Feasibility of using an augmenting solar array for a greenhouse in NW Ohio

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Abstract

The idea of growing plants in environmentally controlled areas has existed since Roman times. By the first century A.D., the Romans were growing fruits and vegetables in simple greenhouses or cold frames. Green houses are a simple example of a green building, making use of renewable energy i.e. sunlight to grow plants during winter, when the temperature is too cold to grow the plants in open in northern latitudes. However often there is not enough sunlight to sufficiently warm the greenhouse in some areas without some additional heating. Such is the case in Northwest Ohio. One such Greenhouse uses natural gas to provide this additional heating. The burning of natural gas, incurs extra cost and furthermore, natural gas being a non renewable energy source, emits Carbon dioxide and hence contributes to global warming. Therefore, there is a need to eliminate or reduce the use of natural gas for this greenhouse. One solution proposed by the owners of the greenhouse was to use a solar collector array placed by the side of the green house to reduce the use of natural gas.

This paper describes the analysis carried out in collaboration with the greenhouse owners to see the feasibility of the use of the solar array. The analysis involved using the design provided to the owners by a consulting company. The study evaluated the design from the perspective of cost savings per year, due to reduced gas usage and against the cost of installation and maintenance of the solar array system. The results were then used to calculate the payback period.

Introduction

An agricultural greenhouse consists of frames of metallic or wooden structure covered with a transparent material which provides a suitable environment for the intensive production of various crops. All greenhouses collect solar energy. The basic operational principles of greenhouses include: collection of light and conversion to heat; storage of thermal energy; release of thermal energy; temperature moderation; controlled environment; and protection from severe weather and animals. A greenhouse is essentially an enclosed structure, which traps short wavelength solar radiation and stores long wavelength thermal radiation to create a favorable microclimate for plant growth. It is not a problem to maintain the temperature inside the greenhouse when there is sun during most times of day except in our (Northwest

Ohio) location where we get much snow during winter and there are less sunny days. Hence, there is a need of additional thermal energy to heat the greenhouse so we can maintain the required temperature for plants to grow.

Different renewable energy sources can be applied in heating the greenhouse such as geothermal, solar and biomass instead of using fossil fuels which are predominantly used up to now. The intent of this study is to analyze the new design of a greenhouse located at J.C. Reuthinger Memorial Preserve on Oregon Road in Perrysburg, Ohio. Currently the heat demand in the greenhouse is provided by heaters that burn natural gas. The main problem with this type of heater is the cost of the fuel. That is why owners decided to utilize a solar energy storage system in the greenhouse. As only low temperature heat is needed for preheating the air in the greenhouse, use of solar panels is proposed to be utilized in order to partially reduce heating demand of the heater thus reducing the amount of fuel consumption. The purpose of this study was to evaluate design of a new heating system for the greenhouse which incorporated solar panels, for its economic viability.

The greenhouse

The greenhouse is 30' X 96' in size and they mostly grow perennial plants. The greenhouse, shown in the Figures 1 and 2, is built with an aluminum frame system which is shrouded by clear plastic sheets. It is a double poly structure with air pumped between two layers. The temperature maintained inside the greenhouse for these plants is 60°F. The greenhouse use starts the first week of January and goes until the first week of June. Since this area faces a severe climate during the winter which starts from December and lasts until March, they needed to heat the greenhouse during this period.

In the proposed design, solar panels are to be used to collect the heat from sun as the first stage of heating. Solar energy collected by solar panels are then used to heat the fluid stored in drain-back tank which would then give power to natural gas heater to operate and heat the tube in heat exchanger thereby heating the floor of the greenhouse.

Figure 1: Exterior view of a greenhouse

Figure 2: Interior view of a greenhouse

Description of the system

A schematic diagram of the proposed heating system is shown in Figure 3.

Solar panels:
The proposed design consisted of five flat-plate solar thermal collector manufactured by Alternate Energy Technologies (AET). The selected solar collector system was chosen based on the availability in local market and domestic demand. Also aluminum flat-plate solar collector is popular one because of its low investment cost. The number of solar thermal collector panels that need to be installed had been determined according to the ground surface area of a greenhouse.

