# Payback Analysis of a Solar Hot Water System for 3500 NE Mallory Ave, Portland, OR

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## Objective:

The objective of this study is to analyze the economic feasibility of a solar hot water system for a single family residence in NE Portland, OR.

## Background:

The intent of this study is to determine the economic feasibility of installing a solar hot water system on a residence in Portland, OR. The study considers performance of a specific solar hot water system for a single home located on the 3500 block of NE Mallory Ave. Along with monthly calculations of incident solar radiation, the analysis also considers shading of the collector by nearby buildings, domestic water use demand, and monthly averaged city water supply temperature. Due to demands of the resident and space constraints, only a roof mounted system was analyzed. Analysis was also restricted to a single tilt angle of 32 degrees, which matches the pitch of the roof. Since this angle is very close to the regional design guideline of 30 degrees, use of a modified angle is not warranted.

With performance of the collector calculated, a payback and sensitivity analysis was conducted. The resident intends to use a backup electric water heater with the solar system. This allows for a comparison of the energy generated by the solar collector to the electrical energy that must be used for backup heating. All savings are compared to a baseline cost of supplying all hot water with an electric heater. The resident intends to only purchase a solar hot water system if the payback period is less than 20 years.

## System Design:

### Domestic hot water requirement

The daily hot water consumption (gallons) for this residence was estimated using a model developed by the Lawrence Berkeley National Lab (Lutz 1996). This model estimates daily residential hot water use per person. Factors considered in the model include: number of occupants, age of occupants, use of clothes washer and dishwasher, and period of the day during which residents occupy the space. The resulting analysis based on 1.5 occupants (current occupancy of the residence) estimates a daily hot water load of 22.7 gallons per person.

### Supply water temperature

Local water temperature data was used to estimate the monthly energy demand for hot water heating. Water temperature data was obtained from the city of Portland. The data was available from a measurement station roughly 3 miles from the residence.

**Shading Analysis**
A shading analysis was performed to evaluate the impact of nearby buildings on collector performance. Figure 1 shows the context of the residence (building A). There are only two buildings, B and C, that are tall enough to potentially shade the roof of building A. Geometric analysis was performed to calculate the altitude and azimuth angles for which buildings B and C will shade building A and is shown below in Figure 2. Note that the azimuth shading between A and C is only performed for angles between zero and -90 degrees (with angles west of south defined as positive). It should be noted that calculations of the incident solar radiation on the collector account for the fact that sun angles less than -90 degrees will provide no direct beam radiation to the collector.

Once the appropriate shading angle ranges were determined, the hourly radiation data (from a TMY3 weather file) was corrected for the shading periods. A code was implemented to identify periods of the year that yielded a solar azimuth of +/- 35.7° and an altitude of 0° to 12.4° (for A-B shading) as well as an azimuth of -90° to -43° with an altitude of 0° to 9.3° (for A-C shading). During these periods, the incident direct beam radiation on the collector was set to zero.

