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Renewable Energy Case Study

Economic Performance of a Glazed Flat Plate Solar Water Heating System

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1. The Problem

It can be difficult for people to obtain credible field information to help them make decisions regarding the adoption of renewable energy technologies. Although there is no shortage of installed equipment, there is a lack of available data and information describing the performance of that equipment. Hence, prospective buyers can feel as though they are assuming a high degree of personal financial risk when considering the purchase of renewable energy equipment.

2. Purpose

The purpose of this case study is to provide an estimate of the economic performance of a glazed flat plate solar water heating system. The estimate is derived from the volume of heating oil displaced by producing domestic hot water using a solar water heating system rather than an oil-fired boiler. By considering the net cost of the solar water heating system and the avoided cost of the heating oil, calculations are performed to yield the simple payback of the system and the return on investment.

3. Background

On May 27, 2009, a Thermo Dynamics glazed flat plate solar water heating system (SB64-9PV) was installed by Renewable Lifestyles Inc. in a Queen's County residence occupied by two adults and two children. A 246-litre Bradford White upright electric water heater (Model M2-HE-65R6DS) was used for a solar storage tank and to produce supplemental hot water as necessary via the heater's upper heating element.

A bypass system was installed so the household's Benjamin CC500 boiler could be turned off during the summer months thereby allowing domestic hot water to be provided entirely by the solar water heating system and, as necessary, the upper heating element in the solar storage tank. A kilowatt-hour meter, installed in-line between the upper heating element and the main power panel, allowed for the measurement of how much supplemental electricity was consumed when the household's domestic water needs could not be satisfied by the solar water heating system alone. Additionally, the upper heating element was wired with an on/off switch so it could be turned off during the space-heating season (i.e., the winter) when the oil-fired boiler was operating and the solar water heating system was being used to preheat domestic water passing through the boiler's tankless coil.

4. Methodology

The following steps were taken in support of the estimate of the solar water heating system's economic performance.

- Fuel delivery records were examined to determine the boiler's summertime oil consumption rate (litres/day) when it operated only to provide domestic hot water.
- For a period of 127 days in 2009 (May 18 to October 2), the oil-fired boiler was turned off and domestic hot water was produced mostly by the solar water heating system with supplemental heating being provided by the upper heating element in the solar storage tank.
- During the 127 day period, readings of the kilowatt-hour meter were recorded every morning to determine how much electricity was consumed by the upper heating element.
- The following supplemental step was taken to determine the solar fraction contributed by the solar water heating system during the summer and winter. For a period of 30 days (December 15, 2009 to January 12, 2010) the boiler was bypassed and domestic hot water was produced entirely by the solar water heating system and the upper heating element. Kilowatt-hour meter readings were recorded every morning.

5. Results

Summer Oil Consumption

Based on fuel consumption records (see Table 1), the boiler would normally consume an average of 4.38 litres of oil per day in the summer (when the room thermostats were turned down as far as they would go) to provide occupants with domestic hot water.

Table 1: Summer Oil Consumption

Year	Time Period	Litres	Days	L/Day
2001	June 30 to September 13	451.5	93	4.85
2002	May 21 to August 5	361.0	76	4.75
2003	Vent whistle not working			
2004	June 22 to October 13	656.3	114	5.76
2005	May 3 to August 5	359.9	94	3.83
2006	April 21 to August 23	585.3	125	~~4.68~~ 3.75
2007	April 18 to July 25	413.2	99	~~4.17~~ 3.34
2008	Tank not completely filled			
Average Summer Oil Consumption				**4.38**

Note: The summer oil consumption rates for 2006 and 2007 have been reduced by 20 percent to account for the periods starting in late April when some space heating is still required.

Net Cost Savings for the Summer of 2009

During the 127 day summer period in 2009 when the boiler was turned off, the solar water heating system displaced 556 litres of oil (127 days x 4.38 litres/day = 556 litres). However, 118 kilowatt-hours of electricity were consumed to maintain the temperature of the water in the solar storage tank at the set point temperature of 120 degree Fahrenheit. (See Appendix A.1 for data and calculations.)

The net cost savings of turning the boiler off during this period plus the cost of supplemental electricity are summarized in Table 2.

Table 2: Net Cost Savings for Summer 2009	
Description	**($)**
Value of Oil Displaced (127 days x 4.38 litres per day x $0.75 per litre)	417
Less Cost of Supplemental Electricity (118 kWh at $0.15 per kWh)	18
Net Cost Savings	**399**

It should be noted that because the circulating pump for the solar water heating system is powered by an 18-watt photovoltaic module, no additional electricity is required for the system's operation.