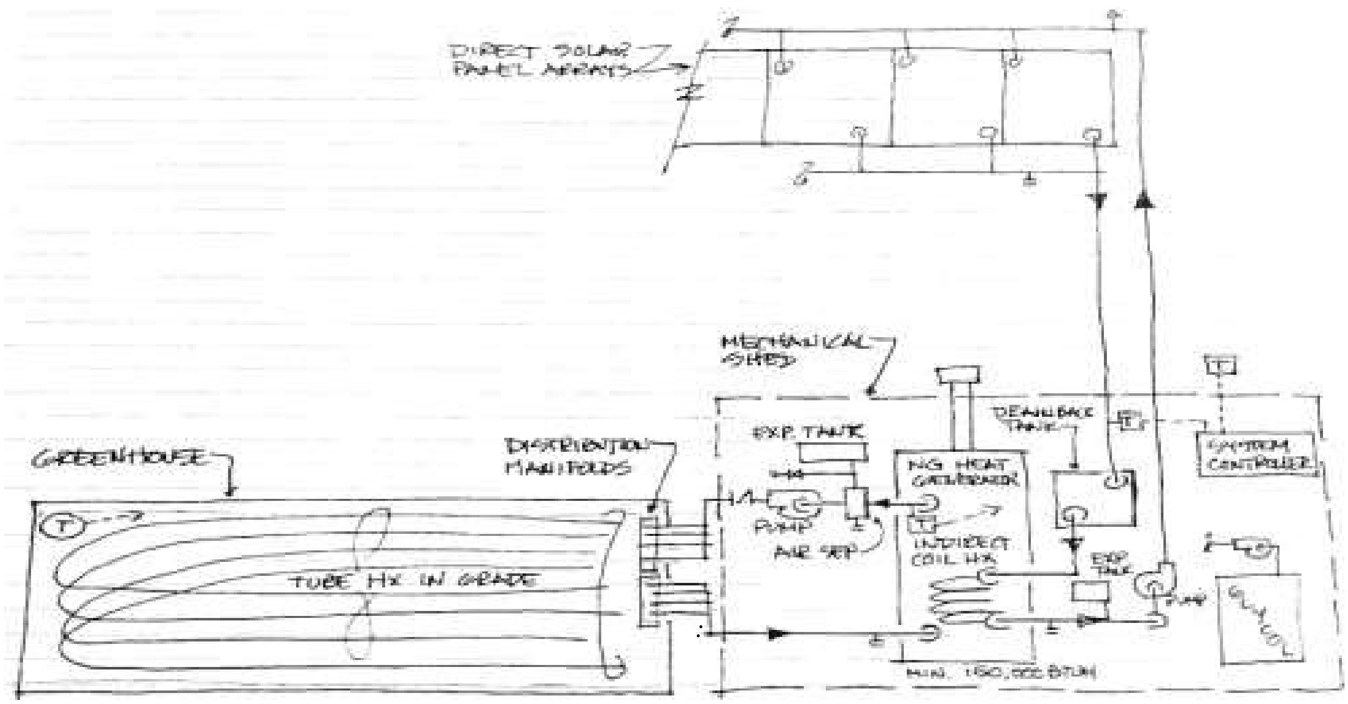

Figure 3: Proposed System Flow Diagram. (Source: Greenhouse owners)

Theory of Operation

As the sun starts to shine on the solar collectors, the collectors begin to heat up. This system has a differential controller that senses temperature differences between water leaving the solar collector and the coldest water in the tank. When the water in the collector is about 12° F warmer than the water in the tank, the controller turns on the pumps. When the temperature difference drops to about 3-5° F, the pump is turned off. In this way, the water always gains heat from the collector when the pump operates. The solar installer manually sets the differential temperature of the controller at the time of the system installation. The pumps are very quiet.