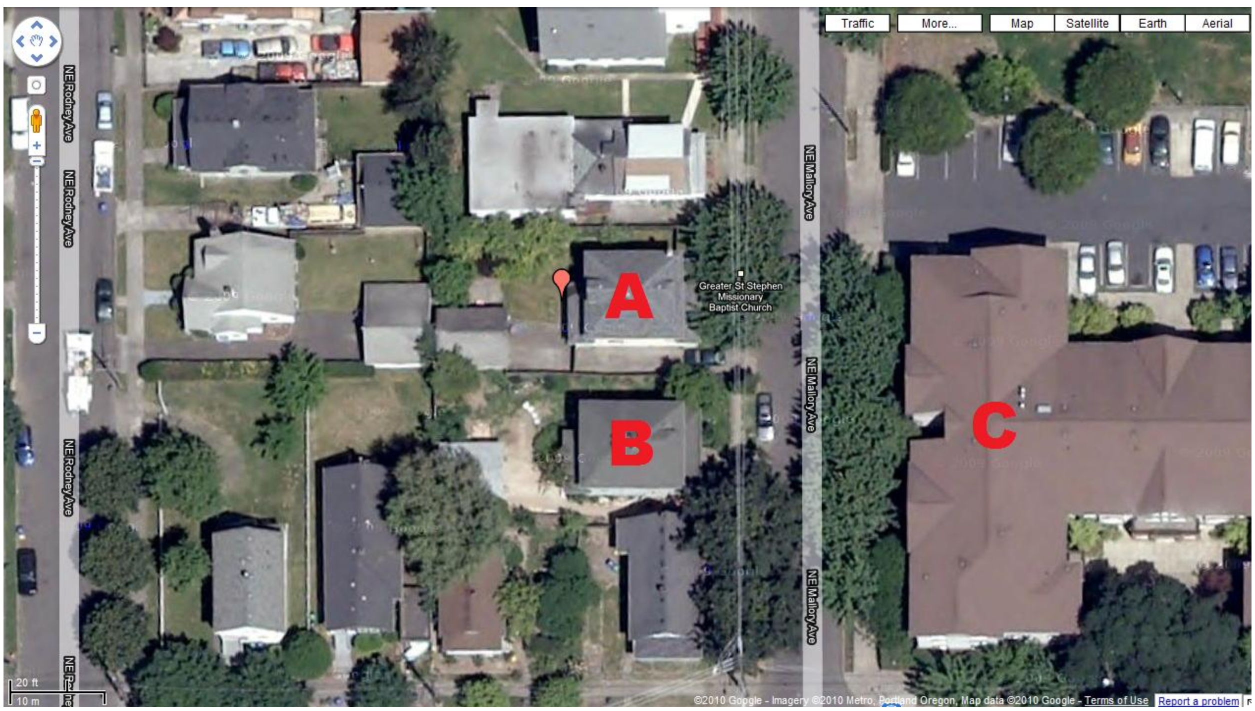


**Figure 1: Site context of residence. Building A is residence, buildings B and C are tall enough to shade the roof of building A.**

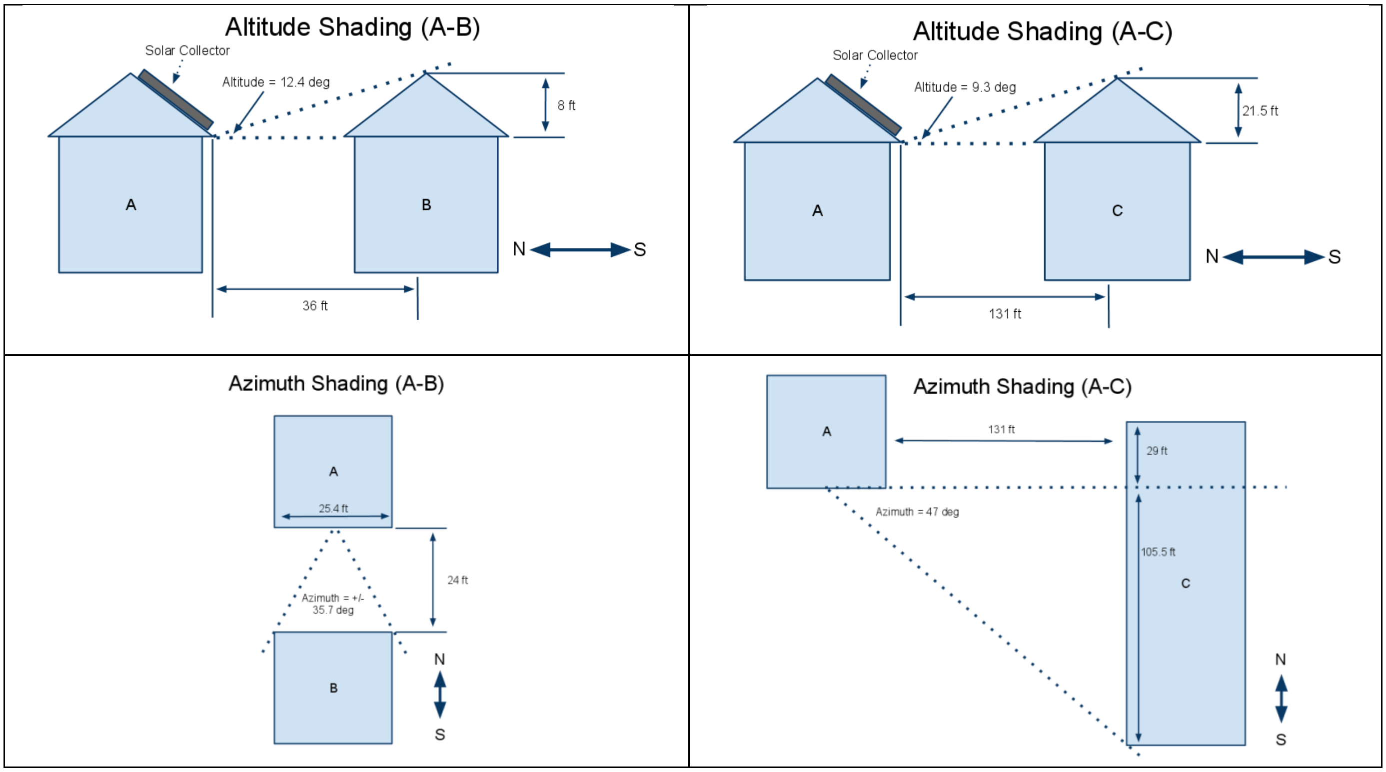


Figure 2: Shading calculations for building B and C.

