fuel prices and lowering the emissions of harmful Green House Gases.

We will quantify both the upfront system cost and the ongoing operating cost for heating systems using fossil fuels and geothermal or solar based renewable energy systems. These costs will be used to calculate the total cost of ownership and a payback period for the additional upfront cost associated with the renewable energy systems. Since we are examining new construction scenarios, the payback analysis assumes that a decision is made to either install a "traditional" fossil fuel system or a renewable energy system in the new structure. The traditional system represents a baseline or minimum cost scenario for providing space and domestic hot water for the building. We compare this baseline cost to the additional cost outlay required to replace the traditional system with a renewable energy system. All the components and piping or duct work associated with delivering heat to the building are the same for traditional and renewable energy systems. Therefore, the cost of the delivery system or other common components is not counted in the comparison. The *system cost premium* that we use for comparison is the cost of the renewable energy system minus the cost of the traditional system's energy generation components (e.g. boiler).

One way to look at return on investment is a simple payback. How long will it take for the renewable energy system to recover or "payback" the system cost premium through operating cost savings? However this method does not provide a good picture of how the investment in renewable energy compares to other possible investments where you receive a known rate of return on money, such as 5% interest.

Therefore we also calculate a net present value (NPV) for each system choice, traditional and renewable, and compare them. The NPV calculation produces a current value for each system by discounting all future cash flows at a *required, or minimum, rate of return*, called the discount rate. The system cost premium puts the renewable energy alternative behind by that amount from the start. Investing in this premium only makes sense if the 30 year NPV for the renewable system ends up being equal or lower than the one for the traditional system. If the renewable NPV is lower there is a benefit of that amount associated with investing in the system cost premium. A positive *NPV benefit* shows that the alternative energy system has a *return on investment advantage* over the traditional system. Higher the NPV benefit amounts indicate a bigger advantage.

Methodology:

A comparison is made between traditional fossil fuel heating systems, a Geoexchange system and a solar thermal heating system utilizing storage. In each case, every effort was made to pick the most appropriate components and properly size the system for the example structure. Two building envelope cases were analyzed. One case, referred to as the ***"Standard"*** envelope, is meant to be typical of current normal (non "green") building practice for the example location. The other case, referred to as the ***"High Efficiency"*** envelope represents a structure optimized for energy efficiency. This case is more typical of the green / low net-energy building model. The initial costs and ongoing operating costs, for 30 years, were compared for each case and type of system. We have not attempted to supply 100% of the building's requirements with the renewable energy system as this could lead to significant oversizing and extra cost. Instead we have sized the equipment chosen for all systems to be a cost effective solution for the example structure. All of the costs associated with the heat and domestic hot water distribution within the building were not counted in the comparison as they would not need to change based on the heating system being used. The pricing of HVAC equipment and installation can vary depending on the company doing the work and the discount level provided to the end user. We have attempted to utilize manufacturer suggested list prices in all cases to provide a reasonable comparison. The prices actually paid by end users would likely be lower in all cases. The current federal and state incentives have been applied consistently to all the systems. The typical heating load for the example structure with the specified building envelope parameters and location was generated using TSS's modeling software. This software was developed by Thermal Energy System Specialists (TESS) and validated on TSS's pilot site in Chelsea, Vermont. (See Appendix A for data on the model validation). The typical DHW load used was calculated using the REM/Design software for a family of two. Finally, the energy prices and inflation rates used in the analysis are based on data from the federal ***Energy Information Agency (EIA)***. The average energy prices for 2009 (from the EIA monthly reports) were used as a starting point and the average inflation rates from the EIA 2008-2035 forecast were applied. We believe the EIA forecast of future energy prices may be much lower than the actual prices we could experience over time. Energy inflation rates higher than the EIA forecast would result in even better results for renewable energy systems that are less dependent on fossil fuels.

Assumptions:

The following parameters were used in the analysis.

1) Example Structure (Residential New Construction)
   a. 32 feet x 32 feet, approximately 2,000 square feet of living space
   b. 2 stories with 9 foot floor to floor height
   c. Oriented South
2) Location: Burlington, Vermont (Examples available for other locations across the U.S.)
3) Building Envelope

Building Envelope	"Standard"	"High Efficiency"
a. Walls:	*R-19*	*R-28*
b. Attic/Roof:	*R-32*	*R-85*
c. Windows/Doors:	*R-2*	*R-5*
d. Window to Wall Ratio:	*30%*	*25%*
e. Infiltration:	*Very Low*	*Very Low*

