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TAOS STATE OFFICE BUILDING

TAOS, NEW MEXICO

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

OCTOBER 1980 THROUGH MAY 1981

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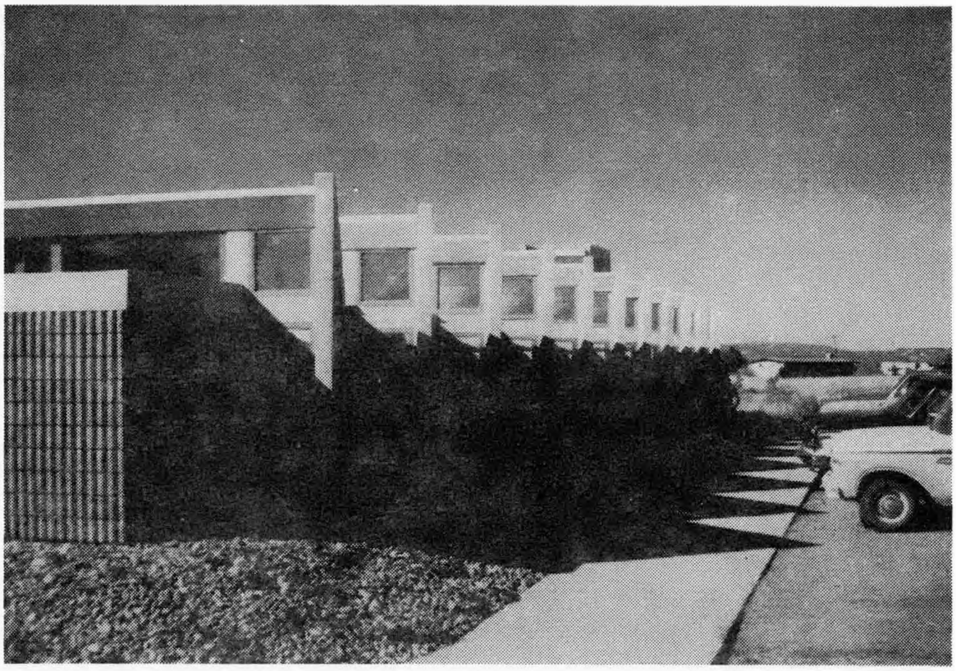
FOREWORD

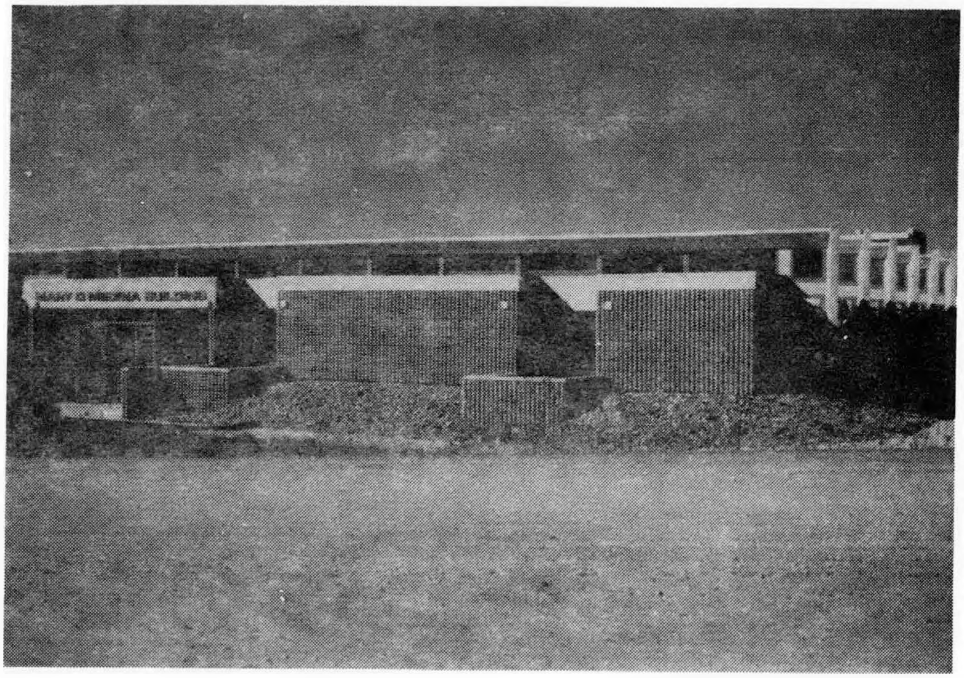
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic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

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. Some "Operational Test Sites" employ prototype Rankine cycle turbines to mechanically drive conventional vapor-compression chillers for cooling.

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.





TAOS STATE OFFICE BUILDING

TAOS STATE OFFICE BUILDING

The Taos State Office Building, otherwise known as the Human Services Field Office, is a single-story office building, located in Taos, New Mexico, which incorporates passive collection and storage of solar energy along with natural lighting for general illumination. The building is oriented 20 degrees east of south to take advantage of early morning sunlight and is designed to supply the following:

Seasonal Design Factors*
October 1980 through May 1981
(Million BTU)

	Total Load	Solar Contribution	% Solar
Heating	600.00	420.00	70

* Design factors provided by the design firm, "The Architects, Taos."

This site is equipped with an integrated passive solar heating and daylighting system consisting of the following:

Collector	Solar energy enters the building via eleven rows of clerestory windows (in a sawtooth configuration totaling 2,695 square feet), south-facing windows (296 square feet), and east and west window scoops (218 square feet).
Storage	The collected solar energy is stored in 14,080 gallons of water contained in drums located at ceiling level in the clerestory area, as well as in the masonry construction mass of the structure.
Auxiliary Heating	The mechanical system provides auxiliary heat via electric strips located in the supply ducts. Each mechanical tower has a split return and supply system. There is a 20 kw heater for the outside wall zones and a 10 kw heater for the extreme side zones. There are two 10 kw heaters for supplying heat to the interior zones.
Daylighting	Daylighting to work areas in the structure is provided through the clerestory windows and is regulated by movable, insulated, shutters which are used to reduce heat loss at night from the clerestory window area.

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TAOS STATE OFFICE BUILDING
OCTOBER 1980 THROUGH MAY 1981

Solar Fraction[1]	67%
Conventional Fuel Savings[2]	4,576 gallons of fuel oil or 621,580 cubic feet of natural gas or 111,484 kwh of electricity

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

	Equipment Heating Load	Solar Contribution	% Solar
Heating	565.36	380.75	67

Environmental Data

	Measured Average	Long-Term Average
Outdoor temperature	40°F	42°F
Heating-degree days	5,733	5,604
Daily incident solar energy to collectors	1,488 BTU/ft^2	1,367 BTU/ft^2
Horizontal total insolation	1,312 BTU/ft^2	1,448 BTU/ft^2

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

2. Conventional Fuel Savings:

equivalent gallons of fuel oil $=$ Solar energy used $\times 0.6 \times 7.21 \times 10^{-6}$ gallons/BTU

equivalent cubic feet of natural gas $=$ Solar energy used $\times 0.6 \times 979.4 \times 10^{-6}$ cubic feet/BTU

equivalent kwh of electricity $=$ Solar energy used $\times 2.928 \times 10^{-4}$ kwh/BTU

1.1 SUMMARY AND CONCLUSIONS

The passive solar energy system at the Taos State Office Building performed very well during the October 1980 through May 1981 heating season. This single-story office building, located in Taos, New Mexico, has 12,000 square feet of conditioned space. Passive solar heating features, including south-facing clerestory windows and water heat storage, are used to satisfy most of the space heating requirements. Solar energy enters the building through 11 rows of roof mounted clerestory windows and is stored by water contained in drums suspended at ceiling level in the clerestory area. Solar energy is also used to provide daylighting for the office space, thus saving electrical lighting energy during the day.

During the eight-month reporting period, solar provided 67% of the 565.36 million BTU equipment heating load. This compared very well with the design solar fraction of 70%. Solar energy use provided a conventional fuel savings of 4,576 gallons of fuel oil, 621,580 cubic feet of natural gas or 11,484 kwh of electricity, depending on the auxiliary fuel source with which thermal savings are compared. There were 380.75 million BTU of solar energy used during the reporting period. In addition, electric strip heaters located in the ducts of the air handling system, provided 184.61 million BTU of auxiliary energy as a supplement to the solar contribution. The building heat load, which included the contribution of 131.45 million BTU of internal energy gains plus the auxiliary electric and solar energy, was 696.81 million BTU. The solar fraction of this load was 55%.

The overall solar system thermal performance is included in Table 1 and shown graphically in Figure 1. In Figure 1, the monthly load profile can be seen for the winter heating season. The contributions of the solar plus the auxiliary electric energy added to the building compose the equipment heating load at Taos State Office Building. The breakdown of this load can be clearly seen in Figure 1. This load remained nearly 80 million BTU for each of the winter months until April when the average outside temperature rose to nearly 50°F. There was also a considerable load in October which was almost completely satisfied by the abundant amount of solar energy available that month.

The overall building load at Taos State Office Building (which includes the equipment heat load plus the internal gains to the building) is listed for each month of the heating season in Table 1. Since the building heat load can also be considered the sum of all energy losses from the building envelope, the building heat load is broken down into conduction and infiltration loss components. The infiltration losses, which result from air exchange through open doors, windows, cracks, etc., between inside and outside air, turned out to be a very sizable portion (41%) of the overall load at Taos State Office Building. Ideally the infiltration loss on new construction buildings is designed to be much less than the conduction heat losses through walls, windows, roof, etc.

There are two main factors involved in the large infiltration loss at Taos State Office Building. The first is that the relatively high wind conditions experienced in the Taos area tended to increase the rate of infiltration. The second is that the actual building construction was not quite as "tight" as it was designed to be. Therefore the high winds forced air exchange through cracks in the building structure and the infiltration loss was increased. The

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

TAOS STATE OFFICE BUILDING
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 Δτ)	INFILTRATION LOSSES	INTERNAL GAINS	AUX ENERGY CONSUMED	PASSIVE SOLAR ENERGY CONSUMED	EQUIPMENT HEATING LOAD	EQUIPMENT SOLAR FRACTION (%)
OCT	589	75	86.17	52.54	33.63	18.04	3.57	64.56	68.13	95
NOV	780	64	94.53	57.26	37.27	14.06	20.36	60.11	80.47	75
DEC	854	46	95.42	58.52	36.90	18.79	32.59	44.04	76.63	57
JAN	999	48	105.06	63.49	41.57	18.49	36.46	50.11	86.57	58
FEB	850	52	96.36	57.72	38.64	15.72	30.48	50.16	80.64	62
MAR	842	41	98.22	56.33	41.89	17.94	39.86	40.42	80.28	50
APR	486	60	73.64	42.23	31.41	14.68	14.63	44.33	58.96	75
MAY	333	57	47.41	27.44	19.97	13.73	6.66	27.02	33.68	80
TOTAL	5,733	-	696.81	415.53	281.28	131.45	184.61	380.75	565.36	-
AVERAGE	717	55	87.10	51.94	35.16	16.43	23.08	47.59	70.67	67

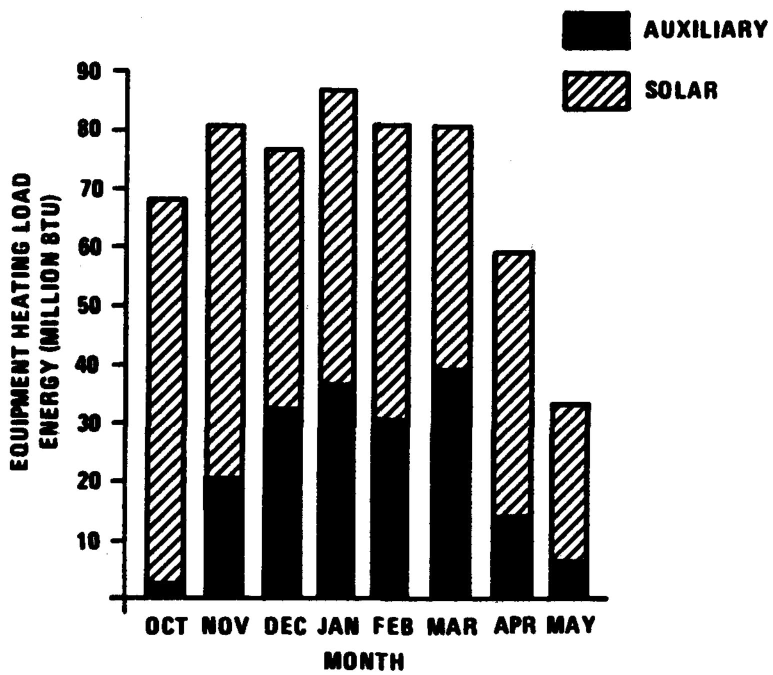


Figure 1. System Thermal Performance
Taos State Office Building
October 1980 through May 1981

average wind speed experienced during the reporting period at Taos was six miles per hour. The air infiltration rate associated with this wind was estimated to be about 0.7 air changes per hour. The air change per hour increased to about 1.0 for periods when the wind speed was near 10 mph. Winds in excess of 10 mph are commonly experienced in Taos. The increased percentage of infiltration loss in the load during March, April and May was due to this high wind, predominantly coming out of the southeast.