**Solar Resource analysis**

Before calculating collector performance parameters, the annual solar radiation characteristics for the site were determined. Solar radiation data was obtained for the Portland International Airport from a TMY3 weather data file. Using methods outlined in Principles of Solar Engineering (Goswami 2000), the incident energy on the solar collector ($I_C$) was calculated for each hour. This data was then adjusted to account for shading as discussed above. The shading adjusted $I_c$ was then used to develop a monthly radiation profile. Figure 3 shows a comparison between shaded and baseline monthly collector insolation. The greatest decrease of 3.4% occurs during the month of January. The small decrease is due to the low altitude angles associated with the obstructing buildings, coupled with the fact that the majority of solar energy is collected during high-altitude-angle summer months.

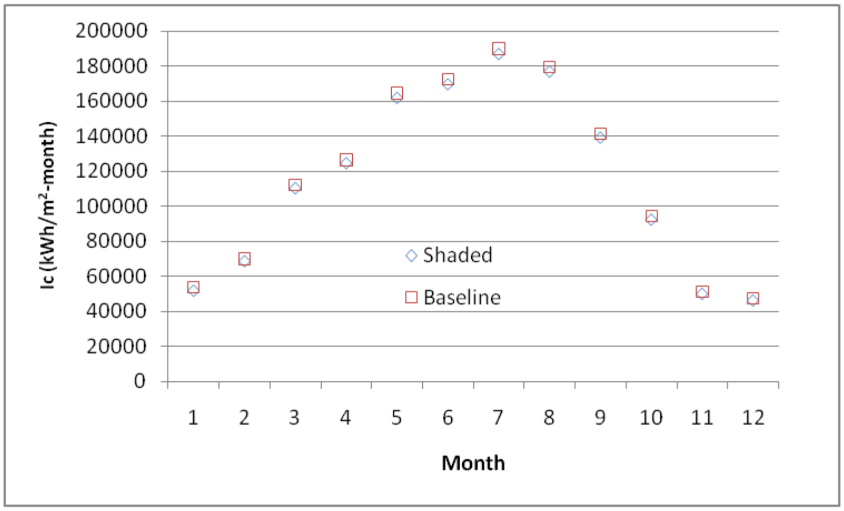


Figure 3: Monthly radiation incident on collector before and after shading analysis.

**Monthly solar collector performance calculations**

Solar collector performance was analyzed using a monthly f-chart method (Goswami 2000). This method is based on detailed simulations for various system configurations that have been correlated to dimensionless parameters. The f-chart analysis performed was for a commonly used closed loop glycol system. A heat exchanger is used to transfer energy from the solar collector glycol loop to the domestic water storage tank. An electric hot water heater is still used to supplement the solar system.

Before beginning the f-chart analysis, a suitable solar collector was selected. The model chosen as a baseline has the follow specifications:

Manufacturer: Vaillant GmbH
Model: VFK 150 H
Y Intercept: 0.776
Slope: -3.464 $W/m^2$ °C

Initial performance analysis was calculated assuming the following baseline system parameters:

Number of occupants: 1.5
Daily Water Use: 22.7 gallons per person
Number of collectors: 2
Water Delivery Temperature: 60 °C
Flow Rate: 53 ml/s per collector
Storage Volume: 75 liters

**Economic Analysis**

An economic analysis was performed to determine the payback period for this system in Portland, OR. The following estimates were made regarding the initial cost of the system:

Cost Per Collector: $2300
Installation Cost: 1000 + 500*(number of collectors)
Storage Tank: $500

Pumps, Controls and Plumbing: $1400
Total Initial Cost: $8500

This is the cost that must be “paid back” by the homeowner. In this case, the homeowner has the capital to cover the initial cost of the system. The homeowner would like to invest this money in the home, and will be considering other home improvements if solar water heating is not installed. With this mind, a simple payback model was used to calculate the time period required to cover the installation cost.

