Phoenix City of Colorado Springs Solar Assisted Heat Pump Project

Technical Report

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Abstract:

This is the third of four technical reports being prepared for the U.S. Department of Energy by Kaman Sciences Corporation under contract EG-77-C-02-4351.

The work completed to date in documenting the design of packaged Solar Assisted Optimized Heat Pump (SAOHP) systems as a step towards stimulating the advancement of an industrial, commercial, and professional capability for producing and distributing this type of system is covered.

The SAOHP system consists of a collector group, a ground coupled seasonal storage (GCSS) group, and an energy transport and distribution (ETD) group. The design for the collector group with first tier parts and assembly lists are included, along with the ETD group designs for the smaller capacity units. Rating curves are included for the 30,000 BtuH (2-1/2 ton), 36,000 BtuH (3 ton), 48,000 BtuH (4 ton), 60,000 BtuH (5 ton) and 90,000 BtuH (7-1/2 ton) units.

All system revisions have been completed and the results of these revisions documented. The system analysis program, modified to compliance with NBS 76-1137 during the second quarter, has been successfully generating daily, weekly and monthly energy balances. Reliability of the SAOHP system has been fair this quarter and problems occurring are documented.

Climatic region definition work is included in complete form. The economic analysis format for making life cycle cost comparisons between various available heating and cooling systems and the SAOHP is included.

A list of visitors, project photographs and presentations are included in the appendices.

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ABBREVIATION GLOSSARY

ACL	Annual Space Cooling Load
AHL	Annual Space Heating Load
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BTU	British Thermal Units
BTUH	British Thermal Units per Hour
BW	Butt Weld
COP	Coefficient of Performance
Coup	Coupling
°F	Degrees Fahrenheit
DDBC	Design Dry Bulb Cooling Season Temperature
DDBH	Design Dry Bulb Heating Season Temperature
DWBC	Design Wet Bulb Cooling Season Temperature
Ecc	Eccentric
ETD	Energy Transport and Distribution
GCSS	Ground Coupled Seasonal Storage
HDR	Header
HVAC	Heating, Ventilating, Air Conditioning
KW	Kilowatt
KWH	Kilowatthour
LB	Pound
MBTU	Million British Thermal Units
PE	Plain End
PSIA	Pounds per Square Inch, Absolute
PSIG	Pounds per Square Inch, Gage
R-22	Refrigerant 22, Monochlorodifluoromethane
Red	Reducer
S.H.	Specific Heat, Grains per Pound
SOAHP	Solar Assisted Optimized Heat Pump
SOW	Socket Weld
STDWGT	Standard Weight
TYP	Typical
UL	Underwriters Laboratories

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1.0 INTRODUCTION

The purpose of this manual is to document the design of Solar Assisted Optimized Heat Pump (SAOHP) systems as a step towards stimulating the advancement of an industrial, commercial, and professional capability for producing and distributing this type solar system.

The designs and specifications in this manual are in a form common to the Heating, Ventilating, and Air Conditioning (HVAC) trade. The SAOHP system has been developed in the National Solar Program since July 1974. The HVAC industry and the utility infrastructure have continuously played a central role in the development, testing, and operation of the prototype system in the Phoenix Corporation-City of Colorado Springs solar demonstration project.

The established HVAC industry and supporting industries have provided the materials and components that are employed in the SAOHP system. These materials and components have all been in successful commercial use for at least twenty years, and have demonstrated their reliability. This manual provides the technical information necessary for the HVAC industry to commercialize this cost effective solar heating and cooling system which is suitable for use in all climatic regions in the continental United States.

The overall objectives of the work performed on the Phoenix Solar Demonstration Project is to employ proven components that are mass produced, primarily in the HVAC industry infrastructure; to provide an advanced solar heating and cooling system that has the improved performance necessary for providing a solar heating

and cooling system that is competitive in reliability and life cycle costs with other commercially available heating and air conditioning systems; and, to provide a solar heating and cooling system that is compatible with the loads it will serve and the utilities with which it will interface.

Figure 1.0-1 shows the basic component groups of the SAOPH System and their functional relationships.

The collector group acts to convert solar energy to thermal energy. The collector group consists of the following components:

- Basic Equipment Group;
 - Solar collector plate with fluid flow connections and headers, coating, connecting fittings, and hangers,
 - Insulation for the back of the plates,
 - Cover with single tempered plate glass, glazing frame, and mounting sealants,
- Optional Equipment Group;
 - Metal collector housing with side wall insulation, and exterior rust preventative coating, mounting brackets, and header covers,
 - Double glazed cover with two sheets of tempered plate glass,
 - Prefabricated metal mounting structure for free standing collector installations.

FIGURE 1.0-1 FUNCTIONAL RELATIONSHIPS OF THE SOLAR ASSISTED OPTIMIZED HEAT PUMP SYSTEM COMPONENTS.

The GCSS group receives thermal energy from the solar collector and the heat pump condenser, and conducts this thermal energy into the ground where it is stored within specific temperature limits. It also removes the thermal energy from the ground when there is a demand for heating at the load. The storage subsystems operating characteristics are designed to optimize the performance of both the collector group and the heat pump which is a part of the ETD group. The GCSS group consists of the following components:

- Basic Equipment Group;
 - Storage container unit,
 - Storage heat exchanger,
- Local Purchase Items;
 - Clean sand,
 - Insulating concrete where desired.

The ETD group is the part of the system that interfaces with the electric utility. This group provides the means for transporting thermal energy from the collectors to storage, from storage to the space and water heating load, and from the space cooling load to storage. The group contains the instrumentation and controls that sense the requirements for energy transport and dispatches the energy within the system as required. It also contains systems safety controls. The ETD Group consists of the following components:

- Basic Equipment Group;
 - Heat transfer fluid to air heat pump ready for operation after field connections are completed,

- Hot water heater connections,
- Collector circulating pump and heat transfer fluid flow selector valve,
- Heating/cooling thermostat,
- Collector temperature controller,
- Basic R-22, Therminol 60 heat transfer fluid, and nitrogen charge.
- Optional Equipment;
 - Various sizes of hot water heater storage tanks with heat exchanger,
 - Hot water circulator,
 - Weatherization for outdoor installations,
 - Various house air fan motor sizes with variable pitch belt drives for use at high altitudes are for high static pressure duct system requirements,
 - Night setback heating and cooling thermostat,
- Local Purchase Items;
 - Collector temperature controller and thermostat field wiring materials,
 - Power wiring materials for the power supply to the unit terminals,
 - Additional Therminol 60 and dry nitrogen gas as required,
 - Humidifier if desired.

The key operating and design characteristics of the Solar Assisted Optimized Heat Pump system are as follows:

- Seasonal thermal storage that precludes a backup system requirement, that provides for collector operating temperature tracking seasonal outdoor air temperature, and that controls heat pump operating conditions to manage both the heating and cooling coefficient of performance of the heat pump and the heat pump's maximum demand on the electric power system,
- The heat pump interfaces between the thermal load and the electric power system so the demand of the thermal load on the electric power system is always the quotient of the ratio of condenser heat rejection rate at applicable storage temperature to the COP for heating and the quotient of the evaporation cooling rate to the COP for cooling,
- The system provides the capability for space and water heating, and space cooling,
- The system complies with existing codes and standards, and utilizes parts and subassemblies that have been freely used for heating and cooling (and related) applications for at least twenty years, so the mass production capability, the parts availability, and trade familiarity all exist for this system to a significant degree.

1.1 Climatic Region Definition

The solar assisted heat pump system as described in the introduction has its individual subsystem component groups identified and parts listed to correspond with various loads as applicable to all climate characteristics in which the systems must operate. Although a detailed integrated system design is dependent on the specific climate characteristics and resulting loads for the immediate locale in which the system will operate, a method of generalizing climate variations and resulting load definitions will assist designers in the appropriate selections of equipment incorporated within the SAOHP system component groups.

In selecting the appropriate component group's equipment to meet various climatic load requirements, the collector group-storage group interdependence play a vital role in the optimization of the energy transport and dispatch group efficiency; which is reflected in its coefficient of performance. The heating and cooling loads to be addressed by the SAOHP system will then enter the selection process which defines this interdependence and the resulting system component matching optimization.

In keeping with a basic premise of this manual that all system components and designs are formed from established HVAC industry standard practices, the climatic characteristics which establish the loads to be addressed by the SAOHP system and, in turn, assist in component group equipment identifications, are divided into seven climatic regions whose boundaries are defined by the heating degree days (65°F base) within each region as follows:

Region	Degree Days (65°F)
● Region I	- 0-2,000
● Region II	- 2,000-4,000
● Region III	- 4,000-6,000
● Region IV	- 6,000-8,000
● Region V	- 8,000-10,000
● Region VI	- Above 10,000
● Region VII	- 0

Figure 1.1 shows graphically the regional boundaries on a map of the Continental United States and is as prescribed by the U.S. Climatological Atlas.

To establish load definitions within these regions, several representative cities are selected within each region and the specific climatic design conditions as prescribed by ASHRAE and the Armed Forces Engineering Weather Data Manual are used to establish design heating and cooling loads for a baseline residence.

The baseline residence used in this analysis is the Phoenix House of Colorado Springs which is a two story, 2200 square foot, wood frame constructed dwelling. It is designed and constructed to be a passive energy conserver and meets the insulation requirements of the new Regional Building Code (R-11 in the walls and R-19 in the ceiling). The house orientation, garage placement and recessed entryways, protect and isolate the living space from the prevailing winter winds. The windows are all double glazed and are situated with overhangs to allow winter sun to enter the living space while excluding summer sun. The window

FIGURE 1.1 CLIMATIC REGION MAP BY DEGREE DAYS

to floor area ratio is .12. The energy conserving aspects of the baseline residence are detailed to establish a reference for use in analysis of loads which are shown for the climatic region representative cities in Tables 1.1.1-1 through 7, Tables 1.1.2-1 through 7, Tables 1.1.3-1 through 7 and Tables 1.1.4-1 through 7 which follow.

1.1.1 Regional Design Conditions

Tables 1.1.1-1 through 7 show the climatic weather design conditions for the representative cities within the seven climatic regions. The heating season degree totals are obtained from the ASHRAE Handbook & Products Directory, 1976 Systems Edition and from the U.S. Climatology Atlas. The heating and cooling season design temperatures are obtained from the Armed Forces "Engineering Weather Data" manual and represent the 97-1/2% frequency of occurrence range. The cooling season's full load cooling hours are obtained by adding the products of the number of hours in each month within each bin range times the percentage of bin temperature to design cooling season temperature. The bin temperature ranges and corresponding hours within each bin are found in the cooling season tables for each representative city in the "Engineering Weather Data" manual.

1.1.2 Baseline Residence Regional Load Data

In Tables 1.1.2-1 through 7, the baseline residence's experimentally determined design heat loss rate of 55,000 Btu's per hour (or 901.67 Btu's per hour per °F of design temperature below 65°) is applied to each representative city's heating season design temperature to obtain a Design Heat Load in Btu's

per hour. The Design Cooling Loads are developed using an assumption that one half the cooling load results from sensible heat gain and will follow a linear relationship to the ratios of the design dry bulb temperatures between the city in question and the baseline city, and that the other half of the cooling load results from latent heat gain which will follow a linear relationship to the ratios of the specific humidities between the city in question and the baseline city. Here, the baseline Design Cooling Load is 10.5 KW (35,826 Btu's per hour) at design temperatures of 90°F dry-bulb and 62°F wet-bulb, which correspond to a specific humidity of 39 grains per pound of dry air. To develop the cooling load for any other climatic condition the following formula is used:

$$Q_c = \frac{T_d}{90} + \frac{S.H.}{39} \times 17913$$

where Q_c = Cooling load in; Btu's per hour

T_d = Specific site design dry bulb temp; °F

S.H. = Specific site design specific humidity;
grs/lbm dry air

Tables 1.1.2-8 through 14 present the same design heating and cooling load information for a residence of similar construction to the baseline residence per 1000 square feet of floor space.

1.1.3 Baseline Residence Regional Total Season Load Data

Tables 1.1.3-1 through 7 give total heating and cooling season thermal energy requirements in MBtu's for the baseline residence in each of the climatic region representative cities.

The column headed AHL/ACL, shows the ratio of the annual heating load total energy requirements to the annual cooling load total rejection requirements. This ratio is shown in Sections 1.3.1.1 and 1.3.2.1 to be of prime importance in determining the sizes and relationships of the collector and storage group component parts. Figure 1.1.3 is a graphic representation of Tables 1.1.3-1 through 7 and shows the regional distribution of total seasonal loads.

Tables 1.1.3-8 through 14 give total annual heating and cooling load information for residences of similar construction to the baseline residence per 1000 square feet of floor space.

This climate and loads definition methodology is used in the selection procedure for the equipment in the three component groups; with the climatic variations most notably influencing the interrelationship of collector and storage group sizing. This interdependence of storage and collector groups will also be governed by climatic region variations of solar availability as is prescribed in Section 1.1.4.

TABLE 1.1.1-1

HEATING AND COOLING DESIGN CONDITIONS FOR REGION I

Region I

City	State	Heating Season Design Conditions		Cooling Season Design Conditions		
		Degree Days	DDBH* °F	DDBC* °F	DWBC* °F	Full Load Cooling Hrs
Mobile	AL	1,560	31	94	80	2,158
Phoenix	AZ	1,765	34	107	79	2,002
San Diego	CA	1,458	45	78	69	1,013
Jacksonville	FL	1,239	35	93	80	2,104
Savannah	GA	1,819	28	95	79	1,618
New Orleans	LA	1,385	35	92	80	2,105
Biloxi	MS	1,425	32	92	81	2,208
Charleston	SC	1,794	27	91	80	1,702
Corpus Christi	TX	914	35	94	80	2,267

* See abbreviation glossary

TABLE 1.1.1-2

HEATING AND COOLING DESIGN CONDITIONS FOR REGION II

Region II

City	State	Heating Season Design Conditions		Cooling Season Design Conditions		
		Degree Days	DDBH* °F	DDBC* °F	DWBC* °F	Full Load Cooling Hrs
Birmingham	AL	2,551	22	94	78	1,628
Little Rock	AR	3,219	20	96	79	1,610
San Francisco	CA	3,015	38	77	63	1,000
Atlanta	GA	2,961	24	93	77	1,600
Shreveport	LA	2,184	27	97	79	1,668
Jackson	MS	2,239	26	96	78	1,660
Las Vegas	NV	2,709	25	106	71	1,880
Charlotte	NC	3,191	22	93	76	1,268
Oklahoma City	OK	3,725	15	98	77	1,456
Columbia	SC	2,484	26	95	79	1,573
Memphis	TN	3,232	21	96	79	1,550
Amarillo	TX	3,985	13	96	70	1,207
Richmond	VA	3,865	18	94	78	1,240

TABLE 1.1.1-3

HEATING AND COOLING DESIGN CONDITIONS FOR REGION III

Region III						
City	State	Heating Season Design Conditions			Cooling Season Design Conditions	
		Degree Days	DDBH* °F	DDBC* °F	DWBC* °F	Full Load Cooling Hrs
Winslow	AZ	4,782	3	94	64	1,256
Pueblo	CO	5,462	4	96	67	695
New Haven	CT	5,897	11	86	74	836
Wilmington	DE	4,930	12	90	77	1,082
Washington, D.C.		4,224	14	93	77	1,050
Boise	ID	5,806	11	94	66	842
Springfield	IL	5,429	3	92	77	1,050
Indianapolis	IN	5,699	6	92	77	1,050
Wichita	KS	4,986	8	98	76	1,368
Louisville	KY	4,660	11	93	77	1,307
Baltimore	MD	4,654	15	91	77	1,000
Boston	MA	5,634	10	82	74	754
Kansas City	MO	4,711	8	96	77	1,384
Newark	NJ	4,589	11	91	76	945
Albuquerque	NM	4,348	17	94	65	1,223
La Guardia	NY	4,811	15	90	76	950
Cincinnati	OH	4,410	8	91	78	1,156
Portland	OR	4,635	22	89	67	430
Pittsburgh	PA	5,987	9	87	74	918
Providence	RI	5,954	10	86	75	782
Seattle	WA	4,424	29	82	68	218
Charleston	WV	4,476	14	90	75	1,700
Wendover	UT	5,778	9	95	66	1,153

FIGURE 1.1 CLIMATIC REGION MAP BY DEGREE DAYS

TABLE 1.1.1-4

HEATING AND COOLING DESIGN CONDITIONS FOR REGION IV

Region IV						
City	State	Heating Season Design Conditions		Cooling Season Design Conditions		
		Degree Days	DDBH* °F	DDBC* °F	DWBC* °F	Full Load Cooling Hrs
Colorado Springs	CO	6,423	4	90	62	760
Hartford	CT	6,235	6	89	76	830
Pocatello	ID	7,033	-2	91	63	820
Chicago	IL	6,639	1	92	76	816
Des Moines	IA	6,588	-4	92	77	1,026
Portland	ME	7,511	0	86	73	528
Worcester	MA	6,969	2	86	73	750
Detroit	MI	6,232	8	89	75	876
Billings	MT	7,049	-11	91	66	792
Omaha	NE	6,612	-1	94	78	1,030
Reno	NV	6,332	11	91	61	743
Concord	NH	7,383	-2	88	74	837
Syracuse	NY	6,756	3	88	74	830
Cleveland	OH	6,351	7	89	75	792
Burns	OR	6,957	6	89	61	600
Erie	PA	6,451	6	85	74	900
Rapid City	SD	7,345	-6	92	69	836
Spokane	WA	6,655	5	88	63	600
Milwaukee	WI	7,635	-2	87	75	925
Cheyenne	WY	7,381	-5	90	62	593
Salt Lake City	UT	6,052	6	93	66	940

TABLE 1.1.1-5

HEATING AND COOLING DESIGN CONDITIONS FOR REGION V

Region V

City	State	Heating Season Design Conditions			Cooling Season Design Conditions	
		Degree Days	DDBH* °F	DDBC* °F	DWBC* °F	Full Load Cooling Hrs
Juneau	AK	9,075	-1	71	64	122
Caribou	ME	9,767	-14	81	70	509
Sault Saint Marie	MI	9,048	-8	81	71	
Minneapolis	MN	8,382	-9	89	75	854
Glasgow	MT	8,996	-20	93	67	680
Bismarck	ND	8,851	-20	90	72	818
Burlington	VT	8,269	-7	85	73	678
Green Bay	WI	8,029	-7	85	73	690

TABLE 1.1.1-6

HEATING AND COOLING DESIGN CONDITIONS FOR REGION VI

Region VI

City	State	Heating Season Design Conditions		Cooling Season Design Conditions		
		Degree Days	DDBH* °F	DDBC* °F	DWBC* °F	Full Load Cooling Hrs
Anchorage	AK	10,864	-20	71	61	
Fairbanks	AK	14,279	-50	78	63	
Nome	AK	14,171	-28	62	56	

TABLE 1.1.1-7

HEATING AND COOLING DESIGN CONDITIONS FOR REGION VII

Region VII						
City	State	Heating Season Design Conditions		Cooling Season Design Conditions		
		Degree Days	DDBH* °F	DDBC* °F	DWBC* °F	Full Load Cooling Hrs
Honolulu	HI	0	—	85	74	2,912
Hilo	HI	0	—	83	73	2,912

TABLE 1.1.2-1

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS

City	Region I						Design Cooling Load	
	(A) DDBH °F	(B) 65-(A) °F	Design Heat Load (B) x 901.67 BtuH	(C) DDBC °F	(D) DWBC °F	(E) S.H. GR/LBM	$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 17913$ BtuH	Tons
Mobile, AL	31	34	30,657	94	80	133	79,800	6.65
Phoenix, AZ	34	31	27,952	107	79	112	72,740	6.06
San Diego, CA	45	20	18,033	78	69	92	57,780	4.82
Jacksonville, FL	35	30	27,050	93	80	134	80,060	6.67
Savannah, GA	28	37	33,362	95	79	124	75,860	6.32
New Orleans, LA	35	30	27,050	92	80	126	76,180	6.35
Biloxi, MS	32	33	29,755	92	81	143	83,990	7.00
Charleston, SC	27	38	34,263	91	80	138	81,500	6.80
Corpus Christi, TX	35	30	27,050	94	80	133	79,800	6.65

TABLE 1.1.2-2

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS

Region II

City	(A) DDBH °F	(B) 65-(A) °F	Design Heat Load (B) x 901.67 BtuH	(C) DDBC °F	(D) DWBC °F	(E) S.H. GR/LBM	Design Cooling Load	
							$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 17913$ BtuH	Tons
Birmingham, AL	22	43	38,770	94	78	120	73,825	6.15
Little Rock, AR	20	45	40,575	96	79	122	75,145	6.25
San Francisco, CA	38	27	24,345	77	63	59	42,425	3.55
Atlanta, GA	24	41	36,970	93	77	115	71,330	5.95
Shreveport, LA	27	38	34,265	97	79	121	74,880	6.25
Jackson, MS	26	39	35,165	96	78	116	72,385	6.05
Las Vegas, NV	25	40	36,065	106	71	58	47,735	4.00
Charlotte, NC	22	43	38,770	93	76	108	68,115	5.70
Oklahoma City, OK	15	50	45,085	98	77	106	68,190	5.70
Columbia, SC	26	39	35,165	95	70	124	75,860	6.30
Memphis, TN	21	44	39,675	96	79	122	75,145	6.25
Amarillo, TX	13	52	46,890	96	70	69	50,800	4.25
Richmond, VA	18	47	42,380	94	78	120	73,825	6.15

TABLE 1.1.2-3

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS

Region III

City	(A) DDBH °F	(B) 65-(A) °F	Design Heat Load (B) x 901.67 BtuH	(C) DDBC °F	(D) DWBC °F	(E) S.H. GR/LBM	Design Cooling Load $\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 17913$	
							BtuH	Tons
Winslow, AZ	3	62	55,900	94	64	42	38,000	3.15
Pueblo, CO	4	61	55,000	96	67	53	43,450	3.60
New Haven, CT	11	54	48,690	86	74	107	66,260	5.5
Wilmington, DE	12	53	47,790	90	77	120	73,030	6.10
Washington, D.C.	14	51	45,985	93	77	115	71,330	5.95
Boise, ID	11	54	48,690	94	66	52	42,595	3.55
Springfield, IL	3	62	55,900	92	77	113	70,210	5.85
Indianapolis, IN	6	59	53,200	92	77	113	70,210	5.85
Wichita, KS	8	57	51,395	98	76	100	65,436	5.45
Louisville, KY	11	54	48,690	93	77	115	71,330	5.95
Baltimore, MD	15	50	45,085	91	77	118	73,705	6.15
Boston, MA	10	55	49,450	88	74	104	65,285	5.45
Kansas City, MO	8	57	51,395	96	77	110	69,630	5.80
Newark, NJ	11	54	48,690	91	76	112	69,555	5.80
Albuquerque, NM	17	48	43,280	94	65	47	40,295	3.35
La Guardia, NY	15	50	45,085	90	76	104	65,680	5.45
Cincinnati, OH	8	57	51,395	91	78	124	75,066	6.25
Portland, OR	22	43	38,770	89	67	64	47,110	3.95
Pittsburgh, PA	9	56	50,495	87	74	106	66,005	5.50
Providence, RI	10	55	49,590	86	75	114	69,480	5.80
Seattle, WA	29	36	32,460	82	68	78	52,145	4.35
Charleston, WV	14	51	45,985	90	75	107	67,060	5.60
Wendover, UT	9	56	50,495	95	66	50	41,875	3.50

TABLE 1.1.2-4

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS

City	Region IV						Design Cooling Load	
	(A)	(B)	Design Heat Load	(C)	(D)	(E)	$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 17913$	
	DDBH °F	65-(A) °F	(B) x 901.67 BtuH	DDBC °F	DWBC °F	S.H. GR/LEH	BtuH	Tons
Colorado Springs, CO	4	61	55,000	90	62	39	35,826	3.00
Hartford, CT	6	59	53,200	89	76	112	69,155	5.75
Pocatello, ID	-2	67	60,410	91	63	42	37,405	3.10
Chicago, IL	1	64	57,705	92	76	110	68,835	5.75
Des Moines, IA	-4	69	62,215	92	77	116	71,590	5.95
Portland, ME	0	65	58,610	86	73	101	63,505	5.30
Worcester, MA	2	63	56,805	86	73	101	63,505	5.30
Detroit, MI	8	57	51,395	89	75	108	67,319	5.60
Billings, MT	-11	76	68,525	91	66	56	43,835	3.65
Omaha, NE	-1	66	59,510	94	78	120	73,826	6.15
Reno, NV	11	54	48,690	91	61	33	33,270	2.75
Concord, NH	-2	67	60,410	88	74	104	65,285	5.45
Syracuse, NY	3	62	55,900	88	74	104	65,285	5.45
Cleveland, OH	7	58	52,295	89	75	112	69,155	5.75
Burns, OR	6	59	53,200	89	61	36	34,250	2.85
Erie, PA	6	59	53,200	85	74	109	66,980	5.60
Rapid City, SD	-6	71	64,020	92	69	70	50,460	4.20
Spokane, WA	5	60	54,100	88	63	46	38,645	3.20
Milwaukee, WI	-2	67	60,410	87	75	112	68,760	5.75
Cheyenne, WY	-5	70	63,115	90	62	39	35,826	3.00
Salt Lake City, UT	6	59	53,200	93	66	53	42,855	3.60

TABLE 1.1.2-5

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS

Region V

City	(A) DDBH °F	(B) 65-(A) °F	Design Heat Load (B) x 901.67 BtuH	(C) DDBC °F	(D) DWBC °F	(E) S.H. GR/LBM	Design Cooling Load $\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 17913$	
							BtuH	Tons
Juneau, AK	-1	66	59,510	71	64	79	50,415	4.20
Caribou, ME	-14	70	71,230	81	70	93	58,835	4.90
Sault Saint Marie, MI	-8	73	65,820	81	71	99	61,595	5.10
Minneapolis, MN	-9	74	66,725	89	75	109	67,780	5.65
Glasgow, MT	-20	85	76,640	93	67	58	45,150	3.75
Bismarck, ND	-20	85	76,640	90	72	90	59,250	4.95
Burlington, VT	-7	72	64,920	85	73	103	64,225	5.35
Green Bay, WI	-7	72	64,920	85	73	103	64,225	5.35

TABLE 1.1.2-6

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS

City	Region VI						Design Cooling Load	
	(A) DDBH °F	(B) 65-(A) °F	Design Heat Load (B) x 901.67 BtuH	(C) DDBC °F	(D) DWBC °F	(E) S.H. GR/LBM	$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 17913$ BtuH	Tons
Anchorage, AK	-20	85	76,642	71	61	60	41,690	3.5
Fairbanks, AK	-50	115	103,690	78	63	62	44,000	3.65
Nome, AK	-28	93	83,855	62	56	57	38,520	3.20

TABLE 1.1.2-7

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS

Region VII

City	(A)	(B)	Design Heat Load	(C)	(D)	(E)	Design Cooling Load	
	DDBH °F	65-(A) °F	(B) x 901.67 BtuH	DDBC °F	DWBC °F	S.H. GR/LBM	$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 17913$ BtuH	Tons
Honolulu, HI	—	—	—	85	74	109	66,980	5.60
Hilo, HI	—	—	—	83	73	107	65,665	5.50

TABLE 1.1.2-8

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS (Per 1000 Sq. Ft.)