The normalized building heat load coefficient, which is the ratio of the building heat load to the heating degree-days (HDD) and the building area, was intended to be in the range of 8-10 BTU/Ft^2/HDD in the design of Taos State Office Building. The actual average building load coefficient calculated for the heating season was 10.1 BTU/Ft^2/HDD; just above the design range. The higher than expected infiltration tended to move the actual coefficient towards the high side of the design range. The calculated monthly load coefficients are given in the following table.

MONTH	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Load Coefficient (BTU/FT^2/HDD)	12.19	10.10	9.31	8.76	9.45	9.72	12.62	11.87

Notice the rise in the load coefficient during the seasonal transition months of October, April and May. This rise was due to periods of solar energy and internal gain contributions when there was no heating requirement. In the summer, this calculation would be valid only for days when the ambient temperature is below 65°F.

The actual number of measured heating degree-days during the eight-month period was 5,733 compared to the long-term average of 5,604. The measured average temperature during the reporting period was 40°F which was slightly lower than the long-term average of 42°F. The average daily incident solar energy reaching the collection subsystem aperture was 1,488 BTU/Ft^2/day compared to the expected long-term average value of 1,367 BTU/Ft^2/day. This difference was due mainly to the reflective roof surface which effectively increased the amount of solar energy entering the window area.

Figure 2 shows the energy flow through the Taos State Office Building solar energy system.

There were 859.35 million BTU of solar radiation available on the window surface of which 845.20 million BTU were available while the shutters were open. Operating energy required to operate the shutters were 7.93 million BTU. Of the 845.20 million BTU of operational incident energy, 375.35 million BTU or 45% was collected and delivered to the building load. Forty-six percent or 171.31 million BTU of this energy was absorbed by the water storage drums and 204.04 million BTU was supplied to the conditioned space directly.

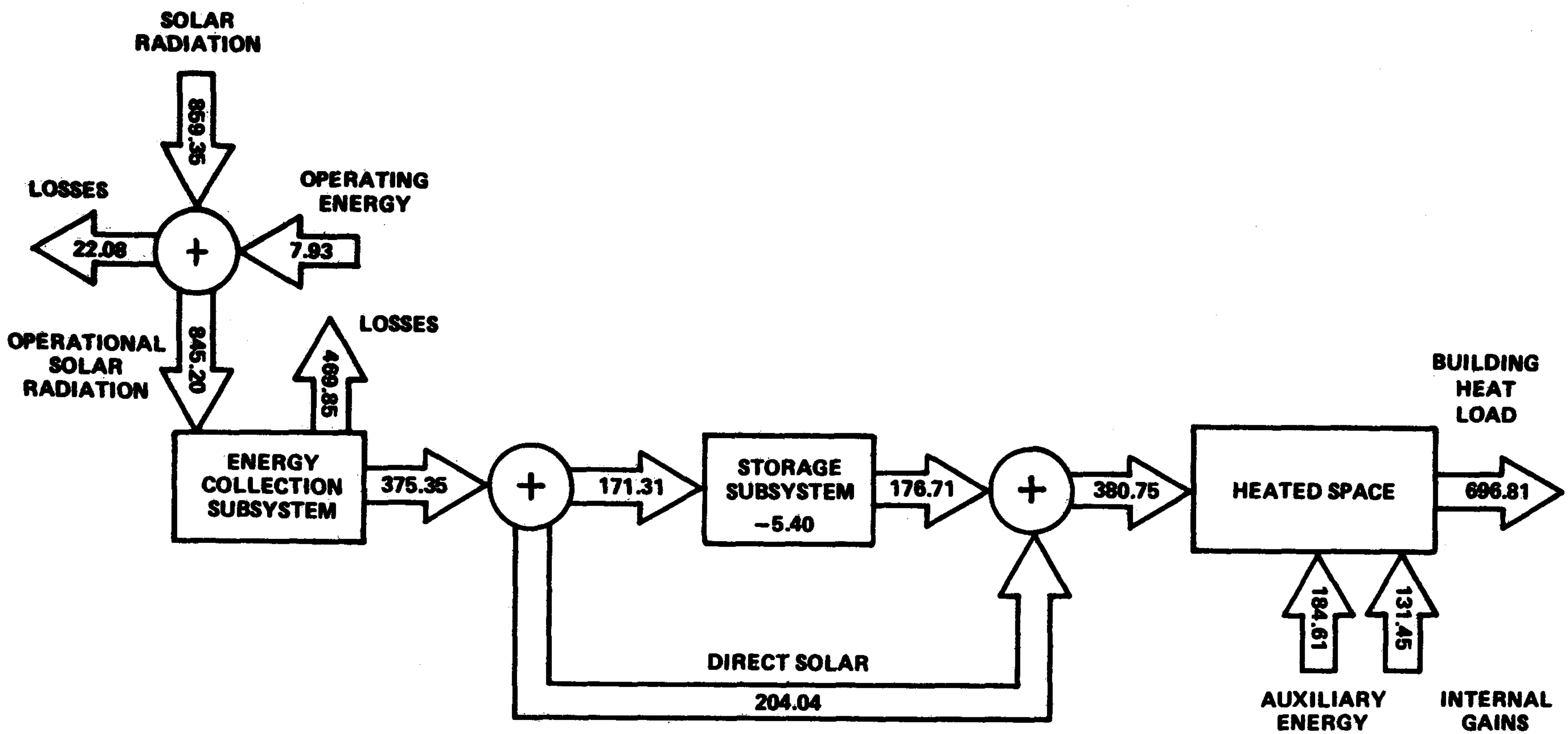


Figure 2. Energy Flow Diagram for Taos State Office Building
October 1980 through May 1981

The storage subsystem delivered 176.71 million BTU to the conditioned space including 5.40 million BTU collected prior to this reporting period. A total of 380.75 million BTU of solar energy was contributed to the space heating load. In addition, 184.16 million BTU of electrical auxiliary energy and 131.45 million BTU of internal energy gains (people, lights, equipment, etc.) contributed to the 696.81 million BTU building heat load.

During the heating season the average building temperature was 73°F and the average storage temperature for the eight-month period was 80°F.

Figures 3 through 10 are monthly summary plots of daily insolation, building temperature, storage temperature, and auxiliary use during the entire heating season.

The need for heat started in mid-October when average outside temperatures dropped sharply from the 50's°F to the 30's°F during a two-day period of early winter weather. Average temperatures remained in the 30's°F and low 40's°F throughout the rest of the month. For the most part, solar insolation was abundant during October and 95% of the load was satisfied by solar energy.

The November profile was very similar to that of October. Again, in the middle of the month, there was a sharp drop in ambient temperature, this time into the 20's°F. Significant amounts of auxiliary energy were needed during this cold snap to supplement the solar contribution and the solar fraction dropped to 75%. However, as in October, solar provided almost 100% of the load during the first half of the month. Storage temperatures averaged in the mid 80's°F for both months, dropping only during the few periods of low insolation. Building temperatures remained in the mid 70's°F throughout most of both months.

Peak insolation levels dropped somewhat in December and January, however storage temperatures remained in the 80's°F except during periods of low insolation. The storage temperatures remained high because the vertical orientation of the glazing coupled with the drum locations maximized collection during these months. Auxiliary energy usage was closely related to insolation levels throughout the period and always followed closely (one or two days) after a period of low insolation. It is interesting to note that during a five-day period of steady insolation from January 19 through 23, the auxiliary electric use gradually dropped to almost zero, indicating the potential of the solar system under ideal conditions. The peak auxiliary usage on January 19 was the result of a three-day period of very low insolation. During this time storage temperatures dropped to room temperature. Then during the following five-day period of good insolation, storage charged up to a high of 85°F. Despite the periodic heavy use of auxiliary energy during December and January, the solar fraction for both months was 57% and 58% respectively.

February showed wide variance in levels of auxiliary energy use. Two peak periods of auxiliary use occurred directly (one day) after days of low insolation. Auxiliary use dropped off and remained low as the insolation levels remained steady during the last half of the month. Whenever storage temperatures approached the mid 80's°F, auxiliary usage dropped to very low levels indicating that enough reserve had been built up to carry the load through the night. The solar fraction for February was 62%.

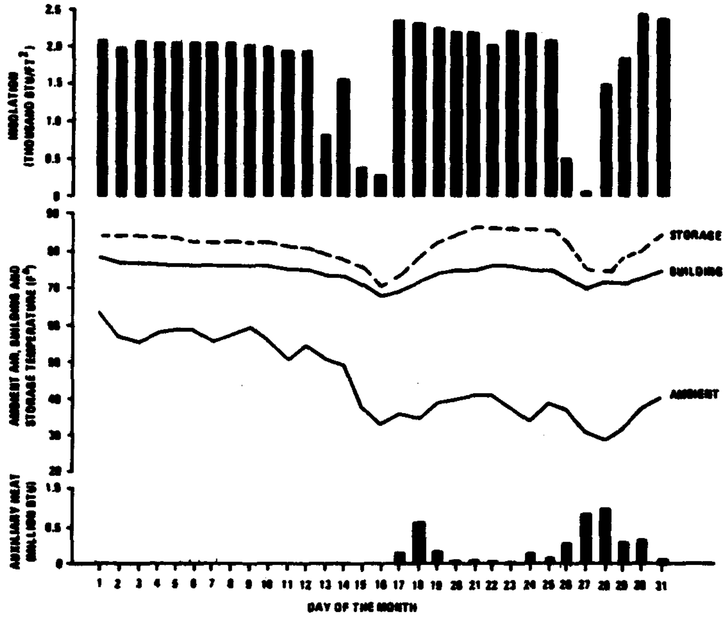


Figure 3. Monthly Summary Graphs for October 1980
Insolation vs Building, Storage, and Ambient
Temperatures vs Auxiliary Energy Used
Taos State Office Building

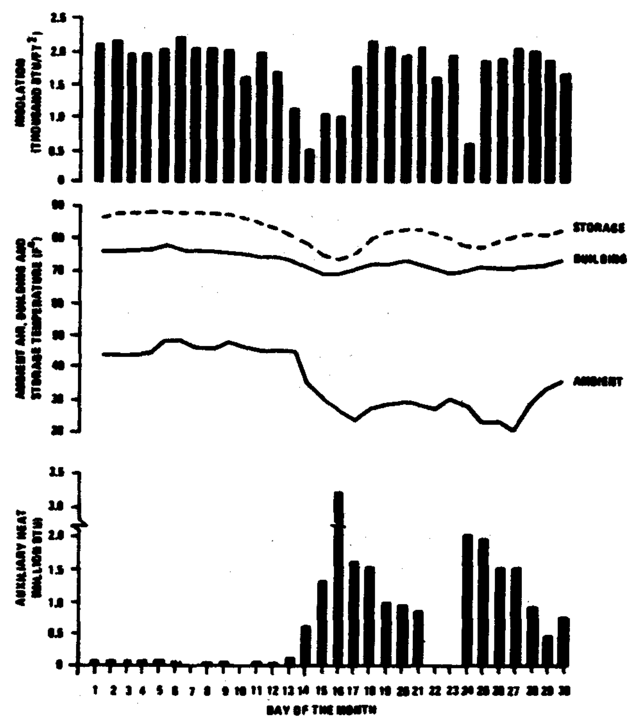


Figure 4. Monthly Summary Graphs for November 1980
Insolation vs Building, Storage, and Ambient
Temperatures vs Auxiliary Energy Used
Taos State Office Building