Net Cost of Solar Water Heating System

The net cost of the system (taxes included) is summarized in Table 3, below.

Table 3: 2009 Net Cost of Solar Water Heater System (SB64-9PV)	
Description	**($)**
Installed Cost of System	7,386
Less ecoEnergy for Homes Grant	1,250
Less Home Renovation Tax Credit	958
Less PEI Energy Efficiency Grant	1,108
Less Provincial Sales Tax Exemption	671
Net Cost	**3,399**

The cumulative effect of federal and provincial incentives that were available in 2009 contributed to a fifty-four percent reduction in the system's cost.

Estimated Annual System Economics

While the solar water heating system is most effective in the summer, it still provides a significant volume of hot water in the spring and fall and even some in the winter. (For example, at 3 p.m. on February 2, 2009, after a

day of full sun and with no hot water having been drawn from the solar storage tank since two early morning showers were taken, the water temperature at the top of the tank was 130 degrees Fahrenheit while the temperature at the bottom of the tank was 105 degrees Fahrenheit.)

Data has been provided in Appendix A.2 from which it has been estimated that the system has displaced 755 litres of oil from the spring to the fall in 2009. At a cost of $0.75 per litre, this has resulted in savings of $566 (755 litres x $0.75 per litre). The estimated annual system economics are summarized in Table 4, below.

Table 4: Estimated Annual System Economics	
Description	
Estimated Annual Cost Savings	$566
Simple Payback ($3,399/($566/year))	6.0 yrs
Return on Investment ($566/$3,399) x 100	16.7 %
Note: The calculations on which the results of this table are based do not account for any hot water production in the winter.	

Solar Fraction

The solar fraction provided by the solar water heating system is defined as the percentage of hot water produced by the system compared to the amount of hot water consumed. The solar fraction for each season will be different because of the variance in sunlight intensity and duration, and seasonal weather patterns.

Appendix A.3 provides data and calculations to support the seasonal solar fractions provided in Table 5, below.

Table 5: Estimated Solar Fraction	
Season	**%**
Summer	86
Winter	7

5. Discussion

Economic Performance

Since the economic performance of using a solar water heating system to provide domestic hot water is based on the cost avoided by not using (or reducing the use of) other methods, it stands to reason that the more inefficient the former methods, the greater will be the avoided cost and the more favourable will be the economic performance of the solar water heating system.

In this case study, an oil-fired boiler was the original means of providing domestic hot water. While boilers can be reasonably efficient in producing domestic hot water during the winter season when they must run to provide hot water for space heating, they can be very inefficient (as low as 25%) in producing domestic hot water in the summer when hot water for space heating is not required. Hence, turning them off during the summer months and relying on a solar water heating system with an appropriate backup (electricity in this case) makes for an attractive economic case.

The economic performance of the solar water heating system will improve further as the cost of heating oil rises. In this case study, oil costs are in the order of $0.75 per litre. However, it is worth remembering that in the fall of 2008, oil prices rose above $1.20 per litre and that in the near future, it is expected that oil costs will rise again as the world economy recovers. Because sunlight is free, the solar water heating system has no operating cost and higher oil costs simply mean higher avoided costs which, in turn, lead to a shorter simple payback and a higher return on investment.

The other element of economic performance is based on the net cost of the solar water heating system. A lower net cost shortens the simple payback and increases the return on investment. The year 2009 was an excellent time during which to invest in a solar water heating system in that four external incentives were available to reduce the net cost of the system. Additionally, at the time the system was purchased, the dealer was offering an internal discount that further reduced the installed cost of the system.

System Operation and Maintenance

As previously mentioned, because it runs on sunlight, the solar water heating system profiled in this case study has no operating costs. There will be maintenance costs (such as replacing the water/glycol mixture – possibly every five years) and some parts may eventually have to be replaced, but the longevity of the system is generally much longer than for other water heating equipment.

Miscellaneous Points

- Using a solar water heating system displaces the use of fossil fuel and results in less carbon dioxide being released into the atmosphere. In this case study, the displacement of 755 litres of heating oil translates into the displacement of 2,039 kilograms of carbon dioxide.
- Typically, boilers run 365 days per year and are never turned off. Turning a boiler off and allowing the water in its reservoir to cool to ambient temperatures may result in some leakage as seals and/or gaskets contract. In regard to the Benjamin boiler, a small amount of leakage was observed and continued until the cold water feed to the boiler was closed. The owner of the boiler was not concerned about the leakage as the boiler was located in a garage with a sloped floor leading to a drain.
- The owner of the boiler had heard that turning a boiler off in the summer could create condensation within the boiler that would lead to corrosion thus reducing the life of boiler. The owner's licensed burner technician and the licensed plumber who installed the solar water heating system both felt this would not be an issue.

