(2)

Dr. 6342

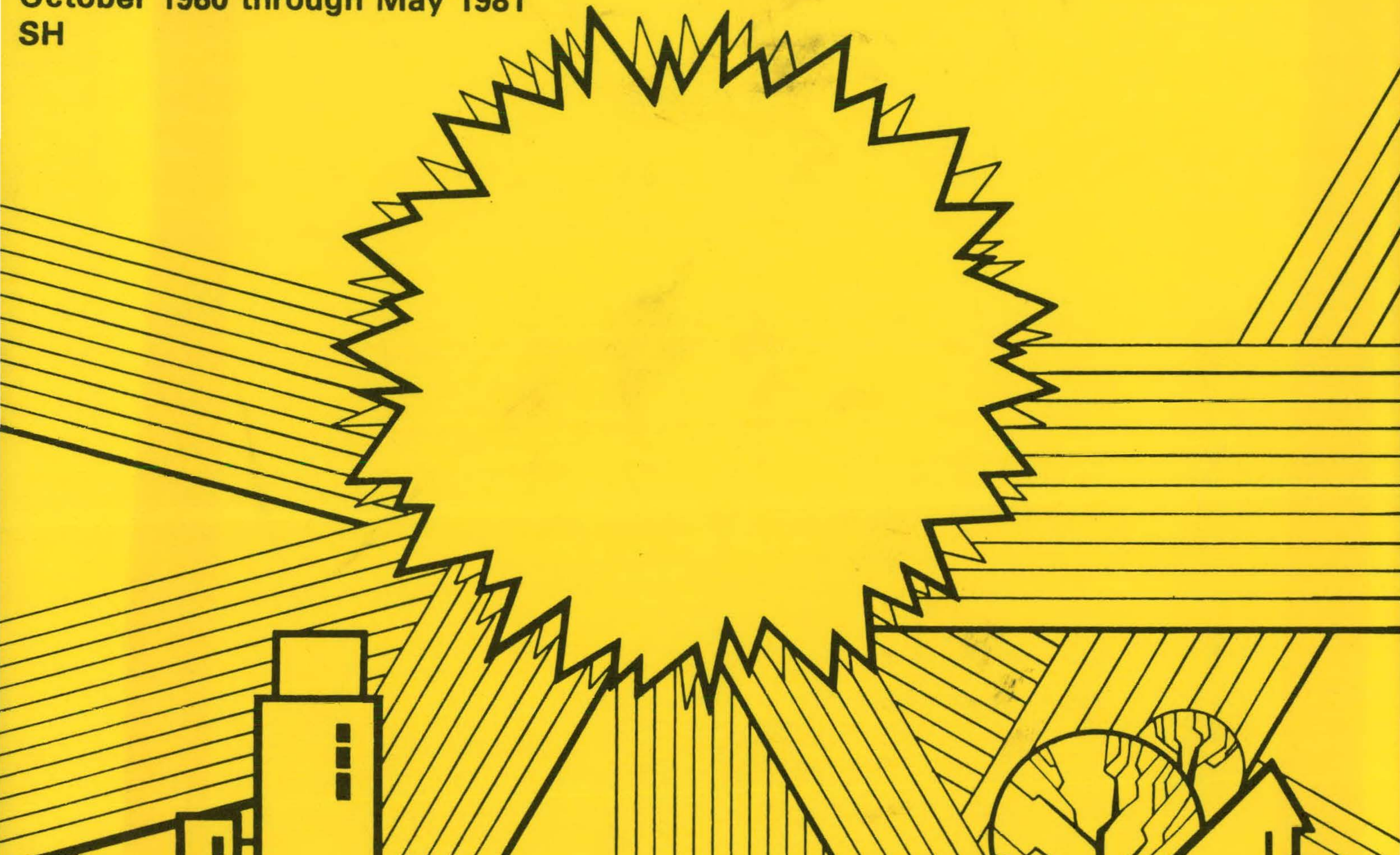
SOLAR/1095-81/14
(DE82007151)

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

MASTER

BAKER CONSTRUCTION

Cincinnati, Ohio
October 1980 through May 1981
SH



U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM

DISCLAIMER

DISCLAIMER

"This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A05
Microfiche A01

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issues of the following publications, which are generally available in most libraries: *Energy Research Abstracts, (ERA); Government Reports Announcements* and Index (*GRA* and I); *Scientific and Technical Abstract Reports (STAR);* and publication, NTIS-PR-360 available from (NTIS) at the above address.

SOLAR/1095-81/14
(DE82007151)
Distribution Category UC-59

BAKER CONSTRUCTION

CINCINNATI, OHIO

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

OCTOBER 1980 THROUGH MAY 1981

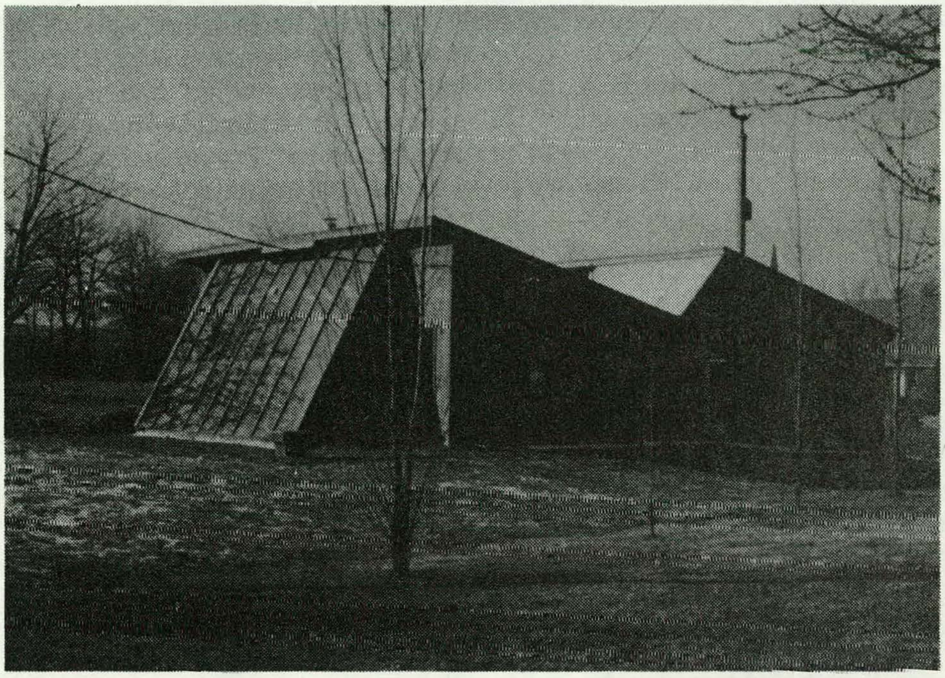
Prepared by J. W. Spears

Approved: TT Bradshaw
T. T. Bradshaw
Program Manager

Vitro Laboratories Division
Automation Industries, Inc.
14000 Georgia Avenue
Silver Spring, Maryland 20910

The National Solar Data Network
Department of Energy Contract Number DE-AC01-79CS30027
Contract Management by:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

G. A. McGinnis, Project Manager



BAKER CONSTRUCTION

FOREWORD

This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic hot water and annual performance reports are issued for such sites. In addition, Monthly Performance Reports, prior to 1981, are available for the solar systems in the network.

The National Solar Data Network consists of instrumented solar energy systems in buildings selected from among the 5,000 installations built (since early 1977) as part of the National Solar Heating and Cooling Demonstration Program. The overall purpose of this program is to assist in the development of solar technologies for buildings by providing data and information on the effectiveness of specific systems, the effectiveness of particular solar technologies, and the areas of potential improvement. Vitro Laboratories Division responsibility in the NSDN, under contract with the Department of Energy, is to collect data daily from the sites, analyze the data, and disseminate information to interested users.

Buildings in the National Solar Data Network are comprised of residential, commercial and institutional structures which are geographically dispersed throughout the continental United States. The variety of solar systems installed employ "active" mechanical equipment systems or "passive" design features, or both, to supply solar energy to typical building thermal loads such as space heating, space cooling, and domestic hot water. Solar systems on some sites are used to supply commercial process heat.

The buildings in the NSDN program are instrumented to monitor thermal energy flows to the space conditioning, hot water, or process loads, from both the solar system and the auxiliary or backup system. Data collection from each site, and transmission to a central computer for processing and analysis is highly automated.

BAKER CONSTRUCTION

The Baker Construction site is a single family residence, in Cincinnati, Ohio. The passive solar energy system is equipped with the following:

Collector	302 square feet of 62 degree sloped greenhouse glazing.
Storage	35,500-pound concrete mass wall, 10,400-pound concrete slab floor and 20 "Thermal 81" phase change storage rods by PSI.
Auxiliary:	Six one-kw Electric baseboard heaters by Intertherm and a wood stove.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

TABLE OF CONTENTS

Section Page

Appendices

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

SECTION 1

SOLAR SYSTEM PERFORMANCE

BAKER CONSTRUCTION
OCTOBER 1980 THROUGH MAY 1981

Solar Fraction[1]	55%
Solar Savings Ratio[2]	0.55
Conventional Fuel Savings[3]	5,639 kwh of electricity, or 31,439 cubic feet of natural gas, or 231 gallons of fuel oil

Seasonal Energy Requirements
October 1980 through May 1981
(Million BTU)

	Equipment Heating Load	Solar Contribution	% Solar
Heating	35.08	19.26	55

Environmental Data

	Measured Average	Long-Term Average
Outdoor temperature	45°F	45°F
Heating degree-days (Total)	4,974	5,017
Daily incident solar energy	1,047 BTU/ft^2	1,058 BTU/ft^2

1. Solar Fraction $= \dfrac{\text{Solar Energy Supplied to Loads}}{\text{Equipment Load}}$

2. Solar Savings Ratio $= \dfrac{\text{Solar Energy Supplied to Load - Solar System Operating Energy}}{\text{Equipment Load}}$

3. Conventional Fuel Savings:

Equivalent Gallons of Fuel Oil = Solar energy used x 0.6 x 7.21 x 10^{-6} gallons/BTU

Equivalent Cubic Feet of Natural Gas = Solar energy used x 0.6 x 979.4 x 10^{-6} cubic feet

Equivalent kwh of Electricity = Solar energy used x 2.928 x 10^{-4} kwh/BTU

1.1 SUMMARY AND CONCLUSIONS

The Baker Construction site is a 1,600-square-foot single family residence in Cincinnati, Ohio. The building incorporates a 60-degree sloped sunspace into this two-story building. The first floor is completely below grade and opens to the lower level of the greenhouse. A one-foot-thick concrete mass wall separates the sunspace from the rest of the building. Additional thermal mass in the form of 20 phase-change thermal storage rods hangs in front of the mass wall. There is a "window quilt" movable insulation to insulate the greenhouse glass at night. A site-built active air collector above the greenhouse was originally incorporated into the design but not used during the monitoring period due to problems with the control system.

The building is well insulated with R-21 walls above grade, R-33 walls below grade, and R-50 ceiling. The air infiltration rate was assumed to be 0.5 air changes per hour. The greenhouse and south-facing windows are double-glazed and the east, west, and north windows are triple-glazed.

The Energy Flow Diagram for the Baker Construction solar energy system is presented in Figure 1. The overall system thermal performance is presented in Table 1 and shown graphically in Figure 2.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

BAKER CONSTRUCTION
OCTOBER 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	EMPIRICAL HEATING DEGREE DAYS	BUILDING SOLAR FRACTION	BUILDING HEAT LOAD	CONDUCTION LOSSES (UA ΔT)	INFIL LOSSES	INTERNAL GAINS	AUX ENERGY CONSUMED	PASSIVE SOLAR ENERGY CONSUMED	EQUIPMENT HEATING LOAD	EQUIP SOLAR FRACTION (%)
OCT	360	92	7.52	5.58	1.94	0.02	0.57	6.93	7.50	92
NOV	656	62	9.30	6.77	2.53	2.17	1.38	5.75	7.13	81
DEC	913	22	7.51	4.38	3.13	2.03	3.83	1.65	5.48	30
JAN	1,161	27	9.06	3.36	3.70	2.46	4.14	2.46	6.60	37
FEB	804	19	6.54	3.90	2.64	2.61	2.67	1.26	3.93	32
MAR	717	9	6.07	3.70	2.37	2.48	3.05	0.54	3.59	15
APR	197	23	2.93	1.90	1.03	2.19	0.07	0.67	0.74	91
MAY	166	0	2.46	1.42	1.04	2.35	0.11	0.00	0.11	0
TOTAL	4,974	-	51.39	33.01	18.38	16.31	15.82	19.26	35.08	-
AVERAGE	622	37	6.42	4.13	2.30	2.04	1.98	2.41	4.39	55

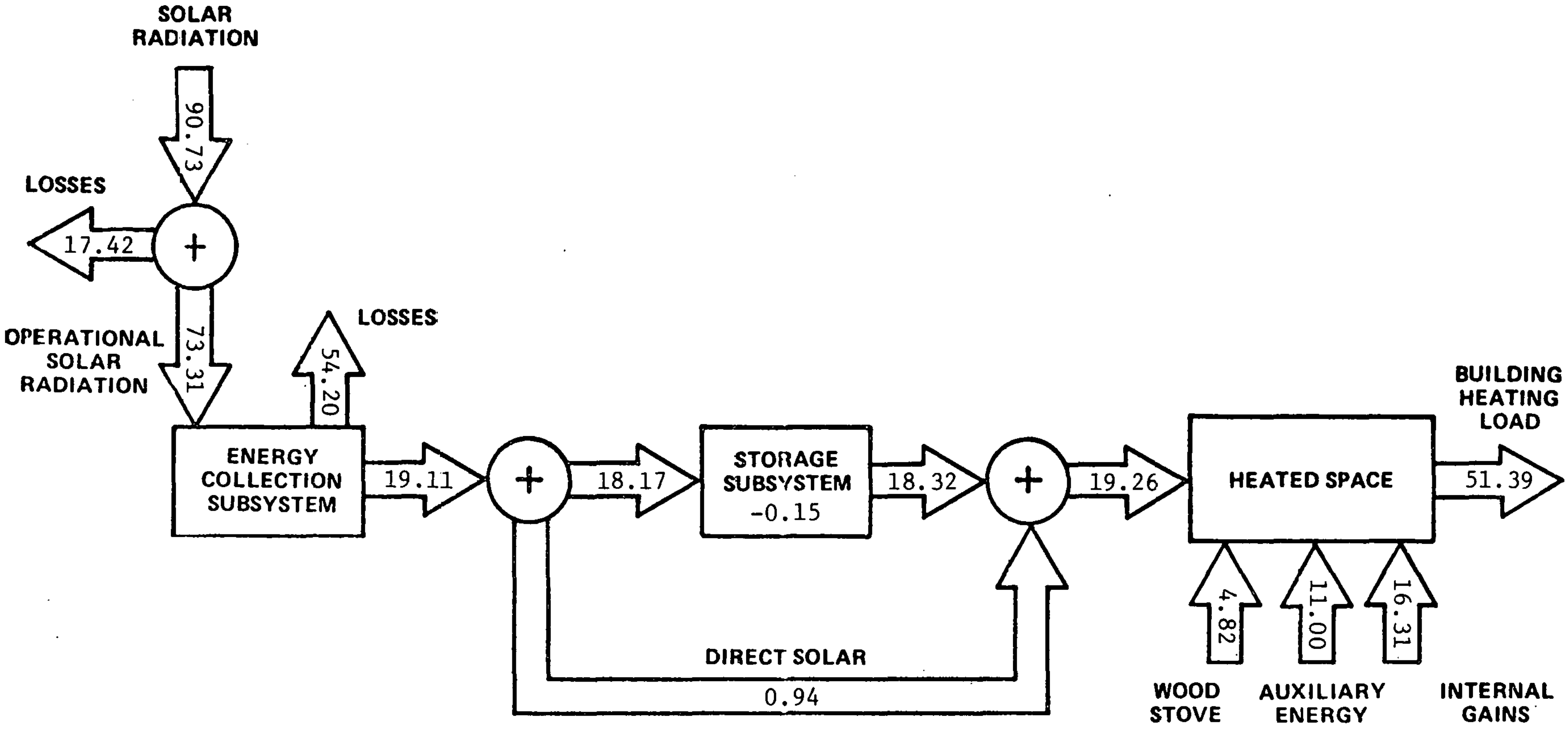


Figure 1. Energy Flow Diagram for Baker Construction
October 1980 through May 1981
(Figures in million BTU)

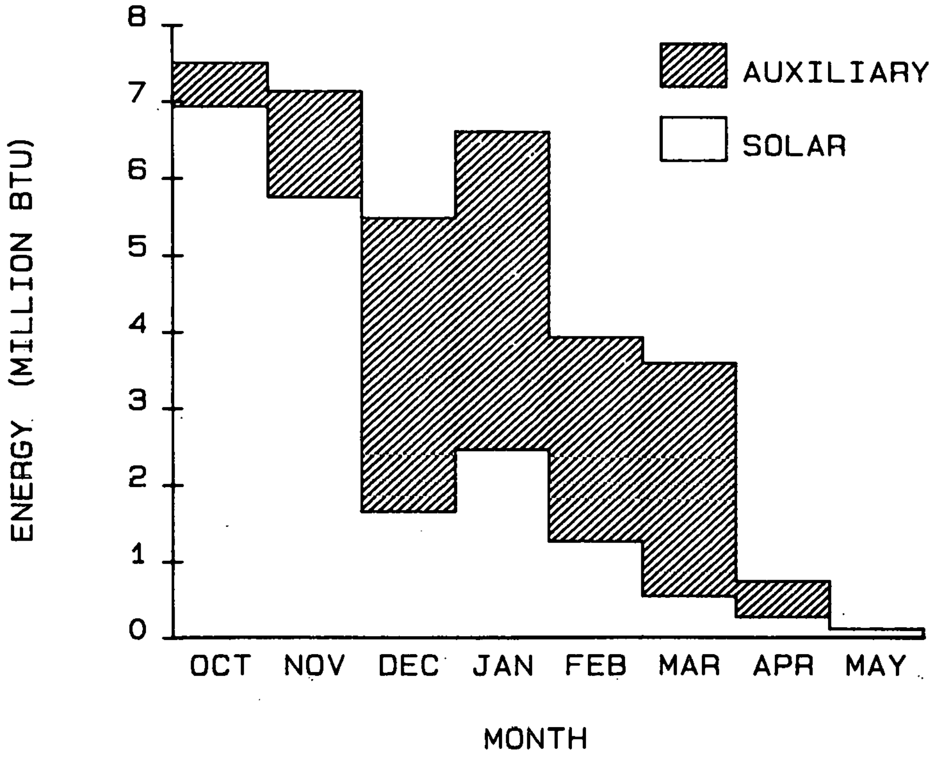


Figure 2. System Thermal Performance
Baker Construction
October 1980 through May 1981

The heating season from October 1980 through May 1981 had 4,974 heating degree-days which is very close to the long-term average. The load on the building was 51.39 million BTU for this period which represents 6.46 BTU per degree-day/per square foot ($BTU/DD/FT^2$) of floor area. This is very low compared to a typical home in that area which may consume as much as 15 $BTU/DD/FT^2$. The infiltration loss was 36% of the building heat load. The internal gains were high (16.31 million BTU). This is due to the frequent use of the electric clothes dryer which was vented indoors during the heating season. The electric baseboard heaters provided 21% of all the building heat load. The electric baseboard heaters were mainly used in the bedrooms on the lower level. The upstairs units rarely come on. This low usage shows the stratification of heat in the building because the upstairs is always warmer than the downstairs. A ceiling fan is used over the stairwell to try to destratify the air but its effectiveness is limited. At times, when the greenhouse is hot, the upstairs will overheat and the downstairs will be cool and require auxiliary heat.

The movable insulation in the greenhouse was used regularly on cold nights and to prevent overheating during warm days. The operation of the "window quilt" was limited for much of the season due to problems with the curtain pulling loose from the track. This type of curtain works well on a vertical window wall but the weight of the curtain on a 60-degree slope tends to pull it out of the track on the edges.

The window insulation was open to collect 81% of the incident solar energy.

The wood stove was used regularly from December through March. The occupants would light a fire in the wood stove every evening and keep it going until they went to bed. Many evenings the wood stove was used when it was not needed and caused slight overheating.