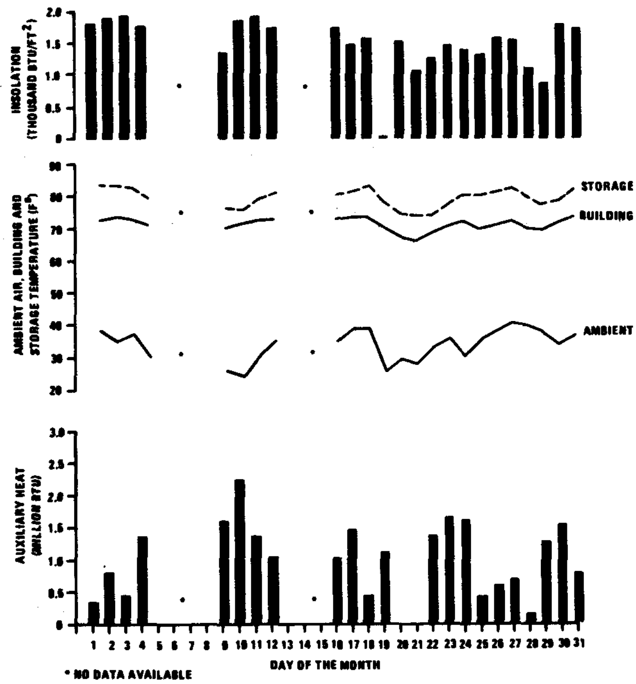


Figure 5. Monthly Summary Graphs for December 1980
Insolation vs Building, Storage, and Ambient
Temperatures vs Auxiliary Energy Used
Taos State Office Building

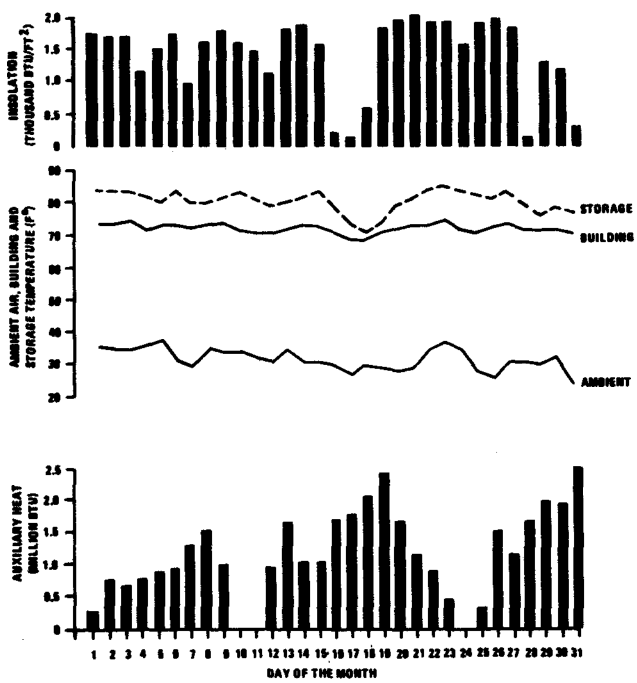


Figure 6. Monthly Summary Graphs for January 1981
Insolation vs Building, Storage, and Ambient
Temperatures vs Auxiliary Energy Used
Taos State Office Building

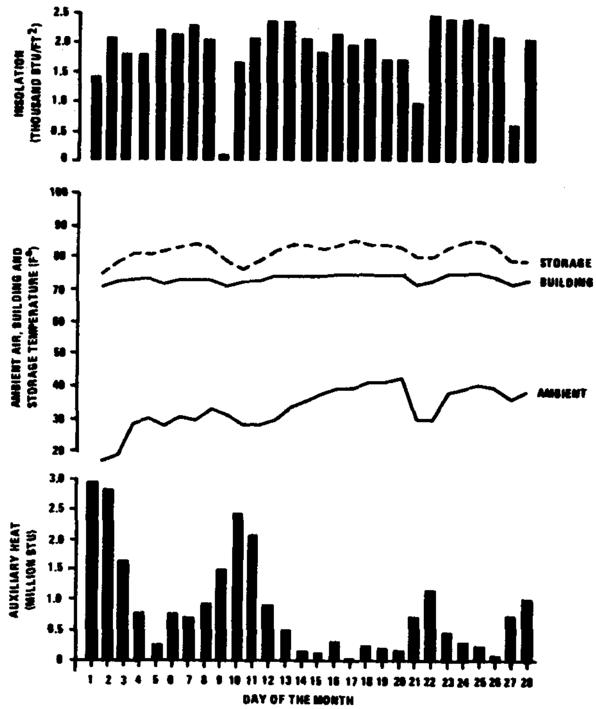


Figure 7. Monthly Summary Graphs for February 1981
Insolation vs Building, Storage, and Ambient
Temperatures vs Auxiliary Energy Used
Taos State Office Building

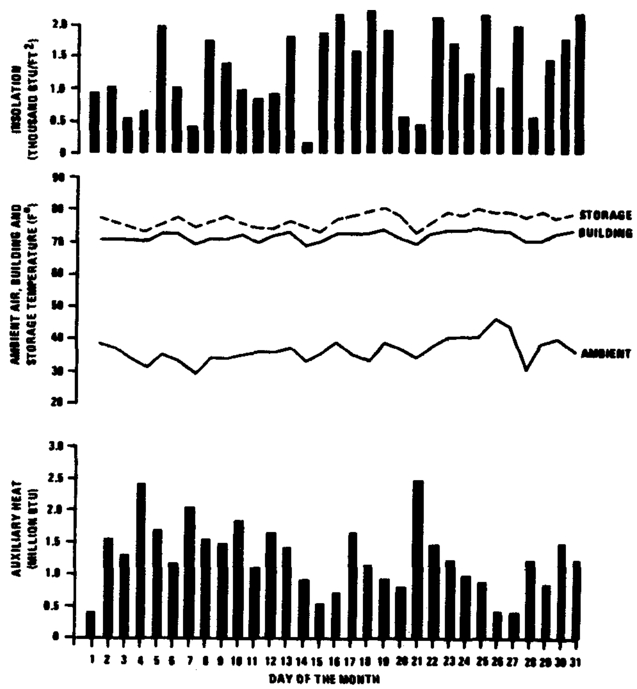


Figure 8. Monthly Summary Graphs for March 1981
Insolation vs Building, Storage, and Ambient
Temperatures vs Auxiliary Energy Used
Taos State Office Building

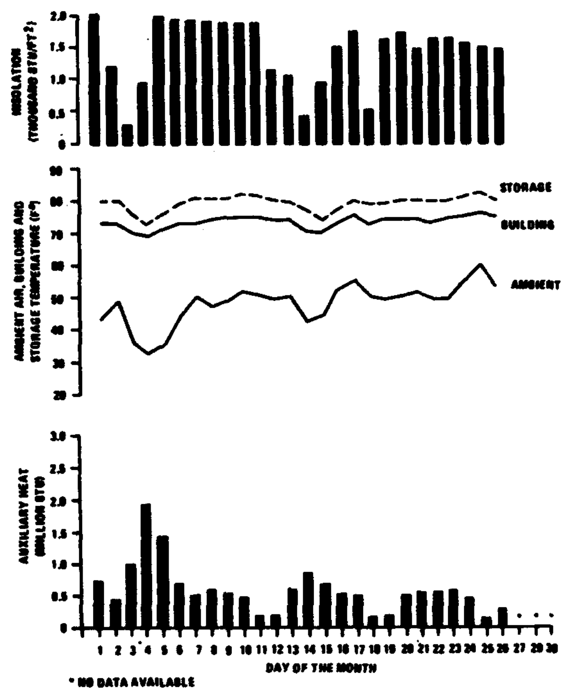


Figure 9. Monthly Summary Graphs for April 1981 Insolation vs Building, Storage, and Ambient Temperatures vs Auxiliary Energy Used Taos State Office Building

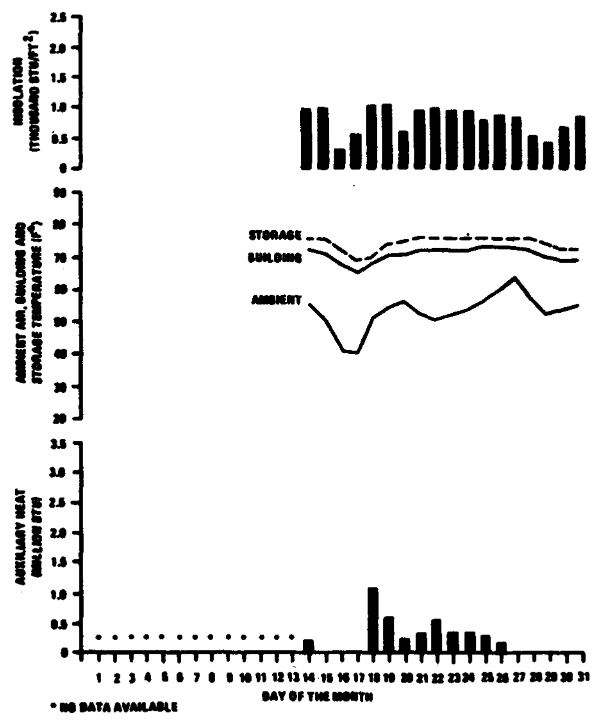


Figure 10. Monthly Summary Graphs for May 1981 Insolation vs Building, Storage, and Ambient Temperatures vs Auxiliary Energy Used Taos State Office Building

March was both cloudier and colder than normal and the equipment solar fraction dropped to a seasonal low of 50%. Storage temperatures rarely climbed above 80°F and auxiliary use was steady throughout the month. Average ambient temperatures were in the 30's°F.

The April solar fraction increased to 75% as there were long periods of optimal insolation, while the average outdoor temperature rose into the 40's°F and 50's°F. Auxiliary usage dropped to very low levels as storage temperatures remained in the 80's°F most of the month.

May marked the end of the heating season as auxiliary use ceased after the 26th of the month. Insolation levels to the collection subsystem dropped sharply as shading prevented much of the insolation from reaching the window aperatures as the solar altitude angles increased. The summer shading feature will help control excessive overheating.

According to the monitored results the system appears to be well sized through selection of adequate collector area and storage mass. Adequate storage mass has been provided to moderate temperature swings in the building and provide a one or two day carry over for periods of low insolation. The solar system is also capable of providing almost 100% of the daily energy requirement in mid winter when the storage is charged up to about 85°F. This was evident by the performance in January and February during periods of good insolation. During an exceptionally clear winter the solar system has the potential of providing over 80% of the space heating needs.

1.2 SOLAR SYSTEM AVAILABILITY

The solar energy system was operational during the entire heating season. Shutter operation controlled the amount of solar energy entering the building, however, the shutters were open 98% of the time when insolation was present (see Table 2). During the seasonal transition months of October and May, and in the summer, the shutters are oriented such that solar radiation is prevented from reaching the water storage drums. Thus, the storage subsystem participation is reduced during the months when space heating is not required.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The solar energy collection subsystem at Taos State Office Building consists of 11 rows of south-facing clerestory windows mounted on the roof in a saw-tooth configuration. Reflective roof surfaces increase the gain through the approximately 2,695 square feet of vertical, double-glazed windows. South-facing hall windows and east and west window scoops also possess some solar collection capability during limited periods of the day. These also contribute to daylighting of the work area.

The clerestory windows are designed also to provide natural lighting for the building. As a result, the electric lighting for the building is designed to be used only as a backup, providing about 1.5 watts of incandescent light per square foot of floor area.

Pneumatically controlled shutters located in the clerestory window area serve two purposes. One function of the shutters is to provide automatic, movable insulation for the glazing. At night the shutters move to a vertical position to help control heat loss when the windows are not in use. The other use of the shutters is to direct the incoming insolation to either light the rooms below or to heat the storage drums located at ceiling level, or both. The shutters have a reflective surface which is tilted to one of several angles by the pneumatic controls according to the desired use of the solar energy. In the summer the solar radiation is prevented from reaching the storage drums since the intended use is for daylighting only. In winter both heating and lighting is required so the solar energy is allowed to reach the storage drums as well as be reflected down into the rooms.

