CHAPTER III

An Economic Analysis of Three-Season SDHW Systems

3.1 Introduction

Economics play a central role in any customer's decision to purchase an SDHW system. The customer, whether a homeowner or a corporation, is unlikely to buy a solar energy system if they know from the start that its only benefit is to the environment. While the renewability of the energy source is certainly attractive, it is not a sufficient selling point. Part of the reason behind the popularity of SDHW systems during the 1980's was the availability of tax credits for renewable energy installations. The tax incentives are no longer available to individual homeowners and the current selling point of SDHW systems is the amount of money that the customer will save on future fuel bills. However, normal business tax credits are still available to electric utilities interested in solar. Obviously, any utility considering solar power generation is going to look very carefully at economics to ensure that such a project will be profitable to themselves and to their shareholders.

Another reason to consider an economic analysis of freeze protection alternatives is that some have the potential of reducing the cost of the SDHW system, although there may be an associated reduction in thermal performance. Eventually it must be decided whether the reduction is justified by the more favorable economics. In the case of the thermo-elastic collector, the cost reduction comes from eliminating the heat exchanger, a pump, the glycol charge, and from the possibility of the collector itself being much more inexpensively manufactured. For the three-season system, the collector would remain standard but the heat exchanger, pump and glycol charge would be unnecessary.

3.2 Economic Indicators and the P_1, P_2 Method

An economic analysis takes into account a great number of variables that describe the strength of the current market. These variables are combined to form a figure of merit that allows comparison of investment alternatives. In the case of solar energy alternatives, figures of merit are typically used in two ways. First, they provide a useful comparison between the SDHW system a conventional method of heating such as electricity or natural gas. Second, they allow designers to evaluate and optimize SDHW systems.

Many figures of merit are available for comparison of SDHW systems and there is no single correct choice; different figures of merit are appropriate to different economic situations. Two such figures of merit have been employed in analyzing the three-season SDHW system: that of life cycle savings, and that of payback period. Life cycle savings, or net present worth is defined as the difference in life cycle costs of a conventional system, and life cycle cost of the SDHW plus auxiliary system. The life cycle cost is the sum of all the costs associated with a system over a chosen analysis period, and is adjusted for inflation so that it is reported in today’s dollars. The payback period is the number of years required for the annual fuel savings (undiscounted or discounted to today's dollars) to equal the initial system cost.

The payback period is calculated in the following manner. The fuel savings for the j^{th} year, Cs_j, are defined in equation 3.2.1 in which *FL* is the energy saved, C_F is the unit cost of fuel, and i_F is the fuel cost inflation rate.

$$Cs_j = FLC_F(1+i_F)^{j-1} \tag{3.2.1}$$

Summing this expression over the time required for payback yields equation 3.2.2

$$Cs = \sum_{j=1}^{N_p} FLC_F(1+i_F)^{j-1} \tag{3.2.2}$$

Summing the geometric series results in equation 3.2.3

$$Cs = \frac{FLC_F\left[(1+i_F)^{N_p}-1\right]}{i_F} \tag{3.2.3}$$

Solving for N_P, the payback period:

$$N_P = \frac{\ln\left[\frac{C_S i_F}{FLC_F}+1\right]}{\ln(1+i_F)} \tag{3.2.4}$$

The above analysis includes the discounting of fuel savings so that they are reported in today's dollars. It is common to neglect the fuel savings discounting in which case the payback period is given by equation 3.2.5 and is referred to as simple payback period. N is the number of years in the analysis and C_{SYS} is the initial system cost.

$$N_P = \frac{C_{SYS}}{NFLC_F} \tag{3.2.5}$$

Life cycle savings are calculated using equation 3.2.6 (Duffie and Beckman, 1991). P_1 is the ratio of the life cycle fuel cost savings to the first year fuel cost savings. P_2 is the ratio of the life cycle expeditures incurred because of the investment to the initial investment amount. C_A is the cost per unit area of the system, and C_E is the area independent cost.

$$LCS = P_1 \sum_{i=1}^{12} C_{F_i} l_i f_i - P_2 (C_A A_C + C_E) \tag{3.2.6}$$

Writing equation 3.2.6 with the summation allows for monthly variation in the cost of fuel. P_1 is given by equation 3.2.7

$$P_1 = \left(1 - C\bar{t}\right) PWF(N_e, i_F, d) \tag{3.2.7}$$

P_2 is given by equation 3.2.8.

$$\begin{aligned} P_2 &= D + (1 - D)\frac{PWF(N_{\min}, 0, d)}{PWF(N_L, 0, d)} \\ &- \bar{t}(1 - D)\left[PWF(N_{\min}, m, d)\left(1 - \frac{1}{PWF(N_L, 0, m)}\right) + \frac{PWF(N_{\min}, 0, d)}{PWF(N_L, 0, m)}\right] \\ &+ M_S\left(1 - C\bar{t}\right)PWF(N_e, i, d) + tV\left(1 - \bar{t}\right)PWF(N_e, i, d) \\ &- \frac{C\bar{t}}{N_D} PWF(N'_{\min}, 0, d) - \frac{R_v}{(1+d)^{N_e}}\left(1 - C\bar{t}\right) \end{aligned} \tag{3.2.8}$$

C = income producing flag (1 for income producing installation, 0 otherwise)
d = market discount rate (best alternative investment)
m = annual mortgage rate
i = general inflation rate
N_e = period of economic analysis
N_L = term of loan
N_{min} = years over which mortgage payments contribute to the analysis
N'_{min} = years over which depreciation contributes to the analysis
N_D = depreciation lifetime in years
t = property tax rate
$\bar{t}$ = effective income tax rate
D = ratio of downpayment to initial investment
M_s = ratio of miscellanious costs to initial investment
V = ratio of assessed valuation of solar energy system in first year to initial investment of system
R_v = ratio of resale value at end of period of analysis to initial investment

Each PWF(N,i,d) term is the present worth factor calculated from the three given parameters using equation 3.2.9. This factor is useful for calculating the present worth of a series of regular future payments, discounted at a rate of d, over N years at an inflation rate of i.

$$PWF(N,i,d) = \sum_{j=1}^{N} \frac{(1+i)^{j-1}}{(1+d)^{j}} \tag{3.2.9}$$

The sheer number of variables appearing in the preceding equations gives a good idea of the complexity and subjectivity of economic analyses. There is no source book that tells what the value of each variable is, and what sources do exist, will likely give conflicting answers to the same question. Furthermore, there is the implicit assumption that the variables (such as inflation rate) will not change over the course of the analysis, a reasonable assumption when the analysis lasts only a few years. However, for solar to be profitable, a much longer analysis must be employed. Further complicating the issue the values of the variables are highly dependent on location. If any new SDHW system is to be marketed successfully, its potential savings must be proven to be insensitive enough to economic changes that it remains an attractive alternative even in unfavorable conditions.

3.3 The Economy Used in Analyzing Three-Season Systems

Unless otherwise stated, the parameters shown in figure 3.3.1 have been used in analyzing the three-season system alternative regardless of location. The parameters were chosen to be reasonably representative of the economy in the late 1990s. No credit was taken for tax incentives as they are currently unavailable and three-season system design should not depend upon them. The price of electricity was 0.074 $/kW-hr from June to September, and was 0.063 $/kW-hr throughout the rest of the year. These values are the current rates for Madison Gas and Electric in Madison, WI (MG&E, 1997). There is significant variation throughout the United States with the highest prices being found in New England at an approximate rate of 0.12 $/kW-hr (CommElectric, 1997). The low Madison prices were chosen so that the three-season system would be shown to work well under sub-optimal conditions.

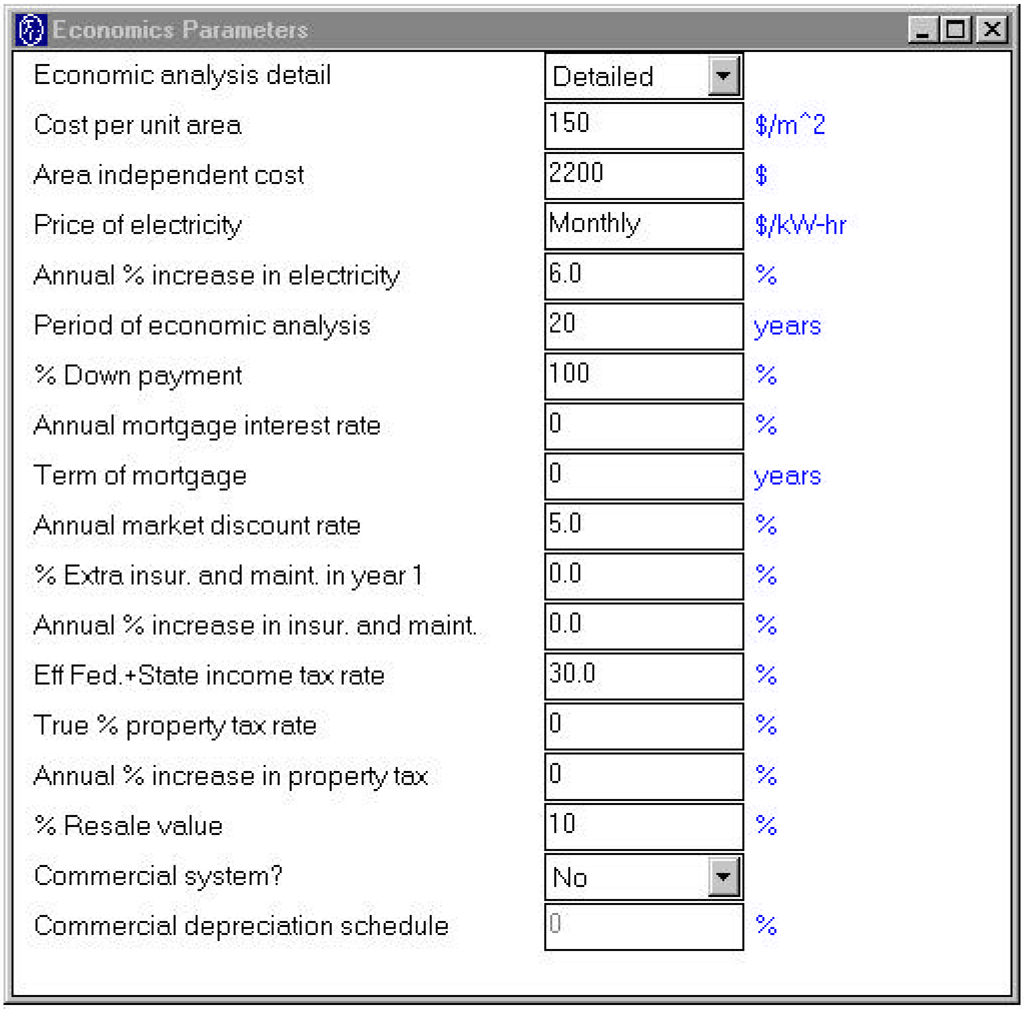

Figure 3.3.1: Economic Parameters (from *f*-Chart version 5.88W)

3.4 Three-Season System Sensitivity

Two types of sensitivity matter in designing SDHW systems. The sensitivity to system design variables and the sensitivity to economic changes. Both contribute to the overall robustness of a design. A robust design is one in which no single variable changes the system performance to any great extent.

