# A Solar Hot Water Sizing and Payback Calculator: an innovation based on hot water consumption models

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## ABSTRACT

Solar hot water heaters can provide a significant fraction of the U.S. residential energy budget. However, to do so, the solar hot water industry must overcome barriers hindering adoption rates. This paper addresses two such barriers with the development of a calculator to allow interested residents to accurately estimate system size and financial payback of solar hot water heaters based on their average daily hot water consumption. The first barrier to residential hot water usage is the general lack of awareness of individual energy needs and how they can be met most economically. In using this calculator, residents will begin to see how they can save significantly on water heating costs and how their hot water consumption affects these costs. To remedy a second market barrier, this calculator enables residents to accurately assess the solar collector area needed for their specific hot water demand. Presently, installations of oversized solar hot water heaters have impaired financial returns and could tarnish the solar industry if left unchecked. Many existing calculators have attempted to spread awareness through system size and financial calculations but fail to predict them accurately. My calculator adds unparalleled accuracy over existing calculators and is the first time a detailed hot water use model is used to estimate collector area and payback period. My calculator is applicable to a broad range of geographic locations, but in this paper, I assessed its accuracy in residential homes in Berkeley, Ca.

## KEYWORDS

payback period, collector area, hot water use, residential hot water demand, natural gas

## INTRODUCTION

In recent years, the U.S. depletion of conventional energy sources, such as coal and oil, and their adverse impact on the environment have created a growing demand for the application of renewable energy. Replacing conventional fossil fuels with renewable energy significantly reduces greenhouse gas emissions and other environmental harms, such as air pollutant emissions, acid rain, and invasive resource extraction practices (U.S. DOE, 2003). Acknowledging the need for both renewable and cleaner fuels, states, such as California, are leading the way to renewable energy independence (Ghanadan & Koomey, 2005). For instance, California's Senate Bill 1, the California Solar Initiative, provides for the allocation of government rebates to encourage the use of solar technology and to combat climate change (Fuller, Kammen, & Portis, 2009).

Solar hot water heaters (SWH) represent one such solar technology capable of cutting significant greenhouse gas emissions. As a well-developed, renewable technology and relatively low-tech system, solar water heating (SWH) systems provide an efficient method for using the sun's energy to heat water (U.S. DOE, 2003). Unlike traditional natural gas heaters, SWH systems source the majority of the energy needed to heat water from the sun (Hughes, 2009). This "free" energy from the sun significantly cuts down on natural gas consumption, as sunlight displaces natural gas as an energy source. In the state of California, if 80 percent of its residential hot water were sourced from SWH systems, California could potentially reduce its carbon dioxide equivalent ($CO_2e$) by 6.8 million metric tons per year, or the equivalent of the pollution emitted by 1.2 million cars annually (Del Chiaro & Telleen-Lawton, 2007). This reduction in emissions represents about 5 percent of the cuts necessary to meet California's Assembly Bill No. 32 target for reducing greenhouse gas emissions to 1990 levels by 2020 (Del Chiaro & Telleen-Lawton, 2007). Thus, SWH systems are carving a niche in the energy market – specifically, the residential hot water market, which accounts for 20 percent of total energy use in the residential sector (U.S. EIA, 2005).

Although a technologically and environmentally feasible option, SWH system's economic feasibility remains largely unknown to residential populations (Sinha & Tiwari, 2007). Despite the verity that virtually any building with a sun exposed roof can have solar hot water and take advantage of notable savings on annual heating costs, fewer than one percent of California buildings have systems installed (Del Chiaro & Telleen-Lawton, 2007; Frantzis, Goffri, Paidipati, Sawyer, & Moffat, 2010). The basis for this under adoption of SWH technology is two-fold. First, hot water heating remains one of the least apparent uses of energy consumption in the home, overshadowed by more obvious uses of energy, such as space heating, air conditioning, and lighting (Fitzmorris, 2010; Margolis & Zuboy, 2006; Mayer, 1999; Zuboy, 2006). Residents continue to be naive to the factors affecting their hot water heating bill, such as age of residents in their home, choice of appliances, and water heater temperature setting. Additionally, the economic reward that solar hot water heating has over conventional natural gas heating goes unnoticed. Second, because industry contractor compensation increases with project size, consumers often purchase systems oversized for their hot water needs (Fitzmorris, 2010; Hirshberg & Schoen, 1974; Margolis, 2006). Unlike solar photovoltaic systems, SWH's cannot sell unused energy back to the grid. Consequently, any oversized system results in an over investment without means to recoup the loss. To aid adoption of SWH technology, the solar industry has attempted to spread awareness of the economic value of installing SWH systems by providing consumers with calculators for estimating system size and payback periods. However, the current calculators are oversimplified and give inaccurate estimates of residential hot water consumption. Because system size and subsequently payback periods are calculated based on water consumption, more accurate estimation models are imperative.