4) Space heating delivery system: Hydronic Radiant Heating
5) Fossil Fuel Systems: Natural Gas, Heating Oil and Propane
6) DHW:
   a. Solar/TSS system provides 75% of the hot water requirement from solar collection (via an in store pre-heat tank) and the remainder from a backup system utilizing fossil fuel. The Solar/TSS system would be able to easily provide 100% of the DHW load for all but the coldest months of the year; therefore we believe that 75% is a conservative estimate.
   b. Geoexchange systems are normally quoted as providing 100% of the heating requirement and 50% of the hot water requirement from the geothermal heat pump. Therefore the remainder of the DHW requirement has to be provided by a backup system. Geoexchange systems often utilize electric backup systems to cover the remaining DHW load but we have chosen to use a less expensive fossil fuel backup system for this comparison, as the high cost of electricity used for DHW generation would have a big impact on the overall results.
7) System Components:

System Components	"Standard"	"High Efficiency"
a. Natural Gas / Propane		
i. Boiler	Modulating, Condensing High Efficiency 75 –100 kBTU/hr *(e.g. Weil-McLain Ultra 105)*	*(e.g. Weil-McLain Ultra 80)*
ii. DHW	Indirect Fired Water Heater *(e.g. SuperStore Ultra SSU-60DW)*	
b. Heating Oil		
i. Boiler	Modulating, Condensing High Efficiency 75 – 100 kBTU/hr *(e.g. Buderus GB125BE/22)*	*(e.g. Buderus GB125BE/30)*
ii. DHW	Indirect Fired Water Heater *(e.g. SuperStore Ultra SSU-60DW)*	
c. Solar/TSS		
i. Collectors	4 Sunda Seido 5-16 *(Evacuated Tube Collectors)*	3 Sunda Seido 5-16 *(Evacuated Tube Collectors)*
ii. Storage	ECX-1500A *(1,500 kBTU Above Ground)*	ECX-1000A *(1,000 kBTU Above Ground)*
iii. Heating Backup	Natural Gas On-demand Water Heater *(e.g. Rinnai RC80HPi)*	
iv. DHW	In Store Pre-heat & On-demand Backup *(e.g. Rinnai RC80HPi)*	
d. Geoexchange		
i. Heating	4 Ton Heat Pump System *(System cost includes the cost of piping & drilling / trenching)*	3 Ton Heat Pump System
ii. DHW	Indirect Fired Water Heater *(e.g. SuperStore Solar SSU-60DW)*	

iii. DHW Backup — Natural Gas On-demand Water Heater *(e.g. Rinnai RC80HPi)*

8) Replacement Costs:
   a. Natural Gas System: One replacement of main heating & hot water components after 20 years.
   b. Solar/TSS System: One replacement of backup systems (heat & hot water) after 20 years.
   c. Geoexchange System: One replacement of heat pump compressor and backup hot water system after 20 years.
9) Maintenance Costs: No yearly maintenance cost was assumed in the model. We believe that regular maintenance for the Solar/TSS and Geoexchange systems would likely be less than that required for the traditional fossil fuel system.

Metrics:

Definitions of the metrics used in the analysis.

1) **Initial Cost:** Total cost of the system components that are unique to each type of system (i.e. common components such as distribution system are not included) less the available federal and state incentives.
2) **Operating Cost:** Operating cost for **year 1** based on 2009 EIA fossil fuel and electricity price data. The yearly operating cost escalation over the 30 year span of the analysis depends on the inflation rate of energy prices. The analysis uses the EIA energy inflation forecast as a base. For comparison the results for inflation rates of 5%, 7.5% and 10% are also calculated.
3) **Simple Payback:** The number of years required for the operating cost savings of the Renewable Energy system to equal the initial cost premium required to upgrade the "Traditional" (fossil fuel) system to the renewable energy system, in essence how long does it take to pay back the additional cost of choosing the renewable energy solution over a traditional natural gas, propane or heating oil system using the fuel cost savings.
4) **Lifetime Cost:** Total cost to purchase and operate heating system for 30 years, including normal replacement components but not including the initial cost of common components (e.g. distribution system).
5) **Net Present Value (NPV) Benefit:** The NPV for each system was calculated based on its total costs over the 30 year period using a discount rate of 8% and tax rate of 40%. Accelerated depreciation available to renewable energy systems was applied to the Solar/TSS and Geoexchange cases. The NPV benefit is the difference between the NPV for the "Traditional" system and the NPV for the Solar/TSS or Geoexchange system. A positive NPV benefit amount represents a return on investment advantage for the Solar/TSS or Geoexchange systems. Larger NPV benefit amounts correlate to better return on investment.

Results:

The tables below summarize the results of our analysis for three cases. The first comparison is with a traditional system fueled with natural gas. Natural gas is the least expensive alternative among the available fossil fuels and therefore the most challenging comparison for renewable energy systems. The other comparisons are with heating oil and propane.