The system collects heat by circulating the water in the collector loop through the collectors, the drain-back reservoir and a heat exchanger. When the pumps turn on, the water in the collector loop is circulated through the solar collectors, where it is heated. The return water from the solar collectors passes through the drain-back tank and to the heat exchanger. The heat exchanger gives up the collected heat to the water in the main underground heat exchanger. The now cooler water is returned to the collectors to continue to collect heat. When there is no longer a marked difference between the temperature at the solar collector and at the solar storage tank (4° F) the controller automatically turns the pumps off – since there is no heat to be gained. This process is repeated continually throughout the day. This is all done automatically and requires no interaction on the part of the system owner. Drain-back systems provide a fail-safe method of ensuring that collectors and collector loop piping never freeze by removing all water from the collectors and collector piping loop when the system is not collecting heat. Freeze protection is provided when the system is in the drain mode. Water in the collectors and exposed piping drains into the insulated drain-back reservoir tank each time the pump shuts off. A slight tilt of the collectors is required in order to allow complete drainage. A sight glass attached to the drain-back reservoir tank shows when the reservoir tank is full and the collectors have been drained. For this reason the Drain-back system is protected from freeze damage at all temperatures.

Methodology

The basic idea was to compare two ways of greenhouse heating system i.e. the conventional fossil-fuel system and a hybrid system in which part of the heating demand was covered by solar collectors, heat storage and a heat pump. The economic feasibility to heat the greenhouse in two different ways was analyzed.

<u>Data collection</u>:

The data collection for the evaluation of the project were done in following areas:

- The monthly averaged, mean maximum and mean minimum temperature through the month of January 2014 to July 2014 were collected. The weather data obtained were used to calculate the greenhouse's thermal need. This data was obtained from commercial database and from the internet source Accu weather.
- The price of natural gas during the recommended period of time was also obtained from Columbia Gas of Ohio, the local gas supplier company.
- Equipment prices for the installation of solar panels were obtained from the manufacturer recommended by the designer. For all the systems, mean costs with reference to a greenhouse ground-surface area of 2,700 sq. ft. were used. This is the actual ground surface of the greenhouse which was being analyzed.
- For the evaluation of new proposed design, the solar system cost, installed collector surface area and operating cost were obtained from the manufacturer and the suppliers.

Energy and cost analysis:

Using all the parameters mentioned, the total thermal needs, the part covered by the solar panel system and the life-cycle costs of two heating system was calculated. Life-cycle cost is the sum of all the costs associated with an energy system, in this case, investment, fuel, electricity and maintenance during its lifetime at today's dollar value.

Analysis and results

Weather Model:

Table 1 shows the the average temperature during the 6 months and the remaining temperature needed to be raised to keep the greenhouse at 60 °F.

Table 1: Data showing temperature difference each month.

Months (2014)	Temperature we need to maintain (°F)	Actual average temperature (°F)	Remaining temperature needed to be raised (°F)
January	60	25.84	34.16
February	60	18.92	41.08
March	60	29.75	30.25
April	60	49.75	10.25
May	60	61.69	-1.69
June	60	72.25	-12.25

Fuel consumption and costs:

Figure 4 shows the location of the two gas heaters currently used to heat the greenhouse in winter.

Figure 4: Location of heaters inside the greenhouse (Source: J.C Reuthinger Preserve, Oregon Road,OH)

The fuel consumed for the six months of year 2014 is shown in Figure 5. The information about the fuel consumed was obtained from gas bills of each month for the year 2014. It was also found that the unit price of gas supplied by Columbia gas of Ohio varied every other month. Data on the fuel consumed every month and the estimated unit rate of natural gas, was used to calculate the cost incurred each month for the consumption of gas and that is provided in Table 2. From the Table 2 it can be observed that the month of February had the most consumption of fuel and it was also evident from the Table 2 that it was the coldest month during that year.

Heat loss and temperature and fuel consumption analysis:

Only about 80-85% of heat produced by heaters is used for heating the space and remaining 15-20% is lost through the ground, covering material and other related avenues [1] . Since the greenhouse being analyzed has two layers of plastic covering, based on published literature [1] , it is assumed that 15% of heat is wasted.