To address the residential market impediments and the water consumption inaccuracy of existing calculators, I constructed a collector area and payback calculator using a detailed estimation model incorporating residential hot water use patterns developed by the Lawrence Berkeley National Laboratory (Lutz, Xiaomin, McMahon, Dunham, & Shown, 1996). The use of accurate hot water consumption modeling allows for accurate estimations of collector area and ensures an appropriately sized system for a residential family's needs. Additionally, the payback period component provides residents financial awareness of the long-term savings of these systems. Moreover, as residents input the information requested by the calculator they become more familiar with their household's hot water heating requirements in comparison to their general energy usage. The individual adjustments afforded in the more detailed calculator model, allow residents to estimate the most accurate, most effective collector area and shortest payback period. Thus, in turn, promoting wider adoption of SWH technology.

## METHODS

This section is broken into three sections. In Part I, I detail the construction, formulas, logic, and assumptions used to build the collector area and payback period calculator. In Part II, I explain how the Lutz model (Lutz et al., 1996) was built into the calculator. In Part III, I analyzed three hypothetical scenarios for families in Berkeley, Ca to demonstrate how my calculator can be used to calculate collector area and payback period for a given hot water demand. I implemented my calculator in Microsoft Excel 2008 and it can be obtained through reaching me at rmac2199@gmail.com.

### Part I: Construction, Formulas, Logic, and Assumptions of Calculator

*Calculating the Collector Area*

The following section explains how the calculator computes collector area (CA). CA is a function of the daily hot water demand needed by a household, denoted by *Use (gallons/day),* as given by the Lutz model (equation 1A) in Part II. Translating *Use (gallons/day*) into units of power, or energy consumed per day, allows for comparison with the power generated by the solar collectors, which is a function of collector area; the larger the collector area the larger the generating capacity (power produced). A simplified equation relating these terms is as follows:

**(1)**

Where,

*"Use (gallons/day)"* is the amount of daily hot water consumed by a residential home, given by the Lutz model; "*Energy/gallon"* is the amount of energy, in thermal units (therms) needed to heat *"Use (gallons/day)"* of piped water from the temperature incoming into the home, "$T_{cold}$," to, "$T_{hot}$," the desired temperature setting for household use; "*Energy/ft*$^2$*"* is the amount of energy, in therms, generated per square foot of collector space; and, "*Collector Area (ft*$^2$*)"* is the variable signifying the amount of collector space, in square feet, needed to heat "*Use (gallons/day)"* to $T_{hot}$ from $T_{cold}$ .

Going further, , the left side of the equality in equation 1, is better represented by the term $\frac{Q_{Load}}{day}$, the daily energy demand of a given residential home. $\frac{Q_{Load}}{day}$ is represented by equation 2.

$$\frac{Q_{Load}}{day} = Use(gallons/day) \times \rho_{H_2O} \times c \times \frac{5}{9}\Delta T \qquad \textbf{(2)}$$

Where,

*"Use (gallons/day)"* is the amount of hot water consumed by a residential home per day in gallons;

"$\rho_{H2O}$" is the density of water given by $3.785\frac{kg}{gallon}$ or $\frac{1g}{cm^3} \times \frac{3785.41178cm^3}{gallon} \times \frac{1kg}{1000g}$;

"c" is the specific heat of water given by $3.965 \times 10^{-5}\frac{therm}{kg°C}$ or $\left(4.184\frac{J}{g°C} \times \frac{1therm}{105,505,600J} \times \frac{1000g}{kg}\right)$; and,

"$\Delta T$" is ($T_{hot}$ - $T_{cold}$) in units of °F.

