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**DIRECT CONTACT LIQUID-LIQUID HEAT EXCHANGER FOR
SOLAR HEATED AND COOLED BUILDINGS**

Final Report for Period January 1, 1979—May 30, 1980

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By
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Colorado State University
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FOR
SOLAR HEATED AND COOLED BUILDINGS

FINAL REPORT
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JANUARY 1, 1979 - MAY 30, 1980

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JUNE, 1980

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EXECUTIVE SUMMARY

Introduction

In a conventional dual-liquid solar system, a counter-flow shell-and-tube heat exchanger is used to separate the antifreeze liquid in the solar collector loop from water in the storage loop. A temperature difference therefore arises between the storage water and the return flow to the collector which will have the effect of reducing collector efficiency below that which could be achieved if the return water and storage water temperatures were the same.

A direct contact liquid-liquid heat exchanger enables heat exchange between droplets of the collector liquid and water in the storage tank. With a sufficient length of water column in storage, all the available thermal energy is transferred from the collector fluid to water in storage and the temperature of the liquid returning to the collector is equal to the storage water temperature. The collector fluid in this study was diethyl phthalate (DEP), which is heavier than water. Flow path of the collector liquid droplets through the storage tank is therefore from the top toward the bottom.

Objective of the Study

The objective of the study is to establish the technical and economic feasibility of using a direct contact liquid-liquid heat exchanger/storage unit in a solar heating and cooling system.

Procedure

The procedure used was to obtain experimental performance data from a solar system using a DCLLHE for both heating and cooling functions, develop a simulation model for the system, validate the model using the data, apply the model in five different climatic regions of the country for a complete year, and estimate the life-cycle cost of the system for each application. The results are compared to a conventional solar system, using a standard shell-and-tube heat exchanger.

System Description

The DCLLHE system, shown in Figure ES-1, was connected to CSU Solar House I. Only the collection system is shown in the figure and the heat delivery from storage to the load is through a water-to-air heat exchanger in a central air distribution system, and direct water circulation to a three-ton LiBr absorption chiller. Because there was another system connected to Solar House I, a computer-driven load simulator was used to deliver (reject) heat from the DCLLHE storage tank at a rate and quantity that matched the actual requirement in the building for solar heating and cooling. By delivering thermal energy from storage at the rate and in quantity sufficient to meet the demand, storage temperature was accurately simulated and the performance of the DCLLHE collection system was properly tested.

The storage tank volume of the DCLLHE facility is 4250 liters, of which 3800 liters is water and 450 liters is DEP. DEP is collected at the bottom of the tank, and to minimize the total volume requirement, the bottom of the tank is conical in shape. DEP is immiscible in water, and since it is heavier, it settles to the bottom and is recirculated to the collector for reheating.

Figure ES-1. Schematic Arrangement of the Solar House I Solar Systems

Results

A solar system with a DCLLHE and DEP as the collector fluid collects more thermal energy for both heating and cooling than a conventional solar system. There is slightly greater percentage difference for cooling than for heating.

In the five cities chosen to represent five different climatic regions of the country, annual collection efficiencies are shown in Table ES-1. Details of system performance are given in the text of the report.

Table ES-1
Annual Collector Efficiencies

Location	Storage Type	
	Conventional	DCLLHE
Boston	.21	.22
Charleston	.22	.23
Dodge City	.24	.25
Madison	.21	.22
Phoenix	.24	.26

Because DEP is denser than water and considerably more viscous, even at elevated temperatures, there is almost twice as much parasitic energy required for operation as compared to a water-ethylene glycol antifreeze solution. This increased operating energy requirement serves to offset some of the solar energy gain achieved by the DCLLHE system.

The annual space heating, cooling, and domestic water heating summaries for both systems in the study regions are given in Table ES-2. There is an overall increase in total solar fraction (SF) of 2 to 3 percentage points in the regions studied.

Based on a consistent set of assumed economic parameters, system costs and life-cycle cost (LCC) analyses, the DCLLHE system has a greater LCC than the conventional system for all areas when a heating-only system is considered. For a heating and cooling system, the DCLLHE system has a lower LCC. The differences in either case are not large, less than 4 percent in all cases. In hot arid regions where heating

requirement is limited, the DCLLHE is not advantageous for heating-only systems, but shows greatest advantage for heating and cooling systems. In cold regions, the life-cycle costs of both systems are about the same.

Table ES-2

Annual Totals for Heating and Cooling and Associated Solar Fractions

Location	Storage Type	DHW		Heating		Cooling		Total	
		(GJ)	SF	(GJ)	SF	(GJ)	SF	(GJ)	SF
Boston	Conv.	25.6	.80	55.1	.59	22.3	.17	103.0	.55
	DCLLHE	25.6	.81	55.3	.61	22.4	.22	103.4	.57
Charleston	Conv.	25.9	.94	23.1	.94	50.6	.24	99.6	.59
	DCLLHE	25.9	.94	23.3	.94	50.7	.29	99.9	.61
Dodge City	Conv.	25.9	.90	54.8	.78	43.7	.47	124.4	.69
	DCLLHE	25.9	.90	55.1	.79	43.9	.52	124.9	.72
Madison	Conv.	25.6	.79	75.9	.46	24.5	.20	126.0	.47
	DCLLHE	25.6	.80	76.2	.47	24.6	.25	126.4	.50
Phoenix	Conv.	26.4	.99	18.6	1.00	98.2	.50	143.2	.66
	DCLLHE	26.4	.99	18.7	1.00	98.4	.55	143.5	.69

Conclusion

While there is a performance advantage with a DCLLHE system over a conventional solar system, the advantage is not sufficiently large to overcome slightly higher capital and operating costs for the DCLLHE system. A fixed-size building and a fixed-size solar system were considered in the analysis, influenced largely by the need to provide a significant fraction of the heat supply to a three-ton lithium-bromide absorption chiller used in the cooling system for all locations.

Different sizes of systems and different loads could be investigated in all regions, but based upon the results of this study it is not expected that the conclusion would change significantly. The DCLLHE unit is technically feasible, provides greater utilization of solar energy for heating and cooling, but there is not sufficient economic advantage to expect the DCLLHE to be chosen by designers over conventional heat exchanger/storage units in liquid-based solar systems.

DIRECT CONTACT LIQUID-LIQUID HEAT EXCHANGER FOR SOLAR HEATED AND COOLED BUILDINGS

1.0 INTRODUCTION

A common, liquid-type, solar heating system uses an antifreeze solution through the collectors and water in storage. The two liquids are separated by a heat exchanger and depending upon the surface area provided, temperature differences as large as 10 to 15 °C can sometimes occur between the storage and collector inlet. A small temperature difference will not significantly affect collection efficiency, but a large temperature difference can cause a reduction in collection efficiency.

With a direct contact liquid-liquid heat exchanger (DCLLHE), heat is exchanged from the collector fluid to storage fluid through direct contact of the two fluids, which essentially eliminates the temperature difference between the storage liquid and the fluid at the collector inlet. Heat transfer occurs from droplets of the collector liquid to water in the storage tank, and by using an immiscible liquid, the collector liquid is recovered and recirculated through the collectors for reheating.

The immiscible liquid may be either lighter or heavier than the storage liquid. From economic considerations, the liquid in storage is generally water. If the liquid is lighter than water the inlet to storage would be at the bottom of the storage tank and droplets created by a special diffuser design, would rise through the storage fluid. If the liquid is heavier than water, the inlet would be at the top and droplets formed by a different diffuser would settle to the bottom. In

this study the collector liquid is diethyl phthalate (DEP) which is heavier than water.

2.0 SCOPE OF WORK

The objective of the work is to establish the technical feasibility and economic practicability of using direct contact liquid-liquid heat exchangers in solar heating and cooling systems. The scope of the work included the following tasks:

1. Install collectors appropriate for the DCLLHE subsystem on CSU Solar House I.
2. Operate the DCLLHE with the new collectors in conjunction with the load requirements in Solar House I for a 3-month period of the 1978-79 heating season.
3. Operate the DCLLHE during the summer of 1979 providing heat input to the solar-driven absorption chiller.
4. Evaluate the thermal performance of the solar system for the heating and cooling season.
5. Conduct a detailed analysis of performance and cost effectiveness of the DCLLHE compared to conventional solar storage and heat exchanger systems and based upon results, provide an appraisal of the economic and technical potential of the DCLLHE.

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3.0 THE SYSTEM

3.1 Direct Contact Heat Exchanger/Storage Facility

A schematic drawing of the direct contact heat exchanger/storage tank is shown in Figure 1 and the tank dimensions are listed in Table 1.

The storage tank is housed in a portable trailer so that the tank can be moved from one CSU solar house to another for tests with different solar systems. Earlier, the direct contact facility was tested with the Solar House III system. During the period of this report, the facility was located adjacent to Solar House I and connected to a flat-plate collector system.

Figure 1. Direct Contact Heat Exchanger/Storage Tank

Table 1

Dimensions of the Direct Contact/Storage Tank

Diameter of the cylindrical section	1.676 m
Height of cylindrical section	1.829 m
Height of conical section	0.610 m
Liquid capacity in cylindrical section	3800 ℓ
Volume of conical section	450 ℓ
Total liquid capacity	4250 ℓ

Fluid flow from the collectors enters the tank at the top and solar-heated DEP fluid is discharged onto a suspended distribution pan with a perforated bottom plate. The DEP is dispersed in the water, settles to the bottom, and is recirculated back to the solar collectors. An overflow pipe is provided at the top of the tank to prevent pressurization from expansion of water or from overfilling the tank.

Connections to the load loop from the storage tank are made in a conventional manner. Hot water is circulated from the top of the tank and returned at the bottom.

3.2 Physical and Thermal Properties of DEP

Diethyl phthalate is heavier than water and is immiscible with water. The viscosity is about three times greater than a 50 percent solution of ethylene glycol and water. Specific heat and thermal conductivity of DEP are less than for an ethylene glycol-water solution. The variations of the physical properties of DEP with temperature are shown in Figures 2 through 5.

Figure 2. Densities of Water, 50 Percent Ethylene Glycol Aqueous Solution and Diethyl Phthalate

Figure 3. Viscosities of Water, 50 Percent Ethylene Glycol Aqueous Solution and Diethyl Phthalate

Figure 4. Specific Heat of Water, Ethylene Glycol Aqueous Solution and Diethyl Phthalate

Figure 5. Thermal Conductivities of Water, 50 Percent Ethylene Glycol Solution and Diethyl Phthalate

The freezing and boiling points of DEP are cited in the literature as -40 and 298 $^{\circ}\text{C}$ respectively, but the freezing point for the technical grade of DEP used in this study was -24 $^{\circ}\text{C}$.

3.3 Collectors

Miromit collectors were installed on the roof of Solar House I. The collectors are single glazed and steel-plate absorbers are coated with a selective surface. The gross area of 26 installed modules is 55.8 m^2 , net aperture area is 48.5 m^2 and the headers occupy additional roof area. Transmittance of the cover glass is 0.91 and absorptance is 0.93 .

Tests of pressure drops through one collector module were made in the laboratory using DEP as the circulating fluid. Results are shown in Figure 6. The tubes in the collectors are 1.3 -cm diameter steel pipes.

Figure 6. Pressure Drop for Flow of DEP Through One Miromit Collector Panel

3.4 Solar House I System

A schematic representation of the physical arrangement of the direct contact heat exchanger/storage unit with the Solar House I system is shown in Figures 7 and 8. A second system which has a conventional heat exchanger is also installed on Solar House I and was operated at the same time as the DCLLHE system. For the conventional system the collectors are Philips evacuated tube-type (Mark IV) and a 50 percent ethylene glycol-water solution is used as the collector fluid. Counter-flow shell-and-tube heat exchangers are used to transfer heat to an 1100-gallon capacity storage tank. During the period of testing, the heat exchanger for domestic water preheating was placed in line with the load loop as shown in Figure 8.

An electric auxiliary boiler is shown in Figure 8, but was not used during the 1978-79 heating season. Auxiliary heating was supplied by an electric off-peak heating unit placed off line from the house air return and controlled to provide house heating when solar storage was unable to carry the load.

The cooling unit is an Arkla, 3-ton absorption water chiller using solar-heated water or the auxiliary boiler when water temperatures in the solar tank are not sufficient to operate the chiller. Although schematically two coils are shown, only one heating/cooling coil is used.

Since there are two solar systems in Solar House I, one system provides the actual house heating and cooling loads and simultaneously, the same amount of thermal energy from the other system is rejected outdoors. To control heat rejection from the second system, heat supply from the first is calculated in real time through an analog-to-digital

Figure 7. Schematic Arrangement of the Solar House I Solar Systems (Sheet 1)

Figure 8. Schematic Arrangement of the Solar House I Solar Systems (Sheet 2)

(A/D) data logger and minicomputer, and a microprocessor controls the load pump which circulates water from storage to the heat rejector. Control of the simulator is shown in Figure 9. By monitoring the quantity of thermal energy delivered by the first system, the second solar system delivers an identical quantity of thermal energy as the first, but the heat is rejected outdoors. Since the A/D data logger scans all instruments in 10-minute increments, in reality there is a ten-minute delay in load following by the second system. Because the size of both systems is large, a delay of 10 minutes has no measurable effect on system performance. Other factors such as control temperature settings can have greater influence on performance of the system.

Figure 9. Simulation Control of House Heating and Cooling Loads

4.0 HEAT EXCHANGE FROM COLLECTOR TO STORAGE

Assuming a steady-state condition in a system, and neglecting heat losses in transport, the solar thermal energy collection rate will equal the heat exchange rate, or

$$\dot{Q}_u = F_R A_c [I_T \tau \alpha - U_L (T_i - T_a)] \quad (4-1)$$

and

$$\dot{Q}_u = \epsilon (\dot{m} c_p)_{\min} (T_o - T_{ST}) \quad (4-2)$$

where Equation (4-1) is the Hottel-Whillier collector performance equation and Equation (4-2) is the heat transfer rate in the heat exchanger.

Equation (4-1) may also be expressed in terms of the collector outlet temperature,

$$\dot{Q}_u \left(1 - \frac{F_R U_L A_c}{(\dot{m} c_p)_c} \right) = F_R A_c [I_T \tau \alpha - U_L (T_o - T_a)] \quad (4-3)$$

where $(\dot{m} c_p)_c$ is the fluid capacitance rate through the collector. Solving for T_o in Equation (4-3) and substituting in Equation (4-2), the result is

$$\dot{Q}_u \left[1 + \left(\frac{F_R U_L A_c}{(\dot{m} c_p)_c} \right) \left(\frac{1}{\epsilon} - 1 \right) \right] = F_R A_c [I_T \tau \alpha - U_L (T_{ST} - T_a)] \quad (4-4)$$

where

ϵ is heat exchanger effectiveness

T_{ST} is storage temperature

When a heat exchanger is not used in the system, $\epsilon = 1$ and the term in brackets on the left side is unity. Rearranging Equation (4-4),

$$\dot{Q}_u = \frac{1}{\left[1 + \frac{F_R U_L A_c}{(mc_p)_c} \left(\frac{1}{\epsilon} - 1\right)\right]} F_R A [I_T^{\tau\alpha} - U_L (T_{ST} - T_a)]$$

or,

$$\dot{Q}_u = \left(\frac{F_R}{F_R}\right) F_R A [I_T^{\tau\alpha} - U_L (T_{ST} - T_a)]$$

and the term in brackets is the heat exchanger factor (F_R'/F_R), which is the penalty imposed by a heat exchanger in a double-loop system.

5.0 HEAD LOSSES FOR DEP CIRCULATION

The piping loop for DEP circulation to the trailer is longer than a piping loop which would be needed if the direct contact device were located within the building. A schematic representation is shown in Figure 10 to illustrate the differences. (The trailer was actually on the south side of the building, but is shown on the north side for reason of clarity in this figure). Since the measured pumping head for the DEP system is greater than that which would be required for a normal installation, for the purpose of computing parasitic energy requirements, the measured head was reduced by the friction losses in the additional piping.

Figure 10. Collector Loop for DEP Circulation

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6.0 EXPERIMENTAL RESULTS

6.1 Collector Performance

6.1.1 Tests at New Mexico State University

The Miromit model 210 collector was tested at New Mexico State University in a test stand on 2 November 1976 and the collector efficiency is expressed as

$$\eta_c = 0.72 - 5.05 \left(\frac{T_i - T_a}{I_T} \right) \quad (6-1)$$

The tests were conducted with ethylene glycol and water solution at a flow rate of 74 W/(m²·°C) and inlet temperature of 60 °C. Results were expressed in terms of average fluid temperature which is corrected to inlet fluid temperature in Equation (6-1) by the factor

$$K = C_c / \left(C_c + \frac{F_R U_L}{2} \right) \quad (6-2)$$

where C_c is the capacitance flow rate through the collector and K has a value 0.966 based on the conditions of the test.

6.1.2 Tests at CSU of the Total Array

Using water as the collector liquid at a capacitance flow rate of about 109 W/(m²·°C) (0.038 gpm per square foot), data from the total collector array indicated collector efficiency to be

$$\eta_c = 0.7 - 5.3 \left(\frac{T_i - T_a}{I_T} \right) \quad (6-3)$$

The test data are given in Table 2.

Table 2

Test Data for Collector Array Efficiency
Collection fluid: Water

Time	Flow Rate ℓ/s	C_p $J/(g^\circ C)$	C_c $W/(m^2 \cdot ^\circ C)$	T_i	T_o	T_a	I_T W/m^2	Q_u W	η_c	$\frac{T_i - T_a}{I_T} (m^2 \cdot ^\circ C)/W$
1030	1.26	4.18	5274.3	10.0	12.6	1.6	1033.1	13450	.268	.0081
1200	1.26	4.18	5274.3	18.3	24.9	1.3	1156.2	34811	.62	.0147
1430	1.26	4.18	5274.3	33.3	37.7	5.2	895.4	23207	.53	.0314
1500	1.26	4.18	5274.3	36.4	40.0	5.1	801.7	18988	.49	.0390
1530	1.26	4.18	5274.3	41.4	43.3	4.7	579.1	10021	.36	.0634

Collector efficiencies with DEP as the collector fluid with varying capacitance flow rates are shown in Table 3. By comparing the results with Equation (6-3) it is evident that the collector performance with DEP as the collecting fluid is the same as that with water at a lower capacitance flow rate (although the volumetric flow rate is 25 percent greater). The high volumetric flow rate was used during the winter heating test period.

Table 3

Test Results with DEP as Collector Fluid
(Based on T_i)

Flow Rate ℓ/sec	C_c $W/(m^2 \cdot ^\circ C)$	$F_R \tau \alpha$	$F_R U_L$ $(m^2 \cdot ^\circ C)/W$
1.58	70	0.70	5.33
1.14	50	0.67	5.00
0.95	42	0.63	4.37
0.76	34	0.67	5.16

6.2 Pressure Drops in the Collection System

The collector array was provided with pressure taps to enable measurements of pressures and pressure drops across various points in the array and across the entire array, as shown in Figure 11. The pressure head drops measured at various flow rates are listed in Table 4. Pressure drops across the array are small for all flow rates and the pressure head drops across the two collector modules in series indicates reasonably uniform distribution of flow across the entire array.

Pressure drops in the collector loop for various flow rates and at two fluid temperatures are listed in Table 5.

Figure 11. Location of Collector Pressure Taps

Table 4

Pressure Head Drops in Collector Array
(cm of water)

Flow Rate l/sec	C_c W/(m ² ·°C)	$P_1 - P_8$ cm	ΔP_1 cm	ΔP_2 cm	ΔP_3 cm	$P_1 - P_4$	$P_5 - P_8$
0.76	34	4.5					
0.95	42	8.5					
1.14	50	13.0	5.5	5.5	6.5	0	2
1.27	56	14.5					
1.58	70	21.5					

Table 5

Pressure Drops in the Collector Loop

Flow Rate l/sec	C_c W/(m ² ·°C)	Fluid Temp. °C	ΔP psi
0.76	34	30	7.9
0.95	42	30	18.2
1.14	50	30	17.7
1.27	56	30	21.4
1.58	70	30	32.0
0.95	42	60	13.0
1.14	50	60	17.0
1.27	56	60	20.0
1.58	70	60	21.4
0.76	Water	30	7.0

6.3 System Performance

6.3.1 Heating Season

The performance of the solar heating system with the DCLLHE unit is listed in Table 6 in terms of monthly mean values.

Table 6
Monthly Mean Daily Performance of the Solar System
Using a DCLLHE Unit

No.	Item	Units	Feb.	Mar.	April
1	Total Solar Insolation	MJ/(m ² ·day)	14.93	21.05	24.33
2	Insolation While Operating	MJ/(m ² ·day)	10.46	12.64	19.34
3	Useful Heat Collected in Storage	MJ/(m ² ·day)	5.50	4.90	8.48
3a	Useful Heat Collected in Storage	MJ/day	266.60	237.50	411.50
4	Daily Collection Efficiency	3/1	0.37	0.23	0.35
5	Collection Efficiency	3/2	0.53	0.39	0.44
6	Total Load	MJ/day	491.90	410.30	468.60
7	Total Solar Contribution	MJ/day	266.60	237.50	411.50
8	Total Auxiliary to Load	MJ/day	225.30	172.80	75.10
9	Solar to Space Heating	MJ/day	231.40	200.60	353.50
10	Solar to DHW	MJ/day	35.20	36.90	58.00
11	Auxiliary to Space Heating	MJ/day	152.00	87.60	54.70
12	Auxiliary to DHW	MJ/day	73.30	85.20	20.40
13	Heat Loss from Tank in (9)	MJ/day	47.00	47.30	60.40
14	Electrical Energy for Collection	MJ/day	5.95	5.08	8.44
15	Collection COP	3a/14	44.80	46.80	48.80
16	Fractional Loss From Storage	13/3a	0.18	0.20	0.15
17	Number of Days of Useable Data		11	22	19

The collection of solar heat with the direct contact system in comparison with the conventional heat exchange system is shown in Figure 12, for the same days of system operation. It should be noted that the solar collectors for the conventional heat exchange system have 50 m² of the Philips Mark IV evacuated tube collectors. In the months of February and March the operating time for the direct contact system was less than the conventional system because of various experiments that were being conducted and some adjustments were being made to the control system to increase optimal energy collection, while the conventional system was operating with an established control strategy. The comparison that can be made between the two systems is collection efficiency while operating, which is listed in Table 7.