Other factors contributing to the homeowner’s out of pocket expense are the incentives available for solar collectors in Portland, which are:

Energy trust: $0.40 per kW-h saved by solar collector, up to $1500 (discount on install cost)
State of Oregon: $0.60 per kW-h saved, up to $1500
Federal Tax Credit: 30% of out of pocket cost
Total Savings: $4311

All incentives were considered in the payback analysis under the assumption that the homeowner has a sufficient tax appetite to take advantage of all available incentives.

The cost of energy was also considered. Instead of using a flat utility rate of $0.07/KW-h, an escalating rate was chosen. The initial estimated utility inflation rate was chosen at 2%.

An initial economic analysis was performed with the following baseline parameters:

Electricity Cost: $0.07/KW-h
Inflation Rate: 2%
Installed System Cost: $8500
Net out of pocket cost: $4189

This analysis yields a payback period of 26 years.

**Sensitivity Analysis**

A sensitivity analysis was conducted to study the impact of various parameters on the overall system payback period. Payback period was chosen as a baseline for the sensitivity analysis because it allows both performance parameters and economic parameters to be varied and compared. Table 1 outlines the parameters that were varied in the sensitivity analysis. The number of collectors was chosen based on typical installations in Portland, OR and available rooftop area. The number of occupants has been varied to consider a realistic occupancy scenario for the current family living in this residence. Water delivery temperature was chosen at 60 °C which is a commonly used setpoint, although many homeowners are beginning to lower their setpoint to 50 °C (EERE 2010). The utility cost was initialized at $0.07/KW-h, with varying rates of inflation. The current electricity inflation rate is estimated to be about 2%, but changing demand for energy may result in increasing inflation rates over time. Figure 4 shows results of sensitivity plots for the parameters discussed above.

**Table 1: Values used in sensitivity analysis of solar collector payback period.**

| Parameter | Baseline Value | Value 2 | Value 3 |
|---|---|---|---|
| Number of collectors | 2 | 1 | 3 |
| Number of occupants | 1.5 | 2.5 | 3.5 |
| Water Delivery Temp | 60 C | 55 C | 50 C |
| Energy Inflation Rate | 2% | 4% | 6% |

Number of Collectors

Observation of the payback sensitivity to changes in the number of collectors reveals that if excess collectors are installed (going from 2 to 3 collectors), there is a 23% increase in the payback period. This is contrasted by the change from 1 to 2 collectors, with an associated payback increase of 7.7%. This behavior is expected, because if too many collectors are installed their increase in energy generation will not be necessarily met by an increase in hot water demand. If fractional collectors could be installed, the optimal number of collectors for the baseline analysis would be something less than 1 collector.

Number of Occupants

Sensitivity to the number of occupants shows that an increase in occupancy results in a reduced payback. Increasing occupancy from 1.5 to 3.5 occupants yielded a 38.5% reduction in payback. This reduction is associated with the increased demand for hot water and ability of the household to utilize all of the energy produced by the system. The trend seen in this plot illustrates a possible exponential relationship between occupancy and payback period for the baseline system. This trend is likely related to the optimal system size (i.e. number of collectors) for a given occupancy. If occupancy were increased to infinity, the payback period would quickly reach a steady value. This plot appears to suggest an optimum occupancy of 4 or more given the baseline system with 2 collectors.

Delivery Temperature

Sensitivity to delivery temperature shows an increasing payback as the delivery temperature is decreased. This counterintuitive result can be explained by a couple of factors. First, as the water delivery temperature is decreased, the energy required for a traditional electric system decreases proportionally. The cost savings of the solar system are now based on a lower electric heating cost. Therefore, the savings gained through use of a solar collector are lower, and the payback period increases. This increase in payback is amplified by a second factor – the nature of the economic incentives offered by the Energy Trust and the state of Oregon. Both of these incentives base savings on the estimated KW-h of energy saved by the solar collector. With decreased savings, the out-of-pocket cost of the collector is increased due to the decrease in incentives.

Energy Inflation Rate

As expected, the sensitivity to energy inflation rate shows a decreasing payback as inflation rate is increased. A change in inflation rate from 2% to 6% results in a 27% decrease in the payback period.

Alternate Collector

A collector with different specifications was selected to investigate the effects of a lower y-intercept and a steeper slope on overall performance and payback period. The specifications are as follows:

Manufacturer: Alternate Energy Technologies

Model: MSC-21E

Y Intercept: 0.655

Slope: -6.370 $W/m^2\,°C$

The payback period for this collector is 34 years which is approximately 31% longer than the baseline collector case.