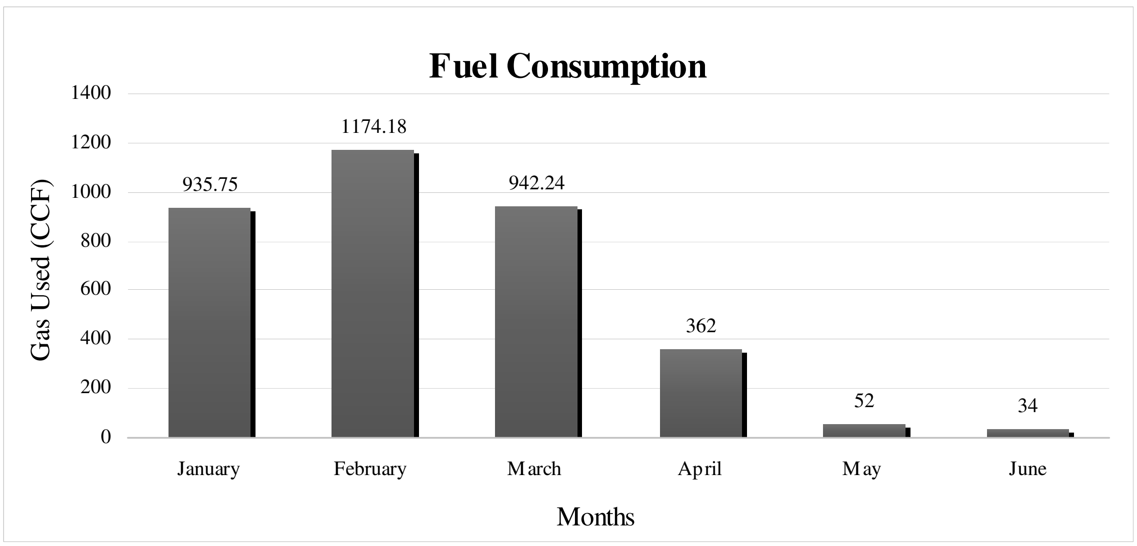

Figure 5: Chart showing fuel consumption for first six months of year 2014

Using the information on the temperature required, the actual temperature, the fuel consumption and the heat loss percentage, the amount of gas used and its cost was determined to maintain the temperature regardless of the fuel used for heat loss and is shown in Table 3. In Table 3 the actual gas used (A) is 85% of total gas used (T).

Table 3 helps us to understand how much fuel was needed to raise the required temperature to 60 degree Fahrenheit in each month assuming a 15% heat loss. It is clear from Table 3 that February, being the coldest month, required the most fuel whereas June, being the hottest month, had the least amount of fuel consumption. There actually wasn't any fuel used for heating during the month of May and June, the numbers for cost and fuel consumption associated with these months were the least cost one had to pay even when no fuel was used at all. This data was used in further calculation and analysis during the later part where the heating was partially replaced by the solar panels.

Table 2: Table showing historic rates in $/CCF (Source: Columbia gas of Ohio, 2014)

Billing Period End Date (2014)	Rate ($/CCF)	Fuel Consumed (CCF)	Total amount ($)
January	$0.5697	935.74	$533.09
February	$0.6547	1174.18	$768.73
March	$0.6145	942.24	$579.00
April	$0.5984	362	$216.62
May	$0.5821	52	$30.26
June	$0.58	34	$19.72

Table 3: Data on temperature and fuel consumption with heat loss in consideration.

Month	Temperature required to raise (°F)	Total Gas used = T (CCF)	Actual Gas used for raising temperature = A (CCF)	Cost incurred in actual Gas (A) used to raise temp.
January	34.16	935.74	795.37	$ 453.12
February	41.08	1174.18	998.05	$ 653.42
March	30.25	942.24	800.90	$ 492.15
April	10.25	362	307.7	$ 184.12
May	-1.69	52	44.2	$ 25.72
June	-12.25	34	28.9	$ 16.76

<u>Heat calculations using solar panels</u>:

The use of five solar panels of size 4' X 8' was based on the ground coverage of the greenhouse which is about 2,700 sq. ft. The storage capacity of the 150 gallons of drain back tank was also based on the surface that needed to be heated (i.e. 27,000 sq. ft).