The following table compares the initial, operating and lifetime costs for the three fossil fuel systems and the two renewable energy systems. In the natural gas case the additional energy required to fulfill the domestic hot water requirement and any heating not covered by the solar system is generated using natural gas. In the heating oil and propane cases propane is used for this purpose as it is assumed that natural gas is not available.

Cost of Ownership Comparison	"Standard" Building Envelope			"High Efficiency" Building Envelope		
	Initial Cost[1]	Operating Cost Per Yr[2]	Lifetime Cost[3]	Initial Cost[1]	Operating Cost Per Yr[2]	Lifetime Cost[3]
Natural Gas (NG)	$ 9,500	$ 1,630	$ 80,077	$ 8,500	$ 681	$ 46,901
Solar/TSS-NG	$ 23,388	$ 491	$ 48,265	$ 21,638	$ 136	$ 31,749
Geoexchange-NG	$ 24,028	$ 975	$ 66,641	$ 19,810	$ 318	$ 40,940
Heating Oil	$ 13,000	$ 1,684	$ 100,465	$ 12,500	$ 689	$ 54,807
Propane (LP)	$ 9,500	$ 2,495	$ 126,939	$ 8,500	$ 1,040	$ 62,595
Solar/TSS-LP	$ 23,388	$ 733	$ 58,892	$ 21,638	$ 202	$ 34,642
Geoexchange-LP	$ 24,028	$ 882	$ 70,845	$ 19,810	$ 410	$ 44,995

1) Net cost to purchase and install after federal and state incentives
2) Operating Cost for Year 1, operating cost will increase as fuel prices increase
3) Total Cost for 30 year lifetime using EIA inflation rates

The Solar/TSS alternative consistently provides the lowest operating cost and this advantage leads to the lowest overall cost of ownership for the 30 year period.

The two tables (below) compare return on investment between the fossil fuel systems and renewable energy alternatives using a range of inflation rates to show the impact of future fossil fuel prices on the comparison.

Return On Investment Comparison	"Standard" Building Envelope							
	EIA Inflation Rate		5%/yr Inflation Rate		7.5%/yr Inflation Rate		10%/yr Inflation Rate	
	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]
Solar/TSS vs. Natural Gas	11 Yrs	$ 15,746	10 Yrs	$ 21,935	9 Yrs	$ 30,953	8 Yrs	$ 45,016
Geoexchange vs. Natural Gas	16 Yrs	$ 8,339	13 Yrs	$ 16,357	11 Yrs	$ 27,550	10 Yrs	$ 45,006
Solar/TSS vs. Heating Oil	10 Yrs	$ 17,199	9 Yrs	$ 21,899	8 Yrs	$ 29,404	8 Yrs	$ 41,122
Geoexchange vs. Heating Oil	14 Yrs	$ 12,187	11 Yrs	$ 19,204	9 Yrs	$ 30,062	8 Yrs	$ 46,995
Solar/TSS vs. Propane	8 Yrs	$ 22,415	7 Yrs	$ 34,059	7 Yrs	$ 47,918	6 Yrs	$ 69,530
Geoexchange vs. Propane	9 Yrs	$ 19,402	8 Yrs	$ 31,373	7 Yrs	$ 48,576	7 Yrs	$ 75,403

4) Number of years required to recover initial cost premium of renewable energy system using fuel cost savings

5) NPV Benefit – positive value represents a return on investment advantage for the renewable energy system

Return On Investment Comparison	"High Efficiency" Building Envelope							
	EIA Inflation Rate		5%/yr Inflation Rate		7.5%/yr Inflation Rate		10%/yr Inflation Rate	
	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]
Solar/TSS vs. Natural Gas	20 Yrs	$ 7,134	15 Yrs	$ 10,170	14 Yrs	$ 14,408	13 Yrs	$ 21,017
Geoexchange vs. Natural Gas	21 Yrs	$ 3,192	19 Yrs	$ 5,952	16 Yrs	$ 9,805	14 Yrs	$ 15,815
Solar/TSS vs. Heating Oil	17 Yrs	$ 10,765	14 Yrs	$ 13,167	12 Yrs	$ 16,932	11 Yrs	$ 22,803
Geoexchange vs. Heating Oil	20 Yrs	$ 6,442	18 Yrs	$ 8,432	14 Yrs	$ 11,606	13 Yrs	$ 16,555
Solar/TSS vs. Propane	14 Yrs	$ 11,335	13 Yrs	$ 15,867	11 Yrs	$ 22,381	10 Yrs	$ 32,538
Geoexchange vs. Propane	16 Yrs	$ 7,011	13 Yrs	$ 11,133	12 Yrs	$ 17,055	11 Yrs	$ 26,290