Furthermore, the right side of the equality in equation 1 is better represented by the term $\frac{P_{Solar}}{day}$, the daily energy produced per day, as a function of the collector area. $\frac{P_{Solar}}{day}$ is represented by equation 3.

$$\frac{P_{Solar}}{day} = SI \times EF \times CA \qquad \textbf{(3)}$$

Where,

"*SI*" is the solar irradiance or energy of incoming sunlight incident on a square foot of the Earth's surface per day given in units of $\frac{therms}{ft^2 day}$ or $\frac{kwh}{m^2\left(\frac{10.7639 ft^2}{m^2}\right)day} \times \frac{1\ therm}{29.307kwh}$;

"*EF*" is the efficiency of the solar collectors; and,

"*CA*" is the area of the collectors given in $ft^2$.

Thus, to solve for collector area (CA), $\frac{Q_{Load}}{day}$ (equation 2) was set equal to $\frac{P_{Solar}}{day}$ (equation 3) and related through the unitless constant, SF, solar fraction (equation 4 & 5). Solar fraction is defined as the percentage of the overall load supplied by the solar collectors of the system over the energy demand needed for a home (NREL, 2010).

$$SF \times \frac{Q_{Load}}{day} = \frac{P_{Solar}}{day} \quad \textbf{(4)}$$

Solving for collector area (CA) yields:

$$CA = \frac{\left(Use(gallons/day) \times \rho_{H_2O} \times c \times \frac{5}{9}\Delta T\right)}{SF\left(SI \times EF\right)} \quad \textbf{(5)}$$

*Calculating Payback Period*

The payback period is the length of time needed before annual savings recoup the initial investment. It considers the initial investment (capital cost) and the resulting annual cash flow (annual savings), in this case, the amount of money saved annually over a conventional natural gas system through the installation of a SWH system (Longmore, 1989; U.S. DOE, 2005). For the purposes of this study, "simple payback" (Black, 2004; U.S. DOE, 2005) was used to allow a resident without prior knowledge of finance to perform and understand the calculations. Simple payback period was built into the calculator using the following equation:

$$Payback\ Period\ (in\ years) = \frac{Capital\,Cost}{Annual\,Savings} \quad \textbf{(6)}$$

*Where*,

"*Capital Cost*" is the cost of installation;

$$"Annual\ Savings" = 365\frac{days}{year}\left(SF \times \frac{Q_{Load}}{day} \times CF\right)$$; and,

"*CF*" is the cost of natural gas in \$/therm.

**Part II: Lutz Hot Water Consumption Model (Lutz et al., 1996)**

Lutz et al. (1996) presents a detailed model of hot water use patterns in individual households and is used to predict *Use (gallons/day)* in the above equations. This model is used to calculate daily hot water consumption values from the number of occupants living in a household and the age of the occupant (0-5, 6-13, and 14 + years old). In addition, the model improved upon an existing model by Gilbert and Associates developed for the Electric Power Research

Institute (EPRI) (Ladd & Harrison, 1985). Lutz's model now includes the effects of four conditions that were previously unaccounted for: the absence of a clothes washer; the absence of a dishwasher; a household consisting of seniors only; and a household that does not pay for its own hot water use. Although these four conditions can significantly affect residential hot water use and have been noted in other studies (Becker, 1990; Goldner 1994; Perlman 1985; Sanik 1990a; Sanik, 1990b), my study is the first time that they have been incorporated into a collector area and payback period calculator.

The Lutz model predicts *Use (gallons/day)* through the following equation:

$$Use\ (gallons/day) = \begin{Bmatrix} -1.78 + .9744 \times per \\ +6.3933 \times age\,1 + 10.5178 \times age\,2 + 15.3052 \times age\,3 \\ -.1277 \times therm \\ -.1794 \times wtmp + .5115 \times atmp + 10.2191 \times at\ home \\ -(.6920 \times per + 1.3350 \times \sqrt{per}) \quad , if\ \ no\ dishwasher \\ -(1.1688 \times per + 4.7737 \times \sqrt{per}) \ \ , if\ \ no\ clothes\ washer \end{Bmatrix}$$

$$\times \begin{Bmatrix} .3790 & , if\ \ senior\ only \\ 1.0 & , if\ \ not\ senior\ only \end{Bmatrix} \qquad \textbf{(1A)}$$

$$\times \begin{Bmatrix} 1.3625 & , if\ \ no\ pay \\ 1.0 & , if\ \ pay \end{Bmatrix}$$