During the winter heating season, solar energy entering the building is either directly absorbed by the storage drums or reflected down into the conditioned space where it causes direct gain of energy to the building structure. In addition, some of the energy is immediately conducted back through the collector glazing and lost to the environment. This loss is significant since a relatively large $\Delta\tau$ exists during collection between the warm inside air in the clerestory area and the cold winter ambient air. At night, when the insulation is in place and the air near the clerestory windows cools down, the loss is reduced.

Table 2 shows the collector performance for the heating season. The net amount of solar energy collected during this period was 375.35 million BTU. This represents 45% of the 845.20 million BTU of insolation reaching the glazing while the shutters were open. The total insolation reaching the collector area was 859.35 million BTU during the heating season.

The loss through the collector glazing while the shutters were open was estimated to be 113.79 million BTU during the heating season. Adding this loss to the net solar energy collected indicates that the total solar energy transmitted by the glazing was 489.14 million BTU yielding an operational glazing transmission effectiveness of about 58%. This value integrates all shading effects and incident angles obtained by insolation to the passive aperture.

Table 2. COLLECTOR SUBSYSTEM PERFORMANCE

TAOS STATE OFFICE BUILDING
OCTOBER 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	OPERATIONAL INCIDENT ENERGY	SOLAR ENERGY COLLECTED (NET GAIN)	COLLECTOR EFFICIENCY (%)	ECSS OPERATING ENERGY	COLLECTOR LOSS	SOLAR ENERGY TRANSMITTED/ TRANSMISSION EFFECTIVENESS	MOVABLE INSULATION IN PLACE (HOURS/DAY)
OCT	134.53	133.28	64.75	49	0.99	12.66	77.41/.58	11
NOV	120.76	119.90	58.27	49	1.00	14.69	72.96/.61	13
DEC	116.69	115.72	41.67	36	1.03	13.80	55.47/.48	14
JAN	105.84	104.37	48.48	46	1.03	16.97	65.45/.63	13
FEB	118.64	117.52	50.80	43	0.93	18.48	69.28/.59	10
MAR	99.68	96.70	40.37	42	1.03	18.25	58.62/.61	10
APR	107.15	104.22	44.88	43	0.95	11.55	56.43/.54	10
MAY	56.06	53.49	26.13	49	0.97	7.39	33.52/.63	10
TOTAL	859.35	845.20	375.35	-	7.93	113.79	489.14/-	-
AVERAGE	107.42	105.65	46.92	45	0.99	14.22	61.14/.58	11

The movable insolation was in place an average of 11 hours during a typical day. The compressor used to operate the pneumatic controls for the shutters consumed 7.93 million BTU of operating energy.

2.2 STORAGE

The solar energy storage system at Taos State Office Building consists of approximately 14,080 gallons of water contained in drums suspended at ceiling level in the clerestory window area. In the winter, solar energy entering the building through the clerestory windows strikes the dark surface of the drums and is absorbed. At night this energy is reradiated to the rooms below. Blowers in the mechanical air handling system are used to help circulate and distribute the air (heated by the drums) to the conditioned space of the building.

The function of the solar storage is to absorb transmitted solar energy during the day and release the energy at night when needed. Therefore, the thermal storage mass must act as a capacitor having a suitable charge and discharge cycle to properly regulate the energy flows. The correct amount of storage mass must be chosen to control this cycle. If insufficient storage mass is used in a particular passive heating application, the storage and room temperatures can quickly rise to uncomfortable levels during the day. Then at night the storage mass will quickly discharge the stored energy to the conditioned space. Excess storage mass will have a very long charge and discharge cycle. Much solar energy will be needed to change the storage temperature even a small amount. In this case it may take several days or weeks to raise the storage temperature to a level sufficient to radiate a significant amount of energy back to the space at night.

The charge and discharge cycle of the water storage mass is plotted along with the building and ambient temperatures in Figures 11 and 12. The daily insolation and auxiliary heat used are also included on this graph for several days in January 1981. Days were picked around a period of low insolation to demonstrate the response of the storage and building temperatures.

Figure 11 shows a full discharge period when the storage temperatures dropped from the mid 80's°F to near room temperature in about two days. From the graph, the fastest rate of discharge is during the first 12 - 16 hours after the storage peak. During the period shown, the storage temperature dropped 5°F in the first 10 hours, then another 5°F over each of the next two 20 hour periods as the difference between the storage and room temperature decreased.

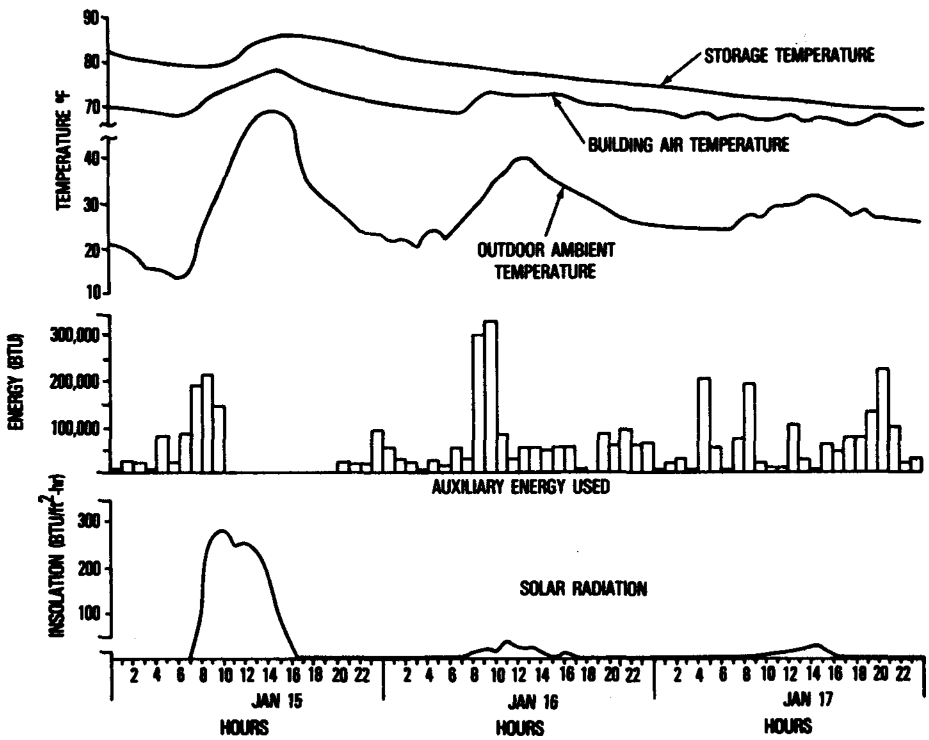


Figure 11. Discharge Cycle
Taos State Office Building
January 15, 16 and 17

The storage charge cycle is shown in Figure 12. By January 20 the storage temperature rose from room temperature back up to the mid 80's°F after two days of good insulation. The storage charge rate is higher than the discharge rate due to the high surface temperatures of the drums. On clear January days, the storage temperature typically rose 10°F during nine or 10 hours of good insolation.

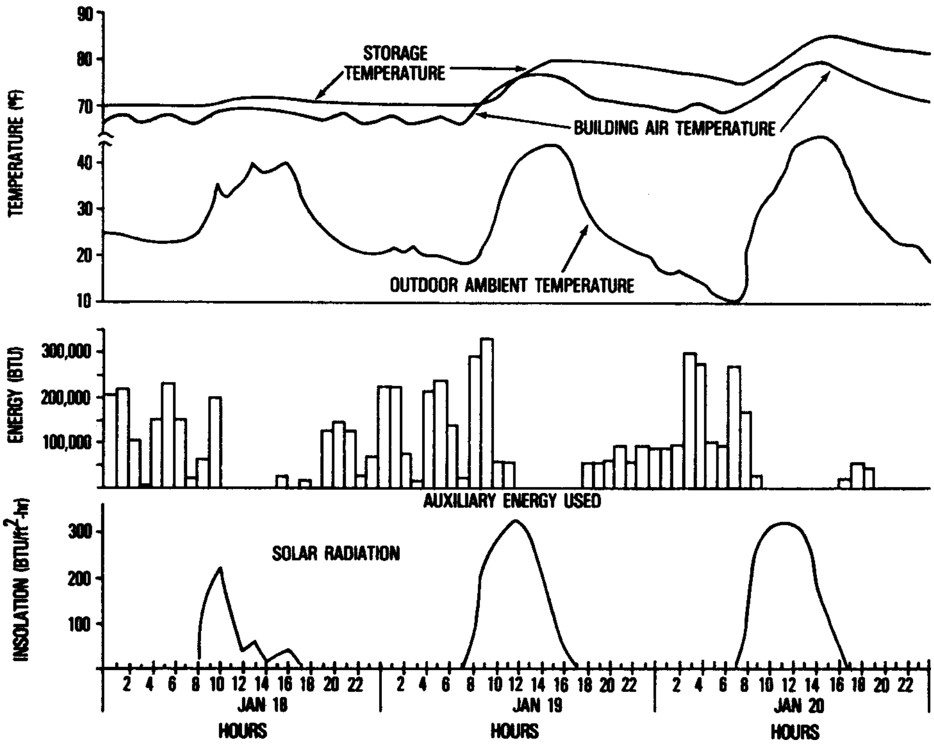


Figure 12. Charging Cycle
Taos State Office Building
January 18, 19 and 20

Figure 12 shows that the building temperature swing was also about 10°F in January on days of good insolation. However the building tended to respond somewhat quicker to the incoming energy than did storage. The building temperature rose slightly quicker and tended to peak 2-3 hours before the storage temperature.

In general, the storage system seems to be responding well and is suitably matched to the solar energy collected. There are about 0.7 cubic feet (or 5.2 gallons) of water per square foot of clerestory glazing area or 0.16 cubic feet of storage water per square foot of floor space (this volume of water is about four times as great as typical collector area to storage volume ratios of active solar systems.) This ratio at Taos State Office Building seems to adequately control the temperature swing and evenly distribute the solar energy at night. The average storage temperature for the heating season was 80°F while the average building temperature for the period was 73°F. As shown in Table 3, the total energy added to storage was 171.31 million BTU and 176.71 million BTU was delivered from storage. The difference of 5.40 million BTU represents the change in stored energy due to the lower storage temperature at the end of the season, 75°F in May, compared to 82°F in October.

Table 3. STORAGE PERFORMANCE

TAOS STATE OFFICE BUILDING
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	20.07	19.88	0.19	82	75
NOV	25.93	27.77	-1.84	83	74
DEC	31.78	34.15	-2.37	80	72
JAN	25.87	27.50	-1.63	80	72
FEB	23.54	22.90	0.64	82	74
MAR	16.89	16.94	-0.05	77	72
APR	16.76	16.21	0.55	80	74
MAY	10.47	11.36	-0.89	75	72
TOTAL	171.31	176.71	-5.40	-	-
AVERAGE	21.41	22.09	-0.67	80	73

2.3 SPACE HEATING

There are three main sources of energy used at Taos State Office Building to satisfy the space heating requirement. The primary source is the passive solar energy collected by the clerestory windows and stored in the water drums and building mass. Additional energy is supplied, if needed, by electric strip heaters located in the ducts of the mechanical air handling system. The third source of heat contributing to the space heating requirement is energy from people and equipment (including lighting) that comprises the internal gains of the building.

The thermostat set point for the building air temperature is set at about 68°F. This can be seen on Figure 11 during times at night when the building temperature dropped to the point where the auxiliary heating strips turned on. The average building temperature for the eight-month period was 73°F. Daytime indoor temperature often rose to the 80°F range as can be seen from the maximum building temperatures shown in Table 4. These maximum and minimum values represent the highest or lowest building temperature shown at any one of seven locations measured in the building. The actual average temperature swing in the building was about 10°F throughout the reporting period. Building temperatures in the low to mid 80's°F are not uncommon in the afternoon hours. These temperatures are not considered uncomfortable, however, due to the low

Table 4. PASSIVE SYSTEM ENVIRONMENT

TAOS STATE OFFICE BUILDING
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	92	60	17	82	46	58	134.53
NOV	74	91	61	12	83	36	49	120.76
DEC	72	84	57	12	80	33	46	116.69
JAN	72	87	58	10	80	31	43	105.84
FEB	74	88	57	8	82	34	46	118.64
MAR	72	85	61	14	77	37	44	99.68
APR	74	88	60	13	80	49	59	107.15
MAY	72	82	61	20	75	54	62	56.06
TOTAL	-	-	-	-	-	-	-	859.35
AVERAGE	73	87	59	13	80	40	51	107.42

relative humidity levels typical of the Taos climatic zone. The average indoor relative humidity during the reporting period was 13%.