Conclusions:

- The Solar/TSS systems provide the ***lowest operating costs*** and the ***best overall cost of ownership*** for the thirty year period of the analysis.
- Return on investment is highly dependent on the initial cost assumptions and projected increases in energy costs. Because estimated "retail" costs were used, it is likely that the upfront premium for the renewable energy systems would be decreased assuming normal industry discounts. Equivalent discounts would result in a larger decrease for the renewable energy system given the higher initial valve that the discount is being applied to. Therefore the ***payback periods listed here represent "worst case" numbers*** and will likely be lower using specific project costs.
- The Solar/TSS systems have ***positive NPV benefit values in all cases***, indicating a good return on investment for their associated system cost premium. The NPV benefit values become extremely attractive if inflation rates above the EIA forecast are used. The current EIA forecast projects average yearly inflation rates of 2.2%, 2.3% and 2.5%

for natural gas, propane and heating oil, respectively, between 2008 and 2035. The return on investment, expressed by the NPV benefits, increases dramatically if the inflation rate grows to any of the three alternatives to the EIA projections shown in the tables above. The NPV benefit increases by 2 to 3 times with a 10%/yr inflation rate and is right around 2 times in most cases for a 7.5%/yr inflation rate. The table below summarizes the increases in value.

Increase in NPV Benefit for Higher Inflation Rates	"Standard" Building Envelope			"High Efficiency" Building Envelope		
	5%/yr	7.5%/yr	10%/yr	5%/yr	7.5%/yr	10%/yr
Versus Natural Gas	40%	97%	186%	43%	102%	195%
Versus Heating Oil	27%	70%	139%	22%	57%	112%
Versus Propane	52%	114%	210%	40%	97%	187%

It is certainly possible, given history and current world affairs, that we could see much higher fuel costs in the future.

- With a Solar/TSS or other renewable energy system the bulk of a structure's heating requirements are supplied at a ***fixed, pre-determined cost of energy***. The future cost of heating the structure is therefore much less dependent on unforeseen changes in the price and availability of fossil fuels.
- High efficiency building envelopes have a tremendous impact on operating costs. All systems benefit from the reduced amount of total energy required. As a result, the payback periods are somewhat longer. However, the year 1 operating costs for the Solar/TSS systems in our example showed a reduction of ***70% to 80%*** over the three fossil fuel system alternatives when the building envelope was upgraded from our "standard" assumption to our "high efficiency" assumption. These operating cost savings would be even higher as the cost of fuel increases.
- Generation of domestic hot water becomes a higher percentage of the overall load in the "high efficiency" case as the improved building insulation does not reduce the demand for hot water. Therefore a higher DHW load assumption would result in ***lower payback periods***.
- Choosing the Solar/TSS system over the traditional fossil fuel system results in a significant reduction in the emission of harmful ***Green House Gases*** by reducing the amount of fossil fuel burned during the 30 year lifetime used in the example. For the "standard" envelope case the reduction is equal to ***2.5 MTCDE*** and for the "high efficiency" envelope case 1.0 MTCDE is avoided. MTCDE = Metric Ton (1000 kg) of Carbon Dioxide Equivalent.

Benefits of Systems with TSS Thermal Storage:

- Cost effective year-around heating using solar thermal collectors becomes a reality with 50% to 80% reductions in yearly operating costs and reasonable payback periods.
- Other thermal energy sources, such as wood gasification (with shorter highly efficient burning cycles), can also be used very effectively with thermal storage.
- TSS Thermal Storage easily scales up for commercial applications
- Fixed cost of energy provides a "worry free" future
- Low operating and maintenance costs are very helpful for anyone living on a fixed income
- Reduced Green House Gas (GHG) emissions. In the example above the Solar/TSS system saves 1 MTCDE (Metric Ton of Carbon Dioxide Equivalent) per year in the High Efficiency case and 2.5 MTCDE in the Standard case!
- LEED qualification is dramatically easier with Solar/TSS system. A zero-energy structure earns 34 LEED points (almost enough to qualify for the basic LEED level).
- The DOE's Net-Zero Energy Building Initiative can be achieved more cost effectively because the amount of electricity needed from high cost sources like PhotoVoltaic (PV) is reduced.
- Future TSS products will enable Combined Heating & Cooling and Combined Heat & Power (CHP) applications for very little additional cost, which will generate an even better return on investment result.

Commercial Example

Overview:

The residential example is easy to relate to as many of us have experience with the heating systems and costs for our homes. However, solar space heating utilizing thermal storage is also very effective on the small to medium size commercial structures that exist throughout the U.S. There are many examples including strip malls, convenient stores, small office buildings and light manufacturing / warehouse space. The following example demonstrates how the application of a solar thermal heating system with expanded TSS thermal storage can provide cost effective performance for a representative commercial structure.