Solar provided 19.26 million BTU or 55% of the equipment heat load of 35.08 million BTU. The equipment heat load includes the contributions from solar and auxiliary energy but does not include internal gains. The performance of the system could have been greatly improved if a means of distributing the high greenhouse temperatures to the lower-level bedrooms were provided.

The storage wall absorbed 18.17 million BTU and gave off 18.32 million BTU. Ninety-five percent of the solar energy used went through storage before going to the load. The phase-change storage system responded very quickly to incoming solar radiation. The top of the storage tubes melted before the bottom and the bottom of the tubes crystalized before the top. The phase-change storage tubes in the vertical position seem to stratify severely. This thermal stratification may be reduced if they were mounted horizontally rather than vertically.

The system performance is presented graphically for each month of the heating season in Figures 3 through 10.

The heating season for the Baker Construction site began in October. There were 360 heating degree-days in October, which was 25% colder than the long-term average. The ambient temperature ranged from a low of 39°F on October 25 to a high of 68°F on October 16. The building temperature ranged from 81°F to 71°F. The mass wall averaged 75°F for the month. Very little auxiliary energy was used until October 20 when the ambient temperature began to drop into the low 40's. The storage temperatures remained high (80°F) for the early part of the month and, as the weather turned cold after the October 20, the storage temperature dropped to 71°F.

November had 656 heating degree-days with a minimum ambient temperature of 30°F on November 26 and a high of 64°F on November 9. The storage temperature for the first two weeks in November remained within 2-3°F of building temperature. The ambient temperature was mild until November 11 when the temperature dropped to 33°F; but, because the day was clear with high solar radiation (1,830 BTU/FT^2), the average storage temperatures rose 3-4°F. From November 11 to 18, the ambient temperature was in the low 30's and the period from November 13 through 18 was very overcast. The effect of the cold temperature and no sun caused the storage temperature to drop to 63°F. The next three days (November 19-21) were clear and the storage gained 10°F but the remainder of the month was cloudy and the storage dropped to 63°F on November 27. The daily average building temperature fluctuated between 70°F to 75°F with a maximum hourly building temperature of 78°F and a low of 68°F. The greenhouse temperature ranged from a high of 112°F to a low of 54°F.

December had 913 heating degree-days with a maximum ambient temperature of 60°F and a minimum of 12°F. The incident solar energy (613 BTU/FT^2) was 16% below the long-term average. The ambient temperatures got colder this month and the storage lost 10°F for the month. The building temperature ranged from a high of 78°F to a low of 66°F. On December 20, the ambient temperature dropped to 12°F and there was good solar energy (1,554 BTU/FT^2) which caused the storage to

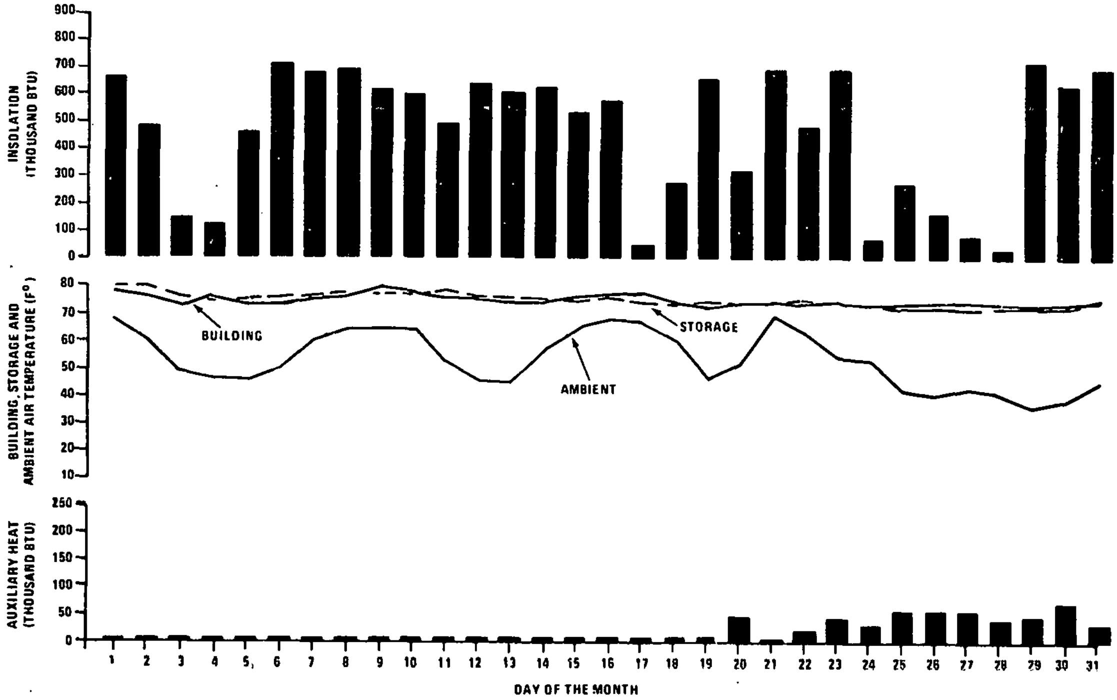


Figure 3. Building Performance
Baker Construction
October 1980

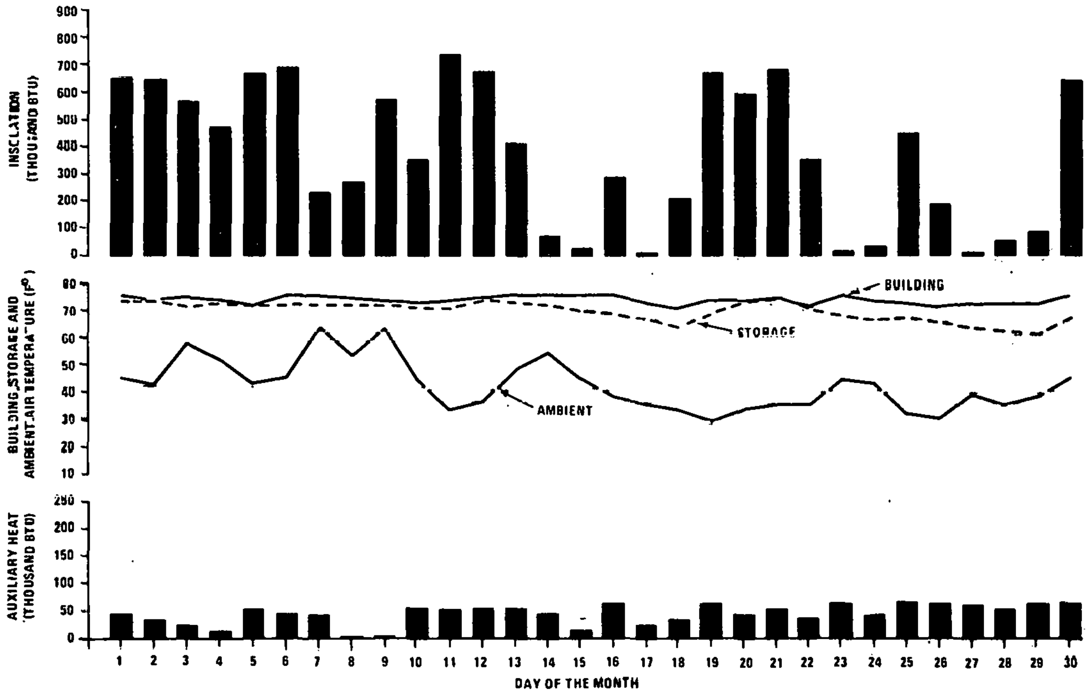


Figure 4. Building Performance
Baker Construction
November 1980

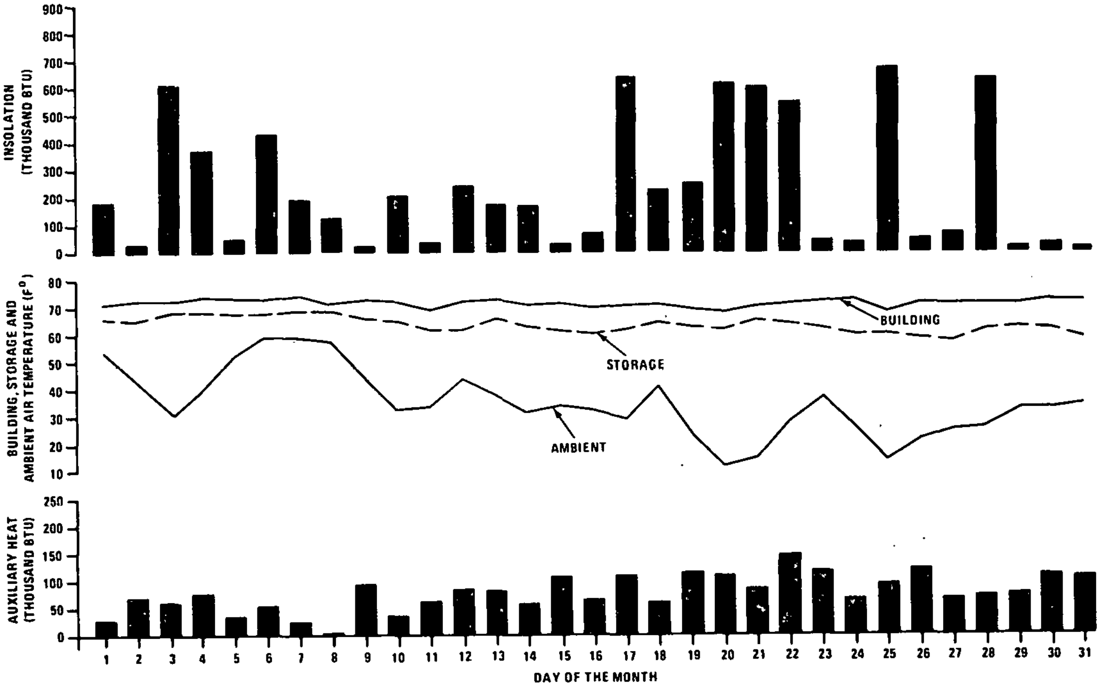


Figure 5. Building Performance
Baker Construction
December 1980

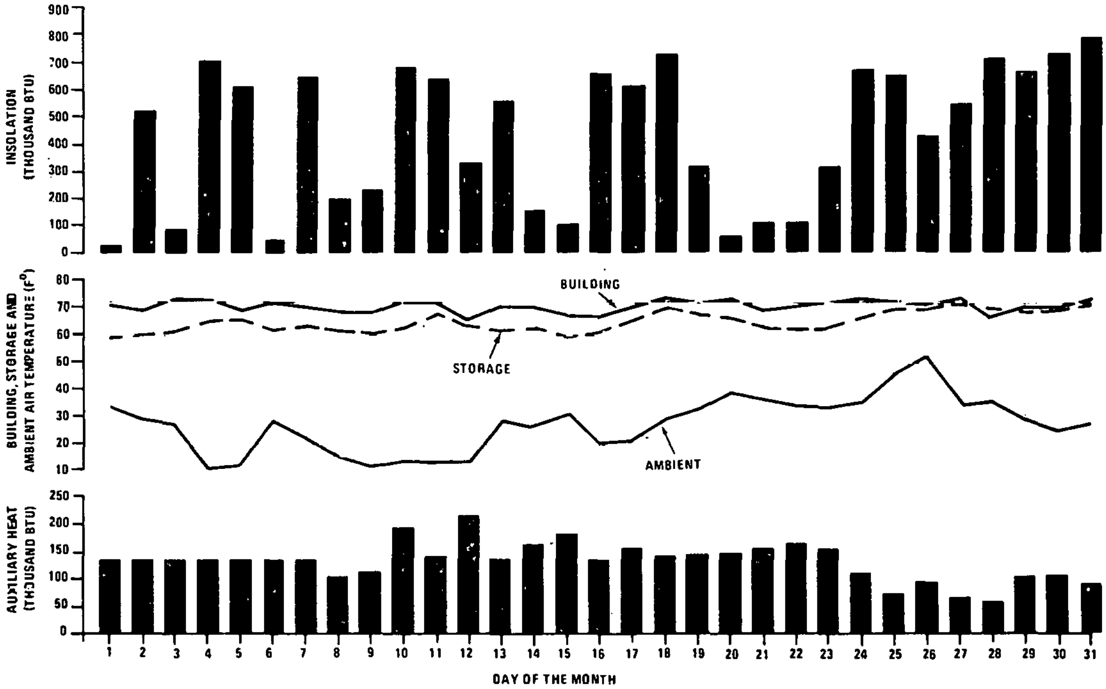


Figure 6. Building Performance
Baker Construction
January 1981

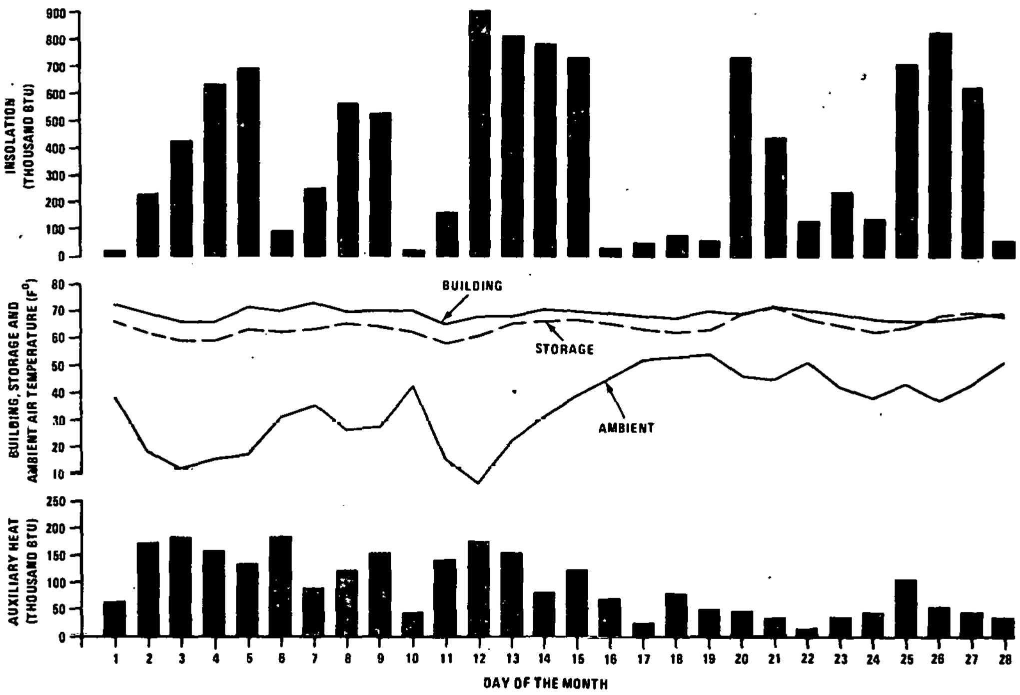


Figure 7. Building Performance
Baker Construction
February 1981

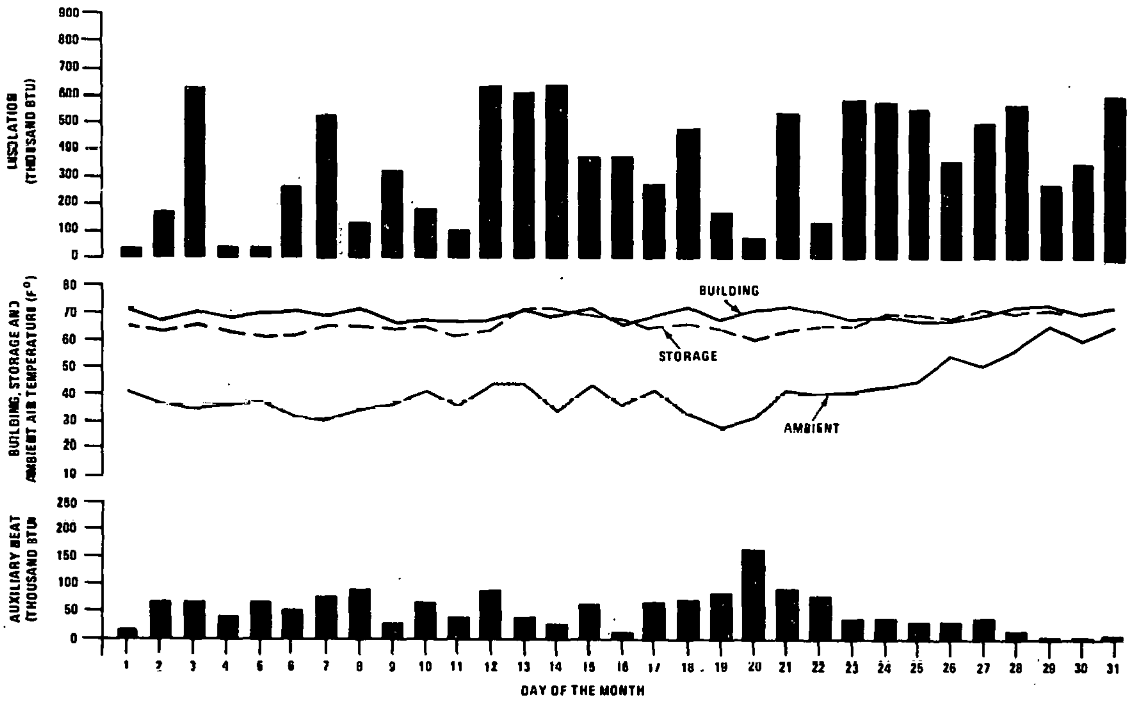


Figure 8. Building Performance
Baker Construction
March 1981

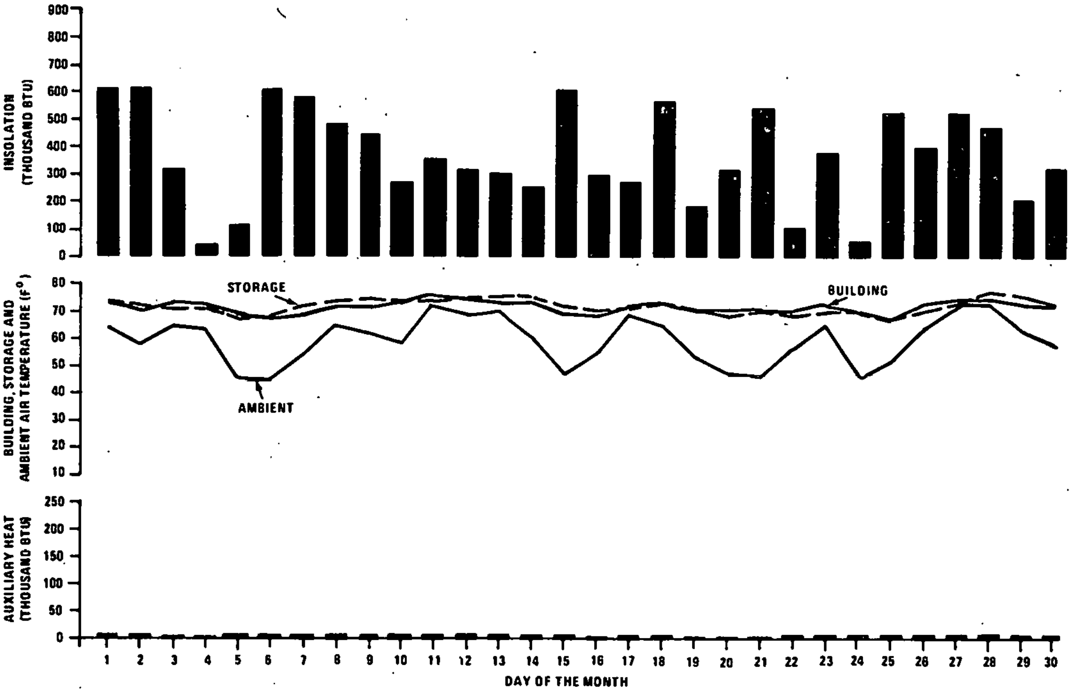


Figure 9. Building Performance
Baker Construction
April 1981

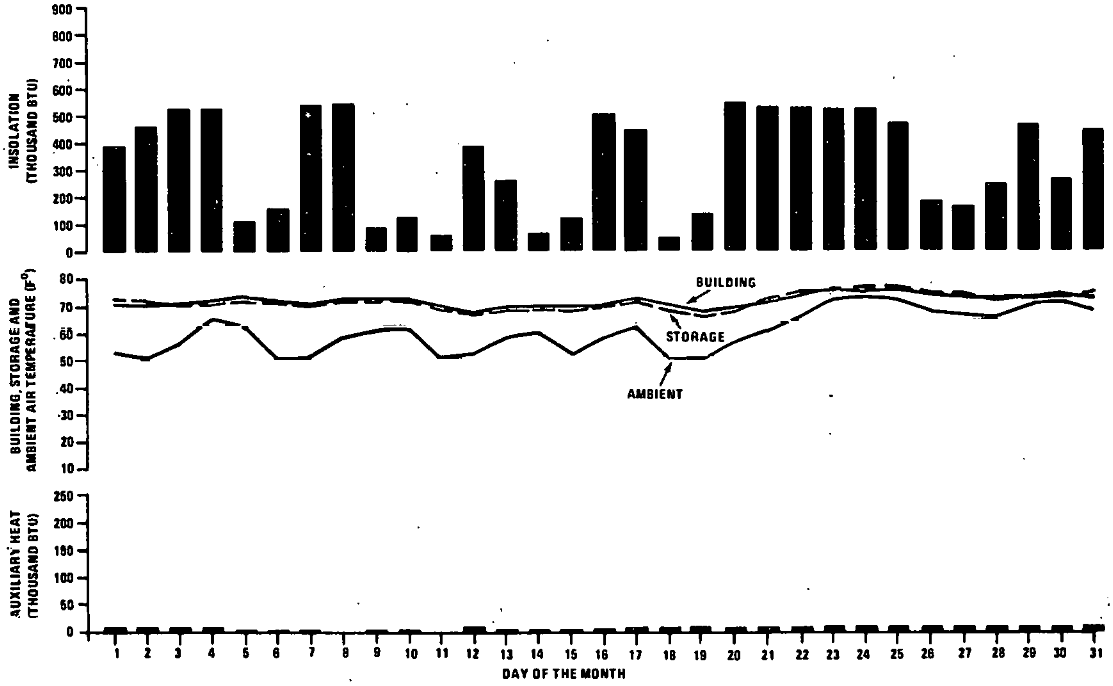


Figure 10. Building Performance
Baker Construction
May 1981

increase by 3°F. The wood stove was used regularly during December. The greenhouse temperature ranged from 102°F to 45°F.