Figure 12. Direct Contact Versus Double Loop System

Table 7
Collection Efficiency While Operating
(Percent)

Month	Direct Contact	Conventional Heat Exchanger	Difference
February	52.7	50.2	5.0
March	38.7	33.6	15.2
April	43.9	33.7	30.3
Average	44.5	37.9	17.4

The data for the three months indicates that the direct contact system is more effective in collecting heat than the conventional heat exchanger system, with the difference increasing, with the warmer months. The comparison, however, is based on an evacuated tube collector in the conventional system and since the collector performance is basically different from the flat plate system, the comparison of collector efficiency reflects the effect of the DCLLHE and the actual difference in the performance of the evacuated tube collector. Generally in terms of the collector parameters, $F_R' \tau \alpha$ is less than 0.7, although $F_R' U_L$ is also less than for the Miromit collectors. Thus, depending upon the operating temperature range, the difference in collector characteristics could account for some of the difference indicated in Table 7. Nevertheless, there appears to be an improvement in the efficiency of heat collection to storage because of the DCLLHE, but because of differences in the experimental systems, conclusions are difficult to formulate.

6.3.2 Cooling Season

The performance of the solar cooling system with the DCLLHE unit is listed in Table 8 in terms of monthly mean values.

Table 8
Monthly Mean Daily Performance of the Solar System
Using a DCLLHE Unit

No.	Item	Units	Aug	Sept
1	Total Solar Insolation	MJ/(m ² ·day)	23.21	23.75
2	Useful Heat Collection in Storage	MJ/(m ² ·day)	6.90	7.91
3	Useful Heat Collection in Storage	MJ/(m ² ·day)	307.00	352.70
4	Daily Collection Efficiency	2/1	0.30	0.33
5	Cooling Load	MJ/day	215.3	143.3
6	Solar Cooling	MJ/day	118.1	129.1
7	Solar Thermal Energy Supplied for Cooling	MJ/day	173.2	199.1
8	Cooling COP	6/7	0.68	0.65
9	Fraction of cooling by solar	6/5	0.55	0.90
10	DHW load	MJ/day	85.0	79.6
11	Water load supplied by solar	MJ/day	67.5	58.1
12	Fraction of DHW by solar	11/10	0.79	0.73
13	No. of Days of Data for Month		9	11

Although the system operated continuously in both months, there were a number of malfunctions with the simulator which rendered some data to be inappropriate for use. For example, on August 10, a large quantity of thermal energy was discharged from storage overnight and

because cool, cloudy weather followed, the storage was not recharged and there was no cooling demand until August 29. In September, cooling demand was artificially created by setting the thermostat "down". However, there were malfunctions of the simulation again on September 6, 9, 14 and 22, and with these incidences and low cooling demand, there were only 11 days of applicable data during the month. There were however sufficient consecutive days of operation for use in the validation of a TRNSYS simulation model described in the next section.

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7.0 COMPARATIVE EVALUATION OF THE DCLLHE AND CONVENTIONAL SYSTEM

It is desired to make comparisons of system performance of a DCLLHE system and a conventional dual-liquid system using identical collectors and loads, and operating in identical weather conditions. Since making such comparisons is experimentally difficult, TRNSYS simulation programs were used to predict the performance of both systems. A schematic representation of the two systems is shown in Figure 13.

Performance factors which can be compared for the solar heating and cooling systems are collection efficiency or quantity of thermal energy collection, average storage temperatures, solar fraction or net thermal energy collection, average storage temperatures, solar fraction or net thermal energy delivery to the load. Economic comparisons can also be made to evaluate the two systems.

Figure 13.. TRNSYS Simulation of DCLLHE and Heat Exchangers Subsystems in a Solar Heating and Cooling System

7.1 TRNSYS Model

In the TRNSYS models, a "typical" dwelling is represented, and the system arrangements are similar to those operated in Solar House I at Colorado State University. To represent a particular building with precision it is necessary to use a complex model with detailed representations of the building construction, its components and the patterns of occupancy. For example, in calculating a heating load the walls, roof, basement and passive gains must all be considered separately. Because in this comparison analysis it is only necessary to represent a "typical" situation, a much simpler degree-hour load model may be used. Similarly, for the domestic hot water subsystem instead of modeling each component separately, a simpler unit in the TRNSYS package was used.

By simplifying the simulation model as much as possible, computing time for each run was reduced, and it was economically possible to extend performance analyses of both systems for a full year at 5 different locations. The locations are chosen to represent different climatic and geographic regions of the continental United States. The sites chosen are Madison, WI, Boston, MA, Charleston, SC, Dodge City, KS, and Phoenix, AZ. The results are presented in terms of monthly totals and average values for each location. In addition, some day-by-day and hour-by-hour performance data are given to illustrate the relative performance of the two systems with different storage units.

TRNSYS is a modular simulation program. Each component of a system is represented as a unit in the computer program and its performance is described by a set of algebraic and/or differential equations. These units are interconnected in a fashion analogous to the physical system;

the output of one unit is an input to another unit. (For example, the output temperature of the storage tank unit will be an input parameter for the heating load). In making performance analyses of systems, the complete set of equations is solved at discrete time steps and the solutions describe the state of the system at the end of that time step.

In this section the TRNSYS model is described under the following headings:

- (1) Data input: TMY and the radiation processor
- (2) Collectors
- (3) Collector pump
- (4) Domestic hot water subsystem
- (5) House load and room temperature calculations
- (6) Storage
 - (a) DCLLHE
 - (b) Conventional storage and the heat exchanger.

The assumptions made in the modeling of each component are discussed and the values of the parameters used in the simulation are given. Many of the parameters are assigned values appropriate to CSU Solar House I and other parameters were chosen to represent commercially available systems.

7.1.1 Data Input, TMY and the Radiation Processor

The meteorological data used to drive the system simulation models are the Typical Meteorological Year (TMY) data prepared by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce. The Typical Meteorological Year consists of actual data (hourly values) for specific months. Each month is chosen from 20 years (or more) of

data as being the most representative for that month. Since these typical months are chosen from different years, the values for 6 hours at the end of one month and the beginning of the next are smoothed to remove discontinuities. A full description of this data base is given in Ref. [1].

The data base is described as providing measurements of radiation on a tilted surface; however, this is in fact not available. The reliable radiation data is global radiation on a horizontal surface. It is then necessary to calculate the radiation incident upon a tilted collector surface. For this purpose the TRNSYS radiation processor component (TYPE 16) is used. The unit utilizes the Liu-Jordan correlation, and calculates the radiation incident upon the plane of the collector.

The other data taken from TMY are ambient temperature, dew-point temperature, and an indicator of the presence of snow. The ground cover reflectivity, ρ , is calculated according to

$$\rho = 0.3 I_{\text{SNOW}} + 0.2,$$

where

$$I_{\text{SNOW}} = \begin{cases} 0 & \text{no snow cover} \\ 1 & \text{snow cover} \end{cases}$$

Reflectivity is then used in the calculation to determine the solar radiation incident on the inclined collector surface.

7.1.2 The Collectors

The collectors modelled in the simulation are those used on Solar House I, namely, Miromit flat-plate collectors. The panels are single-glazed and have steel absorber plates with selective surface coating. The fluid circulated through the collector is diethyl phthalate (DEP) for the DCLLHE system. A 50 percent (by weight)

solution of ethylene glycol and water is assumed for the conventional storage system.

The collector performance test results are summarized in the Table below.

Table 9

Miromit Collector Test Performance

Fluid	$F_R(\tau\alpha)$	$F_{RU_L} \left(\frac{W}{m^2 \cdot ^\circ C} \right)$	$\frac{\dot{m}c_p}{A} \left(\frac{W}{m^2 \cdot ^\circ C} \right)$	Sources of Results
Ethylene glycol/ water 50% solution	.72	5.05	74	New Mexico State Univ. single panel
Water	.70	5.30	109	CSU Solar House I Array
DEP	.70	5.33	70	
	.67	5.00	50	
	.63	4.37	42	
	.67	5.16	34	

The heat removal efficiency factor, F_R , is known to be a function of fluid properties. These results would suggest that the collector, operating at the same capacitance flow rate, gave better performance with an ethylene glycol/water mixture than with DEP (i.e. at $70 W/m^2 \cdot ^\circ C$ for ethylene glycol/water, $F_R\tau\alpha$ is higher and F_{RU_L} is less). However it has been recognized, Ref. [2], that collection in an array gives efficiencies significantly less than those measured for the collector in a test stand.

For the Miromit collector array installed on the roof of Solar House I, water and DEP at high capacitance flow rates yield nearly the same collector efficiency parameters. Thus for this study the $F_R(\tau\alpha)_n$ and $F_R U_L$ values used for DEP and an ethylene glycol/water mixture are the same. Further, for both systems the capacitance flow rates are 50 W/°C per m² of collector area. While recognizing that the heat removal factor is an increasing function of flow rate, 50 W/m²°C is chosen because a higher flow rate results in only a small gain in collected energy (see Ref. [3].).

The collector area was fixed in this study at 60 m² for both the DCLLHE and conventional solar system in all locations. While it is recognized that an economic "optimum" collector area may be determined by conducting thermal performance and economic analyses, there is no convenient low-cost analysis tool available for comparing DCLLHE and conventional heat exchanger systems. The "optimum" collector area would no doubt be different for different regions of the country. Since the main objective in this study is to compare the performance of a solar heating and cooling system with a DCLLHE and a similar solar system with a conventional heat exchanger and storage unit, selection of collector area that may not be optimal should not have a significant effect on the relative results. Also, a collector area 60 m² is sufficient to provide a significant fraction of the winter heating load in the cold climates and a significant fraction of the cooling load in the warmer regions of the country.

The collector performance is modelled by the Hottel-Whillier-Bliss equation

$$\dot{Q}_u = F_R H_T A \tau \alpha - F_R U_L A (T_i - T_a) = \dot{m} c_p (T_o - T_i)$$

where

$\dot{Q}_u$ = useful heat gain

F_R = heat removal fraction

H_T = incident radiation per unit area

A = collector area

τ = transmissivity of the cover glass

α = absorbtivity of the absorber surface

U_L = collector loss coefficient

T_i = fluid inlet temperature

T_a = ambient temperature

$\dot{m}$ = fluid mass flow rate

c_p = fluid specific heat

T_o = fluid outlet temperature

The TRNSYS package offers several collector component options. The simplest (Mode 1) was chosen in which U_L and $\tau\alpha$ are input as constants. It provides reasonable accuracy with minimum computational effort.

The transmittance τ of a single cover glass is given by the manufacturer as .91 for normal incidence (0° incident angle) and .824 for 60° incident angle. The absorptance, α , of the selective surface is given as ranging from 0.92 to 0.94 for incidence angles of 0 to 50° . In the collector model we use $\tau = .91$ and $\alpha = .93$. A more exact treatment would calculate the values τ and α hour-by-hour; but using constants is sufficient for the purpose of this comparison study. The measured (test) parameters for the collector are:

$$F_R \tau \alpha = .67$$

$$F_R U_L = 5.00 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$$

Thus,

$$F_R = .838$$

$$U_L = 5.967 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C}) = 0.21 \text{ MJ}/(\text{hr} \cdot \text{m}^2 \cdot ^\circ\text{C})$$

The collector efficiency parameter required as input to the model is F' , the collector geometry efficiency factor, which is related to F_R by

$$F_R = \frac{\dot{m} c_p}{A U_L} \left[1 - \exp\left(-\frac{F'}{\dot{m} c_p / A U_L}\right) \right].$$

Rewriting,

$$F' = -\frac{\dot{m} c_p}{A U_L} \ln \left(1 - \frac{F_R}{\dot{m} c_p / A U_L} \right)$$

and since we have chosen $\frac{\dot{m} c_p}{A} = 50 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$

$$F' = .70$$

The model parameters used are:

1. Mode = 1 (TRNSYS identification)

2. $A = 60 \text{ m}^2$

3. $F' = 0.70$

4. $c_p = \begin{cases} .00175 \frac{\text{MJ}}{\text{kg} \cdot ^\circ\text{C}} & (\text{DCE}) \\ .00350 \frac{\text{MJ}}{\text{kg} \cdot ^\circ\text{C}} & (\text{ethylene glycol/water}) \end{cases}$

5. $\alpha = .93$

6. $U_L = .021 \text{ MJ}/(\text{m}^2 \cdot \text{hr} \cdot ^\circ\text{C})$

7. $\tau = .86$

Collector Control Strategy

A simple on-off (bang-bang) differential thermostat which uses the difference in temperature of the fluid in a mixed storage unit, T_s , and the fluid temperature at the collector outlet, T_o , is used to control heat collection. For the conventional solar system, the collector pump and the storage side heat exchanger pump are both switched on when $\Delta T > 10^\circ\text{C}$ and switched off when $\Delta T < 2^\circ\text{C}$. For the DCLLHE system, the collector pump is switched on when $\Delta T > 5^\circ\text{C}$, and switched off when $\Delta T < 1^\circ\text{C}$.

The Collector Pump

A capacitance flow rate of $50 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$ implies different mass flow rates for the two fluids.

$$\dot{m}(\text{DEP}) = 4989 \text{ kg/hr}, (c_p = 1750 \text{ J}/(\text{kg} \cdot ^\circ\text{C}))$$

$$\dot{m}(\text{glycol}) = 2494 \text{ kg/hr}, (c_p = 3500 \text{ J}/(\text{kg} \cdot ^\circ\text{C}))$$

$$\dot{m}(\text{DEP}) = 4632 \text{ l/hr} = 21.2 \text{ gpm}, (\rho = 1.079)$$

$$\dot{m}(\text{glycol}) = 2398 \text{ l/hr} = 11.0 \text{ gpm}, (\rho = 1.040)$$

Experimental measurements of head loss for the Solar House I system are listed below:

Flowrate (gpm)	$\Delta p(\text{ft})$		
	DEP - 30°C	DEP - 60°C	Water - 30°C
25	73.8	69.2	16.1
20	49.4	46.1	
18	40.8	39.2	
15	30.9	30.0	
12	18.2		

In choosing pump sizes, the usual design practice is to choose the capacitance flow rate (here, $50 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$), calculate the mass flow rate and head loss, choose a commercially available pump to produce the required flow rate and head and operate at maximum efficiency.

Since we wish to have the capacitance flow rate the same for both systems, a different sizing process is used. Using the chosen flow rates and head losses, the work done by the pump is then calculated. An overall pump efficiency of 60 percent is assumed to determine the required pump size for the model.

The motor sizes for the pump and operating time are used to calculate power requirements of the two systems. Fluid power, P_f , is

$$P_f = \rho g z$$

For the DCLLHE system the pump power requirements, P_{p1} , for fluid circulation through the collector is shown:

$$z = 50 \text{ ft} = 15.2 \text{ m}$$

$$P_f = (4989)(9.81)(15.2)(10^{-6}) = .744 \text{ MJ/hr}$$

$$P_p = \frac{.774}{.6} = 1.24 \text{ MJ/hr} = 345 \text{ W} = .46 \text{ hp}$$

For the conventional system with ethylene glycol in the collector loop, the head loss is $z = 5.2 \text{ m}$ (experimental value) through the collector and piping. There is an additional head loss for flow through the heat exchanger of 6.4 m . It is assumed that the collector loop flows through the shell side of the heat exchanger.

$$P_f = (2494)(9.81)(11.6)(10^{-6}) = 2.84 \text{ MJ/hr}$$

$$P_p = \frac{.284}{.6} = .473 \text{ MJ/hr} = 131 \text{ W} = .176 \text{ hp}$$

7.1.3 The Domestic Hot Water Subsystem

The domestic hot water subsystem consists of a preheat tank which supplies solar-heated water to a conventional domestic hot water tank which heats water to the required supply temperature, T_{req} . There is a heat exchanger between the DHW preheat tank and the larger solar storage tank. The domestic hot water load has a daily profile built in to the TRNSYS subroutine and the total daily usage is an input parameter.

Control Strategy for Domestic Hot Water

Solar energy from storage will be added to the preheat tank whenever the storage temperature is greater than the preheat tank temperature by 2 °C. There is a maximum preheat tank temperature above which no more solar energy will be added. In the conventional DHW tank, auxiliary energy is added when needed to raise the water temperature to T_{req} .

The parameters for the system are based on measurements in Solar House I.

1. M_b = total daily usage of hot water = 330 kg
2. V = volume of pre-heat tank = 0.3 m³
3. ρ = density of water in preheat tank = 1000 kg/m³
4. c_{pc} = specific heat of water in preheat tank = 4.185 kJ/(kg·°C)
5. U = loss coefficient of preheat tank = 1.5 kJ/(m²·hr·°C)
6. R = preheat tank height to diameter ratio = 5
7. T_{req} = required temperature of hot water = 60 °C

8. c_{ph} = specific heat of fluid from storage = 4.185 kJ/(kg·°C)
9. $\dot{m}_c$ = mass flow rate of water in cold side of heat exchanger = 900 kg/hr
10. ϵ = effectiveness of heat exchanger = 0.6
11. ΔT = temperature by which storage must exceed preheat tank to keep pumps on = 2 °C
12. ICNTL = 1 (specify internal control strategy)
13. T_o = initial temperature of preheat tank = 40 °C
14. T_{max} = maximum temperature of preheat tank = 60 °C

Inputs held constant are:

1. $\dot{m}_h$ = mass flow rate of fluid to hot side of heat exchanger
= 900 kg/hr
2. T_{env} = temperature to which preheat loses energy = 20 °C
3. T_s = temperature of water from mains = 10 °C

7.1.4 House Load and Room Temperature Calculations

The house is modeled as a one-node capacitance with a floating room temperature. The load is modelled by a "degree-hour" method. The energy/degree day concept has been shown by ASHRAE to be useful in estimating the monthly heating or cooling load of a residence. In this model, the energy/degree day concept is extended to estimate the hour-by-hour load.

It is recognized that the hour-by-hour load estimated in this manner may be significantly in error. If we wished to match the simulated load with observed data then this model would be inappropriate and a more complex approach would be required. However, this model provides an estimation of the load, with minimum computational effort, and provides

the same loads for the two systems at a given location in order to compare the two solar systems.

Constant Heat Gain

It is assumed that the heat input to the house from people in residence, cooking, etc. is equivalent to a constant heat generation of 1 kW

$$\dot{Q}_{\text{gen}} = 1 \text{ kW} = 3.6 \text{ MJ/hr}$$

Windows

One of the major deficiencies in the "degree-hour" load calculation is that it does not directly account for passive solar gain, i.e solar radiation entering the house through windows. We use a simple model to account for the heat gain from this source.

The house is taken to have windows facing east, south and west, with areas of 2 m², 6 m² and 2 m² respectively. The radiation incident upon these windows is calculated by the radiation processor; this radiation is then transmitted through the windows with a transmissivity τ of 0.8, and an overall absorptivity, α , of 0.8.

Thus the energy input is taken as

$$\dot{Q}_{\text{window}} = H_E A_E \tau \alpha + H_S A_S \tau \alpha + H_W A_W \tau \alpha$$

- where
- H_i is the radiation incident upon the window of given Orientation (E, S, or W)
 - A_E is the area of the window with given orientation (E, S, or W) (2, 6, and 2 m² respectively)
 - τ is the transmissivity (0.8)
 - α is the overall absorptivity (0.8)

Net Gain

The other source of heat gain in the building (apart from the HVAC system) is the heat losses from the storage tank. It is assumed that the room containing the storage tank has a venting system such that the heat losses are directed into the house during the winter and outside the house during the summer.

Hence, the net heat input into the building (from sources other than the HVAC system or the ambient air temperature) is:

$$\dot{Q}_{\text{gain}} = \dot{Q}_{\text{gen}} + \dot{Q}_{\text{window}} + F\dot{Q}_{\text{tank losses}}$$

where F is a flag set for the season as:

$$F = \begin{cases} 0 & \text{summertime} \\ 1 & \text{wintertime} \end{cases}$$

The determination of winter and summer (start and end) dates will vary for different locations. The specific dates used are given in section 7.3 which describes the 5 locations.

Total Load

The useful heat flow rate, $\dot{Q}_L$, through the heating and cooling system into the building is

$$\dot{Q}_L = UA(T_R - T_{\text{amb}}) - \dot{Q}_{\text{gain}}$$

where

UA = effective building heat loss coefficient

T_R = room temperature

and

T_{amb} = ambient (outside) temperature

In this simulation an energy efficient building is assumed with a net UA, including infiltration of

$$UA = 1 \frac{\text{MJ}}{\text{hr}^\circ\text{C}} \quad (= 278 \frac{\text{W}}{^\circ\text{C}})$$

Room Temperature

The energy inputs from the house heating/cooling system are the heat transferred across the load heat exchanger, $\dot{Q}_T$, and the cooling done by the chiller unit, $\dot{Q}_{\text{cool}}$. Heat removed (cooling) is divided into two parts, sensible and latent. The latent load is taken as a constant fraction, λf , of the total load. The ASHRAE recommendation is $\lambda f = .23$.

Hence the net rate of house sensible energy gain is

$$\dot{Q}_{\text{ex}} = \dot{Q}_T - \dot{Q}_L - \dot{Q}_{\text{cool}}(1 - \lambda f);$$

and the room temperature is found by solving

$$CAP \frac{dT_R}{d\tau} = \dot{Q}_{\text{ex}}$$

where CAP is the thermal capacitance of the building and τ is time.