In order to calculate the reduction in fuel due to the use of solar panels, it was required to determine how much heat could one solar panel produce. This information was provided by the expert engineers from Radiant Tech Flooring who has been working in the industry for more than 20 years. According to them, AET 4' x 8' solar panel when exposed to continuous sun for five hours a day can produce about 30,000 BTU of energy. Being in northwest Ohio, it is quiet impossible to get that amount of sunlight during winter every day.

National Renewable Energy Laboratory has monitored the hourly values of direct beam and diffuse horizontal solar radiation in various cities of United States for 29 years from 1961-1990. They have published a table for various cities to show how much direct sunlight a solar flat plate collector received for a given tilt per day[2].The values for Toledo, which is adjacent to Perrysburg, are given for each month. So values for Toledo were used. Therefore, the amount of heat generated each month could be calculated and is shown in figure 6.

The next step was to calculate the amount of heat energy that was required every month to heat the water in the drain back tank to maintain the required temperature. An example of this calculation for the month of January is as follows:
Temperature required to maintain (T) = 60°F
Amount of water needed to be heated (W1) = 150 gallons
1 gallon of water = 8.33 pounds (lbs.)
So, 150 gallons of water (W) = 1249.5 lbs.
Initial temperature in January (T0) = 25.84°F
Temperature difference (ΔT) = T- T0 = 60-25.74 = 34.16°F
Percentage of heat loss to be considered (H0) = 15%
Let the energy required to heat the water to desired temperature without heat losses = Z
$Z = W * \Delta T$
Hence,
Z =1249.5 *34.16 = 42682.92 BTU
Let the energy required to heat the water to desired temperature with heat losses = P
Adding the 15% heat loss factor,
P = 49085.35 BTU

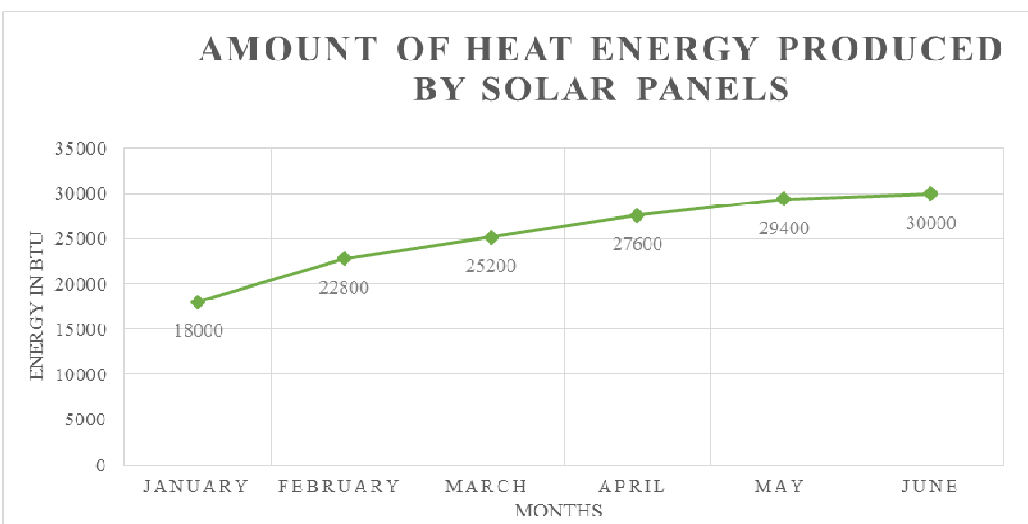

Figure 6: Chart showing amount of heat energy produced by solar panel each month

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This was the actual amount of heat required in January to maintain the temperature of 60°F but the amount of energy produced by solar panel during this month was only 18,000 BTU which can be seen in Figure 6. So, the rest of the energy, which was 31,085.35 BTU, still is needed to be provided by the gas heaters. By the calculation shown below, it would be clear how much temperature can 18,000 BTU raise which is the amount solar panel could produce in month of January.