January had 1,161 heating degree-days with a maximum ambient temperature of 51°F and a minimum of 10°F and 26% more incident solar energy than the long-term average. The building temperature ranged from 77°F to 62°F and the storage ranged from a low of 57°F to a high of 68°F. Due to the good solar condition this month, the storage gained 9°F during the month. The most dramatic change in storage occurred from December 15-18. The combination of good solar conditions and rising ambient temperatures caused the storage to rise from 59°F on December 15 to 69°F on December 18. The greenhouse temperatures ranged from 110°F to 45°F.

February had 804 heating degree-days with a high ambient temperature of 53°F and a low of 8°F which was on the coldest day of the year. The building ranged from a high of 78°F to a low of 62°F. The greenhouse ranged from 115°F to a low of 39°F on the coldest day of the year. The storage temperatures ranged from a low of 58°F on February 11 when the ambient was 16°F, to a high of 70°F on February 27. For a more detailed analysis of February performance, see the Storage Subsystem section of this report.

March began a warming trend with 717 heating degree-days and a maximum ambient temperature of 66°F and a minimum of 27°F. The building fluctuated from a maximum of 77°F to a minimum of 62°F. The greenhouse reached a maximum of 122°F and a low of 51°F. The storage wall went from a low of 61°F during the first week of March to a high of 72°F on March 31. The storage temperatures began to equal or exceed the room temperatures after March 24. The wood stove was used regularly during the month.

April was a relatively warm month with only 197 heating degree-days. This is 42% less than the long-term average. The average ambient temperatures ranged from 93°F to 29°F. The building temperature ranged from 81°F to 65°F and the greenhouse reached a maximum of 121°F and a minimum of 58°F. The auxiliary electric heat only came on occasionally and the wood stove was not used for the month. The storage wall maintained temperatures equal to or 1-2°F greater than average building temperature.

May had 166 heating degree-days with a maximum ambient temperature of 92°F and a minimum of 36°F. The greenhouse temperature fluctuated from a high of 110°F to a low of 60°F. The insulating curtains were kept closed on hot days to prevent overheating. The building temperatures went from a high of 80°F to a low of 67°F. The auxiliary electric heaters were only used occasionally and the wood stove was not used during the month. The storage temperatures ranged from a high of 77°F to a low of 65°F. The average storage temperature tracked very closely with the average building temperatures for the month.

1.2 SOLAR SYSTEM AVAILABILITY

The "window quilt" movable insulation was used regularly during the season on cold nights and on warm days to prevent overheating. The movable insulation was open to receive 81% of the incident solar radiation. The movable insulation was not opened when the owner believed that the solar radiation was not strong enough to offset the heat loss from the greenhouse glass.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The collector subsystem at Baker Construction consists of 302 square feet of south-facing greenhouse. The greenhouse is double-glazed and tilted at 62 degrees. Movable insulating shades are used to prevent high heat loss at night and to prevent overheating on warm days.

The upper portion of the greenhouse was designed as an active hot air collector but has not been used due to controller problems.

The greenhouse temperature fluctuates greatly during sunny days with the maximum temperature for the season reaching 121°F and the minimum being 39°F. The greenhouse reached 39°F on February 12 when the ambient temperature was -7°F and the wind was blowing at approximately 10 mph.

Table 2 shows maximum and minimum greenhouse temperatures from November 1980 through May 1981.

The movable insulation was used most of the year but problems with it made it very difficult to operate. The curtain is installed on a 62 degree slope and each curtain section is approximately nine feet wide. The weight of the curtain across the nine foot width puts a strain on the edge seals and causes them to pull out. This made it very difficult to raise and lower the curtain.

TABLE 2. GREENHOUSE TEMPERATURES (°F)

BAKER CONSTRUCTION
NOVEMBER 1980 THROUGH MAY 1981

MONTH	MAXIMUM	MINIMUM
NOV	112	54
DEC	102	45
JAN	110	45
FEB	115	39
MAR	121	51
APR	121	58
MAY	105	73
AVERAGE	112	52

Table 3 summarizes the performance of the collector subsystem. There were 90.73 million BTU of solar radiation incident to the greenhouse during the heating season. Of this incident energy, 81%, or 73.31 million BTU, was available while the shades were open.

Table 3. COLLECTOR SUBSYSTEM PERFORMANCE

BAKER CONSTRUCTION
OCTOBER 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	OPERATIONAL INCIDENT ENERGY	SOLAR ENERGY USED TRANSMITTED	COLLECTOR EFFICIENCY (%)
OCT	14.55	12.13	6.93	57
NOV	11.32	8.71	5.75	66
DEC	7.54	3.15	1.65	52
JAN	13.63	9.64	2.46	26
FEB	10.99	8.26	1.26	15
MAR	11.35	11.30	0.54	5
APR	11.02	10.96	0.67	6
MAY	10.33	*	0.00	*
TOTAL	90.73	73.31	19.26	-
AVERAGE	11.34	9.16	2.41	26

* DENOTES UNAVAILABLE DATA.

Twenty-six percent, or 19.26 million BTU, was used to help satisfy the heating load. In May the energy collected could not be calculated due to a failure in the shutter sensor. The seasonal average value of 9.16 million BTU was used as the estimate for May and for the calculation of the seasonal total of 73.31 million BTU.

The transmittance of the greenhouse glazing was measured in February with an interior pyranometer. The average transmittance was 55% for the month. The solar energy used by the building was 1.26 million BTU for February or 28% of the transmitted solar energy. The losses through the greenhouse glazing accounted for the 72% loss of transmitted solar during February.

2.2 STORAGE

The storage subsystem at Baker Construction consists of a one-foot-thick 35,500-pound concrete wall between the greenhouse and the house, a four-inch 10,400 pound concrete slab floor in the greenhouse and 20 "Thermal 81" phase-change storage rods suspended in front of the mass wall. The phase-change rods are designed to change phase at 81°F.

Table 4 presents the performance of the sensible heat thermal storage of the concrete elements at Baker Construction. The average storage temperature was 67°F with a high of 75°F in October and a low of 60°F in December. The mass wall and floor absorbed 18.17 million BTU and reradiated 18.32 million BTU to the space with a net storage change of -0.15 million BTU.

Table 4. STORAGE PERFORMANCE

BAKER CONSTRUCTION
OCTOBER 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	AVERAGE STORAGE TEMPERATURE (°F)	AVERAGE BUILDING TEMPERATURE (°F)
OCT	2.00	2.17	-0.17	75	75
NOV	1.96	2.00	-0.04	66	73
DEC	1.96	2.03	-0.07	60	72
JAN	2.85	2.76	0.09	62	70
FEB	2.47	2.47	0.00	62	69
MAR	2.58	2.51	0.07	66	69
APR	2.29	2.32	-0.03	73	72
MAY	2.06	2.06	0.00	72	72
TOTAL	18.17	18.32	-0.15	-	-
AVERAGE	2.27	2.29	-0.02	67	71.5

Figures 11 through 14 present the charging and discharging cycle of the mass wall from February 11 through February 18. February 11 was very cold with ambient temperatures below zero by the end of the day and very little solar radiation. The storage wall reached a low temperature of 57°F and the greenhouse dropped to 43°F. February 12 remained very cold with 10 mph winds but with excellent solar radiation. The greenhouse reached 101°F and the storage rose from 54°F in the early morning to 69°F by 3:00 p.m. The auxiliary heating system did not come on from 11:00 a.m. until 6:00 p.m., except for a small amount of electric heat in the bedroom at 2:00 p.m. At 6:00 p.m., the wood stove was lit and burned all night. February 13 was another excellent solar day and the greenhouse temperature went over 100°F between 2:00 p.m. and 3:00 p.m. The storage temperature was down to 61°F by early morning but rose to 69°F by late afternoon. The auxiliary energy was not used from 8:00 a.m. till 7:00 p.m. except for a small amount in the bedroom at 2:00 p.m. At 7:00 p.m., the wood stove was lit and burned all night.

February 14 and 15 were also good solar days and the greenhouse went over 100°F on both days and dropped to a low of 52°F on the morning of February 14. The storage wall went from 62°F on the morning of February 14 to a high of 70°F both afternoons. The wood stove was still heating the morning of February 15 and was fired back up about 1:00 p.m.

February 16 through February 18 were very cloudy but the ambient temperature was warming from the very cold week before. The storage maintained an average temperature of 63°F for this three day period. The greenhouse and house temperatures remained within a few degrees of each other except the evening of February 16 when the wood stove was used and the building temperature went up to 75°F.

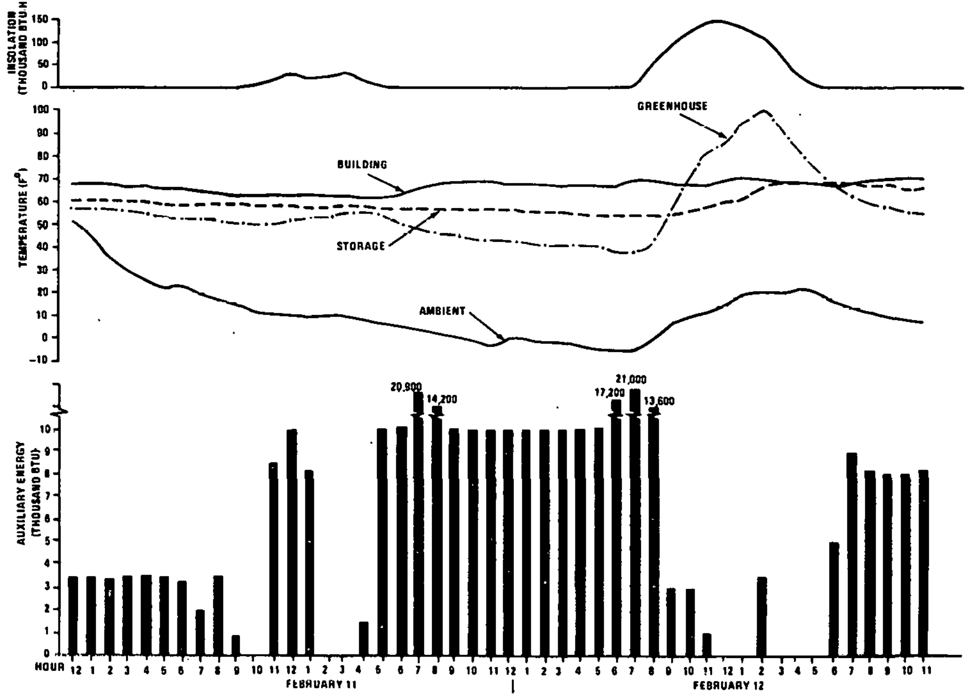


Figure 11. Charging and Discharging Cycle
Baker Construction
February 11-12, 1981

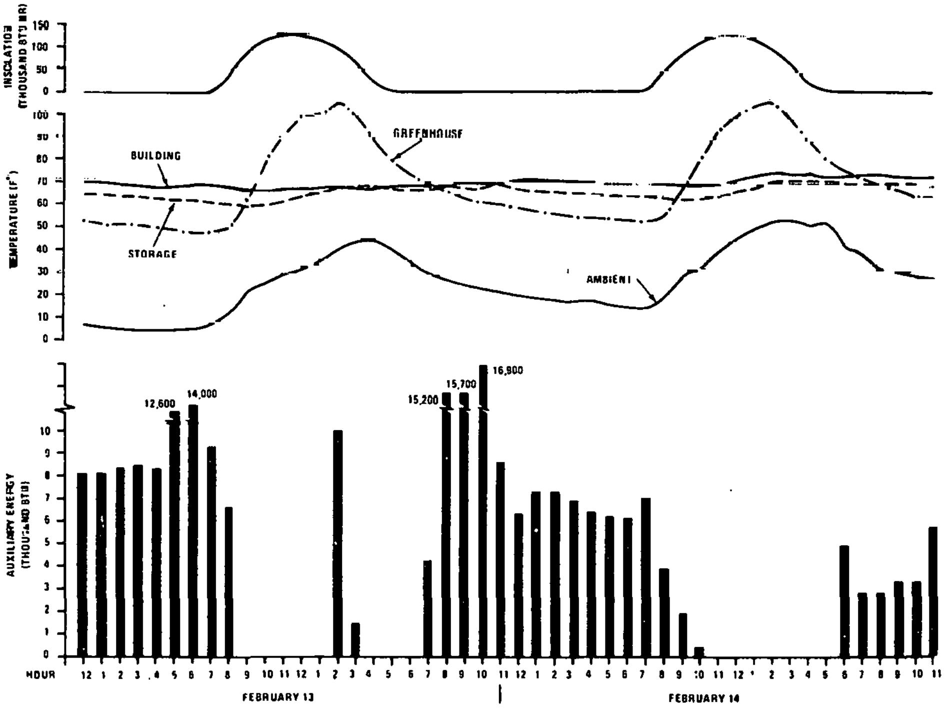


Figure 12. Charging and Discharging Cycle
Baker Construction
February 13-14, 1981

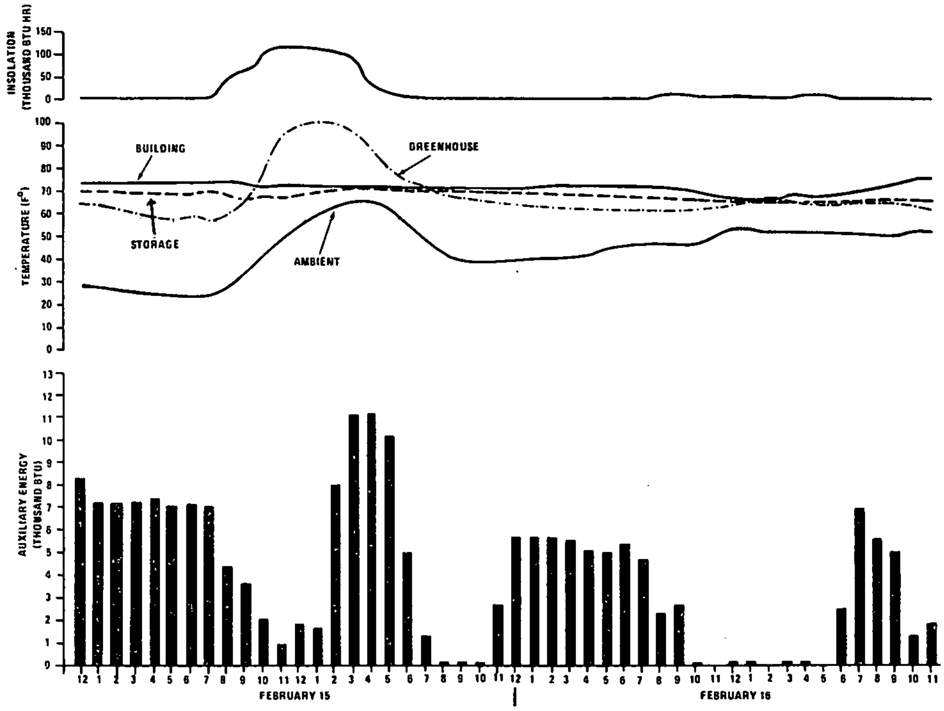


Figure 13. Charging and Discharging Cycle
Baker Construction
February 15-16, 1981

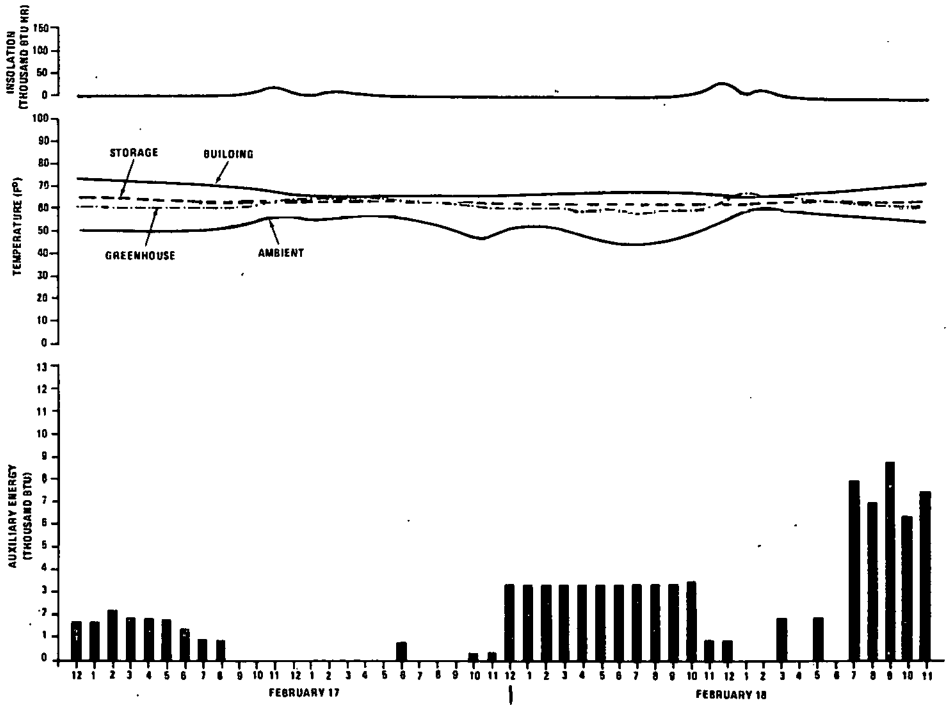


Figure 14. Charging and Discharging Cycle
Baker Construction
February 17-18, 1981

The phase-change storage performance is presented in Figures 15 through 22 for the period from February 11 through February 18.

Two of the 20 "Thermal 81" rods are instrumented with a sensor inside the top and bottom of each of the two rods.

February 11 was cold and very little solar energy was available. The rods reached their lowest temperature (50°F - 56°F) by 7:00 a.m. on February 12. When the sun came out on February 12, the rods responded immediately and were fully melted at 81°F by 1:00 p.m. The top of the rods melted first and then the bottoms. The top of the rods remained melted throughout the night but after midnight the bottoms began to solidify. By 8:00 a.m. February 13, the bottoms of the rods were about 59°F and the tops were still at 80°F-81°F. By the end of the day on February 13, the bottoms warmed up to almost 80°F but never fully melted.

In the morning of February 14, the tops of the rods had partially solidified (average approximately 75°F) and the bottoms had completely solidified. The good solar conditions on February 14 melted the tops fully but only partially melted the bottoms.