Assumptions:

The following parameters were used in the analysis.

1) Example Structure (Commercial New Construction)
    a. 50 feet x 100 feet
    b. 2 stories with 13 foot floor to floor height
    c. Oriented South
2) Location: Burlington, Vermont (Examples available for other locations across the U.S.)
3) Building Envelope

a.	Walls:	*R-38*
b.	Attic/Roof:	*R-80*
c.	Windows/Doors:	*R-5*
d.	Window to Wall Ratio:	*10%*
e.	Infiltration:	*Very Low*

4) Space heating delivery system: Hydronic Radiant Heating
5) Fossil Fuel Systems: Natural Gas, Heating Oil and Propane
6) DHW: DHW requirements vary widely with the type of business occupying a commercial structure. As solar thermal is a very efficient generator of hot water, a larger DHW requirement would increase the return on investment versus a traditional heating system. For this example, we have assumed a relatively small DHW requirement, about 3 times that of a single family house.
7) System Components:

a. Natural Gas / Propane			
	i.	Boiler	Condensing, Modulating High Efficiency *(e.g. Weil-McLain Ultra Commercial)*
	ii.	DHW	Indirect Fired Water Heater *(e.g. SuperStore Ultra SSU-80C)*
b. Heating Oil			
	i.	Boiler	Condensing, Modulating High Efficiency *(e.g. Weil-McLain 88 Series 2)*
	ii.	DHW	Indirect Fired Water Heater *(e.g. SuperStore Ultra SSU-80C)*
c. Solar/TSS			
	i.	Collectors	15 Sunda Seido 5-16 *(Evacuated Tube Collectors)*
	ii.	Storage	3 ECX-2500A *(2,500 k-BTU Above Ground)*
	iii.	Heating Backup	3 Natural Gas On-demand Water Heater *(e.g. Rinnai RC80HPi)*
	iv.	DHW	In Store Pre-heat & On-demand Backup *(e.g. Rinnai RC98HPi)*

8) Replacement Costs:
    a. Natural Gas System: One replacement of boiler after 20 years.
    b. Solar/TSS System: One replacement of backup systems after 20 years.
9) Maintenance Costs: No yearly maintenance cost was assumed in the model. We believe that regular maintenance for the Solar/TSS system would likely be less than that required for the traditional fossil fuel system.

Metrics:

The same metrics have been used for the comparison. The current Vermont state incentive for commercial solar systems is equal to the federal 30% tax credit. The payback period and NPV benefit results are substantially enhanced by this state incentive. Comparisons of installations in other states are available and reflect the incentives available in those locations.

Results:

The results for our commercial structure example are summarized in the tables below. Vermont currently has a very generous solar incentive for C-Corporations (that file a Vermont corporate return). The state offers the "Business Solar Tax Credit" for installations of solar energy equipment on business properties. The credit is equal to 100% of the federal business energy tax credit for solar from 2008 through 2010. In effect, this constitutes a 30% state-level credit for systems and equipment that use solar energy to generate electricity, to heat or cool (or provide hot water for use in) a structure, or to provide solar process heat. This state incentive, coupled with the current federal program results in very short payback times in the commercial comparison below. The Vermont incentive will be reduced to 24% of the federal business energy tax credit for solar (effectively making it a 7.2% tax credit) at the end of 2010. The simple payback and NPV benefit associated with this lower level of state incentive are also shown in the table.

Cost of Ownership Comparison	Commercial Building - 2010			Commercial Building - 2011		
	Initial Cost[1]	Operating Cost Per Yr[2]	Lifetime Cost[3]	Initial Cost[1]	Operating Cost Per Yr[2]	Lifetime Cost[3]
Natural Gas (NG)	$ 28,404	$ 3,114	$ 193,292	$ 28,404	$ 3,114	$ 193,292
Solar/TSS-NG	$ 58,413	$ 545	$ 90,456	$ 77,439	$ 545	$ 109,482
Heating Oil	$ 37,404	$ 3,196	$ 216,628	$ 37,404	$ 3,196	$ 216,628
Propane (LP)	$ 28,404	$ 4,774	$ 265,949	$ 28,404	$ 4,774	$ 265,949
Solar/TSS-LP	$ 58,413	$ 791	$ 101,201	$ 77,439	$ 791	$ 120,227

1) Net cost to purchase and install after federal and state incentives
2) Operating Cost for Year 1, operating cost will increase as fuel prices increase
3) Total Cost for 30 year lifetime using EIA inflation rates