The placement of collectors is obviously important in designing any SDHW system. The ideally placed four-season system in the Northern Hemisphere has collector panels facing due south (azimuth angle = 0^o) and sloped at an angle (β) equal to the latitude of the installation (Duffie and Beckman, 1991). In the Northern Hemisphere, the sun spends half of the day east of due south and half of the day west of due south. Thus a collector pointing directly south receives the most radiation throughout the day. Sloping the collector at an angle equal to the latitude means that beam radiation from the sun is normal to the collector surface (incidence angle = 0^o) at solar noon on the autumnal and vernal equinoxes. Consequently, the incident radiation integrated over the entire year is maximized. Obviously, collector panels cannot always be placed in the optimum location since factors such as supporting structure orientation and local shading cannot be altered. The effects of sub optimal slope and azimuth are well known concerning four-season systems. Less is known, however, about their effects upon three-season systems.

In many of the graphs that follow, system sensitivities are compared using life cycle savings as the figure of merit because it is easily optimizable. The system designer has primary control over only one variable in equation 3.2.6, that of collector area. Both P_1 and P_2 are determined by the current economy, load and fuel cost are determined by the location of the system, and the system costs are driven by local availability of equipment. Thus the designer of an SDHW system can choose a collector area that maximizes the life cycle savings by taking the derivative of equation 3.2.6 and setting it equal to zero to yield equation 3.4.1.

$$\frac{\partial LCS}{\partial A_c} = 0 = P_1 C_F \frac{\partial F}{\partial A_C} - P_2 C_A \qquad (3.4.1)$$

Solving this equation for $\partial F/\partial A_c$ and plotting, the optimal solar fraction and collector area can be read from a graph of life cycle savings versus collector area.

The following sensitivity analyses portray the possible benefits of a three-season system in four locations whose weather patterns are representative of the United States as a whole. Madison, WI which has a medium length, moderately clear winter, Seattle, WA which has a short, cloudy winter, Miami, FL which has essentially no winter at all, and Albuquerque, NM which has a long, clear winter.

3.4.1 System Sensitivity to Collector Slope and Area

The first set of four plots shows the effect that a non-optimum collector slope has upon both the total life cycle savings and the optimum area of a four-season system. In the plots and figures that follow, life cycle savings has been used as the economic figure of merit as it is optimizable and it allows easy comparison.

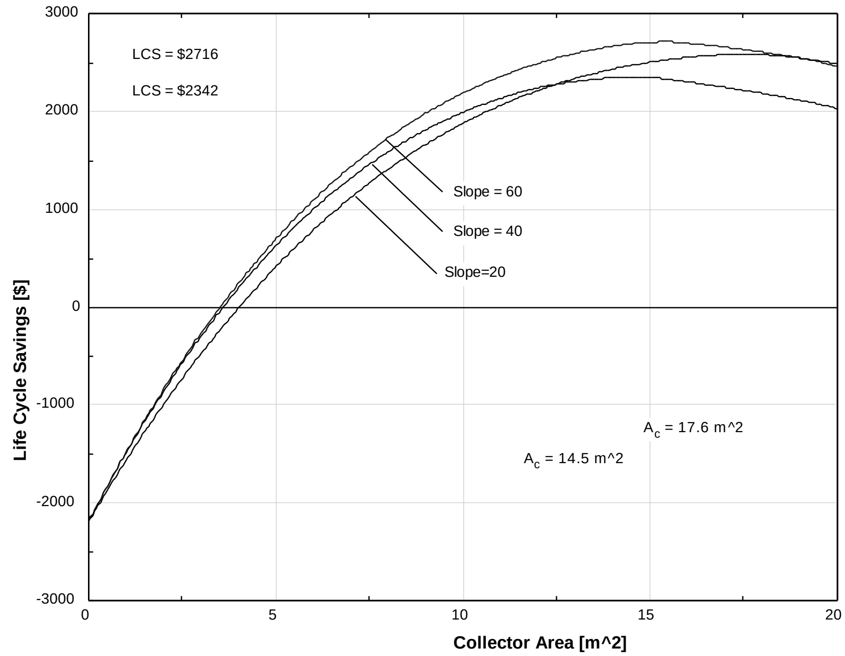

Figure 3.4.1.1a: Four-Season System Sensitivity to Slope in Madison, WI

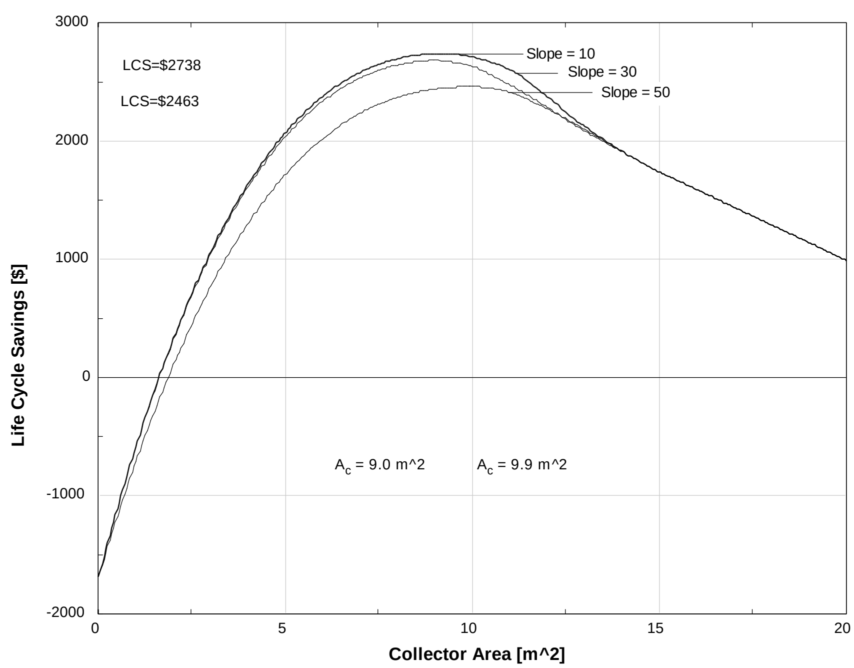

Figure 3.4.1.1b: Four-Season System Sensitivity to Slope in Miami, FL

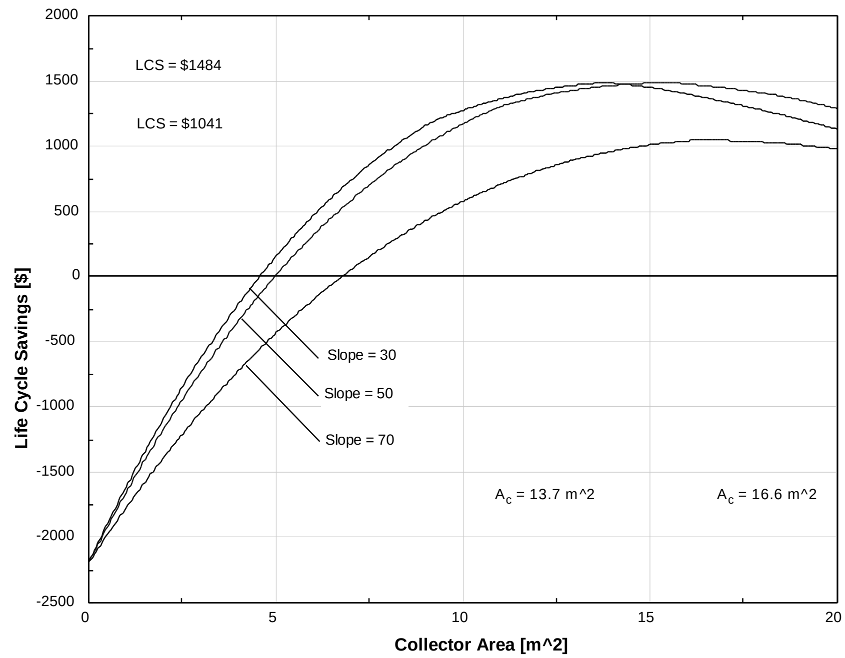

Figure 3.4.1.1c: Four-Season System Sensitivity to Slope in Seattle, WA

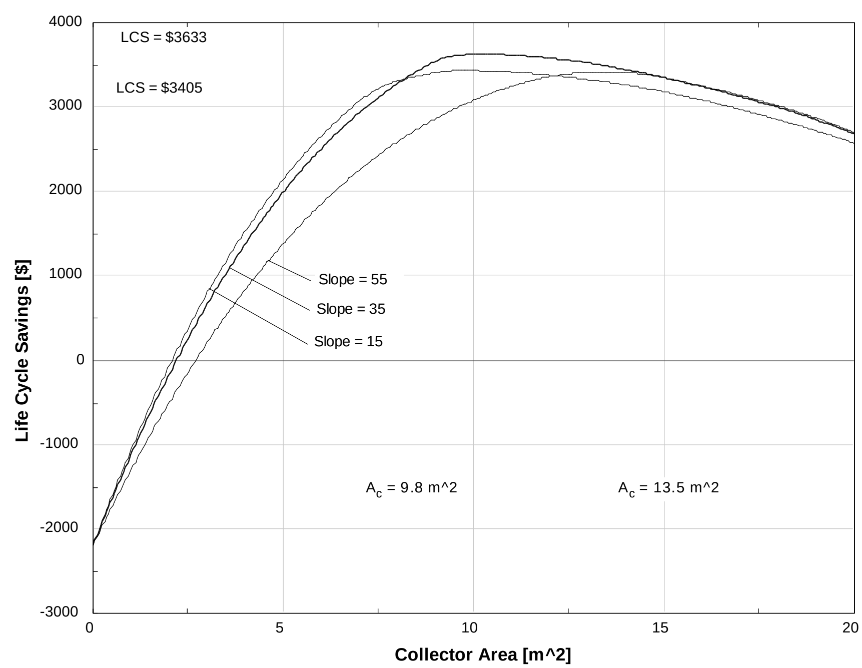

Figure 3.4.1.1d: Four-Season System Sensitivity to Slope in Albuquerque, NM

It can be seen in Figure 3.4.1.1 that the slope nearest to the latitude of the location yields the highest life cycle savings. Both increasing and decreasing the collector slope not only reduces the life cycle savings but changes the optimum area of the system. If the system designer chooses the slope the collector at a non-ideal slope and does not alter the area, the life cycle savings decrease will be more pronounced. Furthermore, in all cases the steeper slope decreases the LCS by a greater extent than the shallower slope because the price of energy is higher in the summer. This means that for a location with seasonally varying electricity rates, the energy collected during the summer is worth more than that collected during the winter. It is also interesting to note that in all four cases, the change in LCS due to a 20^{o} amplitude change in collector slope hovers around \$400 over 20 years. There is no correlation between the level of the optimum life cycle savings and the decrease due to a change in slope. In each location, the change in optimal area is 2 m^2 or less, approximately the area of one collector panel.