Where,

*"Use (gallons/day)"* = hot water consumption;

*"per"* = number of persons in household;

*"age 1"* = number of preschool children (0-5 yrs);

*"age 2"* = number of school age children (6-13 yrs);

*"age 3"* = number of adults (14 yrs and over);

*"therm=$T_{hot}$"* = water heater lower thermostat setting, (°C);

*"wtmp=$T_{cold}$"* = water heater inlet water temperature, (°C);

*"atmp"* = outdoor air temperature, (°C);

*"at home"* = presence of adults at home during day;

*"if no clothes washer"* = a function indicating impact of not owning a clothes washer,

(gal/day);

*"if no dishwasher*" = a function indicating impact of not owning a dishwasher, (gal/day);

*"if senior only/if not senior only*" = a coefficient approximating effect of senior only households; and,

*"if pay/in no pay"* = a coefficient approximating effect of occupants not paying for hot water.

**Part III: Residential Hot Water Example Scenarios**

In this section, I present three hot water consumption scenarios (Table 1), in which I used the Lutz model to calculate the *Use (gallons/day)* for each scenario, followed by using equations 5 and 6 to calculate collector area and payback period, respectively.

**Table 1. Scenario 1, 2, & 3 Hot Water Use Descriptions**

| Scenario # | Hot Water Use Description |
|---|---|
| Scenario 1 | 2 adults, 1 preschool age child, 1 school age child, dish/clothes washer present, residents pay utility bill |
| Scenario 2 | 2 seniors, no dishwasher present, clothes washer present, residents pay utility bill |
| Scenario 3 | 2 adults (1 adult stays at home during day), 1preschool age child, 1 school age child, dish/clothes washer present, residents do not pay utility bill (renting) |

The three Scenarios were assumed to be families living in Berkeley, California under the following assumptions:

Solar Irradiance in Berkeley, California was found to be:

$$\text{"}SI\text{"} = \frac{4.607\,kwh}{m^2\left(\frac{10.672\,ft^2}{m^2}\right)day}$$

Solar irradiance values used for this study were sourced from the Department of Energy's National Renewable Energy Laboratory in its solar radiation research division, which specifies the solar irradiation values as Direct Normal Irradiance (Quinby, 2011). The Direct Normal Irradiance (DNI) describes the average annual solar resource available to solar collectors incident on a flat-plate collector at a given location. Solar Irradiance values are presented in a high-resolution (10 km) interactive map called the Solar Prospector (Quinby, 2011);

"EF" is taken to be an average SWH system efficiency of 41.05% (NREL, 2010);
"CF" is taken to equal $1.5/therm in Berkeley, Ca (PG&E 2011);
*"therm=$T_{hot}$"* is assumed at 130°F for Berkeley, Ca (Robert Cooley, pers com);
*"wtmp=$T_{cold}$"* is assumed at 55 °F for Berkeley, Ca (Robert Cooley, pers com); and,
"atmp" is averaged at 57.6°F for Berkeley, Ca (LIDS, 2011).

For each of the 3 scenarios, I graphed collector area against solar fractions evaluated from 0 to 1 at .1 increments. I graphed payback period against capital cost evaluated from $0 to $20,000 at $1,000 increments at a fixed solar fraction value of .6, which lies in the range of solar fractions most commonly installed in California (Robert Cooley, pers com; Fitzmorris, 2010; Gravely, 2009).

## RESULTS

In this section, I present calculator outputs for collector areas and payback periods for the hypothetical families in Berkeley, Ca, given by scenario 1, 2, and 3. Collector areas are presented in Table 2 for scenarios 1, 2, and 3 for solar fractions: 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1. Figure 1a, 1b, and 1c graphically represent collector areas given the solar fractions presented in Table 2 for scenarios 1, 2, and 3, respectively.