Return On Investment Comparison	Commercial Building - 2010							
	EIA Inflation Rate		5%/yr Inflation Rate		7.5%/yr Inflation Rate		10%/yr Inflation Rate	
	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]
Solar/TSS vs. Natural Gas	11 Yrs	$ 40,103	10 Yrs	$ 54,785	9 Yrs	$ 75,284	8 Yrs	$ 107,252
Solar/TSS vs. Heating Oil	8 Yrs	$ 45,906	8 Yrs	$ 58,208	7 Yrs	$ 77,363	7 Yrs	$ 107,235
Solar/TSS vs. Propane	7 Yrs	$ 59,780	7 Yrs	$ 82,344	6 Yrs	$ 113,848	6 Yrs	$ 162,977

4) Number of years required to recover initial cost premium of renewable energy system using fuel cost savings
5) NPV Benefit – positive value represents a return on investment advantage for the renewable energy system

Return On Investment Comparison	Commercial Building - 2011							
	EIA Inflation Rate		5%/yr Inflation Rate		7.5%/yr Inflation Rate		10%/yr Inflation Rate	
	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]	Simple Payback[4]	NPV Benefit[5]
Solar/TSS vs. Natural Gas	16 Yrs	$ 22,486	14 Yrs	$ 37,168	12 Yrs	$ 57,668	11 Yrs	$ 89,635
Solar/TSS vs. Heating Oil	14 Yrs	$ 28,289	12 Yrs	$ 40,592	11 Yrs	$ 59,747	10 Yrs	$ 89,618
Solar/TSS vs. Propane	11 Yrs	$ 42,164	10 Yrs	$ 64,727	9 Yrs	$ 96,231	8 Yrs	$ 145,360

Conclusions:

- The operating cost reductions are substantial (all over 75%)
- Very good return on investment, especially in 2010 due to the generous Vermont state incentive.
- Higher DHW requirements will lead to further savings in operating costs and even better return on investment
- Corporations will enjoy substantial cash flow benefits as shown by the NPV comparison.
- If some type of cap and trade legislation is put in place to control GHG emissions, the GHG reductions of the Solar/TSS system could provide a further financial benefit to corporations. In the example the GHG reduction is 4.5 MTCDE for natural gas, 6.1 MTCDE for heating oil and 5.0 MTCDE for propane.

Spreadsheets:

The Excel workbooks used to generate all the results used in the comparisons presented in this whitepaper are available from TSS. We have made every effort to provide as equitable comparison as possible with the data we are able to access. We welcome any feedback on the methodology used, improvements that could be made to the assumptions, corrections to the spreadsheets or other input on this cost benefit analysis.

Background on TESS (Thermal Energy System Specialists):

- Founded in 1994
- Three partners and two employees in Madison, WI
- Specialize in computer modeling and analysis of complex energy systems
- Use and develop TRNSYS; a preeminent energy modeling software tool
- Long history with seasonal thermal storage systems
    - Drake Landing
    - Vulcan Solar
    - Natural Resources Canada Residential Seasonal Storage

Task Performed:

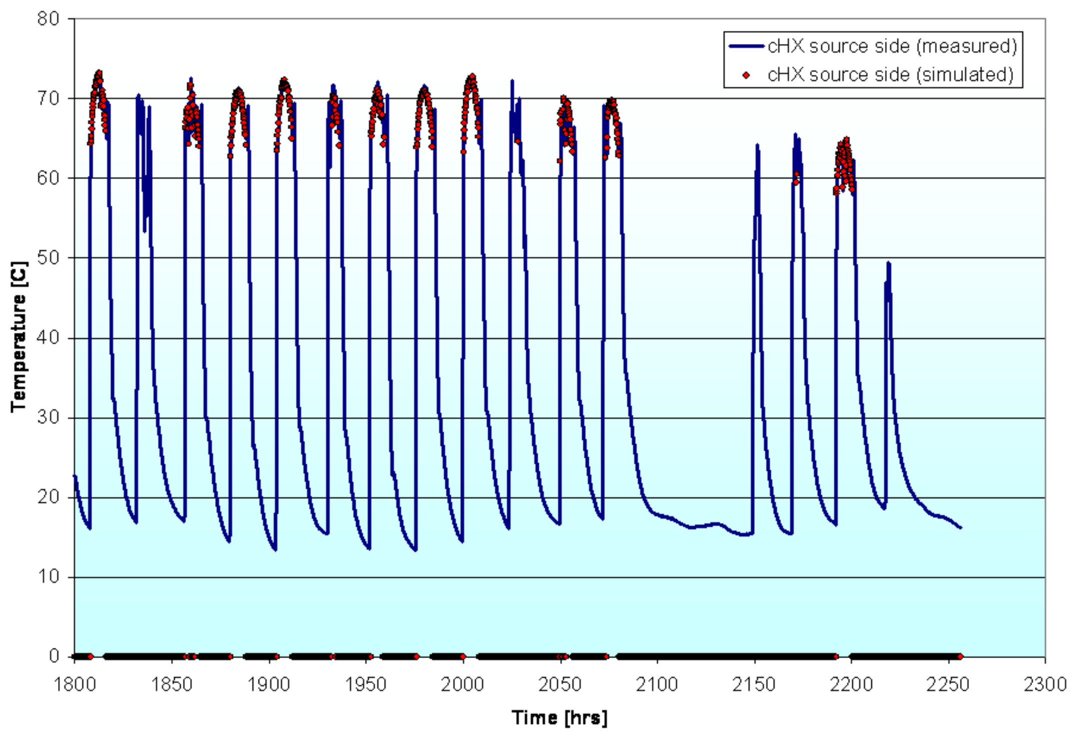
- Develop an analyzer that simulates the annual performance of residential seasonal storage systems