The next four plots are identical to those in Figure 3.4.1.1(a-d) but show the LCS sensitivity of a three-season system to changes in collector slope.

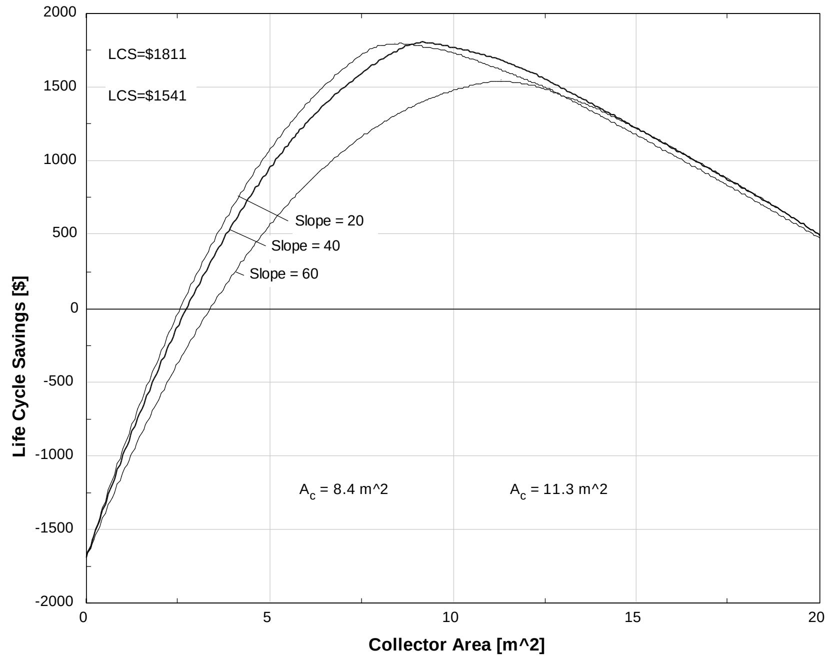

Figure 3.4.1.2a: Three -Season System Sensitivity to Slope in Madison, WI

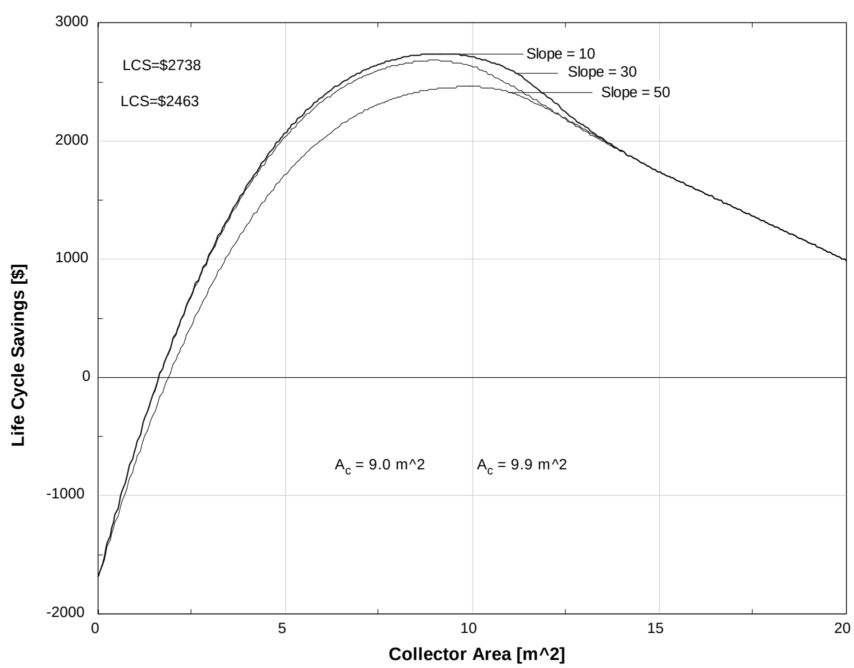

Figure 3.4.1.2b: Three -Season System Sensitivity to Slope in Miami, FL

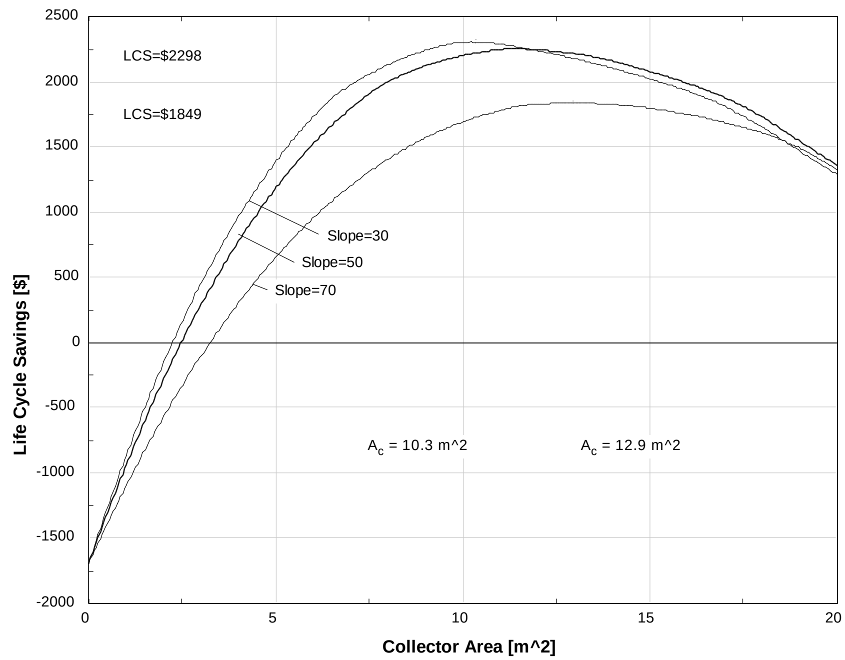

Figure 3.4.1.2c: Three -Season System Sensitivity to Slope in Seattle, WA

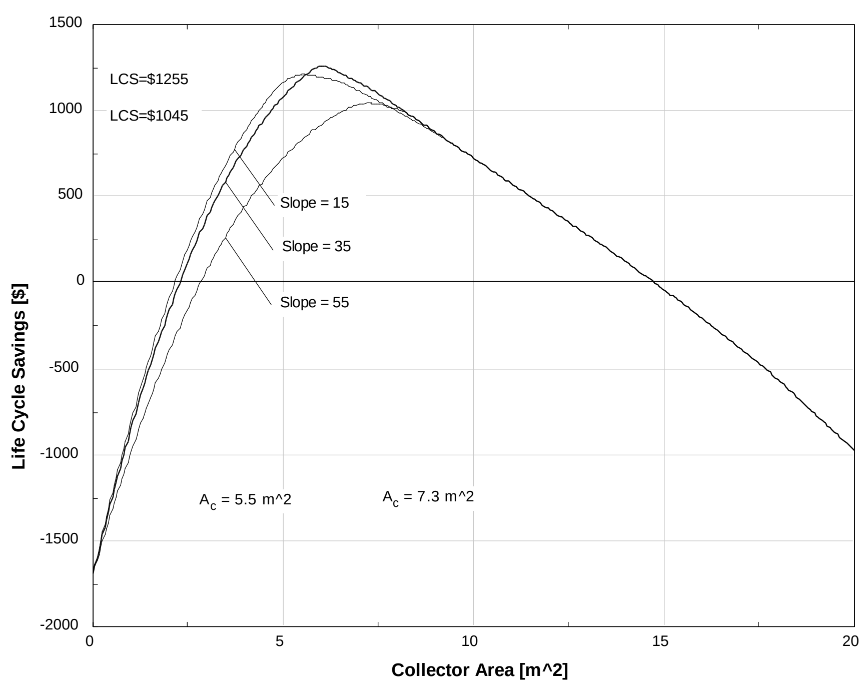

Figure 3.4.1.2d: Three-Season System Sensitivity to Slope in Albuquerque, NM

Many of the features of the four-season system sensitivity reappear in the three-season system, indicating that such a system is no less robust from the point of view of collector slope. Since Miami has no freezing period, plot 3.4.1.1b and 3.4.1.2b are precisely the same. In the other three locations, however, there are a few important differences. First, the life cycle savings are not nearly as high as for the four-season system, a problem that will be addressed at length in section 3.5. Typically, the three-season system LCS values are more than \$1000 lower than those of the corresponding four-season system even after taking a \$500 credit for reduced equipment cost. The change in collector area is another important difference. In all cases except Miami, the optimum area ($\partial LCS/\partial A_c = 0$) is a great deal lower than for the four-season system. Another interesting feature of the three-season system arises from the shape of the plots. The optimums on all the three-season plots (with the exception of Miami) are more pointed and while at first glance it would appear that the life cycle savings drop off more quickly indicating a more sensitive system, this is not the case. Granted it does indicate that the three-season system life cycle savings are more sensitive to area changes. However, the optimums resulting from various collector slopes are more tightly packed meaning that both the life cycle savings and the three-season system's critical areas are less sensitive to slope than those of the four-season system are. The three-season system LCS and optimal areas are less sensitive to changes in collector slope and more sensitive to changes in collector area than the four-season system.

The plots in figures 3.4.1.1 and 3.4.1.2 show that the three-season system does not compare favorably to a four-season system from a life cycle savings point of view.

However, they also show that the system reacts to changes in collector slope in much the same manner as the four-season system.

3.4.2 System Sensitivity to Collector Azimuth Angle

An SDHW system's sensitivity to collector azimuth angle is much simpler to characterize than the sensitivity to slope since the question of optimums does not arise. Any collector that is faced away from due south is unable to collect some amount of energy incident either early in the morning or late in the afternoon. The energy lost to the collector is directly proportional to the azimuth angle. An investigation of sensitivity to azimuth angle is, however, warranted in order to ensure that the three-season system is not overly sensitive to changes in the variable. Figure 3.4.2.1 shows the decrease in life cycle savings due to changes in azimuth angle for various system configurations.