Region I

Design Cooling Load

$$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 8180$$

BtuH Tons

City	(A) DDBH °F	(B) 65-(A) °F	Design Heat Load (B) x 411.7 BtuH	(C) DDBC °F	(D) DWBC °F	(E) S.H. GR/LBM		
Mobile, AL	31	34	14,000	94	80	133	36,440	3.0
Phoenix, AZ	34	31	12,765	107	79	112	33,215	2.75
San Diego, CA	45	20	8,235	78	69	92	26,385	2.20
Jacksonville, FL	35	30	12,350	93	80	134	36,560	3.0
Savannah, GA	28	37	15,235	95	79	124	34,640	2.90
New Orleans, LA	35	30	12,350	92	80	126	34,790	2.90
Biloxi, MS	32	33	13,585	92	81	143	38,355	3.20
Charleston, SC	27	38	15,645	91	80	138	37,215	3.10
Corpus Christi, TX	35	30	12,350	94	80	133	36,440	3.0

TABLE 1.1.2-9

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS (Per 1000 Sq. Ft.)

Region II

City	(A) DDBH °F	(B) 65-(A) °F	Design Heat Load (B) x 411.7 BtuH	(C) DDBC °F	(D) DWBC °F	(E) S.H. GR/LBM	Design Cooling Load	
							$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 8180$ BtuH	Tons
Birmingham, AL	22	43	17,705	94	78	120	33,715	2.80
Little Rock, AR	20	45	18,525	96	79	122	34,315	2.85
San Francisco, CA	38	27	11,115	77	63	59	19,375	1.60
Atlanta, GA	24	41	16,880	93	77	115	32,575	2.70
Shreveport, LA	27	38	15,645	97	79	121	34,195	2.85
Jackson, MS	26	39	16,055	96	78	116	33,055	2.75
Las Vegas, NV	25	40	16,470	106	71	58	21,800	1.80
Charlotte, NC	22	43	17,705	93	76	108	31,105	2.60
Oklahoma City, OK	15	50	20,585	98	77	106	31,140	2.60
Columbia, SC	26	39	16,055	95	79	124	34,640	2.90
Memphis, TN	21	44	18,115	96	79	122	34,315	2.85
Amarillo, TX	13	52	21,410	96	70	69	23,200	1.95
Richmond, VA	18	47	19,350	94	78	120	33,710	2.80

TABLE 1.1.2-10

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS (Per 1000 Sq. Ft.)

City	Region III						Design Cooling Load	
	(A)	(B)	Design Heat Load	(C)	(D)	(E)	$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 8180$	
	DDBH °F	65-(A) °F	(B) x 411.7 BtuH	DDBC °F	DWBC °F	S.H. GR/LBM		
Winslow, AZ	3	62	25,525	94	64	42	17,350	1.45
Pueblo, CO	4	61	25,115	96	67	53	19,840	1.65
New Haven, CT	11	54	22,230	86	74	107	30,260	2.50
Wilmington, DE	12	53	21,820	90	77	120	33,350	2.80
Washington, D.C.	14	51	21,000	93	77	115	32,575	2.70
Boise, ID	11	54	22,230	94	66	152	19,450	1.60
Springfield, IL	3	62	25,525	92	77	113	32,060	2.65
Indianapolis, IN	6	59	24,290	92	77	113	32,060	2.65
Wichita, KS	8	57	23,465	98	76	100	29,880	2.50
Louisville, KY	11	54	22,230	93	77	115	32,575	2.70
Baltimore, MD	15	50	20,585	91	77	118	33,020	2.75
Boston, MA	10	55	22,645	88	74	104	29,810	2.50
Kansas City, MO	8	57	23,465	96	77	110	31,800	2.65
Newark, NJ	11	54	22,230	91	76	112	31,760	2.65
Albuquerque, NM	17	48	19,760	94	65	47	18,400	1.55
La Guardia, NY	15	50	20,585	90	76	104	29,995	2.40
Cincinnati, OH	8	57	23,465	91	78	124	34,280	2.85
Portland, OR	22	43	17,705	89	67	64	21,510	1.80
Pittsburgh, PA	9	56	23,055	87	74	106	30,140	2.50
Providence, RI	10	55	22,645	86	75	114	31,730	2.65
Seattle, WA	29	36	14,820	82	68	78	23,815	2.00
Charleston, WV	14	51	21,000	90	75	107	30,625	2.55
Wendover, UT	9	56	23,055	95	66	50	19,120	1.60

TABLE 1.1.2-11

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS (Per 1000 Sq. Ft.)

Region IV								
City	(A)	(B)	Design Heat Load (B) x 411.7 BtuH	(C)	(D)	(E)	Design Cooling Load	
	DDBH °F	65-(A) °F		DDBC °F	DWBC °F	S.H. GR/LBM	$\left[\frac{(C)}{90} + \frac{(E)}{39} \right]$ BtuH	Tons
Colorado Springs, CO	4	61	25,115	90	62	39	16,360	1.35
Hartford, CT	6	59	24,290	89	76	112	31,580	2.65
Pocatello, ID	-2	67	27,585	91	63	42	17,080	1.40
Chicago, IL	1	64	26,350	92	76	110	31,435	2.60
Des Moines, IA	-4	69	28,405	92	77	116	32,690	2.70
Portland, ME	0	65	26,760	86	73	101	29,000	2.40
Worcester, MA	2	63	25,940	86	73	101	29,000	2.40
Detroit, MI	8	57	23,465	89	75	108	30,740	2.55
Billings, MT	-11	76	31,290	91	66	56	20,015	1.65
Omaha, NE	-1	66	27,170	94	78	120	33,715	2.80
Reno, NV	11	54	22,230	91	61	33	15,190	1.25
Concord, NH	-2	67	27,585	88	74	104	29,810	2.50
Syracuse, NY	3	62	25,525	88	74	104	29,810	2.50
Cleveland, OH	7	58	23,880	89	75	112	31,580	2.65
Burns, OR	6	59	24,290	89	61	36	15,640	1.30
Erie, PA	6	59	24,290	85	74	109	30,590	2.55
Rapid City, SD	-6	71	29,230	92	69	70	23,045	1.90
Spokane, WA	5	60	24,700	88	63	46	17,645	1.45
Milwaukee, WI	-2	67	27,585	87	75	112	31,400	2.60
Cheyenne, WY	-5	70	28,820	90	62	39	16,360	1.35
Salt Lake City, UT	6	59	24,290	93	66	53	19,570	1.65

TABLE 1.1.2-12

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS (Per 1000 Sq. Ft.)

Region V

City	(A)	(B)	Design Heat Load (B) x 411.7 BtuH	(C)	(D)	(E)	Design Cooling Load	
	DDBH °F	65-(A) °F		DDBC °F	DWBC °F	S.H. GR/LBM	$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 8180$ BtuH	Tons
Juneau, AK	-1	66	27,170	71	64	79	23,025	1.90
Caribou, ME	-14	79	32,525	81	70	93	26,870	2.25
Sault Sainte Marie, ME	-8	73	30,055	81	71	99	28,125	2.35
Minneapolis, MN	-9	74	30,465	89	75	109	30,950	2.60
Glasgow, MT	-20	85	35,000	93	67	58	20,620	1.70
Bismarck, ND	-20	85	35,000	90	72	90	27,055	2.25
Burlington, VT	-7	72	29,640	85	73	103	29,330	2.45
Green Bay, WI	-7	72	29,640	85	73	103	29,330	2.45

TABLE 1.1.2-13

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS (Per 1000 Sq. Ft.)

Region VI

City	(A) DDBH °F	(B) 65-(A) °F	Design Heat Load (B) x 411.7 BtuH	(C) DDBC °F	(D) DWBC °F	(E) S.H. GR/LBM	Design Cooling Load $\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 8180$	
							BtuH	Tons
Anchorage, AK	-20	85	35,000	71	61	60	19,040	1.60
Fairbanks, AK	-50	115	47,345	78	63	62	20,095	1.70
Nome, AK	-28	93	38,288	62	56	57	17,590	1.45

TABLE 1.1.2-14

BASELINE RESIDENCE DESIGN HEATING AND COOLING LOADS (Per 1000 Sq. Ft.)

Region VII

City	(A)	(B)	Design Heat Load (B) x 411.7 BtuH	(C)	(D)	(E)	Design Cooling Load	
	DDBH °F	65-(A) °F		DDBC °F	DWBC °F	S.H. GR/LMB	$\left[\frac{(C)}{90} + \frac{(E)}{39} \right] \times 8180$ BtuH	Tons
Honolulu, HI	—	—	—	85	74	109	30,590	2.55
Hilo, HI	—	—	—	83	73	107	29,985	2.50

FIGURE 1

REGIONAL DISTRIBUTION OF TOTAL SEASONAL LOADS

TABLE 1.1.3-1

Region I

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

City	Heating Load MBtu's	Cooling Load MBtu's	AHL* ACL
Mobile, AL	33.76	172.20	.196
Phoenix, AZ	38.20	145.63	.262
San Diego, CA	31.55	58.53	.539
Jacksonville, FL	26.81	168.45	.159
Savannah, GA	39.36	122.74	.321
New Orleans, LA	20.97	160.36	.187
Biloxi, MS	30.84	185.45	.166
Charleston, SC	38.82	138.71	.280
Corpus Christi, TX	19.78	180.91	.109

* See abbreviation glossary

TABLE 1.1.3-2

Region II

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

City	Heating Load MBtu's	Cooling Load MBtu's	$\frac{AHL}{ACL}$
Birmingham, AL	55.20	120.19	.459
Little Rock, AR	69.66	120.98	.576
San Francisco, CA	65.25	42.43	1.538
Atlanta, GA	64.08	114.13	.562
Shreveport, LA	47.26	124.90	.378
Jackson, MS	48.45	120.16	.403
Las Vegas, NV	58.62	89.74	.653
Charlotte, NC	69.05	86.37	.800
Oklahoma City, OK	80.61	107.26	.752
Columbia, SC	53.75	119.33	.450
Memphis, TN	69.94	116.47	.600
Amarillo, TX	86.24	61.32	1.406
Richmond, VA	83.64	91.54	.914

TABLE 1.1.3-3

Region III

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

City	Heating Loads MBtu's	Cooling Loads MBtu's	<u>AHL</u> <u>ACL</u>
Winslow, AZ	103.48	47.73	2.17
Pueblo, CO	118.20	30.20	3.91
New Haven, CT	127.61	55.39	2.30
Wilmington, DE	106.69	79.02	1.35
Washington, D.C.	91.41	74.90	1.22
Boise, ID	125.64	35.87	3.50
Springfield, IL	117.48	73.72	1.60
Indianapolis, IN	123.32	73.72	1.67
Wichita, KS	107.90	89.52	1.21
Louisville, KY	100.84	93.23	1.08
Baltimore, MD	100.71	73.71	1.37
Boston, MA	121.92	49.23	2.48
Kansas City, MO	101.95	96.37	3.53
Newark, NJ	99.31	65.73	1.51
Albuquerque, NM	94.09	49.28	1.91
La Guardia, NY	104.11	62.40	1.67
Cincinnati, OH	95.43	86.78	1.10
Portland, OR	100.30	20.26	4.95
Pittsburgh, PA	129.56	60.59	2.14
Providence, RI	128.85	54.33	2.37
Seattle, WA	95.74	11.37	8.42
Charleston, WV	96.86	114.00	.850
Wendover, UT	125.04	48.28	2.59

TABLE 1.1.3-4

Region IV

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

City	Heating Loads MBtu's	Cooling Loads MBtu's	AHL ACL
Colorado Springs, CO	138.99	27.23	5.10
Hartford, CT	134.93	57.40	2.35
Pocatello, ID	152.19	30.67	4.96
Chicago, IL	143.67	56.17	2.56
Des Moines, IA	142.56	73.45	1.94
Portland, ME	162.54	33.53	4.85
Worcester, MA	150.81	47.63	3.17
Detroit, MI	134.86	58.97	2.29
Billings, MT	152.54	34.72	4.39
Omaha, NE	143.08	76.04	1.88
Reno, NV	137.02	24.72	5.54
Concord, NH	159.77	54.64	2.92
Syracuse, NY	146.20	54.19	2.70
Cleveland, OH	137.44	54.77	2.51
Burns, OR	150.55	20.55	7.33
Erie, PA	139.60	60.28	2.32
Rapid City, SD	158.95	42.19	3.77
Spokane, WA	144.01	23.19	6.21
Milwaukee, WI	165.22	63.60	2.60
Cheyenne, WY	159.72	21.25	7.52
Salt Lake City, UT	130.97	40.28	3.25

TABLE 1.1.3-5

Region V

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

City	Heating Load MBtu's	Cooling Load MBtu's	<u>AHL</u> <u>ACL</u>
Juneau, AK	196.38	6.15	31.93
Caribou, ME	211.36	29.95	7.06
Sault Sainte Marie, MI	195.80		
Minneapolis, MN	181.39	57.88	3.13
Glasgow, MT	194.67	30.80	6.32
Bismarck, ND	191.54	48.47	3.95
Burlington, VT	178.94	43.55	4.11
Green Bay, WI	173.75	44.32	3.92

TABLE 1.1.3-6

Region VI

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

City	Heating Load MBtu's	Cooling Load MBtu's	<u>AHL</u> <u>ACL</u>
Anchorage, AK	235.10		
Fairbanks, AK	309.00		
Nome, AK	306.66		

TABLE 1.1.3-7

Region VII

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

City	Heating Load MBtu's	Cooling Load MBtu's	<u>AHL</u> <u>ACL</u>
Honolulu, HI		195.05	
Hilo, HI		191.22	

TABLE 1.1.3-8

Region I

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS
(Per 1000 Sq. Ft.)

City	Heating Load MBtu's	Cooling Load MBtu's	$\frac{AHL}{ACL}$
Mobile, AL	23.05	117.59	.196
Phoenix, AZ	26.09	99.45	.262
San Diego, CA	21.54	39.97	.539
Jacksonville, FL	18.31	115.03	.159
Savannah, GA	26.88	83.81	.321
New Orleans, LA	14.32	109.50	.187
Biloxi, MS	21.06	126.64	.166
Charleston, SC	26.51	94.72	.280
Corpus Christi, TX	13.51	123.54	.109

TABLE 1.1.3-9

Region II

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS
(Per 1000 Sq. Ft.)

City	Heating Load MBtu's	Cooling Load MBtu's	<u>AHL</u> <u>ACL</u>
Birmingham, AL	37.69	82.07	.459
Little Rock, AR	47.57	82.61	.576
San Francisco, CA	44.56	28.97	1.538
Atlanta, GA	43.76	77.93	.562
Shreveport, LA	32.27	85.29	.378
Jackson, MS	33.08	82.05	.403
Las Vegas, NV	40.03	61.28	.653
Charlotte, NC	47.15	58.98	.800
Oklahoma City, OK	55.05	73.24	.752
Columbia, SC	36.70	81.49	.450
Memphis, TN	47.76	79.53	.600
Amarillo, TX	58.89	41.87	1.406
Richmond, VA	57.11	62.51	.914

TABLE 1.1.3-10

Region III

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

City	Heating Load MBtu's	Cooling Load MBtu's	<u>AHL</u> <u>ACL</u>
Winslow, AR	70.66	32.59	2.17
Pueblo, CO	80.71	20.62	3.91
New Haven, CT	87.14	37.82	2.30
Wilmington, DE	72.85	53.96	1.35
Washington, D.C.	62.42	51.15	1.22
Boise, ID	85.79	24.50	3.50
Springfield, IL	80.22	50.34	1.60
Indianapolis, IN	84.21	50.34	1.67
Wichita, KS	73.68	61.13	1.21
Louisville, KY	68.86	63.66	1.08
Baltimore, MD	68.77	50.33	1.37
Boston, MA	83.25	33.62	2.48
Kansas City, MO	69.62	65.81	3.53
Newark, NJ	67.81	44.88	1.51
Albuquerque, NM	64.25	33.65	1.91
La Guardia, NY	71.09	42.61	1.67
Cincinnati, OH	65.17	59.26	1.10
Portland, OR	68.47	13.84	4.95
Pittsburgh, PA	88.47	41.37	2.14
Providence, RI	87.99	37.10	2.37
Seattle, WA	65.38	7.76	8.42
Charleston, WV	66.14	77.85	.850
Wendover, UT	85.39	32.97	2.59

TABLE 1.1.3-11

Region IV

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS
(Per 1000 Sq. Ft.)

City	Heating Load MBtu's	Cooling Load MBtu's	<u>AHL</u> <u>ACL</u>
Colorado Springs, CO	94.91	18.59	5.10
Hartford, CT	92.14	39.20	2.35
Pocatello, ID	103.92	20.94	4.96
Chicago, IL	98.11	38.36	2.56
Des Moines, IA	97.35	50.16	1.94
Portland, ME	110.99	22.90	4.85
Worcester, MA	102.98	32.53	3.17
Detroit, MI	92.09	40.27	2.29
Billings, MT	104.16	23.71	4.39
Omaha, NE	97.70	51.93	1.88
Reno, NV	93.57	16.88	5.54
Concord, NH	109.10	37.31	2.92
Syracuse, NY	99.83	37.00	2.70
Cleveland, OH	93.85	37.40	2.51
Burns, OR	102.80	14.03	7.33
Erie, PA	95.33	41.16	2.32
Rapid City, SD	108.54	28.81	3.77
Spokane, WA	98.34	15.84	6.21
Milwaukee, WI	112.82	43.43	2.60
Cheyenne, WY	109.07	14.51	7.52
Salt Lake City, UT	89.43	27.51	3.25

TABLE 1.1.3-12

Region V

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS
(Per 1000 Sq. Ft.)

City	Heating Load MBtu's	Cooling Load MBtu's	$\frac{AHL}{ACL}$
Juneau, AK	134.10	4.20	31.93
Caribou, ME	144.33	20.45	7.06
Sault Sainte Marie, MI	133.70	—	—
Minneapolis, MN	123.86	39.52	3.13
Glasgow, MT	132.93	21.03	6.32
Bismarck, ND	130.80	33.10	3.95
Burlington, VT	122.19	29.74	4.11
Green Bay, WI	118.65	30.26	3.92

TABLE 1.1.3-13

Region VI

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

(Per 1000 Sq. Ft.)

City	Heating Load MBtu's	Cooling Load MBtu's	AHL ACL
Anchorage, AK	160.54	—	—
Fairbanks, AK	211.00	—	—
Nome, AK	209.41	—	—

TABLE 1.1.3-14

Region VII

BASELINE RESIDENCE ANNUAL HEATING AND COOLING LOADS

(Per 1000 Sq. Ft.)

City	Heating Load MBtu's	Cooling Load MBtu's	$\frac{AHL}{ACL}$
Honolulu, HI	—	133.19	—
Hilo, HI	—	130.58	—

1.1.4 Regional Solar Availability

Within the aforementioned Regions, Subregion designations will be included to denote the solar availability within the Regions. The Subregion designations will be in the form of a small letter (to be included with the Region number) with the following values of solar availability:

Subregion Designation	Annual Mean Daily Solar Radiation (Langleys Per Day)
a	0-300
b	300-350
c	350-400
d	400-450
e	450-500
f	500-Over

The Annual Mean Daily Solar Radiation will be as prescribed by the U.S. Climatological Atlas and shown graphically with the Subregion boundaries detailed in Figure 1.1.4.

1.1.4.1 Subregion Monthly Solar Availabilities

To provide a heat load versus solar availability load data prescribed for the baseline residence in Sections 1.1.1, 1.1.2 and 1.1.3, the Annual Monthly Mean Daily Solar Radiations for the specific cities used previously are shown in Tables 1.1.4.1-1 through 7. The information source for these figures is the U.S. Climatological Atlas. The data is supplied in mean daily total solar radiations on horizontal surfaces.

FIGURE 1.1.4 SUBREGION SOLAR AVAILABILITY MAP

TABLE 1.1.4.1-1

ANNUAL AND MONTHLY MEAN DAILY SOLAR RADIATION
(on a Horizontal Surface)

Region I

City	State	Sub-region	Annual Mean Daily		Monthly Mean Daily (Btu's per Sq. Ft. per Day)											
			L_y/d	$\frac{\text{Btu}}{\text{Ft}^2 d}$	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mobile	AL	d	425*	1573	888	1258	1314	1850	2130	1945	1850	1905	1646	1406	1073	888
Phoenix	AZ	f	520	1924	1114	1513	1946	2361	2679	2734	2435	2268	2094	1661	1273	1040
San Diego (La Jolla)	CA	c	380	1406	903	1117	1469	1691	1872	1802	1839	1717	1440	1184	1025	818
Jacksonville (Gainesville)	FL	d	410*	1517	988	1270	1580	1913	2142	1938	1806	1788	1546	1284	1110	862
Savannah	GA	d	415*	1540	980	1184	1462	1906	2072	1998	1850	1868	1535	1258	1018	833
New Orleans	LA	b	347	1284	792	958	1240	1524	1661	1640	1543	1540	1417	1321	1029	733
Biloxi (New Orleans)	MS	b	347*	1284	792	958	1240	1524	1551	1640	1543	1540	1417	1321	1029	733
Charleston	SC	d	404	1495	932	1161	1436	1894	2039	2087	1924	1854	1495	1251	1058	833
Corpus Christi (Brownsville)	TX	d	442*	1635	1100	1262	1487	1687	2086	2257	2320	2101	1758	1520	1095	973

TABLE 1.1.4.1-2

ANNUAL AND MONTHLY MEAN DAILY SOLAR RADIATION
(on a Horizontal Surface)

			Region II														
City	State	Sub-region	Annual Mean Daily		Monthly Mean Daily (Btu's per Sq. Ft. per Day)												
			L _y /d	Btu Ft ² d	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Birmingham	AL	c	390*	1443	796	1073	1276	1758	2035	2072	1998	1887	1610	1350	981	740	
Little Rock	AR	c	385	1425	696	962	1306	1650	1935	2068	2057	1916	1624	1269	903	692	
San Francisco	CA		410*	1517	555	944	1314	1905	2165	2442	2497	2294	1665	1184	796	463	
Atlanta	GA	c	396	1465	806	1073	1406	1806	1972	2080	1968	1880	1540	1273	992	781	
Shreveport	LA	c	400	1480	858	1080	1421	1650	2065	2061	2139	1954	1532	1310	940	759	
Jackson	MS	c	405*	1500	833	1036	1258	1740	2128	2016	1998	1924	1572	1387	962	796	
Las Vegas	NV	f	509	1883	1025	1421	1920	2298	2597	2768	2498	2320	2039	1587	1177	955	
Charlotte	NC	c	385*	1425	777	1036	1350	1850	1998	2090	1980	1813	1535	1202	906	703	
Oklahoma City	OK	d	436	1613	929	1180	1513	1828	1983	2276	2257	2194	1802	1395	1077	888	
Columbia	SC	c	405*	1500	870	1118	1388	1924	2035	2128	1980	1850	1554	1221	962	740	
Memphis	TN	c	375*	1388	685	944	1280	1628	1980	2035	2054	1888	1610	1314	888	666	
Amarillo	TX	e	465*	1720	1118	1295	1665	2035	2257	2516	2387	2146	1906	1388	1129	944	
Richmond	VA	c	380*	1406	703	999	1295	1684	1943	2128	1980	1740	1406	1110	814	648	

TABLE 1.1.4.1-3

ANNUAL AND MONTHLY MEAN DAILY SOLAR RADIATION

(on a Horizontal Surface)

		Region III															
City	State	Sub-region	Annual Mean Daily		Monthly Mean Daily												
			L/d	Btu Ft ² /d	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Winslow	AZ	f	510*	1887	1128	1462	1942	2312	2590	2682	2497	2257	2054	1573	1203	981	
Pueblo	CO	d	425*	1573	944	1202	1628	2016	2294	2128	2424	2128	1758	1388	1018	814	
New Haven	CT	b	330*	1221	555	833	1130	1500	1665	1905	1980	1684	1314	907	611	462	
Wilmington (Seabrook)	DE	b	340*	1258	581	840	1176	1490	1783	1950	1883	1683	1425	1029	710	518	
Washington, D.C.		c	356	1317	644	984	1273	1521	2039	1828	1983	1650	1388	1106	781	614	
Boise	ID	c	395	1462	511	873	1265	1795	2165	2353	2480	2131	1702	1114	673	459	
Springfield	IL	c	360*	1332	592	907	1240	1572	1942	2072	2016	1832	1517	1092	648	518	
Indianapolis	IN	b	345	1277	532	788	1170	1465	1806	2009	2002	1813	1500	1084	655	488	
Wichita	KS	d	405*	1500	740	1036	1390	1685	1980	2165	2165	2017	1647	1276	962	740	
Louisville (Lexington)	KY	d	410*	1517	636	973	1321	1776	2150	2324	2283	2083	1828	1321	907	644	
Baltimore (American U.)	MD	b	333*	1232	585	855	1191	1473	1728	1887	1835	1628	1347	1029	710	521	
Boston	MA	b	301	1114	477	718	1073	1295	1647	1787	1798	1521	1236	870	503	426	
Kansas City	MO	c	365*	1351	703	973	1286	1573	1906	2028	2128	1906	1517	1088	795	583	
Newark (New York)	NJ	a	298*	1103	481	736	1073	1365	1498	1739	1698	1440	1224	895	544	426	
Albuquerque	NM	f	512	1894	1121	1428	1891	2287	2538	2686	2527	2316	2050	1621	1236	1021	
La Guardia (Central Park)	NY	a	298*	1103	481	736	1073	1365	1598	1739	1698	1440	1224	895	544	426	
Cincinnati	OH	b	345*	1276	536	796	1166	1480	1887	2128	1998	1795	1517	1092	722	518	
Portland (Astoria)	OR	b	301*	1114	333	600	999	1388	1820	1735	1994	1706	1310	773	411	292	
Pittsburgh	PA	a	280	1036	348	625	800	1173	1587	1817	1839	1513	1254	766	437	285	
Providence (Newport)	RI	b	338*	1251	574	858	1236	1500	1765	1950	1898	1684	1395	1003	651	514	
Seattle	WA	a	300	1110	278	514	980	1491	1861	1891	2094	1672	1199	696	385	237	
Charleston	WV	c	350*	1295	555	740	1110	1480	1850	2054	1943	1684	1498	1018	648	500	
Wendover	UT	c	410*	1517	740	1128	1425	1850	2240	2424	2350	2128	1850	1276	944	740	

TABLE 1.1.4.1-4

ANNUAL AND MONTHLY MEAN DAILY SOLAR RADIATION

(on a Horizontal Surface)

Region IV.