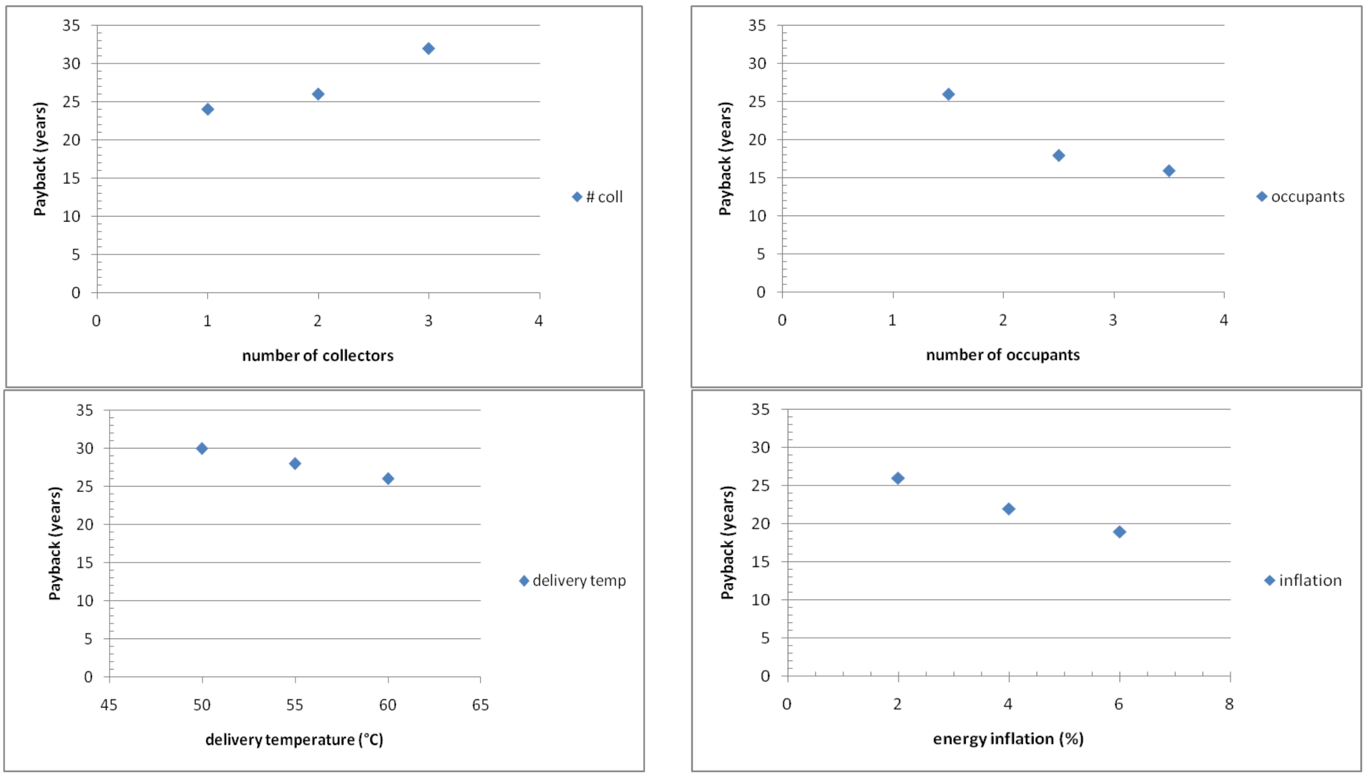


Figure 4: Sensitivity of payback period to number of collectors, occupancy, delivery temperature and energy inflation rate.

## Summary and Conclusion:

Based on the sensitivity analysis documented above, it appears the payback period can be minimized by selecting a system with 1 collector, and a 60 °C delivery temperature. Although a better payback may be attained with more occupants, it is not practical for the homeowner to add additional occupants to the household.

An interesting observation of this study was that shading of the site did not impact the solar collector performance due to the time of year and day during which the collectors are shaded. This emphasizes the importance of conducting a site analysis and shows that even a seemingly shaded site may be suitable for solar.

The preceding analysis and discussion illustrates the regional dependence of solar water heating. For example; if the homeowner chooses to move to a region with higher electric rates of $0.15 KW-h (such as Boston, Mass), the payback period would be reduced to 13 years. When conducting a solar analysis it is imperative that all of the regional factors be considered in order to fully understand the economics of a solar collector system.

For this analysis of Portland, OR – with consideration given to the occupant's constraints, the minimum estimated payback period is 24 years. Based on this result, the homeowner has decided to upgrade their kitchen with granite counter tops instead of installing a solar hot water system.

**References:**

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