### Collector Area

**Table 2. Collector Areas for Differing Solar Fractions (Scenario 1, 2, 3)**

| Solar Fraction | Scenario1: Collector Areas ($ft^2$) | Scenario 2: Collector Areas ($ft^2$) | Scenario 3: Collector Areas ($ft^2$) |
|---|---|---|---|
| 0.1 | 6.7 | 2.1 | 10.6 |
| 0.2 | 13.4 | 4.2 | 21.2 |
| 0.3 | 20.2 | 6.2 | 31.8 |
| 0.4 | 26.9 | 8.3 | 42.4 |
| 0.5 | 33.6 | 10.4 | 53.0 |
| 0.6 | 40.3 | 12.5 | 63.6 |
| 0.7 | 47.0 | 14.5 | 74.2 |
| 0.8 | 53.7 | 16.6 | 84.8 |
| 0.9 | 60.5 | 18.7 | 95.4 |
| 1 | 67.2 | 20.8 | 106.0 |

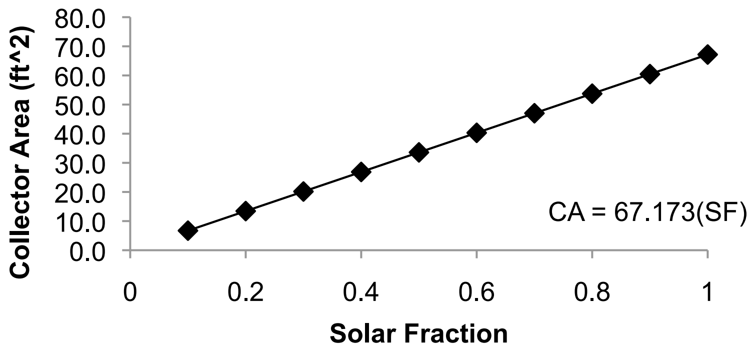


**Figure 1a. Scenario 1: Collector Area vs Solar Fraction, 64.4 gallons/day**

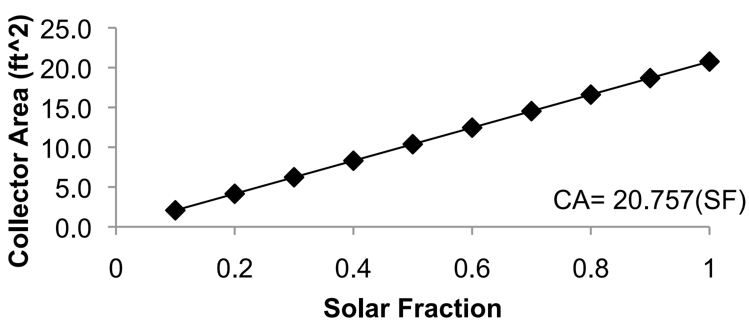


**Figure 1b. Scenario 2:Collector Area vs Solar Fraction, 19.9 gallons/day**

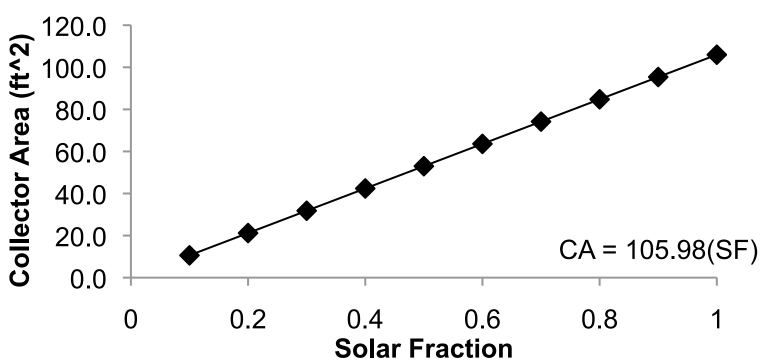


**Figure 1c. Scenario 3: Collector Area vs Solar Fraction 101.6 gallons/day**

The family in scenario 1 consumed 64.4 gallons of hot water heated to an assumed 130°F per day (Figure 1a). The collector area (CA) needed to satisfy a daily hot water demand of 64.4 gallons increased with an increasing solar fraction (SF) through the linear relationship: CA=67.173(SF). Thus, depending on the solar fraction desired by this particular family, this linear equation is used to estimate the collector area needed to suit the family's hot water needs.

The family given by scenario 2 consumed 19.9 gallons of hot water heated to an assumed 130°F per day (Figure 1b). The CA needed to fulfill a daily hot water demand of 19.9 gallons increased with an increasing SF through the linear relationship: CA=20.757(SF).

The family given by scenario 3 consumed 101.6 gallons of hot water heated to an assumed 130°F per day (Figure 1c). The CA needed to generate a daily hot water demand of 101.6 gallons increased with an increasing SF through the linear relationship: CA=105.98(SF).