Figure 13 graphically demonstrates the monthly distribution of auxiliary and solar energy use during the reporting period. The solar energy system performed well as 67% of the equipment heating load was satisfied by solar energy. This compares very well with the design solar fraction of 70%. The equipment heating load represents the sum of the energy contributed by the auxiliary electric heater plus the solar energy used and was 565.36 million BTU for the reporting period. The building space heating load, which includes the contribution of internal gains, was also computed for the heating season. The building load was 696.81 million BTU, of which 55% was supplied by solar energy. There were 184.61 million BTU of auxiliary electrical energy consumed and 131.45 million BTU of internal heat gains were recorded. Table 5 lists the monthly space heating performance for the eight-month heating season.

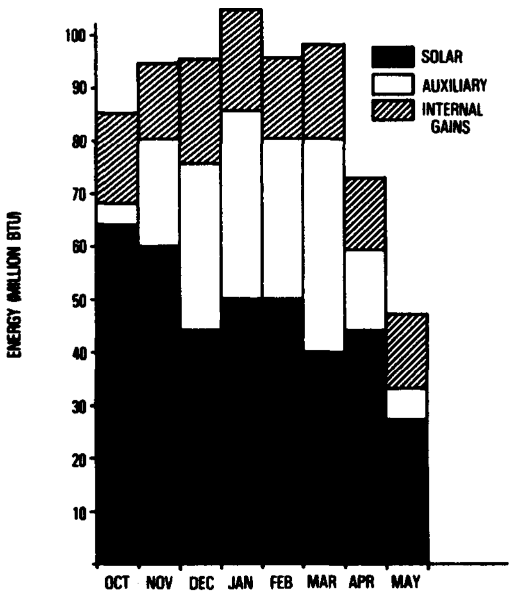


Figure 13. Space Heating Performance
Taos State Office Building
October 1980 through May 1981

Table 5. SPACE HEATING SUBSYSTEM

TAOS STATE OFFICE BUILDING
OCTOBER 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	EQUIPMENT HEATING LOAD	EQUIPMENT SOLAR FRACTION (%)	BUILDING SOLAR FRACTION (%)	BUILDING HEAT LOAD	AUXILIARY ENERGY CONSUMED (ELECTRICAL)	INTERNAL HEAT GAINS	SOLAR ENERGY COLLECTED
OCT	68.13	95	75	86.17	3.57	18.04	64.75
NOV	80.47	75	64	94.53	20.36	14.06	58.27
DEC	76.63	57	46	95.42	32.59	18.79	41.67
JAN	86.57	58	48	105.06	36.46	18.49	48.48
FEB	80.64	62	52	96.36	30.48	15.72	50.80
MAR	80.28	50	41	98.22	39.86	17.94	40.37
APR	58.96	75	60	73.64	14.63	14.68	44.88
MAY	33.68	80	57	47.41	6.66	13.73	26.13
TOTAL	565.36	-	-	696.81	184.61	131.45	375.35
AVERAGE	70.67	67	55	87.10	23.08	16.43	46.92

SECTION 3

SOLAR OPERATING ENERGY

Measured monthly values of the Taos State Office Building solar energy system and subsystem operating energy for the report period are presented in Table 6. A total 7.93 million BTU of operating energy was consumed by the solar system during the reporting period.

Total system operating energy for Taos State Office Building is the electrical energy required to support the ECSS subsystem without affecting its thermal state. This energy was used by the pneumatic control system to operate the shutters. The mechanical air handling system aids in the distribution of solar energy from storage to space heating. However, the electrical energy used to operate the blowers would have been required with or without the addition of the solar system and is therefore not charged against the solar system.

Table 6. SOLAR OPERATING ENERGY

TAOS STATE OFFICE BUILDING
OCTOBER 1980 THROUGH MAY 1981

MONTH	TOTAL SOLAR OPERATING ENERGY (Million BTU)
OCT	0.99
NOV	1.00
DEC	1.03
JAN	1.03
FEB	0.93
MAR	1.03
APR	0.95
MAY	0.95
TOTAL	7.93
AVERAGE	0.99

SECTION 4

ENERGY SAVINGS

The use of solar energy at Taos State Office Building for space heating and natural lighting made possible considerable energy and dollar savings during the October 1980 through May 1981 heating season. The net fossil fuel energy savings for space heating during the reporting period was 634.63 million BTU. The net electrical savings due to daylighting was 52.62 million BTU. The fossil fuel and daylighting energy savings are compared graphically in Figure 14.

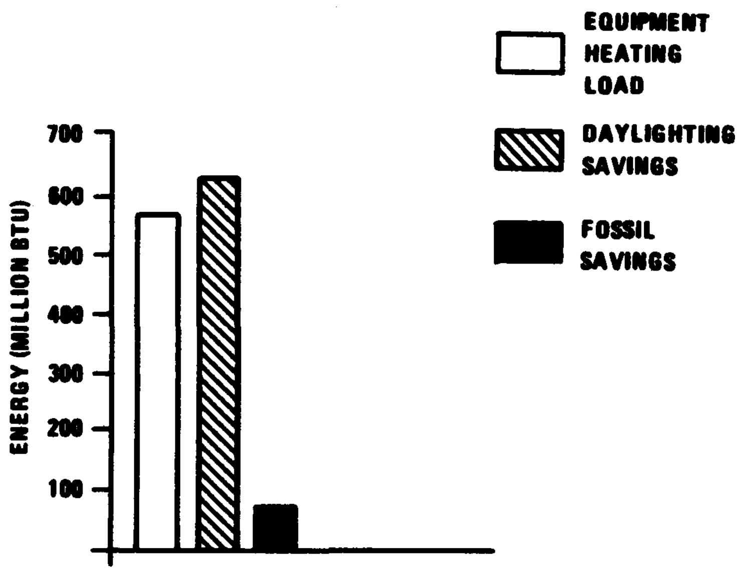


Figure 14. Thermal Energy Savings Compared to Load
Taos State Office Building
October 1980 through May 1981

In Table 7, the space heating savings are expressed in terms of fossil fuel savings since natural gas or oil would be the most likely heating alternatives had the solar energy not been utilized. The fossil fuel savings was derived by dividing the 380.75 million BTU of solar energy used by an assumed combustion efficiency of 0.6. Electrical energy is presently being used as the auxiliary energy source as the backup to the solar contribution. If the solar energy used for space heating was expressed in electrical savings, an efficiency factor of one would be assumed. (Space heating savings expressed as electrical energy is not listed in Table 7).

Table 7. ENERGY SAVINGS

TAOS STATE OFFICE BUILDING
OCTOBER 1980 THROUGH MAY 1981

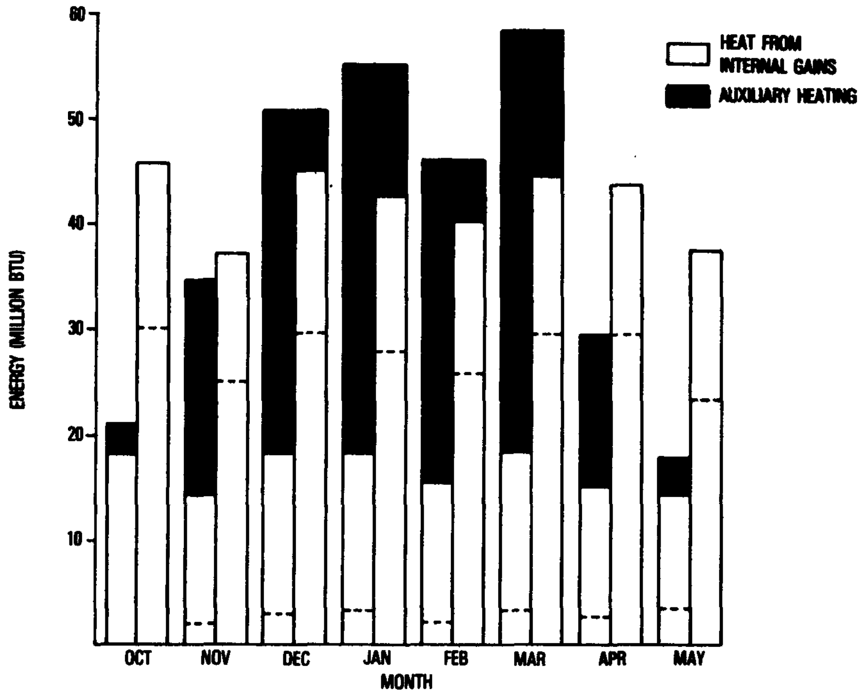
(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY USED	ACTUAL AUXILIARY ENERGY PLUS INTERNAL GAINS	HIGH EFFICIENCY LIGHTING REQUIREMENT	INTERNAL GAINS[1]	SAVINGS ELECTRICAL[2]	SAVINGS FOSSIL FUEL[3]	OPERATING ENERGY	NET ENERGY SAVINGS ELECTRICAL	NET ENERGY SAVINGS FOSSIL FUEL
OCT	64.56	21.62	30.39	47.06	25.45	107.60	0.99	24.46	107.60
NOV	60.11	34.42	25.10	38.12	3.70	100.18	1.00	2.70	100.18
DEC	44.04	51.38	29.07	46.32	-	73.40	1.03	-1.03	73.40
JAN	50.11	54.95	27.74	44.37	-	83.57	1.03	-1.03	83.57
FEB	50.16	46.20	26.42	41.12	-	83.60	0.93	-0.93	83.60
MAR	40.42	57.80	29.07	45.61	-	67.37	1.03	-1.03	67.37
APR	44.33	29.31	29.07	42.46	13.15	73.88	0.95	12.20	73.88
MAY	27.02	20.39	26.42	38.64	18.25	45.03	0.97	17.28	45.03
TOTAL	380.75	316.06	223.28	343.70	60.55	634.63	7.93	52.62	634.63
AVERAGE	47.59	39.51	27.91	42.96	-	79.33	0.99	6.58	79.33

NOTES:

1. The projected internal gain if high efficiency lighting had been used instead of daylighting.
2. Electrical energy savings due to use of daylighting.
3. Fossil energy savings for space heating due to solar energy use.

The net electrical savings listed in Table 7 represent the amount of electrical energy saved as a result of the use of daylighting minus the energy used to operate the clerestory shutters (7.93 million BTU). This energy savings was estimated by considering the amount of high efficiency lighting that would have been necessary to deliver (a conservative) three watts of lighting power per square foot of floor area. This value, 223.28 million BTU, was added to the measured monthly internal gains minus the actual energy consumed for lighting (11.03 million BTU). This value yielded a projected internal gain of 343.70 million BTU which represented the theoretical internal gain in the building had conventional (high efficiency) lighting been used instead of daylighting. The actual auxiliary energy consumed for space heating plus the actual internal gain was subtracted from the projected internal gain to yield the lighting savings of 60.55 million BTU. The lighting savings does not include the energy that would have been used to offset the heating load. So in the mid winter months, all of the savings due to the use of solar energy are counted as fossil fuel savings for space heating. The lighting savings appeared during the seasonal transition months during periods when the lighting energy was not used to displace the space heating requirement. During the summer the most significant daylighting savings will be realized. A graphic presentation of savings due to daylighting compared to the use of high efficiency lighting is presented in Figure 15.



- THE FIRST BAR FOR EACH MONTH REPRESENTS ACTUAL VALUES WITH DAYLIGHTING. THE SECOND BAR REPRESENTS INTERNAL GAINS AND AUXILIARY HEAT REQUIRED IF HIGH EFFICIENCY FLUORESCENT LIGHTING HAD BEEN USED.
- AREA BELOW BROKEN LINE REPRESENTS HEAT FROM LIGHTING FIXTURES.

Figure 15. Savings from Use of Daylighting
Taos State Office Building
October 1980 through May 1981

The energy savings due to the use of solar represented a significant dollar savings. If natural gas was used as the auxiliary fuel source there would have been 621,580 cubic feet of gas saved, which at $0.40 per 100 cubic feet, would have saved $2,486.