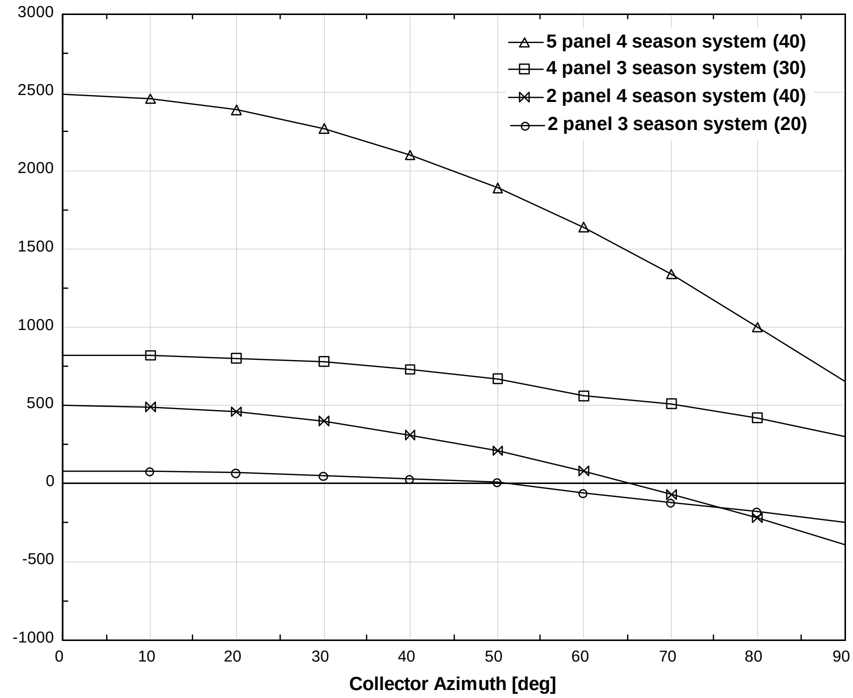

Figure 3.4.2.1 Life Cycle Savings Sensitivity to Collector Azimuth for Various SDHW Configurations

It can be seen from the figure that in fact the four-season systems are more sensitive to azimuth angle than the three-season systems. The phenomenon can be attributed to the fact that the three-season system is dependent only upon summer sunlight. In the Northern Hemisphere during the summer, the sun is up for a longer period of time, setting north of the collector's east-west axis. The four-season system, on the other hand, collects energy during the winter as well when the sun spends comparatively little time above the horizon. Therefore, to perform well, the four-season SDHW system had better collect as much energy as possible when the sun is up during the winter, and consequently needs to face due south. The three-season system has a bit more leeway since there is more sunlight available during its operating period.

In an effort to divorce the economic effects from the system's thermal performance, figure 3.4.2.2 shows the annual solar fraction's sensitivity to collector azimuth. Although not as obvious, the four-season system again suffers more from non-south orientation.

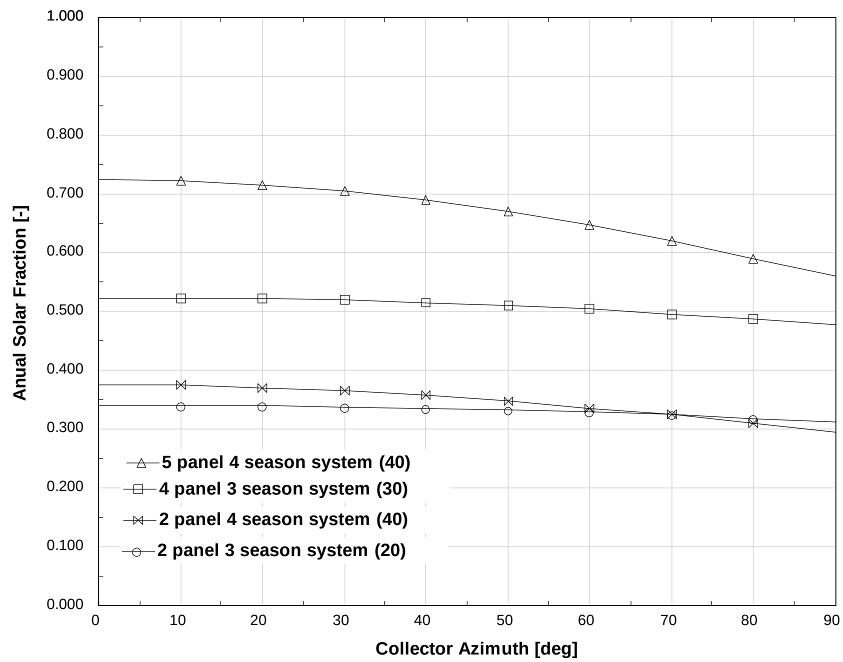

Figure 3.4.2.2 Annual Solar Fraction Sensitivity to Collector Azimuth for Various SDHW Configurations

3.4.3 System Sensitivity to Collector Quality

There are a great many solar collectors on the market, all of which vary in quality. Thankfully, the industry has agreed upon a standard method of describing a solar collector's efficiency that makes comparison between models and brands relatively simple. Essentially, flat-plate collectors are described by a linear efficiency curve for which two parameters are needed to predict performance; the intercept ($F_R(\tau\alpha)$), and the curve's slope (F_RU_L) (Duffie and Beckman, 1991). The intercept efficiency describes how much of the incident radiation is transferred to the working fluid, and the slope describes the losses of the collector. Figure 3.4.3.1 shows two different collector efficiency curves.

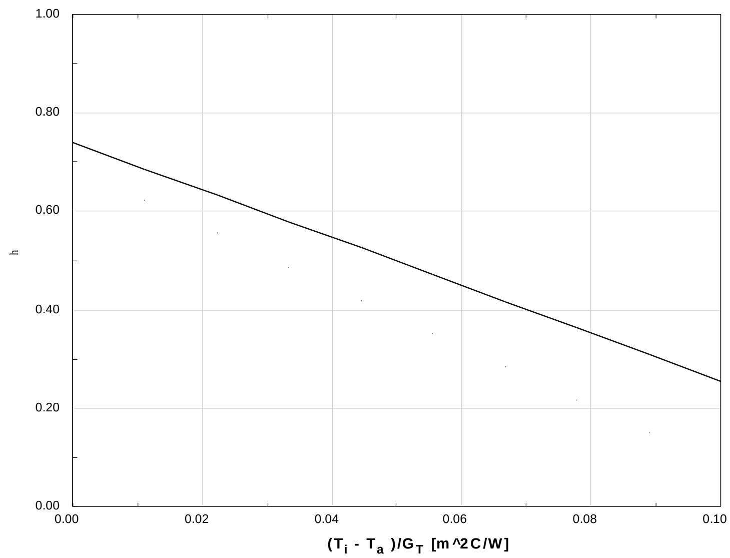

Figure 3.4.3.1: Collector Efficiency Curves

Both the thermal and economic analyses thus far have made use of a comparatively high efficiency collector, the American Energy brand, model AE-32 manufactured by American Energy Technologies (Meaken, 1994). The collector parameters are shown in Table 3.4.3.1 and the efficiency curve appears as the solid line in Figure 3.4.3.1. A number of sensitivity plots were created which investigate the effect of choosing a poorer performing, less expensive collector on the three-season system. The second collector's efficiency appears as the dotted line in Figure 3.4.3.1 and the parameters are shown in Table 3.4.3.1. All collector data was obtained from the Solar

Ratings and Certification Corporation (SRCC) publication of OG-100 standards (Meaken, 1994).

Table 3.4.3.1: Collector Parameters

Collector Model	Efficiency Curve Intercept [-]	Efficiency Curve Slope [W/m^2-C]	Collector Panel Cost [\$/m^2]
American Energy AE-32	0.74	4.86	220
Skylite ASN-45A	0.69	6.08	170

The first set of figures shows the plan view of a three-dimensional plot enabling an estimation of the life cycle savings sensitivity to changes in both area and collector slope of various system alternatives. Figure 3.4.3.2a repeats results already presented and can be used as a basis of comparison for later figures.

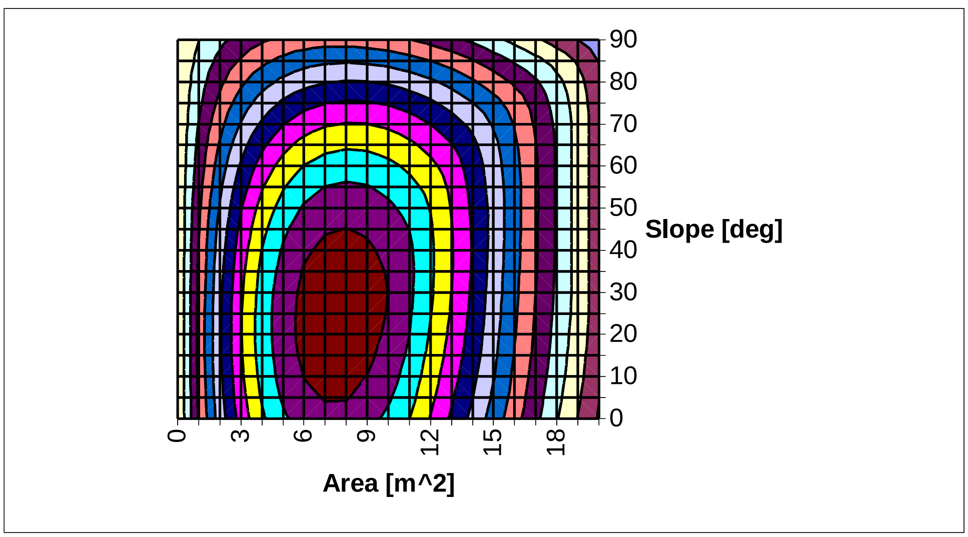

Figure 3.4.3.2a: Three-Season LCS Sensitivity to Slope and Area in Madison, WI (AE-32 Collector, C_A = 220 \$/m^2)

The actual values of the LCS are of secondary importance to the shape of the contours. Suffice it to say that the peak value in figure 3.4.3.2a is approximately $2000 and the bands are $200 wide. Figure 3.4.3.2b shows the same plot but using the lower quality collector. Credit has been taken for a lower cost per unit area.