## Payback Period

**Table 3. Payback Period (Scenario 1, 2, 3)**

| Capital Cost ($) | Scenario 1: Payback (years) | Scenario 2: Payback (years) | Scenario 3: Payback (years) |
|---|---|---|---|
| 1,000 | 1.11 | 3.6 | 0.7 |
| 2,000 | 2.2 | 7.2 | 1.4 |
| 3,000 | 3.3 | 10.8 | 2.1 |
| 4,000 | 4.4 | 14.4 | 2.8 |
| 5,000 | 5.5 | 18.0 | 3.5 |
| 6,000 | 6.7 | 21.6 | 4.2 |
| 7,000 | 7.8 | 25.2 | 4.9 |
| 8,000 | 8.9 | 28.8 | 5.6 |
| 9,000 | 10.0 | 32.4 | 6.3 |
| 10,000 | 11.1 | 36.0 | 7.04 |
| 11,000 | 12.2 | 39.5 | 7.7 |
| 12,000 | 13.3 | 43.1 | 8.5 |
| 13,000 | 14.4 | 46.7 | 9.2 |
| 14,000 | 15.5 | 50.3 | 9.9 |
| 15,000 | 16.7 | 54.0 | 10.6 |
| 16,000 | 17.8 | 57.5 | 11.3 |
| 17,000 | 18.9 | 61.1 | 12.0 |
| 18,000 | 19.9 | 64.7 | 12.7 |
| 19,000 | 21.1 | 68.3 | 13.4 |
| 20,000 | 22.2 | 71.9 | 14.1 |