If fuel oil was used as the alternative fuel source there would have been 4,576 gallons saved. Based on a national average fuel cost of $1.00 per gallon for #2 fuel oil, the dollar savings would have been $4,576 for space heating.

The 380.75 million BTU of solar energy used would have provided a savings of 111,484 kwh if electricity was the alternate fuel source. At $0.055 per kwh, this represents $6,132.

In addition to the space heating dollar savings, there was an additional 52.62 million BTU of electrical energy saved by the use of daylighting. This is equivalent to 15,407 kwh of electricity which at $0.055 per kwh, is a dollar savings of $847. The total dollar savings is listed below for the three combinations of fuels used.

SPACE HEATING FUEL USED	SAVINGS		DAYLIGHTING SAVINGS		TOTAL SAVINGS
Natural Gas	$2,486 (@$0.40 per 100 ft^3)	+	$847	=	$3,333
#2 Fuel Oil	$4,576 (@$1.00 per gallon)	+	$847	=	$5,423
Electricity	$6,132 (@$0.055 per kwh)	+	$847	=	$6,979

SECTION 5

WEATHER CONDITIONS

The Taos State Office Building is located in Taos, New Mexico at 36.4 degrees N latitude and 105.5 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 the SOLMET meteorological stations. The long-term insolation values are total global horizontal radiation converted to collector angle and azimuth orientation.

Table 8. WEATHER CONDITIONS

TAOS STATE OFFICE BUILDING
OCTOBER 1980 THROUGH MAY 1981

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		HORIZONTAL INSOLATION (BTU/FT^2-DAY)		WIND DIRECTION (DEGREES)	WIND SPEED (M.P.H.)
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE		
OCT	1,820	1,531	46	53	589	375	1,347	1,412	86	5
NOV	1,688	1,607	36	39	780	774	1,039	1,062	73	4
DEC	1,579	1,366	33	30	854	1,082	873	807	71	4
JAN	1,432	1,302	31	29	999	1,128	892	848	90	4
FEB	1,777	1,484	34	35	850	840	1,255	1,239	133	6
MAR	1,349	1,407	37	41	842	756	1,335	1,652	155	7
APR	1,498	1,243	49	50	486	465	1,923	2,135	142	9
MAY	759	1,006	54	60	333	184	1,834	2,430	146	7
TOTAL	-	10,937	-	-	5,733	5,604	-	-	-	-
AVERAGE	1,488	1,367	40	42	717	701	1,312	1,448	112	6

During the period from October 1980 through May 1981, the average daily total incident solar radiation on the collector array was 1,488 BTU per square foot per day. This radiation was above the estimated average daily solar radiation for this geographical area during the reporting period of 1,367 BTU per square foot per day for a plane facing 20 degrees east of south with a tilt of 90 degrees to the horizontal. During the period, the highest monthly average insolation was 1,820 BTU per square foot per day during October. The average ambient temperature during the reporting period was 40°F as compared with the long-term average of 42°F. The highest monthly average ambient temperature was 54°F during May, and the lowest monthly average ambient temperature was 31°F during January. The number of heating degree-days for the period (based on a 65°F reference) was 5,733 as compared with the long-term average of 5,604. The range of heating degree-days was from a high of 999 during January to a low of 333 during May.

Extraterrestrial radiation values are computed (see Footnote 1) and given in the following table 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 64% during November and February to a low of 53% during March and May.

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Horizontal Insolation	1,347	1,039	873	892	1,255	1,335	1,923	1,834
Extraterrestrial Insolation (BTU/Ft^2-day)	2,129	1,622	1,394	1,519	1,967	2,532	3,098	3,481
$\frac{\text{HOR INS}}{\text{EXT INS}}$ (%)	63	64	63	59	64	53	62	53

For a more complete set of meteorological data see Appendix F, which contains daily average values for the months of the reporting period.

From Table 8 it is clear that the measured incident solar energy to the collection subsystem was generally higher than the long-term average. This difference was due in part to the reflective roof surface which effectively increased the amount of solar energy reaching the clerestory windows. The only months where the measured insolation to the windows was less than the long-term average were March and May. The clearness index indicates that it was cloudier than normal during these two months.

The winds experienced at Taos were generally out of the east and southeast averaging six miles per hour during the reporting period. Gusts and longer periods with winds in excess of 10 miles per hour are not uncommon at Taos.

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

SECTION 6

REFERENCES

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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 Solar 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, N.Y., 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, N.Y., 1977.

*6A. User's Guide to Monthly Performance Reports, June 1980, SOLAR/0004-80/18, 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, Taos State Office Building, October 1980, SOLAR/2080-80/10, Vitro Laboratories, Silver Spring, Maryland.

*8. Monthly Performance Report, Taos State Office Building, November 1980, SOLAR/2080-80/11, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Taos State Office Building, December 1980, SOLAR/2080-80/12, Vitro Laboratories, Silver Spring, Maryland.

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* 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

The Taos State Office Building, otherwise known as the Human Services Field Office, is a single-story office building which incorporates passive collection and storage of solar energy along with natural lighting for general illumination. The building is oriented 20 degrees east of south to take advantage of early morning sunlight. The solar energy system is shown schematically in Figures A-1, A-2, and A-3.

Solar energy enters the building via 11 rows of clerestory windows (in a sawtooth configuration totalling 2,695 square feet), south-facing windows (296 square feet), and east and west window scoops (218 square feet). The clerestory windows are the main apertures for collecting solar energy with water drum storage located in the clerestory area (see schematics).

In conjunction with the clerestories are pneumatically controlled shutters. These shutters can operate in five positions. During winter, the two most open positions are used to collect as much sun as possible and during summer the other two open positions are used to keep light off the water drums but still reflect light into the space. The fifth position is a totally closed position which blocks out the light and keeps the heat from being transmitted through the glazing. The east and west sun scoops bring in additional daylighting but also increase the thermal losses because no insulating shutters are provided over the glass. Stored solar energy is radiated from the water drums to the space below and to the air in the clerestory surrounding the drums. The warm air is drawn away by the mechanical system and recirculated or rejected.

The mechanical system provides auxiliary heat via electric strips located in the supply ducts. Each mechanical tower has a split return and supply system (see schematics). Towers two and four have a 20 kw heater for the outside wall zones and a 10 kw heater for the extreme side of Zones three and four. Towers three and four each have two 10 kw heaters for supplying heat to the interior zones.

For cooling, the mechanical system incorporates evaporative cooling regeneration tubes. These tubes are stone filled with water sprayed on the stones. Forced air is drawn through the wet stones and into the building.

There are five basic modes of operation which act independently of the shutter control logic. These modes are: Summer Night, Summer Day-Fresh Air Cooling, Summer Day-Evaporation Cooling, Winter Night, and Winter Day.

Mode 1 - Summer Night

This mode is activated when outside temperatures are less than 70°F and inside temperatures are greater than 70°F. When this occurs, the exhaust (return) fans and supply fans are activated to the high speed, thus recirculating inside air and mixing in some outside air.

Mode 2 - Summer Day - (Exhaust)

This mode is activated when the outside temperature is less than 75°F and the inside temperature is greater than 75°F. When these conditions occur, the low speed return and supply fans are activated and all return air is exhausted and all supply air is made up by fresh outside air.

Mode 3 - Summer Day - (Cooling)

In the event that the inside temperature rises above 80°F and the outside temperature is above 70°F, this mode is activated, starting the evaporation cooling cycle. Water is released into the stone-filled regenerative tubes, return air is exhausted, and supply air is drawn in through the wet stones.

Mode 4 - Winter Night

If outside air temperatures fall below 20°F, the duct bypass is energized and internal warm air is circulated.

Mode 5 - Winter Day

When outside temperatures are above 40°F and the inside is above 75°F, the regenerator cycle operates directly. The water valves have to be turned off by the maintenance person in order to keep the water from being sprayed into the stone tube and freezing at night when temperatures typically fall below 32°F. With the water turned off, the supply fan draws in outside air through the dry stones in the regenerative tubes.

It should be noted that during either of the two winter modes above, the inside thermostats may call for additional heat for their respective zones. The duct heaters are activated along with its supply fan to provide auxiliary heat.

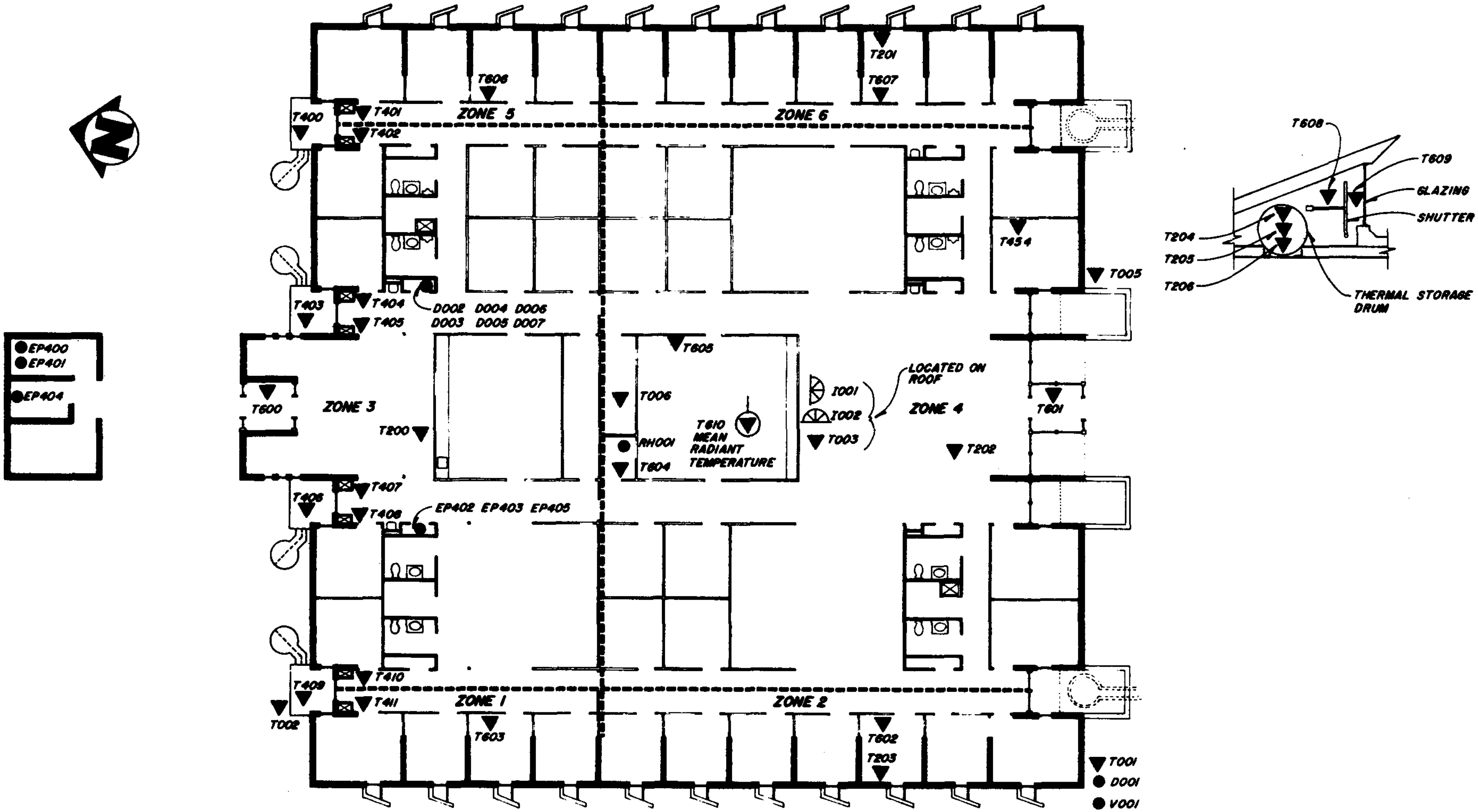
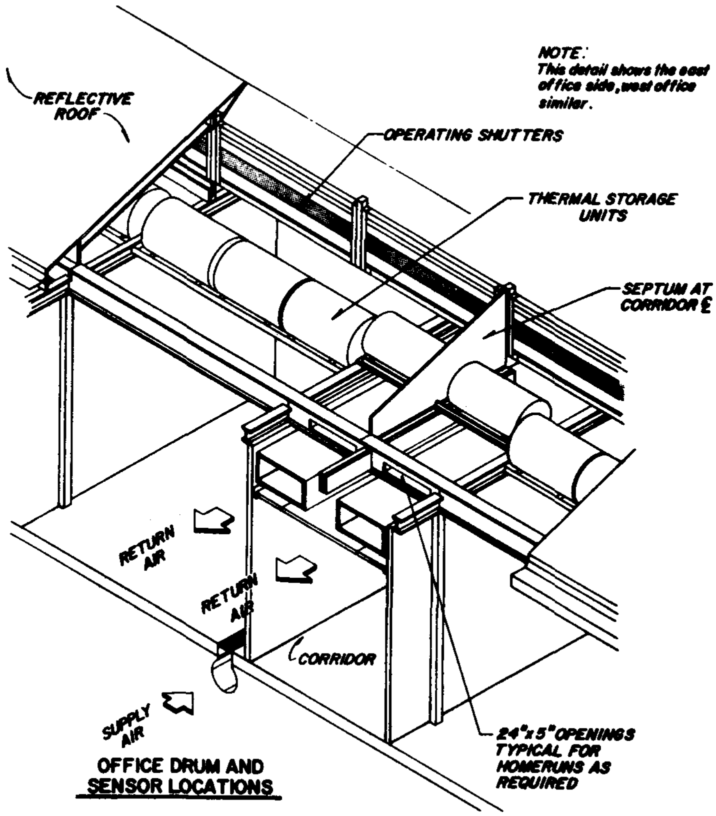
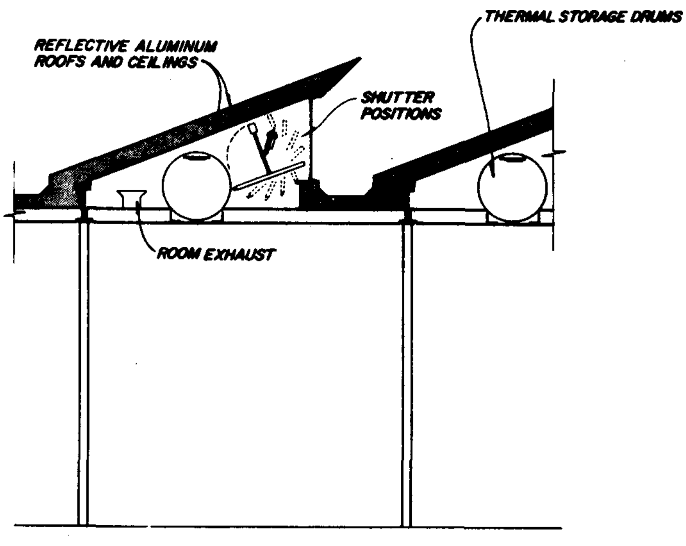