The tops were partially solidified and the bottoms completely solidified by 8:00 a.m. on February 15. The moderate solar conditions on February 15 did not completely melt the top and bottom of the rods.

On the next three days (February 16-18), there was very little solar and the rods stayed completely solidified reaching a low temperature of approximately 59°F by 8:00 a.m. on February 18.

The phase-change storage rods respond very quickly to solar radiation and discharge slowly when fully melted. The rods in the vertical orientation as in Baker Construction tend to stratify, severely limiting the percentage of phase-change material participating. Mounting the rods horizontally may reduce the stratification and improve their performance.

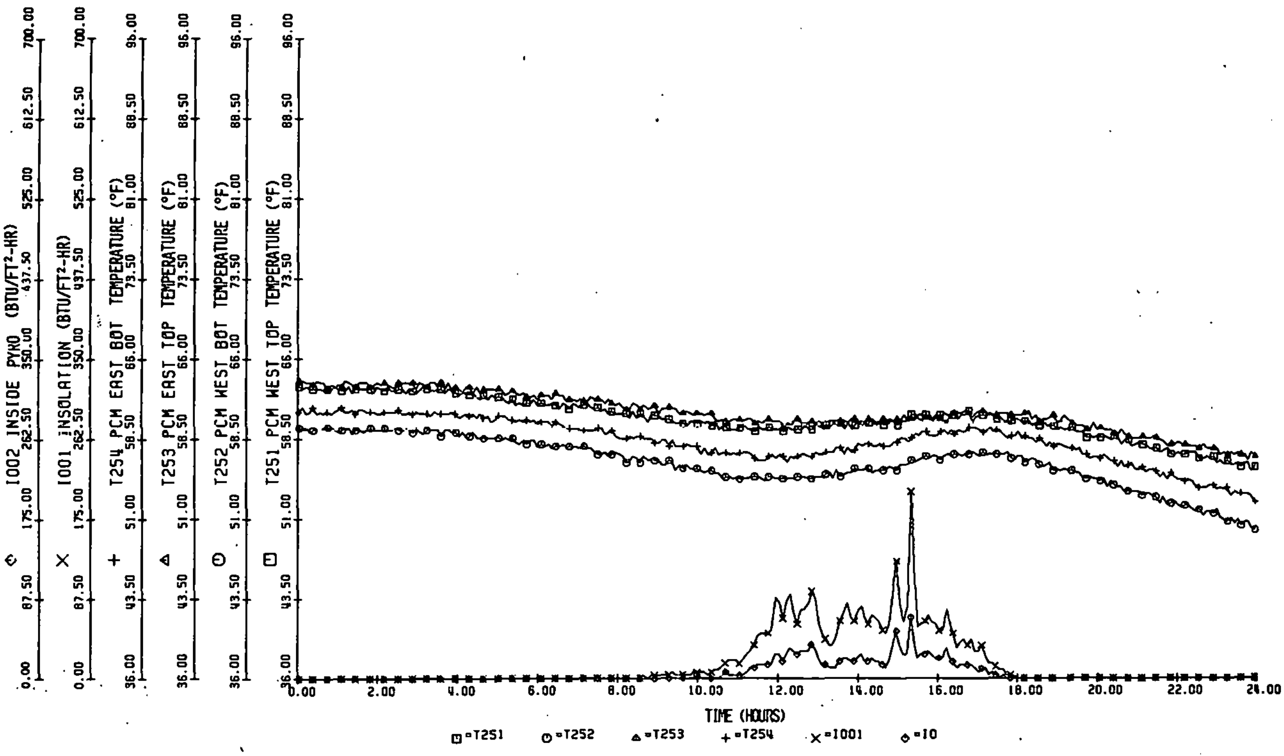


Figure 15. Phase-Change Storage Performance
Baker Construction
February 11, 1981

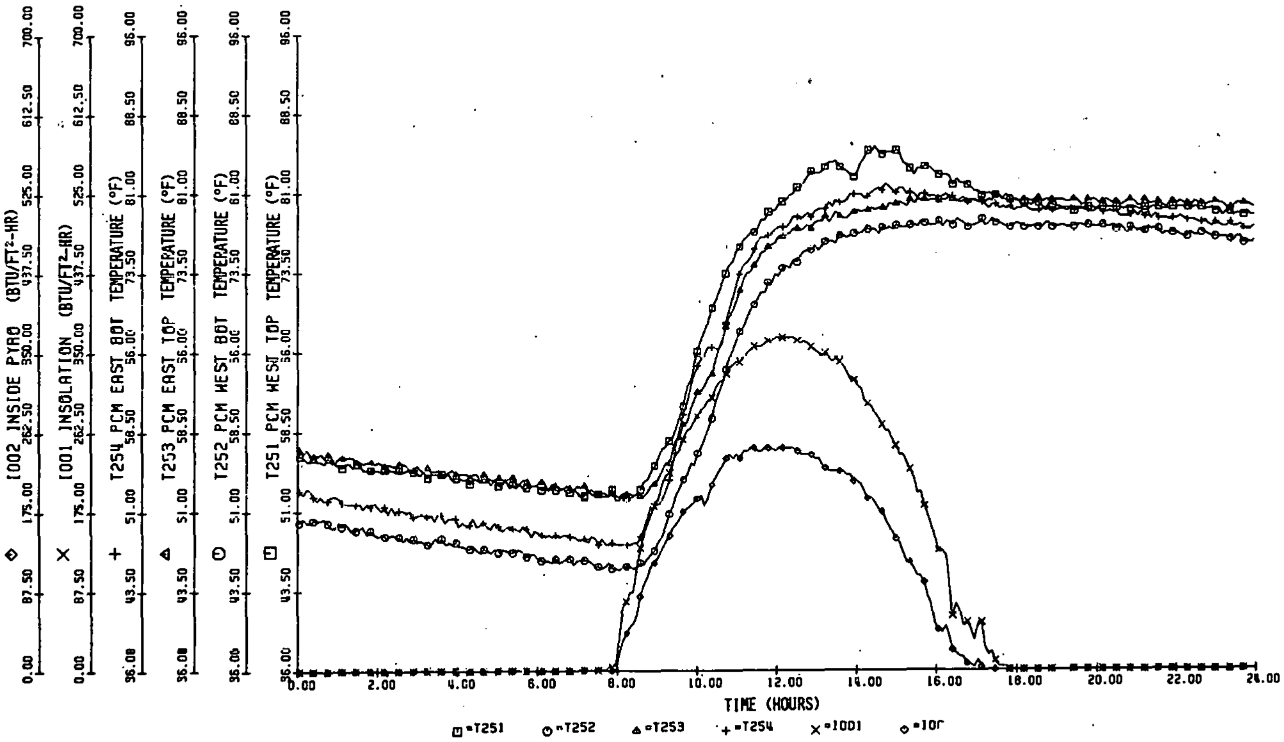


Figure 16. Phase-Change Storage Performance
Baker Construction
February 12, 1981

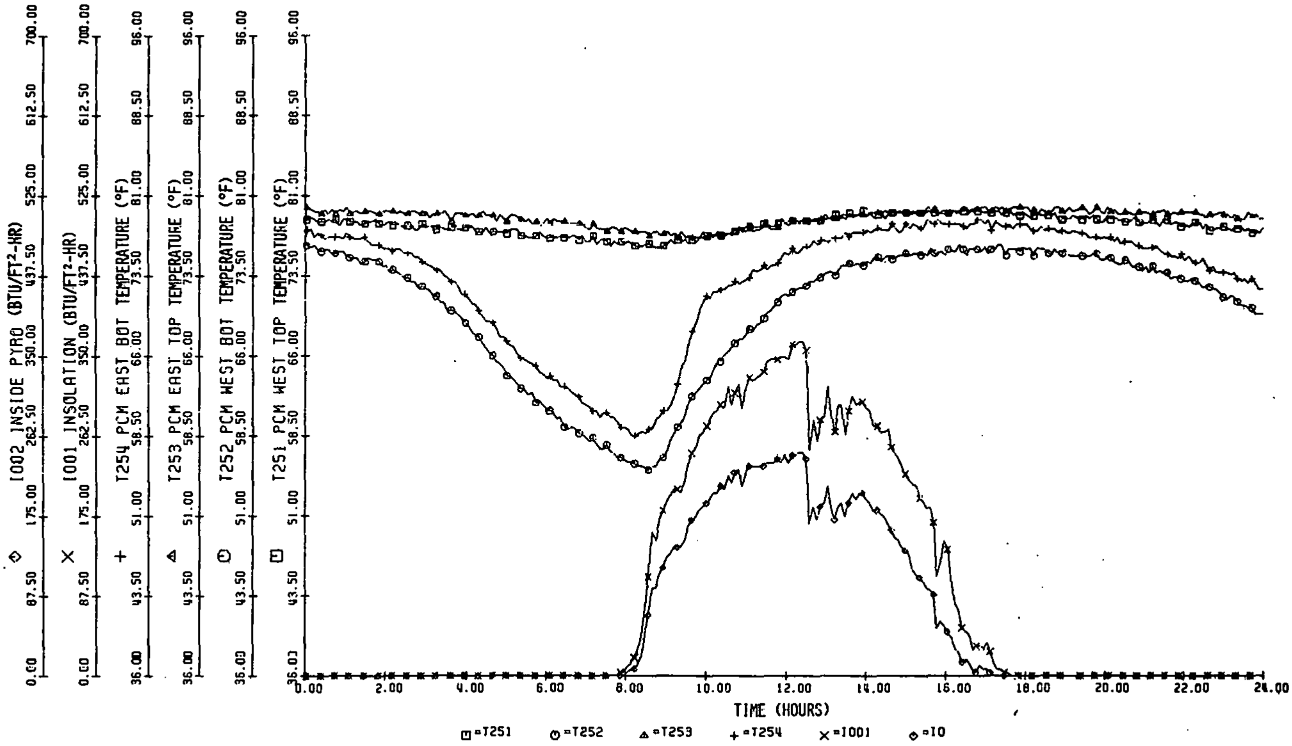


Figure 17. Phase-Change Storage Performance
Baker Construction
February 13, 1981

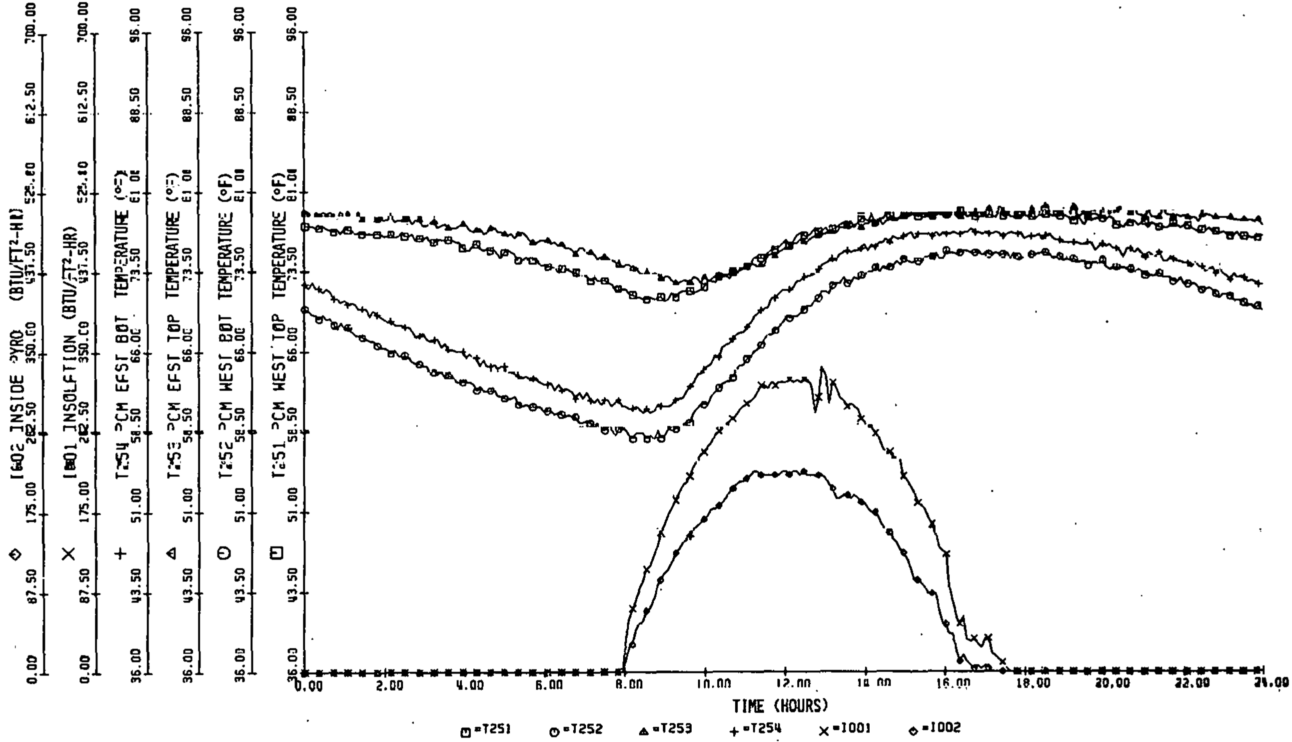


Figure 18. Phase-Change Storage Performance
Baker Construction
February 14, 1981

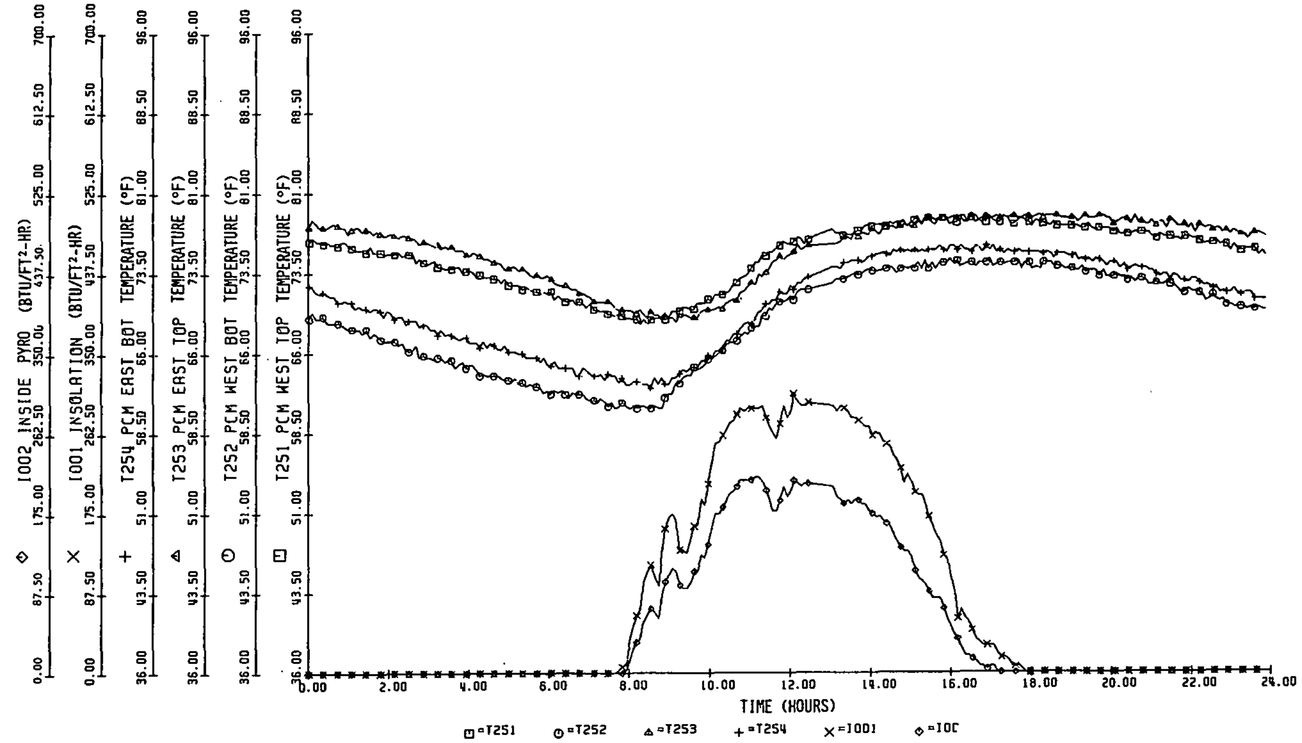


Figure 19. Phase-Change Storage Performance
Baker Construction
February 15, 1981

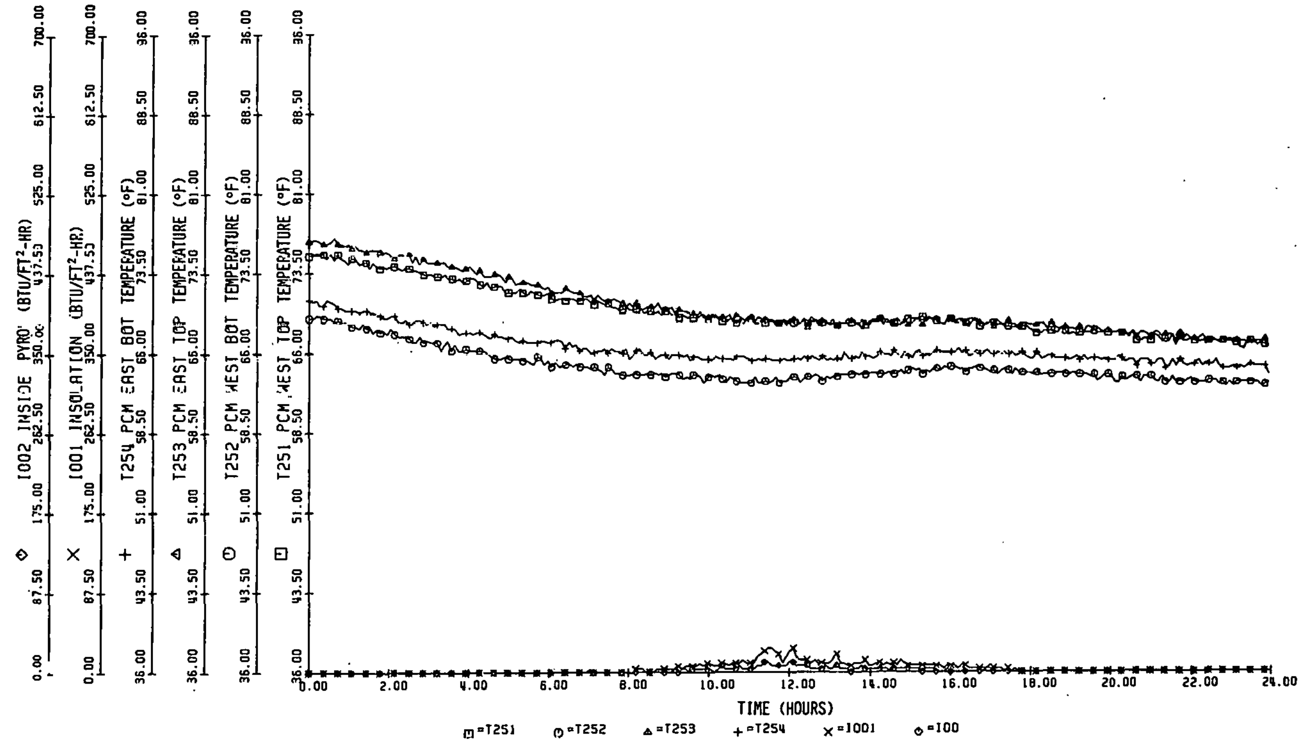


Figure 20. Phase-Change Storage Performance
Baker Construction
February 16, 1981

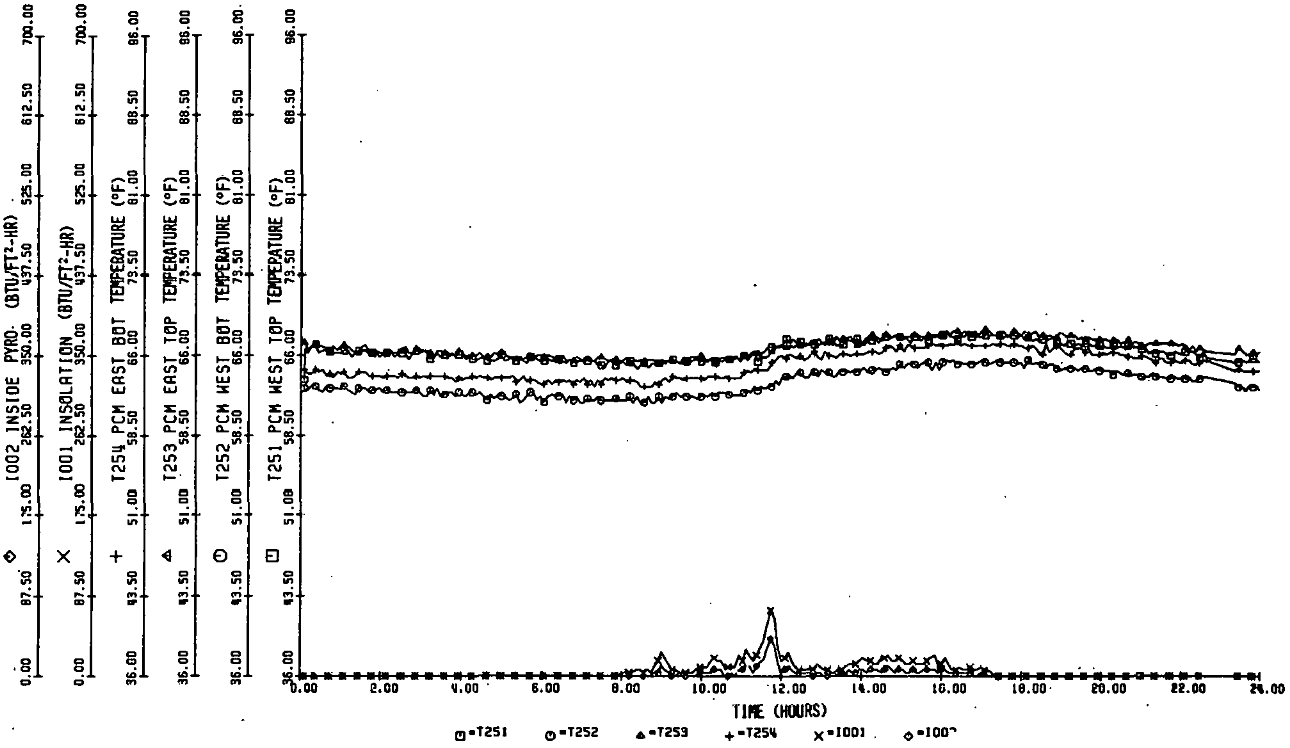


Figure 21. Phase-Change Storage Performance
Baker Construction
February 17, 1981

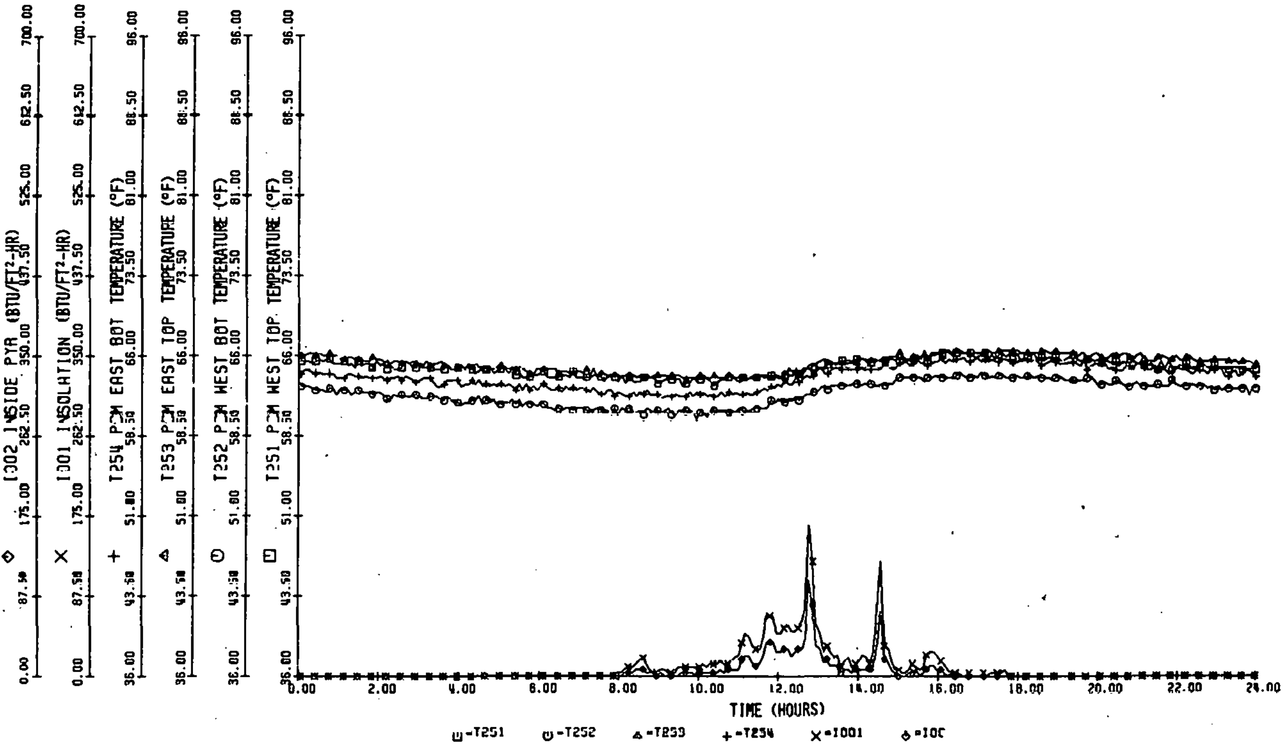


Figure 22. Phase-Change Storage Performance
Baker Construction
February 18, 1981

2.3 SPACE HEATING

The space heating subsystem performance for Baker Construction is shown in Table 5.

Table 5. SPACE HEATING SUBSYSTEM

BAKER CONSTRUCTION
OCTOBER 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	BUILDING SOLAR FRACTION (%)	BUILDING HEAT LOAD	AUXILIARY ENERGY CONSUMED WOOD STOVE	AUXILIARY ENERGY CONSUMED ELECTRICAL	INTERNAL HEAT GAINS	SOLAR ENERGY USED
OCT	92	7.52	0.00	0.57	0.02	6.93
NOV	62	9.30	0.00	1.38	2.17	5.75
DEC	22	7.51	1.38	2.45	2.03	1.65
JAN	27	9.06	1.34	2.80	2.46	2.46
FEB	19	6.54	0.74	1.93	2.61	1.26
MAR	9	6.07	1.36	1.69	2.48	0.54
APR	23	2.93	0.00	0.07	2.19	0.67
MAY	0	2.46	0.00	0.11	2.35	0.00
TOTAL	-	51.39	4.82	11.00	16.31	19.26
AVERAGE	37	6.42	0.60	1.38	2.04	2.41

The space heating load was met by 38% solar, nine percent wood stove, 32% internal gains, and 21% electric. The electric baseboard heaters were used primarily in the lower-level bedrooms. The upper-level heaters rarely came on. Most evenings the wood stove was used to warm the upstairs. The wood stove was used on many days when the room temperature was over 70°F.

The internal gains were high due to the high electrical consumption. The dryer was used almost every day and it was vented indoors.

The passive system environment is presented in Table 6. The average building temperature was 72°F with a maximum of 79°F and a minimum of 65°F. The average indoor relative humidity was 52%. The average storage temperature was 67°F. The average ambient temperature was 46°F and the daytime ambient was 48°F with a total of 90.73 million BTU of solar energy incident in the greenhouse glazing.

Table 6. PASSIVE SYSTEM ENVIRONMENT

BAKER CONSTRUCTION
OCTOBER 1980 THROUGH MAY 1981

MONTH	BUILDING TEMPERATURE (°F)	MAXIMUM BUILDING TEMPERATURE (°F)	MINIMUM BUILDING TEMPERATURE (°F)	INDOOR RELATIVE HUMIDITY (%)	AVERAGE STORAGE TEMPERATURE (°F)	AMBIENT TEMPERATURE (°F)	DAYTIME AMBIENT TEMPERATURE (°F)	INCIDENT SOLAR RADIATION (MILLION BTU)
OCT	75	81	71	39	75	53	58	14.55
NOV	73	78	68	54	66	43	46	11.32
DEC	72	78	66	53	60	35	37	7.54
JAN	70	77	62	52	62	27	30	13.63
FEB	69	78	62	54	62	35	38	10.99
MAR	69	77	62	53	66	42	46	11.35
APR	72	81	65	55	73	60	64	11.02
MAY	72	80	67	57	72	61	66	10.33
TOTAL	-	-	-	-	-	-	-	90.73
AVERAGE	72	79	65	52	67	46	48	11.34

SECTION 3

ENERGY SAVINGS

Energy savings for this site for the reporting period, October 1980 through May 1981, are presented in Table 7. The solar system provided a net energy savings of 19.26 million BTU. This is equivalent to 5,639 kwh of electrical energy which, at $0.05 per kwh, is a savings of $282.00. If fossil fuel were the auxiliary source of energy at the site, energy savings would have been 32.10 million BTU based on a burner efficiency of 0.6. This is equivalent to 31,439 cubic feet of natural gas or 231 gallons of fuel oil. The dollar savings for natural gas (based on $0.40 per 100 cubic feet) would be $126.00 and for fuel oil (at $1.00 per gallon) would be $231.00.

Table 7. ENERGY SAVINGS

BAKER CONSTRUCTION
OCTOBER 1980 THROUGH MAY 1981

(All values in million BTU)

		NET ENERGY SAVINGS
MONTH	SOLAR ENERGY USED	ELECTRICAL
OCT	6.93	6.93
NOV	5.75	5.75
DEC	1.65	1.65
JAN	2.46	2.46
FEB	1.26	1.26
MAR	0.54	0.54
APR	0.67	0.67
MAY	0.00	0.00
TOTAL	19.26	19.26
AVERAGE	2.41	2.41

SECTION 4

WEATHER CONDITIONS

The Baker Construction site is located in Cincinnati, Ohio at 39.04 degrees N latitude and 84.30 degrees W longitude.

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the site during the reporting period are presented in Table 8. Also presented in the table are the corresponding long-term average monthly values of the measured weather parameters. These long-term average weather data were obtained from nearby representative National Weather Service and SOLMET meteorological stations. The long-term insolation values are total global horizontal radiation converted to collector angle and azimuth orientation.

Table 8. WEATHER CONDITIONS

BAKER CONSTRUCTION
OCTOBER 1980 THROUGH MAY 1981

	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS				
MONTH	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	RELATIVE HUMIDITY (%)	WIND DIRECTION (DEGREES)	WIND SPEED (MPH)
OCT	1,183	1,344	53	57	360	271	70	0	2
NOV	950	944	43	44	656	636	73	301	2
DEC	613	726	35	34	913	970	88	306	3
JAN	1,107	816	27	31	1,161	1,051	*	294	3
FEB	988	1,018	35	33	804	888	*	236	3