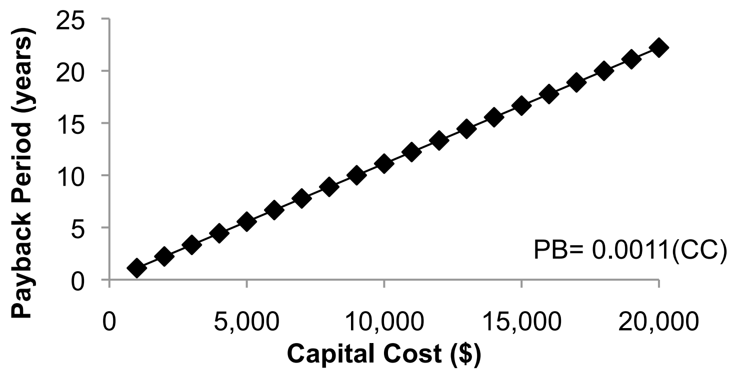


**Figure 2a. Scenario 1: Capital Cost vs Payback Period, 64.4 gallons/day, SF=0.6**

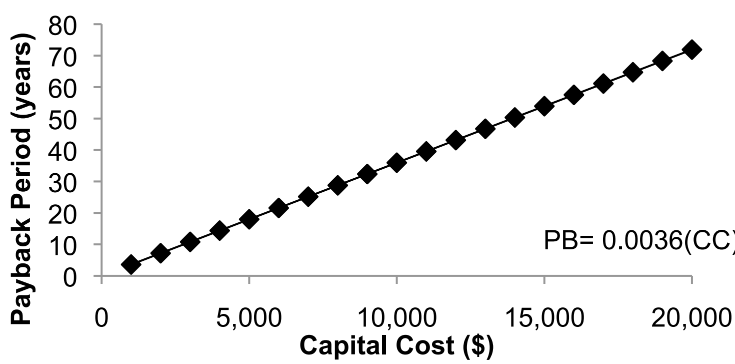


**Figure 2b. Scenario 2: Capital Cost vs Payback Period, 19.9 gallons/day, SF=0.6**

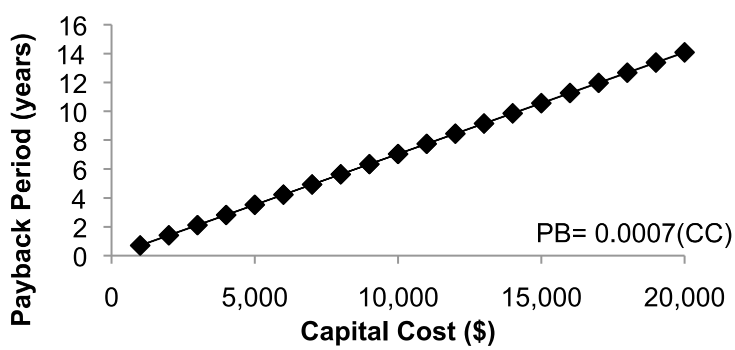


**Figure 2c. Scenario 3: Capital Cost vs Payback Period, 101.6 gallons/day, SF=0.6**

Based on daily hot water demand for scenarios 1, 2, and 3, I calculated payback periods for given capital costs $1,000 through $20,000 at $1,000 intervals (Table 3). From Table 3, I graphed payback periods quantified by the calculator for varying capital cost and at a fixed solar fraction of 0.6 for scenario 1, 2, and 3 (Figure 2a, 2b, 2c). Again, the calculator enables a homeowner to choose any solar fraction; however, for simplicity in displaying payback period results for all three scenarios, a fixed solar fraction of 0.6 was used; a solar fraction of 0.6 is common within installations and considered to be in the "sweet spot" by the solar industry for minimizing payback periods (Robert Cooley, pers com; Fitzmorris, 2010; Gravely, 2009).

The family given by scenario 1 consumed 64.4 gallons of hot water heated to an assumed 130°F per day (Figure 2a). Given this daily hot water demand, payback period (PB) increased with capital cost (CC) through the linear relationship: PB=0.00011(CC). Thus, depending on the capital cost a family accrues, this linear equation can be used to estimate the expected payback period for the SWH system installed.

The family given by scenario 2 consumed 19.9 gallons of hot water heated to an assumed 130°F per day (Figure 2b). Given this daily hot water demand, PB increased with CC through the linear relationship: PB=0.0036(CC).

The family given by scenario 3 consumed 101.6 gallons of hot water heated to an assumed 130°F per day (Figure 2c). Given this daily hot water demand, PB increased with capital cost (CC) through the linear relationship: PB=0.0007(CC).

## DISCUSSION

The purpose of this project was to build a calculator to estimate the collector area needed to satisfy a resident's hot water demand and to provide the expected payback period of that particular SWH system. Solar hot water heaters consume between 50-70 percent less energy than a standard natural gas tank water heater granting obvious financial and environmental benefits (Fitzmorris, 2010). My calculator offers a payback-calculating tool to increase financial awareness of the potential benefits of investing in solar hot water in the residential market and enable residents to see how their hot water use effects their payback period. Furthermore, this calculator seeks to circumvent the second market impediment associated with the industry—the industry's tendency to overestimate system size (Fitzmorris, 2010; Hirshberg & Schoen, 1974; Margolist & Zuboy2006). By providing accurate collector area estimates, residents can negotiate with contractors, confident in the knowledge of their hot water needs and system size—a necessary component to maximizing return on investment and minimizing payback period.

**Outcomes of Hypothetical Scenarios 1, 2, and 3**

*Collector Area Outcomes*

This section discusses how my calculator not only complies with industry approximations for collector areas, but improves the industry's estimates. As seen in the results section, for hypothetical scenarios 1, 2, and 3, respectively, my calculator estimated a collector area range of 33.95ft$^2$ to 47.02ft$^2$, 11.41ft$^2$ to 14.52ft$^2$, and 58.29ft$^2$ to 74.18ft$^2$ for solar fractions 0.5 to 0.7. These collector areas fit closely with the industry's approximation of the typical family needs of 1ft$^2$ of collector space for every 1.5 gallons of hot water consumed (U.S. DOE, 2011). Using this industry approximation, collector areas for scenario 1, 2, and 3 would be as follows: 42.93ft$^2$, 13.26ft$^2$, and 67.73ft$^2$. Each of these values fits within the respective range given above, illustrating that my calculator agrees with industry expectations. Yet, my calculator provides a far more accurate model for gauging collector area than simple industry approximations. My calculator allows users to manipulate hot water consumption for all the variables in the Lutz model (solar irradiance, cost of natural gas, solar fraction, SWH temperature settings, and system efficiency inputs) and to visualize, graphically, the various scenarios unique to different families and geographic. Existing calculators use overly simplistic industry approximations, in place of detailed hot water consumption inputs, leading to inaccurate estimations. This calculator provides the accuracy needed for residents to correctly size their system and minimize payback period.