City	State	Sub-region	Annual Mean Daily		Monthly Mean Daily (Btu's per Sq. Ft. per Day)											
			L_y/d	$\frac{\text{Btu}}{\text{Ft}^2 d}$	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Colorado Springs	CO	c	400*	1480	944	1203	1591	1961	2257	2128	2405	2072	1702	1332	962	740
Hartford	CT	b	325*	1203	555	833	1295	1480	1665	1943	1850	1665	1295	888	611	481
Pocatello	ID	c	380*	1406	685	925	1388	1813	2165	2313	2313	2016	1758	1202	721	518
Chicago	IL	a	273	1010	355	544	840	1225	1569	1695	1750	1491	1158	766	444	281
Des Moines	IA	b	345*	1277	644	936	1206	1491	1776	2002	1613	1702	1358	1014	692	530
(Ames)																
Portland	ME	b	350	1295	562	870	1302	1513	1902	1994	2075	1806	1417	1029	581	507
Worcester	MA	b	338*	1250	555	740	1110	1332	1665	1850	1665	1520	1258	888	518	444
Detroit	MI	b	320*	1184	462	759	1129	1314	1758	2017	2035	1758	1295	962	518	388
Billings	MT	c	380*	1406	555	981	1370	1758	2054	2294	2250	1942	1610	1110	648	481
Omaha	NE	c	379	1402	714	1106	1351	1713	1909	2020	2102	1920	1517	1103	755	629
Reno	NV	e	460*	1702	825	1170	1384	2039	2275	2257	2812	2520	1887	1321	918	673
(Soda Springs)																
Concord	NH	b	310*	1147	463	833	1110	1500	1684	1905	1924	1665	1240	870	573	462
Syracuse	NY	b	300*	1110	407	685	981	1202	1591	1850	1850	1646	1221	796	407	296
Cleveland	OH	b	335	1240	463	677	1121	1058	1857	2080	2080	1828	1029	1069	522	426
Burns	OR	c	385*	1425	481	833	1202	1758	2128	2442	2498	2276	1758	1110	592	370
Erie	PA	b	330*	1221	444	648	1092	1110	1702	2016	2054	1794	980	906	500	388
Rapid City	SD	c	392	1450	677	1025	1480	1783	1968	2164	2183	2002	1610	1166	755	585
Spokane	WA	c	361	1336	440	755	1188	1754	2083	2205	2461	2057	1495	833	485	278
Milwaukee	WI	a	300*	1110	462	851	1202	1425	1702	1905	1924	1646	1240	870	500	407
Cheyenne	WY	c	408*	1510	800	1092	1570	1880	2050	2380	2242	1983	1620	1200	850	688
(Laramie)																
Salt Lake City	UT	c	394	1458	603	947	1310	1772	2109	2298	2294	2039	1650	1170	755	540

TABLE 1.1.4.1-5

ANNUAL AND MONTHLY MEAN DAILY SOLAR RADIATION
(on a Horizontal Surface)

Region V																
City	State	Sub-region	Annual Mean Daily		Monthly Mean Daily (Btu's per Sq. Ft. per Day)											
			L_y/d	$\frac{\text{Btu}}{\text{Ft}^2 d}$	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Juneau (Annette)	AK	a	243*	900	233	425	873	1347	1617	1621	1621	1262	955	451	218	151
Caribou	ME	b	316	1170	492	855	1347	1480	1761	1739	1880	1658	1243	784	411	396
Sault Sainte Marie	MI	b	333	1232	481	833	1317	1539	1935	2061	2120	1746	1191	799	389	355
Minneapolis (St. Cloud)	MN	b	348*	1288	622	962	1362	1576	1835	1980	2061	1746	1354	877	540	459
Glasgow	MT	c	388	1436	570	955	1425	1724	2102	2238	2387	1965	1517	988	570	429
Bismarck	ND	c	369	1365	581	925	1317	1654	2035	2183	2283	1909	1443	1006	596	459
Burlington	VT	a	275*	1018	444	777	944	1480	1572	1610	1610	1461	1092	814	462	370
Green Bay	WI	b	335*	1240	500	824	1147	1295	1813	1943	2035	1646	1276	870	500	388

TABLE 1.1.4.1-6

ANNUAL AND MONTHLY MEAN DAILY SOLAR RADIATION
(on a Horizontal Surface)

City	State	Sub-region	Region VI													
			Annual Mean Daily		Monthly Mean Daily											
			L_y/d	$\frac{\text{Btu}}{\text{Ft}^2 d}$	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anchorage	AK	a	224	829	118	340	895	1317	1613	1709	1513	1162	733	370	141	55
Fairbanks	AK	a	224	829	59	262	788	1391	1705	1864	1605	1173	666	303	96	22
Nome	AK	a	220*	814												

TABLE 1.1.4.1-7

ANNUAL AND MONTHLY MEAN DAILY SOLAR RADIATION
(on a Horizontal Surface)

Region VII

City	State	Sub-region	Annual Mean Daily		Monthly Mean Daily (Btu's per Sq. Ft. per Day)											
			L_y/d	$\frac{\text{Btu}}{\text{Ft}^2 d}$	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Honolulu	HI	f	516	1909	1343	1561	1909	2068	2283	2276	2276	2264	2120	1876	1576	1372
Hilo	HI	f	512*	1894												

1.1.4.2 Optimal Collector Tilt Angle

Detailed studies conducted by Lof and Tybout in "Solar Energy", Volume 14, page 25, 1973; indicate that the optimum; i.e., least cost per Btu delivered, collector tilt for building heating is approximately the latitude of the site in question plus 15°. This figure has become widely accepted throughout the scientific community and the solar industry and will be used in this manual as the standard for the optimal collector tilt angle for use in design of the SAOHP system.

The solar availability data given in the previous section is detailed for all collection sites in mean daily total Langley's per day on a horizontal surface and, therefore, is converted to Btu's per hour per square foot of collector surface for assisting in the system sizing since all factors in the SAOHP system sizing methodology are derived from seasonal heating-cooling load energy balances.

In keeping with the standard optimal collector tilt angle, the mean daily total horizontal solar radiation data is converted to an estimated total solar radiation on an optimally tilted solar collector. Table 1.1.4.2 provides tilt factors for each latitude from 20 degrees to 50 degrees and their corresponding optimal tilt angle (Lat. + 15°) for each month. The table is constructed according to the following relationship:

$$I_{\text{coll}} = \frac{I_H \cos i}{\sin \alpha}$$

where I_{coll} = solar insolation incident on collector

I_H = Horizontal solar insolation

i = incident angle

α = solar-altitude angle

The tilt factors in Table 1.1.4.2 are the monthly average values of the $\cos i / \sin$ factor for each latitude and its corresponding optimal collector tilt angle and, when multiplied by the mean daily horizontal total radiation data, yields an estimated mean daily total radiation on an optimally tilted collector.

Tables 1.1.4.3-1 through 7 give the above mentioned estimated monthly mean daily, monthly total and season total solar availability on an optimally tilted collector for the representative cities in the seven selected regions for the heating season. The purpose for providing this information only for the heating season may be found in the system sizing information in Sections 1.3.1.1 and 1.3.2.1; where it is shown that the SAOHP system collector-storage groups' interdependent design is partially governed by the heating season solar availability.

TABLE 1.1.4.2

TILT FACTORS

Latitude (Deg)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Optimum Tilt Angle (Deg)
20.	1.48	1.27	1.04	.87	.76	.69	.72	.82	.97	1.19	1.41	1.55	35.
21.	1.51	1.29	1.05	.87	.75	.68	.71	.82	.98	1.21	1.44	1.59	36.
22.	1.55	1.31	1.06	.87	.75	.68	.71	.82	.99	1.23	1.47	1.62	37.
23.	1.58	1.33	1.07	.87	.74	.67	.70	.82	.99	1.25	1.50	1.66	38.
24.	1.62	1.36	1.08	.87	.74	.67	.70	.81	1.00	1.26	1.53	1.70	39.
25.	1.65	1.38	1.10	.88	.73	.66	.69	.81	1.00	1.28	1.56	1.74	40.
26.	1.69	1.40	1.11	.88	.73	.66	.69	.81	1.01	1.30	1.59	1.78	41.
27.	1.72	1.43	1.12	.88	.72	.65	.68	.81	1.01	1.31	1.62	1.81	42.
28.	1.76	1.45	1.14	.88	.72	.65	.68	.81	1.02	1.33	1.66	1.84	43.
29.	1.79	1.48	1.15	.88	.72	.64	.68	.80	1.02	1.34	1.69	1.89	44.
30.	1.83	1.50	1.16	.88	.71	.64	.67	.80	1.03	1.36	1.72	1.93	45.
31.	1.89	1.54	1.18	.89	.71	.64	.67	.81	1.04	1.39	1.77	2.01	46.
32.	1.96	1.57	1.20	.89	.71	.64	.67	.81	1.05	1.41	1.82	2.08	47.
33.	2.02	1.61	1.21	.90	.71	.64	.67	.81	1.07	1.44	1.86	2.16	48.
34.	2.08	1.65	1.23	.90	.71	.64	.67	.81	1.08	1.47	1.91	2.24	49.
35.	2.15	1.69	1.25	.91	.72	.64	.68	.82	1.09	1.50	1.96	2.32	50.
36.	2.22	1.72	1.26	.91	.72	.64	.68	.82	1.10	1.52	2.01	2.39	51.
37.	2.28	1.76	1.28	.92	.72	.64	.68	.82	1.11	1.55	2.06	2.47	52.
38.	2.35	1.80	1.30	.93	.72	.64	.68	.82	1.13	1.58	2.10	2.56	53.
39.	2.42	1.84	1.31	.93	.72	.64	.68	.82	1.14	1.61	2.15	2.64	54.
40.	2.49	1.88	1.33	.94	.72	.65	.69	.83	1.15	1.64	2.20	2.72	55.
41.	2.62	1.94	1.36	.95	.72	.65	.69	.83	1.17	1.68	2.31	2.88	56.
42.	2.75	2.02	1.39	.96	.72	.65	.69	.84	1.19	1.73	2.42	3.04	57.
43.	2.89	2.09	1.42	.97	.72	.64	.69	.84	1.21	1.78	2.52	3.21	58.
44.	3.02	2.16	1.45	.98	.72	.64	.69	.85	1.23	1.83	2.63	3.37	59.
45.	3.16	2.23	1.48	.99	.72	.64	.69	.85	1.25	1.88	2.74	3.54	60.
46.	3.29	2.30	1.51	1.00	.71	.64	.68	.86	1.27	1.93	2.85	3.71	61.
47.	3.43	2.37	1.54	1.01	.71	.63	.68	.86	1.29	1.98	2.96	3.88	62.
48.	3.57	2.44	1.57	1.02	.71	.63	.68	.87	1.31	2.03	3.06	4.05	63.
49.	3.71	2.51	1.60	1.03	.71	.63	.68	.87	1.33	2.08	3.17	4.22	64.
50.	3.85	2.59	1.63	1.04	.71	.62	.68	.88	1.35	2.13	3.28	4.40	65.

TABLE 1.1.4.3-1

MONTHLY MEAN DAILY, MONTHLY AND HEATING SEASON TOTAL
SOLAR INSOLATION OF AN OPTIMALLY TILTED COLLECTOR

Region I

City	State	Lat °	CTA °	Tilt Factor	October		Tilt Factor	November		Tilt Factor	December		Tilt Factor	January		Tilt Factor	February		Tilt Factor	March		Season Total Insolation Btu/SP
					Mean Daily Btu/SP	Monthly Total Btu/SP		Mean Daily Btu/SP	Monthly Total Btu/SP		Mean Daily Btu/SP	Monthly Total Btu/SP		Mean Daily Btu/SP	Monthly Total Btu/SP		Mean Daily Btu/SP	Monthly Total Btu/SP		Mean Daily Btu/SP	Monthly Total Btu/SP	
Mobile	AL	32°	47°	1.41	1983	61,456	1.82	1953	58,586	2.08	1847	57,258	1.96	1740	53,955	1.57	1975	55,302	1.20	1577	48,881	335,438
Phoenix	AZ	33°	48°	1.44	2392	74,147	1.86	2368	71,033	2.16	2246	69,638	2.02	2250	69,759	1.61	2436	68,206	1.21	2355	72,995	425,777
San Diego	CA	33°	48°	1.44	1705	52,854	1.86	1907	57,195	2.16	1767	54,773	2.02	1824	56,546	1.61	1798	50,354	1.21	1778	55,102	326,825
Jacksonville	FL	30°	45°	1.36	1746	54,133	1.72	1909	57,276	1.93	1664	51,574	1.83	1808	56,049	1.50	1905	53,340	1.16	1833	56,817	329,189
Savannah	GA	32°	47°	1.41	1774	54,987	1.82	1853	55,583	2.08	1733	53,711	1.96	1921	59,545	1.57	1859	52,049	1.20	1754	54,386	330,262
New Orleans	LA	30°	45°	1.36	1797	55,693	1.72	1770	53,096	1.93	1415	43,855	1.83	1449	44,930	1.50	1437	40,236	1.16	1438	44,590	282,402
Biloxi	MS	31°	46°	1.39	1836	56,922	1.77	1821	54,640	2.01	1473	45,673	1.89	1497	46,403	1.54	1475	41,309	1.18	1463	45,359	290,306
Charleston	SC	33°	48°	1.44	1801	55,845	1.86	1968	59,036	2.16	1799	55,778	2.02	1883	58,362	1.61	1869	52,338	1.21	1738	53,664	335,223
Corpus Christi	TX	28°	43°	1.33	2022	62,670	1.66	1818	54,531	1.85	1800	55,802	1.76	1936	60,016	1.45	1830	51,237	1.14	1695	52,551	336,807

TABLE 1.1.4.3-2

MONTHLY MEAN DAILY, MONTHLY AND HEATING SEASON TOTAL
SOLAR INSOLATION OF AN OPTIMALLY TILTED COLLECTOR

Region II

City	State	Lat	CTA	Tilt Factor	October			November			December			January			February			March		Season Total Insolation Btu/SF
					Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	
Birmingham	AL	34°	49°	1.47	1985	61,520	1.91	1874	56,211	2.24	1658	51,386	2.08	1656	51,326	1.65	1771	49,573	1.23	1570	48,654	318,669
Little Rock	AR	35°	50°	1.50	1904	59,009	1.96	1770	53,096	2.32	1605	49,769	2.15	1496	46,388	1.69	1626	45,522	1.25	1633	50,608	304,391
San Francisco	CA	38°	53°	1.58	1871	57,992	2.10	1672	50,148	2.56	1185	34,744	2.35	1304	40,432	1.80	1699	47,578	1.30	1708	52,954	285,848
Atlanta	GA	34°	49°	1.47	1871	57,992	1.91	1895	56,842	2.24	1749	54,233	2.08	1677	51,971	1.65	1771	49,573	1.23	1729	53,610	324,221
Shreveport	LA	33°	48°	1.44	1886	58,478	1.86	1748	52,452	2.16	1639	50,823	2.02	1733	53,728	1.61	1739	48,686	1.21	1719	53,302	317,469
Jackson	MS	32°	47°	1.41	1956	60,626	1.82	1751	52,525	2.08	1656	51,326	1.96	1633	50,613	1.57	1627	45,543	1.20	1510	46,798	307,430
Las Vegas	NV	36°	51°	1.52	2412	74,780	2.01	2366	70,973	2.39	2283	70,756	2.22	2276	70,541	1.72	2444	68,435	1.26	2419	74,995	430,480
Charlotte	NC	35°	50°	1.50	1803	55,893	1.96	1776	53,273	2.32	1631	50,560	2.15	1671	51,787	1.69	1751	49,024	1.25	1688	52,313	312,849
Oklahoma City	OK	35°	50°	1.50	2093	64,868	1.96	2111	63,328	2.32	2060	63,865	2.15	1997	61,918	1.69	1994	55,838	1.25	1891	58,629	368,444
Columbia	SC	34°	49°	1.47	1795	55,641	1.91	1837	55,123	2.24	1658	51,386	2.08	1810	56,098	1.65	1845	51,652	1.23	1707	52,924	322,823
Memphis	TN	35°	50°	1.50	1971	61,101	1.96	1741	52,214	2.32	1545	47,899	2.15	1473	45,655	1.69	1595	44,670	1.25	1600	49,600	301,139
Amarillo	TX	35°	50°	1.50	2082	64,542	1.96	2213	66,385	2.32	2190	67,893	2.15	2404	74,515	1.69	2189	61,279	1.25	2081	64,419	399,133
Richmond	VA	38°	53°	1.58	1754	54,368	2.10	1709	51,282	2.56	1659	51,425	2.35	1652	51,214	1.80	1798	50,350	1.30	1684	52,189	310,827

TABLE 1.1.4.3-3

MONTHLY MEAN DAILY, MONTHLY AND HEATING SEASON TOTAL
SOLAR INSOLATION OF AN OPTIMALLY TILTED COLLECTOR

Region III

City	State	Lat °	CTA °	Tilt Factor	October			November			December			January			February			March			Season
					Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF
Winslow	AZ	35°	50°	1.50	2360	73,145	1.96	2358	70,736	2.32	2276	70,554	2.15	2425	75,181	1.69	2471	69,182	1.25	2428	75,253	434,050	
Pueblo	CO	38°	53°	1.58	2193	67,984	2.10	2138	64,134	2.56	2084	64,599	2.35	2218	68,770	1.80	2164	60,581	1.30	2116	65,608	391,676	
New Haven	CT	41°	56°	1.68	1524	47,237	2.31	1411	42,342	2.88	1331	41,247	2.62	1454	45,077	1.94	1616	45,249	1.36	1537	47,641	268,797	
Wilmington	DE	40°	55°	1.64	1688	52,314	2.20	1562	46,860	2.72	1409	43,678	2.49	1447	44,847	1.88	1579	44,218	1.33	1564	48,487	280,404	
Washington, D.C.		39°	54°	1.61	1781	55,200	2.15	1679	50,375	2.64	1621	50,250	2.42	1559	48,313	1.84	1811	50,696	1.31	1668	51,697	306,530	
Boise	ID	44°	59°	1.83	2039	63,197	2.63	1770	53,100	3.37	1547	47,952	3.02	1543	47,840	2.16	1886	52,800	1.45	1834	56,862	321,749	
Springfield	IL	40°	55°	1.64	1791	55,517	2.20	1426	42,786	2.72	1409	43,678	2.49	1474	45,697	1.88	1705	47,745	1.33	1649	51,125	286,529	
Indianapolis	IN	40°	55°	1.64	1778	55,111	2.20	1441	43,230	2.72	1327	41,148	2.49	1325	41,065	1.88	1481	41,480	1.33	1556	48,239	270,273	
Wichita	KS	38°	53°	1.58	2016	62,499	2.10	2020	60,606	2.56	1894	58,726	2.35	1739	53,909	1.80	1865	52,214	1.30	1807	56,017	343,971	
Louisville	KY	38°	53°	1.58	2087	64,703	2.10	1905	57,141	2.56	1649	51,108	2.35	1495	46,333	1.80	1751	49,039	1.30	1717	53,236	321,559	
Baltimore	MD	39°	54°	1.61	1657	51,357	2.15	1527	45,795	2.64	1375	42,639	2.42	1416	43,887	1.84	1573	44,050	1.31	1560	48,367	276,094	
Boston	MA	42°	57°	1.73	1505	46,658	2.42	1217	36,518	3.04	1295	40,146	2.75	1312	40,664	2.02	1450	40,610	1.39	1492	46,236	250,832	
Kansas City	MO	39°	54°	1.61	1752	54,302	2.15	1709	51,278	2.64	1539	47,713	2.42	1701	52,739	1.84	1790	50,129	1.31	1685	52,225	308,385	
Newark	NJ	41°	56°	1.68	1504	46,612	2.31	1257	37,699	2.88	1227	38,033	2.62	1260	39,067	1.94	1428	39,980	1.36	1460	45,238	246,628	
Albuquerque	NM	35°	50°	1.50	2432	75,377	1.96	2423	72,677	2.32	2369	73,430	2.15	2410	74,715	1.69	2413	67,573	1.25	2364	73,276	437,048	
La Guardia	NY	41°	56°	1.68	1504	46,612	2.31	2157	36,699	2.88	1227	38,033	2.62	1260	39,067	1.94	1428	39,980	1.36	1460	45,238	246,628	
Cincinnati	OH	39°	54°	1.61	1758	54,502	2.15	1552	46,569	2.64	1368	42,393	2.42	1297	40,211	1.84	1465	41,010	1.31	1528	47,351	272,036	
Portland	OR	45°	60°	1.88	1415	45,050	2.74	1126	33,784	3.54	1034	32,044	3.16	1052	32,621	2.23	1338	37,464	1.48	1479	45,834	226,798	
Pittsburgh	PA	40°	55°	1.64	1256	38,943	2.20	961	28,842	2.72	775	24,031	2.49	866	26,862	1.88	1175	32,900	1.33	1064	32,984	184,562	
Providence	RI	42°	57°	1.73	1735	53,791	2.42	1575	47,263	3.04	1563	48,440	2.75	1579	48,934	2.02	1733	48,529	1.39	1718	53,259	300,214	
Seattle	WA	48°	63°	2.03	1413	43,800	3.06	1178	35,343	4.05	960	29,755	3.57	993	30,766	2.44	1254	35,117	1.57	1539	47,697	222,477	
Charleston	WV	38°	53°	1.58	1608	49,862	2.10	1361	40,824	2.56	1280	39,680	2.35	1304	40,432	1.80	1332	37,296	1.30	1443	44,733	252,826	
Mendover	UT	41°	56°	1.68	2144	66,454	2.31	2181	65,419	2.88	2131	66,067	2.62	1939	60,103	1.94	2188	61,273	1.36	1938	60,078	379,394	

TABLE 1.1.4.3-4

MONTHLY MEAN DAILY, MONTHLY AND HEATING SEASON TOTAL
SOLAR INSOLATION OF AN OPTIMALLY TILTED COLLECTOR

Region IV

City	State	Lat °	CTA °	October		November		December		January		February		March		Season Total Insolation Btu/SF
				Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	
Colorado Springs	CO	39°	54°	1.61	2145	66,480	2.15	2068	62,049	2.64	1954	60,562	2.42	2285	70,819	386,499
Hartford	CT	42°	57°	1.73	1536	47,623	2.42	1479	44,359	3.04	1462	45,329	2.75	1526	47,314	287,541
Pocatello	ID	43°	58°	1.78	2140	66,326	2.52	1817	54,508	3.21	1663	51,546	2.89	1980	61,370	348,980
Chicago	IL	42°	57°	1.73	1325	41,081	2.42	1075	32,234	3.04	854	26,481	2.75	976	30,264	197,024
Des Moines	IA	42°	57°	1.73	1754	54,381	2.42	1675	50,239	3.04	1611	49,947	2.75	1771	54,901	314,375
Portland	ME	44°	59°	1.83	1883	58,375	2.63	1528	45,841	3.37	1709	52,966	3.02	1697	52,614	320,939
Worcester	MA	42°	57°	1.73	1536	47,623	2.42	1254	37,607	3.04	1350	41,843	2.75	1526	47,314	264,071
Detroit	MI	42°	57°	1.73	1664	51,592	2.42	1254	37,607	3.04	1180	36,565	2.75	1271	39,386	256,727
Billings	MT	46°	61°	1.93	2142	66,411	2.85	1847	55,404	3.71	1785	55,320	3.29	1826	56,605	48,649
Omaha	NE	41°	56°	1.68	1853	57,444	2.31	1744	52,322	2.88	1818	56,352	2.62	1871	57,991	361,046
Reno	NV	40°	55°	1.64	2166	67,160	2.20	2020	60,588	2.72	1831	56,747	2.49	2054	63,682	341,145
Concord	NH	43°	58°	1.78	1549	48,007	2.52	1444	43,319	3.21	1483	45,974	2.89	1338	41,480	276,389
Syracuse	NY	43°	58°	1.78	1417	43,923	2.52	1026	30,769	3.21	950	29,455	2.89	1176	36,463	223,880
Cleveland	OH	42°	57°	1.73	1849	47,330	2.42	1263	37,897	3.04	1295	40,146	2.75	1273	39,471	261,440
Eurns	OR	44°	59°	1.83	2031	62,970	2.63	1557	46,709	3.37	1247	38,654	3.02	1453	45,031	297,774
Erie	PA	42°	57°	1.73	1567	48,589	2.42	1210	36,300	3.04	1180	36,565	2.75	1331	37,851	243,010
Rapid City	SD	44°	59°	1.83	2134	66,147	2.63	1986	50,570	3.37	1972	61,115	3.02	2045	63,381	378,730
Spokane	WA	48°	63°	2.03	1691	52,421	3.06	1484	44,523	4.05	1126	34,903	3.57	1571	48,695	289,943
Milwaukee	WI	43°	58°	1.78	1549	48,007	2.52	1260	37,800	3.21	1307	40,501	2.89	1335	41,391	270,410
Cheyenne	WY	41°	56°	1.68	2016	62,496	2.31	1964	58,905	2.88	1981	61,425	2.62	2096	64,976	373,310
Salt Lake City	UT	41°	56°	1.68	1966	60,994	2.31	1744	52,322	2.88	1555	48,211	2.62	1580	48,976	317,113

TABLE 1.1.4.3-5

MONTHLY MEAN DAILY, MONTHLY AND HEATING SEASON TOTAL
SOLAR INSOLATION OF AN OPTIMALLY TILTED COLLECTOR

Region V																						
City	State	Lat °	CTA °	Tilt Factor	October		November		Tilt Factor	December		January		February		March		Season Total Insolation Btu/SF				
					Mean Daily Btu/SF	Monthly Total Btu/SF	Mean Daily Btu/SF	Monthly Total Btu/SF		Mean Daily Btu/SF	Monthly Total Btu/SF	Mean Daily Btu/SF	Monthly Total Btu/SF	Mean Daily Btu/SF	Monthly Total Btu/SF	Mean Daily Btu/SF	Monthly Total Btu/SF					
Juneau	AK	59°	74°																			
Caribou	ME	47°	62°	1.98	1552	48,122	2.96	1217	36,497	3.88	1537	47,631	3.43	1688	52,314	2.37	2026	56,738	1.54	2074	64,306	305,607
Saint Sault Marie	MI	47°	62°	1.98	1582	49,043	2.96	1151	34,543	3.88	1377	42,699	3.43	1650	51,145	2.37	1974	55,278	1.54	2028	62,874	295,581
Minneapolis	MN	45°	60°	1.88	1649	51,112	2.74	1480	44,388	3.44	1625	50,371	3.16	1966	60,931	2.23	2145	60,067	1.48	2016	62,489	329,357
Glasgow	MT	48°	63°	2.03	2006	62,175	3.06	1744	52,326	4.05	1738	53,861	3.57	2035	63,082	2.44	2330	65,246	1.57	2237	69,355	366,045
Bismarck	ND	47°	62°	1.98	1992	61,748	2.96	1764	52,925	3.88	1781	55,209	3.43	1993	61,778	2.37	2192	61,383	1.54	2028	62,874	355,916
Burlington	VT	45°	60°	1.88	1530	47,440	2.74	1266	37,976	3.54	1310	40,604	3.16	1403	43,494	2.23	1733	48,516	1.48	1397	43,311	261,341
Green Bay	WI	45°	60°	1.88	1636	50,704	2.74	1370	41,100	3.54	1374	42,579	3.16	1580	48,900	2.23	1838	51,451	1.48	1698	52,624	287,438

TABLE 1.1.4.3-6

MONTHLY MEAN DAILY, MONTHLY AND HEATING SEASON TOTAL
SOLAR INSOLATION OF AN OPTIMALLY TILTED COLLECTOR

Region VI																						
City	State	Lat °	CTA °	October			November			December			January			February			March			Season Total Insolation Btu/SF
				Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	Tilt Factor	Mean Daily Btu/SF	Monthly Total Btu/SF	
Anchorage	AK	62°	77°	2.72	1006	31,198	4.58	646	19,373	6.42	353	10,946	5.48	647	20,046	3.44	1170	32,749	1.67	1495	46,334	127,898
Fairbanks	AK	65°	80°	2.87	870	26,958	4.90	470	14,112	6.92	152	4,720	5.88	347	10,755	3.66	959	26,850	1.68	1324	41,040	124,433
Nome	AK	64°	79°	2.82			4.79			6.75			5.75			3.48			1.67			

TABLE 1.1.4.3-7

MONTHLY MEAN DAILY, MONTHLY AND HEATING SEASON TOTAL
SOLAR INSOLATION OF AN OPTIMALLY TILTED COLLECTOR

Region VII

City	State	Lat °	CTA °	Tilt Factor	October		Tilt Factor	November		Tilt Factor	December		Tilt Factor	January		Tilt Factor	February		Tilt Factor	March		Season Total Insolation Btu/SF
					Mean Daily Btu/SF	Monthly Total Btu/SF		Mean Daily Btu/SF	Monthly Total Btu/SF		Mean Daily Btu/SF	Monthly Total Btu/SF		Mean Daily Btu/SF	Monthly Total Btu/SF		Mean Daily Btu/SF	Monthly Total Btu/SF				
Honolulu	HI	21°	36°	1.21	2270	70,369	1.41	2222	66,665	1.59	2182	67,626	1.51	2028	62,866	1.29	2014	56,383	1.05	2004	62,138	386,047
Hilo	HI	20°	35°																			

1.2 Specifications

The specifications set forth in this section are design specifications. They set forth the maximum physical stress levels that applicable materials are selected for in accordance with the trade practice and several standards and codes.