Energy produced (E) = 18,000 BTU
Water weight (W) = 1249.5 lbs.
Temperature = TT
TT = E/W = 18,000/1249.5 = 14.40°F
For the month of January, the average temperature is 25.84 (from Table 1)
So the temperature achieved through solar panel = Average temperature + TT = 5.84+14.40 = 40.24°F

It was clear that 18,000 BTU could only raise the temperature to 40.24°F from 25.84°F and we still needed to raise additional (60 - 40.24) =19.76°F. To achieve this additional heat was then supplied by the existing natural gas heaters. The amount of gas and the associated cost was then determined to be 460.01 CCF and about $262.06. Similarly the energy required for rest of the months and the cost associated with it can be seen in Table 4.

Table 4: Data on heat energy required, fuel consumed and cost associated for each six months.

Month	Heat required to maintain the temp. + 15% heat loss (BTU)	Actual heat produced by Solar Panel (P) (BTU)	Temp. raised by Heat P (°F)	Remaining temp. (Tr) (°F)	Fuel consumed to raise Tr (CCF)	Cost associated with fuel ($)
Jan.	49,085.35	18,000	40.24	19.76	460.01	262.06
Feb.	51,329.46	22,800	37.16	22.84	554.78	362.82
Mar.	37,797.37	25,200	49.91	10.09	267.08	163.98
Apr.	12,807.37	27,600	71.83	-11.83	0	0
May	-2428.40	29,400	85.21	-25.21	0	0
June	-17602.33	30,000	96.25	-36.25	0	0

Comparison between the two heating systems:

Using the findings reported in above paragraphs, the costs and savings can be compared if the solar heating system is installed. This data is summarized in Table 5, and graphically presented in Figure 7.

So, from Table 5 it is clear that after the installation of solar panel the amount of fuel consumption went down then before and in six months the owners would be able to save $1,036.43 in their gas bill. However, we also needed to take the installation cost of the solar panel and its components in account to calculate the payback period. The comparative chart can be seen in Figures 7.

Table 5: Comparison between two heating systems.

Month	Conventional Heating System(A)		Solar Panel based Heating System (B)		Total Saving
	Fuel Consumed	Total Cost	Fuel Consumed	Total Cost	Saving cost (A-B)
Jan.	795.37 Ccf	$453.12	460.01 Ccf	$262.06	$191.06
Feb.	998.05 Ccf	$653.42	554.78 Ccf	$362.82	$290.60
Mar.	800.90 Ccf	$492.15	267.08 Ccf	$163.98	$328.17
Apr.	307.7 Ccf	$184.12	0	0	$184.12
May	44.2 Ccf	$25.72	0	0	$25.72
June	28.9 Ccf	$16.76	0	0	$16.76
	Total				$1,036.43

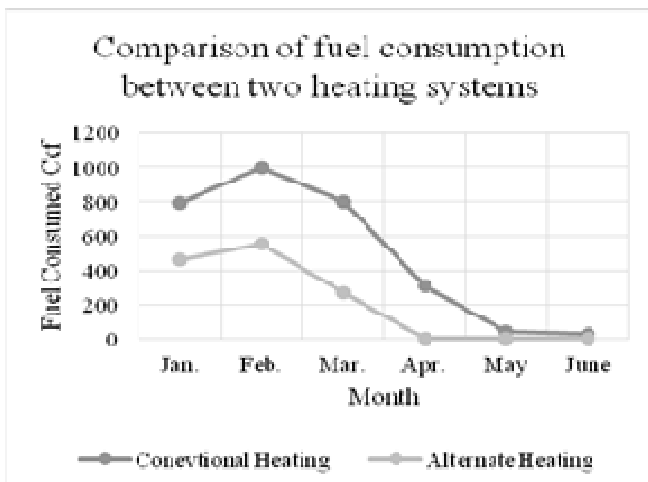

Figure 7: Comparative chart of fuel consumed.