The capacitance is chosen as $CAP = 5 \frac{\text{MJ}}{^\circ\text{C}}$. With $\dot{Q}_T = \dot{Q}_L = 0$,

$$\dot{Q}_{\text{cool}} = 3 \text{ tons} = 40 \frac{\text{MJ}}{\text{hr}}, \quad \left. \frac{dT_R}{d\tau} \right|_{\text{max}} = 8 \frac{^\circ\text{C}}{\text{hr}}$$

Summary

Summarizing the parameter of the model (UNIT 43, TYPE 12, MODE 4) we have

$$\text{Mode} = 4$$

$$UA = 1 \frac{\text{MJ}}{\text{hr}^\circ\text{C}}$$

$$CAP = 5 \frac{\text{MJ}}{^{\circ}\text{C}}$$

$$\dot{m}_c = 2498 \frac{\text{kg}}{\text{hr}}$$

$$c_p = 4.185 \frac{\text{kJ}}{\text{kg} \cdot ^{\circ}\text{C}}$$

$$\epsilon = .8$$

$$c_{\min} = 2.04 \frac{\text{MJ}}{\text{hr} \cdot ^{\circ}\text{C}}$$

$$\dot{Q}_{\text{gen}} = 0 = \text{constant heat gain}$$

$$\ell f = .23$$

The Thermostat

The house is controlled by a two-stage heating and one-stage cooling thermostat. Cooling is indicated when room air temperature is above T_c . First stage (solar) heating is controlled below a temperature T_{H1} and second stage (auxiliary) heating is controlled by a set temperature T_{H2} .

The thermostat has a deadband ΔT_{db} . Once the cooling is switched on, it does not switch off until the temperature has reached $T_c - \Delta T_{\text{db}}$. Once a heating stage has switched on, it does not switch off until the temperature has reached $T_H + \Delta T_{\text{db}}$.

If the solar storage water temperature is less than a minimum temperature, $T_{\min}$, solar heating will not be used, i.e. the first-stage heating is "disabled". In any event, the first-stage heating is switched off when second-stage heating is required.

The parameters used in the simulation are:

$$T_{\min} = 38 ^{\circ}\text{C}$$

$$T_c = 24 ^{\circ}\text{C}$$

$$T_{H1} = 19 ^{\circ}\text{C}$$

$$T_{H2} = 17 \text{ }^{\circ}\text{C}$$

$$\Delta T_{db} = 2 \text{ }^{\circ}\text{C}$$

7.1.5 Heating/Cooling System

The system used in the simulation is based on CSU Solar House I. The house is heated or cooled by ducted air circulating to each room in the house. Energy is transferred to or from this air by a water/air heat exchanger.

The heat exchanger parameters are:

$$\text{Air flow} = \dot{C}_{\text{air}} = 2.04 \frac{\text{MJ}}{\text{hr} \cdot ^{\circ}\text{C}} (0.57 \text{ m}^3/\text{s})$$

$$\text{Water flow} = \dot{C}_{\text{meter}} = 9.50 \frac{\text{MJ}}{\text{hr} \cdot ^{\circ}\text{C}} (0.63 \text{ l/s})$$

$$\text{Heat exchanger effectiveness: } \epsilon_L = 0.8$$

Heating is provided either from the solar storage tank or by an auxiliary boiler. Cooling is provided by chilled water from an Arkla 3-ton lithium-bromide absorption chiller, which is driven by hot water from either the solar storage tank or the auxiliary boiler.

The boiler supplies water at a constant temperature $T_{\text{aux}} = 87.8 \text{ }^{\circ}\text{C}$. Both the heating and the cooling systems use the boiler in parallel, with an either/or control strategy; i.e. either the solar tank or the boiler provides all the hot water.

The Chiller

The chiller modelled is the Arkla lithium-bromide absorption cooler model WF-36, with a nominal capacity of 3 tons. Used in temperature level control in this simulation, the start-up and shut-down transients are considered.

The auxiliary is run in parallel. When the temperature of the solar store becomes too low ($T_{hw} < T_{min}$), the auxiliary supplies all the heat (at a constant temperature T_{aux}). There is a deadband (ΔT_{db}) in the control such that once the auxiliary is being used the machine does not switch back to solar until $T_{hw} > T_{min} + \Delta T_{db}$.

The condensing water is cooled by a cooling tower. The performance of the cooling tower is modeled by

$$T_c = T_{wb} + T_{app}$$

where

T_c = condensing water temperature

T_{wb} = ambient wet bulb temperature

T_{app} = cooling tower approach to ambient wet bulb temperature

The approach temperature chosen is $T_{app} = 3^\circ\text{C}$, which corresponds to a commercially available device that is sufficient to produce 26.5 degrees cooling water in all cities in all but the most severe conditions.

The performance characteristics of the ARKLA WF-36 as shown in Figure 14. The control points have been chosen in accordance with the characteristics.

The parameters of the model (UNIT 47, TYPE 7) are summarized below.

1. IAUX = -2 (temperature level control, parallel auxiliary)
2. CAPY = $37980 \frac{\text{kJ}}{\text{hr}}$ (3-ton)
3. τ_h = -1 hour (start-up time constant) $\rightarrow$.133 hour (measured value)
4. T_c = -1 hour (shut-down time constant) $\rightarrow$ 1.05 hour (measured value)
5. T_g° = 20°C (initial generator temperature)
6. $T_s^{\min}$ = 76.7°C (minimum solar temperature for cooling = 180°F)

Figure 14. Performance of Standard Arkla WF-36

7. $\Delta T_{db} = 5 \text{ }^{\circ}\text{C}$ (dead band)
8. $T_{aux} = 87.8 \text{ }^{\circ}\text{C}$ (auxiliary supply temperature)

A tempering valve is used (UNIT 48 TYPE 11) if the supply water from the solar store is hotter than 190 $^{\circ}\text{F}$. Hot water is mixed with the return flow from the generator to achieve the optimum operating temperature in terms of COP for the required capacity.

7.1.6 Storage

The two different kinds of storage units are taken to be as similar as possible, apart from their fundamental differences. That is, the same volume (4.25 m^3) (1100 gallons) and the same heat loss rate ($.050 \frac{\text{MJ}}{\text{hr}\cdot^{\circ}\text{C}}$) were selected for the two systems,

DCLLHE

The TRNSYS model of this component is described in an appendix to this report. The parameters are listed below:

1. $V_w = \text{volume of water} = 3.84 \text{ m}^3$
2. $\rho_w = \text{density of water} = 1000 \frac{\text{kg}}{\text{m}^3}$
3. $c_{pw} = \text{specific heat of water} = 4.185 \frac{\text{kJ}}{\text{kg}\cdot^{\circ}\text{C}}$
4. $V_D = \text{volume of DEP} = 0.41 \text{ m}^3$
5. $\rho_D = \text{density of DEP} = 1.080 \frac{\text{kg}}{\text{m}^3}$
6. $c_{pd} = \text{specific heat of DEP} = 1.75 \frac{\text{kJ}}{\text{kg}\cdot^{\circ}\text{C}}$
7. $UA = \text{total heat loss coefficient} = .50 \frac{\text{kJ}}{\text{hr}\cdot^{\circ}\text{C}}$

Conventional Storage and the Heat Exchangers

This unit has the following parameters:

1. $V = \text{volume of tank} = 4.25 \text{ m}^3$
2. $H = \text{height of tank} = 2 \text{ m}$
3. $c_p = \text{specific heat of storage fluid} = 4.185 \frac{\text{kJ}}{\text{kg} \cdot ^\circ\text{C}}$
4. $\rho = \text{density} = 1000 \frac{\text{kg}}{\text{m}^3}$
5. $U = \text{heat loss coefficient} = 3.43 \frac{\text{kJ}}{\text{m}^2 \cdot \text{hr} \cdot ^\circ\text{C}}$

The TRNSYS component assumes that the tank is cylindrical and the given volume, height, and U-value result in a UA of $50 \frac{\text{kJ}}{\text{hr} \cdot ^\circ\text{C}}$. The water in the storage tank is taken to be fully mixed. The heat exchanger is sized by requiring the heat exchanger penalty factor to be no less than 0.95.

If the capacitance flow rate on the storage side is greater than or equal to the capacitance flow rate on the collector side (Ref. 4) then:

$$\epsilon = \frac{1}{1 + \frac{C_{\min}}{(UA)_{\text{HX}}}}$$

$$(UA)_{\text{HX}} = 16.57 \frac{\text{MJ}}{\text{hr} \cdot ^\circ\text{C}}$$

Storage Side Pump and Power Requirement

The capacitance flow rate is

$$50 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}} \times 48.5 \text{ m}^2 = 2425 \frac{\text{W}}{^\circ\text{C}} = 8.73 \frac{\text{MJ}}{\text{hr} \cdot ^\circ\text{C}}$$

and mass flow rate is

$$\dot{m} = 2086 \frac{\text{kg}}{\text{hr}} \quad (9.2 \text{ gpm})$$

The measured head loss is 1.5 m in the load loop, hence,

$$P_f = (2086) (9.81) (1.5) \times 10^{-3} = 31 \text{ kJ/hr}$$

$$P_p = \frac{31}{.0} = 52 \text{ kJ/hr} = 14.4 \text{ W} = .02 \text{ hp}$$

Pressure Relief Valve

Both systems are provided with pressure relief valves in case the water temperature in storage exceeds 100 °C.

Venting

The storage tank room is ventilated so that all storage heat loss is vented to the outside of the house during the summer and onto the house during the winter. Identification of winter and summer seasons was based on climatic data (see Section 7.3). Accordingly the following months were selected for venting the heat losses to the outside:

Boston:	June through August
Charleston:	April through October
Dodge City:	June through September
Madison:	June through August
Phoenix:	April through October

7.2 Operation of the Model

7.2.1 Time Step

The sensitivity of the simulation to change in the time step was investigated by running the program with a week of January data. The results are summarized in the table below. A time step of 15 minutes was chosen to retain computational accuracy at moderate computer cost.

Table 10
Sensitivity of Calculations to Time Steps

Time Step ()	Computer Time (CPU sec)	Energy Flows in Tanks (MJ)			
		Q_U	Q_{LOSS}	Q_{LOAD}	ΔE
5	86	490.3	152.7	568.0	-230.4
10	50	490.3	153.2	567.1	-230.0
15	43	489.8	152.5	567.1	-229.8
30	30	484.6	150.8	571.6	-237.8
60	24	578.3	157.0	647.4	-226.1

7.2.2 Convergence Tolerances

At each time step in a simulation, the TRNSYS program solves a set of algebraic and differential equations. The program does this iteratively by successively calling component subroutines until all the outputs from the previous computation in the iteration converge within a set tolerance. It is possible to use either relative tolerances, where the difference between two iterative solutions is compared to a fixed fraction of the average value of the solution, or absolute tolerances, where the difference between two iterative solutions is compared to an absolute quantity. Because the performance of the heat exchanger is of critical importance in this investigation an absolute error tolerance of .01 was chosen. This means that all calculated quantities converge to within .01 units; for example, the temperatures across the heat exchanger converge to within .01 °C. Although the computational accuracy demanded exceeds practical realizations, we want to ensure that comparisons are based on reasonably accurate performance results.

7.2.3 Iteration Limits

The program contains a limit on the number of iterations it will perform at any one time-step. The default value is 10 iterations. However for certain components like the collector-heat exchanger loop, convergence is "slow". Thus in the program a limit of 20 iterations was used; this enabled the computed results to converge within the tolerance at all times.

7.2.4 Heat Balances

A necessary check for any computation is an energy balance on components and systems. Of particular concern is the storage subsystem in this study. Computed values were analyzed for a one-week period. Over the week the "error of closure" was 0.06 percent. The average error of closure for a day was 0.04 percent.

7.2.5 Computation Time/Expense

The run time of the program is expressed in seconds of central processor unit (CPU) usage. However at Colorado State University computer time is charged by System Resource Units (SRU) where the number of SRU's is a function of CPU time, input/output activity and central memory usage.

CPU time and SRU's are listed in the table below for different simulation lengths. It will be noted that whereas CPU time is proportional to the length of the simulation, SRU's are not.

Table 11
Run Time and Expense Factor for Computer Simulations

Simulation Length	CPU (secs)	SRU
Week	43	71
Month	185	280
Year	2270	2996

The values given in the table are for the conventional storage system. The simulation of the direct contact system typically requires 3 percent less CPU time.

7.3 The Five Cities

The performance of the conventional storage and direct contact storage systems were simulated for a full year in five different locations. These locations were chosen to give a geographic and climatic spread across the United States. The five cities chosen were:

- Boston, Massachusetts
- Charleston, South Carolina
- Dodge City, Kansas
- Madison, Wisconsin
- Phoenix, Arizona

The annual climatic parameters of these cities are summarized in Table 12 and the monthly figures are given in Table 13. The degree days are Fahrenheit degree-days, with a 65 °F base. The radiation is the global radiation incident upon a horizontal surface.

These data are taken from "Monthly Normal of Temperature, Precipitation and Heating and Cooling Degree-Days" by the National Oceanic and Atmospheric Administration, Department of Commerce, and represent long-term averages.

Table 12
Annual Climatic Data for the 5 Cities

Item	Boston	Charleston	Dodge City	Madison	Phoenix
Average Temperature, T_{amb} , (°F)	51	66	55	45	70
Average Daily Radiation, H , MJ/(m ² ·day)	13.0	16.9	18.8	14.3	21.4
Heating Degree Days, (°F·day)	5621	1904	5046	7730	1552
Cooling Degree Days, (°F·day)	661	2354	1411	460	3508

Table 13
Monthly Climatic Data

City/Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<u>BOSTON</u>												
T _{amb} , (°F)	29	30	38	49	59	69	73	71	65	55	45	33
H, MJ/(m ² ·day)	6	8	12	15	20	21	21	18	14	10	6	5
Heating, °F·day	1110	969	834	492	218	27	0	8	76	301	594	992
Cooling, °F·day	0	0	0	0	20	117	260	203	61	0	0	0
<u>CHARLESTON</u>												
T _{amb} , (°F)	50	52	57	66	73	79	81	81	77	68	59	51
H, MJ/(m ² ·day)	11	13	16	22	23	23	22	21	17	14	12	9
Heating, °F·day	481	393	282	52	0	0	0	0	0	50	211	435
Cooling, °F·day	16	15	37	76	263	426	508	493	348	143	22	7
<u>DODGE CITY</u>												
T _{amb} , (°F)	31	35	41	54	64	74	79	78	69	58	43	33
H, MJ/(m ² ·day)	11	14	18	23	24	28	27	24	21	16	12	10
Heating, °F·day	1060	834	738	344	115	21	0	0	41	247	666	980
Cooling, °F·day	0	0	0	14	84	282	440	406	158	27	0	0
<u>MADISON</u>												
T _{amb} , (°F)	17	20	30	45	56	66	70	69	60	50	35	22
H, MJ/(m ² ·day)	6	9	14	17	20	23	23	20	16	11	6	6
Heating, °F·day	1494	1252	1079	591	297	72	14	39	173	474	909	1336
Cooling, °F·day	0	0	0	41	125	276	484	412	267	66	0	0
<u>PHOENIX</u>												
T _{amb} , (°F)	51	55	60	68	76	85	91	89	84	72	60	53
H, MJ/(m ² ·day)	12	17	22	27	30	31	27	26	24	19	14	12
Heating, °F·day	428	292	185	60	0	0	0	0	0	17	182	388
Cooling, °F·day	0	14	21	141	355	588	812	747	564	240	26	0

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8.0 RESULTS OF THE SIMULATION

The simulations were run on 15-minute time steps. Integrated hourly quantities were calculated and these values were stored on tape. The results are analyzed on a daily basis, and for convenience the "day" is defined to be the 24 hours between 6 a.m., to 6 a.m., of the following day. This time period is chosen because it corresponds to the charge-discharge cycle of storage.

Complete daily records for all systems are presented in a separately bound appendix volume. In the following tables, monthly and annual totals are reported for all the cases considered.

8.1 Collector Efficiency

The direct contact system had in all cases a slightly higher annual collection efficiency; typically by one percentage point. The annual collector efficiencies for all cases are summarized in Table 14. Monthly average efficiencies are listed for different cities in Tables 15 through 19.

Table 14

Annual Collector Efficiencies

Location	Storage Type	
	Conventional	DCLLHE
Boston	.21	.22
Charleston	.22	.23
Dodge City	.24	.25
Madison	.21	.22
Phoenix	.24	.26

Table 15
Yearly Summaries for Boston

ENERGY IN MJ, TEMPERATURE IN DEGREES

PLACE: Boston, MA

1. CONVENTIONAL STORAGE

MONTH	COLLECTION					AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL ENERGY SUPPLIED		
	RAD	QU	EFF	PUMP QELEC QELEC/QU		STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW Q QSOL SF		
1	17453.	4015.	.23	55.	.014	37.7	18.8	-1.7	2144.	1113.	.52	11181.	3262.	.29	0.	0.	0.00	13325.	4374.	.33
2	24344.	6308.	.26	67.	.011	44.8	19.5	1.5	1937.	1276.	.66	7869.	4873.	.62	30.	0.	0.00	9836.	6150.	.63
3	30725.	7724.	.25	82.	.011	48.6	19.9	2.6	2149.	1544.	.72	8201.	5602.	.68	175.	0.	0.00	10525.	7146.	.68
4	27467.	5999.	.22	74.	.012	56.0	20.5	3.5	2094.	1712.	.82	4774.	4210.	.88	670.	9.	.01	7538.	5931.	.79
5	30016.	5609.	.19	82.	.015	63.7	21.5	13.6	2192.	1945.	.89	3240.	2874.	.89	2552.	449.	.18	7984.	5269.	.66
6	29974.	5214.	.17	81.	.016	70.1	22.2	19.6	2132.	2086.	.98	597.	597.	1.00	4090.	556.	.14	6819.	3239.	.47
7	30169.	5750.	.19	84.	.015	72.0	22.9	22.5	2210.	2196.	.99	0.	0.	0.00	5520.	877.	.15	7730.	3017.	.39
8	30046.	5525.	.18	80.	.014	72.6	22.7	21.8	2215.	2200.	.99	0.	0.	0.00	5119.	1118.	.22	7334.	3318.	.45
9	28626.	5387.	.19	80.	.015	68.3	21.8	17.0	2129.	2029.	.95	726.	726.	1.00	2328.	468.	.20	5182.	3223.	.62
10	26843.	5471.	.20	70.	.013	63.7	21.2	12.2	2183.	1991.	.91	3317.	3063.	.92	1522.	314.	.21	7022.	5368.	.76
11	20234.	4976.	.25	63.	.013	44.8	19.9	6.9	2075.	1364.	.66	5532.	3782.	.68	323.	0.	0.00	7930.	5246.	.65
12	18693.	4421.	.24	54.	.012	37.7	18.9	.3	2144.	1110.	.52	9691.	3332.	.34	0.	0.	0.00	11835.	4442.	.38
YEAR TOTAL	314590.	66398.	.21	872.	.013	56.7	20.8	10.4	25604.	20566.	.80	55128.	32321.	.59	22327.	3736.	.17	3059.	56623.	.55

2. DCLLHE

MONTH	COLLECTION					AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL ENERGY SUPPLIED		
	RAD	QU	EFF	PUMP QELEC	QELEC/QU	STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW Q	QSOL	SF
1	17453.	4229.	.24	131.	.031	38.0	18.8	-1.7	2144.	1127.	.53	11202.	3452.	.31	0.	0.	0.00	13346.	4579.	.34
2	24344.	6534.	.27	157.	.024	46.2	19.6	1.5	1938.	1322.	.68	7894.	5068.	.64	30.	0.	0.00	9862.	6390.	.65
3	30725.	8012.	.26	195.	.024	50.1	20.0	2.6	2153.	1587.	.74	8220.	5819.	.71	175.	0.	0.00	10548.	7406.	.70
4	27467.	6200.	.23	177.	.029	57.3	20.6	8.5	2099.	1743.	.83	4803.	4267.	.89	672.	85.	.13	7574.	6095.	.80
5	30016.	5841.	.19	199.	.034	64.6	21.4	13.6	2197.	1965.	.89	3245.	2935.	.90	2604.	553.	.21	8045.	5454.	.68
6	29974.	5514.	.18	200.	.036	70.3	22.3	19.6	2133.	2066.	.98	592.	592.	1.00	4073.	747.	.18	6798.	3424.	.50
7	30169.	6112.	.20	205.	.034	71.9	22.9	22.5	2209.	2195.	.99	0.	0.	0.00	5522.	1153.	.21	7732.	3348.	.43
8	30046.	5852.	.19	194.	.033	72.8	22.8	21.8	2217.	2200.	.99	0.	0.	0.00	5109.	1269.	.25	7325.	3470.	.47
9	28626.	5666.	.20	195.	.034	68.9	21.8	17.0	2133.	2038.	.96	739.	739.	1.00	2327.	668.	.29	5199.	3445.	.66
10	26843.	5735.	.21	168.	.029	64.2	21.2	12.2	2186.	2004.	.92	3337.	3112.	.93	1574.	445.	.28	7097.	5561.	.78
11	20234.	5125.	.25	148.	.029	46.2	19.9	6.9	2076.	1416.	.68	5553.	3887.	.70	351.	0.	0.00	7980.	5303.	.66
12	18693.	4694.	.25	131.	.028	38.0	18.9	.3	2144.	1122.	.52	9721.	3617.	.37	0.	0.	0.00	11865.	4739.	.40
YEAR TOTAL	314590.	69514.	.22	2101.	.030	57.4	20.8	10.4	25628.	20805.	.81	55306.	33488.	.61	22436.	4921.	.2210	3371.	59214.	.57