The SAOHP system is suitable for operation in any climate and at any load. However, this manual will address system for single family residence to small commercial building load applications. Nominal industry tonnage (1 ton equals 12,000 Btu per hour) ratings for heat pumps will govern the nominal ratings for the SAOHP designs in this manual. For the loads specified earlier, the nominal SAOHP system ratings to be covered by this design specifications manual are 2-1/2, 3, 4, 5, 7-1/2, 10 and 15 ton.

The use of these specifications is intended to provide for fail safe conditions within the SAOHP system, and to provide an expected high level of long term self-regulating quality control measures within the system.

1.2.1 Component Groups

The SAOHP system is composed of three component groups which are the collector group, the GCSS group, and the ETD group. These are functional groups. These functional groups are employed for the following reasons:

- Variations in climatic regions and load requirements cause various collector group and GCSS group capacities to be matched to specific heat pumps,

- Single building and multiple building application capabilities are provided by separating the collector group with the GCSS group from the ETD group,
- Three separate types of manufacturing capabilities are required for the three component groups.

Figure 1.2.1, System Component Groups, shows the relationship of the three component groups. The function of each component group is as follows:

- Collector Group,
Convert solar energy to thermal energy,
- GCSS Group,
Store thermal energy, and act as an infinite heat energy sink for thermal energy from the solar collectors and from the heat pump when it operates to cool a building, and act as an infinite heat energy source for the heat pump when it operates to heat a building.
- Energy Transport and Disptach Group,
Move thermal energy from the points of collection to storage or into end use as required and dispatched by the control subsystem.

The design conditions for each component and the parts and subassemblies are listed in the following sections.

1.2.1.1 Collector Group

- Working fluid - Therminol 60

FIGURE 1.2.1 SYSTEM COMPONENT GROUPS.

1.2.1.1.1 Collector Plate

- Design fluid pressure - 44 PSIA (30 PSIG)
- Design temperature - 400°F
- Factory applied baked on coating, emissivity - .95, absorptivity - .95
- Factory air pressure test 50 PSIA (36 PSIG)

1.2.1.1.2 Insulation for Back of Collector Plate

- Minimum K Factor - $2.5 \frac{\text{Btu}}{\text{Square foot-°F-inch-hour}}$
- Minimum thickness - 2-1/2",
- No organic binder,
- Minimum smoldering temperature - 1500°F,
- Minimum bearing pressure with - 2 pounds per square foot 1/4" depression.

1.2.1.1.3 Cover

- Glazing, tempered plate glass, minimum breaking stress 25,000 psi with a stress duration of 2,500 hours, 1/8" thickness, maximum iron content 0.01%.
- Aluminum glazing frame, sealant service temperature, maximum 325°F,
- Mounting sealant, one-part silicon sealant with primerless adhesion to wood, aluminum, and steel, and a maximum service temperature limit of 600°F.

- Housing, vented sheet metal (18 Ga maximum) with grey primer on outside, and 1" thick side wall insulation conforming to 1.2.1.1.2.

1.2.1.2 GCSS Group

- Stored fluid, water at atmospheric pressure,
- Working Fluid, Therminol 60.

1.2.1.2.1 Storage Containment Vessel

- Suitable for underground service for appropriate traffic loading and nonpressurized service,
- Constructed of welded steel plate or spiral welded corrugated galvanized steel sheet,
- Atmospheric pressure factory leak test.

1.2.1.2.2 Storage Heat Exchanger

- Serpentine coil made from copper pipe with expansion bonded copper fins,
- Design conditions:
 - Design pressure, 44 PSIA (30 PSIG)
 - Design temperature, 200°F,
 - Factory pneumatic test pressure, 50 PSIA (36 PSIG)
- Copper dielectrically separated from steel tank.

1.2.1.3. Energy Transport and Dispatch Group

This group is composed of all system elements not included in the collector and storage group. These specifications cover factory and jobsite design conditions.

1.2.1.3.1 Heat Pump Refrigeration Design Conditions

- Working fluid - Refrigerant 22
- Design conditions for refrigerant piping and equipment materials:

	Temperature	Pressure
High Pressure Side	350°F	300 PSIA
Low Pressure Side	100°F	100 PSIA

- See Figure 1.2.1.3.1-1, Heat Pump Refrigeration Circuit, for the designation of the high and low pressure side of the refrigeration circuit.

1.2.1.3.2 Heat Transfer Fluid Piping Circuit

- Working fluid - Therminol 60
- Design pressure, 44 PSIA (30 PSIG)
- Design temperature, 400°F,
- Pneumatic test pressure, 50 PSIA (36 PSIG)
- All piping materials will be metal with a minimum of threaded joints, all threaded joints employed will be readily accessible and a Teflon impregnated pipe sealant known as "LOC-TITE-Hi-Performance Pipe Sealant No. 92-41" will be used.

FIGURE 1.2.1.3.1-1 HEAT PUMP REFRIGERATION CIRCUIT.

KEY

- High Pressure Side
- - - Low Pressure Side

- Where copper pipe with solder joints is used, the solder will have a solidus (starting) melting temperature in excess of 400°F.
- Where compression type fittings are used, they will be of the three piece type with nut, compression ring, and fitting socket.
- Where steel fittings are used, they will be 2000 lb forged steel with either socket weld ends or back-welded threaded ends.
- Proper allowances for thermal expansion and contraction will be made.
- The heat transfer fluid circulating pump will be a fluid lubricated pump with a magnetic drive or have a mechanical carbon on cast iron or ceramic seal and teflon coated gaskets or O-rings,
- All controls will be low voltage,
- The hot water storage tanks will be galvanized steel glass lined tanks with factory openings and heat exchanger, the tank will be designed for 139 PSIA (125 PSIG) pressure at 200°F and will be hydrostatically tested at 202 PSIA (188 PSIG) or pneumatically tested at 164 PSIA (150 PSIG) at the factory.
- Weatherization for outdoor installation will consist of moisture proofing, adding a thermostatically controlled crankcase heater to the compressor, and properly insulating the air moving unit if required,

- The unit will comply with all applicable codes and standards, and will carry a UL label.

1.3 Component Group Details

This section of the SAOHP system design manual includes the design methodology, the equipment selection examples, drawings and dimension tables and performance rating curves for selected items in each component group.

The design engineer should be advised that all equipment selections in the manual are for example only and should be considered "as specified or acceptable equal" for the selection of equipment for specific applications.

1.3.1 Collector Group

The design of the collector group cannot be considered independently and must not be designed solely on the projected site solar availability. The collector group, the GCSS group, and the ETD group work together to meet the heating and cooling loads and their interdependent functions must be analyzed synergistically in designing a total system.

1.3.1.1 Regional Sizing Methodology

The seasonal storage characteristics of the GCSS group are such that cooling load thermal energy rejected to the GCSS group is partially recoverable for use in the heating mode. Thus, the capacity of the collector group is matched to the net energy deficit between the recoverable cooling load and the total heating load required. Analysis work in this area of SAOHP system design was performed in Task II of EPRI RP 924-1. This work led to a collector group vs GCSS group sizing methodology and was based on an annual energy balance formula for describing the SAOHP system operating characteristics, as follows:

where I = Total solar insolation for heating season,
Btu/ft²

Q_{CR} = Total thermal input to storage from collectors
for heating season, Btu

Q_{HPH} = Total thermal withdrawal from storage for
heating season, Btu

Q_H = Total heating load for heating season, Btu

Q_L = Total cooling load for cooling season, Btu

Q_{HPC} = Total thermal rejection to storage during
cooling season, Btu

Governing Equations:

(I) $Q_{CR} = \eta I A$

where η = seasonal collector system efficiency (.37
for Phoenix House)

A = collector area

(II) $\rho = \frac{Q_{HPH}}{Q_{CR} + Q_{HPC}}$ (defined as yearly storage efficiency)

$$(III) \quad Q_{HPH} = Q_H (1 - 1/COP_H)$$

where COP_H = seasonal heat pump heating mode coefficient of performance

$$(IV) \quad Q_{HPC} = Q_C (1 + 1/COP_C)$$

where COP_C = seasonal heat pump cooling mode coefficient of performance

Now substituting (I) into (II) and solving for A:

$$(V) \quad A = \frac{Q_{HPH}}{I} \frac{1/\rho - \frac{Q_{HPC}}{Q_{HPH}}}{\eta} = \theta \frac{(1/\rho - \gamma)}{\eta}$$

where θ = the ratio of heat pump heating season storage demand to heating season insolation

γ = the ratio of heat pump cooling season thermal rejection to heat pump heating season storage demand

Equation V can be reduced to a single equation to determine collector group area requirements, when the heating and cooling season loads and heating season solar availability are known, by substituting four experimentally determined constants into their proper places in the derivation and reducing to simple terms.

First, the collector efficiency (η) was determined to be .37 (or 37%) for a seasonal average and this would not vary greatly from region to region. The coefficients of performance - COP_H in Equation III and COP_C in Equation IV - were determined to be 2.85 and 1.85, respectively, and, again, these quantities would vary little from region to region. The storage efficiency (ρ) was determined from the Phoenix/City of Colorado Springs SAHP Project data to be .68 (or 68%), but cannot be assumed regionally constant.

Additional documentation of seasonal storage efficiencies of GCSS groups functioning in different climatic regions - with different soil makeup - is needed and has been proposed for extension work for the Phoenix/City of Colorado Springs SAHP Project. However, until further information is available on the GCSS group storage efficiency sensitivities to varying soil conductivities, compactions, and moisture contents, the empirical value of .68 for the storage efficiency (ρ) will be used in Equation V with allowances for engineering judgement.

When these four constants are assumed and placed into the derivation for Equation V, that equation reduces to:

$$(Va) \quad A = \frac{Q_H}{I} \left[2.59 - .74 \left(\frac{Q_H}{Q_C} \right)^* \right]$$

where A = Collector Group Area Required, FT^2

Q_H = Total Heating Season Load, Btu's

Q_C = Total Cooling Season Load, Btu's

I = Total Heating Season Solar
Availability, $BTU's/FT^2$

* $\frac{AHL}{ACL}$ in Tables 1.1.3-8 through 14

Using this formula and appropriate specific site values of Q_H , $\frac{Q_H}{Q_C}$ and I - obtained from Tables 1.1.3-8 through 14 and 1.1.4.3-1 through 7 (or from the specific site locally available information) - the required collector group area for support of the ETD group in its heating mode may be determined.

1.3.1.2 Equipment Selections

The collector plates used in the Phoenix/City of Colorado Springs were aluminum Olin Brass Roll Bond™ panels, now under the trade name Solar Bond™ panels. These panels have proven highly

reliable over a period of four years of extensive field testing. The panels selected for the SAOHP system should be Olin-Brass Solar Bond™ or acceptable equal.

The piping for the Collector Group is Schedule 40 steel pipe with forged-steel, threaded, and back-welded joints. All valves, meters or joints (not back-welded) in the piping system should be threaded and sealed with "LOC-TITE Hy-Performance Pipe Sealant #92-41". This particular sealant has been the only successful sealant to stop the seepage of the heat transfer fluid through threaded connections in the Phoenix SAOHP piping system. Pump connections should be flanged and have teflon coated O-rings.

The heat transfer fluid in the piping system should be Monsanto Therminol™ 60 or acceptable equal. this is a noncorrosive, nonelectrolytic ester based heat transfer fluid with a freezing point of -60°F and a boiling point of 600°F. The piping system should be flooded with nitrogen prior to filling and capped with a 25 psi nitrogen cushion in an expansion tank.

1.3.1.3 Drawings

The following drawings detail the design and installation specifications for the Collector Group components, both field assembled and factory built, with associated piping, anchors and expansion joint recommendations.

Drawings of yard mounted support structures will be included with the final manual.

1.3.1.4 Dimension

FIGURE 1.5.1.1-1 FIELD ASSEMBLED COLLECTOR

TYPICAL CONNECTION OF HEADER TO COLLECTOR PLATE SHOWN AT REDUCING COUPLING

FIGURE 1.3.1.1-2. STANDARD COLLECTOR HEADER (See Figure 1.3.1.1-3 For Expansion Control)

FIGURE 1.3.1.1-3 STANDARD COLLECTOR HEADER ANCHORS AND EXPANSION JOINTS

FIGURE 1.3.1.1-4 FACTORY ASSEMBLED COLLECTOR

TABLE 1.4.1.1.-1

SOLAR ASSISTED OPTIMIZED HEAT PUMP SYSTEM

SOLAR COLLECTOR GROUP (SCG)

FIELD ASSEMBLED COLLECTOR (FIC)

Part No.	Nomenclature	Source	Weight-Pounds				Total
			Net	R-22	Fluid	Insulation	
1001-CPA	Collector Plate, Aluminum	Olin Brass	19	—	5	—	24
1001-CIB	Collector Insulation, Bottom	Rock Wool Industries	—	—	—	—	—
1001-CPH	Collector Plate Hanger	Plumblng Supply House	1	—	—	—	1
1001-CS	Cover Sealant	General Electric	1½	—	—	—	1½
1001-PTI	Paint, Exposed Surface	PPG Industries	1	—	—	—	1
1001-CVR	Cover Assembly	Window Fabricator		—	—	—	

TABLE 1.4.1.1-2

SOLAR ASSISTED OPTIMIZED HEAT PUMP SYSTEM

SOLAR COLLECTOR GROUP (SCG)

COLLECTOR HEADER PIPING (CHP)

Part No.	Nomenclature	Source	Weight-Pounds				Total
			Net	R-22	Fluid	Insulation	
1000-A	Adaptor-Flareless	Weatherhead-Haskall	2	—	.02	—	2.02
1000-N	STD Black Nipple 3/4"x1-1/2" Toe	Plumbing Supply House	1	—	.03	—	1.03
1000-P3	3/4"x PE Header Pipe-Black	Plumbing Supply House					
1000-P4	1"x PE Header Pipe-Black	Plumbing Supply House					
1000-P5	1-1/4"x PE Header Pipe-Black	Plumbing Supply House					
1000-P6	1-1/2"x PE Header Pipe-Black	Plumbing Supply House					
1000-E3	3/4" 2000# SOW 90° Ell	Plumbing Supply House					
1000-E34	3/4"x1" Sch 40 BW Ecc Red Coup	Plumbing Supply House					
1000-E45	1"x1-1/4" Sch 40 BW Ecc Red Coup	Plumbing Supply House					
1000-E56	1-1/4"x1-1/2" Sch 40 BW Ecc Red Coup	Plumbing Supply House					
1000-W3	3/4" Pipe Wear Pad	Plumbing Supply House					
1000-W4	1" Pipe Wear Pad	Plumbing Supply House					
1000-W5	1-1/4" Pipe Wear Pad	Plumbing Supply House					
1000-W6	1-1/4" Pipe Wear Pad	Plumbing Supply House					
1000-PH	Perforated Metal Tape Assembly	Plumbing Supply House					
1000-ECA	Expansion Control Assembly	Plumbing Supply House					

TABLE 1.4.1.1-3

SOLAR ASSISTED OPTIMIZED HEAT PUMP SYSTEM

SOLAR COLLECTOR GROUP (SCG)

COLLECTOR HEADER PIPING EXPANSION CONTROL ASSEMBLY

Part No.	Nomenclature	Source	Weight-Pounds				Total
			Net	R-22	Fluid	Insulation	
<u>Field Assembled Collector</u>							
1001-FICUEA	Field Assembled Collector Upper End Anchor	Steel Supplier	1	—	—	—	1
1001-FICLEA	Field Assembled Collector Lower End Anchor	Steel Supplier	3	—	—	—	3
1001-FICTHA	Field Assembled Collector Top Header Anchor	Steel Supplier	2	—	—	—	2
1001-FICBHA	Field Assembled Collector Bottom Header Anchor	Steel Supplier	4	—	—	—	4
1001-EJ5	1-1/4" Expansion Joint Butt Weld Ends	Packless Metal Hose Co.	6				
1001-EJ6	1-1/2" Expansion Joint Butt Weld Ends	Packless Metal Hose Co.	8				
<u>Factory Assembled Collector</u>							
1002-FACUEA	Factory Assembled Collector Upper End Anchor	Steel Supplier	3				
1002-FACLEA	Factory Assembled Collector Lower End Anchor	Steel Supplier	6				
1002-FACTHA	Factory Assembled Collector Top Header Anchor	Steel Supplier	3				
1002-FACLHA	Factory Assembled Collector Lower Header Anchor	Steel Supplier	1				
1002-EJ5	1-1/4" Expansion Joint Butt Weld Ends	Packless Metal Hose Co.	6				
1002-EJ6	1-1/2" Expansion Joint Butt Weld Ends	Packless Metal Hose Co.	8				

TABLE 1.4.1.1-4

SOLAR ASSISTED OPTIMIZED HEAT PUMP SYSTEM

SOLAR COLLECTOR GROUP (SCG)

FACTORY ASSEMBLED COLLECTOR (FAC)

Part No.	Nomenclature	Source	Weight-Pounds				Total
			Net	R-22	Fluid	Insulation	
1002-CPA	Collector Plate, Aluminum	Olin Brass	19	—	5	—	24
1002-CIB	Collector Insulation, Bottom	Rock Wool Industries	—	—	—	—	—
1002-CIS	Collector Insulation, Side	Rock Wool Industries	—	—	—	—	—
1002-CS	Collector Sealant	General Electric	1½	—	—	—	1½
1001-PT	Paint, Exposed Surface	PPG Industries	1	—	—	—	1
1001-CVR	Cover Assembly	Window Fabricator	—	—	—	—	—
1001-HSG	Metal Housing Assembly	Sheet Metal Fabricator	—	—	—	—	—

1.3.2 GCSS Group

The ground coupled seasonal storage group is designed not by its volume heat capacity but by its surface area contact with the earth. In actuality, the GCSS group acts as much as a heat exchanger as it does a storage device. Since the storage tank is uninsulated and in indirect* contact with the earth, the tank must be designed such that the surface area will allow required maximum design loads to be met, either absorbing heat for the ETD heating load or rejecting heat from the ETD cooling load.

The design of a ground coupled seasonal storage tank will vary from region to region depending on variations in soil conductivities, compaction and moisture content. The amount of empirical information gathered on GCSS systems' performance in various soils is extremely limited; however, work in this area is being conducted and has been proposed for further studies. The results of analysis of parametric studies conducted for the Electric Power Research Institute under Contract # RP 924-1 revealed some indication of the GCSS system's sensitivities to varying soil conductivities and suggested changes in GCSS system instrumentation to better determine performance characteristics. Also in this analysis effort, GCSS system configuration changes were suggested to improve the system's performance efficiency when supporting a heat pump.

1.3.2.1 Regional Sizing Methodology

Sufficient information on the performance of GCSS systems operating in various regions is not available to prescribe a standard format for the design of a GCSS system in all regions. When such information becomes available through studies in this

*The tank is surrounded by a quartz sand envelope of variable thickness.

area of SAHP system design, a method to determine storage tank surface area and sand envelope thicknesses will be added to this manual.

However, for purposes of estimating storage tank size, the information gathered on the GCCS system at the Phoenix/City of Colorado Springs Project suggests steady state heat transfer coefficients (U factors) for determining storage tank sizes when operating to support heat pumps.

The following basic formula is used to estimate storage tank/ground interface area requirements:

$$\dot{Q} = UA \Delta T \Rightarrow A = \frac{\dot{Q}}{U \Delta T}$$

where $\dot{Q}$ = Maximum demand heating (and cooling)
heat transfer rate to (and from) the
tank from (and to) the ground.

U = Heat transfer coefficients

3.37 Btu/hr FT²°F (heating)

2.85 Btu/hr FT²°F (cooling)

T = Tank-Ground Temperature Differential,

16°F (heating)

54°F (cooling)

A = Req'd Storage Tank/Ground Interface Area

1.3.2.2 Equipment Selection

1.3.2.3 Drawings

Figure 1.3.2.3-1, Storage Component of the GCCS Group, shows both the original storage unit design (designated Basic Equipment Group) and a unit configuration compatible with the

FIGURE 1.3.2.3-1 STORAGE TANK COMPONENT OF THE GCSS GROUP

suggested changes for improved performance (designated Optional Equipment Group), as prescribed by the EPRI RP 924-1 work mentioned previously.

1.3.2.4 Dimensions

Table 1.3.2.4-1, GCSS Group Dimensions, show the anticipated requirements for storage sizes for the nominal rated load ETD groups based on the design constants as prescribed in Section 1.3.2.1, Regional Sizing Methodology.

1.3.3 ETD Group

The Energy Transport and Dispatch Group is composed of a fluid-to-air heat pump with a heat transfer fluid-to-freon exchanger; house air coil and fan (and a freon-to-water domestic hot water pre-heat exchanger, optional); collector circulating pump; flow selector 3-way solenoid valve; heating/cooling thermostat; collector/storage temperature differential thermostat; and R-22, Therminol™ 60, nitrogen charge basic working fluids.

The systems prescribed in this manual are for common nominal ratings of 2.5, 3, 4, 5, 7.5, 10 and 15 tons, which encompass applications from small single family residence, to small commercial and institutional.

1.3.3.1 Equipment Selections

Unit Size (Ton)	Basic Equipment Group									(lbs) T
	(inches)									
	A	B	C	D	E	F	G	H	I	
2.5	216	72	36	18	9	1.5	2	8	6	4800
3										
4										
5										
7.5										
10										
15										

Unit Size (Ton)	Optional Equipment Group																(lbs) T
	(inches)																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
2.5	144	72	36	54	84	42	24	152	72	36	24	12	9	1.5	1.5	2	2582
3																	
4																	
5																	
7.5																	
10																	
15																	

TABLE 1.3.2.4-1
GCSS GROUP DIMENSIONS

RATING CURVE 30H25C
1209 CFM

FIGURE 1.6.1.3.1
COOLING CAPACITY
ENERGY TRANSPORT GROUP 30HC ETG
(COP BASED ON COMPRESSOR AND INDOOR AIR FAN)

RATING CURVE 30H25C
1209 CFM

FIGURE 1.6.1.3 - 1
HEATING CAPACITY
ENERGY TRANSPORT GROUP 30H25C ETG
(COP BASED ON COMPRESSOR AND INDOOR AIR FAN)

RATING CURVE 36H31C
1680 CFM

FIGURE 1.6.1.3.2
COOLING CAPACITY
ENERGY TRANSPORT GROUP 36H31C ETG
(COP BASED ON COMPRESSOR AND INDOOR AIR FAN)

FIGURE 1.6.1.3.2
HEATING CAPACITY
ENERGY TRANSPORT GROUP 36H31C ETG
(COP BASED ON COMPRESSOR AND INDOOR AIR FAN)

RATING CURVE 36H31C
1680 CFM

FIGURE 1.6.1.3.3
COOLING CAPACITY
ENERGY TRANSPORT GROUP 46H44C ETG
(COP BASED ON COMPRESSOR AND INDOOR AIR FAN)

RATING CURVE 46H44C
2304 CFM

FIGURE 1.6.1.3.3
HEATING CAPACITY
ENERGY TRANSPORT GROUP 46H44C
(COP BASED ON COMPRESSOR AND INDOOR AIR FAN)

RATING CURVE 46H44C
2304 CFM

FIGURE 1.6.1.3.4
COOLING CAPACITY
ENERGY TRANSPORT GROUP 52H52C ETG
(COP BASED ON COMPRESSOR AND INDOOR AIR FAN)

RATING CURVE 52H52C
2560 CFM

FIGURE 1.6.1.3.5
 COOLING CAPACITY
 ENERGY TRANSPORT GROUP 84H78C ETG
 (COP BASED ON COMPRESSOR AND INDOOR AIR FAN)

RATING CURVE 84H78C
 3944 CFM

Q_r - Cooling Capacity, BTUH x 1000

FIGURE 1.6.1.3.5
HEATING CAPACITY
ENERGY TRANSPORT GROUP 84H78C ETG
(COP BASED ON COMPRESSOR AND INDOOR AIR FAN)

RATING CURVE 84H78C
3944 CFM

SOLAR ASSISTED OPTIMIZED HEAT PUMP SYSTEM DRWG. NO. 1.3.1.3.2

ENERGY TRANSPORT GROUP-HEAT PUMP UNIT-INDOOR APPLICATION

KAMAN SCIENCES CORPORATION 1500 Garden of the Gods Road
 Colorado Springs, Colo. 80907 Telephone (303) 599-1500 DES. DMJ 10-7-77
 DBN JRH 10-12-77

U.S. DEPARTMENT OF ENERGY CONTRACT NO. EG-77-C-02-4351

1.3.3.3 Drawings

1.3.3.4 Dimensions

TABLE 1.4.1.3-1

SOLAR ASSISTED OPTIMIZED HEAT PUMP SYSTEM

ENERGY TRANSPORT GROUP (ETG)

HORIZONTAL ZIR MOVING UNIT INDOOR APPLICATION (HAMUI)

Part No.	Nomenclature	Source	Weight-Pounds				Total
			Net	R-22	Fluid	Insulation	
3025-1000	Baseplate Assembly	Steel Fabricator					
3025-2000	Fan Assembly	Westinghouse					
3025-3000	Coil Assembly	See Assembly Parts List					
3025-4000	Fan Intake/Filter Assembly	Sheet Metal Fabricator					
3025-4000	Fan/Coil Discharge Plenum	Sheet Metal Fabricator					
3025-6000	Condensate Drain	Plumbing Supply House					

TABLE 1.4.1.3-2

SOLAR ASSISTED HEAT PUMP SYSTEM

ENERGY TRANSPORT GROUP (ETG)

HEAT PUMP UNIT INDOOR APPLICATIONS (HPUI)

Part No.	Nomenclature	Source	Weight-Pounds			
			Net	R-22	Fluid	Insulation Total
3025-1000	Baseplate and Support Assembly	Steel Fabricator				
3025-2000	Evaper Assembly	Bell and Gossett				
3025-3000	Expansion Tank Assembly	Bell and Gossett				
3025-4000	Compressor Assembly	Copeland				
3025-5000	Circulator Assembly	Bell and Gossett				
3025-6000	Fluid Piping Assembly	See Assembly Parts List				
3025-7000	Refrigerant Piping Assembly	See Assembly Parts List				
3025-8000	Control Panel Assembly	See Assembly Parts List				
3025-9000	Control Wiring Assembly	See Assembly Parts List				
3025-10000	Power Wiring Assembly	See Assembly Parts List				

TABLE 1.5.1-1

SOLAR ASSISTED OPTIMIZED HEAT PUMP SYSTEM

ENERGY TRANSPORT GROUP

DIMENSIONS

Unit No.	Dimensions-Inches												
	A	B	C	D	E	F	G	H	I	J	K	L	M
HAMUI-30H25C-ETG	64.69	28.00	11.00	28.62	21.81	17.13	5.5	14.89	27.00	20.00	36.78	11.84	12.00
VAMUI-30H25C-ETG													
HAMUO-30H257-ETG													
VAMUO-30H25C-ETG													
HPI-30H25C-ETG	1½	1½	1½	1½	½	83	40	50	7	73	38	24	4
HPO-30H25C-ETG													

Unit No.	Dimensions-Inches												
	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
HAMUL-30H25C-ETG	18.00	9.00	28.00	24.00	12.00	28.94	24.94	49.94	1.00	9.62	2.00	0.50	0.75
VAMUI-30H25C-ETG													
HAMUO-30H257-ETG													
VAMUO-30H25C-ETG													
HPI-30H25C-ETG	4	16	8	0.75	1	16	8						
HPO-30H25C-ETG													

1.6 SHAC Systems Life-Cycle-Cost Economic Evaluation Methodology

A basic premise of the KSC long term solar heating and cooling system economic evaluation methodology is that there is a direct relationship between a solar system's economic feasibility and the utility and/or the auxiliary energy supplier. The ETD group consists of pumps and fans that are driven by electric power and the reliable auxiliary energy sources to be utilized in the situation of insufficient storage capacity are electric or fossil fuels.