MAR	1,212	1,140	42	42	717	722	*	301	3
APR	1,216	1,233	60	54	197	341	64	277	3
MAY	1,103	1,243	61	63	166	138	77	0	1
TOTAL	-	-	-	-	4,974	5,017	-	-	-
AVERAGE	1,047	1,058	45	45	622	627	74	304	3

*DENOTES UNAVAILABLE DATA.

During the period from October 1980 through May 1981, the average daily incident solar radiation on the collector array was 1,047 BTU per square foot per day. This radiation was below the estimated average daily solar radiation for this geographical area during the reporting period of 1,058 BTU per square foot per day for a south-facing plane with a tilt of 62 degrees to the horizontal. During the period, the highest monthly average insolation was 1,216 BTU per square foot per day during April. The average ambient temperature during the reporting period was 45°F as compared with the long-term annual average of 45°F. The highest monthly average ambient temperature was 61°F during May, and the lowest monthly average ambient temperature was 27°F during January. The number of heating degree-days for the period (based on a 65°F reference) was 4,974 as compared with the long-term average of 5,017. The range of heating degree-days was from a high of 1,161 during January to a low of 166 during May.

Extraterrestrial radiation values are computed (see Footnote 1) and given in the table below for each month. The ratio of total insolation on a tilted surface to extraterrestrial radiation on a parallel surface is called the clearness index.

This parameter quantifies the effects of cloudiness and atmospheric transmission on the insolation received at the earth's surface. The clearness index ranged from a high of 48% during May to a low of 19% during December.

The average relative humidity was 74%. The average wind speed was 2.5 mph from 304°.

MONTH	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Extra-terrestrial Insolation	3,244	3,241	3,177	3,231	3,298	3,138	2,671	2,220
$\frac{\text{TTL INS}}{\text{EXT INS}}$ (%)	36	29	19	34	30	38	45	48

---

1. Computation method given in "TRNSYS, a Transient Simulation Program," Engineering Experiment Station Report #38, Solar Energy Laboratory, University of Wisconsin, Madison.

SECTION 5

REFERENCES

*1. National Solar Data Network, Department of Energy, prepared under Contract Number DE-AC01-79CS30027, Vitro Laboratories, Silver Spring, Maryland, January 1980.

2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.

3. E. Streed, et al, Thermal Data Requirements and Performance Evaluation Procedures for the National Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.

4. Mears, J. C., Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.

5. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, NY, 1977.

**6. ASHRAE Standard 94-77, Methods of Testing Thermal Storage Devices Based on Thermal Performance, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, NY, 1977.

*6A. User's Guide to Monthly Performance Reports, November 1981, SOLAR/0004-81/18, Vitro Laboratories, Silver Spring, Maryland.

*6B. Instrumentation Installation Guidelines March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.

*7. Monthly Performance Report, Baker Construction, December 1980, SOLAR/1095-80/12, Vitro Laboratories, Silver Spring, Maryland.

---

* Copies of these reports may be obtained from Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

**Note: Reference [6] only used if the heat transfer coefficient discussion in Section 5.3.1.2 applies.

APPENDIX A

SYSTEM DESCRIPTION

Baker Construction is a three-bedroom, two-level home in Cincinnati, Ohio. The floor area is 1,600 square feet consisting of living room, dining room, kitchen, and study on the upper level and bedrooms on the lower level. The passive heating system consists of a south-facing greenhouse with 302 square feet of double-glazed glass tilted at 62 degrees, and a 12-inch concrete and brick mass wall located between the greenhouse and the living area. Phase-change material has been added to the concrete wall to increase the thermal storage capacity. Movable insulating shades are drawn over the greenhouse glass at night to inhibit heat loss. This system is shown schematically in Figures A-1 through A-4.

The upper portion of the greenhouse consists of 95 square feet of site-built active solar air collector. A small fan is used to force the heated air into the greenhouse and living space. Passive summer cooling is provided by two fifty-foot-long air tunnels constructed of sections of vitreous clay and corrugated galvanized steel pipe buried seven feet below grade. Both tunnels provide a path for cooler outside ambient air to enter the structure at the lower passageway. Natural air flow through the home is induced by opening the dampers at both tunnels and the thermal chimney. A temperature difference between the chimney and passageway is set up and cool air is drawn through the home and exhausted to the outside through the thermal chimney damper. A fan located in the greenhouse serves as a booster to induce additional airflow when natural means are not adequate. Electrical baseboard radiation and a wood-burning stove are utilized for backup heat sources.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Components	Manufacturer	Model No.
Phase-Change Storage	PSI	Thermal "81"
Movable Insulation	Window Quilt	

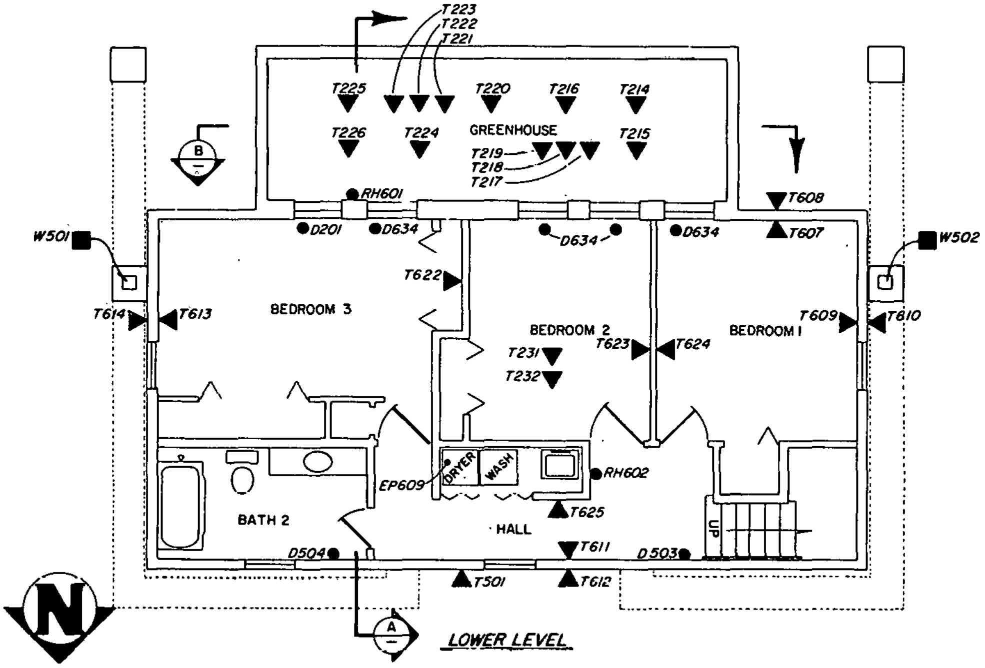


Figure A-1. Baker Construction Solar Energy System Schematic, Lower Level

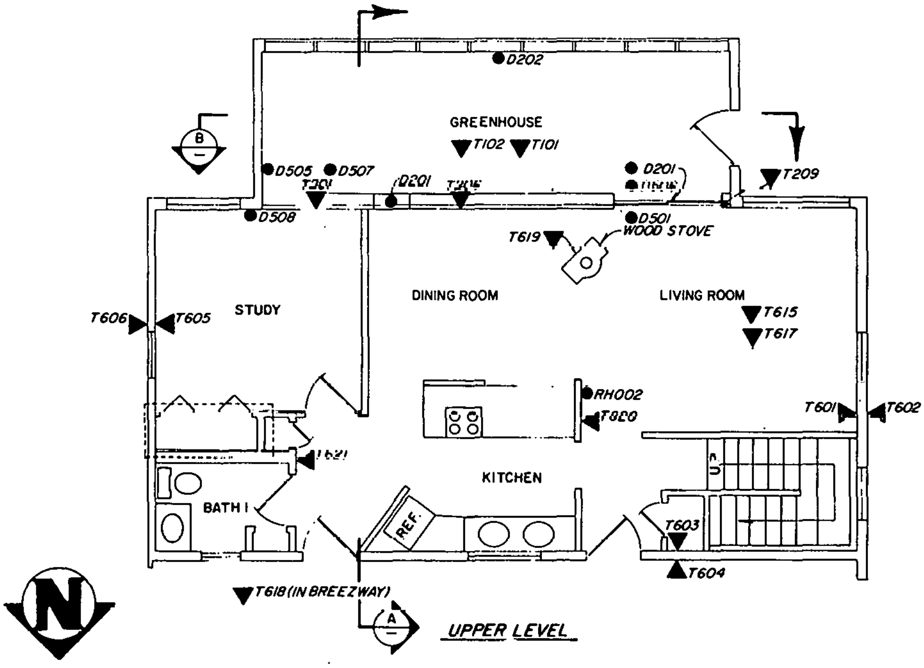


Figure A-2. Baker Construction Solar Energy System Schematic, Upper Level

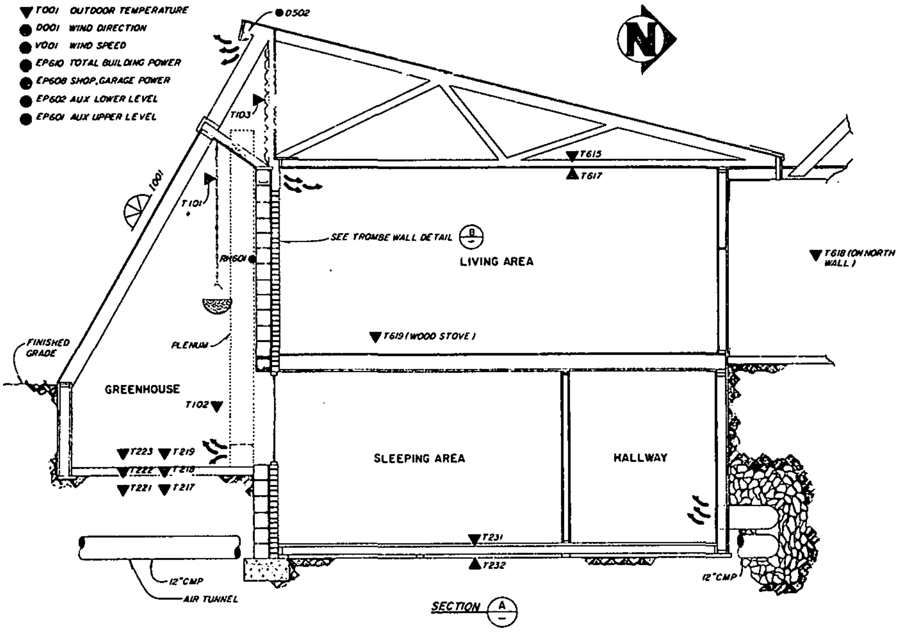


Figure A-3. Baker Construction Solar Energy System Schematic, Section

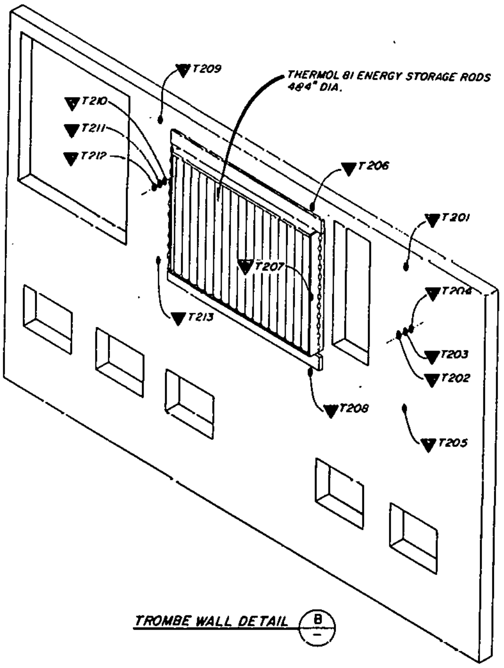


Figure A-4. Baker Construction Solar Energy System Schematic, Trombe Wall Detail

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Baker Construction solar energy system is evaluated by calculating a set of primary performance factors which are based on those in the intergovernmental agency report "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program" (NBSIR-76/1137).