Table 16
Yearly Summaries for Charleston

ENERGY IN MJ, TEMPERATURE IN DEGREES

PLACE: Charleston, SC

1. CONVENTIONAL STORAGE

MONTH	COLLECTION					AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL ENERGY SUPPLIED		
	RAD	QU	EFF	PUMP		STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW		
				Q/LEC	Q/EC/QU													Q	QSOL	SF
1	23535.	5712.	.24	64.	.011	53.6	20.6	9.3	2154.	1724.	.80	4771.	4263.	.89	970.	0.	0.00	7895.	5987.	.76
2	28395.	6729.	.24	75.	.011	62.7	21.1	9.3	1967.	1785.	.91	4364.	4336.	.99	1055.	119.	.11	7386.	6240.	.84
3	32842.	6618.	.20	87.	.013	70.8	21.9	13.7	2202.	2182.	.99	3593.	3593.	1.00	2915.	319.	.11	8710.	6094.	.70
4	26620.	5926.	.22	71.	.012	65.4	22.1	18.0	2131.	1900.	.89	932.	932.	1.00	2793.	1029.	.37	5857.	3861.	.66
5	35058.	6622.	.19	97.	.015	74.9	22.7	21.8	2229.	2226.	1.00	113.	113.	1.00	5164.	1268.	.25	7506.	3607.	.48
6	30255.	6043.	.20	91.	.015	72.1	23.0	24.2	2139.	2126.	.99	16.	16.	1.00	6553.	1353.	.21	8708.	3495.	.40
7	34635.	7190.	.21	101.	.014	74.5	23.3	26.1	2225.	2224.	1.00	0.	0.	0.00	8624.	1762.	.20	10849.	3986.	.37
8	35278.	8079.	.23	99.	.012	74.5	23.2	25.6	2227.	2219.	1.00	0.	0.	0.00	8368.	2533.	.30	10595.	4753.	.45
9	32633.	7236.	.22	91.	.013	75.3	23.1	23.9	2159.	2158.	1.00	0.	0.	0.00	6665.	2138.	.32	8824.	4296.	.49
10	34067.	7595.	.22	86.	.011	73.5	22.2	18.0	2227.	2183.	.98	920.	920.	1.00	3550.	1444.	.41	6697.	4547.	.68
11	28855.	5876.	.20	82.	.014	68.3	21.6	13.3	2133.	2011.	.94	3684.	3515.	.95	3100.	397.	.13	8917.	5924.	.66
12	20016.	4997.	.25	68.	.014	47.7	20.6	9.6	2144.	1540.	.72	4663.	3929.	.84	813.	0.	0.00	7620.	5468.	.72
YEAR TOTAL	362189.	78623.	.22	1011.	.013	67.8	22.1	17.7	25936.	24278.	.94	23057.	21618.	.94	50571.	12363.	.24	99563.	58258.	.59

2. DCLLHE

MONTH	COLLECTION					AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL ENERGY SUPPLIED		
	RAD	QU	EFF	PUMP		STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW		
				Q/LEC	Q/EC/QU													Q	QSOL	SF
1	23535.	5838.	.25	152.	.026	55.6	20.6	9.3	2160.	1776.	.82	4807.	4299.	.89	1008.	11.	.01	7975.	6087.	.76
2	28395.	5965.	.25	175.	.025	64.2	21.1	9.3	1973.	1811.	.92	4423.	4423.	1.00	1099.	206.	.19	7496.	6440.	.86
3	32842.	6876.	.21	209.	.030	71.6	21.9	13.7	2207.	2192.	.99	3578.	3578.	1.00	2951.	532.	.18	8736.	6301.	.72
4	26620.	6284.	.24	172.	.027	65.5	22.1	18.0	2134.	1897.	.89	975.	975.	1.00	2835.	1184.	.42	5943.	4056.	.68
5	35058.	6927.	.20	233.	.034	75.7	22.8	21.8	2234.	2233.	1.00	138.	138.	1.00	5169.	1455.	.28	7541.	3826.	.51
6	30255.	6405.	.21	219.	.034	72.2	23.0	24.2	2140.	2128.	.99	16.	16.	1.00	6553.	1579.	.24	8709.	3723.	.43
7	34635.	7603.	.22	246.	.032	74.8	23.3	26.1	2226.	2225.	1.00	0.	0.	0.00	8617.	2054.	.24	10843.	4279.	.39
8	35278.	8569.	.24	240.	.028	74.6	23.2	25.6	2228.	2220.	1.00	0.	0.	0.00	8327.	2821.	.34	10556.	5040.	.48
9	32633.	7653.	.23	219.	.029	75.4	23.1	23.9	2161.	2160.	1.00	0.	0.	0.00	6636.	2387.	.36	8797.	4547.	.52
10	34067.	7988.	.23	205.	.026	74.0	22.2	18.0	2230.	2185.	.98	917.	917.	1.00	3551.	1676.	.47	6699.	4778.	.71
11	28855.	6176.	.21	197.	.032	68.9	21.7	13.3	2136.	2026.	.95	3696.	3526.	.95	3067.	537.	.18	8898.	6090.	.68
12	20016.	5164.	.26	163.	.032	49.2	20.6	9.6	2145.	1600.	.75	4726.	4077.	.86	837.	0.	0.00	7708.	5677.	.74
YEAR TOTAL	362189.	82448.	.23	2431.	.029	68.5	22.1	17.7	25975.	24453.	.94	23276.	21949.	.94	50650.	14442.	.29	99900.	60844.	.61

Table 17
Yearly Summaries for Dodge City

ENERGY IN MJ, TEMPERATURE IN DEGREES

PLACE: Dodge City, KS

1. CONVENTIONAL STORAGE

MONTH	COLLECTION				AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL ENERGY SUPPLIED			
	RAD	QU	EFF	PUMP Q/EC Q/EC/QU	STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW Q QSOL SF			
1	35966.	9580.	.27	93.	.010	48.9	19.9	-2.4	2149.	1578.	.73	11234.	7979.	.71	205.	0.	0.00	13588.	9557.	.70
2	31360.	7933.	.25	81.	.010	51.8	20.1	1.1	1945.	1511.	.78	8319.	6621.	.80	365.	0.	0.00	10629.	8132.	.77
3	37677.	9634.	.26	95.	.010	56.4	20.5	4.2	2171.	1766.	.81	7850.	6720.	.86	1136.	650.	.57	11157.	9136.	.82
4	33799.	7258.	.21	88.	.012	65.7	21.4	12.0	2121.	1962.	.93	3992.	3879.	.97	2439.	905.	.37	8553.	6747.	.79
5	40334.	8742.	.22	99.	.011	76.1	22.5	18.4	2238.	2220.	1.00	2220.	2220.	1.00	6166.	2797.	.51	10013.	7347.	.73
6	37142.	8246.	.22	104.	.013	75.3	22.9	24.2	2159.	2158.	1.00	18.	18.	1.00	7248.	3004.	.41	9426.	5181.	.55
7	40505.	9399.	.23	112.	.012	70.3	23.1	24.9	2238.	2237.	1.00	0.	0.	0.00	8284.	3819.	.46	10522.	8048.	.51
8	41406.	10252.	.25	112.	.011	76.7	23.1	25.4	2241.	2240.	1.00	0.	0.	0.00	8880.	4471.	.50	11121.	6711.	.60
9	38218.	8320.	.22	98.	.012	75.3	22.1	18.8	2160.	2156.	1.00	598.	598.	1.00	4275.	2543.	.59	7033.	5298.	.75
10	38494.	8853.	.23	95.	.011	73.3	21.9	13.7	2225.	2189.	.98	3930.	3930.	1.00	4255.	2008.	.47	10410.	8126.	.78
11	29602.	6545.	.22	76.	.012	59.2	20.6	5.8	2108.	1782.	.85	6606.	5165.	.78	948.	209.	.22	9662.	7156.	.74
12	27783.	7003.	.25	80.	.011	44.3	19.6	-0.	2144.	1396.	.65	9972.	5470.	.55	211.	0.	0.00	12327.	6866.	.56
YEAR TOTAL	432346.	101766.	.24	1134.	.011	64.9	21.5	12.2	25900.	23206.	.90	54839.	42699.	.78	43701.	20397.	.4712	4440.	86303.	.69

2. DCLLHE

MONTH	COLLECTION					AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL FNFRGY SUPPLI TFN		
	RAD	QU	EFF	PUMP Q/EC Q/EC/QU	STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW Q QSOL SF			
1	35966.	9940.	.28	220.	.022	50.5	19.9	-2.4	2152.	1632.	.76	11279.	8250.	.73	212.	30.	.14	13644.	9912.	.73
2	31360.	8251.	.26	195.	.024	53.2	20.2	1.1	1949.	1545.	.79	8399.	6815.	.81	383.	41.	.11	10731.	8400.	.78
3	37677.	9993.	.27	225.	.022	57.9	20.6	4.2	2176.	1811.	.83	7888.	6787.	.86	1149.	783.	.68	11213.	9381.	.84
4	33799.	7525.	.22	210.	.028	67.0	21.5	12.0	2127.	1992.	.94	4041.	3928.	.97	2464.	1113.	.45	8631.	7033.	.81
5	40263.	9190.	.23	241.	.026	76.4	22.5	18.4	2240.	2232.	1.00	2307.	2307.	1.00	5476.	3124.	.57	10022.	7663.	.76
6	37140.	8688.	.23	251.	.029	75.8	22.9	24.2	2162.	2161.	1.00	18.	18.	1.00	7205.	3350.	.46	9384.	5528.	.59
7	40505.	9884.	.24	268.	.027	76.7	23.1	24.9	2242.	2241.	1.00	0.	0.	0.00	8306.	4154.	.50	10548.	6394.	.61
8	41488.	10843.	.26	270.	.025	77.2	23.1	25.4	2246.	2245.	1.00	0.	0.	0.00	8885.	4833.	.54	11130.	7078.	.64
9	38263.	8721.	.23	236.	.027	76.3	22.1	18.8	2167.	2164.	1.00	571.	571.	1.00	4293.	2807.	.65	7030.	5542.	.79
10	38393.	9289.	.24	227.	.024	73.8	21.9	13.7	2228.	2190.	.98	3936.	3936.	1.00	4257.	2291.	.54	10421.	8417.	.81
11	29602.	6825.	.23	182.	.027	60.0	20.6	5.8	2112.	1799.	.85	6640.	5227.	.79	972.	344.	.35	9723.	7369.	.76
12	27783.	7310.	.26	192.	.026	45.5	19.7	-0.	2145.	1444.	.67	10020.	5746.	.57	255.	0.	0.00	12420.	7190.	.58
YEAR TOTAL	432239.	108468.	.25	2716.	.026	65.9	21.5	12.2	25944.	23456.	.90	55097.	43583.	.79	42856.	22870.	.5212	4898.	89908.	.72

Table 18
Yearly Summaries for Madison

ENERGY IN MJ, TEMPERATURE IN DEGREES

PLACE: Madison, WI

1. CONVENTIONAL STORAGE

MONTH	COLLECTION				AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL ENERGY SUPPLIED			
	RAD	QU	EFF	PUMP Q/LEC	Q/QU	STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW		
																		Q	QSOL	SF
1	21046.	4051.	.19	60.	.015	37.0	18.5	-8.4	2144.	1075.	.50	15746.	3214.	.20	0.	0.	0.00	17890.	4289.	.24
2	25001.	5307.	.21	69.	.013	38.9	18.8	-6.0	1936.	1053.	.54	12287.	4218.	.34	0.	0.	0.00	14224.	5271.	.37
3	34391.	8764.	.25	87.	.010.	45.3	19.6	-1.9	2144.	1448.	.68	10704.	7195.	.67	58.	0.	0.00	12907.	8642.	.67
4	28616.	6256.	.22	73.	.012	56.2	20.8	8.8	2086.	1767.	.85	4973.	4494.	.90	1061.	0.	0.00	8121.	6261.	.77
5	30806.	5979.	.19	86.	.014	62.9	21.6	14.7	2178.	1974.	.91	3066.	2671.	.87	3329.	513.	.15	8573.	5159.	.60
6	31104.	5596.	.18	87.	.015	69.8	22.3	19.6	2126.	2101.	.99	412.	412.	1.00	3928.	791.	.20	6465.	3304.	.51
7	33765.	6360.	.19	94.	.015	72.3	22.8	22.1	2213.	2193.	.99	62.	62.	1.00	5656.	1495.	.26	7931.	3750.	.47
8	34874.	6641.	.19	96.	.014	74.0	22.4	20.0	2222.	2218.	1.00	495.	495.	1.00	4642.	1149.	.25	7360.	3863.	.52
9	31250.	5920.	.19	80.	.014	72.6	22.3	16.7	2141.	2136.	1.00	2697.	2697.	1.00	4322.	990.	.23	9159.	5824.	.64
10	25869.	5827.	.23	69.	0.12	58.5	21.1	10.5	2159.	1906.	.88	4441.	4159.	.94	1354.	0.	0.00	7954.	6065.	.76
11	18439.	3920.	.21	52.	0.13	42.0	19.2	2.3	2077.	1238.	.60	8290.	2922.	.35	197.	0.	0.00	10564.	4159.	.39
12	14770.	3278.	.22	44.	.013	36.3	18.6	-3.8	2144.	1040.	.48	12750.	2181.	.17	0.	0.	0.00	14894.	3221.	.22
YEAR TOTAL	329931.	67899.	.21	897.	.013	55.5	20.7	7.9	25570.	20148.	.79	75925.	34720.	.46	24546.	4939.	.20	126041.	59807.	.47

2. DCLLHE

MONTH	COLLECTION					AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL ENERGY SUPPLIED		
	RAD	QU	EFF	PUMP		STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW		
				Q/LEC	Q/EC/QU													Q	QSOL	SF
1	21046.	4314.	.20	147.	.034	37.2	18.6	-8.4	2144.	1083.	.50	15773.	3466.	.22	0.	0.	0.00	17916.	4548.	.25
2	25001.	5631.	.23	168.	.030	39.2	18.9	-6.0	1936.	1066.	.55	12318.	4533.	.37	0.	0.	0.00	14254.	5599.	.39
3	34391.	9114.	.27	210.	.023	46.8	19.7	-1.9	2146.	1505.	.70	10762.	7479.	.69	59.	0.	0.00	12966.	8984.	.69
4	28616.	6400.	.22	173.	.027	58.3	20.9	8.8	2093.	1816.	.87	5049.	4625.	.92	1085.	0.	0.00	8227.	6442.	.78
5	30806.	6200.	.20	210.	.034	63.9	21.6	14.7	2184.	1992.	.91	3087.	2692.	.87	3373.	725.	.22	8643.	5409.	.63
6	31104.	5924.	.19	212.	.036	70.1	22.3	19.6	2128.	2105.	.99	426.	426.	1.00	3946.	957.	.24	6500.	3489.	.54
7	33765.	6718.	.20	227.	.034	72.5	22.7	22.1	2216.	2193.	.99	63.	63.	1.00	5684.	1756.	.31	7962.	4012.	.50
8	34874.	7044.	.20	232.	.033	74.1	22.5	20.0	2224.	2220.	1.00	470.	470.	1.00	4565.	1429.	.31	7259.	4119.	.57
9	31250.	6210.	.20	193.	.031	73.0	22.4	16.7	2144.	2141.	1.00	2712.	2712.	1.00	4311.	1172.	.27	9167.	6025.	.66
10	25869.	6003.	.23	164.	.027	60.1	21.2	10.5	2163.	1946.	.90	4478.	4196.	.94	1371.	52.	.04	8013.	6194.	.77
11	18439.	4106.	.22	129.	.031	42.8	19.2	2.3	2079.	1257.	.60	8296.	3096.	.37	187.	0.	0.00	10562.	4353.	.41
12	14770.	3481.	.24	107.	.031	36.4	18.6	-3.8	2144.	1045.	.49	12787.	2387.	.19	0.	0.	0.00	14930.	3432.	.23
YEAR TOTAL	329931.	71144.	.22	2171.	.031	56.2	20.7	7.9	25600.	20369.	.80	76221.	36147.	.47	24580.	6091.	.25	126400.	62608.	.50

Table 19
Yearly Summaries for Phoenix

ENERGY IN MJ, TEMPERATURE IN DEGREES

PLACE: Phoenix, AZ

1. CONVENTIONAL STORAGE

MONTH	COLLECTION					AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL ENERGY SUPPLIED		
	RAD	QU	EFF	PUMP		STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW		
				QELEC	QELEC/QU													Q	QSOL	SF
1	34688.	7497.	.22	92.	.012	68.5	21.5	11.3	2190.	2140.	.98	4152.	4152.	1.00	2253.	562.	.25	8596.	6854.	.80
2	38131.	8011.	.21	93.	.012	74.5	21.8	12.3	2013.	1995.	.99	3454.	3454.	1.00	2828.	1709.	.60	8296.	7158.	.86
3	46638.	10693.	.23	113.	.011	78.5	22.3	16.4	2256.	2255.	1.00	2975.	2975.	1.00	5603.	3938.	.70	10834.	9168.	.85
4	46676.	11033.	.24	115.	.010	79.2	22.4	20.1	2190.	2186.	1.00	417.	417.	1.00	5221.	4328.	.83	7827.	6930.	.89
5	48122.	12206.	.25	132.	.011	78.2	23.1	26.0	2254.	2253.	1.00	0.	0.	0.00	9644.	5963.	.62	11898.	8216.	.69
6	43545.	11388.	.26	128.	.011	77.2	23.2	31.4	2172.	2171.	1.00	0.	0.	0.00	13882.	6005.	.43	16055.	8177.	.51
7	42622.	11347.	.27	130.	.011	76.6	23.5	33.9	2242.	2241.	1.00	0.	0.	0.00	16281.	5658.	.35	18523.	7899.	.43
8	44545.	12036.	.27	130.	.011	77.0	23.3	32.4	2244.	2243.	1.00	0.	0.	0.00	15336.	6242.	.41	17580.	8486.	.48
9	45450.	12526.	.28	125.	.010	77.9	23.2	29.4	2177.	2176.	1.00	0.	0.	0.00	12663.	6704.	.53	14840.	8880.	.60
10	44026.	11096.	.28	117.	.011	77.8	22.7	22.6	2219.	2218.	1.00	195.	195.	1.00	7491.	4909.	.66	9035.	7352.	.74
11	38700.	8707.	.22	99.	.011	77.5	22.3	15.9	2174.	2173.	1.00	2717.	2717.	1.00	4482.	2810.	.63	9372.	7700.	.82
12	32172.	6814.	.21	84.	.012	67.8	21.5	11.0	2193.	2115.	.96	4717.	4632.	.98	2538.	370.	.15	9448.	7118.	.75
YFAR TOTAL	509313.	123353.	.24	1357.	.011	75.5	22.6	21.9	20306.	20197.	.99	10627.	10342.	1.00	90223.	49199.	.50	143206.	93930.	.68

2. DCLLME

MONTH	COLLECTION					AVERAGE TEMPERATURES			DHW			HEATING			COOLING			TOTAL ENERGY SUPPLIED		
	RAD	QU	EFF	PUMP		STORAGE	ROOM	AMB	LOAD	QSOL	SF	Q	QSOL	SF	Q	QSOL	SF	HEAT+COOL+DHW		
ELEC	QELEC/QU	Q	QSOL	SF																
1	34688.	7822.	.23	222.	.028	69.5	21.5	11.3	2197.	2154.	.98	4225.	4225.	1.00	2345.	779.	.33	8767.	7159.	.82
2	38131.	8350.	.22	222.	.027	75.5	21.8	12.3	2020.	2002.	.99	3407.	3407.	1.00	2786.	1986.	.71	8213.	7395.	.90
3	46638.	11158.	.24	269.	.024	79.8	22.3	16.4	2265.	2264.	1.00	3019.	3019.	1.00	5619.	4286.	.76	10903.	9569.	.88
4	46676.	11497.	.25	275.	.024	80.7	22.4	20.1	2200.	2197.	1.00	407.	407.	1.00	5230.	4604.	.88	7837.	7208.	.92
5	48122.	12810.	.27	317.	.025	79.0	23.0	26.0	2261.	2260.	1.00	0.	0.	0.00	9658.	6401.	.66	11919.	8662.	.73
6	43545.	12022.	.28	307.	.026	77.5	23.2	31.4	2174.	2173.	1.00	0.	0.	0.00	13913.	6540.	.47	16087.	8713.	.54
7	42622.	12020.	.28	314.	.026	76.9	23.4	33.9	2242.	2241.	1.00	0.	0.	0.00	16326.	6180.	.38	18568.	8421.	.45
8	44545.	12711.	.29	313.	.025	77.4	23.3	32.4	2246.	2245.	1.00	0.	0.	0.00	15337.	6774.	.44	17583.	9019.	.51
9	45450.	13187.	.29	299.	.023	78.5	23.2	29.4	2182.	2181.	1.00	0.	0.	0.00	12648.	7202.	.57	14829.	9383.	.63
10	44026.	11622.	.26	280.	.024	78.8	22.7	22.6	2258.	2257.	1.00	200.	200.	1.00	7629.	6264.	.70	9996.	7720.	.77
11	38700.	9143.	.24	239.	.026	78.3	22.4	15.9	2179.	2178.	1.00	2730.	2730.	1.00	4479.	3168.	.71	9388.	8076.	.86
12	32172.	7103.	.22	201.	.028	69.0	21.5	11.0	2199.	2133.	.97	4719.	4634.	.98	2522.	574.	.23	9441.	7341.	.78
YEAR TOTAL	509313.	129444.	.26	3255.	.025	76.7	22.6	21.9	26423.	26285.	.99	18708.	18623.	1.00	98402.	53757.	.55	143532.	98665.	.69

8.2 Collection Parasitics

The conventional storage system has two pumps in its collection subsystem while the direct contact system uses only one. However, because of the high viscosity of the collector fluid (diethyl phthalate), this one pump consumes significantly more power than the two pumps of the conventional system. The basic data were obtained from the two experimental systems in CSU Solar House I.

In Table 20, the power used in the collection of solar energy is presented as a percentage of the energy collected. These figures were determined from annual totals tabulated in Table 15 through 19.

Table 20

Collection Parasitics as a Percentage of Energy Collected

Location	Storage Type	
	Conventional	DCLLHE
Boston	1.3	3.0
Charleston	1.3	2.9
Dodge City	1.1	2.6
Madison	1.3	3.1
Phoenix	1.1	2.5

8.3 System Performance

The annual totals for heating and cooling (of room air) and the associated solar fractions, are summarized in Table 21. Typically the direct contact system supplies:

- (1) The same, or a little (one percentage point) more heat for domestic hot water
- (2) Between zero and two percentage points more heating
- (3) Five percentage points more cooling.

Overall, the direct contact system provides an increase in total solar fraction of two to three percentage points over the conventional system.