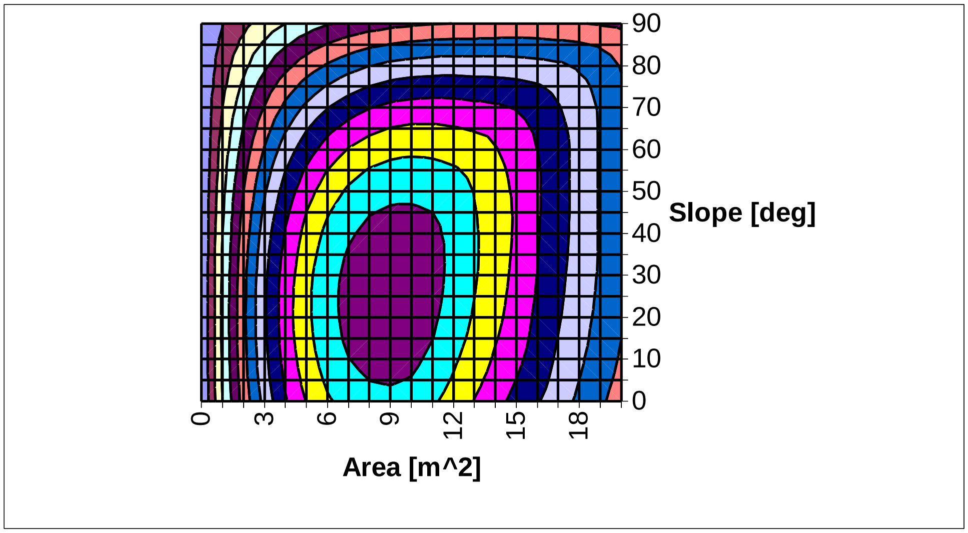

Figure 3.4.3.2b: Three-Season LCS Sensitivity to Slope and Area in Madison, WI (ASN-45A Collector, C_A = 170 $/m^2)

While the peak value of this plot has dropped to about $800, the shape has barely changed at all. Both the optimum area and the optimum slope have increased slightly, but the plot is flat enough near the optimum that the changes are inconsequential.

Other locations exhibit many of the same features. Figures 3.4.3.3a and 3.4.3.3b duplicate the plots in figures 3.4.3.2a and b except that the analysis was performed in Miami, FL instead of Madison, WI.

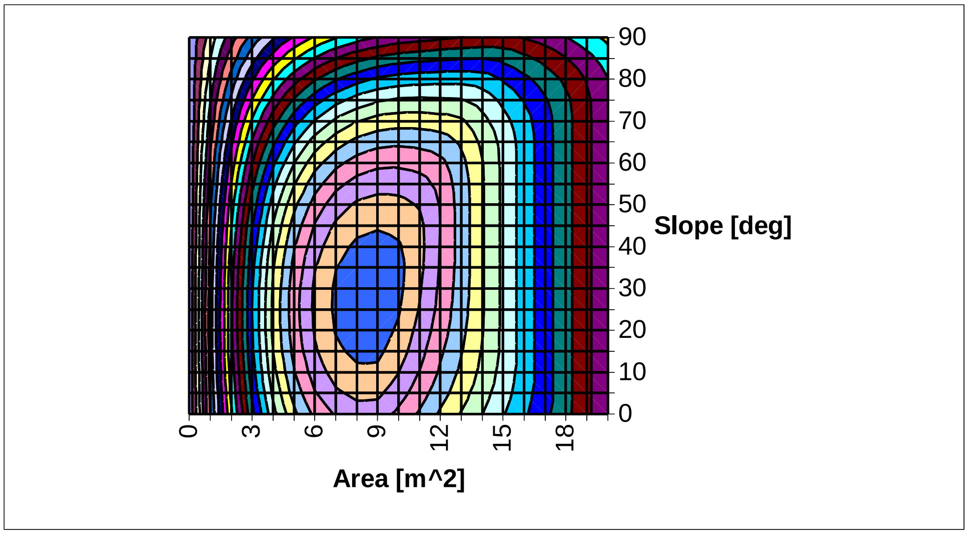

Figure 3.4.3.3a: Three-Season LCS Sensitivity to Slope and Area in Miami, FL (AE-32 Collector, C_A = 220 \$/m^2)

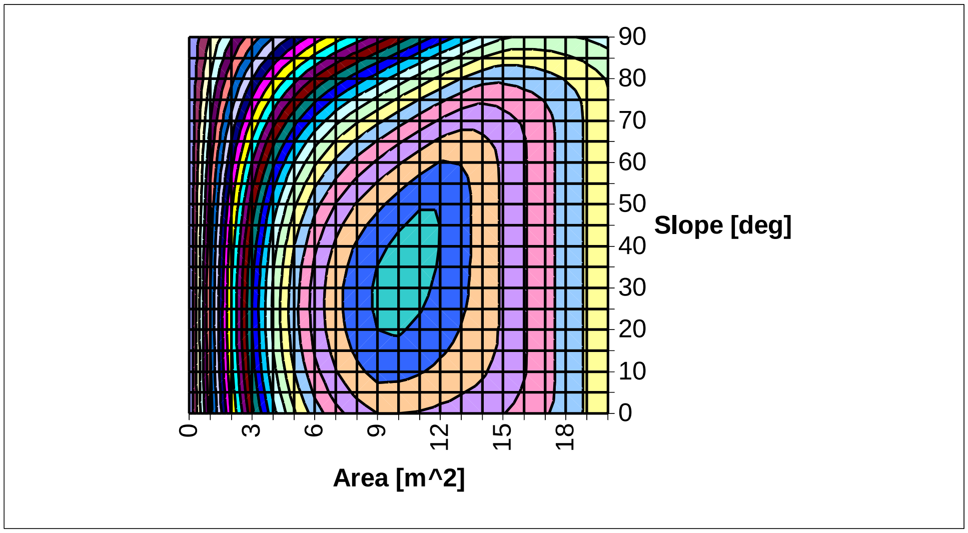

Figure 3.4.3.3b: Three-Season LCS Sensitivity to Slope and Area in Miami, FL (ASN-45A Collector, CA = 170 $/m2)

Again the shapes of the two plots are quite similar. Both exhibit low dependence on slope at high areas although the dependence does become more significant for the lower quality collector at steep collector angles. Again, the optimum shifts up slightly in both area and slope for the lower quality collector.

The above plots have shown that the three-season system life cycle savings is not very dependent upon collector quality. However, the actual value of the life cycle savings drops significantly with collector quality, which is true for four-season systems as well. Figures 3.4.3.3a and 4.4.3.4b show the effect of collector quality on the life cycle savings of a four-season system in Albuquerque, NM.

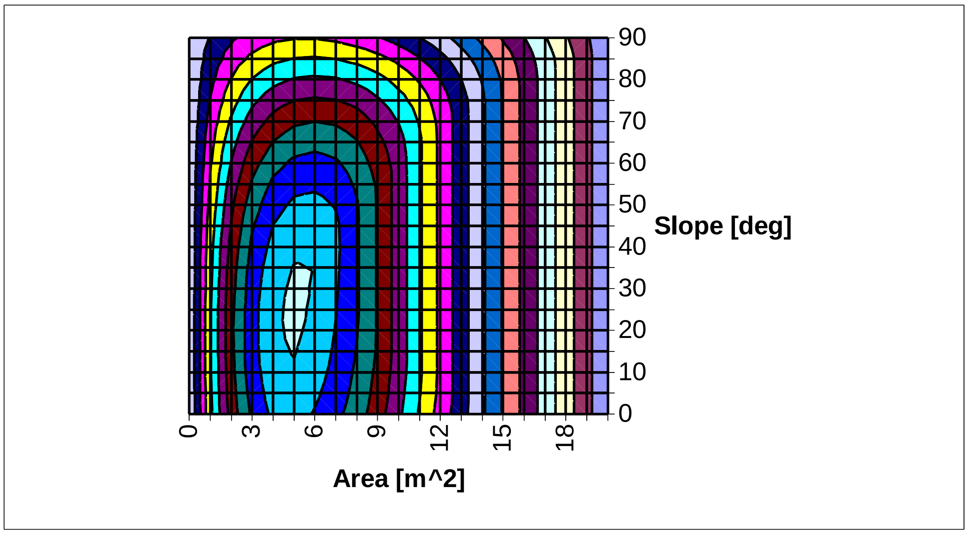

Figure 3.4.3.4a: Four-Season LCS Sensitivity to Slope and Area in Albuquerque, NM (AE-32 Collector, CA = 220 $/m2)

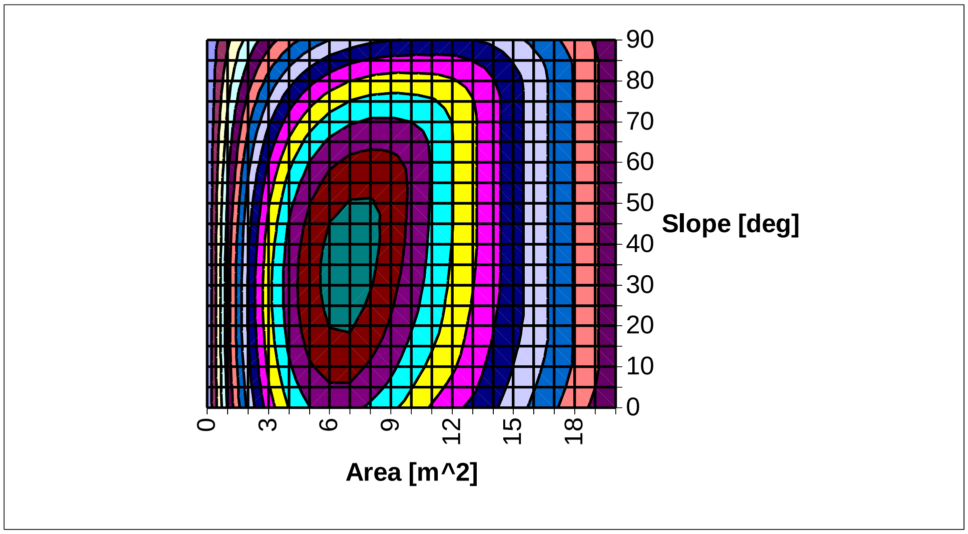

Figure 3.4.3.4b: Four-Season LCS Sensitivity to Slope and Area in Albuquerque, NM (ASN-45A Collector, CA = 170 $/m2)

As in section 3.4.2, the four-season system life cycle savings appears to be more dependent upon slope and area. The above plots also show that the four-season system is more dependent upon collector quality as well. There are some features in common with the three-season system; the higher area systems are less dependent upon collector slope, and switching to a lower quality collector increases the optimum slope and area. The value of LCS at the optimum for the high quality collector is $4000 and is $800 for the low quality collector. As with the three-season system, the LCS values are highly dependent upon collector quality, but the shape of the plot is not.

3.4.4 System Sensitivity to Economic Parameters

Thus far, the sensitivities examined impact the design of three-season systems. It is also important to understand how the economic predictor will hold up over the course of its lifetime. Since the economic parameters shown in figure 3.3.1 are by no means guaranteed to remain constant over the course of 20 years, the three-season system should be shown to save the customer money even when the economy is performing strongly and there are attractive alternative investments.