The primary factor in determining a solar system's viability is the cost of installing, operating, and maintaining a system throughout its expected lifetime; i.e., life cycle costs. The cost of ETD Group's motive power and any auxiliary energy required will be factors in determining operating costs, and, therefore, the relationship between the solar system and the specific utility with which it interfaces can be critical.

Other important considerations in a solar system's viability analysis are local climate and construction and conservation practices employed on the structure to which the solar systems will be applied. These considerations dictate the amount of load to be met by the system and the solar availability to help meet the load requirements.

The following is an example of the KSC evaluation methodology:

In this example, a specific solar conversion site residential load is used as a standard for evaluating

several heating systems. The utility interface requirements (rates and tariffs) are the same for all systems and are indicative of National energy policy on electric power service conditions for a residential heating customer.

The first step consists of a load definition for the specific locale under consideration. For this example that locale and load are as follows:

Location: Denver Colorado (Lat. 39°30')
Degree Day Heating Season: 6306 OD
Ambient Design Condition: Temperature = -9°F
Wind = 7 mph
Indoor Design Temperature: 72°F
Heated Floor Space: 1896 SF
Peak Heating Demand: 25 Btu/HR SF (47,400 Btu/HR)
Peak Hot Water Demand: 4 KW (13,648 Btu/HR)
House Cost wo/Heating System: \$64,960.00

The house thermal load and Public Service Company of Colorado peak load are coincidental during a six week period in December, January, and February. The coincident house thermal load on which heating system size will be based is as follows:

		Electric	Gas
Space	47,400 Btu/HR	14 KW	93 CFH
Water	<u>13,648 Btu/HR</u>	<u>4 KW</u>	<u>27 CFH</u>
	60,125 Btu/HR	18 KW	120 CFH

Second, the monthly loads and climate data are listed to summarize the annual load, the annual solar availability, and to show average monthly temperatures. This is shown in Table 1.

TABLE 1.6-1
SUMMARY OF LOADS AND CLIMATE DATA

Month	Incident Solar Million Btu's	Space Heating Load Million Btu's	Water Heating Load Million Btu's	Average Outdoor Temperature °F
Jan	19.7	15.52	1.24	28
Feb	18.2	12.86	1.12	32
March	19.0	12.16	1.24	39
April	17.4	7.96	1.20	50
May	16.6	3.95	1.24	61
June	16.7	0.91	1.20	66
July	17.4	0.08	1.24	73
Aug	18.4	0.12	1.24	72
Sept	19.2	1.60	1.20	63
Oct	20.3	5.87	1.24	52
Nov	18.2	11.23	1.20	37
Dec	<u>17.3</u>	<u>14.19</u>	<u>1.24</u>	32
Totals	218.42	86.48	14.64	

The total annual load for space and hot water heating are as follows:

		Electric	Gas
Space	86,480,000 Btu	25,346 KWH	172.9 MCF
Water	<u>14,640,000 Btu</u>	<u>4,291 KWH</u>	<u>29.3 MCF</u>
Total	101,120,000 Btu	29,637 KWH	202.2 MCF

The applicable utility interface rates and tariffs are as follows:

Electric Power

Customer with Demand Cost	\$139.83 per KW per year
Commodity Cost	\$0.010 per KWH

Natural Gas

Customer with Demand Cost	\$0.3417 per CF per year
Commodity Cost	\$0.00175 per CF

Next, descriptions and design information are assimilated on the heating and hot water systems proposed to meet these demands. An assumption is made that there is no gas available for new heating loads, but the utility would allow old gas heating systems to be retrofitted to a solar system with natural gas backup. The four systems proposed to meet the prescribed heating demand are as follows:

System 1) Electric Resistance Heating and Hot Water

Installed System Cost: \$4800.00

Annual Maintenance Cost: \$72.00 (based on 1.5% of first cost)

Electric Power Demand: 18 KW

Annual Power Use: 29,637 KWH

Load Factor: 18.8%

System 2) Air Heating and DHW Preheating Solar System with Rock Storage and Electric Resistance Backup:

Installed System Cost: \$13,852.00 (based on 312 SF collectors)

Solar Utilization: 58.4% of load

Annual Maintenance Cost: \$208.00 (based on 1.5% of first cost)

Electric Power Demand: 18 KW

Annual Power Use: 12,329 KWH = [29,637 KWH (1-.584)]

Load Factor: 7.82%

System 3) Air Heating and DHW Preheating Solar System with Rock Storage and Natural Gas Backup

Installed System Cost: \$14,352.00
 Solar Utilization: 58.4%
 Annual Maintenance Cost: \$216.00 (Based on 1.5%
 of cost)
 Electric Power Demand: 0.3 KW
 Annual Power Use: 825 KWH
 Load Factor (Electric): 31.39%
 Natural Gas Demand: 120 CFH
 Annual Natural Gas Use: 84.13 MCF = 202.2 MCF x
 (1-.584)
 Load Factor (Natural Gas): 8.0%

System 4) Solar Assisted Optimized Heat Pump Heating and DHW Heating System w/Underground Seasonal Storage

Installed System Cost: \$12,110.00
 Solar Utilization: 70% of load
 Annual Maintenance Cost: \$303.00 (based on 2.5% of
 first cost)
 Electric Power Demand: 5.3 KW=(14 KW/2.64)*
 Annual Power Use: 8,891 KWH = (29,637 KWH x (1-.70))
 Load Factor: 24.18%

*2.64 is the assumed heat pump heating coefficient of performance

The comparative evaluation then proceeds to an economic analysis based on a "discounted life cycle cost" and benefit analysis using a present value based on 10% discount rate and a 20 year system life.

The basic assumption here is that the 10% discount rate reflects a relative stability of return on private-sector investment and adjusts for normal inflation, even though average future inflation rates are not specifically known.

An important contribution to the choice of a 10% discount rate is the paper "Measuring the Opportunity Cost of Government Investment", IDA Research Paper P-490, March, 1969, by J. A. Stockfish. The main effort of the Stockfish paper is directed at estimating the private-sector rate of return on investment capital. The result of Stockfish's analysis is a 12% nominal rate of return which is unadjusted for inflation. To correct for this overstatement, Stockfish netted a 1.6% average annual consumer price increase against the nominal return of 12% and obtained a 10.4% real return on investment rate.

With the systems defined, the economic evaluation begins with a determination of the specific cost components for owning, operating and maintaining each system. The owning cost, assumed to be the first cost of installation, and the maintenance costs are obtained from the systems design information acquired from the supplier catalog data.

The cost components of the operating costs are the customer-marginal demand costs and the commodity-energy costs, as follows:

System 1) Customer-Marginal Demand Cost

Cost of Electric Plant = \$600.00/KW, 20 year life
8% interest

$$\text{Principal and Interest Cost/KW yr} = \frac{600(1.08)^{20}}{20} = \$139.83 \text{ KW yr}$$

$$\text{Annual Demand Cost} = \frac{\$139.8 (18 \text{ KW})}{\text{KW yr}} = \$2516.04/\text{yr}$$

$$\text{Annual Commodity Energy Cost} = 29,637 \frac{\text{KW}}{\text{yr}} \left(\frac{\$.01}{\text{KW}} \right) = \$297.00/\text{yr}$$

System 2) Annual Customer-Marginal Demand Cost = (18 KW) \$139.83/KW yr = \$2516.94/yr

$$\text{Annual Commodity-Energy Cost} = 12,329 \frac{\text{KWH}}{\text{yr}} \left(\frac{\$.01}{\text{KWH}} \right) = \$124.00/\text{yr}$$

System 3) Electric Costs

Annual Customer-Marginal Demand Cost = \$139.83/KW yr (.3) = \$42/yr

$$\text{Commodity-Energy Cost} = \frac{825 \text{ KWH}}{\text{yr}} (\$.01/\text{KWH}) = \$8.24/\text{yr}$$

Gas Cost

$$\text{Annual Demand Cost} = \left(101.12 \frac{\text{MMBtu}}{\text{yr}} \right) \left(1 - (.92) * (.94) * \left(\frac{\$3.00}{\text{MMBtu}} \right) \right) = \$41.00/\text{yr}$$

Annual Marginal Energy Cost (\$1.75/MCF AT WELLHEAD) =

$$84.13 \frac{\text{MCF}}{\text{yr}} \times \$1.75/\text{MCF} = \$147.23/\text{yr}$$

System 4) Annual Marginal Demand Cost = $\left(\frac{14 \text{ KW}}{2.64} \right) (\$139.83/\text{KW yr}) = \$742/\text{yr}$

$$\text{Annual Commodity-Energy Cost} = 8,891 \text{ KWH} (\$.01/\text{KWH}) = \$89.00/\text{yr}$$

*.92 and .94 are the utility company and pipeline operating ratios, respectively.

Now that the costs associated with owning, operating, and maintaining the systems for one year have been determined, a present value analysis is performed based on a cumulative-uniform-series methodology with a discount rate of 10% applied to all cost components except first cost and variable differential inflation rates of 0%, 5%, 7%, and 10% applied to the energy cost component of the operating cost.

The present value formula is:

$$\begin{aligned} \text{Present Value} = & (\text{Owning-First Cost}) + (\text{Maintenance Cost}) \times (A) \\ & (\text{Customer-Demand Cost}) \times (A) + (\text{Commodity-Energy Cost}) \times (B) \end{aligned}$$

where A and B are the cumulative-uniform-series factors from the tables in Section 1.6.1 as follows:

$$A \text{ (for 20 year life and 0\% differential inflation rate)} = 8.933$$

$$B \text{ (for 20 year life and...)}$$

$$0\% \text{ differential inflation} = 8.933$$

$$5\% \text{ differential inflation} = 13.018$$

$$7\% \text{ differential inflation} = 15.363$$

$$10\% \text{ differential inflation} = 20.000$$

Therefore each system's present value is as follows:

System 1)

Diff
Infl

$$\begin{aligned} 0\% \text{ PV} &= 4800 + (72) \times (8.933) + (2517) \times (8.933) + (297) \times (8.933) = 30,580 \\ 5\% \text{ PV} &= 4800 + (72) \times (8.933) + (2517) \times (8.933) + (297) \times (13.018) = 31,794 \\ 7\% \text{ PV} &= 4800 + (72) \times (8.933) + (2517) \times (8.933) + (297) \times (15.363) = 32,490 \\ 10\% \text{ PV} &= 4800 + (72) \times (8.933) + (2517) \times (8.933) + (297) \times (20.000) = 33,868 \end{aligned}$$

System 2)

Diff

Infl

$$\begin{aligned} 0\% \text{ PV} &= (13,852) + (208) \times (8.933) + (2517) \times (8.933) + (124) \times (8.933) = 39,302 \\ 5\% \text{ PV} &= (13,852) + (208) \times (8.933) + (2517) \times (8.933) + (124) \times (13.018) = 39,809 \\ 7\% \text{ PV} &= (13,852) + (208) \times (8.933) + (2517) \times (8.933) + (124) \times (15.363) = 40,099 \\ 10\% \text{ PV} &= (13,852) + (208) \times (8.933) + (2517) \times (8.933) + (124) \times (20.000) = 40,674 \end{aligned}$$

System 3)

Diff

Infl

$$\begin{aligned} 0\% \text{ PV} &= (14,352) + (216) \times (8.933) + (83) \times (8.933) + (155) \times (8.933) = 18,408 \\ 5\% \text{ PV} &= (14,352) + (216) \times (8.933) + (83) \times (8.933) + (155) \times (13.018) = 19,041 \\ 7\% \text{ PV} &= (14,352) + (216) \times (8.933) + (83) \times (8.933) + (155) \times (15.363) = 19,404 \\ 10\% \text{ PV} &= (14,352) + (216) \times (8.933) + (83) \times (8.933) + (155) \times (20.000) = 20,123 \end{aligned}$$

System 4)

Diff

Infl

$$\begin{aligned} 0\% \text{ PV} &= (12,110) + (303) \times (8.933) + (742) \times (8.933) + (89) \times (8.933) = 22,240 \\ 5\% \text{ PV} &= (12,110) + (303) \times (8.933) + (742) \times (8.933) + (89) \times (13.018) = 22,604 \\ 7\% \text{ PV} &= (12,110) + (303) \times (8.933) + (742) \times (8.933) + (89) \times (15.363) = 22,812 \\ 10\% \text{ PV} &= (12,110) + (303) \times (8.933) + (742) \times (8.933) + (89) \times (20.000) = 23,225 \end{aligned}$$

By dividing the above present values by the total load to be supplied over the twenty years life of the systems, a cost in dollars per million Btu delivered energy is obtained for each system as follows:

$$\text{Total 20 Year Load} = 101.12 \frac{\text{MMBtu}}{\text{yr}} \times 20 \text{ yr} = 2202.4 \text{ MMBtu}$$

System 1) Owning and Maintenance Cost = \$5443.00

Cost (\$/MMBtu) = 2.47

(Diff Infl)	0%	5%	7%	10%
Customer-Demand (\$)	22,484	22,484	22,484	22,484
Commodity-Energy (\$)	<u>2,653</u>	<u>3,866</u>	<u>4,564</u>	<u>5,940</u>
Operating Total (\$)	25,137	26,350	27,048	28,424
Cost (\$/MMBtu)	11.41	11.96	12.28	12.90
Total Own, Oper, & Maint (\$)	30,580	31,794	32,490	33,868
Total Cost (\$/MMBtu)	13.88	14.44	14.75	15.38

System 2) Owning and Maintenance Cost = \$15,710.00

Cost (\$/MMBtu) = 7.13

(Diff Infl)	0%	5%	7%	10%
Customer-Demand (\$)	22,484	22,484	22,484	22,484
Commodity-Energy (\$)	<u>1,108</u>	<u>1,614</u>	<u>1,905</u>	<u>2,480</u>
Operating Total (\$)	23,592	24,098	24,389	24,964
Cost (\$/MMBtu)	10.71	10.94	11.07	11.33
Total Own, Oper, & Maint (\$)	39,302	39,808	40,099	40,674
Total Cost (\$/MMBtu)	17.85	18.08	18.21	18.46

System 3) Owning and Maintenance Cost = \$16,282.00

Cost (\$/MMBtu) = 7.39

(Diff Infl)	0%	5%	7%	10%
Customer-Demand (\$)	741	741	741	741
Commodity-Energy (\$)	<u>1,385</u>	<u>2,018</u>	<u>2,381</u>	<u>3,100</u>
Operating Total (\$)	2,126	2,759	3,122	3,841
Cost (\$/MMBtu)	.97	1.25	1.42	1.74

Total Own, Oper, & Maint (\$)	18,408	19,041	19,404	20,123
Total Cost (\$/MMBtu)	8.36	8.65	8.81	9.14

System 4) Owning and Maintenance Cost = \$14,817

Cost (\$/MMBtu) = 6.73

(Diff Infl)	0%	5%	7%	10%
Customer-Demand (\$)	6,628	6,628	6,628	6,628
Commodity-Energy (\$)	<u>795</u>	<u>1,158</u>	<u>1,367</u>	<u>1,780</u>
Operating Total (\$)	7,423	7,786	7,995	8,408
Cost (\$/MMBtu)	3.37	3.54	3.63	3.82
Total Own, Oper, & Maint (\$)	22,240	22,604	22,812	23,225
Total Cost (\$/MMBtu)	10.10	10.26	10.36	10.55

By this example, it would seem that System 3 has a lower cost per million Btu than System 4. However, built into System 4 is an air conditioning capability that would be an additional cost to System 3. The analysis would go as follows:

$$\begin{aligned}\text{Denver A/C Load} &= 600 \frac{\text{hrs}}{\text{yr}} \text{ at } 5 \text{ KW} \\ &= 3000 \text{ KWH/yr}\end{aligned}$$

System 3) A/C First Cost = 2500

Total System First Cost = 16,852

System Maintenance Cost = 253

Customer-Demand Cost = $(139.83) \times (5.0) + 41$
= $699 + 41 = \$740/\text{yr}$

Commodity-Energy Cost = $(3825) \times (.01) + 147$
= $38.25 + 147 = \$185/\text{yr}$

System 3' (Continued)

Diff
Infl

$$\begin{aligned}
 0\% \quad PV &= 16,852 + (253)(8.933) + (740)(8.933) + (185)(8.933) = 27,375 \\
 5\% \quad PV &= 16,852 + (253)(8.933) + (740)(8.933) + (185)(13.018) = 28,130 \\
 7\% \quad PV &= 16,852 + (253)(8.933) + (740)(8.933) + (185)(15.363) = 28,564 \\
 10\% \quad PV &= 16,852 + (253)(8.933) + (740)(8.933) + (185)(20.000) = 29,422
 \end{aligned}$$

Owning and Maintenance Cost = \$19,112

Cost (\$/MMBtu) = \$8.67

(Diff Infl)	0%	5%	7%	10%
Customer-Demand (\$)	6,610	6,610	6,610	6,610
Commodity-Energy (\$)	<u>1,653</u>	<u>2,408</u>	<u>2,842</u>	<u>3,700</u>
Operating Total (\$)	8,263	9,018	9,452	10,310
Cost (\$/MMBtu)	3.75	4.09	4.29	4.68
Total Own, Oper, & Maint (\$)	27,375	28,130	28,564	29,422
Total Cost (\$/MMBtu)	12.43	12.77	12.97	13.36

System 4' System First Cost = (Same) \$12,110

System Maintenance Cost = (Same) \$303/yr

Customer-Demand Cost = (Same) \$742/yr

$$\text{Commodity-Energy Cost} = \left[8,891 \text{ KWH} + \frac{3000}{1.85*} \right] (.01) = \$105/\text{yr}$$

Diff
Infl

$$\begin{aligned}
 0\% \quad PV &= (12,110) + (303)(8.933) + (742)(8.933) + (105)(8.933) = 22,383 \\
 5\% \quad PV &= (12,110) + (303)(8.933) + (742)(8.933) + (105)(13.018) = 22,812 \\
 7\% \quad PV &= (12,110) + (303)(8.933) + (742)(8.933) + (105)(15.363) = 23,058 \\
 10\% \quad PV &= (12,110) + (303)(8.933) + (742)(8.933) + (105)(20.000) = 23,545
 \end{aligned}$$

*1.85 is the heat pump cooling coefficient of performance

Owning and Maintenance Cost = \$14,817

Cost (\$/MMBtu) = 6.73

(Diff Infl)	0%	5%	7%	10%
Customer-Demand (\$)	6,628	6,628	6,628	6,628
Commodity-Energy (\$)	<u>937</u>	<u>1,367</u>	<u>1,613</u>	<u>2,100</u>
Operating Total (\$)	7,565	7,985	8,241	8,728
Cost (\$/MMBtu)	3.44	3.63	3.74	3.96
Total Own, Oper, & Maint (\$)	22,383	22,812	23,058	23,545
Total Cost (\$/MMBtu)	10.16	10.36	10.47	10.69

The results of this discounted life cycle cost comparative evaluation example are shown in Table 1.6-2 and graphically in Figure 1.6-1 and indicate that, for the specific site chosen, the Solar Assisted Optimized Heat Pump System is more economically viable than the other three systems, if air conditioning is included with the heating and domestic hot water loads.

HEATING SYSTEM'S TOTAL 20 YEAR COSTS
 BASED ON A DISCOUNTED LIFE CYCLE COST ANALYSIS

System	Owning Cost (\$)	Maintenance Cost (\$)	Operating Cost (\$)	Total Cost (\$)	<u>(\$)</u> Cost MMBtu
#1	4,800	643	25,138 to 28,424	30,580 to 33,868	13.88 to 15.38
#2	13,852	1,858	23,592 to 24,964	39,302 to 40,674	17.85 to 18.46
#3	14,352	1,930	2,126 to 3,841	18,408 to 20,123	8.36 to 9.14
#4	12,110	2,707	7,423 to 8,408	22,240 to 23,225	10.10 to 10.55
#3 (w/AC)	16,852	2,206	8,263 to 10,310	27,375 to 29,422	12.43 to 13.36
#4 (w/AC)	12,110	2,707	7,566 to 8,728	22,383 to 23,545	10.16 to 10.69

FIGURE 1. OWNING AND OPERATING COSTS FOR VARIOUS HEATING SYSTEMS (PRESENT VALUE)

1.6.1 INFLATION-DISCOUNT FACTORS

NOTE: In these tables the single-amount factors are to be applied to one-time costs occurring in isolated years. Cumulative-uniform-series factors are to be applied to identical annually recurrent cash flows.

Table -5

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -5%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.933	0.933
2	0.812	1.745
3	0.706	2.450
4	0.614	3.064
5	0.534	3.598
6	0.464	4.062
7	0.403	4.465
8	0.351	4.816
9	0.305	5.121
10	0.265	5.386
11	0.231	5.617
12	0.201	5.818
13	0.174	5.992
14	0.152	6.144
15	0.132	6.276
16	0.115	6.390
17	0.100	6.490
18	0.087	6.577
19	0.075	6.652
20	0.066	6.718
21	0.057	6.775
22	0.050	6.824
23	0.043	6.868
24	0.037	6.905
25	0.033	6.938
26	0.028	6.966
27	0.025	6.991
28	0.021	7.012
29	0.019	7.031
30	0.016	7.047

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 5% slower than general price levels.

Table -4

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -4%*
Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.937	0.937
2	0.822	1.759
3	0.721	2.481
4	0.633	3.113
5	0.555	3.668
6	0.487	4.155
7	0.427	4.582
8	0.374	4.956
9	0.329	5.285
10	0.288	5.573
11	0.253	5.826
12	0.222	6.048
13	0.195	6.242
14	0.171	6.413
15	0.150	6.563
16	0.131	6.694
17	0.115	6.809
18	0.101	6.910
19	0.089	6.999
20	0.078	7.077
21	0.068	7.145
22	0.060	7.205
23	0.052	7.257
24	0.046	7.303
25	0.040	7.344
26	0.035	7.379
27	0.031	7.410
28	0.027	7.437
29	0.024	7.461
30	0.021	7.482

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 4% slower than general price levels.

Table -3

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -3%*
Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.941	0.941
2	0.833	1.774
3	0.737	2.511
4	0.652	3.164
5	0.577	3.741
6	0.511	4.252
7	0.452	4.704
8	0.400	5.104
9	0.354	5.458
10	0.313	5.772
11	0.277	6.049
12	0.245	6.294
13	0.217	6.512
14	0.192	6.704
15	0.170	6.874
16	0.151	7.024
17	0.133	7.158
18	0.118	7.275
19	0.104	7.380
20	0.092	7.472
21	0.082	7.554
22	0.073	7.626
23	0.064	7.690
24	0.057	7.747
25	0.050	7.797
26	0.044	7.841
27	0.039	7.880
28	0.035	7.915
29	0.031	7.946
30	0.027	7.973

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 3% slower than general price levels.

Table -2

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -2%*
Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.945	0.945
2	0.844	1.790
3	0.754	2.543
4	0.673	3.216
5	0.601	3.817
6	0.536	4.353
7	0.479	4.832
8	0.428	5.260
9	0.382	5.642
10	0.341	5.983
11	0.304	6.287
12	0.272	6.559
13	0.243	6.802
14	0.217	7.018
15	0.193	7.212
16	0.173	7.385
17	0.154	7.539
18	0.137	7.676
19	0.123	7.799
20	0.110	7.909
21	0.098	8.007
22	0.088	8.095
23	0.078	8.173
24	0.070	8.243
25	0.062	8.305
26	0.056	8.360
27	0.050	8.410
28	0.044	8.454
29	0.040	8.494
30	0.035	8.529

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 2% slower than general price levels.

Table -1

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = -1%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.950	0.950
2	0.855	1.805
3	0.771	2.576
4	0.694	3.270
5	0.626	3.896
6	0.564	4.459
7	0.508	4.967
8	0.457	5.424
9	0.412	5.836
10	0.371	6.207
11	0.334	6.542
12	0.301	6.843
13	0.271	7.115
14	0.245	7.359
15	0.220	7.579
16	0.198	7.778
17	0.179	7.957
18	0.161	8.118
19	0.145	8.263
20	0.131	8.394
21	0.118	8.511
22	0.106	8.618
23	0.096	8.713
24	0.086	8.799
25	0.078	8.877
26	0.070	8.947
27	0.063	9.010
28	0.057	9.066
29	0.051	9.118
30	0.046	9.164

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 1% slower than general price levels.

Table 0

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 0%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.954	0.954
2	0.867	1.821
3	0.788	2.609
4	0.717	3.326
5	0.652	3.977
6	0.592	4.570
7	0.538	5.108
8	0.489	5.597
9	0.445	6.042
10	0.405	6.447
11	0.368	6.815
12	0.334	7.149
13	0.304	7.453
14	0.276	7.729
15	0.251	7.980
16	0.228	8.209
17	0.208	8.416
18	0.189	8.605
19	0.172	8.777
20	0.156	8.933
21	0.142	9.074
22	0.129	9.203
23	0.117	9.320
24	0.107	9.427
25	0.097	9.524
26	0.088	9.612
27	0.080	9.692
28	0.073	9.765
29	0.066	9.831
30	0.060	9.891

* These factors are to be applied to cost elements which are anticipated to escalate at the same rate as the general price level. (This table coincides with Tables A and B, Appendix D.)

Table 1

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 1%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.959	0.959
2	0.880	1.839
3	0.808	2.647
4	0.742	3.389
5	0.681	4.070
6	0.626	4.695
7	0.574	5.270
8	0.527	5.797
9	0.484	6.281
10	0.445	6.726
11	0.408	7.134
12	0.375	7.509
13	0.344	7.853
14	0.316	8.169
15	0.290	8.459
16	0.266	8.726
17	0.245	8.970
18	0.225	9.195
19	0.206	9.401
20	0.189	9.590
21	0.174	9.764
22	0.160	9.924
23	0.147	10.070
24	0.135	10.205
25	0.124	10.328
26	0.113	10.442
27	0.104	10.546
28	0.096	10.642
29	0.088	10.730
30	0.081	10.810

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 1% faster than general price levels.

Table 2

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 2%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.963	0.963
2	0.893	1.856
3	0.828	2.684
4	0.768	3.452
5	0.712	4.165
6	0.660	4.825
7	0.612	5.437
8	0.568	6.005
9	0.526	6.531
10	0.488	7.020
11	0.453	7.472
12	0.420	7.892
13	0.389	8.281
14	0.361	8.642
15	0.335	8.977
16	0.310	9.287
17	0.288	9.575
18	0.267	9.842
19	0.247	10.089
20	0.229	10.319
21	0.213	10.531
22	0.197	10.729
23	0.183	10.911
24	0.170	11.081
25	0.157	11.238
26	0.146	11.384
27	0.135	11.519
28	0.125	11.645
29	0.116	11.761
30	0.108	11.869

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 2% faster than general price levels.

Table 3

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 3%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.968	0.968
2	0.906	1.874
3	0.849	2.723
4	0.795	3.517
5	0.744	4.261
6	0.697	4.958
7	0.652	5.610
8	0.611	6.221
9	0.572	6.793
10	0.536	7.329
11	0.501	7.830
12	0.470	8.300
13	0.440	8.739
14	0.412	9.151
15	0.386	9.536
16	0.361	9.897
17	0.338	10.235
18	0.316	10.552
19	0.296	10.848
20	0.277	11.126
21	0.260	11.386
22	0.243	11.629
23	0.228	11.857
24	0.213	12.070
25	0.200	12.270
26	0.187	12.457
27	0.175	12.632
28	0.164	12.796
29	0.154	12.950
30	0.144	13.093

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 3% faster than general price levels.