Table 21
Annual Totals for Heating and Cooling and Associated Solar Fractions

Location	Storage Type	DHW		Heating		Cooling		Total	
		(GJ)	SF	(GJ)	SF	(GJ)	SF	(GJ)	SF
Boston	Conv.	25.6	.80	55.1	.59	22.3	.17	103.0	.55
	DCLLHE	25.6	.81	55.3	.61	22.4	.22	103.4	.57
Charleston	Conv.	25.9	.94	23.1	.94	50.6	.24	99.6	.59
	DCLLHE	25.9	.94	23.3	.94	50.7	.29	99.9	.61
Dodge City	Conv.	25.9	.90	54.8	.78	43.7	.47	124.4	.69
	DCLLHE	25.9	.90	55.1	.79	43.9	.52	124.9	.72
Madison	Conv.	25.6	.79	75.9	.46	24.5	.20	126.0	.47
	DCLLHE	25.6	.80	76.2	.47	24.6	.25	126.4	.50
Phoenix	Conv.	26.4	.99	18.6	1.00	98.2	.50	143.2	.66
	DCLLHE	26.4	.99	18.7	1.00	98.4	.55	143.5	.69

The additional DHW heating is a result of slightly higher temperature in storage because of fractionally greater heat collection. At the same time, the slightly higher storage temperature in the DCLLHE system offsets (in the long term) the elimination of a temperature drop at the heat exchanger. It should be recalled that the value of F'_R/F_R was 0.97, which is typical of a reasonably sized shell-and-tube heat exchanger for a conventional solar heating system.

The combined effect of the DCLLHE and higher water temperature in storage results in slightly greater total heating from the system. On a long term basis, the best that can be expected is three percentage points because $F_R'/F_R = 0.97$. The net gain is not 3 percent however, when the direct contact system is used, because DEP is not as effective as water for heat transfer from the collector. The significant gain in solar cooling of five percentage points is achieved because the water temperature in storage is higher than for the conventional system. Since hot water delivery to the generator of the chiller is tempered in the modified chiller, the additional thermal energy in storage increases the fraction of solar cooling achieved with the DCLLHE system. The hotter water in storage, however, has an effect on collection efficiency so that the net gain is five percentage points.

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9.0 ECONOMIC ANALYSIS

9.1 System Cost

The costs of purchase and installation of the solar systems used in the TRNSYS analysis are presented in two parts:

- (1) Those costs common to both a conventional storage and a direct contact storage system
- (2) Those costs specific to each kind of storage.

All costs are presented in 1978 dollars and are representative costs. The component costs are taken from the CSU Design of Systems Training Manual and for the direct contact unit the prices are based on actual construction costs, but are adjusted to represent "manufactured" costs, rather than experimental system costs.

9.1.1 Costs Common to Both Systems

1.	Collectors	
	equipment 60 m ² @\$160/m ²	\$9600
	installation 60 hours @\$15/hour	900
2.	Piping Loops (less one pump, heat exchanger, and expansion tanks)	
	equipment	1510
	installation 60 hours @\$15/hour	900
3.	DHW subsystem	
	equipment	280
	installation	180
4.	Controls	
	equipment	750
	installation 12 hours @\$15/hour	180
5.	Insulation	
	materials	750
	installation 20 hours @\$15/hour	300
6.	Testing and Balancing	<u>225</u>
	Total Common Cost	\$15575

9.1.2 Storage Related Costs

Conventional System

1.	Storage Tank	\$1500
	installation 10 hours @\$15/hour	150
2.	Heat Exchanger	300
3.	Storage side pump	180
4.	Expansion tank	80
5.	Collector fluid (ethylene glycol/water, 50% mixture 277 l @\$\$.44/l)	<u>122</u>
	Total	\$2332

DCLLHE

1.	Storage Tank	\$1500
	installation 10 hours @\$15/hour	150
2.	Distribution plate in tank	300
3.	Teflon seal in collector pump	107
4.	Collector fluid (Di-ethyl phthalate, 410 l @\$1.24/l)	<u>508</u>
	Total	\$2565

9.1.3 Total System Costs

Conventional Storage system

\$15575
2332
\$17907

DCLLHE Storage System

\$15575
2565
\$18140

The cost of an absorption chiller and ancillary equipment are estimated to be \$6000 and this cost is added to the total in making an economic analysis of a heating and cooling system. The system costs are listed in Table 22.

Table 22
Total System Costs

Storage	Solar System	
	Heating Only	Heating and Cooling
Conventional	17907	23907
DCLLHE	18140	24140

9.2 Economic Parameters

The economic parameters needed for life-cycle cost analyses of solar energy systems are either highly indeterminate, such as future fuel prices, or are in a period of continuing appraisal and change, such as income tax credits, and property taxes on solar equipment.

Thus, the initial economic analysis is made using a specific set of values believed to be appropriate at the time of this analysis. The parameters vary with location, particularly with regard to state income tax incentives and property tax credits. Subsequently sensitivity studies are made to determine the effect of changes to selected parameter values. The emphasis in the analysis is on relative economics of the DCLLHE system compared to the conventional system.

The values of the economic parameters are enumerated below:

Energy Prices

Electrical energy	14.00 \$/GJ
Conventional fuel	14.00 \$/GJ
Energy cost inflation rate	.15

System Operating Costs

Operating energy as fraction of solar collected	
Conventional	.05
DCLLHE	.065
Operating cost inflation rate	.15
Maintenance cost as fraction of system cost	.007
Maintenance cost inflation rate	.08
Insurance (fraction of system cost)	.003
Insurance cost inflation rate	.08

Terms of the Loan

Period of the loan	25 years
Downpayment	.20
Interest rate	.10

Personal Finances

Effective income tax rate	.35
Federal tax credit for solar	4000 \$*
State tax credit for solar	varies **
Property tax rate	varies **
Market discount rate	.08 ***
"Life Cycle": Period of analysis	20 years

* 40 percent of cost to maximum of \$4000

** Varies according to state

*** For individuals it is assumed that an appropriate discount rate is two percentage points below mortgage interest rate

9.3 System Performance and Life-Cycle Costs

A discussion in detail of the system performances was given in Section 8. The pertinent results are reproduced here in Table 23.

Table 23

Work Done in the House

Location	Storage	DHW		Heating		Cooling		Total	
		(GJ)	SF	(GJ)	SF	(GJ)	SF	(GJ)	SF
Boston	Conv.	25.6	.80	55.1	.59	22.3	.17	103.0	.55
	DCLLHE	25.6	.81	55.3	.61	22.4	.22	103.4	.57
Charleston	Conv.	25.9	.94	23.1	.94	50.6	.24	99.6	.59
	DCLLHE	25.9	.94	23.3	.94	50.7	.29	99.9	.61
Dodge City	Conv.	25.9	.90	54.8	.78	43.7	.47	124.4	.69
	DCLLHE	25.9	.90	55.1	.79	43.9	.52	124.9	.72
Madison	Conv.	25.6	.79	75.9	.46	24.5	.20	126.0	.47
	DCLLHE	25.6	.80	76.2	.47	24.6	.25	126.4	.50
Phoenix	Conv.	26.4	.99	18.6	1.00	98.2	.50	143.2	.66
	DCLLHE	26.4	.99	18.7	1.00	98.4	.55	143.5	.69

An economic analysis is concerned not so much with the work done (heating of room air or heat removal from room air) in the house as with the energy needed to perform that work. With heating systems, DHW and space heating, the two have the same value. However this is not so for cooling.

To calculate the amount of energy input needed for cooling, the amount of cooling provided is divided by the COP of the chiller. There we take the COP as that of the absorption chiller when it is operating on auxiliary heat; i.e. COP = 0.8. The amount of energy from a conventional

source that is replaced by solar is the amount of cooling done, divided by the COP and multiplied by the solar fraction (SF).

The economic analyses are performed for two cases (1) for a heating only system and (2) for a heating and cooling system. The energy requirements are listed in Table 24, the values being derived from Table 23.

Table 24
Energy Requirements

Location	Storage	Heating Only		Cooling		Heating and Cooling	
		(GJ)	SF	(GJ)	SF	(GJ)	SF
Boston	Conv.	80.7	.66	27.9	.17	108.6	.53
	DCLLHE	80.9	.67	28.0	.22	108.9	.55
Charleston	Conv.	49.0	.94	63.3	.24	112.3	.55
	DCLLHE	40.2	.94	63.4	.29	112.6	.57
Dodge City	Conv.	80.7	.82	54.6	.47	135.3	.68
	DCLLHE	81.0	.83	54.9	.52	135.9	.70
Madison	Conv.	101.5	.54	30.6	.20	132.1	.46
	DCLLHE	101.8	.55	30.8	.25	132.6	.48
Phoenix	Conv.	45.0	.99	122.8	.50	167.8	.63
	DCLLHE	45.1	.99	123.0	.55	168.1	.67

It should be noted that the figures in the "heating only" column are derived from the simulation results in which both heating and cooling systems were operating and in certain times of the year both heating and cooling are required on the same day. While the performance of the system would be different if the system were run in a "heating only" mode because of differences in storage temperature, the differences are not expected to be significant.

The economic evaluations of the DCLLHE system in relation to a conventional solar system are made on the basis of life-cycle cost analyses. Since we are primarily interested in the difference in life-cycle costs for a conventional storage solar system and a DCLLHE storage solar system, the measure taken here is the decrease in total life-cycle cost obtained by using a direct contact system. That is,

$$\begin{aligned} \text{Decrease} = & (\text{Life-cycle cost of solar system with conventional} \\ & \text{storage}) \\ & - (\text{Life-cycle cost of solar system with DCLLHE storage}) \end{aligned}$$

Thus the benefit of using a DCLLHE storage system is seen as a positive decrease in life-cycle cost; a negative decrease indicates that the use of a DCLLHE storage system involves an economic penalty.

The decrease is presented in two ways; as a numerical dollar value and as a fraction of the life-cycle cost of the conventional storage system.

In Table 25 a summary of the results is presented for all 5 cities, for heating-only systems and in Table 26, a summary is given for heating and cooling systems. For heating-only systems the use of DCLLHE storage results in an increased life-cycle cost. For heating and cooling systems the use of DCLLHE storage results in some savings. However, in 4 cities this saving is less than 1 percent. In the 5th city, Phoenix, the saving is slightly more than 3 percent. Details of the economic analyses are presented in a set of tables in Appendix B to this report. In each case the set of parameters used in the analysis is given, then a year-by-year cash flow, and present worth of annual cash flow are presented.

9.4 Sensitivity Analysis

In this section we look at the sensitivity of the life-cycle costs to variations in the values of the economic parameters. Three parameters are considered:

- (1) Initial fuel cost
- (2) Fuel cost inflation rate
- (3) Mortgage interest rate

It can be noted that the amount of the total tax credit has no effect on the relative economic merit of the two types of storage. Total federal and state income tax credits for Boston is \$5000, Charleston is \$4000 (federal only), Dodge City is \$7000 (Colorado economic conditions assumed), Madison is \$6400, and Phoenix is \$5000.

9.4.1 Initial Fuel Cost

The effects of different fuel costs to \$46 per gigajoule (16.6¢/kWh) were considered in a sensitivity analysis for all 5 cities and the results are given in Tables 27 and 28. Fuel inflation rate is fixed at 15 percent and mortgage interest rate is 10 percent. In all cases higher fuel cost resulted in relatively higher life-cycle cost for the heating-only system using a DCLLHE storage system and decrease in relative life-cycle cost for the heating and cooling system. However, even at \$46 per gigajoule, the DCLLHE system had savings less than 1.5 percent in 4 cities, and for Phoenix, the saving was just over 5 percent.

9.4.2 Fuel Cost Inflation Rate

The fuel inflation rate was varied from 8 percent per annum to 20 percent per annum. Fuel cost is fixed at \$14 per GJ and mortgage interest rate is 10 percent. The results in Table 29 show that for heating-only systems the DCLLHE storage does not exhibit economic benefit over the conventional storage system. In Table 30, for heating and cooling systems, at a fuel inflation rate of 20 percent the economic benefit of using DCLLHE storage was less than 1 percent for 4 cities; for Phoenix, it reached just over 4 percent. There is little sensitivity in percent change to different fuel inflation rates.

9.4.3 Mortgage Interest Rates

The mortgage interest rates were varied from 8 percent per annum to 18 percent per annum with fuel cost fixed at \$14 per GJ and fuel inflation rate held to 15 percent. The results are given in Tables 31 and 32. It was assumed that the alternative investment available to the homeowner was to save his money with a bank. This suggests that the discount rate and the mortgage rate would be linked and it was assumed that the discount rate was 0.80 times the mortgage rate, and the coupling of rates results in a phenomenon of life-cycle cost decreases with increases in mortgage rates. If the discount rate is fixed and the mortgage rate increases, then the life-cycle cost will also increase.

For the heating-only system, the DCLLHE storage is never financially attractive compared to the conventional storage system. For the heating and cooling system the benefit of the DCLLHE decreases with increasing mortgage rate because of the higher initial cost of the system.

Table 25

Life-Cycle Cost Comparisons for Heating-Only Systems

SOLAR HEATING SYSTEM									
LIFE CYCLE COST DECREASE IN PERCENT									
LOCATION	CONVENTIONAL	DCLLHE	LIFE CYCLE COST	DECREASE	PERCENT				
BOSTON	\$ 28145	\$ 28439	\$ -294	-1.04					
CHARLESTON	\$ 23066	\$ 23743	\$ -677	-2.93					
DODGE CITY	\$ 21051	\$ 21453	\$ -402	-1.90					
MADISON	\$ 42860	\$ 43188	\$ -328	-0.76					
PHOENIX	\$ 20777	\$ 21434	\$ -657	-3.16					

Table 26

Life-Cycle Cost Comparisons for Heating and Cooling Systems

SOLAR HEATING AND COOLING SYSTEM									
LIFE CYCLE COST DECREASE IN PERCENT									
LOCATION	CONVENTIONAL	DCLLHE	LIFE CYCLE COST	DECREASE	PERCENT				
BOSTON	\$ 46148	\$ 45870	\$ 278	0.60					
CHARLESTON	\$ 55553	\$ 55352	\$ 201	0.36					
DODGE CITY	\$ 42548	\$ 42323	\$ 225	0.52					
MADISON	\$ 63575	\$ 63248	\$ 327	0.51					
PHOENIX	\$ 61458	\$ 59477	\$ 1981	3.22					

Table 27. Sensitivity to Fuel Cost Heating-Only System

(a) BOSTON

FUEL COST PER GIGAJoule	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCILHE	PERCENT DECREASE
\$ 0	\$ 13025	\$ -234	-1.79
\$ 8	\$ 21665	\$ -270	-1.25
\$ 14	\$ 28149	\$ -290	-1.03
\$ 20	\$ 34625	\$ -319	-0.92
\$ 26	\$ 41103	\$ -347	-0.84
\$ 36	\$ 51904	\$ -388	-0.74
\$ 46	\$ 62701	\$ -432	-0.68

(b) CHARLESTON

FUEL COST PER GIGAJoule	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCILHE	PERCENT DECREASE
\$ 0	\$ 20434	\$ -319	-1.56
\$ 8	\$ 21936	\$ -525	-2.39
\$ 14	\$ 23066	\$ -678	-2.93
\$ 20	\$ 24194	\$ -829	-3.42
\$ 26	\$ 25324	\$ -984	-3.88
\$ 36	\$ 27205	\$ -1238	-4.55
\$ 46	\$ 29086	\$ -1497	-5.14

(c) DODGE CITY

FUEL COST PER GIGAJoule	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCILHE	PERCENT DECREASE
\$ 0	\$ 12095	\$ -246	-2.03
\$ 8	\$ 17211	\$ -337	-1.95
\$ 14	\$ 21053	\$ -401	-1.90
\$ 20	\$ 24889	\$ -471	-1.89
\$ 26	\$ 28730	\$ -533	-1.85
\$ 36	\$ 35130	\$ -640	-1.82
\$ 46	\$ 41526	\$ -754	-1.81

Table 27. (continued)

(d) MADISON

FUEL COST PER GIGAJoule	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
\$ 0	\$ 18034	\$ -319	-1.76
\$ 8	\$ 32219	\$ -324	-1.00
\$ 14	\$ 42859	\$ -330	-0.76
\$ 20	\$ 53501	\$ -330	-0.61
\$ 26	\$ 64143	\$ -335	-0.52
\$ 36	\$ 81875	\$ -344	-0.42
\$ 46	\$ 99611	\$ -349	-0.35

(e) PHOENIX

FUEL COST PER GIGAJoule	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
\$ 0	\$ 19434	\$ -319	-1.64
\$ 8	\$ 20201	\$ -512	-2.53
\$ 14	\$ 20778	\$ -659	-3.17
\$ 20	\$ 21353	\$ -805	-3.76
\$ 26	\$ 21931	\$ -945	-4.30
\$ 36	\$ 22892	\$ -1191	-5.20
\$ 46	\$ 23852	\$ -1432	-6.00

Table 28. Sensitivity to Fuel Costs Heating and Cooling System

(a) BOSTON

FUEL COST PER GIGAJoule	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
0	\$ 19065	\$ -236	-1.23
\$ 8	\$ 34540	\$ 57	0.16
\$ 14	\$ 46149	\$ 277	0.60
\$ 20	\$ 57756	\$ 499	0.86
\$ 26	\$ 69365	\$ 720	1.03
\$ 36	\$ 88707	\$ 1084	1.22
\$ 46	\$ 108052	\$ 1452	1.34

(b) CHARLESTON

\$ 0	\$ 28620	\$ -319	-1.11
\$ 8	\$ 44011	\$ -21	-0.04
\$ 14	\$ 55553	\$ 203	0.36
\$ 20	\$ 67098	\$ 423	0.63
\$ 26	\$ 78642	\$ 648	0.82
\$ 36	\$ 97877	\$ 1016	1.03
\$ 46	\$ 117118	\$ 1388	1.18

(c) DODGE CITY

\$ 0	\$ 18492	\$ -248	-1.34
\$ 8	\$ 32238	\$ 20	0.06
\$ 14	\$ 42546	\$ 226	0.53
\$ 20	\$ 52861	\$ 429	0.81
\$ 26	\$ 63169	\$ 630	0.99
\$ 36	\$ 80352	\$ 966	1.20
\$ 46	\$ 97538	\$ 1308	1.34

Table 28. (continued)

(d) MADISON

FUEL COST	LIFE-CYCLE COST	DECREASE IN	PERCENT
PER	WITH CONVENTIONAL	LIFE-CYCLE COST	DECREASE
GIGAJoule	STORAGE	WITH DCLHE	
\$ 0	\$ 26220	\$ -319	-1.21
\$ 8	\$ 47566	\$ 52	0.10
\$ 14	\$ 63574	\$ 326	0.51
\$ 20	\$ 79585	\$ 603	0.75
\$ 26	\$ 95594	\$ 878	0.91
\$ 36	\$ 122277	\$ 1339	1.09
\$ 46	\$ 148962	\$ 1801	1.20

(e) PHOENIX

FUEL COST	LIFE-CYCLE COST	DECREASE IN	PERCENT
PER	WITH CONVENTIONAL	LIFE-CYCLE COST	DECREASE
GIGAJoule	STORAGE	WITH DCLHE	
\$ 0	\$ 27620	\$ -319	-1.15
\$ 8	\$ 46958	\$ 1001	2.13
\$ 14	\$ 61459	\$ 1979	3.22
\$ 20	\$ 75961	\$ 2965	3.90
\$ 26	\$ 90466	\$ 3953	4.36
\$ 36	\$ 114638	\$ 5599	4.88
\$ 46	\$ 138806	\$ 7236	5.21

Table 29. Sensitivity to Fuel Inflation Rate Heating-Only Systems

(a) BOSTON

FUEL INFLATION RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
8	\$ 20830	\$ -265	-1.27
10	\$ 22368	\$ -271	-1.21
12	\$ 24294	\$ -279	-1.14
14	\$ 26712	\$ -288	-1.08
16	\$ 29752	\$ -300	-1.01
18	\$ 33578	\$ -315	-0.94
20	\$ 38399	\$ -334	-0.87

(b) CHARLESTON

FUEL INFLATION RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
8	\$ 21792	\$ -503	-2.30
10	\$ 22059	\$ -539	-2.44
12	\$ 22395	\$ -585	-2.61
14	\$ 22816	\$ -643	-2.81
16	\$ 23346	\$ -715	-3.06
18	\$ 24012	\$ -806	-3.35
20	\$ 24852	\$ -920	-3.70

(c) DODGE CITY

FUEL INFLATION RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
8	\$ 16717	\$ -327	-1.95
10	\$ 17629	\$ -343	-1.94
12	\$ 18770	\$ -362	-1.93
14	\$ 20202	\$ -387	-1.91
16	\$ 22004	\$ -418	-1.89
18	\$ 24271	\$ -456	-1.88
20	\$ 27127	\$ -505	-1.86

Table 29. (continued)

(d) MADISON

FUEL	LIFE-CYCLE COST	DECREASE IN	
INFLATION	WITH CONVENTIONAL	LIFE-CYCLE COST	PERCENT
RATE (%)	STORAGE	WITH DCLLHE	DECREASE
8	\$ 30848	\$ -322	-1.04
10	\$ 33374	\$ -323	-0.97
12	\$ 36537	\$ -324	-0.88
14	\$ 40507	\$ -326	-0.80
16	\$ 45499	\$ -328	-0.72
18	\$ 51783	\$ -330	-0.63
20	\$ 59700	\$ -333	-0.55

(e) PHOENIX

FUEL	LIFE-CYCLE COST	DECREASE IN	
INFLATION	WITH CONVENTIONAL	LIFE-CYCLE COST	PERCENT
RATE (%)	STORAGE	WITH DCLLHE	DECREASE
8	\$ 20126	\$ -493	-2.44
10	\$ 20263	\$ -527	-2.60
12	\$ 20435	\$ -570	-2.79
14	\$ 20650	\$ -625	-3.02
16	\$ 20920	\$ -693	-3.31
18	\$ 21260	\$ -779	-3.66
20	\$ 21689	\$ -887	-4.09

Table 30. Sensitivity to Fuel Costs Heating and Cooling Systems

(a) BOSTON

FUEL INFLATION RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLHE	PERCENT DECREASE
8	\$ 33045	\$ 30	0.09
10	\$ 35800	\$ 82	0.23
12	\$ 39251	\$ 147	0.37
14	\$ 43582	\$ 230	0.52
16	\$ 49027	\$ 333	0.67
18	\$ 55882	\$ 463	0.82
20	\$ 64517	\$ 626	0.97

(b) CHARLESTON

8	\$ 42521	\$ -49	-0.11
10	\$ 45261	\$ 2	0.00
12	\$ 48693	\$ 68	0.14
14	\$ 53000	\$ 151	0.28
16	\$ 58416	\$ 256	0.43
18	\$ 65233	\$ 387	0.59
20	\$ 73820	\$ 553	0.74