(Case Study revised to February 27, 2010)

Appendix 1 - Supplemental Electricity Required in the Summer of 2009

Thermo Dynamics SB64-9PV Solar Boiler

Family of 4 (2 adults, 2 children ages 9 and 11)

(Oil-fired boiler/tankless coil bypassed for the summer months)
(Previous summer oil consumption rate averaged over 6 summers: 4.6 L/day for domestic hot water)

Collector Angle: 39.2 degrees above horizontal
Orientation: Within 20 degrees of South

Summer of 2009
KiloWatt-Hours Used for Top Element of Bradford-White Electric Heater/Storage Tank (245 L capacity)
Bottom Element is Disconnected

2009	June	July	Aug	Sept	Oct
Date	kWh	kWh	kWh	kWh	kWh
1		3	0	1	0
2		2	0	0	1
3		3	0	0	
4		2	0	0	
5		7	0	0	
6		2	0	0	
7		0	0	0	
8		0	0	0	
9		1	0	0	
10		0	1	0	
11		0	1	0	
12		0	0	0	
13		0	0	3	
14		0	0	5	
15		0	0	1	
16		0	0	2	
17		0	0	1	
18	0	4	0	0	
19	0	1	0	3	
20	0	0	0	4	
21	6	0	0	0	
22	5	0	0	0	
23	5	1	0	0	
24	1	1	5	0	
25	2	0	1	2	
26	0	1	2	1	
27	0	0	1	4	
28	0	0	0	3	
29	3	0	0	2	
30	4	0	1	1	
31		0	0		
Total	26	28	12	33	1

Cost of Operating Bradford White Electric Heater/Storage Tank					
	June	July	Aug	Sept	Oct
Total kWh Consumed for Month	26	28	12	33	1
Number of Days	13	31	31	30	2
Average kWh Consumed per Day	2.00	0.90	0.39	1.10	0.50
Cost per kWh, 5% gst incl. (cents)	15.68	15.55	15.61	15.61	15.61
Average Cost per Day ($)	0.31	0.14	0.06	0.17	0.08
Total Cost for Month ($)	4.08	4.35	1.87	5.15	0.16
Displaced Cost of Not Heating Domestic Water Using Tankless Coil in Oil-Fired Boiler					
Litres of Oil Not Consumed Per day	4.38	4.38	4.38	4.38	4.38
Number of Days	13	31	31	30	2
Total Litres of Oil Not Consumed for Month	56.94	135.78	135.78	131.40	8.76
Cost per Litre of Oil, 5% gst incl. ($)	0.75	0.74	0.77	0.76	0.74
Average Displaced Cost per Day ($)	3.30	3.24	3.37	3.33	3.24
Total Displaced Cost for Month ($)	42.88	100.48	104.55	99.86	6.48
Net Savings (Displaced Cost of Oil less Cost of Electricity)					
Average Net Savings per Day ($)	2.98	3.10	3.31	3.16	3.16
Total Net Savings for Month ($)	38.80	96.12	102.68	94.71	6.33

Cost of Heating Oil from Island Petroleum Website (gst incl.)

June 15	0.75
July 9	0.77
July 15	0.73
Aug 1	0.75
Aug 15	0.79
Sep 1	0.79
Sep 15	0.74
Oct 1	0.74

Notes:

- Solar water heater installed on May 27
- Turned boiler off on May 29
- Kilowatt-hour meter installed on June 18
- Absent from house for 4 days in July and 4 days in August
- Turned boiler on on October 3

Calculations

Although the solar water heating system was installed on May 27, 2009, the kilowatt-hour meter was not installed until June 18. Therefore, the supplemental electricity consumption data above which begins on June 18 will be prorated over the full 127 day period when the boiler was turned off.