Table 4

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 4%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.972	0.972
2	0.919	1.892
3	0.869	2.761
4	0.822	3.583
5	0.777	4.360
6	0.735	5.095
7	0.695	5.789
8	0.657	6.446
9	0.621	7.067
10	0.587	7.654
11	0.555	8.209
12	0.525	8.734
13	0.496	9.230
14	0.469	9.699
15	0.443	10.142
16	0.419	10.561
17	0.396	10.958
18	0.375	11.333
19	0.354	11.687
20	0.335	12.022
21	0.317	12.339
22	0.299	12.638
23	0.283	12.921
24	0.268	13.189
25	0.253	13.442
26	0.239	13.681
27	0.226	13.908
28	0.214	14.121
29	0.202	14.324
30	0.191	14.515

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 4% faster than general price levels.

Table 5

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 5%*
Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.977	0.977
2	0.933	1.910
3	0.890	2.800
4	0.850	3.650
5	0.811	4.461
6	0.774	5.235
7	0.739	5.974
8	0.706	6.680
9	0.673	7.353
10	0.643	7.996
11	0.614	8.610
12	0.586	9.196
13	0.559	9.755
14	0.534	10.288
15	0.509	10.798
16	0.486	11.284
17	0.464	11.748
18	0.443	12.191
19	0.423	12.614
20	0.404	13.018
21	0.385	13.403
22	0.368	13.771
23	0.351	14.122
24	0.335	14.458
25	0.320	14.777
26	0.305	15.083
27	0.292	15.374
28	0.278	15.653
29	0.266	15.918
30	0.254	16.172

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 5% faster than general price levels.

Table 6

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 6%*
Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.982	0.982
2	0.946	1.928
3	0.912	2.839
4	0.878	3.718
5	0.847	4.564
6	0.816	5.380
7	0.786	6.166
8	0.757	6.923
9	0.730	7.653
10	0.703	8.357
11	0.678	9.035
12	0.653	9.688
13	0.629	10.317
14	0.607	10.924
15	0.584	11.508
16	0.563	12.071
17	0.543	12.614
18	0.523	13.137
19	0.504	13.641
20	0.486	14.127
21	0.468	14.595
22	0.451	15.046
23	0.435	15.480
24	0.419	15.899
25	0.404	16.303
26	0.389	16.692
27	0.375	17.066
28	0.361	17.427
29	0.348	17.775
30	0.335	18.111

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 6% faster than general price levels.

Table 7

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 7%*
Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.986	0.986
2	0.959	1.946
3	0.933	2.879
4	0.908	3.787
5	0.883	4.670
6	0.859	5.529
7	0.836	6.364
8	0.813	7.177
9	0.791	7.968
10	0.769	8.737
11	0.748	9.485
12	0.728	10.212
13	0.708	10.920
14	0.688	11.608
15	0.670	12.278
16	0.651	12.930
17	0.634	13.563
18	0.616	14.180
19	0.600	14.779
20	0.583	15.363
21	0.567	15.930
22	0.552	16.482
23	0.537	17.019
24	0.522	17.541
25	0.508	18.049
26	0.494	18.543
27	0.481	19.023
28	0.467	19.491
29	0.455	19.946
30	0.442	20.388

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 7% faster than general price levels.

Table 8

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 8%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.991	0.991
2	0.973	1.964
3	0.955	2.919
4	0.938	3.857
5	0.921	4.777
6	0.904	5.681
7	0.888	6.569
8	0.871	7.440
9	0.856	8.296
10	0.840	9.136
11	0.825	9.961
12	0.810	10.770
13	0.795	11.565
14	0.781	12.346
15	0.766	13.112
16	0.752	13.865
17	0.739	14.603
18	0.725	15.329
19	0.712	16.041
20	0.699	16.740
21	0.687	17.427
22	0.674	18.101
23	0.662	18.762
24	0.650	19.412
25	0.638	20.050
26	0.626	20.676
27	0.615	21.291
28	0.604	21.895
29	0.593	22.488
30	0.582	23.070

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 8% faster than general price levels.

Table 9

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 9%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	0.995	0.995
2	0.986	1.982
3	0.977	2.959
4	0.969	3.928
5	0.960	4.887
6	0.951	5.839
7	0.942	6.781
8	0.934	7.715
9	0.925	8.640
10	0.917	9.557
11	0.909	10.465
12	0.900	11.366
13	0.892	12.258
14	0.884	13.142
15	0.876	14.018
16	0.868	14.886
17	0.860	15.746
18	0.852	16.598
19	0.845	17.443
20	0.837	18.279
21	0.829	19.109
22	0.822	19.930
23	0.814	20.745
24	0.807	21.551
25	0.800	22.351
26	0.792	23.143
27	0.785	23.928
28	0.778	24.706
29	0.771	25.477
30	0.764	26.241

* These factors are to be applied to cost elements which are anticipated to escalate at a rate 9% faster than general price levels.

Table 10

PROJECT YEAR INFLATION-DISCOUNT FACTORS

Differential Inflation Rate = 10%*

Discount Rate = 10%

<u>Project Year</u>	<u>Single Amount</u>	<u>Cumulative Uniform Series</u>
1	1.000	1.000
2	1.000	2.000
3	1.000	3.000
4	1.000	4.000
5	1.000	5.000
6	1.000	6.000
7	1.000	7.000
8	1.000	8.000
9	1.000	9.000
10	1.000	10.000
11	1.000	11.000
12	1.000	12.000
13	1.000	13.000
14	1.000	14.000
15	1.000	15.000
16	1.000	16.000
17	1.000	17.000
18	1.000	18.000
19	1.000	19.000
20	1.000	20.000
21	1.000	21.000
22	1.000	22.000
23	1.000	23.000
24	1.000	24.000
25	1.000	25.000
26	1.000	26.000
27	1.000	27.000
28	1.000	28.000
29	1.000	29.000
30	1.000	30.000

*These factors are to be applied to cost elements which are anticipated to escalate at a rate 10% faster than general price levels.

2.0 RELIABILITY TESTING

Several modifications were made to the Phoenix/City of Colorado Springs solar assisted heat pump system, the operation of the system with modifications was monitored and its performance documented during this phase of the Phoenix/City of Colorado Springs SAHP Project. The results of the modifications and discussion of reliability problems encountered are contained in the following sections.

2.1 System Modifications

The modifications made on the Phoenix SAHP system are as follows:

- The fluid heat transfer piping system had its malleable iron fittings replaced with forged steel threaded fittings which were then backwelded in an attempt to remedy leakage problems encountered with the use of Therminol™ 60 heat transfer fluid,
- The underground storage tank integral heat exchange tubing had its surface area doubled by the addition of copper fins to the tubing,
- The earth above the storage tank was excavated to a depth of eight inches, a 4 inch vermiculite insulating concrete layer poured and a 4 inch driveway slab poured and finished on top, in an attempt to reduce surface losses from the underground storage tank,
- A domestic hot water tank with integral U-tube heat exchanger was designed and installed to operate off of the superheated freon from the heat pump compressor discharge,

- The system analysis program and reporting format was modified to compliance with the NBSIR 76-1137, Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program.

The results of the above modifications are as follows:

- The problem of containment of the poly-aromatic heat transfer fluid, Therminol™ 60, was significantly reduced by incorporation of forged steel backwelded fittings. The recommendations resulting from analysis of this task indicate that piping systems containing polyaromatic heat transfer fluids should have either solder joint fittings, welded butt joint fittings, threaded backwelded fittings, threaded fittings sealed with "LOC-TITE High Performance Pipe Sealant #92-41" (or acceptable equal), or flanged fittings sealed with teflon gaskets or o-rings, all joint types materially and functionally dependent,
- The enlargement of the storage tank heat exchange tubing surface area permitted the removal of a counter-flow heat-exchanger, pump and storage water booster circuit which reduced the overall system electric energy consumption, thereby, increasing the overall system efficiency,
- The addition of an insulating blanket above the underground storage tank is expected to

reduce surface losses although a detailed comparison against previous years performance has not as yet been conducted. Observation of general storage system performance characteristics have shown that thermal stratification of the water in the storage tank has occurred for the first time and indicates possible improvements in the storage system configuration. Also, snow buildup and ice formations remained on an area of the driveway immediately above the insulating blanket; where in previous winters, ice and snow on this area of the driveway melted off much quicker than on other areas not above the storage units,

- The addition of a heat pump powered domestic hot water heater was unsuccessful. The conceptual design did not adequately anticipate problems of freon cycle balancing and compressor oil pool out. Two compressors were lost to mechanical seizure resulting from loss of oil. The Westinghouse Hi-Re-Li compressor used in this heat pump is a reliable compressor when used in the air-to-air mode for which it was designed and performed reliably for over two years while operating with a modified fluid source evaporator heat exchanger. This exchanger and the exchanger installed to operate the domestic hot water heater were both Bell & Gossett u-tube exchangers designed for operation with steam. Properly sized tube-in-shell or tube-in-tube evaporators and condensers designed for refrigerant circuits would allow proper balancing of the freon cycle. A good example

would be the Solargy™ system manufactured by the Vaughn Corporation.

- The results of the SAOHP system analysis program and reporting format modifications may be reviewed in Appendix IV, Operational Data and Performance Analysis.

2.2 Data Acquisition System Operation

A Kaye 8000 Data Analyzer receives data acquisition instrument signals, converts the input signals to ASCII character sets and transmits the data to a Texas Instruments Silent 700 ASR Data Recording Terminal. The TI700 ASR then records the input information on cassette tapes. The taped information is transmitted via a phone coupler to Kaman Sciences and stored on disc by a PDP-11-34 Minicomputer. This information is then fed to the CYBER 70 computer for input to the data reduction and analysis program.

The data reduction and analysis program which provides continuous SAOHP system daily energy balances has generated daily, weekly and monthly energy balances in accordance with NBSIR 76-1137 from November 29th to present. The monthly energy balance sheets and an analysis of the SAOHP system operation for the months of December (1977), January, February, and March (1978), are in Appendix IV, Operational Data and Performance Analysis.

2.3 Reliability Analysis

Equipment failures resulted in significant down time of the Phoenix SAOHP system during this third quarter of Phase II. The failures, their determined or projected causes, the solutions imposed and the result on SAOHP system reliability are detailed in the following sections.

2.3.1 Freon Piping Connection Failures

On January 17th, 1978 the SAOHP system heat pump compressor was shut down and installation of the heat pump powered hot water heater begun. The installation was completed and the compressor started on the 23rd of January. The control wiring to the heat pump powered hot water heater remained disconnected awaiting negotiations and work date for an electrical contractor.

On the 11th of February, the compressor inlet supply line dryer suction connection broke. The connection was an original factory joint and the break was attributed to fatigue failure of the silfos soldered joint. This could be justification for requesting the manufacturer to silver solder all heat pump refrigerant piping connections. The loss of freon triggered the low pressure cut-off compressor protection circuit. The system was down for four weeks and during this time the refrigerant piping was plagued with leakage problems at the dryer connection and at the heat pump powered hot water heater solenoid valve connections. These valves were placed in the refrigerant lines with compression fittings which would not hold against the compressor discharge pressure. The compression fitting solenoid valves were replaced with sweat-end solenoids, silver soldered into place, with satisfactory results. The heat pump powered hot water heater heat exchanger connections were compression type and were replaced with flare type compression fittings. Finally on 15 March 1978 the heat pump compressor was put back in service successfully.

Subsequent to the repairing of freon piping leaks and restarting of the heat pump, two compressors were lost to mechanical seizure attributable to loss of oil. The domestic hot water heat exchanger was removed from the freon circuit and a new compressor was installed. This new compressor has been functioning satisfactorily.

The project team believes that the reliability of the SAOHP system has not been effected by the failure of this specific domestic hot water heating circuit design. As has been stated previously, the Westinghouse Hi-Re-Li unit operating in this modified solar assisted fluid source application functioned very well for over 2 years and would have continued to perform well had the freon circuit not been disturbed.

All system modifications (except the heat pump powered domestic hot water heat design) have yielded very good results.

Appendix I

The following photographs show the SAOHP system fluid transfer piping, energy transport and dispatch group (heat pump and air handling unit), data acquisition and recording system, and electrical input metering station.

FIGURE 1 ENERGY TRANSPORT AND DISPATCH GROUP (HEAT PUMP AND AIR HANDLING UNIT)

FIGURE 2 ENERGY TRANSPORT AND DISPATCH GROUP (FLUID TRANSFER PIPING)

FIGURE 3 DATA ACQUISITION AND RECORDING SYSTEM

FIGURE 4 ELECTRICAL INPUT METERING STATION

APPENDIX II

Appendix II

As part of the Phoenix Project philosophy, education of the public and dissemination of information to the scientific community play vital roles in the completeness of any work performed under the project. The following is a list of presentations, interviews, broadcasts and tours of the Project this year:

Event	Date
EPRI Project Managers (Presentation in Monterey, California)	March 16-18
EPRI Project Managers Conference (Tour of Phoenix House)	June 24
Carver Elementary School (Tour of Phoenix House)	July 15
Citizens for Goals Committee of Oklahoma City (Tour of Phoenix House)	July 21
ERDA Project Managers Conference (Presentation in Washington, D.C.)	August 8-10
KRDO Channel 13 News Staff (Tour of Phoenix House & TV Program Taped) (Taped program aired on TV)	September 28 October 1
Stratton Elementary School (Presentation)	October 5
Northwest Kansas Area Vocational Technical School (Tour of Phoenix House)	October 13
USAF Academy Cadet Science Class (Tour of Phoenix House)	October 13
Steele Elementary School (Presentation)	October 18
Study by Colorado Springs Citizens for Goals Natural Resources Committee	Jun-Sep

Detailed Project Briefing to DoE Program Manager Mike Maybaum and Sandia Division 5742	November 17
5 French Scientists Representing <u>Elf</u> <u>France</u> , Division Développement (Tour of Phoenix House)	February 23
USAF Academy Cadet Science Class (Tour of Phoenix House)	March 15
Association of Homebuilders (Tour of Phoenix House)	March 15
Presentation of Continuation Proposal (Doug Jardine in Washington, D.C.)	April 13

APPENDIX III

KAMAN SCIENCES CORPORATION

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A KAMAN COMPANY

SPECIFICATIONS FOR BIDS FOR WORK TO BE PERFORMED
ON THE PHOENIX HOUSE SOLAR ASSISTED OPTIMIZED
HEAT PUMP SYSTEM

Prepared by: Energy Systems
Development Group
Douglas M. Jardine
Senior Engineer

August 1977

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IV. Task III - Specification for Repairing Heat Transfer Fluid Piping Leaks and Obtaining Solar Collector Plate and Transfer Fluid Samples	
V. Task IV - Specification for the Installation of Vermiculite Insulating Concrete Above the Underground Storage Tank	

I. GENERAL ABSTRACT

The following specifications detail work to be performed on the solar assisted optimized heat pump system in the Phoenix House, 5925 Del Paz Drive, Colorado Springs, Colorado. The work is divided into four major tasks; 1) enlarging the heat transfer surface area of the primary heat exchanger in the underground storage tank with the addition of copper fins, 2) supplying and installing a heat pump powered hot water heater, 3) repairing heat transfer fluid piping leaks and obtaining solar collector plate and heat transfer fluid samples, 4) installing a slab of vermiculite insulating concrete above the underground storage tank.

Prospective Contractors may bid on any one or all of the tasks specified by a separate bid for each task. The bids should include itemized price quotations for materials and labor, as well as, a lump sum price for each task bid.

Work will be scheduled to commence within 14 days of notification of awards. Specific dates will be dictated by completion of written contractual agreements.

II. TASK I

SPECIFICATIONS FOR ENLARGING THE CAPACITY OF THE PRIMARY HEAT EXCHANGER IN THE UNDERGROUND STORAGE TANK AT THE PHOENIX HOUSE

II.1 Scope of the Work

The work to be performed under this specification consists of enlarging the heat transfer surface area of the primary heat exchanger in the underground storage tank by soldering copper plate fins to the top of the heat exchange tubing. The time duration for the task is anticipated to be two days and will require the services of two welders.

II.2 Details of the Work

The underground storage tank will be drained by others prior to the start of this work.

Personnel performing this work will enter the underground storage tank through a manhole on the west end of the tank located in an access pit beneath the driveway at the Phoenix House. No more than two personnel should enter the tank at any one time. All necessary care will be taken to insure the integrity of the storage tank, its appurtenances, heat exchange tubing, joints and couplings. In addition to all safety measures performed as standard practice for protection of personnel by the contractor, adequate lighting and ventilation will be provided for personnel during performance of work inside the tank.

The primary heat exchanger inside the storage tank is a four section loop of 1-1/2" Type "K" copper tube, in accordance with Dwg. No. M-01, attached herein and hereby made part of this specification. The heat transfer surface area of this heat exchanger will be doubled by the addition of two 3" wide x 12 foot long strips of 1/16" thick copper to the top of each

straight section of the exchanger. The tubing sections to be revised will be cleaned and dried prior to soldering to insure integrity of the soldered joints. The copper strips will be soldered to the tops of the copper tube, in accordance with Detail A-A of Dwg. No. M-01, with 50-50 solder which has a melting point below 365°F. During the soldering work, the tubes will be filled with a heat transfer fluid, Therminol 60, which has a boiling point of 550°F, and, therefore, the tubing will not be subjected to temperatures in excess of 500°F. The flame point of the heat transfer fluid is 310°F and, therefore, the Contractor will take extreme care and necessary action to prevent direct contact of flame to the fluid.

The storage tank will be refilled by others upon completion of the work.

II.3 Materials

All materials and equipment necessary for completion of the work, as specified, will be supplied by the Contractor. The following list of materials and recommended manufacturers is given as the minimum equivalents which will be accepted:

Item	Material	Recommended Manufacturer
Tube Fins	1/16" Copper Strips	Contractor Preference

TOP VIEW

SIDE VIEW

DETAIL A-A
FIN EMPLACEMENT
(FULL SCALE)

KAMAN SCIENCES CORPORATION
1500 GARDEN OF THE GODS ROAD
COLORADO SPRINGS, COLORADO

TITLE: STORAGE TANK HEAT EXCHANGE REVISION

DWN. BY: D. W. JONES

APRVD. BY: D. M. JARDINE

SCALE: 3/8" = 1'

DATE: 8-19-77

DWG. NO. M-01

III. TASK II

SPECIFICATIONS FOR THE SUPPLY AND INSTALLATION OF A HEAT PUMP POWERED HOT WATER HEATER AT THE PHOENIX HOUSE

III.1 Scope of the Work

This specification covers the supply and installation of a heat pump powered hot water heater and associated piping onto the heat pump system at the Phoenix House, 5925 Del Paz Drive. The superheated freon from the compressor discharge of the heat pump will be routed to a U-tube heat exchanger located internally in a 52 gallon storage tank. Two bronze solenoid valves will perform the function of directing the superheated freon compressor discharge to either the hot water heat exchanger or the heat pump condenser coil.

III.2 Details of the Work

The heat pump refrigerant, R-22, will be drained from the heat pump prior to initiating work. A 26" x 36" x 1/4" steel support plate will be fabricated and erected on 1-1/2" Schedule 40 steel pipe support legs in accordance with Dwg. M-02, attached herein and hereby made a part of these specifications. A 52 gallon glass-lined hot water storage tank with an integral U-tube heat exchanger, connections, and all appurtenances, in accordance with Dwg. M-02, will be supplied and emplaced on the support plate as shown in the aforementioned drawing. The inlet and outlet ports of the U-tube heat exchanger will be bushed to 1/2" O.D. Type "L" copper tube and piped to the discharge of the heat pump compressor, as per the schematic and details of Dwg. M-02. The two 3/4" solenoid valves will be installed as per the aforementioned drawing. The U-tube heat exchanger, valves, piping, joints, and fittings should be suitable for a working pressure of 300 psia and a design pressure of 400 psia. The corresponding working and design temperatures are 225°F and 300°F, respectively.

Cleanliness in making all taps into refrigerant lines is imperative for safe operation of the heat pump subsequent to the revisions. The Contractor is requested to insure that all solder spatter, metal filings, dirt, etc., are kept from contaminating the interior of the refrigerant piping.

Subsequent to completion of solenoid valves and discharge freon piping installation onto the heat pump compressor discharge, the hot water piping and valves will be routed and installed according to Dwg. No. M-03, attached herein and hereby made a part of these specifications. The incoming water line loop to the storage tank booster coil has been shown capped and isolated from the system. The pipe routing shown in Dwg. No. M-03 is designed to allow operation of the heat pump powered hot water heater by itself, or as a booster to the already operating electric hot water heater. The HPP hot water heater may also be isolated from the hot water system and the present electric water heater used alone.

When all piping is complete, the heat pump refrigeration lines shall be recharged and the 52 gallon hot water tank filled to capacity. All refrigerant, hot and cold water lines shall be checked for leaks and any discrepancies corrected.

The heat pump will then be operated and solenoid valve operation checked.

III.3 Controls

The control of the system shall be automatic, activated by signal from the 52 gallon hot water tank aquastats. The signal will start the heat pump (without the indoor fan) and switch the

solenoid valves to route the superheated compressor discharge freon to the hot water heat exchanger.

The controls shall be wired in accordance with Figure II.1, Control Wiring Diagram, attached herein and hereby made part of these specifications.

Selection of hot water heating system mode, shall be by manual setting of hot water supply and delivery piping valves, and by the positioning of the manual switches in the electric and heat pump powered hot water heater controls.

III.4 Materials

All materials and equipment necessary for the completion of the work, as detailed in the previous sections, will be supplied by the Contractor. The following list gives material minimum standards and equivalents for the work in Task II:

Item	Material	Recommended Manufacturer
52 Gallon Hot Water Tank	Steel w/Glall Lining	Rheem
Integral Heat Exchanger	3/4" OD Copper U Tubes	*B&G TCW-824 Tank Heater
Solenoid Vlaves	3/4" OD Bronze	Sporeland Model A17P3
Immersion Heater	1 KW	Contractor Preference
Relief Value	Bronze	B&G Simplex
Aquastats	Immersion Type	Honeywell L6008 90°F - 140°F ON OFF
Thermocouples	Immersion Type	Honeywell Y2T2M13G S Mega Pak w/ 752Y30 (A) 728097 - 4 plug and jack connections

*Must be suitable for operating and design temperatures and pressures as previously outlined.

KAMAN SCIENCES CORP.

TITLE: HOT WATER HEATER PIPING

DWN BY D.W. JONES

DATE: 8-19-77

APRVD BY D.M. JORDINE

DWG. NO. M-03

FIGURE II.1 - PHOENIX HEAT PUMP SYSTEM CONTROL

Pump "A" Controls

- TP1 - Collector Temp. Sensor
 TP2 - Storage Temp. Sensor
 P - Variable Resistance Bridge
 (closes when TP1 > TP2)
 R1 & C1 - Relay #1 Coil & Contacts
 TS1 - Storage Temp. Ws (Opens
 Above 190°F)
 LS - Valve #1 Limit Switch
 (Closes when valve in
 Mode 3 position)
 R2 & C2 - Relay #2 Coil & Contacts

Pump "B" & HPPHWH Controls

- T1 - 120 V to 24 V Control Transf.
 TRH - Room Thermostat (Heat
 Contact)
 R3, C3a, b, c & d - Relay #3
 Coil & Contacts
 TS2 - Storage Tank Thermostat
 (Closes when water temp.
 below °F)
 R4 & C4 - Relay #4 Coil & Contacts
 TS3 - HW Tank Thermostat (Closes
 below 90°F - opens above
 140°F)
 TS4 - Room Thermostat (Opens
 below 68°F)
 R5, C5a, b, c & d - Relay #5 Coil
 & Contacts (C5b & C5d nor-
 mally closed)
 S1 - Manual Switch

Heat Pump Controls

- T2 - Heat Pump Control Trans.
 R6 & C6 - Relay #6 Coil & Contacts
 S - Manual Switch #1
 TRC - Room Thermostat (Cooling
 Contact)

Control
 Wiring
 to Heat
 Pump

IV. TASK III

SPECIFICATIONS FOR REPAIRING HEAT TRANSFER FLUID PIPING LEAKS AND OBTAINING SOLAR COLLECTOR PLATE AND TRANSFER FLUID SAMPLES

IV.1 Scope of the Work

The work to be performed under this specification consists of the replacement of all valves and fittings in the Phoenix House heat pump system's heat transfer fluid piping which are leaking. Dwgs. No. M-04 and M-05 designate which valves and fittings are to be replaced. As a subtask, transfer fluid and solar collector plate samples will be taken from the system for the purpose of corrosion, contamination and caustic embrittlement testing.

IV.2 Details of the Work

The piping system, as shown in Dwgs. No. M-04 and M-05, attached herein and hereby made a part of this specification, is filled with Therminol 60, an ether based heat transfer fluid. This fluid will be drained from the system prior to valve and fitting replacement operations.

To drain the piping system, remove the plug in Valve #1 shown at A in Section D-D of Dwg. No. M-04 and replace with a garden hose adapter. Install a garden hose on the connection and open collector vent Valves #6, #7, and #8, shown on Dwg. No. M-05. Open the Valve #1 and begin draining the Therminol 60 into a clean and dry 55 gallon drum. When the nitrogen in the expansion tank equalizes to atmospheric pressure, the draining will slow to a trickle or stop. At that time, the vent plug on the expansion tank will be removed, Valve #10 opened, and draining continued. When the piping is drained to the level of Valve #1, the plug located at B will be removed and the remaining Therminol drained into a large relatively flat pan. After all fluid has drained, the plug at B and the expansion tank vent plug will be replaced. The system should contain

approximately 55 gallons of Therminol 60; however, any excess should also be stored in a clean, dry container.

All fittings and valves shown back-circled on Dwg. No M-04 will be replaced. The fittings will be replaced with screwed forged steel fittings and the valves replaced with Mueller type plug valves. A Teflon impregnated threading compound, as specified in the materials section, will be used on all threads, and fitting and valve replacements screwed in place. The fittings will then be arc-welded. Prior to welding the O-ring seals (supplied by others) in the main transfer pump will be replaced and a gage glass installed on the expansion tank, as shown in Section A-A of Dwg. No. M-05.

Also, at this time, one of the collector panels (to be specified later) will be disassembled, the collector plate removed, and replaced with a new plate (to be supplied by others). The collector panel assembly is shown in Dwg. No. M-06, attached herein and hereby made a part of this specification. To disassemble the panel, the wood battens must first be unscrewed and removed from their sealant bed. The glass cover plates may then be pryed up from their sealant beds and removed. The collector plate will then be disconnected from the lower supply header and the upper return header, removed, and the new plate installed. The connector couplings' nuts and ferrules remaining on the old plate will have to be replaced with new nuts and ferrules on the new plate. After installation of the new plate, the cover glass plates and wood battens will be cleaned of old sealant and embedded in place in new sealant. The wood battens will then be securely screwed in place.

The Contractor will then proceed with the welding of the forged steel fittings. During the welding procedure, the system will be continuously purged with nitrogen. A pressurized nitrogen tank will be connected to the expansion tank at C and all valves in the system (except Valve #2) will be opened. The nitrogen will be bled out through the drain down hose and discharged outside the house. The welds will be made by arc-welding, gas welding will be prohibited. Upon completion of welding, the hose and adapter at A will be removed and the valve replugged. All new welds will then be soaped and leak tested to 45 psi with nitrogen.

After welds have satisfactorily completed the leak test, the system will be refilled with the Therminol previously removed. A one quart sample will be retained in a clean, dry, and capped plastic container.

To refill the system, shut off the nitrogen supply and close Valve #11. Remove the expansion tank vent plug and replace the hose adapter and hose to Valve #1. Using a hand pump on the storage drum, pump the Therminol back into the piping system until the gage glass just registers Therminol in the expansion tank. Close Valve #10 and proceed with filling until all lines are flooded and the collector header vent lines begin to fill the expansion tank. When the gage glass on the expansion tank registers 3-5 inches of Therminol in the tank, cease filling, replace expansion tank vent plug, close Valve #1, remove hose and adapter and replace its plug. Now, open Valves #10, #11, and nitrogen supply and put a nitrogen cushion in the expansion tank until the pressure indicator at C registers 25 psi. Close Valve #11 and remove the nitrogen supply. (Any additional Therminol 60 needed for make-up will be supplied by others.)