(c) DODGE CITY

8	\$ 30909	\$ -4	-0.01
10	\$ 33356	\$ 44	0.13
12	\$ 36421	\$ 104	0.28
14	\$ 40269	\$ 180	0.44
16	\$ 45106	\$ 275	0.61
18	\$ 51194	\$ 395	0.77
20	\$ 58865	\$ 546	0.92

Table 30. (continued)

(d) MADISON

FUEL	LIFE-CYCLE COST	DECREASE IN		
INFLATION	WITH CONVENTIONAL	LIFE-CYCLE COST	PERCENT	
RATE (%)	STORAGE	WITH DCLLHE	DECREASE	
8	\$ 45501	\$ 14	0.03	
10	\$ 49301	\$ 80	0.16	
12	\$ 54061	\$ 162	0.30	
14	\$ 60035	\$ 265	0.44	
16	\$ 67545	\$ 395	0.58	
18	\$ 77000	\$ 558	0.72	
20	\$ 88911	\$ 763	0.85	

(e) PHOENIX

FUEL	LIFE-CYCLE COST	DECREASE IN		
INFLATION	WITH CONVENTIONAL	LIFE-CYCLE COST	PERCENT	
RATE (%)	STORAGE	WITH DCLLHE	DECREASE	
8	\$ 45086	\$ 868	1.92	
10	\$ 48528	\$ 1102	2.27	
12	\$ 52840	\$ 1395	2.64	
14	\$ 58252	\$ 1763	3.02	
16	\$ 65055	\$ 2225	3.42	
18	\$ 73620	\$ 2807	3.81	
20	\$ 84410	\$ 3541	4.19	

Table 31. Sensitivity to Mortgage Interest Rate Heating-Only Systems

(a) BOSTON

MORTGAGE INTEREST RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
8	\$ 31881	\$ -314	-0.98
10	\$ 28145	\$ -294	-1.04
12	\$ 25207	\$ -278	-1.10
14	\$ 22879	\$ -266	-1.16
16	\$ 21019	\$ -256	-1.22
18	\$ 19519	\$ -248	-1.27

(b) CHARLESTON

MORTGAGE INTEREST RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
8	\$ 25297	\$ -774	-3.06
10	\$ 23066	\$ -677	-2.93
12	\$ 21298	\$ -600	-2.81
14	\$ 19886	\$ -539	-2.71
16	\$ 18746	\$ -490	-2.61
18	\$ 17819	\$ -450	-2.52

(c) DODGE CITY

MORTGAGE INTEREST RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
8	\$ 23681	\$ -443	-1.87
10	\$ 21051	\$ -401	-1.90
12	\$ 18984	\$ -368	-1.94
14	\$ 17346	\$ -342	-1.97
16	\$ 16036	\$ -321	-2.00
18	\$ 14979	\$ -304	-2.03

Table 31. (continued)

(d) MADISON

MORTGAGE INTEREST RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
8	\$ 49749	\$ -351	-0.70
10	\$ 42860	\$ -327	-0.76
12	\$ 37418	\$ -308	-0.82
14	\$ 33085	\$ -293	-0.88
16	\$ 29606	\$ -281	-0.94
18	\$ 26790	\$ -271	-1.01

(e) PHOENIX

MORTGAGE INTEREST RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLLHE	PERCENT DECREASE
8	\$ 22738	\$ -750	-3.29
10	\$ 20777	\$ -657	-3.16
12	\$ 19223	\$ -583	-3.03
14	\$ 17980	\$ -525	-2.92
16	\$ 16977	\$ -478	-2.81
18	\$ 16159	\$ -440	-2.72

Table 32. Sensitivity to Mortgage Interest Rate Heating and Cooling Systems

(a) BOSTON

MORTGAGE INTEREST RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLHE	PERCENT DECREASE
8	\$ 52584	\$ 378	0.72
10	\$ 46148	\$ 278	0.60
12	\$ 41085	\$ 199	0.48
14	\$ 37069	\$ 136	0.36
16	\$ 33858	\$ 85	0.25
18	\$ 31269	\$ 44	0.14

(b) CHARLESTON

MORTGAGE INTEREST RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLHE	PERCENT DECREASE
8	\$ 63446	\$ 288	0.45
10	\$ 55553	\$ 201	0.36
12	\$ 49316	\$ 132	0.26
14	\$ 44348	\$ 78	0.17
16	\$ 40359	\$ 34	0.08
18	\$ 37128	\$ -0	-0.00

(c) DODGE CITY

MORTGAGE INTEREST RATE (%)	LIFE-CYCLE COST WITH CONVENTIONAL STORAGE	DECREASE IN LIFE-CYCLE COST WITH DCLHE	PERCENT DECREASE
8	\$ 48597	\$ 314	0.64
10	\$ 42548	\$ 225	0.52
12	\$ 37786	\$ 154	0.40
14	\$ 34006	\$ 97	0.28
16	\$ 30982	\$ 52	0.17
18	\$ 28542	\$ 16	0.05

Table 32. (continued)

(d) MADISON

MORTGAGE	LIFE-CYCLE COST	DECREASE IN	
INTEREST	WITH CONVENTIONAL	LIFE-CYCLE COST	PERCENT
RATE (%)	STORAGE	WITH DCLLHE	DECREASE
8	\$ 73654	\$ 440	0.59
10	\$ 63575	\$ 326	0.51
12	\$ 55613	\$ 237	0.42
14	\$ 49273	\$ 166	0.33
16	\$ 44185	\$ 109	0.24
18	\$ 40068	\$ 63	0.15

(e) PHOENIX

8	\$ 70800	\$ 2442	3.44
10	\$ 61458	\$ 1981	3.22
12	\$ 54079	\$ 1618	2.99
14	\$ 48202	\$ 1329	2.75
16	\$ 43484	\$ 1098	2.52
18	\$ 39666	\$ 911	2.29

10.0 CONCLUSIONS

From the results of this study it is concluded that:

1. A collector array with diethyl phthalate as the working fluid has equal efficiencies to water-glycol mixtures or water, provided that the capacitance flow rates are about the same.
2. A DCLLHE system simplifies the mechanical coupling of a collector array to a storage tank, compared to a conventional heat exchanger/storage unit.
3. A solar system with a DCLLHE unit, although requiring only one collector circulation pump, has greater operating energy requirement than a conventional system with two pumps because of the physical properties of diethyl phthalate used as the collector fluid.
4. Use of a direct contact liquid-liquid heat exchanger storage unit, with diethyl phthalate as the working fluid, offers performance advantages for heating-only and heating and cooling systems compared to a solar system with a conventional heat exchanger/storage unit.
5. The performance differences between the DCLLHE and conventional heat exchanger storage units are small for domestic water heating, generally less than two percentage points for heating-only systems, five percentage points for cooling systems, all of which results in an overall increase in performance of two to three percentage points for heating and cooling systems in all cities studied.

6. Based on prevalent (1980) economic conditions, there appears to be no economic advantage to use a DCLLHE unit with a solar heating system. A conventional heat exchanger and storage unit has lower life-cycle costs in all locations studied with various prices for energy, inflation rates and mortgage interest rates. The slightly higher performance of the system is not sufficient to overcome the slightly higher cost of the DCLLHE system and slightly greater operating cost compared to a conventional heat exchanger system.
7. For heating and cooling systems, the study indicates a slight economic advantage by using a DCLLHE unit. The difference, however, is generally less than one percent, excepting for Phoenix where a gain of about four percent could be realized.

11.0 REFERENCES

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5. Ward, J.C., Loss, W.M. and Lof, G.O.G. (1977) "Direct Contact Liquid-Liquid Heat Exchanger: Pilot Plant Results," Report No. C00-2867-2, Prepared for the U.S. Energy Research and Development Administration, September.

APPENDICES

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APPENDIX A. THE DCLLHE TRNSYS SUBROUTINE

1.0 DESCRIPTION OF THE MODEL

The heat transfer rate in the DCLLHE is a function of a number of variables; the droplet size, the droplet fall velocity, the dimensions of the tank, and the physical properties of the liquids. Analysis of these factors is a complicated problem in heat transfer. However in the pilot plant study [Ref. 5] of the device two critical factors were determined:

- (1) For depth of over 1 meter, there is complete heat transfer,
- (2) There is no thermal stratification in the tank.

Since the tank is greater than 1 meter deep, the modeling of the device becomes relatively simple; it becomes a "one-node" tank, with the heat input being uniformly distributed. A schematic representation of the DCLLHE tank is shown below:

In the sketch above, the abbreviations are:

T_H - temperature of fluid from collector

T_L - temperature of water from load

T_{env} - temperature environment of tank

T - temperature of contents of tank

- $\dot{m}_H$ - mass flow rate of fluid to collector
- $\dot{m}_L$ - mass flow rate of water to load
- U - heat loss coefficient of tank
- A - surface area of tank
- V_W - volume of water in tank
- ρ_W - density of water in tank
- c_{pw} - heat capacity of water in tank
- V_D - volume of DEP in tank
- ρ_D - density of DEP in tank
- c_{pD} - heat capacity of DEP in tank

Thus we have heat flows expressed as:

$$\dot{Q}_{in} = \dot{m}_{DEP} c_{pD} (T_H - T)$$

$$\dot{Q}_{out} = \dot{m}_L c_{pw} (T - T_L)$$

$$\dot{Q}_{env} = UA(T - T_{env})$$

$$\text{and } \dot{Q}_{net} = \dot{Q}_{in} - \dot{Q}_{out} - \dot{Q}_{env}$$

$$= (V_W \rho_W c_{pw} + V_D \rho_D c_{pD}) dT/dt$$

Hence

$$dT/dt = \frac{\dot{m}_H c_{pD} (T_H - T) - \dot{m}_L c_{pw} (T - T_L) - UA(T - T_{env})}{V_W \rho_W c_{pw} + V_D \rho_D c_{pD}} \quad (A-1)$$

A description of the TRNSYS subroutine for the DCLLHE follows, in the style of the TRNSYS manual.

2.0 TRNSYS COMPONENT: THE DIRECT CONTACT LIQUID-LIQUID HEAT EXCHANGER

2.1 General Description

This is a one node (no thermal stratification) storage tank that circulates antifreeze to the collectors and water to the load. There is perfect heat transfer; the energy that is brought in from the collector is shared proportionately between the water and the DEP in the storage tank.

2.2 Mathematical Description

The temperature in the tank is given by Equation (A-1):

$$dT/dt = \frac{\dot{m}_H c_{pD} (T_H - T) - \dot{m}_L c_{pw} (T - T_L) - UA(T - T_{env})}{V_W \rho_W c_{pw} + V_D \rho_D c_{pD}}$$

2.3 Component Configuration

2.3.1 Inputs

1. T_H - the temperature of the fluid from the collector
2. $\dot{m}_H$ - the mass flow rate of fluid from the collector
3. T_L - the temperature of water from the load
4. $\dot{m}_L$ - the mass flow rate of water from the load
5. T_{env} - the temperature of the environment of the tank

2.3.2 Parameters

1. V_W - the volume of water in the tank
2. ρ_W - the density of water in the tank
3. c_{pw} - the heat capacity of water in the tank
4. V_D - the volume of DEP in the tank

5. ρ_D - the density of DEP in the tank
6. c_{pD} - the heat capacity of DEP in the tank
7. U - the heat loss coefficient of the tank
8. A - the surface area of the tank

2.3.3 Output

1. T - the temperature of the tank
2. $\dot{m}_L$ - the mass flow rate of the load
3. $\dot{m}_H$ - the mass flow rate of the collector
4. $\dot{Q}_{in}$ - the heat input from the collectors
5. $\dot{Q}_{out}$ - the heat output to the load
6. $\dot{Q}_{env}$ - the heat loss to the environment of the tank

2.3.4 Derivative

Initial value of tank temperature T

2.3.5 Information Flow Diagram

Parameter

1. V_w
2. ρ_w
3. C_{pw}
4. V_p
5. ρ_p
6. C_{pp}
7. u
8. A

Input: 5
 Output: 6
 Parameter: 8
 Deviation: 1

3.0 VALIDATION OF THE SUBROUTINE

To validate the model, the performance of the TRNSYS component was compared to that of the actual device. A TRNSYS program was run centered on the DCLLHE storage unit. In the program, the mass and energy flows in the collector and the load loops were set to be those measured in the performance of the actual system. The temperature of the TRNSYS model tank was then compared to the temperature measured in the actual tank.

The program was run with 10 minute time steps, for one week (2-8 August 1979). The results are presented in Figures A-1 and A-2. The simulated temperature tracks the measured temperature within about 1 °C. The larger differences in early morning hours is caused by slight stratification in the tank when there is no fluid movement. The measurements plotted in these figures are from a sensor installed near the top of the tank where the measured values are higher during these hours.

Statistical displays of differences between measured and simulated storage tank temperatures are given in Table A-1 and Figure A-3. The mean of the differences is less than 1 °C, standard deviation is 1.05 with skewness to the right. The differences are considered small, and the simulation model is considered valid when compared to measured data.

Figure A-1. Storage Tank Temperatures - DCLLHE

Figure A-2. Storage Tank Temperatures - DCLLHE

Table A-1

Frequency Distribution of Δ for 168 Values

$$\Delta = T_{\text{simulated}} - T_{\text{measured}}$$

For 168 values, we have the following frequency distribution of Δ

Δ °C	# of Occurrences	Relative Frequency
-3.5 to -3	3	.02
-3 to -2.5	6	.04
-2.5 to -2	14	.08
-2 to -1.5	21	.13
-1.5 to -1	39	.23
-1 to -.5	28	.17
-.5 to 0	30	.18
0 to .5	8	.05
.5 to 1	12	.07
1 to 1.5	3	.02
1.5 to 2	3	.02
2 to 2.5	1	.01
	<u>168</u>

Figure A-3. Frequency Distribution of Δ

APPENDIX B. LIFE-CYCLE COST ANALYSIS

Details on the economic analysis and life-cycle cost analysis for the five cities are tabulated on the following pages. Economic conditions applicable to the particular city and state are used in the analyses. For Dodge City, however, economic factors for Colorado are used instead of factors appropriate for Kansas since the original comparison city chosen was Denver. Unfortunately TMY data does not exist for Denver, hence Dodge City was selected to be representative of climatic conditions of the central plains.

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DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: BOSTON

BUILDING DATA

1. ANNUAL HEATING LOAD	80.70 GJ
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SOLAR SYSTEM DATA

2. COLLECTOR AREA	60 M**2
3. SOLAR FRACTION	0.66

ENERGY PRICES

4. ELECTRICAL ENERGY	14.00 \$/GJ
5. HEATING FUEL	14.00 \$/GJ

TERMS OF THE LOAN

6. PERIOD OF THE LOAN	25 YRS
7. DOWN PAYMENT	0.20
8. INTEREST RATE	0.10

ECONOMIC DATA

9. COLLECTOR DEPENDENT INSTALLED COST	175.00 \$/M**2
10. SYSTEM FIXED COST	7407.00 \$
11. OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	37 \$
12. MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	125 \$
13. HEATING FUEL COST	14.00 \$/GJ
14. PROPERTY TAX RATE	0.000
15. INSURANCE RATE	0.003
16. EFFECTIVE INCOME TAX RATE	0.35
17. MARKET DISCOUNT RATE	0.08
18. FUEL INFLATION RATE	0.15
19. OPERATING COST INCREASE	0.15
20. GENERAL AND MAINTENANCE	0.08

SOLAR SYSTEM COST ITEMS

21. INSTALLED SYSTEM COST	17907 \$
22. FEDERAL TAX CREDIT FOR SOLAR	4000 \$
23. STATE TAX CREDIT FOR SOLAR	1000 \$
24. AMOUNT OF THE LOAN	14325 \$

LIFE CYCLE COST FACTORS

25. PERIOD OF ANALYSIS	20 YRS
------------------------	--------

LIFE CYCLE COST ANALYSIS

LOCATION: BOSTON
CONVENTIONAL SOLAR HEATING SYSTEM

MORTGAGE INTEREST RATE = 0.10	COLLECTOR AREA = 60 M**2	SYSTEM COST = 17907 \$
FUEL INFLATION RATE = 0.15	SOLAR FRACTION = 0.66	DOWN PAYMENT = 3581 \$
ELECT. INFLATION RATE = 0.15	TOTAL LOAD = 80.70 GJ	FEDERAL TAX CREDIT = 4000 \$
GENERAL INFLATION RATE = 0.08		STATE TAX CREDIT = 1000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1578	37	125	0	53	384	1432	509	250	126
2	1578	42	135	0	58	441	1417	504	1751	1501
3	1578	49	146	0	62	508	1401	499	1845	1464
4	1578	56	157	0	67	584	1384	492	1951	1434
5	1578	63	170	0	73	671	1364	485	2072	1410
6	1578	74	184	0	78	772	1343	478	2210	1393
7	1578	86	198	0	85	888	1320	469	2367	1381
8	1578	99	214	0	92	1021	1294	460	2545	1375
9	1578	114	232	0	99	1175	1265	450	2748	1374
10	1578	131	250	0	107	1351	1234	439	2979	1379
11	1578	150	270	0	115	1554	1200	427	3242	1390
12	1578	173	292	0	125	1787	1162	413	3542	1406
13	1578	199	315	0	135	2055	1121	399	3884	1428
14	1578	229	340	0	146	2363	1075	382	4275	1455
15	1578	263	368	0	157	2713	1025	364	4721	1488
16	1578	303	397	0	170	3125	969	345	5230	1526
17	1578	348	429	0	184	3594	908	323	5811	1570
18	1578	401	463	0	198	4133	841	299	6476	1620
19	1578	461	500	0	214	4753	768	273	7235	1676
20	1578	530	540	0	231	5466	687	244	8103	1738
SUM	31564	3819	5736	0	2458	39351	23221	8266	73244	28145

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS	= 28145 \$
PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS	= 40534 \$
PRESENT WORTH OF SAVINGS WITH SOLAR	= 12388 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: BOSTON

BUILDING DATA

1.	ANNUAL HEATING AND COOLING LOAD	108.60	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.53	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST INCLUDING CHILLER	13407.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	40	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	167	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.000	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	23907	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	1000	\$
24.	AMOUNT OF THE LOAN	19125	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: BOSTON
CONVENTIONAL SOLAR HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.53
 TOTAL LOAD = 108.60 GJ

SYSTEM COST = 23907 \$
 DOWN PAYMENT = 4781 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 1000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2107	40	167	0	71	714	1912	680	2201	2022
2	2107	46	180	0	77	821	1893	673	2559	2194
3	2107	53	195	0	83	945	1871	666	2717	2157
4	2107	61	210	0	90	1086	1848	657	2898	2130
5	2107	70	227	0	97	1249	1822	648	3103	2112
6	2107	81	245	0	105	1437	1793	638	3338	2103
7	2107	93	265	0	113	1652	1762	627	3605	2103
8	2107	107	286	0	122	1900	1728	615	3909	2112
9	2107	123	309	0	132	2185	1690	601	4257	2129
10	2107	141	334	0	143	2513	1648	586	4653	2155
11	2107	162	361	0	154	2890	1602	570	5106	2190
12	2107	187	390	0	167	3324	1552	552	5623	2233
13	2107	215	421	0	180	3823	1496	532	6215	2285
14	2107	247	455	0	195	4396	1435	511	6890	2346
15	2107	285	491	0	210	5056	1368	487	7663	2415
16	2107	327	530	0	227	5814	1294	460	8546	2494
17	2107	377	573	0	245	6686	1213	431	9557	2583
18	2107	433	619	0	265	7689	1124	400	10714	2681
19	2107	498	668	0	286	8843	1025	365	12039	2789
20	2107	573	722	0	309	10169	917	326	13555	2908
SUM	42140	4127	7658	0	3282	73204	31002	11036	119157	46148

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 46148 \$
 PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 48528 \$
 PRESENT WORTH OF SAVINGS WITH SOLAR = 2380 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: BOSTON

BUILDING DATA

1.	ANNUAL HEATING LOAD	80.90	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.67	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST	7640.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	49	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	126	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.000	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	18140	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	1000	\$
24.	AMOUNT OF THE LOAN	14512	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: BOSTON
DCLLHF SOLAR HEATING SYSTEM

MORTGAGE INTEREST RATE = 0.10
FUEL INFLATION RATE = 0.15
ELECT. INFLATION RATE = 0.15
GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
SOLAR FRACTION = 0.67
TOTAL LOAD = 30.90 GJ

SYSTEM COST = 18140 \$
DOWN PAYMENT = 3628 \$
FEDERAL TAX CREDIT = 4000 \$
STATE TAX CREDIT = 1000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1598	49	126	0	54	373	1451	516	314	189
2	1598	56	137	0	58	429	1436	511	1769	1517
3	1598	65	148	0	63	494	1420	505	1864	1479
4	1598	75	159	0	68	568	1402	499	1971	1449
5	1598	86	172	0	74	653	1382	492	2093	1424
6	1598	99	186	0	79	751	1361	484	2231	1406
7	1598	114	201	0	86	864	1337	476	2389	1394
8	1598	131	217	0	93	994	1311	466	2568	1387
9	1598	150	235	0	100	1143	1282	456	2772	1386
10	1598	173	253	0	108	1314	1250	445	3004	1391
11	1598	199	274	0	117	1512	1216	432	3269	1402
12	1598	229	296	0	126	1738	1177	419	3570	1418
13	1598	263	319	0	137	1999	1135	404	3914	1439
14	1598	303	345	0	148	2299	1089	387	4307	1466
15	1598	349	372	0	159	2644	1038	369	4755	1499
16	1598	401	402	0	172	3041	982	349	5267	1537
17	1598	461	435	0	186	3497	920	327	5851	1581
18	1598	530	469	0	201	4022	852	303	6519	1631
19	1598	610	507	0	217	4625	778	277	7282	1687
20	1598	701	548	0	234	5319	696	247	8154	1749
SUM	31975	5053	5810	0	2490	38289	23523	8374	73872	28439

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 28439 \$
PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 40634 \$
PRESENT WORTH OF SAVINGS WITH SOLAR = 12194 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: BOSTON