An overview of the NSDN data collection and dissemination process is shown in Figure B-1.

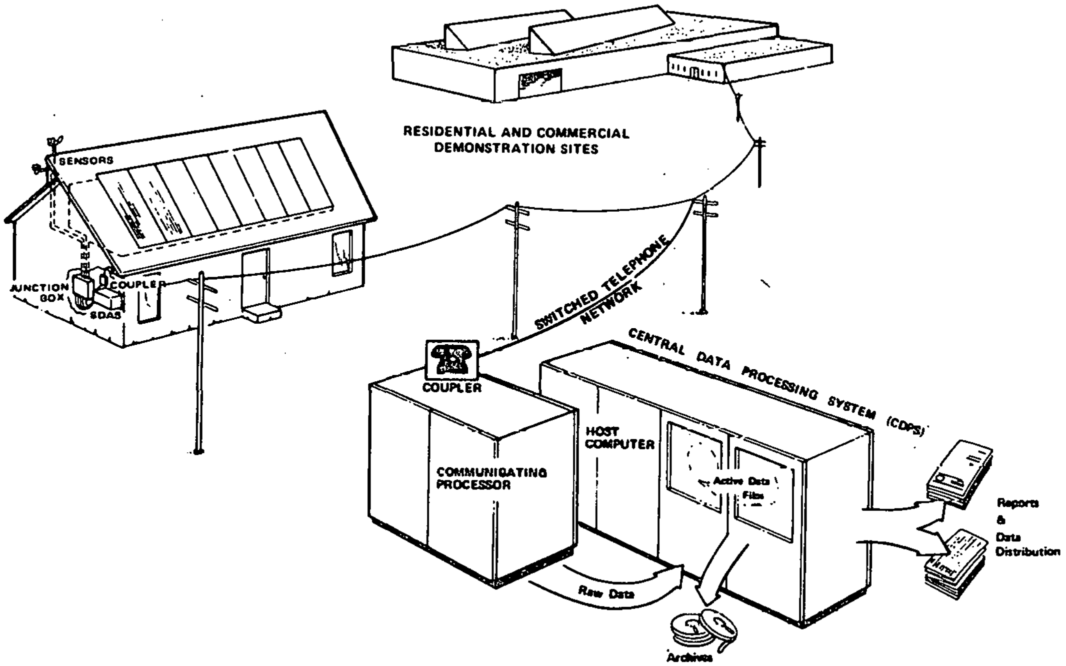


Figure B-1. The National Solar Data Network

DATA COLLECTION AND PROCESSING

Each site contains standard industrial instrumentation modified for the particular site. Sensors measure temperatures, flows, insolation, electric power, fossil fuel usage, and other parameters. These sensors are all wired into a junction box (J-box), which is in turn connected to a microprocessor data logger called the Site Data Acquisition Subsystem (SDAS). The SDAS can read up to 96 different channels, one channel for each sensor. The SDAS takes the analog voltage input to each channel and converts it to a 10-bit word. At intervals of every 320 seconds, the SDAS samples each channel and records the values on a cassette tape. Some of the channels can be sampled 10 times in each 320 second interval, and the average value is recorded in the tape.

Each SDAS is connected through a modem to voice-grade telephone lines which are used to transmit the data to a central computer facility. This facility is the Central Data Processing System (CDPS), located at Vitro Laboratories in Silver Spring, Maryland. The CDPS hardware consists of an IBM System 7, an IBM 370/145, and an IBM 3033. The System 7 periodically calls up each SDAS in System 7. Typically, the System 7 collects data from each SDAS six times a week, although the tape can hold three to five days of data, depending on the number of channels.

The data received by the System 7 are in the form of digital counts in the range of 0-1023. These counts are then processed by software in the CDPS, where they are converted from counts to engineering units (EU) by applying appropriate calibration constants. The engineering unit data called "detailed measurements" in the software are then tabulated on a daily basis for the site analyst. The CDPS is also capable of transforming this data into plots, graphs, and processed reports.

Solar system performance reports present system parameters as monthly values. If some of the data during the month is not collected due to solar system instrumentation system, or data acquisition problems, or if some of the collected data is invalid, then the collected valid data is extrapolated to provide the monthly performance estimates. Researchers and other users who require unextrapolated, "raw" data may obtain data by contacting Vitro Laboratories.

DATA ANALYSIS

The analyst develops a unique set of "site equations" (given in Appendix D) for each site in the NSDN, following the guidelines presented herein.

The equations calculate the flow of energy through the system, including solar energy, auxiliary energy, and losses. These equations are programmed in PL/1 and become part of the Central Data Processing System. The PL/1 program for each site is termed the site software. The site software processes the detailed data, using as input a "measurement record" containing the data for each scan interval. The site software produces as output a set of performance factors; on an hourly, daily, and monthly basis.

These performance factors (Appendix C) quantify the thermal performance of the system by computing energy flows throughout the various subsystems. The system performance may then be evaluated based on the efficiency of the system in transferring these energies.

Performance factors which are considered to be of primary importance are those which are essential for system evaluation. Without these primary performance factors (which are denoted by an asterisk in Appendix C), comparative evaluation of the wide variety of solar energy systems would be impossible. An example of a primary performance factor is SECA - Solar Energy Collected by the Array. This is quite obviously a key parameter in system analysis.

Secondary performance factors are data deemed important and useful in comparison and evaluation of solar systems, particularly with respect to component interactions and simulation. In most cases these secondary performance factors are computed as functions of primary performance factors.

There are irregularly occurring cases of missing data as is normal for any real time data collection from mechanical equipment. When data for individual scans or whole hours are missing, values of performance factors are assigned which are interpolated from measured data. If no valid measured data are available for interpolation, a zero value is assigned. If data are missing for a whole day, each hour is interpolated separately. Data are interpolated in order to provide solar system performance factors on a whole hour, whole day and whole month basis for use by architects and designers.

REPORTING

The performance of the Baker Construction solar energy system from October 1980 through May 1981 was analyzed and Monthly Performance Reports were published through December 1980 for the months when sufficient valid data were available. See the following page for a list of these reports.

In addition, data are included in this report which are not in Monthly Performance Reports.

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Report:

December 1980, SOLAR/1095-80/12

---

* This report can be obtained (free) by contacting: U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830.

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

The performance factors identified in the site equations (Appendix D) by the use of acronyms or symbols are defined in this Appendix in Section 1. Section 1 includes the acronym, the actual name of the performance factor, and a short definition.

Section 2 contains a glossary of solar terminology, in alphabetical order These terms are included for quick reference by the reader.

Section 3 describes general acronyms used in this report.

Section 1. Performance Factor Definitions and Acronyms

Section 2. Solar Terminology

Section 3. General Acronyms

SECTION 1. PERFORMANCE FACTOR DEFINITIONS AND ACRONYMS

ACRONYM	NAME	DEFINITION
AXE	Auxiliary Electric Fuel Energy to Load Subsystem	Amount of electrical energy required as a fuel source for all load subsystems.
AXF	Auxiliary Fossil Fuel Energy to Load Subsystem	Amount of fossil energy required as a fuel source for all load subsystems.
* AXT	Auxiliary Thermal Energy to Load Subsystems	Thermal energy delivered to all load subsystems to support a portion of the subsystem loads, from all auxiliary sources.
CAE	SCS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SCS to be converted and applied to the SCS load.
CAF	SCS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SCS to be converted and applied to the SCS load.
CAREF	Collector Array Efficiency	Ratio of the collected solar energy to the incident solar energy.
CAT	SCS Auxiliary Thermal Energy	Amount of energy provided to the SCS by a BTU heat transfer fluid from an auxiliary source.
* CL	Space Cooling Subsystem Load	Energy required to satisfy the temperature control demands of the space cooling subsystem.
CLAREA	Collector Array Area	The gross area of one collector panel multiplied by the number of panels in the array.
COPE	SCS Operating Energy	Amount of energy required to support the SCS operation which is not intended to be applied directly to the SCS load.
CSAUX	Auxiliary Energy to ECSS	Amount of auxiliary energy supplied to the ECSS.
* CSCEF	ECSS Solar Conversion Efficiency	Ratio of the solar energy supplied from the ECSS to the load subsystems to the incident solar energy on the collector array.

---

* Primary Performance Factors

ACRONYM	NAME	DEFINITION
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.
CSEO	Energy Delivered from ECSS to Load Subsystems	Amount of energy supplied from the ECSS to the load subsystems (including any auxiliary energy supplied to the ECSS).
* CSFR	SCS Solar Fraction	Portion of the SCS load which is supported by solar energy.
CSOPE	ECSS Operating Energy	Amount of energy used to support the ECSS operation (which is not intended to be supplied to the ECSS thermal state).
CSRJE	ECSS Rejected Energy	Amount of energy intentionally rejected or dumped from the ECSS subsystem.
* CSVE	SCS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional SCS and the actual electrical energy required to support the demonstration SCS, for identical SCS loads.
* CSVF	SCS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional SCS and the actual fossil energy required to support the demonstration SCS, for identical loads.
HAE	SHS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SHS to be converted and applied to the SHS load.
HAF	SHS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SHS to be converted and applied to the SHS load.
HAT	SHS Auxiliary Thermal Energy	Amount of energy provided to the SHS by a heat transfer fluid from an auxiliary source.
* HL	Space Heating Subsystem Load	Energy required to satisfy the temperature control demands of the space heating subsystem.

---

* Primary Performance Factors

ACRONYM	NAME	DEFINITION
HOPE	SHS Operating Energy	Amount of energy required to support the SHS operation (which is not intended to be applied directly to the SHS load).
HOURCT	Record Time	Count of hours elapsed from the start of 1977.
* HSFR	SHS Solar Fraction	Portion of the SHS load which is supported by solar energy.
HSE	Solar Energy to SHS	Amount of solar energy delivered to the SHS.
* HSVE	SHS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional SHS and the actual electrical energy required to support the demonstration SHS, for identical SHS loads.
* HSVF	SHS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional SHS and the actual fossil energy required to support the demonstration SHS, for identical SHS loads.
HWAE	HWS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the HWS to be converted and applied to the HWS load.
HWAF	HWS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the HWS to be converted and applied to the HWS load.
HWAT	HWS Auxiliary Thermal Energy	Amount of energy provided to the HWS by a heat transfer fluid from an auxiliary source.
HWCSM	Service Hot Water Consumption	Amount of heated water delivered to the load from the hot water subsystem.
* HWL	Hot Water Subsystem Load	Energy required to satisfy the temperature control demands of the building service hot water system.

---

* Primary Performance Factors

ACRONYM	NAME	DEFINITION
HWOPE	HWS Operating Energy	Amount of energy required to support the HWS operation which is not intended to be applied directly to the HWS load.
HWSE	Solar Energy to HWS	Amount of solar energy delivered to the HWS.
* HWSFR	HWS Solar Fraction	Portion of the HWS load which is supported by solar energy.
* HWSVE	HWS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional HWS and the actual electrical energy required to support the demonstration HWS, for identical HWS loads.
* HWSVF	HWS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional HWS and the actual fossil energy required to support the demonstration HWS, for identical loads.
RELH	Relative Humidity	Average outdoor relative humidity at the site.
* SE	Incident Solar Energy	Amount of solar energy incident upon one square foot of the collector plane.
SEA	Incident Solar Energy on Array	Amount of solar energy incident upon the collector array.
* SEC	Collector Solar Energy	Amount of thermal energy added to the heat transfer fluid for each square foot of the collector area.
SECA	Collected Solar Energy by Array	Amount of thermal energy added to the heat transfer fluid by the collector array.
SEDF	Diffuse Insolation	Amount of diffuse solar energy incident upon one square foot of a collector plane.
SEOP	Operational Incident Solar Energy	Amount of incident solar energy upon the collector array whenever the collector loop is active.

---

* Primary Performance Factors

ACRONYM	NAME	DEFINITION
* SEL	Solar Energy to Load Subsystems	Amount of solar energy supplied by the ECSS to all load subsystems.
* SFR	Solar Fraction of System Load	Portion of the system load which was supported by solar energy.
STECH	Change in ECSS Stored Energy	Change in ECSS stored energy during reference time period.
STEFF	ECSS Storage Efficiency	Ratio of the sum of energy supplied by ECSS storage and the change in ECSS stored energy to the energy delivered to the ECSS storage.
STEI	Energy Delivered to ECSS Storage	Amount of energy delivered to ECSS storage by the collector array and from auxiliary sources.
STEO	Energy Supplied by ECSS Storage	Amount of energy supplied by ECSS storage to the load subsystems.
* SYSL	System Load	Energy required to satisfy all desired temperature control demands at the output of all subsystems.
* SYSOPE	System Operating Energy	Amount of energy required to support the system operation, including all subsystems, which is not intended to be applied directly to the system load.
* SYSPF	System Performance Factor	Ratio of the system load to the total equivalent fossil energy expended or required to support the system load.
* TA	Ambient Temperature	Average temperature of the ambient air.
* TB	Building Temperature	Average temperature of the controlled space of the building.
TCECOP	TCE Coefficient of Performance	Coefficient of performance of the thermodynamic conversion equipment.
TCEI	TCE Thermal Input Energy	Equivalent thermal energy which is supplied as a fuel source to thermodynamic conversion equipment.

---

* Primary Performance Factors

ACRONYM	NAME	DEFINITION
TCEL	Thermodynamic Conversion Equipment Load	Controlled energy output of thermodynamic conversion equipment.
TCEOPE	TCE Operating Energy	Amount of energy required to support the operation of thermodynamic conversion equipment which is not intended to appear directly in the load.
TCERJE	TCE Reject Energy	Amount of energy intentionally rejected or dumped from thermodynamic conversion equipment as a by-product or consequence of its principal operation.
TDA	Daytime Average Ambient Temperature	Average temperature of the ambient air during the daytime (during normal collector operation period).
* TECSM	Total Energy Consumed by System	Amount of energy demand of the system from external sources; sum of all fuels, operating energies, and collected solar energy.
THW	Service Hot Water Temperature	Average temperature of the service hot water supplied by the system.
TST	ECSS Storage Temperature	Average temperature of the ECSS storage medium.
* TSVE	Total Electrical Energy Savings	Difference in the estimated electrical energy required to support an assumed similar conventional system and the actual electrical energy required to support the system, for identical loads; sum of electrical energy savings for all subsystems.
* TSVF	Total Fossil Energy Savings	Difference in the estimated fossil energy required to support an assumed similar conventional system and the actual fossil energy required to support the system, for identical loads; sum of fossil energy savings of all subsystems.
TSW	Supply Water Temperature	Average temperature of the supply water to the hot water subsystem.

---

* Primary Performance Factors

ACRONYM	NAME	DEFINITION
WDIR	Wind Direction	Average wind direction at the site.
WIND	Wind Velocity	Average wind velocity at the site.

---

* Primary Performance Factors

SECTION 2. SOLAR TERMINOLOGY

Absorptivity	The ratio of absorbed radiation by a surface to the total incident radiated energy on that surface.
Active Solar System	A system in which a transfer fluid (liquid or air) is circulated through a solar collector where the collected energy is converted, or transferred, to energy in the medium.
Air Conditioning	Popularly defined as space cooling, more precisely, the process of treating indoor air by controlling the temperature, humidity and distribution to maintain specified comfort conditions.
Ambient Temperature	The surrounding air temperature.
Auxiliary Energy	In solar energy technology, the energy supplied to the heat or cooling load from other than the solar source, usually from a conventional heating or cooling system. Excluded are operating energy, and energy which may be supplemented in nature but does not have the auxiliary system as an origin, i.e., energy supplied to the space heating load from the external ambient environment by a heat pump. The electric energy input to a heat pump is defined as operating energy.
Auxiliary Energy Subsystem	In solar energy technology the Auxiliary Energy System is the conventional heating and/or cooling equipment used as supplemental or backup to the solar system.
Array	An assembly of a number of collector elements, or panels, into the solar collector for a solar energy system.
Backflow	Reverse flow.
Backflow Preventer	A valve or damper installed to prevent reverse flow.
Beam Radiation	Radiated energy received directly, not from scattering or reflecting sources.
Collected Solar Energy	The thermal energy added to the heat transfer fluid by the solar collector.

Collector Array Efficiency	Same as Collector Conversion Efficiency. Ratio of the collected solar energy to the incident solar energy. (See also Operational Collector Efficiency.)
Collector Subsystem	The assembly of components that absorbs incident solar energy and transfers the absorbed thermal energy to a heat transfer fluid.
Concentrating Solar Collector	A solar collector that concentrates the energy from a larger area onto an absorbing element of smaller area.
Conversion Efficiency	Ratio of thermal energy output to solar energy incident on the collector array.
Conditioned Space	The space in a building in which the air is heated or cooled to maintain a desired temperature range.
Control System or Subsystem	The assembly of electric, pneumatic, or hydraulic, sensing, and actuating devices used to control the operating equipment in a system.
Cooling Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is above 65°F.
Cooling Tower	A heat exchanger that transfers waste heat to outside ambient air.
Diffuse Radiation	Solar Radiation which is scattered by air molecules, dust, or water droplets and incapable of being focused.
Drain Down	An arrangement of sensors, valves and actuators to automatically drain the solar collectors and collector piping to prevent freezing in the event of cold weather.
Duct Heating Coil	A liquid-to-air heat exchanger in the duct distribution system.
Effective Heat Transfer Coefficient	The heat transfer coefficient, per unit plate area of a collector, which is a measure of the total heat losses per unit area from all sides, top, back, and edges.
Energy Gain	The thermal energy gained by the collector transfer fluid. The thermal energy output of the collector.

Energy Savings	The estimated difference between the fossil and/or electrical energy requirements of an assumed conventional system (carrying the full measured load) and the actual electrical and/or fossil energy requirements of the installed solar-assisted system.
Expansion Tank	A tank with a confined volume of air (or gas) whose inlet port is open to the system heat transfer fluid. The pressure and volume of the confined air varies as to the system heat transfer fluid expands and contracts to prevent excessive pressure from developing and causing damage.
F-Curve	The collector instantaneous efficiency curve. Used in the "F-curve" procedure for collector analysis (see Instantaneous Efficiency).
Fixed Collector	A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.
Flat Plate Collector	A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).
Focusing Collector	A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.
Fossil Fuel	Petroleum, coal, and natural gas derived fuels.
Glazing	In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel.

Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is below 65°F.
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{Ti-Ta}{I}$, under steady state conditions (see Operating Point).
Instantaneous Efficiency Curve	A plot of solar collector efficiency against operating point, $\frac{Ti-Ta}{I}$ (see Operating Point).
Incidence Angle	The angle between the line to a radiating source (the sun) and a line normal to the plane of the surface being irradiated.
Incident Solar Energy	The amount of solar energy irradiating a surface taking into account the angle of incidence. The effective area receiving energy is the product of the area of the surface times the cosine of the angle of incidence.
Insolation	Incoming solar radiation.
Load	That to which energy is supplied, such as space heating load or cooling load. The system load is the total solar and auxiliary energy required to satisfy the required heating or cooling.
Manifold	The piping that distributes the transport fluid to and from the individual panels of a collector array.
Microclimate	Highly localized weather features which may differ from long term regional values due to the interaction of the local surface with the atmosphere.

Nocturnal Radiation	The loss of thermal energy by the solar collector to the night sky.
Operating Energy	The amount of energy (usually electrical energy) required to operate the solar and auxiliary equipments and to transport the thermal energy to the point of use, and which is not intended to directly affect the thermal state of the system.
Operating Point	A solar energy system has a dynamic operating range due to changes in level of insolation (I), fluid input temperature (T), and outside ambient temperature (Ta). The operating point is defined as: $\frac{Ti-Ta}{I} \quad \frac{°F \times hr. \times sq.\ ft.}{BTU}$
Operational Collector Efficiency	Ratio of collected solar energy to incident solar energy only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.
Outgassing	The emission of gas by materials and components, usually during exposure to elevated temperature, or reduced pressure.
Passive Solar System	A system which uses architectural components of the building to collect, distribute, and store solar energy.
Pebble Bed (Rock Bed)	A space filled with uniform-sized pebbles to store solar-source energy by raising the temperature of the pebbles.
Reflected Radiation	Insolation reflected from a surface, such as the ground or a reflecting element onto the solar collector.
Rejected Energy	Energy intentionally rejected, dissipated, or dumped from the solar system.
Retrofit	The addition of a solar energy system to an existing structure.
Selective Surface	A surface that has the ability to readily absorb solar radiation, but re-radiates little of it as thermal radiation.

Sensor	A device used to monitor a physical parameter in a system, such as temperature or flow rate, for the purpose of measurement or control.
Solar Conditioned Space	The area in a building that depends on solar energy to provide a fraction of the heating and cooling needs.
Solar Fraction	The fraction of the total load supplied by solar energy. The ratio of solar energy supplied to loads divided by total load. Often expressed as a percentage.
Solar Savings Ratio	The ratio of the solar energy supplied to the load minus the solar system operating energy, divided by the system load.
Storage Efficiency, N_s	Measure of effectiveness of transfer of energy through the storage subsystem taking into account system losses.
Storage Subsystem	The assembly of components used to store solar-source energy for use during periods of low insolation.
Stratification	A phenomenon that causes a distinct thermal gradient in a heat transfer fluid, in contrast to a thermally homogeneous fluid. Results in the layering of the heat transfer fluid, with each layer at a different temperature. In solar energy systems, stratification can occur in liquid storage tanks or rock beds, and may even occur in pipes and ducts. The temperature gradient or layering may occur in a horizontal, vertical or radial direction.
System Performance Factor	Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
Ton of Refrigeration	The heat equivalent to the melting of one ton (2,000 pounds) of ice at 32°F in 24 hours. A ton of refrigeration will absorb 12,000 BTU/hr, or 288,000 BTU/day.
Tracking Collector	A solar collector that moves to point in the direction of the sun.
Zone	A portion of a conditioned space that is controlled to meet heating or cooling requirements separately from the other space or other zones.

SECTION 3. GENERAL ACRONYMS

ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineering.
BTU	British Thermal Unit, a measure of heat energy. The quantity of heat required to raise the temperature of one pound of pure water one Fahrenheit degree. One BTU is equivalent to 2.932 x 10^{-4} kwh of electrical energy.
COP	Coefficient of Performance. The ratio of total load to solar-source energy.
DHW	Domestic Hot Water.
ECSS	Energy Collection and Storage System.
HWS	Domestic or Service Hot Water Subsystem.
KWH	Kilowatt Hours, a measure of electrical energy. The product of kilowatts of electrical power applied to a load times the hours it is applied. One kwh is equivalent to 3,413 BTU of heat energy.
NSDN	National Solar Data Network.
SCS	Space Cooling Subsystem.
SHS	Space Heating Subsystem.
SOLMET	Solar Radiation/Meteorology Data.

APPENDIX D

PERFORMANCE EQUATIONS

BAKER CONSTRUCTION

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance calculations on the system and its major subsystems. These calculations are based on physical measurement data taken from each sensor every 320 seconds.* This data is then mathematically combined to determine the hourly, daily, and monthly performance of the system. This appendix describes the general computational methods and the specific energy balance equations used for this site.

Data samples from the system measurements are integrated to provide discrete approximations of the continuous functions which characterize the system's dynamic behavior. This integration is performed by summation of the product of the measured rate of the appropriate performance parameters and the sampling interval over the total time period of interest.

There are several general forms of integration equations which are applied to each site. These general forms are exemplified as follows: the total solar energy available to the collector array is given by

$$\text{SOLAR ENERGY AVAILABLE} = (1/60)\ \Sigma\ [\text{I001} \times \text{AREA}] \times \Delta\tau$$

where I001 is the solar radiation measurement provided by the pyranometer in BTU per square foot per hour, AREA is the area of the collector array in square feet, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given typically by

$$\text{COLLECTED SOLAR ENERGY} = \Sigma\ [\text{M100} \times \Delta H] \times \Delta\tau$$

where M100 is the mass flow rate of the heat transfer fluid in lb_m/min and ΔH is the enthalpy change, in BTU/lb_m, of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is generally given by

$$\Delta H = \overline{C}_p\ \Delta T$$

where C_p is the average specific heat, in BTU/lb_m-°F, of the heat transfer fluid and ΔT, in °F, is the temperature differential across the heat exchanging component.

---

* See Appendix B.

For an air system ΔH is generally given by

$$\Delta H = H_a(T_{out}) - H_a(T_{in})$$

where $H_a(T)$ is the enthalpy, in BTU/lb_m, of the transport air evaluated at the inlet and outlet temperatures of the heat exchanging component.

$H_a(T)$ can have various forms, depending on whether or not the humidity ratio of the transport air remains constant as it passes through the heat exchanging component.

For electrical power, a general example is

$$\text{ECSS OPERATING ENERGY} = (3413/60)\ \Sigma\ [\text{EP100}] \times \Delta\tau$$

where EP100 is the power required by electrical equipment in kilowatts and the two factors (1/60) and 3413 correct the data to BTU/min.

Letter Designations

C or CP = Specific Heat

D = Direction or Position

EE = Electric Energy

EP = Electric Power

F = Fuel Flow Rate

H = Enthalpy

HR = Humidity Ratio

HWD = Functional procedure to calculate the specific heat of water at the average of the inlet and outlet temperatures

I = Incident Solar Flux (Insolation)

M = Mass Flow Rate

N = Performance Parameter

P = Pressure

PD = Differential Pressure

Q = Thermal Energy

RHO = Density

T = Temperature

TD = Differential Temperature

V = Velocity

W = Heat Transport Medium Volume Flow Rate

TI = Time

_P = Appended to a function designator to signify the value of the function during the previous iteration.

Subsystem Designations

Number Sequence	Subsystem/Data Group
001 to 099	Climatological
100 to 199	Collector and Heat Transport
200 to 299	Thermal Storage
300 to 399	Hot Water
400 to 499	Space Heating
500 to 599	Space Cooling
600 to 699	Building/Load

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

NOTE: Sensor identification (measurement) numbers reference system schematics, Figures A-1 through A-4.

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \Sigma\ T001$$

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \Sigma\ [T621 + T620 + T601 + T605 + T622 + T623 + T624 + T609 + T607 + T611 + T625/11]$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$TDA = (1/360) \times \Sigma\ T001$$

for ± three hours from solar noon

TIME OF DAY BUILDING TEMPERATURES (ONCE PER DAY)

$$TMID = TB$$

at 12 hours from local solar noon

$$T6AM = TB$$

at six hours before local solar noon

$$TNOON = TB$$

at local solar noon

$\mathrm{T6PM} = \mathrm{TB}$

at six hours past local solar noon

INCIDENT SOLAR ENERGY PER SQUARE FOOT ($\mathrm{BTU/FT^2}$)

$\mathrm{SE} = (1/60) \times \Sigma\ \mathrm{I001}$

GREENHOUSE TEMPERATURE

$\mathrm{GHTA} = (1/60) + \Sigma\ [(\mathrm{T101} + \mathrm{T102})/3]$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$\mathrm{SEOP} = (1/60) \times \Sigma\ [\mathrm{I001} \times (\mathrm{D202} \times 300)]$

TRANSMITTED SOLAR ENERGY (BTU)

$\mathrm{SECAMP} = (1/60 \times \Sigma\ [\mathrm{I002} \times \mathrm{D202} \times 300]$

AVERAGE STORAGE WALL TEMPERATURE

$$\mathrm{TSTWALL} = (1/60 \times \Sigma\ [(\mathrm{T201} + \mathrm{T202} + \mathrm{T203} + \mathrm{T204} + \mathrm{T205} + \mathrm{T206} + \mathrm{T207} + \mathrm{T208} + \mathrm{T209} + \mathrm{T210} + \mathrm{T211} + \mathrm{T212} + \mathrm{T213})/13]$$

AVERAGE FLOOR STORAGE TEMPERATURE

$$\mathrm{TSTFLOOR} = (1/60) \times \Sigma\ [(\mathrm{T214} + \mathrm{T215} + \mathrm{T216} + \mathrm{T217} + \mathrm{T218} + \mathrm{T219} + \mathrm{T220} + \mathrm{T225} + \mathrm{T226})/9]$$

SUM OF CONDUCTION LOSSES (U X A)

$\mathrm{HLUA} = \mathrm{HTN} + \mathrm{HTS} + \mathrm{HTW} + \mathrm{HTE} + \mathrm{HFL} + \mathrm{HRF} + \mathrm{HGH}$

ELECTRICAL HEAT INCIDENTLY APPLIED TO SPACE HEATING

$\mathrm{HOTHER} = \mathrm{EP600} = (\mathrm{EP603} \times 0.25) - (\mathrm{EP600} \times 0.25) - \mathrm{EP601} - \mathrm{EP602}$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$\mathrm{HAT} = \mathrm{HAE}$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$\mathrm{BL} = \mathrm{HLUA} + \mathrm{HI}$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$\mathrm{SEA} = \mathrm{CLAREA} \times \mathrm{SE}$

COLLECTED SOLAR ENERGY (BTU)

$\mathrm{SEC} = \mathrm{SECA}/\mathrm{CLAREA}$

COLLECTOR ARRAY EFFICIENCY

CAREF = SECA/SEA

CHANGE IN STORED ENERGY (BTU)

FLOOR: FLSTECH = STO_MASS.FLOOR x TSTFLOOR - TSTFLOORp x CPFL
WALL: WSTECH = STO_MASS.WALL x TSTWALL - TSTWALLp x CPW
TOTAL: MSTECH = FLSTECH + WSTECH

where the subscript p refers to a prior reference value

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = HSE

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

HSFR = 100 x HSE/BL

WIND NORTH - SOUTH COMPONENT

WNS = V001 x COSD (D001)/60

WIND EAST - WEST COMPONENT

WEW = V001 x SIND (D001)/60

WIND VELOCITY

WIND = V001/60

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

HSE = BL - HAT

HEAT OF INFILTRATION

HI = VOLUME x 0.07216 x HRF x (TB - TA) x HINF

where HINF = air changes per hour

SYSTEM LOAD (BTU)

SYSL = BL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = HSFR

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HAT

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

AXE = EP601 + EP602 x EPCONST

WIND DIRECTION

WDR = ATAN (WEW, WNS)

add or subtract 360 to get between 0° and 360°

APPENDIX E

LONG-TERM WEATHER DATA

BAKER CONSTRUCTION LONG-TERM WEATHER DATA

COLLECTOR TILT: 62.00 DEGREES
LATITUDE: 39.04 DEGREES

LOCATION: CINCINNATI, OHIO
COLLECTOR AZIMUTH: 0.00 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
OCT	2,009	992	0.49356	1.355	1,344	271	17	57
NOV	1,484	590	0.39745	1.600	944	636	0	44
DEC	1,252	431	0.34468	1.684	726	970	0	34
JAN	1,378	501	0.36390	1,627	816	1,051	0	31
FEB	1,839	737	0.40105	1.380	1,018	888	0	33
MAR	2,431	1,029	0.42320	1.108	1,140	722	0	42
APR	3,042	1,397	0.45941	0.883	1,233	341	8	54
MAY	3,468	1,674	0.48270	0.743	1,243	138	82	63

LEGEND:

HOBAR - Monthly average daily extraterrestrial radiation (ideal) in BTU/day-ft^2

HBAR - Monthly average daily radiation (actual) in BTU/day-ft^2.

KBAR - Ratio of HBAR to HOBAR.

RBAR - Ratio of monthly average daily radiation on tilted surface to that on a horizontal surface for each month (i.e., multiplier obtained by tilting).

SBAR - Monthly average daily radiation on a tilted surface (i.e., RBAR x HBAR) in BTU/day-ft^2.

HDD - Number heating degree-days per month.

CDD - Number of cooling degree-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

The site was occupied for all of the reporting period and the passive system operated for the entire period. The greenhouse upper active collector area has never operated due to a problem with the controller.

The movable insulating curtain did not operate smoothly because it kept pulling out of the side tracks. This problem has not been resolved.

APPENDIX G

CONVERSION FACTORS

Energy Conversion Factors

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[1]	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil[2]	149,690 BTU/gallon	6.68×10^{-6} gallon/BTU
Kerosene	135,000 BTU/gallon	7.41×10^{-6} gallon/BTU
Propane	91,500 BTU/gallon	10.93×10^{-6} gallon/BTU
Natural gas	1,021 BTU/cubic feet	979.4×10^{-6} cubic feet/ BTU
Electricity	3,413 BTU/kilowatt-hour	292.8×10^{-6} kwh/BTU

---

[1] No. 1 and No. 2 heating oils, diesel fuel, No. 4 fuel oils

[2] No. 5 and No. 6 oils

APPENDIX H

SENSOR TECHNOLOGY

Temperature Sensors

Temperatures are measured by a Minco Products S53P platinum Resistance Temperature Detector (RTD). Because the resistance of platinum wire varies as a function of temperature, measurement of the resistance of a calibrated length of platinum wire can be used to accurately determine the temperature of the wire. This is the principle of the platinum RTD which utilizes a tiny coil of platinum wire encased in a copper-tipped probe to measure temperature.

Ambient temperature sensors are housed in a WeatherMeasure Radiation Shield in order to protect the probe from solar radiation. Care is taken to locate the sensor away from extraneous heat sources which could produce erroneous temperature readings. Temperature probes mounted in pipes are installed in stainless steel thermowells for physical protection of the sensor and to allow easy removal and replacement of the sensors. A thermally-conductive grease is used between the probe and the thermowell to assure faster temperature response.

All temperature sensors are individually calibrated at the factory. In addition, the bridge circuit is calibrated in the field using a five-point check.

Nominal Resistance @ 25°C:	100 ohms
No. of Leads:	3
Electrical Connection:	Wheatstone Bridge
Time Constant	1.5 seconds max. in water at 3 fps
Self Heating:	27 mw/°F

WIND SENSOR

Wind speed and direction are measured by a WeatherMeasure W102-P-DC/540 or W101-P-DC/540 wind sensor. Wind speed is measured by means of a four-bladed propeller coupled to a DC generator.

Wind direction is sensed by means of a dual-wiper 1,000-ohm long-life conductive plastic potentiometer. It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

Size:	29-3/4"L X 30"H
Starting Speed:	1 mph
Complete Tracking:	3 mph
Maximum Speed:	200 mph
Distance Constant (30 mph):	6.2'
Accuracy:	± 1% below 25 mph ± 3% above 25 mph
Time Constant:	0.145 second

HUMIDITY SENSORS

The WeatherMeasure HMP-14U Solid State Relative Humidity Probe is used for the measurement of relative humidity. The operation of the sensor is based upon the capacitance of the polymer thin film capacitor. A one-micron-thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance change proportional to relative humidity.

Range:	0-100% R.H.
Response Time:	1 second to 90% humidity change at 20°C
Temperature Coefficient:	0.05% R.H./°C
Accuracy:	± 3% from 0-80% R.H.
	± 5-6% 80-100% R.H.
Sensitivity:	0.2% R.H.

INSOLATION SENSORS

The Eppley Model PSP pyranometer is used for the measurement of insolation. The pyranometer consists of a circular multijunction thermopile of the plated, (copper-constantan) wirewound type which is temperature compensated to render the response essentially independent of ambient temperature. The receiver is coated with Parsons' black lacquer (non-wavelength-selective absorption). The instrument is supplied with a pair of precision-ground polished concentric hemispheres of Schott optical glass transparent to light between 285 and 2800 nm of wavelength. The instrument is provided with a dessicator which may be readily inspected. Pyranometers designated as shadowband pyranometers are equipped with a shadowband which may be adjusted to block out any direct solar radiation. These instruments are used for the measurement of diffuse insolation.

Sensitivity:	9 μ V/W/m^2
Temperature Dependence:	± 1% over ambient temperature range -20°C to 40°C
Linearity:	0.5% from 0 to 2,800 W/M^2
Response Time:	1 second
Cosine Error:	± 1% 0-70° zenith angle
	± 3% 70-80° zenith angle

LIQUID FLOW SENSORS (NON-TOTALIZING)

The Ramapo Mark V strain gauge flow meters are used for the measurement of liquid flow. The flow meters sense the flow of the liquids by measuring the force exerted by the flow on a target suspended in the flow stream. This force is transmitted to a four active arm strain gauge bridge to provide a signal proportional to flow rate squared. The flow meters are available in a screwed end configuration, a flanged configuration, and a wafer configuration. Each flow meter is calibrated for the particular fluid being used in the application.

Materials:	Target - 17-PH stainless steel Body - Brass or stainless steel Seals - Buna-N
Fluid Temperature:	-40°F to 250°F
Calibration Accuracy:	± 1% (½" to 3½" line size) ± 2% (4" and greater line size)
Repeatability and Hysteresis:	0.25% of reading

LIQUID FLOW SENSORS (TOTALIZING)

Hersey Series 400 flow meters are used to measure totalized liquid flow. The meter is a nutating disk, positive displacement type meter. An R-15 register with an SPDT reed switch is used to provide an output to the data acquisition subsystem.

The output of the reed switch is input to a Martin DR-1 Digital Ramp which counts the number of pulses and produces a zero to five volt analog signal corresponding to the pulse count.

Materials:	Meter body	- bronze
	Measuring chamber	- plastic
Accuracy:	± 1.5%	

AIR FLOW SENSORS

The Kurz 430 Series of thermal anemometers is used for the measurement of air flow. The basic sensing element is a probe which consists of a velocity sensor and a temperature sensor. The velocity sensor is heated and operated as a constant temperature thermal anemometer which responds to a "standard" velocity (referenced to 25°C and 760 mm Hg) or mass flow by sensing the cooling effect of the air as it passes over the heated sensor. The temperature sensor compensates for variations in ambient temperature.

Since the probe measures air velocity at only one point in the cross section of the duct, it is necessary to perform a careful duct mapping to relate the probe reading to the amount of air flowing through the entire duct. This is done by dividing the duct into small areas and taking a reading at the center of each area using a portable probe. The readings are then averaged to determine the overall duct velocity. The reading at the permanently installed probe is then ratioed to this reading. This duct mapping is done for each mode.