The study of sensitivity to economic parameters can be cast as a study in uncertainty propagation. Both changes in and uncertainty in economic indicators have the same impact upon the life cycle savings of an SDHW system. Based upon equation 3.2.6, the change in life cycle savings due to a change in a given parameter can be approximated by equation 3.4.4.1 (Duffie and Beckman, 1991).

$$\Delta LCS = \frac{\partial LCS}{\partial X_j}\Delta x_j = \frac{\partial}{\partial x_j}\left[P_1 C_F LF - P_2\left(C_A A_C + C_E\right)\right]\Delta x_j$$

(3.4.4.1)

Rewriting part of the above equation yields equation 3.4.4.2

$$\frac{\partial LCS}{\partial x_j} = \frac{\partial\left(P_1 C_F LF\right)}{\partial x_j} - \frac{\partial P_2\left(C_A A_C + C_E\right)}{\partial x_j}$$

(3.4.4.2)

It suffices now to calculate the partial derivatives of P_1 and P_2 for the changing variable in question. The derivatives appear in table 3.4.4.1 below for a number of commonly changing variables.

Table 3.4.4.1: The Partial Derivatives of P1 and P2 for Commonly Changing Variables (Duffie and Beckman, 1991)

Variable (x_j)	$\frac{\partial P_1}{\partial x_j}$	$\frac{\partial P_2}{\partial x_j}$
i_f	$\left(1-C\bar{t}\right)\frac{\P PWF(N_e, i_F, d)}{\P i_F}$	-
i	-	$\left[\left(1-C\bar{t}\right)M_s+\left(1-\bar{t}\right)tV\right]\frac{\partial PWF\left(N_e, i, d\right)}{\partial i}$
t	-	$V\left(1-\bar{t}\right)PWF\left(N_e, i, d\right)$
R_v	-	$\frac{1-C\bar{t}}{\left(1+d\right)^{N_e}}$

The partial derivatives of various present worth factors are also required. Equations 3.4.4.3 through 3.4.4.5 show such partials.

$$\frac{\partial}{\partial N}PWF\left(N, i, d\right)=-\frac{1}{d-i}\left(\frac{1+i}{1+d}\right)^{N}\ln\left(\frac{1+i}{1+d}\right) \tag{3.4.4.3}$$

$$\frac{\partial}{\partial i}PWF\left(N, i, d\right)=\frac{1}{d-i}\left[PWF\left(N, i, d\right)-\frac{N}{1+i}\left(\frac{1+i}{1+d}\right)^{N}\right] \tag{3.4.4.4}$$

$$\frac{\partial}{\partial d}PWF\left(N, i, d\right)=\frac{1}{d-i}\left[\frac{N}{1+d}\left(\frac{1+i}{1+d}\right)^{N}-PWF\left(N, i, d\right)\right] \tag{3.4.4.5}$$

As an example, say that the fuel inflation for a system in Madison, which was taken as 6%, changes to 8%. Equation 3.4.4.4 and table 3.4.4.1 entry 1 are used to compute that the partial derivative of P_1 with respect to fuel inflation rate is \$194. The uncertainty in life cycle savings is calculated to be \$2567 from terms from equation 3.4.4.1 and rewriting as equation 3.4.4.6. \$2567 is well over half of the projected savings of the SDHW system.

$$\Delta LCS = C_F \, LF \, \frac{\partial P_1}{\partial i_F} \Delta i_F \tag{3.4.4.6}$$

The last two multipliers in this equation are independent of whether the system is a three or a four-season design. Since the cost of fuel and the load also remain unchanged by the difference in system type, only the annual solar fraction matters in computing the difference in life cycle savings due to a change in an economic parameter. Furthermore, the three-season systems tend to have lower solar fractions so that the change in life cycle savings of a three-season system would actually be less than for a four-season system. It would appear that the three-season system is therefore less sensitive to economic change. However, it must be kept in mind that the life cycle savings of each system are different and that the amount of change in LCS might be smaller, but the percentage of the total might be larger depending upon the location.

3.5 System Design Using the Life Cycle Savings Indicator

The life cycle savings of an SDHW alternative have been useful so far in comparing system sensitivities for a number of reasons, the first of which is that there is an optimum point obtained by plotting equation 3.4.1. However, to use this equation in a design capacity, there is another important dynamic that should be mentioned. On the plot, the y-intercept is equal to the initial cost of area independent equipment (C_E). At this point, the collector area is zero, the customer has not spent any money on collectors and other area dependent equipment but has purchased the rest of the system. An investment has been made but since no energy is collected, the system will never save any fuel cost and the life cycle savings is negative. Altering the area independent cost not only shifts the y-intercept, but shifts the entire plot evenly up and down as shown by the dotted lines in figure 3.5.1.

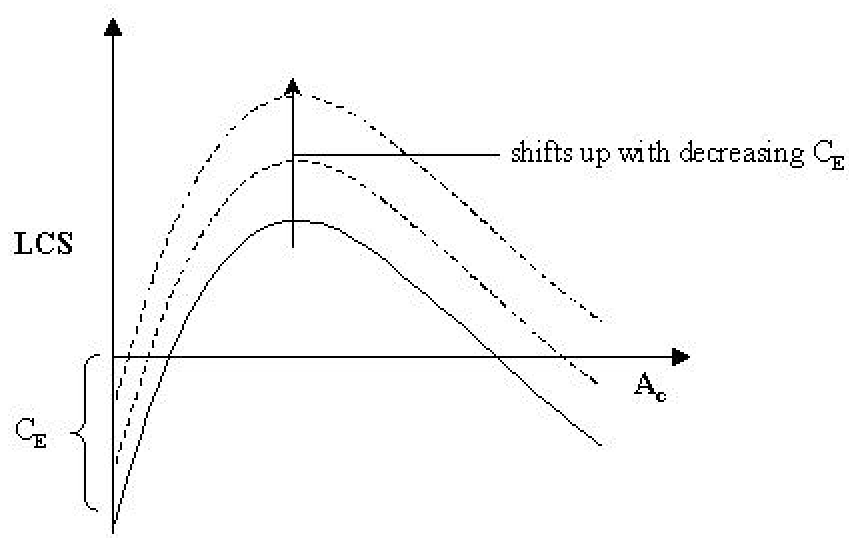

Figure 3.5.1: Effect of Altering Area Independent Cost

The goal of this analysis is to design three-season systems in various locations that are as economically attractive as a four-season system would be. To achieve this, the life cycle savings of the three-season system will be set equal to that of the four-season system by adjusting the three-season initial cost as shown in figure 3.5.2. The difference between the three and four-season initial costs correspond to the purchase price of the equipment that is unnecessary to the three-season system: the heat exchanger, the glycol and a pump. If these three pieces of equipment cost more than the projected cost difference, then the three-season system is the more attractive alternative and will save the customer more money over the course of its lifetime.

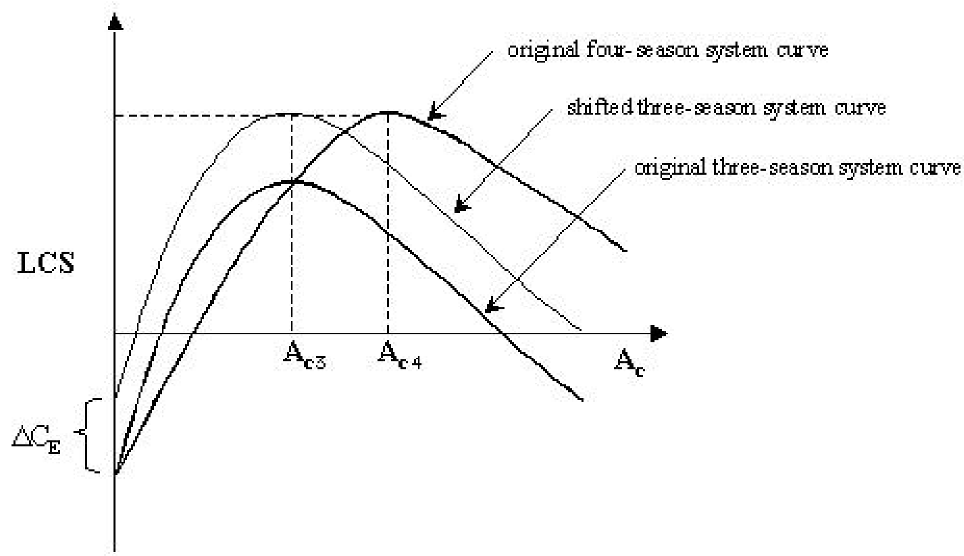

Figure 3.5.2: Three-Season System Design Methodology

The three-season system design proceeded as follows. First, the optimum slope for a four-season system in a given location is found and the plot of LCS versus collector area for that slope is created. Second, the optimum slope for a three-season system in the same location is found, and its plot of LCS versus collector area is created. Next, the two plots are superimposed and the area independent initial cost of the three-season system is adjusted until the optimum life cycle savings of the two systems are equal. The designer may then compare the cost of the four-season system specific equipment (pump, heat exchanger and glycol) with the cost reduction required to obtain equal life cycle savings, and may make the decision of whether a three or four-season system will save more money.

Figures 3.5.3 through 3.5.6 show the superimposed plots and the required three-season system initial cost reduction for four cities that have diverse weather conditions.