BUILDING DATA

1.	ANNUAL HEATING AND COOLING LOAD	108.90	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.55	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST INCLUDING CHILLER	13640.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	54	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	168	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.000	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	24140	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	1000	\$
24.	AMOUNT OF THE LOAN	19312	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: BOSTON

DCLHE SOLAR HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.55
 TOTAL LOAD = 108.90 GJ

SYSTEM COST = 24140 \$
 DOWN PAYMENT = 4828 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 1000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2127	54	168	0	72	686	1931	687	2250	2070
2	2127	62	182	0	78	788	1911	680	2559	2194
3	2127	72	197	0	84	907	1889	672	2715	2155
4	2127	82	212	0	91	1043	1866	664	2893	2126
5	2127	95	229	0	98	1199	1840	655	3096	2107
6	2127	109	248	0	106	1379	1811	644	3326	2096
7	2127	126	268	0	114	1586	1779	633	3590	2094
8	2127	144	289	0	124	1824	1744	621	3890	2101
9	2127	166	312	0	134	2098	1706	607	4232	2117
10	2127	191	337	0	144	2413	1654	592	4622	2141
11	2127	220	364	0	156	2775	1618	576	5068	2173
12	2127	253	394	0	168	3191	1557	557	5577	2215
13	2127	291	425	0	182	3670	1511	538	6159	2264
14	2127	335	459	0	196	4221	1449	516	6824	2323
15	2127	385	496	0	212	4854	1331	491	7584	2391
16	2127	443	536	0	229	5582	1307	465	8454	2467
17	2127	510	578	0	248	6419	1225	436	9448	2553
18	2127	586	625	0	267	7382	1135	404	10586	2649
19	2127	674	675	0	289	8490	1035	368	11888	2754
20	2127	775	729	0	312	9763	926	329	13379	2870
SUM	42551	5583	7732	0	3314	70283	31304	11144	118148	45870

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 45870 \$
 PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 48092 \$
 PRESENT WORTH OF SAVINGS WITH SOLAR = 2222 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: CHARLESTON

BUILDING DATA

1.	ANNUAL HEATING LOAD	49.00	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.94	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST	7407.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	32	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	125	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.030	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	17907	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	0	\$
24.	AMOUNT OF THE LOAN	14325	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: CHARLESTON
CONVENTIONAL SOLAR HEATING SYSTEM

MORTGAGE INTEREST RATE = 0.10
FUEL INFLATION RATE = 0.15
ELECT. INFLATION RATE = 0.15
GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
SOLAR FRACTION = 0.94
TOTAL LOAD = 49.00 GJ

SYSTEM COST = 17907 \$
DOWN PAYMENT = 3581 \$
FEDERAL TAX CREDIT = 4000 \$
STATE TAX CREDIT = 0 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1578	32	125	537	53	41	1432	701	1248	1124
2	1578	37	135	530	58	47	1417	711	1724	1478
3	1578	42	146	626	62	54	1401	722	1788	1419
4	1578	49	157	676	67	62	1384	733	1858	1365
5	1578	56	170	730	73	71	1364	746	1934	1316
6	1578	64	184	789	78	82	1343	759	2018	1272
7	1578	74	198	852	85	95	1320	773	2111	1231
8	1578	85	214	920	92	109	1294	788	2212	1195
9	1578	98	232	994	99	125	1265	804	2323	1162
10	1578	113	250	1073	107	144	1234	821	2446	1133
11	1578	130	270	1159	115	166	1200	840	2581	1107
12	1578	150	292	1252	125	191	1162	859	2730	1084
13	1578	172	315	1352	135	220	1121	880	2893	1064
14	1578	198	340	1461	146	253	1075	902	3074	1046
15	1578	228	368	1577	157	291	1025	926	3274	1032
16	1578	262	397	1704	170	334	969	951	3495	1020
17	1578	301	429	1840	184	385	908	978	3740	1010
18	1578	346	463	1987	198	442	841	1007	4011	1003
19	1578	399	500	2146	214	509	768	1037	4311	998
20	1578	458	540	2318	231	585	687	1070	4644	996
SUM	31564	3302	5736	24583	2458	4216	23221	17018	54425	23066

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 23066 \$
PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 24611 \$
PRESENT WORTH OF SAVINGS WITH SOLAR = 1545 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: CHARLESTON

BUILDING DATA

1. ANNUAL HEATING AND COOLING LOAD 112.30 GJ

SOLAR SYSTEM DATA

2. COLLECTOR AREA 60 M**2
3. SOLAR FRACTION 0.55

ENERGY PRICES

4. ELECTRICAL ENERGY 14.00 \$/GJ
5. HEATING FUEL 14.00 \$/GJ

TERMS OF THE LOAN

6. PERIOD OF THE LOAN 25 YRS
7. DOWN PAYMENT 0.20
8. INTEREST RATE 0.10

ECONOMIC DATA

9. COLLECTOR DEPENDENT INSTALLED COST 175.00 \$/M**2
10. SYSTEM FIXED COST INCLUDING CHILLER 13407.00 \$
11. OPERATING COST AS FRACTION OF
SOLAR COLLECTED = 0.05 OF FIRST YR COST 43 \$
12. MAINTENANCE COST AS FRACTION
OF SYSTEM COST = 0.007 OF FIRST YR COST 167 \$
13. HEATING FUEL COST 14.00 \$/GJ
14. PROPERTY TAX RATE 0.030
15. INSURANCE RATE 0.003
16. EFFECTIVE INCOME TAX RATE 0.35
17. MARKET DISCOUNT RATE 0.08
18. FUEL INFLATION RATE 0.15
19. OPERATING COST INCREASE 0.15
20. GENERAL AND MAINTENANCE 0.08

SOLAR SYSTEM COST ITEMS

21. INSTALLED SYSTEM COST 23907 \$
22. FEDERAL TAX CREDIT FOR SOLAR 4000 \$
23. STATE TAX CREDIT FOR SOLAR 0 \$
24. AMOUNT OF THE LOAN 19125 \$

LIFE CYCLE COST FACTORS

25. PERIOD OF ANALYSIS 20 YRS

LIFE CYCLE COST ANALYSIS

LOCATION : CHARLESTON
HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.55
 TOTAL LOAD = 112.30 GJ

SYSTEM COST = 23907 \$
 DOWN PAYMENT = 4781 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 0 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2107	43	167	717	71	707	1912	936	3659	3446
2	2107	49	180	774	77	813	1893	949	3053	2617
3	2107	57	195	835	83	935	1871	964	3251	2580
4	2107	65	210	903	90	1076	1848	979	3473	2553
5	2107	75	227	975	97	1237	1822	996	3724	2535
6	2107	86	245	1053	105	1423	1793	1013	4008	2525
7	2107	100	265	1133	113	1636	1762	1032	4328	2525
8	2107	115	286	1229	122	1831	1728	1052	4690	2533
9	2107	132	309	1327	132	2154	1690	1074	5099	2550
10	2107	152	334	1433	143	2438	1648	1097	5562	2576
11	2107	174	361	1543	154	2852	1602	1121	6086	2610
12	2107	201	390	1672	167	3291	1552	1147	6681	2653
13	2107	231	421	1805	180	3735	1496	1175	7355	2704
14	2107	266	455	1950	195	4353	1435	1205	8121	2764
15	2107	305	491	2105	210	5095	1368	1237	8990	2834
16	2107	351	530	2275	227	5756	1294	1270	9978	2912
17	2107	404	573	2457	245	6620	1213	1306	11101	3000
18	2107	465	619	2653	265	7613	1124	1344	12379	3097
19	2107	535	668	2865	286	8755	1025	1385	13833	3205
20	2107	615	722	3095	309	10058	917	1428	15489	3323
SUM	42140	4429	7658	32820	3282	72477	31002	22721	140869	55553

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS

= 55553 \$

PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS

= 39717 \$

PRESENT WORTH OF SAVINGS WITH SOLAR

= -15836 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: CHARLESTON

BUILDING DATA

1.	ANNUAL HEATING LOAD	49.20	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.94	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST	7640.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	42	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	126	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.030	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	18140	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	0	\$
24.	AMOUNT OF THE LOAN	14512	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: CHARLESTON
DCILLHE SOLAR HEATING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.94
 TOTAL LOAD = 49.20 GJ

SYSTEM COST = 18140 \$
 DOWN PAYMENT = 3628 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 0 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1598	42	126	544	54	41	1451	710	1325	1199
2	1598	48	137	587	58	47	1436	720	1757	1506
3	1598	55	148	634	63	54	1420	731	1823	1447
4	1598	64	159	685	68	62	1402	743	1896	1393
5	1598	73	172	740	74	72	1382	755	1975	1344
6	1598	84	186	799	79	83	1361	769	2063	1300
7	1598	97	201	863	86	95	1337	783	2159	1260
8	1598	111	217	932	93	109	1311	798	2265	1223
9	1598	128	235	1007	100	126	1282	815	2381	1191
10	1598	148	253	1087	108	145	1250	832	2510	1162
11	1598	170	274	1174	117	167	1216	851	2651	1137
12	1598	195	296	1268	126	192	1177	871	2807	1114
13	1598	225	319	1370	137	221	1135	892	2980	1095
14	1598	258	345	1480	148	254	1089	914	3170	1079
15	1598	297	372	1598	159	292	1038	938	3381	1065
16	1598	342	402	1726	172	336	982	964	3614	1055
17	1598	393	435	1864	186	386	920	991	3873	1046
18	1598	452	469	2013	201	444	852	1020	4160	1041
19	1598	520	507	2174	217	511	778	1051	4479	1037
20	1598	598	548	2348	234	588	696	1083	4833	1036
SUM	31975	4311	5810	24903	2490	4233	23523	17240	56113	23743

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 23743 \$
 PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 24712 \$
 PRESENT WORTH OF SAVINGS WITH SOLAR = 968 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: CHARLESTON

BUILDING DATA

1. ANNUAL HEATING AND COOLING LOAD 112.60 GJ

SOLAR SYSTEM DATA

2. COLLECTOR AREA 60 M**2
3. SOLAR FRACTION 0.57

ENERGY PRICES

4. ELECTRICAL ENERGY 14.00 \$/GJ
5. HEATING FUEL 14.00 \$/GJ

TERMS OF THE LOAN

6. PERIOD OF THE LOAN 25 YRS
7. DOWN PAYMENT 0.20
8. INTEREST RATE 0.10

ECONOMIC DATA

9. COLLECTOR DEPENDENT INSTALLED COST 175.00 \$/M**2
10. SYSTEM FIXED COST INCLUDING CHILLER 13640.00 \$
11. OPERATING COST AS FRACTION OF
SOLAR COLLECTED = 0.05 OF FIRST YR COST 58 \$
12. MAINTENANCE COST AS FRACTION
OF SYSTEM COST = 0.007 OF FIRST YR COST 168 \$
13. HEATING FUEL COST 14.00 \$/GJ
14. PROPERTY TAX RATE 0.030
15. INSURANCE RATE 0.003
16. EFFECTIVE INCOME TAX RATE 0.35
17. MARKET DISCOUNT RATE 0.08
18. FUEL INFLATION RATE 0.15
19. OPERATING COST INCREASE 0.15
20. GENERAL AND MAINTENANCE 0.08

SOLAR SYSTEM COST ITEMS

21. INSTALLED SYSTEM COST 24140 \$
22. FEDERAL TAX CREDIT FOR SOLAR 4000 \$
23. STATE TAX CREDIT FOR SOLAR 0 \$
24. AMOUNT OF THE LOAN 19312 \$

LIFE CYCLE COST FACTORS

25. PERIOD OF ANALYSIS 20 YRS

LIFE CYCLE COST ANALYSIS

LOCATION: CHARLESTON
DCLLHE SOLAR HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.57
 TOTAL LOAD = 112.60 GJ

SYSTEM COST = 24140 \$
 DOWN PAYMENT = 4828 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 0 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2127	58	168	724	72	677	1931	945	3712	3498
2	2127	67	182	732	78	779	1911	958	3058	2621
3	2127	77	197	844	84	896	1889	973	3253	2583
4	2127	88	212	912	91	1030	1866	989	3474	2553
5	2127	102	229	985	98	1185	1840	1005	3723	2533
6	2127	117	248	1064	106	1363	1811	1023	4003	2522
7	2127	135	268	1149	114	1567	1779	1042	4320	2520
8	2127	155	289	1241	124	1803	1744	1063	4677	2527
9	2127	178	312	1340	134	2073	1706	1084	5082	2542
10	2127	205	337	1447	144	2384	1664	1107	5539	2566
11	2127	236	364	1553	156	2742	1618	1132	6058	2598
12	2127	271	394	1663	168	3153	1567	1159	6645	2638
13	2127	312	425	1823	182	3526	1511	1187	7311	2688
14	2127	359	459	1959	196	4170	1449	1217	8066	2746
15	2127	413	496	2127	212	4796	1381	1249	8924	2813
16	2127	475	536	2297	229	5515	1307	1283	9898	2889
17	2127	546	578	2481	248	6343	1225	1319	11005	2974
18	2127	628	625	2679	267	7294	1135	1357	12265	3069
19	2127	722	675	2893	289	8388	1035	1398	13698	3174
20	2127	831	729	3125	312	9547	926	1442	15330	3289
SUM	42551	5983	7732	33140	3314	69441	31304	22942	140049	55352

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS

= 55352 \$

PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS

= 39814 \$

PRESENT WORTH OF SAVINGS WITH SOLAR

= -15537 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: DODGE CITY

BUILDING DATA

1.	ANNUAL HEATING LOAD	80.70	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.82	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST	7407.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	46	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	125	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.005	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	17907	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	3000	\$
24.	AMOUNT OF THE LOAN	14325	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION :DODGE CITY
HEATING SYSTEM ONLY

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.82
 TOTAL LOAD = 30.70 GJ

SYSTEM COST = 17907 \$
 DOWN PAYMENT = 3581 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 3000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENACE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1578	46	125	89	53	203	1432	541	-1863	-1979
2	1578	53	135	96	58	233	1417	539	1616	1385
3	1578	61	146	104	62	268	1401	536	1685	1337
4	1578	70	157	112	67	309	1384	532	1763	1296
5	1578	81	170	121	73	355	1364	529	1851	1259
6	1578	93	184	131	78	409	1343	525	1949	1228
7	1578	107	198	142	85	470	1320	520	2061	1202
8	1578	123	214	153	92	540	1294	515	2187	1181
9	1578	141	232	165	99	622	1265	509	2329	1165
10	1578	162	250	178	107	715	1234	503	2490	1153
11	1578	187	270	193	115	822	1200	496	2672	1146
12	1578	215	292	208	125	946	1162	488	2877	1142
13	1578	247	315	225	135	1088	1121	479	3111	1143
14	1578	285	340	243	146	1251	1075	469	3375	1149
15	1578	327	368	262	157	1438	1025	458	3675	1158
16	1578	376	397	284	170	1654	969	446	4015	1172
17	1578	433	429	306	184	1903	908	432	4402	1189
18	1578	498	463	331	198	2188	841	417	4841	1211
19	1578	573	500	357	214	2516	768	400	5340	1237
20	1578	659	540	386	231	2894	687	382	5908	1267
SUM	31564	4745	5736	4097	2458	20833	23221	9725	56290	21051

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS

= 21051 \$

PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS

= 40534 \$

PRESENT WORTH OF SAVINGS WITH SOLAR

= 19482 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: DODGE CITY

BUILDING DATA

1.	ANNUAL HEATING AND COOLING LOAD	135.30	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.68	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST INCLUDING CHILLER	13407.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	64	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	167	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.005	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	23907	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	3000	\$
24.	AMOUNT OF THE LOAN	19125	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION :DODGE CITY
HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.68
 TOTAL LOAD = 135.30 GJ

SYSTEM COST = 23907 \$
 DOWN PAYMENT = 4781 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 3000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2107	64	167	119	71	606	1912	723	194	15
2	2107	74	180	129	77	697	1893	719	2545	2182
3	2107	85	195	139	83	801	1871	715	2696	2140
4	2107	97	210	150	90	921	1848	711	2867	2107
5	2107	112	227	162	97	1060	1822	706	3061	2083
6	2107	129	245	175	105	1219	1793	701	3281	2067
7	2107	148	265	189	113	1402	1762	694	3532	2060
8	2107	171	286	204	122	1612	1728	688	3817	2062
9	2107	197	309	221	132	1854	1690	680	4141	2071
10	2107	225	334	238	143	2132	1648	671	4510	2089
11	2107	260	361	258	154	2452	1602	662	4931	2115
12	2107	299	390	278	167	2820	1552	651	5411	2148
13	2107	344	421	301	180	3243	1496	639	5957	2190
14	2107	396	455	325	195	3729	1435	626	6581	2240
15	2107	455	491	351	210	4288	1368	612	7292	2298
16	2107	524	530	379	227	4932	1294	595	8104	2365
17	2107	602	573	409	245	5672	1213	577	9032	2441
18	2107	693	619	442	265	6522	1124	557	10092	2525
19	2107	797	668	477	286	7501	1025	535	11303	2619
20	2107	916	722	515	309	8626	917	510	12687	2722
SUM	42140	6597	7658	5470	3282	62095	31002	12984	112041	42548

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 42548 \$
 PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 53904 \$
 PRESENT WORTH OF SAVINGS WITH SOLAR = 11356 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: DODGE CITY

BUILDING DATA

1. ANNUAL HEATING LOAD	81.00	GJ
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SOLAR SYSTEM DATA

2. COLLECTOR AREA	60	M**2
3. SOLAR FRACTION	0.83	

ENERGY PRICES

4. ELECTRICAL ENERGY	14.00	\$/GJ
5. HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6. PERIOD OF THE LOAN	25	YRS
7. DOWN PAYMENT	0.20	
8. INTEREST RATE	0.10	

ECONOMIC DATA

9. COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10. SYSTEM FIXED COST	7640.00	\$
11. OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	61	\$
12. MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	126	\$
13. HEATING FUEL COST	14.00	\$/GJ
14. PROPERTY TAX RATE	0.005	
15. INSURANCE RATE	0.003	
16. EFFECTIVE INCOME TAX RATE	0.35	
17. MARKET DISCOUNT RATE	0.08	
18. FUEL INFLATION RATE	0.15	
19. OPERATING COST INCREASE	0.15	
20. GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21. INSTALLED SYSTEM COST	18140	\$
22. FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23. STATE TAX CREDIT FOR SOLAR	3000	\$
24. AMOUNT OF THE LOAN	14512	\$

LIFE CYCLE COST FACTORS

25. PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: DODGE CITY
DCLLHE SOLAR HEATING SYSTEM

MORTGAGE INTEREST RATE = 0.10
FUEL INFLATION RATE = 0.15
ELECT. INFLATION RATE = 0.15
GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
SOLAR FRACTION = 0.83
TOTAL LOAD = 81.00 GJ

SYSTEM COST = 18140 \$
DOWN PAYMENT = 3628 \$
FEDERAL TAX CREDIT = 4000 \$
STATE TAX CREDIT = 3000 \$

YR.	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1598	61	126	90	54	192	1451	548	-1796	-1912
2	1598	70	137	97	58	221	1436	546	1638	1404
3	1598	80	148	105	63	254	1420	543	1708	1356
4	1598	93	159	114	68	293	1402	539	1787	1314
5	1598	107	172	123	74	337	1382	536	1876	1277
6	1598	123	186	133	79	387	1361	531	1977	1246
7	1598	141	201	143	86	445	1337	527	2090	1219
8	1598	162	217	155	93	512	1311	522	2218	1198
9	1598	187	235	167	100	589	1282	516	2362	1182
10	1598	215	253	181	108	678	1250	509	2526	1170
11	1598	247	274	195	117	779	1216	502	2710	1162
12	1598	284	296	211	126	896	1177	494	2920	1159
13	1598	327	319	228	137	1031	1135	485	3157	1160
14	1598	376	345	246	148	1186	1089	475	3425	1166
15	1598	432	372	266	159	1364	1038	464	3730	1175
16	1598	497	402	287	172	1568	982	452	4076	1189
17	1598	572	435	310	186	1803	920	438	4469	1207
18	1598	658	469	335	201	2074	852	423	4915	1230
19	1598	757	507	362	217	2385	778	406	5422	1256
20	1598	870	548	391	234	2743	696	387	6000	1287
SUM	31975	6267	5810	4150	2490	19749	23523	9852	57219	21453

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS

= 21453 \$

PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS

= 40684 \$

PRESENT WORTH OF SAVINGS WITH SOLAR

= 19231 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: DODGE CITY

BUILDING DATA

1.	ANNUAL HEATING AND COOLING LOAD	135.90	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.70	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST INCLUDING CHILLER	13640.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	86	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	168	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.005	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	24140	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	3000	\$
24.	AMOUNT OF THE LOAN	19312	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: DODGE CITY
DCLLHE SOLAR HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
FUEL INFLATION RATE = 0.15
ELECT. INFLATION RATE = 0.15
GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
SOLAR FRACTION = 0.70
TOTAL LOAD = 135.90 GJ

SYSTEM COST = 24140 \$
DOWN PAYMENT = 4828 \$
FEDERAL TAX CREDIT = 4000 \$
STATE TAX CREDIT = 3000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2127	86	168	120	72	570	1931	730	244	65
2	2127	99	182	130	78	656	1911	726	2547	2184
3	2127	114	197	140	84	754	1889	722	2696	2140
4	2127	131	212	152	91	868	1866	718	2864	2105
5	2127	151	229	164	98	998	1840	713	3056	2080
6	2127	174	248	177	106	1148	1811	707	3273	2063
7	2127	200	268	191	114	1320	1779	701	3520	2054
8	2127	230	289	206	124	1518	1744	694	3801	2054
9	2127	264	312	223	134	1746	1706	687	4121	2061
10	2127	304	337	241	144	2007	1654	678	4485	2077
11	2127	350	364	260	156	2309	1618	668	4899	2101
12	2127	402	394	281	168	2655	1557	658	5371	2133
13	2127	463	425	303	182	3053	1511	646	5910	2173
14	2127	532	459	328	196	3511	1449	632	6523	2221
15	2127	612	496	354	212	4038	1381	618	7224	2277
16	2127	704	536	382	229	4644	1307	601	8023	2341
17	2127	810	578	413	248	5341	1225	583	8935	2415
18	2127	931	625	446	267	6142	1135	563	9978	2497
19	2127	1071	675	482	289	7063	1035	540	11169	2588
20	2127	1232	729	520	312	8123	926	515	12530	2688
SUM	42551	8868	7732	5523	3314	58472	31304	13110	111180	42323