Accuracy:	± 2% of full scale over temperature range -20°C to 60°C ± 5% of full scale over temperature range -60°C to 250°C
Response Time:	0.025 second
Repeatability:	0.25% full scale

FUEL OIL FLOW SENSOR

The Kent Mini-Major is used as a flow oil flow meter. The meter utilizes an oscillating piston as a positive displacement element. The oscillating piston is connected to a pulser which sends pulses to the Site Data Acquisition Subsystem for totalization.

Operating Temperature: 100°C (max)
Flow Range: 0.6 to 48 gph
Accuracy: ± 1% of full scale

FUEL GAS FLOW SENSOR

The American AC-175 gas meter is used for the measurement of totalized fuel gas flow. The drop in pressure between the inlet and outlet of the meter is responsible for the action of the meter. The principle of measurement is positive displacement. Four chambers in the meter fill and empty in sequence. The exact volume of compartments is known, so by counting the number of displacements the volume is measured. Sliding control valves control the entrance and exit of the gas to the compartments. The meter is temperature compensated to reference all volumetric readings to 60°F.

Rated Capacity: 175 cubic ft/hr
Max Working Pressure: 5 psi

ELECTRIC POWER SENSORS

Ohio Semitronics Series PC5 wattmeters are used as electric power sensors. They utilize Hall effect devices as multipliers taking the product of the instantaneous voltage and current readings to determine the electrical power. This technique automatically takes power factor into consideration and produces a true power reading.

Power Factor Range: 1 to 0 (lead or lag)
Response Time: 250 ms
Temperature Effect: 1% of reading
Accuracy: 0.5% of full scale

HEAT FLUX SENSORS

The Hy-Cal Engineering Model BI-7X heat flow sensor is used for the measurement of heat flux. The sensor consists basically of an insulating wafer, with a series of thermocouples arranged such that consecutive thermoelectric junctions fall on opposite sides of the wafer. This assembly is bonded to a heat sink to assure heat flow through the sensor. Heat is received on the exposed surface of the wafer and conducted through the heat sink. A temperature drop across the wafer is thus developed and is measured directly by each junction combination embodied along the wafer. Since the differential thermocouples are connected electrically in series, the voltages produced by each set of junctions is additive, thereby amplifying the signal directly proportional to the number of junctions. The temperature drop across the wafer, and thus the output signal, is directly proportional to the heating rate.

Operation Temperature: -50° to 200°F
Response Time: 6 seconds
Linearity: 2%
Repeatability: 0.5%
Sensitivity: 2 mv/BTU/ft^2-hr
Size: 2" X 2"

APPENDIX I

TYPICAL MONTHLY DATA

```
                   MONTHLY REPORT:  FEBRUARY 1981
                 SITE SUMMARY:  BAKER CONSTRUCTION

                                                                  SI UNITS
__________________________________________________________________________
GENERAL SITE DATA:
   INCIDENT SOLAR ENERGY                                 11.590 GIGA JOULES
                                                         314243 KJ/SQ.M.
   COLLECTED SOLAR ENERGY                                 4.514 GIGA JOULES
                                                         122377 KJ/SQ.M.
   AVERAGE AMBIENT TEMPERATURE                                2 DEGREES C
   AVERAGE BUILDING TEMPERATURE                              21 DEGREES C
   ECSS SOLAR CONVERSION EFFICIENCY                        0.00
   ECSS OPERATING ENERGY                                  0.000 GIGA JOULES
   STORAGE EFFICIENCY                                    100.01 PERCENT
   EFFECTIVE HEAT TRANSFER COEFFICIENT                        * W/SQ M-DEG K
   TOTAL SYSTEM OPERATING ENERGY                          0.000 GIGA JOULES
___TOTAL ENERGY CONSUMED__________________________________0.000_GIGA_JOULES
SUBSYSTEM SUMMARY:
                      HOT WATER        HEATING       COOLING       SYSTEM TOTAL
   LOAD                    N.A.          7.329         0.000        N.A. GIGA JOULES
   SOLAR FRACTION          N.A.             64             0          64 PERCENT
   SOLAR ENERGY USED       N.A.          4.514          N.A.       4.514 GIGA JOULES
   OPERATING ENERGY        N.A.          0.000         0.000       0.000 GIGA JOULES
   AUX. THERMAL ENG        N.A.          2.815          N.A.       2.815 GIGA JOULES
   AUX. ELECTRIC FUEL      N.A.          2.035          N.A.       2.035 GIGA JOULES
   AUX. FOSSIL FUEL        N.A.           N.A.         0.000        N.A. GIGA JOULES
   ELECTRICAL SAVINGS      N.A.          4.514          N.A.       4.514 GIGA JOULES
___FOSSIL SAVINGS__________N.A.__________0.000__________N.A._______0.000_GIGA_JOULES
SYSTEM PERFORMANCE FACTOR:                *
INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS:    1.06
__________________________________________________________________________

* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED.

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980.
           SOLAR/0004-80/18
```

```
                    MONTHLY REPORT:  FEBRUARY 1981
                  SITE SUMMARY:  BAKER CONSTRUCTION

                                                             CONVENTIONAL UNITS
_______________________________________________________________________________
GENERAL SITE DATA:
   INCIDENT SOLAR ENERGY                                     10.986 MILLION BTU
                                                              27672 BTU/SQ.FT.
   COLLECTED SOLAR ENERGY                                     4.278 MILLION BTU
                                                              10776 BTU/SQ.FT.
   AVERAGE AMBIENT TEMPERATURE                                   35 DEGREES F
   AVERAGE BUILDING TEMPERATURE                                  69 DEGREES F
   ECSS SOLAR CONVERSION EFFICIENCY                            0.00
   ECSS OPERATING ENERGY                                      0.000 MILLION BTU
   STORAGE EFFICIENCY                                        100.01 PERCENT
   EFFECTIVE HEAT TRANSFER COEFFICIENT                            * BTU/DEG F-
                                                                    SQ FT-HR
   TOTAL SYSTEM OPERATING ENERGY                              0.000 MILLION BTU
   TOTAL ENERGY CONSUMED                                      0.000 MILLION BTU
_______________________________________________________________________________
SUBSYSTEM SUMMARY:
                       HOT WATER        HEATING       COOLING       SYSTEM TOTAL
   LOAD                   N.A.           6.947         0.000       N.A. MILLION BTU
   SOLAR FRACTION         N.A.            64             0           64 PERCENT
   SOLAR ENERGY USED      N.A.           4.278          N.A.      4.278 MILLION BTU
   OPERATING ENERGY       N.A.           0.000         0.000      0.000 MILLION BTU
   AUX. THERMAL ENERGY    N.A.           2.668          N.A.      2.668 MILLION BTU
   AUX. ELECTRIC FUEL     N.A.           1.929          N.A.      1.919 MILLION BTU
   AUX. FOSSIL FUEL       N.A.            N.A.         0.000       N.A. MILLION BTU
   ELECTRICAL SAVINGS     N.A.           4.278          N.A.      4.278 MILLION BTU
   FOSSIL SAVINGS         N.A.           0.000          N.A.      0.000 MILLION BTU
_______________________________________________________________________________
SYSTEM PERFORMANCE FACTOR:               *
INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS:     1.06
_______________________________________________________________________________

* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED.

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980.
           SOLAR/0004-80/18
           READ THIS BEFORE TURNING PAGE.
```

MONTHLY REPORT: BAKER CONSTRUCTION FEBRUARY 1981
COLLECTOR SUBSYSTEM PERFORMANCE

DAY OF MONTH (NBSID)	INCIDENT SOLAR ENERGY MILLION BTU (Q001)	OPERATIONAL INCIDENT ENERGY MILLION BTU	COLLECTED SOLAR ENERGY MILLION BTU (Q100)	DAYTIME AMBIENT TEMP DEG F	COLLECTOR SUBSYSTEM EFFICIENCY (N100)
1	0.022	0.000	0.112	39	5.081
2	0.230	0.173	0.125	18	0.543
3	0.429	0.322	0.148	13	0.345
4	0.603	0.454	0.256	18	0.424
5	0.697	0.494	0.274	21	0.393
6	0.085	0.064	0.122	33	1.434
7	0.258	0.195	0.128	40	0.498
8	0.561	0.424	0.225	24	0.401
9	0.525	0.397	0.186	31	0.354
10	0.019	0.015	0.046	42	2.388
11	0.163	0.123	0.148	12	0.906
12	0.908	0.686	0.315	13	0.347
13	0.818	0.618	0.238	30	0.291
14	0.782	0.591	0.257	39	0.328
15	0.738	0.558	0.104	48	0.141
16	0.032	0.024	0.073	48	2.285
17	0.052	0.039	0.060	55	1.150
18	0.088	0.067	0.120	54	1.356
19	0.059	0.045	0.076	58	1.292
20	0.743	0.563	0.192	51	0.259
21	0.437	0.331	0.160	47	0.365
22	0.135	0.102	0.059	56	0.441
23	0.244	0.185	0.126	45	0.518
24	0.145	0.110	0.069	40	0.480
25	0.710	0.538	0.137	49	0.193
26	0.823	0.624	0.265	44	0.322
27	0.619	0.469	0.143	45	0.232
28	0.061	0.046	0.114	53	1.857
SUM	10.986	8.255	4.278	-	-
AVG	0.392	0.295	0.153	38	0.389
PFRV	1.0000	1.0000	1.0000	1.0000	1.0000

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: BAKER CONSTRUCTION FEBRUARY 1981

PASSIVE SYSTEM ENVIRONMENT

DAY OF MONTH (NBS ID)	MAX BLDG TEMP DEG F	MIN BLDG TEMP DEG F	BUILDING TEMP MIDNIGHT DEG F	BUILDING TEMP 6 AM DEG F	BUILDING TEMP NOON DEG F	BUILDING TEMP 6 PM DEG F	INTERIOR RELATIVE HUMIDITY PERCENT	AMB TEMP DEG F (N113)	DAYTIME AMB TEMP DEG F	INCIDENT SOLAR ENERGY MILLION BTU	AVG STOR TEMP DEG F
1	73	70	73#	72#	72#	73#	55	38	39	0.022	65
2	72	66	71#	68#	70#	68#	53	19	18	0.230	61
3	71	64	67#	68#	65#	66#	49	12	13	0.429	59
4	72	63	70#	67#	66#	63#	48	16	18	0.603	59
5	73	69	72#	69#	71#	72#	51	17	21	0.697	61
6	78	67	74#	70#	69#	68#	52	31	33	0.085	60
7	78	71	71#	74#	73#	72#	53	36	40	0.258	60
8	72	67	72#	71#	68#	67#	51	27	24	0.561	62
9	76	68	74#	71#	68#	69#	53	27	31	0.525	62
10	76	67	67#	74#	70#	67#	53	42	42	0.019	60
11	69	62	69#	66#	64#	63#	50	16	12	0.163	57
12	71	67	71#	67#	68#	68#	50	8	13	0.908	58
13	71	67	69#	69#	67#	67#	52	22	30	0.818	61
14	74	68	72#	70#	69#	73#	52	32	39	0.782	64
15	73	69	70#	72#	72#	71#	53	40	48	0.738	64
16	75	65	75#	71#	66#	67#	54	47	48	0.032	63
17	74	65	66#	72#	67#	66#	55	53	55	0.052	61
18	74	66	73#	67#	67#	67#	56	53	54	0.088	61
19	74	68	71#	72#	70#	68#	58	54	58	0.059	61
20	73	66	69#	72#	69#	66#	57	47	51	0.743	66
21	75	69	74#	71#	70#	73#	60	45	47	0.437	68
22	74	66	72#	72#	70#	68#	58	51	56	0.135	65
23	73	67	71#	70#	69#	68#	57	42	45	0.244	63
24	71	66	67#	70#	67#	66#	55	39	40	0.145	61
25	68	64	67#	65#	65#	67#	54	43	49	0.710	63
26	71	66	70#	67#	66#	67#	55	37	44	0.823	67
27	71	66	68#	71#	66#	67#	55	44	45	0.619	68
28	75	67	74#	67#	69#	70#	55	51	53	0.061	67
SUM	-	-	-	-	-	-	-	-	-	10.986	-
AVG	78	62	71	70	68	68	54	35	38	0.392	62
PFRV	N.A.	N.A.	0.3333	0.3333	0.3333	0.3333	1.0000	1.0000	1.0000	1.0000	1.0000

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: BAKER CONSTRUCTION FEBRUARY 1981

ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ.FT (Q001)	DIFFUSE INSOLATION BTU/SQ.FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)	HEAT DEGREE DAYS	COOL DEGREE DAYS
1	56	N	38	39	100	165	6	29	0
2	579	O	19	18	100	256	7	45	0
3	1080	T	12	13	100	238	5	52	0
4	1520		16	18	100	288	6	51	0
5	1755	A	17	21	100	164	3	48	0
6	215	P	31	33	100	228	4	34	0
7	649	P	36	40	100	187	3	30	0
8	1413	L	27	24	100	287	5	38	0
9	1323	I	27	31	100	182	3	37	0
10	49	C	42	42	100	132	7	22	0
11	411	A	16	12	100	267	7	39	0
12	2286	B	8	13	100	0	2	57	0
13	2060	L	22	30	100	0	1	39	0
14	1969	E	32	39	100	0	0	30	0
15	1858		40	48	100	0	1	22	0
16	81		47	48	100	0	1	20	0
17	131		53	55	100	0	1	12	0
18	223		53	54	100	0	1	12	0
19	149		54	58	100	0	1	12	0
20	1873		47	51	100	321	3	18	0
21	1101		45	47	100	0	2	17	0
22	339		51	56	100	140	5	12	0
23	614		42	45	100	199	6	23	0
24	365		39	40	100	259	3	23	0
25	1788		43	49	100	0	1	20	0
26	2073		37	44	100	61	2	27	0
27	1559		44	45	100	125	3	20	0
28	154		51	53	100	264	5	15	0
SUM	27672	N.A.	-	-	-	-	-	804	0
AVG	988	N.A.	35	38	100	236	3	29	0
PFRV	1.0000	N.A.	1.0000	1.0000	1.0000	1.000	1.000	N.A.	N.A.

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: BAKER CONSTRUCTION FEBRUARY 1981

PASSIVE SYSTEM THERMAL PERFORMANCE

DAY OF MONTH (NBS ID)	BLDG SOLAR FRACTION PERCENT	BUILDING HEAT LOAD MILLION BTU	U*A*DT MILLION BTU	INFIL LOSSES MILLION BTU	AUX ENERGY FIREPLACE MILLION BTU	AUX ENERGY INTERNAL GAINS MILLION BTU	AUX THERMAL USED MILLION BTU (Q401)	PASSIVE SOLAR USED MILLION BTU	EQUIP HEAT LOAD MILLION BTU (Q402)	SOLAR FRACTION EQUIP HEAT LOAD PERCENT (N400)
1	44	0.343	0.249	0.093	0.000	0.124	0.064	0.155	0.218	72
2	40	0.433	0.293	0.140	0.082	0.093	0.175	0.165	0.340	49
3	42	0.438	0.287	0.151	0.107	0.067	0.183	0.187	0.371	51
4	50	0.432	0.291	0.141	0.059	0.060	0.160	0.212	0.372	57
5	52	0.462	0.312	0.150	0.027	0.089	0.133	0.240	0.373	64
6	26	0.360	0.253	0.107	0.104	0.081	0.187	0.092	0.278	33
7	46	0.360	0.256	0.104	0.022	0.100	0.091	0.169	0.260	65
8	51	0.411	0.291	0.120	0.000	0.082	0.124	0.205	0.329	62
9	40	0.404	0.285	0.119	0.061	0.086	0.156	0.162	0.318	51
10	51	0.292	0.214	0.078	0.005	0.088	0.049	0.154	0.203	76
11	45	0.398	0.261	0.138	0.060	0.080	0.147	0.171	0.318	54
12	50	0.479	0.310	0.169	0.028	0.066	0.176	0.236	0.412	57
13	53	0.423	0.301	0.127	0.069	0.052	0.157	0.219	0.376	58
14	56	0.411	0.301	0.110	0.000	0.095	0.083	0.233	0.316	74
15	30	0.364	0.278	0.086	0.043	0.108	0.125	0.131	0.256	58
16	19	0.291	0.226	0.065	0.001	0.154	0.071	0.066	0.137	74
17	59	0.232	0.188	0.044	0.002	0.071	0.023	0.138	0.161	86
18	14	0.214	0.174	0.040	0.010	0.093	0.081	0.039	0.120	47
19	42	0.217	0.172	0.045	0.007	0.076	0.053	0.089	0.142	63
20	53	0.293	0.229	0.064	0.005	0.092	0.049	0.152	0.201	79
21	40	0.316	0.243	0.074	0.002	0.145	0.039	0.132	0.171	82
22	39	0.249	0.196	0.053	0.002	0.124	0.018	0.107	0.124	100
23	55	0.285	0.209	0.076	0.001	0.094	0.037	0.154	0.191	81
24	52	0.271	0.191	0.080	0.000	0.081	0.048	0.142	0.190	75
25	26	0.267	0.205	0.062	0.040	0.087	0.107	0.074	0.181	50
26	65	0.345	0.261	0.084	0.000	0.070	0.054	0.220	0.274	80
27	55	0.310	0.243	0.068	0.000	0.097	0.045	0.168	0.213	80
28	30	0.253	0.203	0.050	0.005	0.152	0.035	0.066	0.101	85
SUM	-	9.557	6.920	2.637	0.740	2.610	2.668	4.278	6.947	-
AVG	44	0.341	0.247	0.094	0.026	0.093	0.095	0.153	0.248	64
PFRV	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: BAKER CONSTRUCTION FEBRUARY 1981

PASSIVE STORAGE THERMAL PERFORMANCE

DAY OF MON. (NBS)	INCIDENT SOLAR ENERGY MILLION BTU	PASSIVE SOLAR USED MILLION BTU	SOLAR ENERGY COLLECTED MILLION BTU	ENERGY TO STORAGE MILLION BTU	ENERGY FROM STORAGE MILLION BTU	CHANGE IN STORED ENERGY MILLION BTU	AVG STORAGE TEMP DEG F	AVG BLDG TEMP DEG F
1	0.022	0.155	0.112	0.047	0.089	-0.043	65	72
2	0.230	0.165	0.125	0.084	0.125	-0.041	61	69
3	0.429	0.187	0.148	0.076	0.116	-0.039	59	67
4	0.603	0.212	0.256	0.113	0.069	0.043	59	67
5	0.697	0.240	0.274	0.126	0.092	0.034	61	71
6	0.085	0.092	0.122	0.121	0.091	0.031	60	70
7	0.258	0.169	0.128	0.054	0.095	-0.041	60	73
8	0.561	0.205	0.225	0.103	0.083	0.019	62	70
9	0.525	0.162	0.186	0.133	0.109	0.024	62	71
10	0.019	0.154	0.046	0.018	0.126	-0.108	60	71
11	0.163	0.171	0.148	0.079	0.103	-0.024	57	66
12	0.908	0.236	0.315	0.157	0.078	0.079	58	69
13	0.818	0.219	0.238	0.106	0.087	0.019	61	68
14	0.782	0.233	0.257	0.130	0.106	0.024	64	71
15	0.738	0.131	0.104	0.052	0.079	-0.027	64	71
16	0.032	0.066	0.073	0.110	0.102	0.007	63	70
17	0.052	0.138	0.060	0.015	0.093	-0.078	61	69
18	0.088	0.039	0.120	0.094	0.014	0.081	61	68
19	0.059	0.089	0.076	0.051	0.063	-0.012	61	71
20	0.743	0.152	0.192	0.108	0.067	0.040	66	70
21	0.437	0.132	0.160	0.125	0.098	0.028	68	72
22	0.135	0.107	0.059	0.065	0.112	-0.047	65	70
23	0.244	0.154	0.126	0.066	0.094	-0.028	63	69
24	0.145	0.142	0.069	0.018	0.090	-0.072	61	68
25	0.710	0.074	0.137	0.132	0.069	0.063	63	66
26	0.823	0.220	0.265	0.117	0.072	0.045	67	68
27	0.619	0.168	0.143	0.083	0.107	-0.025	68	68
28	0.061	0.066	0.114	0.089	0.042	0.048	67	69
SUM	10.986	4.278	4.278	2.472	2.472	0.000	-	-
AVG	0.392	0.153	0.153	0.088	0.088	0.000	62	69
PFRV	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED;
# <40% VALID DATA; PFRV RELIABILITY VALUE.

*U.S. GOVERNMENT PRINTING OFFICE: 1981-740-146/2783