Supplemental electricity consumption rate: 100 kWh/ 107 days = 0.93 kWh/day

Total electricity consumption for 127 days: 0.93 kWh/day x 127 days = 118 kWh

Appendix A.2 – Estimated Spring to Fall Oil Savings

The intent of the information in this appendix is to provide an estimate of the avoided oil consumption over the spring to fall period in 2009 resulting from the use of the solar water heating system. Any inaccuracy in completing the estimate arises from the reality that an oil-fired boiler with a tankless coil consumes fuel not only for the purpose of providing domestic hot water but also for the purpose of providing space heating. Therefore, when comparing oil consumption from the 2009 period to other periods, it is necessary to account for the variability in consumption relating to space heating.

Table 6, below, summarizes household oil deliveries for recent years that most closely correspond to the spring to fall period. As per the Table, there is a significant decrease in the volume of oil delivered during the 2009 period. It should also be noted that the 2009 period begins on April 21 which is approximately 5 weeks before the solar water heating system was installed. It would therefore be expected that the oil savings would be even greater if the solar water heating system had been installed earlier. (For the purpose of this estimate, however, the 5 week discrepancy will be disregarded. This will make the estimate more conservative than would otherwise be the case.)

Table 6: Spring to Fall Oil Deliveries

	2005	2006	2007	2008	2009
From	May 3	Apr. 21	Apr. 18	Apr. 22	Apr. 21
To	Dec. 21	Dec. 20	Dec. 31	Dec. 26	Dec. 26
Days	233	224	258	249	250
Litres	1,403	1,353	1,525	1,638	794
L/day	**6.02**	**6.04**	**5.91**	**6.58**	**3.18**
Please see the note at the bottom of this appendix.					

When comparing boiler oil consumption for periods in different years, it is necessary to account for the variation in outside temperature which, in turn, affects heating load and therefore oil consumption. An adjustment can be made to oil consumption by considering the number of heating degree days over the time period. Heating degree days are calculated by subtracting the outside temperature from 18 degrees Celsius. For example, an average daily temperature of 3 degrees would result in 15 heating degree days. Table 7, above, summarizes Environment Canada's heating degree day data for the Charlottetown Airport. (Data for the months of July and August has been omitted from Table 7 as there is little need for space heating during these months.)

Table 7: Celsius Heating Degree Days (Charlottetown Airport)

Month	2005	2006	2007	2008	2009
April	406.2	410.9	491.0	418.4	419.5
May	314.4	204.2	307.6	285.7	245.0
June	117.3	54.8	120.5	95.1	101.8
Sept	81.5	115.7	120.3	121.3	134.8
Oct	246.9	289.8	247.7	300.6	345.1
Nov	401.5	374.4	446.6	421.2	392.1
Dec	628.4	592.0	730.7	619.6	642.9
Total	**2196.2**	**2041.8**	**2464.4**	**2261.9**	**2281.2**

Table 8, to the right, indicates the adjustment factors that will be applied to the 2005 to 2008 consumption rates (in litres/day) in Table 6 for the spring to fall period. This is done to allow them to be compared directly to the period consumption rate for 2009.

Table 8: Adjustments to Period Oil Consumption Rates

	2005	2006	2007	2008
Unadjusted Rate (L/day)	6.02	6.04	5.91	6.58
Adj. Factor (%)	3.73	10.49	-8.03	0.85
Adj. Factor x 0.6	2.24	6.29	-4.82	0.51
Adjusted Rate	**6.15**	**6.42**	**5.63**	**6.61**
Average Adjusted Rate (L/day)	**6.20**			

The adjustment factors are then reduced to 60 percent of their original value because although space heating is influenced by heating degree days, domestic hot water consumption is not and it is entirely probable that the boiler would not be running in July or August for the purpose of providing space heating. (Keep in mind that this adjustment is applied only to account for the variation in space heating oil consumption relating to seasonal temperature variation. Because the oil consumed during the spring to fall period for domestic water heating is not influenced by seasonal temperature variation, the adjustment factor is intended to apply only to that portion of the delivered oil that is uses for space heating, hence the reason for reducing the adjustment factor to 60 percent of its original value.)

Here is a worked example using the 2005 period.

Unadjusted consumption rate = 6.02 litres per day

Adjustment factor = ((2281.2 – 2196.2)/2281.2) x 100 = 3.73 which means that in terms of heating degree days, the 2005 period required 3.73 percent less heating than 2009 period

Adjustment factor x 0.6 = 3.73 x 0.6 = 2.24

Adjusted rate = 6.02 + ((2.24/100) x 6.02) = 6.15 litres/day

As per Tables 6 and 8, the average spring to fall oil consumption rate of 3.18 litres per day for 2009 when the solar water heater was operating is considerably less than the average oil consumption rate of 6.20 litres/day for the 2005 to 2008 spring to fall periods. The difference is 6.20 – 3.18 = 3.02 litres/day. Therefore, it is estimated that the oil savings over the 250 day spring to fall period in 2009 (April 21 to December 26) is 3.02 litres/day x 250 days = 755 litres.