Discounted Payback period:

The cost of the project which in our case was the installation cost of solar panel and its components and was obtained from from the manufacturers. The breakdown of the price obtained from the manufacturer is shown below:

5 – 4’ X 8’ Solar Collector $7,826
Mounting hardware & Strut $600
150 gallon storage tank $1,500
Plumbing Mechanical Package $525

Pumps	$500
Passive Solar heat exchanger	$2,500
Labor cost for installation	$4,500
Misc. Components	$1549
Total =	$19,500

Discounted payback period accounts for time value of money by discounting the cash inflows of the project [3]. The discounted cash inflow for each period is to be calculated using the formula:

Discounted Cash flow = $CF/(1+i)^n$

Where,
CF = Actual Cash flow
i is the discount rate;
n is the period to which the cash inflow relates.

The rest of the procedure is similar to the calculation of simple payback period except that we have to use the discounted cash flows as calculated above instead of actual cash flows. The cumulative cash flow will be replaced by cumulative discounted cash flow [3].

Discounted Payback period = $A+\frac{B}{C}$

Where,
A = Last period with a negative discounted cumulative cash flow;
B = Absolute value of discounted cumulative cash flow at the end of the period A;
C = Discounted cash flow during the period after A.
Now, calculating the discounted payback period using our values,
Initial investment = $19,500
Annual Saving each year = $1036.43
Discount rate/interest rate = 5% (most commonly used)
Years = 18 yrs. (From simple payback period)

The calculated discounted cash flow of each period and cumulative cash flow is shown in Table 6.

From Table 6, Last period with a negative discounted cumulative cash flow (A) = 17 yrs.
Absolute value of discounted cumulative cash flow at the end of the period A (B) =$7823.57

Discounted cash flow during the period after A (C) = $430.118

Discounted Payback period = $A+\frac{B}{C}$

Discounted Payback period = 17 + (7823.57/430.118) = 35.18 years.

Thus, the discounted payback period is almost 35 years.

Table 6: Cumulative discounted cash flow table.

Year (N)	Cash Flow (CF) ($)	Present Value Factor ($) PV= $1/(1+i)^n$	Discounted Cash Flow =CF x PV ($)	Cumulative Discounted Cash Flow
0	-19,500	1	-19500	-19500
1	1036.43	0.952	986.6814	-18513.31864
2	1036.43	0.907	940.042	-17573.27663
3	1036.43	0.863	894.4391	-16678.83754
4	1036.43	0.822	851.9455	-15826.89208
5	1036.43	0.783	811.5247	-15015.36739
6	1036.43	0.746	773.1768	-14242.19061
7	1036.43	0.71	735.8653	-13506.32531
8	1036.43	0.676	700.6267	-12805.69863
9	1036.43	0.644	667.4609	-12138.23771
10	1036.43	0.613	635.3316	-11502.90612
11	1036.43	0.584	605.2751	-10897.631
12	1036.43	0.556	576.2551	-10321.37592
13	1036.43	0.53	549.3079	-9772.06802
14	1036.43	0.505	523.3972	-9248.67087
15	1036.43	0.481	498.5228	-8750.14804
16	1036.43	0.458	474.6849	-8275.4631
17	1036.43	0.436	451.8835	-7823.57962
18	1036.43	0.415	430.1185	7393.46117

Conclusion

With the installation and operation of solar panels we could see that for the first three months of 2014 , the owners would be able to reduce the fuel consumption. But since the temperature rose after April there was a need to vent out excess heat to maintain the temperature. Thus it may be better that instead of heating the greenhouse from January, the owners could start up the heating with the solar panels from November as it is quite evident that temperature starts to fall in Northwest Ohio from these months.

However, the payback period of more than 35 years is excessive, and so the owners may not want to invest in this venture.

References

[1] Karlsson, M., & Wayne, V. (2014). Controlling the Greenhouse Environment. Kenai: University of Alaska.

[2] Marion, W., & Wilcox, S. (1994). Solar Radiation Data Manual for Flat- Plate and Concentrating Collectors. Golden, Colorado: National Renewable Energy Laboratory.

[3] AccountingExplained (2013): http://accountingexplained.com/managerial/capital-budgeting/discounted-payback-period

Biographies

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