IV.3 Materials

All materials and equipment necessary for the performance of this work shall be supplied by the Contractor (except as specified otherwise). The following list gives material minimum standards and recommended equivalent materials for the work in Task III:

Item	Material	Recommended Manufacturer
Fittings	Forged Steel	Contractor Preference
Gage Glass		Contractor Preference
Collector Sealant	Silicon Rubber Adhesive Sealant	G&E RTV 108
Collector Plate Coupling Nuts & Ferrules	Stainless Steel	Swagelok SS-1212-1, SS-1214-1 & SS-1213-1
Valves	Forged Steel w/bronze discs and seats	Mueller
Threading Compound	Teflon Impregnated Pipe Sealant	LOC-TITE Hi-Performance Pipe Sealant #92-41

SECTION A-A

SECTION C-C

SECTION B-B

SECTION D-D

PHOENIX HOUSE SOLAR ASSISTED HEAT PUMP PIPING

KAMAN SCIENCES CORPORATION 1500 GARDEN OF THE GODS ROAD COLORADO SPRINGS, COLORADO		
TITLE HEAT TRANSFER FLUID PIPING		
DWN. BY: D.W. JONES	APRV. BY: D.M. JARDINE	
SCALE: 1" = 1'	DATE: 8-19-77	DWG NO: M-04

SECTION A-A

KAMAN SCIENCES CORP.	
TITLE: THERMINOL PIPING VENT LINES	
DWN. BY: D.W. JONES	DATE: 8-19-77
APPRV. BY: D.M. JARDINE	DWG. NO. M-05

COLLECTOR PANEL ASSEMBLY

KAMAN SCIENCES CORPORATION	
TITLE: COLLECTOR PANEL ASSEMBLY	
DWN BY: D.W. JONES	DATE: 8 19-77
APRVD BY: D.M. TARDINE	DWG NO: M-06

V. TASK IV

SPECIFICATIONS FOR THE INSTALLATION OF
VERMICULITE INSULATING CONCRETE ABOVE THE
UNDERGROUND STORAGE TANK AT THE PHOENIX HOUSE

IV. Scope of the Work

The work included under this specification consists of pouring of a 4" thick layer of vermiculite insulating concrete above the underground storage tank at the Phoenix House. A 12' x 10' section of driveway will be removed, the vermiculite layer poured and the driveway section repoured and finished.

IV.2 Details of the Work

A 12' x 10' section of driveway slab, as shown on Dwg. No. M-07, attached herein and hereby made a part of this specification, will be broken out and removed. The perimeter of the section to be removed will be sawed to a sufficient depth to insure a clean break out and to prevent damage to the access pit wall. The earth beneath the broken out section and a 3' wide 10' long section of yard immediately adjacent to the driveway, in accordance with Dwg. No. M-07, will be excavated and leveled to a depth of 8" below driveway slab finished grade. The leveled section will be compacted and fill added as necessary to prevent settlement of slab sections to be poured. A 10' x 15' x 4" thick slab of vermiculite insulating concrete will then be poured in the broken out, compacted and leveled section. After sufficient curing time, the 4" driveway slab will be repoured and finished over the vermiculite slab. Reinforcing wire mesh will be emplaced with the driveway slab and the slab finished surface will be matched to the original driveway finished slab grade and the decorative rock adjacent to the driveway replaced.

IV.3 Materials

All materials and equipment necessary for the completion of the work, as specified, will be supplied by the Contractor.

The following list of materials and recommended manufacturers is given as minimum acceptable equivalents for the work:

Item	Material	Recommended Manufacturer
Insulating Concrete	Vermiculite or Pearlite Impregnated Concrete (1/6 Mixture)	Transit Mix

TOP VIEW

SIDE VIEW

UNDERGROUND STORAGE
TANK ACCESS PIT
MANHOLE

PLOT PLAN

KAMAN SCIENCES CORPORATION		
1500 GARDEN OF THE GODS ROAD		
COLORADO SPRINGS, COLORADO		
TITLE: INSULATING VERMICULITE CONCRETE SLAB		
DWN BY: D.W. JONES	APRVD BY: D.M. JARDINE	
SCALE: $\frac{3}{8}" = 1'$	DATE: 8-19-77	DWG. NO. - M-07

APPENDIX IV

APPENDIX IV

OPERATIONAL DATA AND PERFORMANCE ANALYSIS

Figure IV-1 shows the instrumentation and data flow for the system operating at the Phoenix Project.

Table IV-1 is a definition of the energy balance parameters for the operating system.

Various constants are used in the daily energy balance calculations in order to facilitate data handling. The following generic constants are employed:

- Therminol 60 flow rates through each collector array and the heat pump's Therminol 60 to Freon 22 heat exchanger,
- Power demands for all electric power equipment.

The daily energy balances are calculated using these constants. The monthly summaries are made based on the daily summaries. At the end of the month the totalizer readings on the fluid flow meters and the kilowatt hour meters are reduced to monthly totals. Average fluid flow and electric energy demand constants are then calculated using these totalizer meter readings and the actual run times of the equipment in the system. The monthly energy balance is adjusted to compensate for the variance between the average calculated values and the program input values of the fluid flow and electric energy demand constants. Tables IV-2, IV-3, IV-4, and IV-5 are the conformed Energy Balance Parameters for December 1977, and January, February, and March, 1978. During these months, the SAOHP system ran under automatic control, and the data acquisition system operated continuously. There were equipment down times in the solar

Misc. Thermocouples

T • Inside 1st Floor Temp.

T • Inside 2nd Floor Temp.

T • Outside Ambient Air Temp.

Wind Speed & Direction Recorder

FIGURE IV-1 PHOENIX PROJECT-SYSTEM SCHEMATIC, INSTRUMENTATION, AND DATA FLOW

- Daily Data
- Daily Energy Balance
- Weekly Energy Balance
- Monthly Energy Balance
- Annual Energy Balance

TABLE IV-1
ENERGY BALANCE PARAMETERS DEFINITION

Q001	Average Insolation Rate Q002 divided by the hours of collector pump operation and collector area.
Q002	Total Insolation on Collector The sum of averaged solarimeter readings during the time collector pump is operating times collector area (780 FT ²).
Q100	Thermal Energy Delivered to Storage The sum of averaged temperature difference across the collector fluid side of the storage heat exchanger times a thermal mass flow constant.
N111A	Collection System Efficiency Q100 divided by Q002 times 100.
Q203A	Thermal Energy from Storage to Space Heat Load The sum of averaged temperature difference across the evaporator fluid side of the storage heat exchanger times thermal mass flow constant when heat pump is operating coupled to the space heating load.
Q203B	Thermal Energy from Storage to Hot Water Load The sum of averaged temperature difference across the evaporator fluid side of the storage heat exchanger times thermal mass flow constant when heat pump is operating coupled to the hot water heating load.

Q203C Thermal Energy Stored in Storage Tank

The product of the mass of water in the storage tank and specific heat of the water times the difference of the water temperature at the end of a designated time period minus the water temperature at the start of that designated time. (Note, a negative number indicates a net withdrawal of thermal energy from the water in the storage tank, while a positive number indicates a net deposit of thermal energy in the water in the storage tank.)

Q203D Thermal Energy Transferred to the Ground

The quantity of energy transferred from the water in the storage tank to the ground. (Note, a positive number indicates a net transfer of thermal energy from the water in the storage tank into the ground surrounding the tank, while a negative number indicates a net transfer of thermal energy from the ground into the water in the storage tank.)

Q203 Total Solar Energy Utilized

Q203 = Q203A + Q203B for a designated time period.

N111B Storage System Efficiency (η_s):

$$\eta_s = \frac{Q203}{Q100} \times 100$$

An η_s value greater than 100% demonstrates that, for a specific period of time, more thermal energy was removed from storage than was placed in storage during that period of time - thus the proof of seasonal thermal energy storage is demonstrated.

N406 ~ Average Building Indoor Dry Bulb Temperature

The average indoor dry bulb temperature for a specific period of time.

N113 Average Ambient Dry Bulb Temperature (t_a)

The average outdoor (ambient) dry bulb temperature for a specific period of time.

N113A Total Number of Degree Days

The total number of 24 hour days times ($65^\circ\text{F} - t_a$), where t_a is less than 65°F .

N002 Average Wind Velocity

Averaged from wind speed strip chart.

N003 Average Wind Direction

Averaged from wind direction strip chart, and/or taken as weighted average of surrounding meteorological station data.

Q402 Total Building Heat Load

$$Q402 = Q402A + Q402C + Q402D$$

Q701 Natural Passive Contribution

This is an arbitrary value derived as follows:

$$Q701 = (Q001) (.85 \text{ WINDOW TRANSMISSION FACTOR})(137 \text{ SF WINDOW OPENING AREA}) (.5 \text{ WINDOW ORIENTATION FACTOR})$$

This value is expressed for a specific period of time.

N700 Building Thermal Performance

$$N700 = \frac{Q402}{N113A}$$

This value is expressed for a specific period of time.

Q402A Thermal Energy Delivered to Building from Heat Pump

$$Q402A = Q203A + Q402B$$

This value is expressed for a specific period of time.

Q402B Thermal Energy Equivalent of Heat Pump Motive Power
(Space Heat Mode)

$$Q402B = \text{Heat Pump Compressor Space Heating Service Run Time} \times \text{Power Demand Constant} \times 3412 \text{ BTU/KWH}$$

This value is expressed for a specific period of time.

Q402C Supplemental Electric Resistance Heater No. 1 (Space Heating)

$$Q402C = \text{Supplemental Electric Resistance Heater No. 1 Run Time for Space Heating} \times \text{Power Demand Constant} \times 3412 \text{ BTU/KWH}$$

Q402D Supplemental Electric Resistance Heater No. 2 (Space Heating)

$$Q402D = \text{Supplemental Electric Resistance Heater No. 2 Run Time for Space Heating} \times \text{Power Demand Constant} \times 3412 \text{ BTU/KWH}$$

Q402 Total Space Heating Load

$$Q402 = Q402A + Q402C + Q402D$$

N400 Solar Contribution to Space Heating Load

$$N400 = \frac{Q203A}{Q402} \times 100$$

N401 Heat Pump Compressor Coefficient of Performance (Space Heating Load)

$$N401 = \frac{Q402A}{Q402B}$$

Q302A Thermal Energy Delivered to Hot Water Load from Heat Pump

$$Q302A = Q203B + Q302B$$

Q302B Thermal Energy Equivalent of Heat Pump Motive Power (Water Heat Mode)

$$Q302B = \text{Heat Pump Compressor Water Heating Run Time} \\ \times \text{Power Demand Constant} \times 3412 \text{ BTU/KWH}$$

Q302C Supplemental Electric Resistance Heat (Water Heating)

$$Q302C = (\text{Heat Pump Powered Domestic Hot Water Heater} \\ \text{Coil Run Time} \times \text{Power Demand Constant} + \text{Electric} \\ \text{Domestic Hot Water Heater Upper Coil Run Time} \\ \times \text{Power Demand Constant} + \text{Electric Domestic Hot} \\ \text{Water Heater Lower Coil Run Time} \times \text{Power Demand} \\ \text{Constant}) \times (3412 \text{ BTU/KWH})$$

Q302 Total Hot Water Heating Load

$$Q302 = Q302A + Q302C$$

N300 Solar Contribution to Hot Water Load

$$N300 = \frac{Q203B}{Q302} \times 100$$

N301 Heat Pump Compressor Coefficient of Performance (Hot Water Load)

$$COP = \frac{Q302A}{Q302B}$$

Q500 Thermal Equivalent of Total Auxiliary Energy

$$Q500 = Q402C + Q402D + Q302C$$

Q601A Thermal Equivalent of Heat Pump Motive Power (Total)

$$Q601A = Q402B + Q302B$$

Q601B Thermal Equivalent of Main Transfer Pump Motive Power
(Collector Mode)

$$Q601B = \text{Main Transfer Pump (Collection) Run Time} \times \text{Power Demand Constant} \times 3412 \text{ BTU/KWH}$$

Q601C Thermal Equivalent of Main Transfer Pump Motive Power
(Heat Pump Assist)

$$Q601C = \text{Main Transfer Pump (HP Assist) Run Time} \times \text{Power Demand Constant} \times 3412 \text{ BTU/KWH}$$

Q601D Thermal Equivalent of Main Transfer Pump Motive Power
(Total)

$$Q601D = Q601B + Q601C$$

Q601E Thermal Equivalent of Indoor Fan Motive Power

$$Q601E = \text{Indoor Fan Run Time} \times \text{Power Demand Constant} \times 3412 \text{ btu/KWH}$$

Q601 Thermal Equivalent of Total Motive Power

$$Q601 = Q601A + Q601D + Q601E$$

Q602 Thermal Equivalent of Total System Heating Load

$$Q602 = Q203A + Q203B + Q402C + Q402D + Q302C + Q601$$

Q603 Thermal Equivalent of Total Heating System Power Consumed

$$Q603 = Q601 + Q302C + Q402C + Q402D$$

N601 Solar Contribution to Toal Load

$$N601 = \frac{Q203}{Q602} \times 100$$

N602 Total Heat Pump Coefficient of Performance

$$N602 = \frac{Q402A + Q302A}{Q402B + Q302B}$$

N603 Total System COP

$$N603 = \frac{Q602}{Q603}$$

TABLE IV-2
PHOENIX PROJECT - SAOHP SYSTEM
CONFORMED ENERGY BALANCE PARAMETERS

December 1977

			SI UNITS	METRIC UNITS				SI UNITS	METRIC UNITS
Q	Avg Insolation Rate		184 $\frac{\text{BTU}}{\text{FT}^2\text{HR}}$	2.09 $\frac{\text{MJ}}{\text{M}^2\text{HR}}$					
Q002	Total Insolation on Collectors		27,918,576 BTU's	8,182 KWH	N406	Avg Bldg Indoor Temperature	71°F	21.7°C	
Q100	Thermal Energy Delivered to Storage		7,172,751 BTU's	2,102 KWH	N113	Avg Ambient DB Temperature	36°F	2.2°C	
N111A	Collection System Efficiency		25.69%	25.69%	N113A	Total Degree Days	896 DD	623.7	
Q203A	Thermal Energy from Strg to SHL		10,617,457 BTU's	3,112 KWH	N002	Avg Wind Velocity	—	—	
Q203B	Thermal Energy from Strg to HWL		0 BTU's	0 KWH	N003	Avg Wind Direction	—	—	
Q203C	Thermal Energy Stored in Strg Tank		340,865 BTU's	100 KWH	Q402	Total Building Heat Load	17,756,176 BTU	5,204 KWH	
Q203D	Thermal Energy Transfer to Grnd		-3,785,571 BTU's	-1,110 KWH	Q701	Natural Passive Contribution	2,084,050 BTU	611 KWH	
Q203	Total Solar Energy Utilized		10,617,457 BTU's	3,112 KWH	N700	Building Thermal Performance	19,817 BTU/DD	8.34 KWH/DD	
N111C	Storage System Efficiency		148%	148%	N400	Solar Contribution to SHL	59.80%	59.80%	
Q402A	Thermal Energy Delvd to Building from Heat Pump		16,940,707 BTU's	4,965 KWH	N401	Heat Pump Comp. COP (SHL)	2.68	2.68	
Q402B	Thermal Energy Equiv of Heat Pump Motive Power (Space Heat Mode)		6,323,250 BTU's	1,853 KWH					
Q402C	Supplemental Electric Resistance Heat No. 1		815,469 BTU's	239 KWH					
Q402D	Supplemental Electric Resistance Heat No. 2		0 BTU's	0 KWH					
Q402	Total Space Heating Load		17,756,176 BTU's	5,204 KWH	N300	Solar Contribution to HWL	0	0	
Q302A	Thermal Energy Delvd to Hot Water Load from Heat Pump		0 BTU's	0 KWH	N301	Heat Pump Comp. COP (HWL)	0	0	
Q302B	Thermal Energy Equiv of Heat Pump Motive Power (Hot Water Mode)		0 BTU's	0 KWH					
Q302	Total Hot Water Heating Load		358,334 BTU's	105 KWH	N601	Solar Contribution to Total Load	52.62%	52.62%	
Q600	Thermal Equiv of Total Auxiliary Energy		1,173,803 BTU's	344 KWH	N602	Total Heat Pump Comp COP	2.68	2.68	
Q601A	Thermal Equiv of Heat Pump Motive Power (Total)		6,323,250 BTU's	1,853 KWH	N603	Total System COP	1.674	1.674	
Q601B	Thermal Equiv of Main Transfer Pump Motive Power (Collector Mode)		561,785 BTU's	165 KWH					
Q601C	Thermal Equiv of Main Transfer Pump Motive Power (HP Assist)		1,314,772 BTU's	385 KWH					
Q601D	Thermal Equiv of Main Transfer Pump Motive Power (Total)		1,876,557 BTU's	550 KWH					
Q601E	Thermal Equiv of Indoor Fan Motive Power		747,190 BTU's	219 KWH					
Q601	Thermal Equiv of Total Motive Power		8,946,997 BTU's	2,622 KWH					
Q602	Thermal Equiv of Total System Heating Load		20,176,472 BTU's	5,913 KWH					
Q603	Thermal Equiv of Total Heating System Power Consumed		10,120,800 BTU's	2,966 KWH					
Q001A	Solarimeter Totalizer		43,575,870 BTU's	12,771 KWH					

ELECTRIC ENERGY SAVED		TOTAL MAXIMUM POWER DEMAND KW				EQUIPMENT RUN TIMES (HRS)				
		CONNECTED THERMAL AND MOTIVE LOAD 25.792 KW (COINCIDENT)								
Net Saved Hot Water Load	0 KWH						Hours	Demand Constant	KW Actual	
Net Saved Space Heat Load	3112 KWH									
Total Electric Saved	3112 KWH									
FUEL ENERGY SAVED (NATURAL GAS) (SAOHP vs Natural Gas System)		Time	Maximum Constant	Maximum Actual	Demand on Utility - % of Connected Load					
Net Saved Hot Water Load	8 CCF	A	1200 to 1600 hrs	15.756	13.927	54%	Electric Resistance Heater No. 1	29.35	8.40	8.143
Net Saved Space Heat Load	355 CCF	*B	1600 to 2200 hrs	15.756	13.927	54%	Electric Resistance Heater No. 2	0.00	8.40	8.143
Total Fossil Fuel Saved	363 CCF	C	2200 to 0700 hrs	20.256	18.427	71%	Electric DWH Htr Upper Coil	0.00	4.50	4.17
		D	0700 to 1200 hrs	20.256	18.427	71%	Electric DWH Htr Lower Coil	25.16	4.50	4.17
							Heat Pump Powrd DWH Htr Coil	0.00	1.00	—
							Heat Pump Compressor (Space Heat)	424.39	6.48	4.37
							Heat Pump Compressor (Hot Water)	0.00	6.48	—
							Main Trnsfr Pump (Collection)	181.32	.310	.908
							Main Trnsfr Pump (HP Assist)	424.39	.310	.908
							Indoor Fan	434.09	.566	.506

*Annual daily electric system peak load time.
Marginal demand cost saving = \$7,119
Heating system load factor (coincidentally) = 26.8

TABLE IV-3
PHOENIX PROJECT - SAOHP SYSTEM
CONFORMED ENERGY BALANCE PARAMETERS

JANUARY 1978

		SI UNITS	METRIC UNITS			SI UNITS	METRIC UNITS
Q001	Avg Insolation Rate	159 $\frac{\text{BTU}}{\text{HR FT}^2}$	1.806 $\frac{\text{MJ}}{\text{HR M}^2}$				
Q002	Total Insolation on Collectors	22,092,535 BTU	6,475 KWH	N406	Avg Bldg Indoor Temperature	70°F	21.1°C
Q100	Thermal Energy Delivered to Storage	4,376,253 BTU	1,283 KWH	N113	Avg Ambient DB Temperature	28°F	-2.2°C
N111A	Collection System Efficiency	19.8%	19.8%	N113A	Total Degree Days	1,141	794
Q203A	Thermal Energy from Strg to SHL	9,033,792 BTU	2,648 KWH	N002	Avg Wind Velocity	9.0 mph	4.0 m/s
Q203B	Thermal Energy from Strg to HWL	0	0	N003	Avg Wind Direction	17°E of N	17°E of N
Q203C	Thermal Energy Sotred in Strg Tank	-722,068 BTU	-212 KWH	Q402	Total Building Heat Load	19,811,680 BTU	5,806 KWH
Q203D	Thermal Energy Transfer to Grnd	-3,935,471 BTU	-1,153 KWH	Q701	Natural Passive Contribution	1,297,199 BTU	380 KWH
Q203	Total Solar Energy Utilized	9,033,792 BTU	2,648 KWH	N700	Building Thermal Performance	17,363 BTU/DD	7.31 KWH/DD
N111B	Storage System Efficiency	206.43%	206.43%				
Q402A	Thermal Energy Delvd to Building from Heat Pump	15,403,785 BTU	4,515 KWH	N400	Solar Contribution to SHL	45.60%	45.60%
Q402B	Thermal Energy Equiv of Heat Pump Motive Power (Space Heat Mode)	6,369,993 BTU	1,867 KWH	N401	Heat Pump Comp. COP (SHL)	2.418	2.418
Q402C	Supplemental Electric Resistance Heat No. 1	4,407,895 BTU	1,292 KWH				
Q402D	Supplemental Electric Resistance Heat No. 2	0	0				
Q402	Total Space Heating Load	19,811,680 BTU	5,806 KWH	N300	Solar Contribution to HWL	0	0
Q302A	Thermal Energy Delvd to Hot Water Load from Heat Pump	0	0	N301	Heat Pump Comp. COP (HWL)	-	-
Q302B	Thermal Energy Equiv of Heat Pump Motive Power (Hot Water Mode)	0	0				
Q302	Total Hot Water Heating Load	757,299 BTU	222 KWH	N601	Solar Contribution to Total Load	39.23%	39.23%
Q600	Thermal Equiv of Total Auxiliary Energy	5,165,194 BTU	1,514 KWH	N602	Total Heat Pump Comp COP	2.418	2.418
Q601A	Thermal Equiv of Heat Pump Motive Power (Total)	6,369,993 BTU	1,867 KWH	N603	Total System COP	1.594	1.594
Q601B	Thermal Equiv of Main Transfer Pump Motive Power (Collector Mode)	448,283 BTU	131 KWH				
Q601C	Thermal Equiv of Main Transfer Pump Motive Power (HP Assist)	1,479,664 BTU	434 KWH				
Q601D	Thermal Equiv of Main Transfer Pump Motive Power (Total)	1,927,947 BTU	565 KWH				
Q601E	Thermal Equiv of Indoor Fan Motive Power	978,487 BTU	287 KWH				
Q601	Thermal Equiv of Total Motive Power	9,276,427 BTU	2,719 KWH				
Q602	Thermal Equiv of Total System Heating Load	23,027,130 BTU	6,749 KWH				
Q603	Thermal Equiv of Total Heating System Power Consumed	14,441,621 BTU	4,233 KWH				
Q001A	Solarimeter Totalizer	33,997,080 BTU	9,964 KWH				

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ELECTRIC ENERGY SAVED			TOTAL MAXIMUM POWER DEMAND KW				EQUIPMENT RUN TIMES (HRS)			
			CONNECTED THERMAL AND MOTIVE LOAD 25.792 KW (COINCIDENT)						Demand	KW
Q311	Net Saved Hot Water Load	0						Hours	Constant	Actual
Q415	Net Saved Space Heat Load	2,648 KWH				Demand on	Electric Resistance Heater No. 1	143.73	8.40	8.99
Q604	Total Electric Saved	2,648 KWH				Utility - %	Electric Resistance Heater No. 2	0.00	8.40	—
			Time		Maximum	of Connected	Electric DWH Htr Upper Coil	0.00	4.50	—
				Constant	Actual	Load	Electric DWH Htr Lower Coil	47.52	4.50	4.672
FOSSIL FUEL ENERGY SAVED (NATURAL GAS)			A	1200 to 1600 hrs	11.856	10.157	Heat Pump Powrd DWH Htr Coil	0.00	1.00	—
(SAOHP vs Natural Gas System)			*B	1600 to 2200 hrs	20.256	19.147	Heat Pump Compressor (Space Heat)	462.45	6.48	4.037
Q313	Net Saved Hot Water Load	15 CCF	C	2200 to 0700 hrs	20.256	19.147	Heat Pump Compressor (Hot Water)	0.00	6.48	—
Q417	Net Saved Space Heat Load	396 CCF	D	0700 to 1200 hrs	20.256	19.147	Main Trnsfr Pump (Collection)	140.12	.226	.938
Q605	Total Fossil Fuel Saved	411 CCF					Main Trnsfr Pump (HP Assist)	462.45	.310	.938
			*Annual daily electric system peak load time.				Indoor Fan	562.97	.566	.510
			Marginal demand cost saving = \$3,987							
			Heating system load factor (coincidentally) = 22.1							

TABLE IV-4
PHOENIX PROJECT - SAOHP SYSTEM
CONFORMED ENERGY BALANCE PARAMETERS
FEBRUARY 1978

		SI UNITS	METRIC UNITS			SI UNITS	METRIC UNITS
Q001	Avg Insolation Rate	185 $\frac{\text{BTU}}{\text{HR FT}^2}$	2.10 $\frac{\text{MJ}}{\text{HR M}^2}$				
Q002	Total Insolation on Collectors	27,011,768 BTU	7,917 KWH	N406	Avg Bldg Indoor Temperature	69°F	20.5°C
Q100	Thermal Energy Delivered to Storage	4,584,354 BTU	1,344 KWH	N113	Avg Ambient DB Temperature	31°F	-5.5°C
N111A	Collection System Efficiency	12.46%	12.46%	N113A	Total Degree Days	960	668
Q203A	Thermal Energy from Strg to SHL	3,050,580 BTU	894 KWH	N002	Avg Wind Velocity	8.4 mph	3.77 m/s
Q203B	Thermal Energy from Strg to HWL	0	0	N003	Avg Wind Direction	60°E of N	60°E of N
Q203C	Thermal Energy Stored in Strg Tank	1,331,463 BTU	390 KWH	Q402	Total Building Heat Load	13,285,593 BTU	3,984 KWH
Q203D	Thermal Energy Transfer to Grnd	202,311 BTU	49 KWH	Q701	Natural Passive Contribution	1,851,642 BTU	543 KWH
Q203	Total Solar Energy Utilized	3,050,580 BTU	894 KWH	N700	Building Thermal Performance	13,839 BTU/DD	5.83 KWH/DD
N111B	Storage System Efficiency	66.5%	66.5%	N400	Solar Contribution to SHL	22.96%	22.96%
402A	Thermal Energy Delvd to Building from Heat Pump	5,275,956 BTU	1,546 KWH	N401	Heat Pump Comp. COP (SHL)	2.37	2.37
Q402B	Thermal Energy Equiv of Heat Pump Motive Power (Space Heat Mode)	2,225,376 BTU	652 KWH				
Q402C	Supplemental Electric Resistance Heat No. 1	8,009,637 BTU	2,347 KWH				
Q402D	Supplemental Electric Resistance Heat No. 2	0	0				
Q402	Total Space Heating Load	13,285,593 BTU	3,894 KWH				
Q302A	Thermal Energy Delvd to Hot Water Load from Heat Pump	0	0	N300	Solar Contribution to HWL	0	0
Q302B	Thermal Energy Equiv of Heat Pump Motive Power (Hot Water Mode)	0	0	N301	Heat Pump Comp. COP (HWL)	-	-
Q302	Total Hot Water Heating Load	733,366 BTU	215 KWH				
Q600	Thermal Equiv of Total Auxiliary Energy	8,743,003 BTU	2,562 KWH	N601	Solar Contribution to Total Load	19.74%	19.74%
Q601A	Thermal Equiv of Heat Pump Motive Power (Total)	2,225,376 BTU	652 KWH	N602	Total Heat Pump Comp COP	2.37	2.37
Q601B	Thermal Equiv of Main Transfer Pump Motive Power (Collector Mode)	529,964 BTU	155 KWH	N603	Total System COP	1.20	1.20
Q601C	Thermal Equiv of Main Transfer Pump Motive Power (HP Assist)	464,808 BTU	136 KWH				
Q601D	Thermal Equiv of Main Transfer Pump Motive Power (Total)	994,772 BTU	292 KWH				
Q601E	Thermal Equiv of Indoor Fan Motive Power	973,245 BTU	285 KWH				
Q601	Thermal Equiv of Total Motive Power	4,193,393 BTU	1,229 KWH				
Q602	Thermal Equiv of Total System Heating Load	15,457,012 BTU	4,530 KWH				
Q603	Thermal Equiv of Total Heating System Power Consumed	12,936,396 BTU	3,791 KWH				
Q001A	Solarimeter Totalizer	36,791,040 BTU	10,783 KWH				