Figure A-1. Taos State Office Building
Passive Solar Energy System Schematic - Floor Plan



OFFICE DRUM AND SENSOR LOCATIONS



TYPICAL ROOM MONITOR SECTION

Figure A-2. Taos State Office Building
Passive Solar Energy System Schematic –
Typical Sections of Passive Storage and Glazing

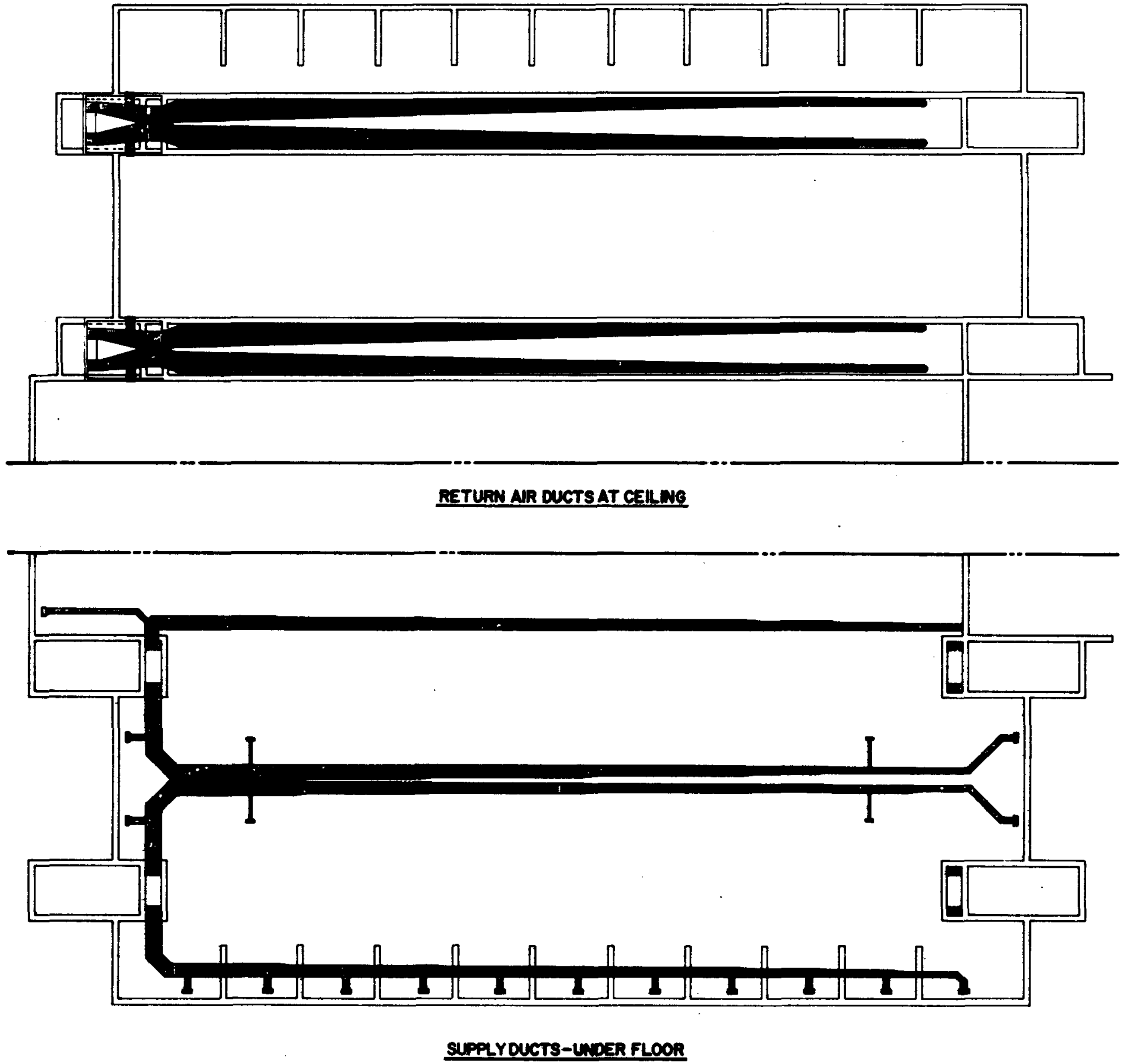


Figure A-3. Taos State Office Building
Passive Solar Energy System Schematic - Duct Layouts

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Taos State Office Building 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.

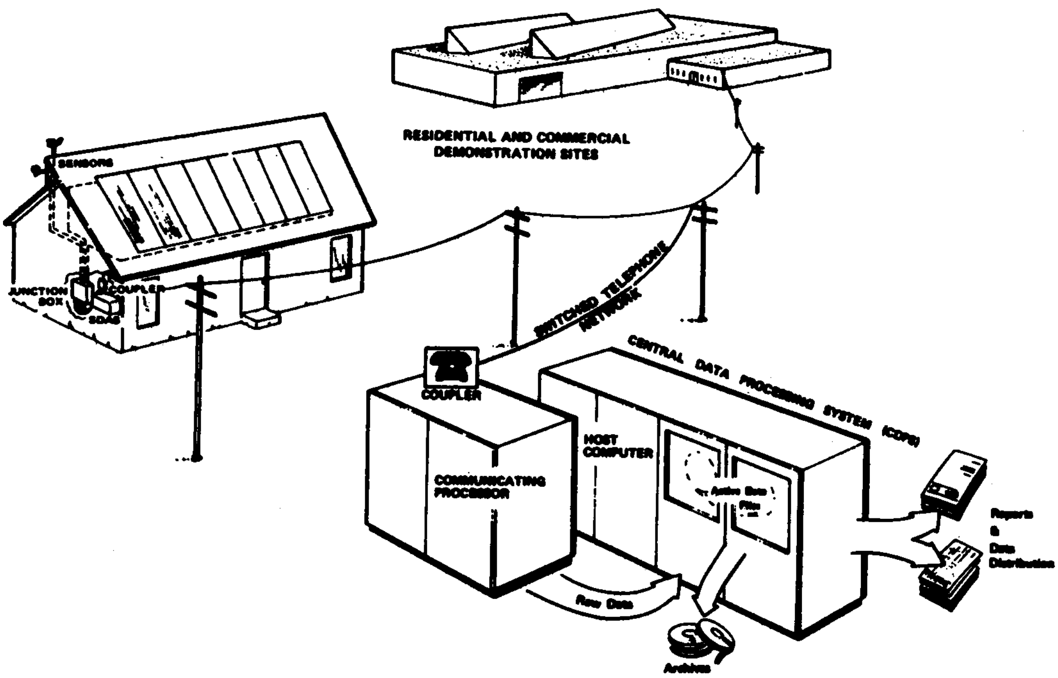


Figure B-1. The National Solar Data Network

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 the system and has the SDAS transmit the data on the cassette tape back to the 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 0-1,023. 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 realtime 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 Taos State Office Building solar energy system from October 1980 through May 1981 was analyzed during the heating season, and Monthly Performance Reports were published through December 1980. 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 FOR THIS SITE*

Monthly Performance Reports:

October 1980, SOLAR/2080-80/10
November 1980, SOLAR/2080-80/11
December 1980, SOLAR/2080-80/12

* These reports 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

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: $\frac{Ti-Ta}{I}$ $\frac{°F \times hr. \times sq. ft.}{BTU}$
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 param eter 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 2.932×10^{-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

TAOS STATE OFFICE BUILDING

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance computations 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

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

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

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

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

SITE EQUATIONS FOR TAOS STATE OFFICE BUILDING

SCAN LEVEL EQUATIONS

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \Sigma\ (T001 + T002)/2 \times \Delta\tau$$

DAYTIME AVERAGE TEMPERATURE (°F)

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

for ± three hours from noon

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \Sigma\ (T602 + T603 + T604 + T605 + T606 + T607 + T610)/7 \times \Delta\tau$$

TIME OF DAY BUILDING TEMPERATURES (ONCE PER DAY, °F)

TMID = T610

at 12 hours from local solar noon

T6AM = T610

at six hours before local solar noon

TNOON = T610

at local solar noon

T6PM = T610

at six hours past local solar noon

VERTICAL SOLAR RADIATION (INCIDENT TO WINDOWS, BTU/FT^2)

$SE = (1/60) \times \Sigma\ I001 \times \Delta\tau$

HORIZONTAL SOLAR RADIATION (BTU/FT^2)

$SEH = (1/60) \times \Sigma\ I002 \times \Delta\tau$

INSOLATION ON GLAZING WITH SHUTTERS OPEN (BTU)

$SEOP = (1/60) \times \Sigma\ I001 \times CLAREA2 + CLAREA1) \times \Delta\tau$

when D004 < 85° and D004 is the shutter position indicator measuring degrees.