Calibration Methodology:

- Calibrate individual components of the system
    - Collector
    - Heat exchanger
    - Storage
    - Drive models with known inlet and environmental conditions
- Simulate outlet conditions
- Define an “error function” and optimization parameters
- Run hundreds of simulations automatically to find the combination of parameters that minimizes the error

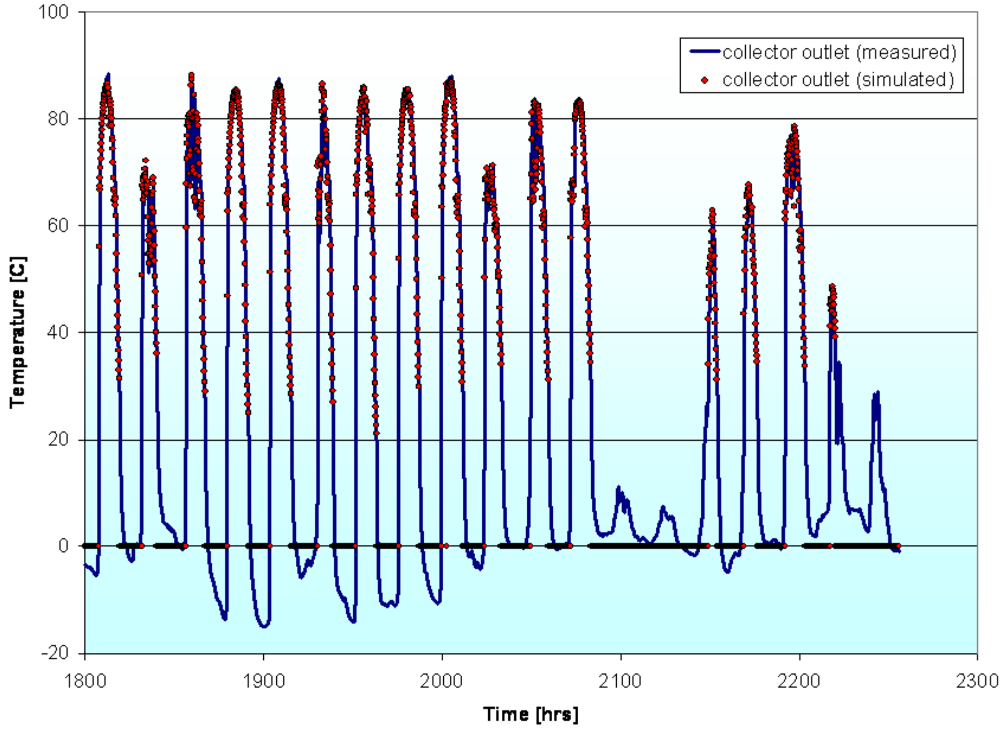
Heat Exchanger Calibration:

- Effectiveness: 0.54 (10% lower than expected)
- Collector side flow rate: 0.145 L/s (no change)