It is worth noting that this estimate does not consider any avoided oil consumption which will occur during the winter. While the solar water heating system is least efficient in the winter, it still produces some hot water.

One variable that has not been addressed in this estimate is that the homeowner typically burns three cords of wood per year in the Benjamin CC500 boiler (which is a combination wood/oil-fired boiler). However, very little wood is burned in the late-spring/ early-fall period and none is burned in the summer.

Note: The actual amount of fuel oil delivered to the household for the April 21/09 to December 26/09 period was 783 litres. However, 11 litres have been added to this amount to account for the boiler being bypassed while the data in Appendix A.3 was being collected. The rationale is below.

The period of overlap was December 14 to December 26 during which time 80 kWh of supplemental electricity was consumed to produce hot water. The oil equivalency of 80 kWh of electricity is as follows.

80 kWh x 3.6 MJ per kWh = 288 MJ

288 MJ / (38.2 MJ per litre of oil x 0.70 efficiency) = 11 litres of oil

Appendix A.3 - Supplemental Electricity Required in Winter 2009/2010 and Solar Fraction

Thermo Dynamics SB64-9PV Solar Boiler

Family of 4 (2 adults, 2 children ages 9 and 11)

Collector Angle: 39.2 degrees above horizontal
Orientation: Within 20 degrees of South

December 2009/January 2010
KiloWatt-Hours Used for Top Element of Bradford-White
Electric Heater/Storage Tank (245 L capacity)
Bottom Element is Disconnected/Boiler is Bypassed

Month/Year	Date	kWh	System Running	kWh on Days When System Not Running
Dec. 2009	14	3	No	3
	15	5	No	5
	16	7	No	7
	17	5	No	5
	18	5	No	5
	19	10	Yes	
	20	12	No	12
	21	4	No	4
	22	4	No	4
	23	8	No	8
	24	5	Minimal	
	25	6	Minimal	
	26	6	No	6
	27	9	Minimal	
	28	3	Minimal	
	29	6	No	6
	30	8	No	8
	31	4	Minimal	
Jan. 2010	1	8	No	8
	2	9	No	9
	3	10	No	10
	4	3	Minimal	
	5	3	No	3
	6	6	No	6
	7	7	No	7
	8	3	Minimal	
	9	10	No	10
	10	9	No	9
	11	4	No	4
	12	3	Yes	
Total	**30**	**185**		**139**
Total Days		**30**		**21**
Total kWh		**185**		**139**
Avg. kWh/Day		**6.17**		**6.62**

In normal operation, the upper heating element in the solar storage tank would be turned off during the winter when the boiler's tankless coil would provide the major portion of domestic hot water to the household - the solar water heating system would be used to reduce some of the load on the boiler by preheating the water being drawn through the tankless coil. However, to gain some indication as to how much electricity would be required to provide domestic hot water to the household if the electric water heater was the only source of hot water, the data in this appendix was collected by turning the upper heating element on and bypassing the boiler's tankless coil. This meant that domestic hot water was provided entirely by the solar water heating system and the upper heating element.

The weather for the 30 day winter period in December 2009 and January 2010 was characterized mostly by cloudy skies and flurries. As a result, there were 21 days when the pump on the solar water heating system did not run at all and the household's domestic hot water was provided only by the upper heating element in the solar storage tank. The average electricity consumption over these 21 days was 6.62 kWh/day.

In the electricity consumption data from Appendix A.1, it was determined that the average electricity consumption rate over the 127 day summer period was 0.93 kWh/day. This indicates that the balance of energy required to satisfy the household's domestic hot water needs was provided by the solar water heating system. Therefore, the solar fraction provided by the solar water heating system in the summer can be calculated as follows.

((6.62 – 0.90)/6.62) x 100 = 86 percent

For the 30 day winter period, there were 2 days when the circulating pump was running strongly and 7 days when it was running for short periods of time at reduced capacity. Therefore, it may be said that there were 9 days when at least some portion of the domestic hot water was provided by the solar water heating system. Over these 9 days, the average electricity consumption of the upper heating element was 6.17 kWh/day. Therefore, the solar fraction for the 30 day winter period may be calculated as follows.

((6.62 – 6.17)/6.62) x 100 = 7 percent