My calculator results also support the important, more subtle relationship between solar fraction and payback period. In the case of scenarios 1, 2 and 3, as solar fraction increases, the SWH system delivers more energy from the solar collectors and less from the combustion of natural gas. Thus, more money is saved through the displacement of natural gas. However, as solar fraction increases, more collectors are needed, adding to total system cost. For this reason, solar collectors are never sized to satisfy one hundred percent (SF=1) of total hot water demand; the installed cost of this system would simply be too high to provide an effectual payback period. In fact, more commonly, solar fractions lie in the range of fifty-five to seventy percent of total energy load (SF=0.55-0.70) (Fitzmorris, 2010; Gravely, 2009)—the range, which maximizes annual savings while minimizing payback period.

*Payback Period Outcomes*

Because payback period is a direct function of collector area, this calculator also precisely estimates the payback period, determining the amount of annual saving incurred by a resident. Recall in the methods section that payback period results were calculated at a fixed solar fraction value of 0.6— a value within the industry range of 0.55-0.7. Consequently, scenarios 1, 2, and 3, demonstrate that for a fixed solar fraction, the payback period increases with capital cost. In other words, holding the solar fraction constant, fixes the savings generated by the collector area. With annual savings fixed, the payback period increases with growing capital costs. For varying capital costs it is interesting to note that the payback period for scenario 2 is roughly 340 percent higher than the average payback period for scenario 1 and 3. This is because, with only two seniors living at home, scenario 2's hot water consumption differs significantly from that of scenario 1 and 3. Therefore, the high payback period experienced by scenario 2 comes largely from minimal hot water usage. Regardless, the payback period should be less than 10 years because "installed capital costs for such a system capable of meeting the couple's hot water needs can easily be obtained for under $3,000" (Robert Cooley, pers com). Thus, the installation of a much smaller, less costly system diminishes the high payback period that would otherwise be incurred by low hot water volume users.

**Limitations and Future Work**

During the course of my study, limitations were recognized in my calculator that could be improved upon by adding more variables and thus enhancing accuracy. In future work, additional variables, as represented in the following three sections, could be included to improve the accuracy of the payback period portion of the calculator and further broaden the audience of the calculator.

*Payback Period Future Work*

My calculator used the "simple payback" method, which ignores the time value associated with currency and other inflation factors. "Simple payback" calculations were justified in this study because the calculator seeks to provide basic information to the general public. Future work could include inputs for residents interested in computing discount rates, opportunity cost of capital, and inflation adjusted natural gas rates into the payback period**.**

*Capital Cost Future Work*

Although my calculator allows for the installation costs of contractors, many additional add-ons concerning the systems themselves can be built into this calculator. For example, a future calculator could allow a user to select a desired model of SWH system, thus yielding incite into the capital costs, operational and maintenance costs, as well as the government incentives and financing options associated with different systems.

*Home Appreciation and Radiant Flooring Future Work*

Both a home's appreciation from the installation of a SWH system and the use of a SWH system for space heating in radiant flooring could drastically decrease the expected payback period. Just like any home upgrade, the resale value of a home should increase with SWH installation and lead to a greater return on investment. In fact, installing solar hot water may return up to 15 times the annual utility savings received by the SWH system; the rationale is that the money from the reduction in operating costs can be spent on a larger mortgage with no net change in monthly cost of ownership (Nevin & Watson, 1998; Nevin, Bender, & Gazan, 1999). However, little information exists to validate an increase in property value due to the savings on utility bills. Thus, a survey and comparison of home sale prices with and without SWH systems is needed to build this model into the calculator.

Secondly, radiant flooring, or the use of hot water to heat a home through floorboard circulation can yield great financial return; with radiated flooring, a SWH system can now be used to save on space heating expenditures, which accounts for 41 percent of in home energy consumption (U.S. DOE, 2005). Building both home appreciation and radiated flooring components into the calculator could widen the scope of the calculator.

*Conclusion*

Solar hot water heating continues to make headway across the globe as a relatively unrealized renewable technology. My calculator provides a useful tool for calculating collector area and payback period for differing hot water demands. It is my hope that this calculator can be used to increase awareness and confer residents the expertise in understanding the financial benefits and sizing concerns involved in purchasing a system. Solar heating will make economic sense for many, but only a careful look at the numbers will tell. I encourage the reader to use the calculator and compare the numbers when evaluating bids from solar providers.

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