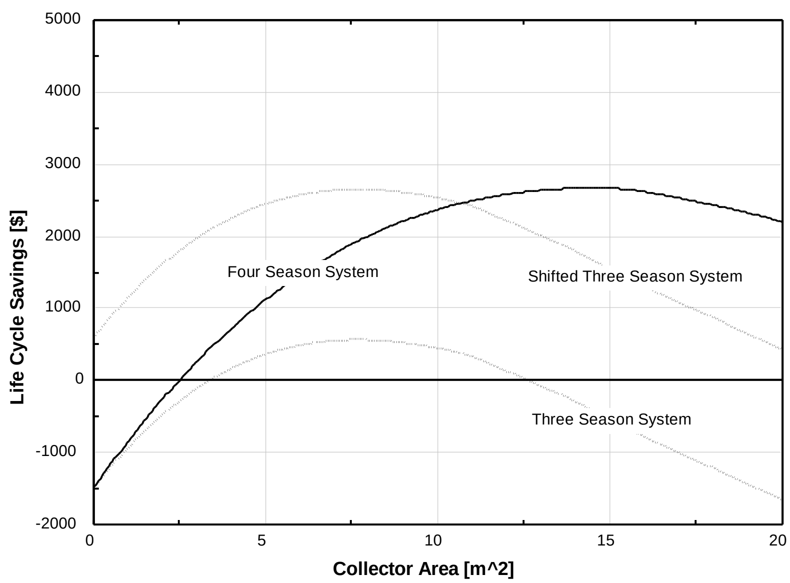

Figure 3.5.3: LCS System Design for Madison, WI

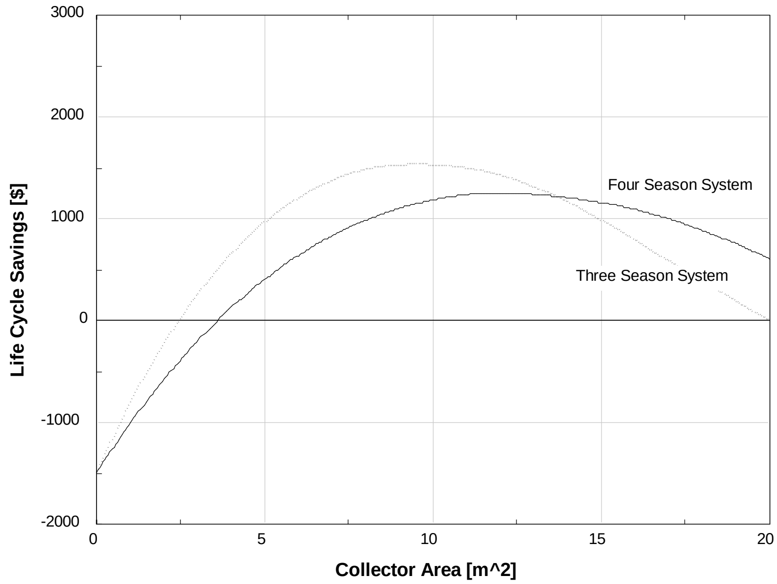

Figure 3.5.4: LCS System Design for Seattle, WA

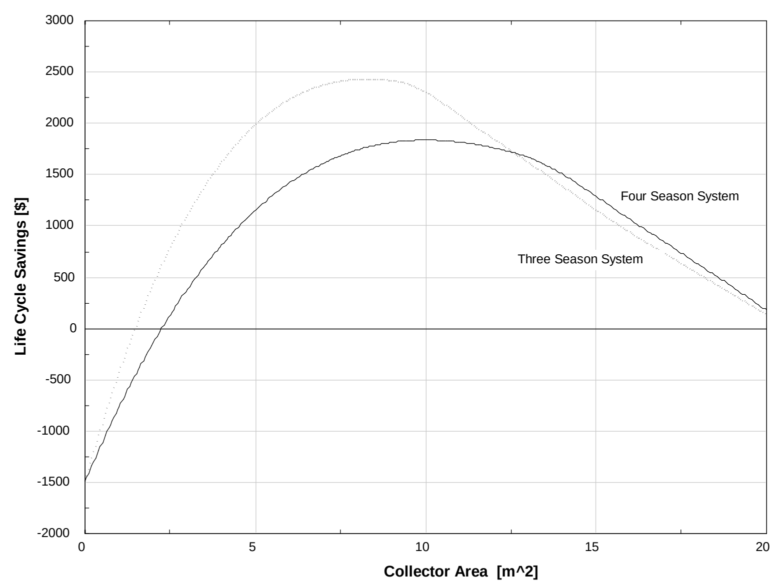

Figure 3.5.5: LCS System Design for Miami, FL

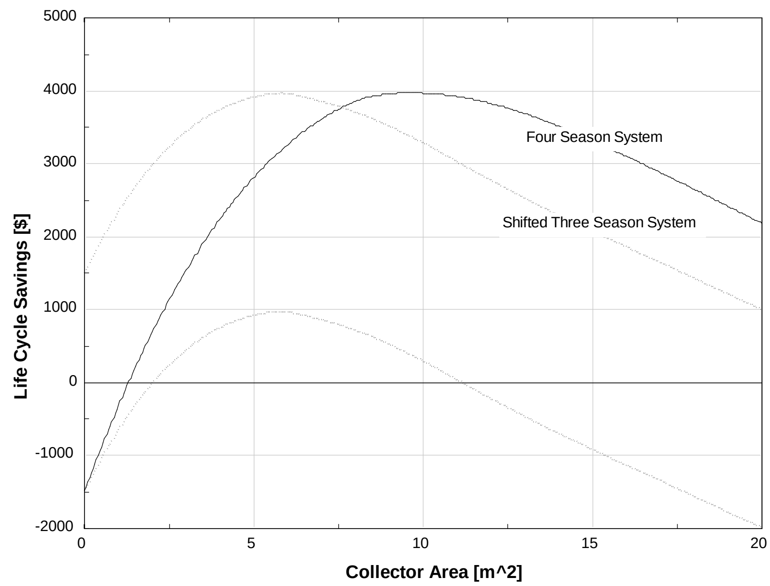

Figure 3.5.6: LCS System Design for Albuquerque, NM

The above figures show two different situations. In Miami and Seattle, the three-season system is preferable from an economic point of view as the three-season life cycle savings is higher than that of the four-season system even without a difference in initial cost. In Madison and Albuquerque, on the other hand, the three-season LCS is nowhere near as high as that of the four-season system. In fact, the required reduction in three-season system cost is greater than the four-season system cost. In other words, the system provider would have to actually pay the customer to install a three-season system. Unfortunately, Miami and Seattle are the exceptions to the norm and almost all the cities across the United States fall into the other category of places where the three-season system is unattractive from an economic point of view.

The results of designing three-season systems by calulating a required cost reduction were both disappointing and contrary to intuition. Eventually, it was determined that the life cycle savings indicator was preferentially penalizing the three-season system in a number of ways. First, the optimum areas for the four-season systems were coming out to be much higher than those of the three-season systems. Because of this, the four-season systems were collecting far more energy and meeting a much higher proportion of the load. The larger amount of collected energy meant that the annual fuel savings (in dollars) were far greater and therefore the life cycle savings were higher. The two square meter collector area operating for a fraction of the year was obviously having a difficult time economically outperforming fifteen square meters of collector operating year round, all be it at a lower efficiency.

The other reason for the poor results is more subtle and has to do with the fact that a comparison of life cycle savings is only valid when it compares the same initial investment. In the case of this analysis, two different investmets were being compared. To correct it, the life cycle savings of the initial cost difference would have to be added to the three-season system savings. The problem can be better visualised using a banking analogy. A customer has the option of either either investing $1000 at a 5% rate of return or $500 at a 7% rate of return. Obviously the latter choice is preferable even though the first investment option earns $50 in the first year as opposed to $35 for the second. The important economic indicator is the return on the investment, not the amount of the dividend. Based upon the fact that life cycle savings gives preferential results it was discarded as a design indicator in favor of return on investment.

3.6 System Design Using the Simple Payback Period Indicator

The number of years that it takes for the cumulative fuel savings to equal the purchase price of the SDHW system is referred to as the payback period as described in section 3.3. Because annual residential fuel bills tend to be comparatively small, because SDHW systems are only designed to meet a fraction of the total load, and because the SDHW system purchase price tends to be high, the payback period is often on the order of 10 years. Simple payback period is also the inverse of return on investment. If a system pays for itself in 10 years then 1/10 of it is paid off each year and the return on investment is 10%. The relationship between payback period and return on investment is not valid if the fuel savings are discounted to today's dollars.

Plots of payback period versus area at optimum slopes for the four representative locations are shown in figures 3.6.1 through 3.6.4. Unlike the plots of LCS versus area, a $500 difference in system price has been built into these plots.