ELECTRIC ENERGY SAVED		TOTAL MAXIMUM POWER DEMAND KW			EQUIPMENT RUN TIMES (HRS)			
Q311	Net Saved Hot Water Load	0	CONNECTED THERMAL AND MOTIVE LOAD 24.027 KW (COINCIDENT)			Hours	Demand Constant	KW Actual
Q415	Net Saved Space Heat Load	894 KWH						
Q604	Total Electric Saved	894 KWH						
FOSSIL FUEL ENERGY SAVED (NATURAL GAS) (SAOHP vs Natural Gas System)		Time	Maximum Constant	Maximum Actual	Demand on Utility - % of Connected Load			
Q313	Net Saved Hot Water Load	1.46 CCF	A 1200 to 1600 hrs	14.327	62%	Electric Resistance Heater No. 1	267.68	8.77
Q417	Net Saved Space Heat Load	265.71 CCF	*B 1600 to 2200 hrs	13.405	58%	Electric Resistance Heater No. 2	0.0	—
Q605	Total Fossil Fuel Saved	267.17 CCF	C 2200 to 0700 hrs	14.027	60%	Electric DWH Htr Upper Coil	0.38	4.70
			D 0700 to 1200 hrs	14.327	62%	Electric DWH Htr Lower Coil	45.37	4.70
			*Annual daily electric system peak load time.			Heat Pump Powrd DWH Htr Coil	0.0	—
			Marginal demand cost saving = \$6,015			Heat Pump Compressor (Space Heat)	150.77	4.31
			Heating system load factor (coincidentally) = 23.4			Heat Pump Compressor (Hot Water)	0.0	—
						Main Trnsfr Pump (Collection)	171.90	.922
						Main Trnsfr Pump (HP Assist)	150.77	.922
						Indoor Fan	537.94	.505
								.532

TABLE IV-5

PHOENIX PROJECT - SAOHP SYSTEM
CONFORMED ENERGY BALANCE PARAMETERS

MARCH 1978

		SI UNITS	METRIC UNITS			SI UNITS	METRIC UNITS
Q001	Avg Insolation Rate	181 $\frac{\text{BTU}}{\text{HR FT}^2}$	2.056 $\frac{\text{MJ}}{\text{HR M}^2}$				
Q002	Total Insolation on Collectors	30,170,633 BTU	8,843 KWH	N406	Avg Bldg Indoor Temperature	71°F	21.67°C
Q100	Thermal Energy Delivered to Storage	5,038,040 BTU	1,476 KWH	N113	Avg Ambient DB Temperature	40°F	4.44°C
N111A	Collection System Efficiency	16.69%	16.69%	N113A	Total Degree Days	760	529
Q203A	Thermal Energy from Strg to SHL	2,763,514 BTU	810 KWH	N002	Avg Wind Velocity	10.7 mph	4.8 m/s
Q203B	Thermal Energy from Strg to HWL	0	0	N003	Avg Wind Direction	48°E of N	48°E of N
Q203C	Thermal Energy Stored in Strg Tank	422,467 BTU	124 KWH	Q402	Total Building Heat Load	10,862,556 BTU	3,184 KWH
Q203D	Thermal Energy Transfer to Grnd	1,852,059 BTU	543 KWH	Q701	Natural Passive Contribution	2,252,160 BTU	660 KWH
Q203	Total Solar Energy Utilized	2,763,514 BTU	810 KWH	N700	Building Thermal Performance	14,292 BTU/DD	6.02 KWH/DD
N111B	Storage System Efficiency	54.85%	54.85%	N400	Solar Contribution to SHL	25.46%	25.46%
Q402A	Thermal Energy Delvd to Building from Heat Pump	4,743,705 BTU	1,390 KWH	N401	Heat Pump Comp. COP (SHL)	2.40	2.40
Q402B	Thermal Energy Equiv of Heat Pump Motive Power (Space Heat Mode)	1,980,191 BTU	580 KWH				
Q402C	Supplemental Electric Resistance Heat No. 1	6,118,851 BTU	1,793 KWH				
Q402D	Supplemental Electric Resistance Heat No. 2	0	0				
Q402	Total Space Heating Load	10,862,556 BTU	3,184 KWH				
Q302A	Thermal Energy Delvd to Hot Water Load from Heat Pump	0	0	N300	Solar Contribution to HWL	0	0
Q302B	Thermal Energy Equiv of Heat Pump Motive Power (Hot Water Mode)	0	0	N301	Heat Pump Comp. COP (HWL)	—	—
Q302	Total Hot Water Heating Load	1,024,573 BTU	300 KWH				
Q600	Thermal Equiv of Total Auxiliary Energy	7,143,424 BTU	2,094 KWH	N601	Solar Contribution to Total Load	21.23%	21.29%
Q601A	Thermal Equiv of Heat Pump Motive Power (Total)	1,980,191 BTU	580 KWH	N602	Total Heat Pump Comp COP	2.40	2.40
Q601B	Thermal Equiv of Main Transfer Pump Motive Power (Collector Mode)	583,574 BTU	171 KWH	N603	Total System COP	1.20	1.20
Q601C	Thermal Equiv of Main Transfer Pump Motive Power (HP Assist)	298,079 BTU	87 KWH				
Q601D	Thermal Equiv of Main Transfer Pump Motive Power (Total)	881,653 BTU	258 KWH				
Q601E	Thermal Equiv of Indoor Fan Motive Power	792,602 BTU	233 KWH				
Q601	Thermal Equiv of Total Motive Power	3,654,446 BTU	1,071 KWH				
Q602	Thermal Equiv of Total System Heating Load	12,977,810 BTU	3,804 KWH				
Q603	Thermal Equiv of Total Heating System Power Consumed	10,797,870 BTU	3,165 KWH				
Q001A	*Solarimeter Totalizer	*81,199,560 BTU	*23,798 KWH				

*Solarimeter Totalizer Malfunction - returned to Eppley for repairs

ELECTRIC ENERGY SAVED			TOTAL MAXIMUM POWER DEMAND KW			EQUIPMENT RUN TIMES (HRS)					
			CONNECTED THERMAL AND MOTIVE LOAD 24.027 KW (COINCIDENT)				Hours	Demand Constant	KW Actual		
Q311	Net Saved Hot Water Load	0									
Q415	Net Saved Space Heat Load	809 KWH			Demand on Utility - % of Connected Load	Electric Resistance Heater No. 1	194.08	8.4	9.24		
Q604	Total Electric Saved	809 KWH				Electric Resistance Heater No. 2	0	8.4	9.24		
			Time	Maximum Constant	Maximum Actual	Electric DWH Htr Upper Coil	0	4.5	4.90		
FOSSIL FUEL ENERGY SAVED (NATURAL GAS) (SAOHP vs Natural Gas System)			A	1200 to 1600 hrs	14.327	15.569	65%	Electric DWH Htr Lower Coil	61.20	4.5	4.90
			*B	1600 to 2200 hrs	14.327	15.569	65%	Heat Pump Powrd DWH Htr Coil	0	1.0	—
Q313	Net Saved Hot Water Load	20.5 KWH	C	2200 to 0700 hrs	13.405	14.685	61%	Heat Pump Compressor (Space Heat)	98.70	4.2	5.90
Q417	Net Saved Space Heat Load	217 KWH	D	0700 to 1200 hrs	14.327	15.569	65%	Heat Pump Compressor (Hot Water)	0	4.2	—
Q605	Total Fossil Fuel Saved	237.5 KWH	*Annual daily electric system peak load time.				Main Trnsfr Pump (Collection)	193.23	.922	.884	
			Marginal demand cost saving = \$5,075				Main Trnsfr Pump (HP Assist)	98.70	.922	.884	
			Heating system load factor (coincidentally) = 27.3				Indoor Fan	425.92	.505	.545	

system during January (3 days), February (17 days) and March (14 days). The reasons for this system downtime have been discussed in Section 2.2. The data acquisition system and analysis program functioned satisfactorily with one exception. The Eppley Integrator malfunctioned in late March and was sent to the factory for repairs in early April.

It should be noted that the entire system was shut down from 2 November 1977 through 22 November in order to obtain metal samples and to make modifications. The storage system was drained and ventilated during this time for the work to be performed on the storage heat exchanger. The storage water temperature was 127°F on 2 November when the tank was drained. When the tank was refilled on 20 November 1977 with 56°F water, the storage water was heated from thermal energy stored in the ground. An equilibrium temperature of 64°F between the stored water and the ground 1' away from the tank was achieved on 1 December 1975 with a ground temperature of 67°F existing 2' away from the tank. A large part of the thermal energy stored in the ground prior to 2 November 1977 was lost through ventilating the tank for the workmen through 22 November 1977. This situation decreased the availability of thermal energy from the storage system below the availability in a normal seasonal cycle. The lower storage temperature reduces the COP and capacity of the heat pump for the balance of the heating season, but very valuable performance data based on lower boundary thermal conditions will be achieved.

Tables IV-6, IV-7, IV-8, and IV-9 are the unconformed energy balance parameters for the months of December 1977, and January, February and March, 1978; respectively. Some of the daily energy balance parameters are shown graphically in the plots of Figures IV-2 through IV-5 in an effort to determine the interdependence and/or interaction of the load the SAOHP system with the solar availability and climatic conditions.

DAY 335 TO DAY 365
SAOHF SYSTEM
ENERGY BALANCE PARAMETERS

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TABLE IV-7

DAY 1 TO DAY 31:
SAOHP SYSTEM
ENERGY BALANCE PARAMETERS

Q001	AVG INSOLATION RATE	=	159. BTU/FT ² HR				
Q002	TOTAL INSOLATION ON COLLECTORS	=	22092535. BTU	+	N406	AVG BLDG INDOOR DB TEMP	= 70. DEG F
Q100	THERMAL ENERGY DEL#VD TO STORAGE	=	5499878. BTU	+	N113	AVG AMBIENT DB TEMP	= 28. DEG F
N111A	COLLECTION SYSTEM EFFICIENCY	=	24.89 PERCENT	+	N113A	TOTAL DEGREE DAYS	= 1141.
				+	N002	AVG WIND VELOCITY	= MPH
Q203A	THERMAL ENERGY FROM STR TO SHL	=	10072240. BTU	+	N003	AVG WIND DIRECTION	= DEG
Q203B	THERMAL ENERGY FROM STR TO HML	=	0. BTU				
Q203C	THERMAL ENERGY STORED IN STR TANK	=	-722068. BTU	+	Q402	TOTAL BLDG HEAT LOAD	= 24416476. BTU
Q203D	THERMAL ENERGY TRANSFER TO GRND	=	-3850294. BTU	+	Q701	NATURAL PASSIVE CONTRIBUTION	= 1649151. BTU
Q203	TOTAL SOLAR ENERGY UTILIZED	=	10072240. BTU				
N111B	STORAGE SYSTEM EFFICIENCY	=	183.14 PERCENT	+	N700	BUILDING THERMAL PERFORMANCE	= 21402. BTU/DD

Q402A	THERMAL ENERGY DEL#VD TO BLDG FROM HEAT PUMP	=	20296748. BTU				
Q402B	THERMAL ENERGY EQUIV OF HEAT PUMP MOTIVE POWER (SPACE HEAT MODE)	=	16224708. BTU	N400	SOLAR CONTRIBUTION TO SHL	=	41.25 PERCENT
Q402C	SUPPLEMENTAL ELECTRIC RESISTANCE HEAT NO. 1	=	4119528. BTU				
Q402D	SUPPLEMENTAL ELECTRIC RESISTANCE HEAT NO. 2	=	0. BTU	N401	HEAT PUMP COMP COP (SHL)	=	1.985:
Q402	TOTAL SPACE HEATING LOAD	=	24416476. BTU				
Q302A	THERMAL ENERGY DEL#VD TO HOT WATER LOAD FROM HEAT PUMP	=	0. BTU				
Q302B	THERMAL ENERGY EQUIV OF HEAT PUMP MOTIVE POWER (HOT WATER MODE)	=	0. BTU	N300	SOLAR CONTRIBUTION TO HML	=	0.00 PERCENT
Q302C	SUPPLEMENTAL ELECTRIC RESISTANCE HEAT	=	729575. BTU				
Q302	TOTAL HOT WATER HEATING LOAD	=	729575. BTU	N301	HEAT PUMP COMP COP (HML)	=	0.000:
Q600	THERMAL EQUIV OF TOTAL AUXILIARY ENERGY	=	4849103. BTU				
Q601A	THERMAL EQUIV OF HEAT PUMP MOTIVE POWER (TOTAL)	=	16224708. BTU				
Q601B	THERMAL EQUIV OF MAIN TRNSFR PUMP MOTIVE POWER (COLLECTION MODE)	=	108046. BTU				
Q601C	THERMAL EQUIV OF MAIN TRNSFR PUMP MOTIVE POWER (HP ASSIST)	=	489145. BTU				
Q601D	THERMAL EQUIV OF MAIN TRNSFR PUMP MOTIVE POWER (TOTAL)	=	597191. BTU				
Q601E	THERMAL EQUIV OF INDOOR FAN MOTIVE POWER	=	1087208. BTU				
Q601	THERMAL EQUIV OF TOTAL MOTIVE POWER	=	11909107. BTU	N601	SOLAR CONTRI. TO TOT. LOAD	=	37.69 PERCENT
Q602	THERMAL EQUIV OF TOTAL SYSTEM HEATING LOAD	=	26722404. BTU	N602	TOTAL HEAT PUMP COMP. COP	=	1.985
Q603	THERMAL EQUIV OF TOTAL HEATING SYSTEM POWER CONSUMED	=	16758211. BTU	N603	TOTAL SYSTEM COP	=	1.211

ELECTRIC ENERGY SAVED			DEMAND - (KW)		EQUIPMENT RUN TIMES - (HRS)		
			TIME	HOUSE (T)	MECH (M)		
Q311	NET SAVED HOT WATER LOAD	=	0. KWH			ELECTRIC RESISTANCE HEATER NO. 1	= 143.73
Q415	NET SAVED SPACE HEAT LOAD	=	2952. KWH	DMD A		ELECTRIC RESISTANCE HEATER NO. 2	= 0.00
Q604	TOTAL ELECTRIC SAVED	=	2952. KWH	1200-1600		ELECTRIC DHW HTR UPPER COIL	= 0.00
						ELECTRIC DHW HTR LOWER COIL	= 47.52
				DMD B		HEAT PUMP POWRD DHW HTR COIL	= 0.00
	FOSSIL FUEL ENERGY SAVED			1600-2200		HEAT PUMP COMP. (SPACE HEAT)	= 462.45
						HEAT PUMP COMP (HOT WATER)	= 0.00
				DMD C		MAIN TRNSFR PUMP (COLLECTION)	= 140.12
Q313	NET SAVED HOT WATER LOAD	=	15. CCF	2200-0700		MAIN TRNSFR PUMP (HP ASSIST)	= 462.45
Q417	NET SAVED SPACE HEAT LOAD	=	480. CCF			INDOOR FAN	= 562.97
Q605	TOTAL FOSSIL FUEL SAVED	=	503. CCF	DMD D			
				0700-1200			

DAY 32 TO DAY 59
SAOHP SYSTEM
ENERGY BALANCE PARAMETERS

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TABLE IV-9

DAY 60 TO DAY 90
SAOHP SYSTEM
ENERGY BALANCE PARAMETERS

Q001	AVG INSOLATION RATE	=	181. BTU/FT2HR		
Q002	TOTAL INSOLATION ON COLLECTORS	=	30170633. BTU	N406	AVG BLDG INDOOR DB TEMP = 71. DEG F
Q100	THERMAL ENERGY DEL#VD TO STORAGE	=	5247958. BTU	N113	AVG AMBIENT DB TEMP = 40. DEG F
N111A	COLLECTION SYSTEM EFFICIENCY	=	17.39 PERCENT	N113A	TOTAL DEGREE DAYS = 760.
Q203A	THERMAL ENERGY FROM STR TO SHL	=	2683023. BTU	N002	AVG WIND VELOCITY = MPH
Q203B	THERMAL ENERGY FROM STR TO HWL	=	0. BTU	N003	AVG WIND DIRECTION = DEG
Q203C	THERMAL ENERGY STORED IN STR TANK	=	422467. BTU	Q402	TOTAL BLDG HEAT LOAD = 9660037. BTU
Q203D	THERMAL ENERGY TRANSFER TO GRND	=	2142468. BTU	Q701	NATURAL PASSIVE CONTRIBUTION = 2252160. BTU
Q203	TOTAL SOLAR ENERGY UTILIZED	=	2683023. BTU		
N111B	STORAGE SYSTEM EFFICIENCY	=	51.13 PERCENT	N700	BUILDING THERMAL PERFORMANCE = 12711. BTU/DD
Q402A	THERMAL ENERGY DEL#VD TO BLDG FROM HEAT PUMP	=	4097446. BTU		
Q402B	THERMAL ENERGY EQUIV OF HEAT PUMP MOTIVE POWER (SPACE HEAT MODE)	=	1414422. BTU	N400	SOLAR CONTRIBUTION TO SHL = 27.77 PERCENT
Q402C	SUPPLEMENTAL ELECTRIC RESISTANCE HEAT NO. 1	=	5562592. BTU		
Q402D	SUPPLEMENTAL ELECTRIC RESISTANCE HEAT NO. 2	=	0. BTU	N401	HEAT PUMP COMP COP (SHL) = 2.897
Q402	TOTAL SPACE HEATING LOAD	=	9660037. BTU		
Q302A	THERMAL ENERGY DEL#VD TO HOT WATER LOAD FROM HEAT PUMP	=	0. BTU		
Q302B	THERMAL ENERGY EQUIV OF HEAT PUMP MOTIVE POWER (HOT WATER MODE)	=	0. BTU	N300	SOLAR CONTRIBUTION TO HWL = 0.00 PERCENT
Q302C	SUPPLEMENTAL ELECTRIC RESISTANCE HEAT	=	939975. BTU		
Q302	TOTAL HOT WATER HEATING LOAD	=	939975. BTU	N301	HEAT PUMP COMP COP (HWL) = 0.000
Q600	THERMAL EQUIV OF TOTAL AUXILIARY ENERGY	=	6502566. BTU		
Q601A	THERMAL EQUIV OF HEAT PUMP MOTIVE POWER (TOTAL)	=	1414422. BTU		
Q601B	THERMAL EQUIV OF MAIN TRNSFR PUMP MOTIVE POWER (COLLECTION MODE)	=	607890. BTU		
Q601C	THERMAL EQUIV OF MAIN TRNSFR PUMP MOTIVE POWER (HP ASSIST)	=	310499. BTU		
Q601D	THERMAL EQUIV OF MAIN TRNSFR PUMP MOTIVE POWER (TOTAL)	=	918390. BTU		
Q601E	THERMAL EQUIV OF INDOOR FAN MOTIVE POWER	=	733891. BTU		
Q601	THERMAL EQUIV OF TOTAL MOTIVE POWER	=	3066702. BTU	N601	SOLAR CONTRI. TO TOT. LOAD = 23.04 PERCENT
Q602	THERMAL EQUIV OF TOTAL SYSTEM HEATING LOAD	=	11644402. BTU	N602	TOTAL HEAT PUMP COMP. COP = 2.897
Q603	THERMAL EQUIV OF TOTAL HEATING SYSTEM POWER CONSUMED	=	9569269. BTU	N603	TOTAL SYSTEM COP = .428

ELECTRIC ENERGY SAVED

DEMAND - (KW)

EQUIPMENT RUN TIMES - (HRS)

			TIME	HOUSE (T)	MECH (M)	
Q311	NET SAVED HOT WATER LOAD	=	0. KWH			ELECTRIC RESISTANCE HEATER NO. 1 = 194.08
Q415	NET SAVED SPACE HEAT LOAD	=	786. KWH	DMD A		ELECTRIC RESISTANCE HEATER NO. 2 = 0.00
Q604	TOTAL ELECTRIC SAVED	=	786. KWH	1200-1600		ELECTRIC DHW HTR UPPER COIL = 0.00
						ELECTRIC DHW HTR LOWER COIL = 61.20
				DMD B		HEAT PUMP POWRD DHW HTR COIL = .08
				1600-2200		HEAT PUMP COMP. (SPACE HEAT) = 98.70
						HEAT PUMP COMP (HOT WATER) = 0.00
				DMD C		MAIN TRNSFR PUMP (COLLECTION) = 193.23
Q313	NET SAVED HOT WATER LOAD	=	19. CCF	2200-0700		MAIN TRNSFR PUMP (HP ASSIST) = 98.70
Q417	NET SAVED SPACE HEAT LOAD	=	193. CCF			INDOOR FAN = 425.92
Q605	TOTAL FOSSIL FUEL SAVED	=	212. CCF	DMD D		
				0700-1200		

FOSSIL FUEL ENERGY SAVED

FIGURE IV-2 STORAGE TEMPERATURE AND BUILDING LOAD VS SOLAR AVAILABILITY

FIGURE IV-3 BUILDING THERMAL PERFORMANCE VS WIND SPEED AND DIRECTION

FIGURE IV-4 COLLECTOR AND HEAT PUMP PERFORMANCE AMBIENT VS STORAGE TEMPERATURE

FIGURE IV-5 STORAGE SYSTEM PERFORMANCE

Figure IV-2 is a graph of the four month daily solar availability, the Phoenix House heating load and the average midnight storage water temperatures. The plot supports an anticipated result that storage temperatures track solar availability except on the few occurrences when building heat load is high on days of high solar availability. An interesting result revealed by the plot is that although reciprocal tracking between solar availability and building load does occur it is not predominant. This would follow from an analysis of general climatic conditions in the Pikes Peak Region; in that, many times clear weather, days of high solar availability, is associated with the presence of a cold air mass in the region and conversely cloudy overcast conditions are many times result of the influx of a warmer humid air mass. Another result of graphic representation of system characteristics displays that as building load declines in early spring, storage temperatures escalate.

Figure IV-3 shows the four month building thermal performance (rated in BTU's per degree day) and its relationship to wind speed and direction. The anticipated result of building performance tracking wind speed is not supported by the plot. In fact, little correlation seems to exist at all between these two factors. The building performance declines between the 15th and the 22nd of January which could correspond to a recaulk at all window and door frames which occurred at that time.

Figure IV-4 displays the four month average daily ambient dry bulb temperature, heat pump coefficient of performance, collector efficiency, and midnight storage water temperature. Although collector efficiency was expected to inversely track storage temperature, this result is not supported by the graph. There appears to be some correlation between collector efficiency and ambient temperature, but this correlation is not

total and by no means conclusive. In fact, the seemingly independent variability of the factors which could influence collector efficiency - solar availability, ambient temperature, wind speed and direction, and storage temperature - makes establishing a positive correlation, between collector efficiency and any one of the other factors, very difficult if not impossible. A positive correlation does exist between heat pump coefficient of performance and ambient temperature. This relationship results from changes in evaporator temperature when heating loads change. For example, when ambient temperatures drop, heating loads increase which lowers evaporator temperatures and hence, lowers heat pump coefficient of performance.

Figure IV-5 is a plot of the four month average evaporator fluid temperature, upper storage water temperature, lower storage water temperature, ground temperature 9" from the storage tank and ground temperature 18" from the storage tank; each corresponding with the time of the lowest lower water temperature reading each day. The graph indicates several processes. First, a positive correlation is displayed between evaporator and storage water temperatures. Anomalies in this relationship result from variances in solar availability and, hence, in thermal energies input to storage from the collectors. A one day lag can be seen between lower and upper storage water temperatures as well as thermal stratification of the water in the storage tank. The temperature difference between the near and far ground thermocouples indicate heat flowing into the storage tank in early December, mid-January and late January to early February. These times correspond with high building load periods of Figure IV-2. From mid-February to mid-March, these thermocouples indicate heat flowing into the ground, which agrees with the system being down and not utilizing storage. A discrepancy exists in the performance data; in

that, the daily energy balance sheets indicate a negative transfer of energy to the ground in December, January and February and yet Figure IV-5 indicates higher upper storage water temperatures than the ground temperatures at these times. The reason for this discrepancy is the inappropriate location of instrumentation for the proper evaluation of the storage tank to ground heat transfer interface as the following description indicates:

The storage tank is an uninsulated steel cylindrical tank buried 8'9" to centerline underground, as the following sketch indicates:

The graph of Figure IV-5 shows the daily lows for the thermocouples shown; that is:

- T_u = Upper Storage Water Temp
- T_L = Lower Storage Water Temp
- T_N = Temp Ground 9" from tank

- T_F = Temp Ground 18" from tank
- $T_T = \frac{T_i - T_o}{2}$; average Therminol temp

As mentioned previously, the energy balances indicate a net flow of energy from the ground into the tank, while Figure IV-5 shows consistently higher temperatures for T_u than for T_N and T_F during these periods of heat flow into storage. This can be explained by the location of these four thermocouples with respect to the primary heat exchange coil. The results of the energy balances and the thermocouple readings suggest that the thermal energy transferred to the storage water is entering the tank from ground nearer the bottom of the tank. This result suggests a storage configuration improvement by providing an upper tank heat exchange coil for providing the source heat to the heat pump.

Figures IV-6, IV-7, IV-8, and IV-9 show the SAOHP system Heat Load Profiles for December 1977, and January, February, and March 1978. These profiles indicate the total building load each day and the relative amounts of electric resistance, electric heat pump and stored solar thermal energies utilized to meet these daily loads.

In conclusion, analysis of the performance data of the SAOHP system for the months of December 1977 and January, February and March suggests three primary results. First, building thermal containment is affected directly by the climatic conditions, but with little correlation to the wind speed and direction. Secondly, the collector efficiency cannot be related directly to the influence of any one particular factor. Finally, the underground uninsulated storage system does display seasonal characteristics, but that its performance and, in turn, the performance of the heat pump could be improved by the

FIGURE IV-6

SAOHP SYSTEM HEAT LOAD PROFILE

December 1977

FIGURE IV-7
SAOHP SYSTEM HEAT LOAD PROFILE

FIGURE IV-8
SAOHP SYSTEM HEAT LOAD PROFILE

February 1978

FIGURE IV-9

SAOHP SYSTEM HEAT LOAD PROFILE

addition of an upper heat exchange coil for extracting heat from the storage unit to provide source heat to the heat pump.

In addition, it should be noted that the thermal stratification in the storage tank displayed in December is the first occurrence of this phenomenon in the two years of operation of this system. However, in November 1977 the following changes were made to the storage system:

- An insulating blanket was applied above the storage tank
- The primary heat exchanger coil surface area was increased by the addition of copper fins
- A storage water to heat transfer booster coil circuit was removed from the piping configuration.

Any one or all of the above modifications could have been responsible for the changes in the storage system performance from its previously documented operating characteristics.