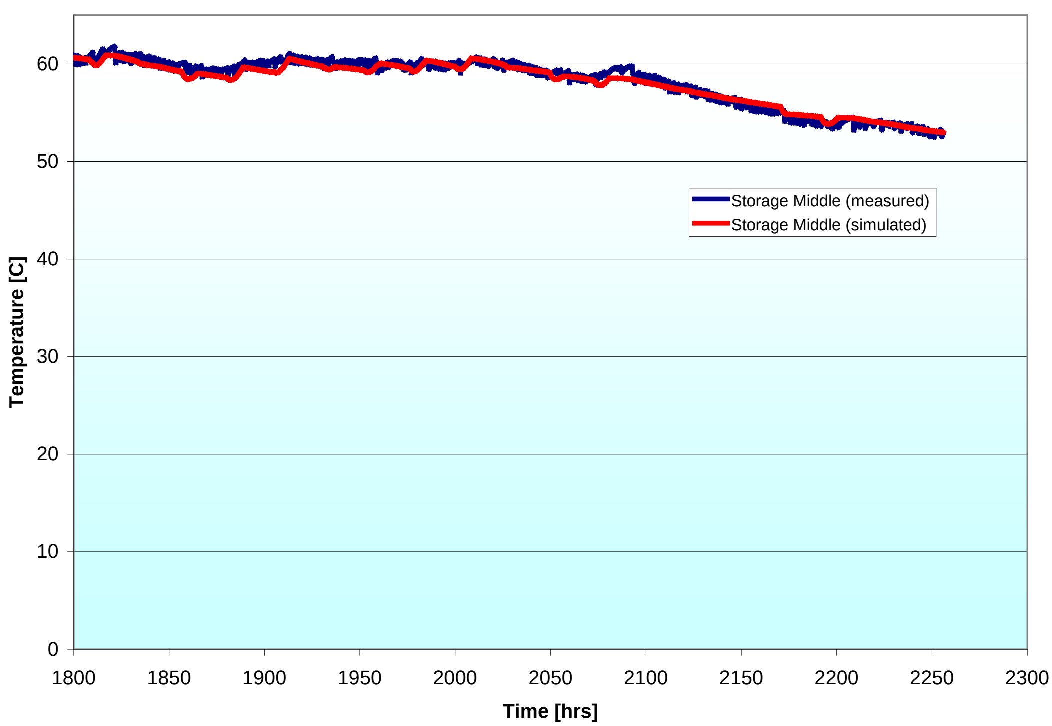
Collector Calibration:

- Intercept Efficiency (a0): 0.459 (4% lower than expected)
- Efficiency Coefficient (a1): 6.20 kJ/kg.K (9% higher than expected)

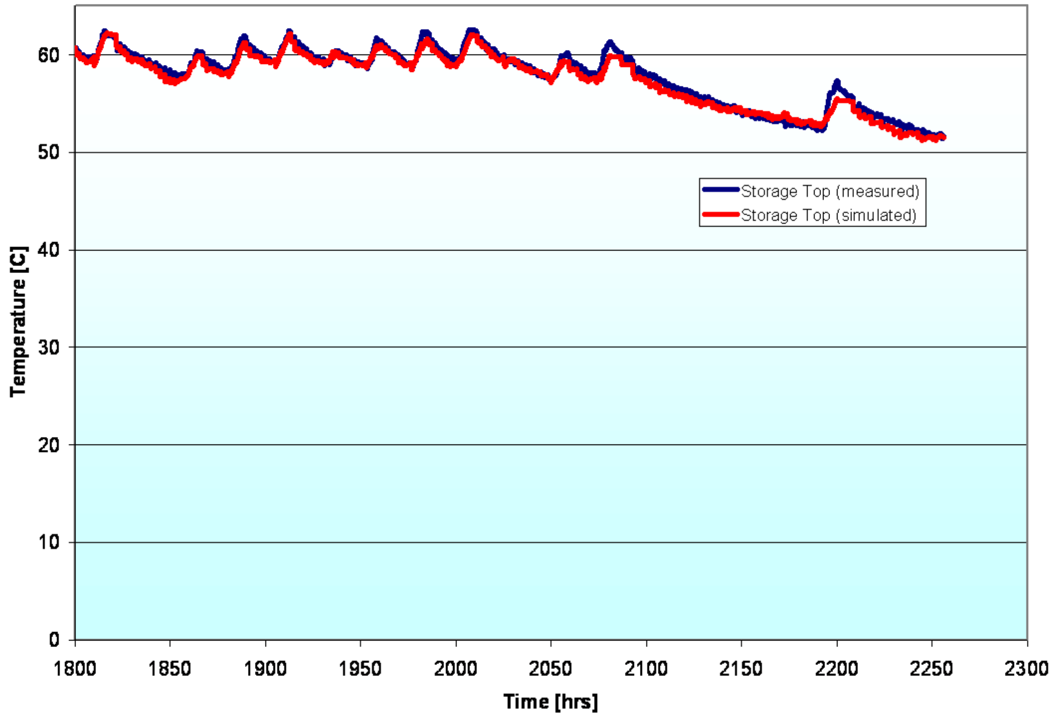


Storage Calibration:

- Storage – Middle Temperature



- Storage – Top Temperature



Conclusions:

- Collector Model
    - Efficiency parameters are very reasonable
- Heat Exchanger
    - Effectiveness is very reasonable
- Thermal Storage
    - High quality prediction of bed temperatures
- A longer term optimization is planned to further calibrate the model