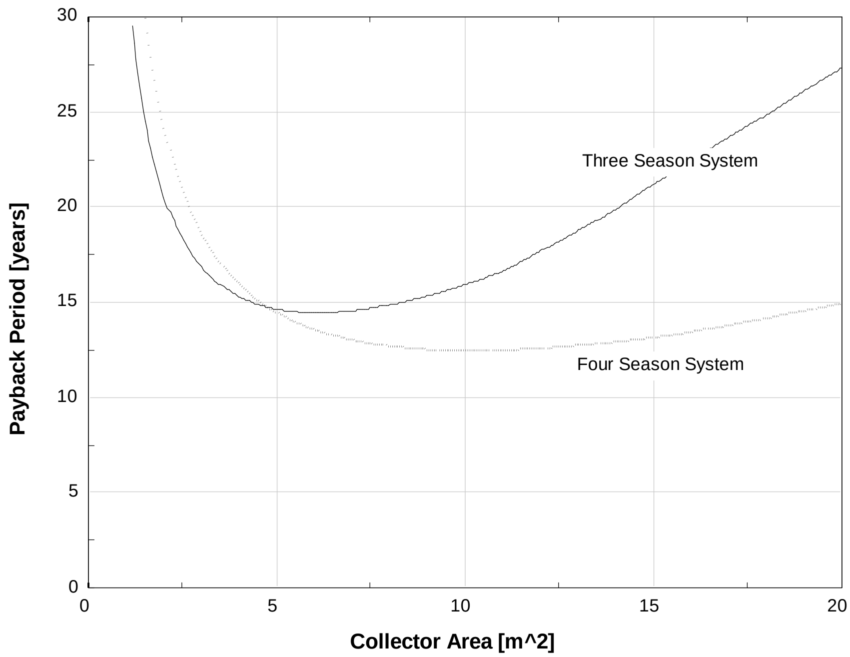

Figure 3.6.1: Payback Period System Design for Madison, WI

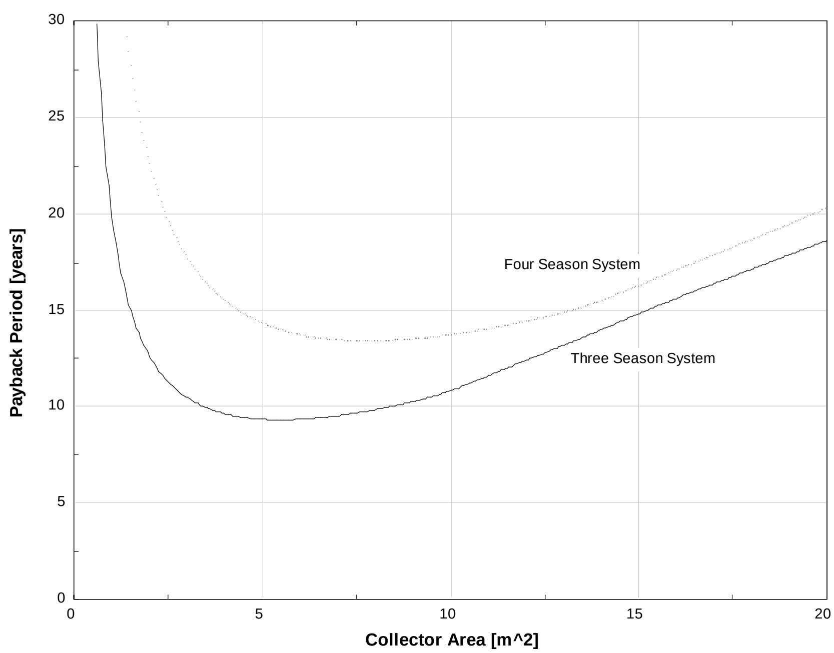

Figure 3.6.2: Payback Period System Design for Miami, FL

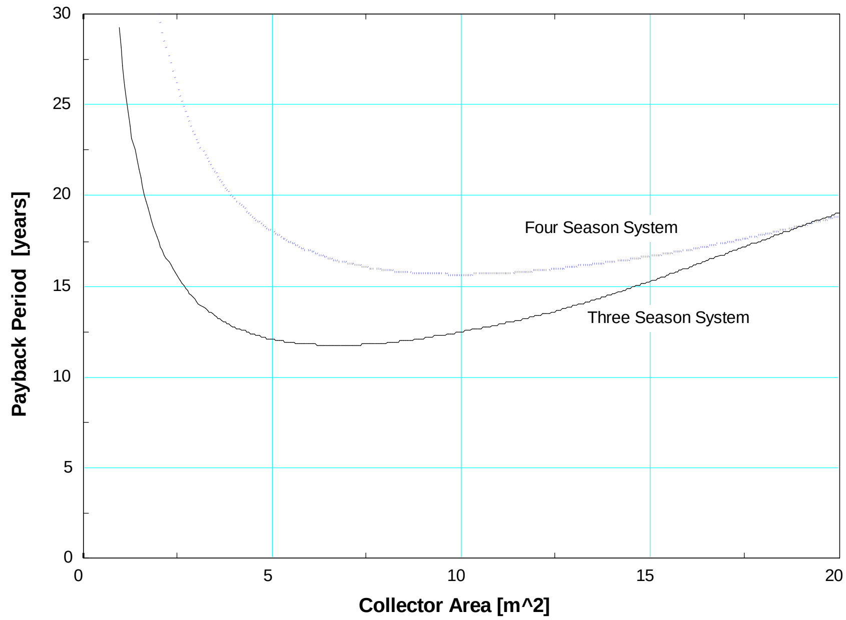

Figure 3.6.3: Payback Period System Design for Seattle, WA

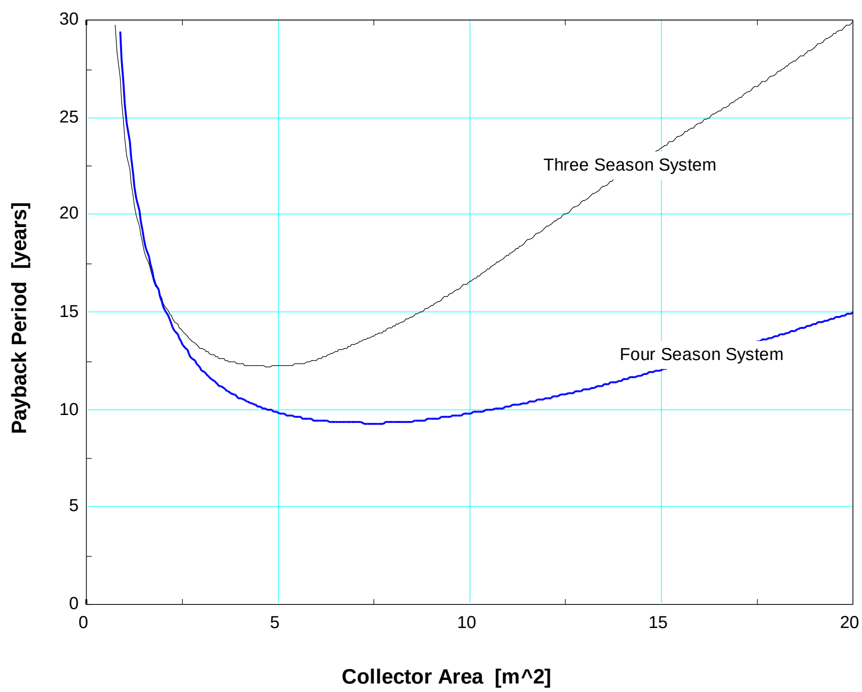

Figure 3.6.4: Payback Period System Design for Albuquerque, NM

As with the life cycle savings analysis, Miami and Seattle are favorable locations for three-season systems from a return on investment point of view. Madison and Albuquerque are also favorable locations under certain circumstances. Examination of figure 3.6.1 shows that below a certain collector area, the three-season system has a shorter payback period. One method of designing three-season systems would then be to calculate this critical area for each location. Then if the system designed to meet the customer's budget has an area smaller than the critical area, the three-season alternative should be chosen. For Madison, WI, the critical area is approximately 5 m^2 of collector area, or about 2 collector panels.

There are a number of variables that have an effect upon the critical area. Obviously the difference in system cost plays an important role; the greater the initial savings of the three-season system, the shorter time it will take for the cumulative fuel savings to reach the purchase price. Since the four-season cost does not change, and thus the four-season curve does not change, the critical area is shifted upwards (Figure 3.6.5).

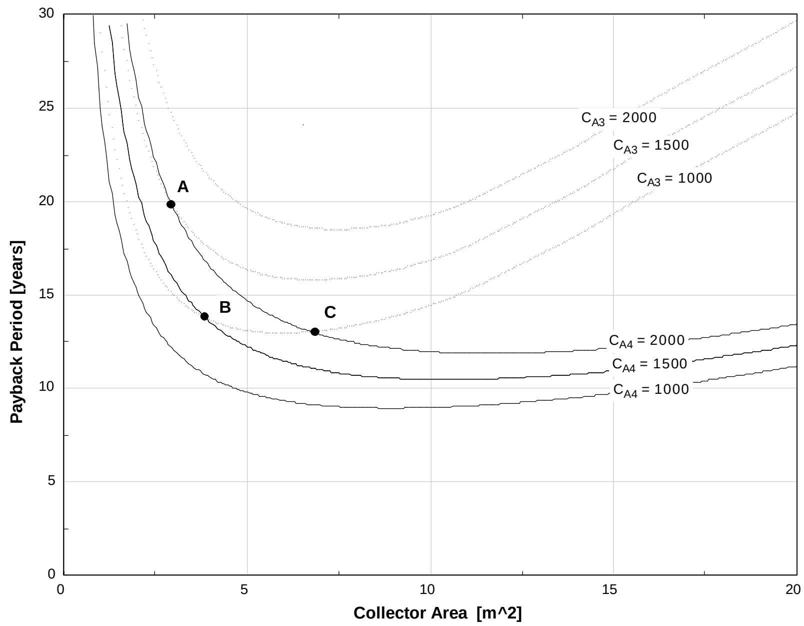

Figure 3.6.5: The Effect of System Prices upon Critical Area

As evident in figure 3.6.5, not only is the cost difference between the two systems important, but the base price is important as well. Point A shows the critical area for a three-season system costing \$1500 and a four-season system costing \$2000. Point B shows the same for a three-season system costing \$1000 and a four-season system costing \$1500. Both cost differences are \$500, but the less expensive systems have a shorter payback period and therefore a higher rate of return.

The critical area is not influenced by changes in cost of electricity (Figure 3.6.6). This makes some logical sense as the change in electricity rates affect both systems equally from the customer's point of view. No analysis was performed with electricity rates varrying within the month.

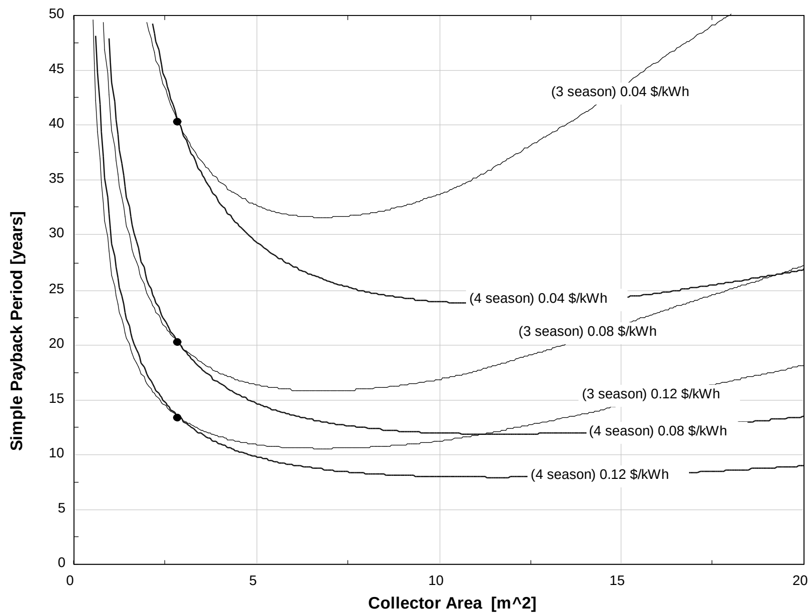

Figure 3.6.6: The Effect of Various Electricity Prices upon Critical Area

While using the payback period indicator has solved the problem of examining the amount of savings versus the return on investment; the collector area problem still exists. Plots 3.6.1 through 3.6.4 again indicate that the optimal area (lowest point on the payback period curve) for the four-season system is much higher than that of the three-season system and that the system will therefore collect more energy and pay for itself more rapidly.

3.7 Conclusions

A great deal has been learned through performing an economic analysis of three-season and four-season systems. Encouragingly, it has been shown that both system types are similarly sensitive to changes in various variables. Thus choosing a three-season system does not entail a sacrifice in system robustness. More disappointingly, the results of the analysis show that the three-season alternative is a poor one from an economic point of view. The optimum three-season system is simply unable to match the economic performance of the optimum four-season system. However, before abandoning the idea, the whole concept of an economic analysis should be examined.

First, an economic analysis is fraught with estimation. For example, the reported inflation rate is derived from the price increases of a "market basket" of commonly purchased goods. The list of goods is standard but there is no guarantee that different areas of the country rely upon the same goods. Consequently there are a number of inflation rates reported; the consumer price index for all urban consumers (CPI-U) and the consumer price index for Urban Wage Earners and Clerical Workers (CPI-W) are just two in a long list. (http://stats.bls.gov/news.release/cpi.nws.htm) The problem is that someone needs to decide what items urban wage earners and clerical workers are buying in order to report upon inflation. Such decisions are, at the heart, somewhat arbitrary.

Another example of estimation in economic analysis is the market discount rate. The market discount rate is supposed to reflect the rate of return of the best alternative investment. In other words, how much money would the consumer have made had he/she invested it in some other manner? The problem is choosing what this value should be. If invested in a savings account, the money might return 3% currently. If invested in a stock that happened to do well, it might return 50%. If the best alternative investment is chosen to be 50%, it is guaranteed that no SDHW system would ever be profitable.

Basically, the lesson learned from this economic analysis is that the results are interesting but should not be used to design SDHW systems; there are simply too many variables which, when tweaked, can preferentially benefit one option. Since ultimately a list of locations and their friendliness to three-season systems is desired, some performance indicator is needed and economic analysis is simply too uncertain to be of any use.