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 42323 \$
PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 53606 \$
PRESENT WORTH OF SAVINGS WITH SOLAR = 11283 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: MADISON

BUILDING DATA

1. ANNUAL HEATING LOAD	101.50	GJ
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SOLAR SYSTEM DATA

2. COLLECTOR AREA	60	M**2
3. SOLAR FRACTION	0.54	

ENERGY PRICES

4. ELECTRICAL ENERGY	14.00	\$/GJ
5. HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6. PERIOD OF THE LOAN	25	YRS
7. DOWN PAYMENT	0.20	
8. INTEREST RATE	0.10	

ECONOMIC DATA

9. COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10. SYSTEM FIXED COST	7407.00	\$
11. OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	38	\$
12. MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	125	\$
13. HEATING FUEL COST	14.00	\$/GJ
14. PROPERTY TAX RATE	0.030	
15. INSURANCE RATE	0.003	
16. EFFECTIVE INCOME TAX RATE	0.35	
17. MARKET DISCOUNT RATE	0.08	
18. FUEL INFLATION RATE	0.15	
19. OPERATING COST INCREASE	0.15	
20. GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21. INSTALLED SYSTEM COST	17907	\$
22. FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23. STATE TAX CREDIT FOR SOLAR	2400	\$
24. AMOUNT OF THE LOAN	14325	\$

LIFE CYCLE COST FACTORS

25. PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: MADISON
CONVENTIONAL SOLAR HEATING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.54
 TOTAL LOAD = 101.50 GJ

SYSTEM COST = 17907 \$
 DOWN PAYMENT = 3581 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 2400 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	ALXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1578	38	125	537	53	653	1432	701	-533	-702
2	1578	44	135	580	58	751	1417	711	2436	2088
3	1578	50	146	626	62	864	1401	722	2606	2069
4	1578	58	157	676	67	994	1384	733	2799	2057
5	1578	67	170	730	73	1143	1364	746	3016	2053
6	1578	77	184	789	78	1314	1343	759	3263	2056
7	1578	88	198	852	85	1511	1320	773	3542	2066
8	1578	102	214	920	92	1738	1294	788	3858	2084
9	1578	117	232	994	99	1999	1265	804	4216	2109
10	1578	134	250	1073	107	2299	1234	821	4622	2141
11	1578	155	270	1159	115	2644	1200	840	5084	2180
12	1578	178	292	1252	125	3041	1162	859	5608	2227
13	1578	205	315	1352	135	3497	1121	880	6203	2281
14	1578	236	340	1461	146	4021	1075	902	6881	2342
15	1578	271	368	1577	157	4625	1025	926	7652	2412
16	1578	312	397	1704	170	5318	969	951	8529	2489
17	1578	359	429	1840	184	6116	908	978	9529	2575
18	1578	412	463	1987	198	7034	841	1007	10668	2669
19	1578	474	500	2146	214	8089	768	1037	11966	2772
20	1578	546	540	2318	231	9302	687	1070	13448	2885
SUM	31564	3930	5736	24583	2458	66963	23221	17018	115399	42860

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 42860 \$
 PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 50981 \$
 PRESENT WORTH OF SAVINGS WITH SOLAR = 8120 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: MADISON

BUILDING DATA

1. ANNUAL HEATING AND COOLING LOAD 132.10 GJ

SOLAR SYSTEM DATA

2. COLLECTOR AREA 60 M**2
3. SOLAR FRACTION 0.46

ENERGY PRICES

4. ELECTRICAL ENERGY 14.00 \$/GJ
5. HEATING FUEL 14.00 \$/GJ

TERMS OF THE LOAN

6. PERIOD OF THE LOAN 25 YRS
7. DOWN PAYMENT 0.20
8. INTEREST RATE 0.10

ECONOMIC DATA

9. COLLECTOR DEPENDENT INSTALLED COST 175.00 \$/M**2
10. SYSTEM FIXED COST INCLUDING CHILLER 13407.00 \$
11. OPERATING COST AS FRACTION OF
SOLAR COLLECTED = 0.05 OF FIRST YR COST 42 \$
12. MAINTENANCE COST AS FRACTION
OF SYSTEM COST = 0.007 OF FIRST YR COST 167 \$
13. HEATING FUEL COST 14.00 \$/GJ
14. PROPERTY TAX RATE 0.030
15. INSURANCE RATE 0.003
16. EFFECTIVE INCOME TAX RATE 0.35
17. MARKET DISCOUNT RATE 0.08
18. FUEL INFLATION RATE 0.15
19. OPERATING COST INCREASE 0.15
20. GENERAL AND MAINTENANCE 0.08

SOLAR SYSTEM COST ITEMS

21. INSTALLED SYSTEM COST 23907 \$
22. FEDERAL TAX CREDIT FOR SOLAR 4000 \$
23. STATE TAX CREDIT FOR SOLAR 2400 \$
24. AMOUNT OF THE LOAN 19125 \$

LIFE CYCLE COST FACTORS

25. PERIOD OF ANALYSIS 20 YRS

LIFE CYCLE COST ANALYSIS

LOCATION: MADISON

CONVENTIONAL SOLAR HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.46
 TOTAL LOAD = 132.10 GJ

SYSTEM COST = 23907 \$
 DOWN PAYMENT = 4781 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 2400 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2107	42	157	717	71	998	1912	936	1549	1315
2	2107	48	180	774	77	1148	1893	949	3387	2904
3	2107	56	195	836	83	1320	1871	964	3635	2885
4	2107	64	210	903	90	1518	1848	979	3915	2878
5	2107	74	227	975	97	1746	1822	996	4233	2880
6	2107	85	245	1053	105	2008	1793	1013	4592	2894
7	2107	98	265	1138	113	2309	1762	1032	5000	2917
8	2107	113	286	1229	122	2656	1728	1052	5462	2951
9	2107	130	309	1327	132	3054	1590	1074	5987	2995
10	2107	149	334	1433	143	3513	1548	1097	6584	3049
11	2107	172	361	1548	154	4040	1502	1121	7262	3114
12	2107	197	390	1672	167	4646	1552	1147	8032	3189
13	2107	227	421	1806	180	5343	1496	1175	8910	3276
14	2107	261	455	1950	195	6144	1435	1205	9908	3373
15	2107	300	491	2106	210	7066	1368	1237	11045	3482
16	2107	346	530	2275	227	8126	1294	1270	12342	3602
17	2107	398	573	2457	245	9345	1213	1306	13819	3735
18	2107	457	619	2653	265	10747	1124	1344	15505	3880
19	2107	526	668	2865	286	12359	1025	1385	17428	4038
20	2107	605	722	3095	309	14212	917	1428	19623	4210
SUM	42140	4357	7658	32820	3282	102307	31002	22721	168227	63575

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS

= 63575 \$

PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS

= 59528 \$

PRESENT WORTH OF SAVINGS WITH SOLAR

= -4047 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: MADISON

BUILDING DATA

1.	ANNUAL HEATING LOAD	101.80	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.55	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST	7640.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	50	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	126	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.030	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	18140	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	2400	\$
24.	AMOUNT OF THE LOAN	14512	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: MADISON
DCLLHF SOLAR HEATING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.55
 TOTAL LOAD = 101.80 GJ

SYSTEM COST = 18140 \$
 DOWN PAYMENT = 3628 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 2400 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1598	50	126	544	54	641	1451	710	-465	-636
2	1598	58	137	587	58	737	1436	720	2457	2107
3	1598	67	148	634	63	848	1420	731	2629	2087
4	1598	77	159	685	68	975	1402	743	2822	2074
5	1598	89	172	740	74	1121	1382	755	3040	2069
6	1598	102	186	799	79	1289	1361	769	3288	2072
7	1598	117	201	863	86	1483	1337	783	3567	2081
8	1598	135	217	932	93	1705	1311	798	3884	2098
9	1598	155	235	1007	100	1961	1232	815	4244	2123
10	1598	179	253	1087	108	2256	1250	832	4652	2154
11	1598	206	274	1174	117	2594	1216	851	5114	2193
12	1598	237	296	1268	126	2983	1177	871	5640	2239
13	1598	272	319	1370	137	3431	1135	892	6237	2293
14	1598	313	345	1480	148	3946	1089	914	6916	2354
15	1598	360	372	1598	159	4537	1038	938	7689	2424
16	1598	414	402	1726	172	5218	982	964	8569	2501
17	1598	476	435	1864	186	6001	920	991	9571	2586
18	1598	548	469	2013	201	6901	852	1020	10712	2680
19	1598	630	507	2174	217	7936	778	1051	12014	2783
20	1598	725	548	2348	234	9127	696	1083	13498	2896
SUM	31975	5219	5810	24903	2490	55701	23523	17240	116088	43188

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 43188 \$
 PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 51132 \$
 PRESENT WORTH OF SAVINGS WITH SOLAR = 7944 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: MADISON

BUILDING DATA

1.	ANNUAL HEATING AND COOLING LOAD	132.60	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.48	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST INCLUDING CHILLER	13640.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	57	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	168	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.030	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	24140	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	2400	\$
24.	AMOUNT OF THE LOAN	19312	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: MADISON
DCLLHE SOLAR HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.48
 TOTAL LOAD = 132.60 GJ

SYSTEM COST = 24140 \$
 DOWN PAYMENT = 4828 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 2400 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2127	57	168	724	72	965	1931	945	1599	1364
2	2127	66	182	782	78	1110	1911	958	3388	2904
3	2127	76	197	844	84	1276	1889	973	3633	2884
4	2127	88	212	912	91	1468	1866	989	3911	2874
5	2127	101	229	985	98	1688	1840	1005	4225	2875
6	2127	116	248	1064	106	1941	1811	1023	4580	2886
7	2127	133	268	1149	114	2232	1779	1042	4983	2908
8	2127	154	289	1241	124	2567	1744	1063	5441	2939
9	2127	177	312	1340	134	2952	1706	1084	5960	2981
10	2127	203	337	1447	144	3395	1664	1107	6549	3033
11	2127	234	364	1563	156	3905	1618	1132	7219	3096
12	2127	269	394	1688	168	4491	1567	1159	7980	3169
13	2127	309	425	1823	182	5164	1511	1187	8846	3252
14	2127	356	459	1969	196	5939	1449	1217	9832	3347
15	2127	409	496	2127	212	6830	1381	1249	10954	3453
16	2127	471	536	2297	229	7854	1307	1283	12233	3570
17	2127	541	578	2481	248	9033	1225	1319	13691	3700
18	2127	523	625	2679	267	10388	1135	1357	15353	3842
19	2127	716	675	2893	289	11946	1035	1398	17250	3997
20	2127	824	729	3125	312	13738	926	1442	19414	4165
SUM	42551	5933	7732	33140	3314	98891	31304	22942	167049	63248

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 63248 \$
 PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 59679 \$
 PRESENT WORTH OF SAVINGS WITH SOLAR = -3568 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: PHOENIX

BUILDING DATA

1.	ANNUAL HEATING LOAD	45.00	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.99	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST	7407.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	31	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	125	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.030	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	17907	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	1000	\$
24.	AMOUNT OF THE LOAN	14325	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: PHOENIX
CONVENTIONAL SOLAR HEATING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.99
 TOTAL LOAD = 45.00 GJ

SYSTEM COST = 17907 \$
 DOWN PAYMENT = 3581 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 1000 \$

YR.	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1578	31	125	537	53	6	1432	701	212	91
2	1578	35	135	580	58	7	1417	711	1683	1443
3	1578	41	146	626	62	8	1401	722	1741	1382
4	1578	47	157	676	67	9	1384	733	1803	1325
5	1578	54	170	730	73	11	1364	746	1872	1274
6	1578	62	184	789	78	12	1343	759	1946	1226
7	1578	72	198	852	85	14	1320	773	2028	1183
8	1578	82	214	920	92	16	1294	788	2116	1143
9	1578	95	232	994	99	19	1265	804	2214	1107
10	1578	109	250	1073	107	22	1234	821	2320	1074
11	1578	126	270	1159	115	25	1200	840	2436	1044
12	1578	145	292	1252	125	29	1162	859	2562	1017
13	1578	166	315	1352	135	33	1121	880	2701	993
14	1578	191	340	1461	146	38	1075	902	2853	971
15	1578	220	368	1577	157	44	1025	926	3020	952
16	1578	253	397	1704	170	51	969	951	3203	935
17	1578	291	429	1840	184	58	908	978	3404	920
18	1578	335	463	1987	198	67	841	1007	3624	907
19	1578	385	500	2146	214	77	763	1037	3866	895
20	1578	443	540	2318	231	89	687	1070	4132	886
SUM	31564	3194	5736	24583	2458	645	23221	17018	49745	20777

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS

= 20777 \$

PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS

= 22602 \$

PRESENT WORTH OF SAVINGS WITH SOLAR

= 1825 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: PHOENIX

BUILDING DATA

1.	ANNUAL HEATING AND COOLING LOAD	167.80	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.63	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST INCLUDING CHILLER	13407.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	73	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	167	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.030	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	23907	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	1000	\$
24.	AMOUNT OF THE LOAN	19125	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: PHOENIX
CONVENTIONAL SOLAR HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
FUEL INFLATION RATE = 0.15
ELECT. INFLATION RATE = 0.15
GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
SOLAR FRACTION = 0.63
TOTAL LOAD = 167.80 GJ

SYSTEM COST = 23907 \$
DOWN PAYMENT = 4781 \$
FEDERAL TAX CREDIT = 4000 \$
STATE TAX CREDIT = 1000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2107	73	167	717	71	869	1912	936	2851	2624
2	2107	85	180	774	77	999	1893	949	3274	2807
3	2107	97	195	836	83	1149	1871	964	3505	2782
4	2107	112	210	903	90	1321	1848	979	3766	2768
5	2107	129	227	975	97	1520	1822	996	4061	2764
6	2107	148	245	1053	105	1748	1793	1013	4395	2769
7	2107	171	265	1138	113	2010	1762	1032	4773	2785
8	2107	196	286	1229	122	2312	1728	1052	5202	2810
9	2107	226	309	1327	132	2658	1690	1074	5688	2845
10	2107	260	334	1433	143	3057	1648	1097	6239	2890
11	2107	299	361	1548	154	3516	1602	1121	6865	2944
12	2107	344	390	1672	167	4043	1552	1147	7576	3008
13	2107	395	421	1806	180	4650	1496	1175	8385	3083
14	2107	455	455	1950	195	5348	1435	1205	9305	3168
15	2107	523	491	2106	210	6150	1368	1237	10352	3263
16	2107	602	530	2275	227	7072	1294	1270	11544	3369
17	2107	692	573	2457	245	8133	1213	1306	12902	3487
18	2107	796	619	2653	265	9353	1124	1344	14450	3616
19	2107	915	668	2865	286	10756	1025	1385	16215	3757
20	2107	1053	722	3095	309	12370	917	1428	18228	3910
SUM	42140	7580	7658	32820	3282	89044	31002	22721	159587	61458

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 61458 \$
PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 49659 \$
PRESENT WORTH OF SAVINGS WITH SOLAR = -11799 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: PHOENIX

BUILDING DATA

1.	ANNUAL HEATING LOAD	45.10	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.99	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST	7640.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	40	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	126	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.030	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	18140	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	1000	\$
24.	AMOUNT OF THE LOAN	14512	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: PHOENIX
DCLLHE SOLAR HEATING SYSTEM

MORTGAGE INTEREST RATE = 0.10
FUEL INFLATION RATE = 0.15
ELECT. INFLATION RATE = 0.15
GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
SOLAR FRACTION = 0.99
TOTAL LOAD = 45.10 GJ

SYSTEM COST = 18140 \$
DOWN PAYMENT = 3628 \$
FEDERAL TAX CREDIT = 4000 \$
STATE TAX CREDIT = 1000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	1598	40	126	544	54	6	1451	710	288	165
2	1598	46	137	537	58	7	1436	720	1715	1471
3	1598	53	148	634	63	8	1420	731	1775	1409
4	1598	61	159	635	68	9	1402	743	1840	1353
5	1598	71	172	740	74	11	1382	755	1912	1301
6	1598	81	186	799	79	12	1361	769	1990	1254
7	1598	93	201	863	86	14	1337	783	2075	1210
8	1598	108	217	932	93	16	1311	798	2168	1171
9	1598	124	235	1007	100	19	1282	815	2270	1135
10	1598	142	253	1087	108	22	1250	832	2381	1103
11	1598	164	274	1174	117	25	1216	851	2504	1073
12	1598	189	296	1268	126	29	1177	871	2637	1047
13	1598	217	319	1370	137	33	1135	892	2784	1024
14	1598	249	345	1480	148	38	1089	914	2946	1003
15	1598	287	372	1598	159	44	1038	938	3123	984
16	1598	330	402	1726	172	51	982	964	3318	968
17	1598	380	435	1864	186	59	920	991	3532	954
18	1598	437	469	2013	201	67	852	1020	3768	942
19	1598	502	507	2174	217	78	778	1051	4027	933
20	1598	578	548	2348	234	89	696	1083	4314	925
SUM	31975	4162	5810	24903	2490	646	23523	17240	51377	21434

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS = 21434 \$
PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS = 22652 \$
PRESENT WORTH OF SAVINGS WITH SOLAR = 1218 \$

DATA SHEET FOR ECONOMIC ANALYSIS

LOCATION: PHOENIX

BUILDING DATA

1.	ANNUAL HEATING AND COOLING LOAD	168.10	GJ
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SOLAR SYSTEM DATA

2.	COLLECTOR AREA	60	M**2
3.	SOLAR FRACTION	0.67	

ENERGY PRICES

4.	ELECTRICAL ENERGY	14.00	\$/GJ
5.	HEATING FUEL	14.00	\$/GJ

TERMS OF THE LOAN

6.	PERIOD OF THE LOAN	25	YRS
7.	DOWN PAYMENT	0.20	
8.	INTEREST RATE	0.10	

ECONOMIC DATA

9.	COLLECTOR DEPENDENT INSTALLED COST	175.00	\$/M**2
10.	SYSTEM FIXED COST INCLUDING CHILLER	13640.00	\$
11.	OPERATING COST AS FRACTION OF SOLAR COLLECTED = 0.05 OF FIRST YR COST	102	\$
12.	MAINTENANCE COST AS FRACTION OF SYSTEM COST = 0.007 OF FIRST YR COST	168	\$
13.	HEATING FUEL COST	14.00	\$/GJ
14.	PROPERTY TAX RATE	0.030	
15.	INSURANCE RATE	0.003	
16.	EFFECTIVE INCOME TAX RATE	0.35	
17.	MARKET DISCOUNT RATE	0.08	
18.	FUEL INFLATION RATE	0.15	
19.	OPERATING COST INCREASE	0.15	
20.	GENERAL AND MAINTENANCE	0.08	

SOLAR SYSTEM COST ITEMS

21.	INSTALLED SYSTEM COST	24140	\$
22.	FEDERAL TAX CREDIT FOR SOLAR	4000	\$
23.	STATE TAX CREDIT FOR SOLAR	1000	\$
24.	AMOUNT OF THE LOAN	19312	\$

LIFE CYCLE COST FACTORS

25.	PERIOD OF ANALYSIS	20	YRS
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LIFE CYCLE COST ANALYSIS

LOCATION: PHOENIX
ECLLHE SOLAR HEATING AND COOLING SYSTEM

MORTGAGE INTEREST RATE = 0.10
 FUEL INFLATION RATE = 0.15
 ELECT. INFLATION RATE = 0.15
 GENERAL INFLATION RATE = 0.08

COLLECTOR AREA = 60 M**2
 SOLAR FRACTION = 0.67
 TOTAL LOAD = 168.10 GJ

SYSTEM COST = 24140 \$
 DOWN PAYMENT = 4828 \$
 FEDERAL TAX CREDIT = 4000 \$
 STATE TAX CREDIT = 1000 \$

YR	ANNUAL MORTGAGE PAYMENT	OPERATING COST	MAINTENANCE COST	PROPERTY TAX	INSURANCE	AUXILIARY FUEL COST	INTEREST PAID	INCOME TAX SAVINGS	EXPENSE WITH SOLAR	PRESENT WORTH OF EXPENSES
1	2127	102	168	724	72	776	1931	945	2854	2630
2	2127	117	182	782	78	893	1911	958	3222	2762
3	2127	135	197	844	84	1027	1889	973	3442	2733
4	2127	155	212	912	91	1181	1866	989	3691	2713
5	2127	179	229	985	98	1358	1840	1005	3973	2703
6	2127	206	248	1064	106	1562	1811	1023	4290	2704
7	2127	237	268	1149	114	1796	1779	1042	4650	2713
8	2127	272	289	1241	124	2065	1744	1063	5057	2732
9	2127	313	312	1340	134	2375	1706	1084	5519	2761
10	2127	360	337	1447	144	2732	1664	1107	6042	2798
11	2127	414	364	1563	156	3141	1618	1132	6636	2846
12	2127	476	394	1688	168	3613	1567	1159	7309	2902
13	2127	548	425	1823	182	4155	1511	1187	8075	2969
14	2127	630	459	1969	196	4778	1449	1217	8945	3045
15	2127	725	496	2127	212	5495	1381	1249	9934	3131
16	2127	833	536	2297	229	6319	1307	1283	11060	3228
17	2127	959	578	2481	248	7267	1225	1319	12342	3335
18	2127	1102	625	2679	267	8357	1135	1357	13802	3454
19	2127	1268	675	2893	289	9611	1035	1398	15466	3583
20	2127	1458	729	3125	312	11052	926	1442	17363	3725
SUM	42551	10499	7732	33140	3314	79559	31304	22942	153683	59477

PRESENT WORTH OF TOTAL EXPENSES FOR SOLAR OVER 20 YEARS

= 59477 \$

PRESENT WORTH OF FUEL COSTS FOR A NON-SOLAR SYSTEM OVER THE SAME NUMBER OF YEARS

= 49709 \$

PRESENT WORTH OF SAVINGS WITH SOLAR

= -9768 \$