INDOOR RELATIVE HUMIDITY (%)

$RELHIN = (1/60) \times \Sigma\ RH001 \times \Delta\tau$

AVERAGE STORAGE TEMPERATURE (°F)

$TST = (1/60) \times \Sigma\ [((T204 + T205 + T206)/3) + T200 + T201 + T202 + T203]/5 \times \Delta\tau$

SHUTTER OPERATING ENERGY (BTU)

$CSOPE = EPCONST \times \Sigma\ EP404 \times \Delta\tau$

AUXILIARY ELECTRIC ENERGY (BTU)

$HAE = EPCONST \times \Sigma\ EP401 \times \Delta\tau$

INTERNAL ENERGY GAINS FROM LIGHTS AND EQUIPMENT (BTU)

$HOTHER\_ELEC = EPCONST \times \Sigma\ (EP400 - EP401 - EP404) \times \Delta\tau$

ELECTRIC USAGE FOR ILLUMINATION (BTU)

$TOT\_LIGHTS = EPCONST \times \Sigma\ (EP403 + EP402) \times \Delta\tau$

SAVINGS DUE TO DAYLIGHTING (BTU)

$ILLUM\_SAV = EPCONST \times \Sigma\ [(EP402 + EP403) - TLC] \times \Delta\tau$

where TLC = total lighting power consumption when all lights are on = 18 kw

NORTH SIDE HEAT LOSS (BTU)

$$HLN = (1/60) \times \Sigma\ (UAWALLS \times \Delta\tau + UAGLASS + \Delta\tau + UAPERIM \times \Delta\tau) \times \Delta\tau$$

SOUTH SIDE HEAT LOSS, HLS
EAST SIDE HEAT LOSS, HLE
WEST SIDE HEAT LOSS, HLW

equations similar to North Side using applicable U values, Areas and Temperature Differences.

ROOF HEAT LOSS (BTU)

$$HLR = (1/60) \times \Sigma\ UAGLASS \times \Delta\tau + UAROOF) \times \Delta\tau \times \Delta\tau$$

calculated for each of 6 zones using applicable U-values, AREAS and TEMPERATURES

FLOOR HEAT LOSS (BTU)

$$HLF = (1/60) \times \Sigma\ FLAREA \times U\_FLOOR \times (TB - T006) \times \Delta\tau$$

TOTAL CONDUCTION HEAT LOSS (BTU)

$$HLUA = (1/60) \times \Sigma\ (HLN + HLS + HLE + HLW + HLR + HLF) \times \Delta\tau$$

WIND SPEED (MPH)

$$WIND = (1/60) \times \Sigma\ V001 \times \Delta\tau$$

WIND DIRECTION (N-S COMPONENT AND E-W COMPONENT)

$$WNS = (1/60) \times \Sigma\ V001 \times COSD\ (D001) \times \Delta\tau$$

$$WEW = (1/60) \times \Sigma\ V001 \times SIND\ (D001) \times \Delta\tau$$

where D001 is the directional indicator in degrees

HOURLY LEVEL EQUATIONS

INFILTRATION LOSS (BTU)

$$HI = VOLUME \times 0.075 \times HRF \times (TB - TA) \times ACH$$

where VOLUME is the air volume of the building and 0.07 is the air density, HRF is the humidity ratio which is a function of building relative humidity and temperature, and ACH which is the number of air changes per hour and is dependent on wind speed as follows:

for WIND:

0 to 5 MPH; ACH = .5
5 to 10 MPH; ACH = .75
10 to 15 MPH; ACH = 1.00
15 to 20 MPH; ACH = 1.25
20 + MPH: ACH = 1.50

BUILDING LOAD (BTU)

BL = HLUA + HI

CHANGE IN WATER STORAGE ENERGY (BTU)

$MSTECH = STO\_MASS \times (TST - TST_{previous}) \times CP_{water}$

CHANGE IN BUILDING STORED ENERGY (BTU)

$HSTECH = BLDG\_MASS \times (TB - TB_{previous}) \times CP_{building}$

TOTAL CHANGE IN STORED ENERGY (BTU)

PSTECH = MSTECH + HSTECH

AUXILIARY THERMAL ENERGY USED (BTU)

HAT = HAE

INTERNAL ENERGY GAINS FROM PEOPLE (BTU)

HOTHER_PEOPLE = NO_PEOPLE x BODY_GAIN

when building is occupied

TOTAL INTERNAL ENERGY GAINS (BTU)

HOTHER = HOTHER_ELECTRIC + HOTHER_PEOPLE

EQUIPMENT HEATING LOAD (BTU)

EHL = BL - HOTHER

PASSIVE SOLAR ENERGY USED (BTU)

HSEP = EHL - HAT

EQUIPMENT HEATING SOLAR FRACTION

HSFR = 100 x HSEP/EHL

BUILDING SOLAR FRACTION

BHSRF = 100 x HSEP/BL

TOTAL INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

SEA = SE x CLAREA

ENERGY TO STORAGE (BTU)

STEI = PSTECH

when PSTECH > ZERO

ENERGY FROM STORAGE (BTU)

STEO = PSTECH

when PSTECH < ZERO

SOLAR ENERGY COLLECTED (BTU)

SECA = HSEP + PSTECH

SOLAR ENERGY COLLECTED PER SQUARE FOOT OF GLAZING (BTU/FT^2)

COLLECTOR EFFICIENCY (%)

CSCEF = HSEP/SEA

FOSSIL FUEL SAVINGS (BTU)

HSVF = HSEP/0.60

ELECTRICAL SAVINGS (BTU)

TSVE = ILLUM_SAV - CSOPE

WIND DIRECTION

WDIR = ATAND (WEW, WNS)

TA MAX, TA MIN

maximum and minimum values for T001 during the scan, integrated to hourly, daily and monthly periods

TB MAX, TB MIN

maximum and minimum values for T001 during the scan, integrated to hourly, daily and monthly periods

APPENDIX E

METEOROLOGICAL CONDITIONS

TAOS STATE OFFICE BUILDING LONG-TERM WEATHER DATA

COLLECTOR TILT: 89.99 DEGREES
LATITUDE: 36.40 DEGREES

LOCATION: TAOS, NEW MEXICO
COLLECTOR AZIMUTH: -20.00 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
OCT	2,129	1,412	0.66314	1.084	1,531	375	0	53
NOV	1,622	1,062	0.65463	1.513	1,607	774	0	39
DEC	1,394	807	0.57929	1.691	1,366	1,082	0	30
JAN	1,519	848	0.55830	1.535	1,302	1,128	0	29
FEB	1,967	1,239	0.62967	1.198	1,484	840	0	35
MAR	2,532	1,652	0.65245	0.852	1,407	756	0	41
APR	3,098	2,135	0.68898	0.582	1,243	465	6	50
MAY	3,481	2,430	0.69796	0.414	1,006	184	13	60

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 of heating degrees-days per month.

CDD - Number of cooling degrees-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

MONTHLY REPORT: TAOS STATE OFFICE BUILDING
OCTOBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	TOTAL HORIZONTAL INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMPERATURE DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	2115	1751	63	79	33	6
2	2018	1664	57	67	45	6
3	2085	1698	56	71	61	6
4	2097	1698	58	72	78	5
5	2085	1693	59	74	18	10
6	2099	1582	59	69	8	8
7	2095	1628	56	71	28	4
8	2052	1592	58	74	69	4
9	2048	1608	60	73	30	7
10	2020	1553	57	68	74	11
11	1979	1552	52	66	83	6
12	1978	1517	55	69	86	5
13	792	922	52	58	158	8
14	1640	1258	50	64	118	4
15	401	491	38	42	130	7
16	320	517	34	36	180	11
17	2347	1541	37	44	166	9
18	2315	1563	36	47	*	3
19	2283	1544	40	53	69	3
20	2238	1463	41	55	112	4
21	2244	1488	42	57	56	3
22	2055	1397	42	56	86	5
23	2233	1477	38	51	182	8
24	2217	1435	35	47	55	4
25	2143	1401	40	59	68	3
26	544	624	38	48	171	6
27	115	159	32	33	0	1
28	1555	970	30	36	113	4
29	1857	1252	33	40	135	2
30	2243	1368	39	53	43	3
31	2214	1359	42	55	49	2
SUM	56429	41765	-	-	-	-
AVG	1820	1347	46	58	86	5

* = UNAVAILABLE DATA

MONTHLY REPORT: TAOS STATE OFFICE BUILDING
NOVEMER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	TOTAL HORIZONTAL INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMPERATURE DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)	HEAT DEGREE DAYS	COOL DEGREE DAYS
1	2068	1303	44	59	46	3	16	0
2	2071	1297	44	58	111	4	18	0
3	1881	1229	44	59	51	3	18	0
4	1869	1222	45	58	83	3	17	0
5	1998	1289	48	65	156	2	17	0
6	2164	1403	48	71	162	6	11	0
7	1969	1197	47	60	139	5	18	0
8	1993	1231	47	61	130	5	16	0
9	1982	1210	48	65	43	5	13	0
10	1550	1049	47	62	50	3	15	0
11	1907	1185	46	62	58	4	16	0
12	1183	918	46	57	142	4	18	0
13	1049	762	46	53	106	6	18	0
14	425	489	36	44	201	5	28	0
15	977	796	31	36	38	8	32	0
16	920	756	27	32	26	15	36	0
17	1720	1010	25	34	51	4	39	0
18	2094	1187	28	40	48	2	34	0
19	2010	1102	29	43	48	3	33	0
20	1858	1056	30	45	3	4	33	0
21	2010	1101	29	43	50	3	33	0
22	1562	976	28	42	123	4	36	0
23	1914	1052	31	43	155	4	32	0
24	505	187	29	34	26	8	34	0
25	1788	1049	24	31	345	3	38	0
26	1803	1067	24	34	146	3	36	0
27	1995	1064	22	33	133	4	41	0
28	1931	1043	29	43	41	2	33	0
29	1806	1005	35	50	29	3	25	0
30	1651	941	37	50	85	4	26	0
SUM	50653	31181	-	-	-	-	780	0
AVG	1688	1039	36	49	73	4	26	0

MONTHLY REPORT: TAOS STATE OFFICE BUILDING
DECEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	TOTAL HORIZONTAL INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMPERATURE DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)	HEAT DEGREE DAYS	COOL DEGREE DAYS
1	1830	963	38	50	128	7	26	0
2	1853	988	35	50	48	4	28	0
3	1864	1029	37	52	36	3	23	0
4	1770	984	30	43	64	3	*	*
5	1770	984	30	43	64	3	*	*
6	1770	984	30	43	64	3	*	*
7	1770	984	30	43	64	3	*	*
8	1770	984	30	43	64	3	*	*
9	1320	709	26	28	70	2	41	0
10	1834	1053	24	35	63	2	38	0
11	1879	943	31	43	86	3	31	0
12	1746	900	35	48	83	4	*	*
13	1746	900	35	48	83	4	*	*
14	1746	900	35	48	83	4	*	*
15	1746	900	35	48	83	4	*	*
16	1746	900	35	48	83	4	*	*
17	1502	836	38	57	83	5	16	0
18	1620	863	38	53	93	5	25	0
19	35	116	26	27	196	3	36	0
20	1546	853	29	40	0	2	30	0
21	1119	733	28	40	0	2	33	0
22	1272	815	33	47	78	5	29	0
23	1740	958	36	46	176	7	27	0
24	1698	927	31	44	40	3	29	0
25	1347	798	36	50	33	5	26	0
26	1690	912	38	55	41	3	22	0
27	1661	909	41	58	40	3	19	0
28	1190	734	40	40	43	3	23	0
29	852	584	38	43	37	6	27	0
30	1768	963	34	48	43	2	26	0
31	1747	946	37	54	51	3	22	0
SUM	48946	27053	-	-	-	-	854	0
AVG	1579	873	33	46	71	4	28	0

* = UNAVAILABLE DATA

MONTHLY REPORT: TAOS STATE OFFICE BUILDING
JANUARY 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	TOTAL HORIZONTAL INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMPERATURE DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)	HEAT DEGREE DAYS	COOL DEGREE DAYS
1	1732	946	35	49	69	3	27	0
2	1678	946	34	49	54	4	27	0
3	1683	948	34	49	60	4	29	0
4	1127	778	35	48	54	3	27	0
5	1533	908	37	51	135	5	26	0
6	1724	988	30	45	48	3	32	0
7	923	715	28	38	47	3	33	0
8	1633	988	34	47	26	7	30	0
9	1768	1012	33	49	43	3	27	0
10	1627	965	33	46	46	5	29	0
11	1484	905	31	41	23	2	33	0
12	1115	796	30	42	0	2	35	0
13	1796	1058	33	46	42	5	30	0
14	1817	1061	30	45	54	3	31	0
15	1671	1027	30	44	44	3	34	0
16	197	384	29	37	206	3	36	0
17	121	268	27	28	0	1	37	0
18	667	532	29	37	0	1	32	0
19	1804	1039	28	37	239	5	34	0
20	1946	1150	27	41	309	7	37	0
21	2046	1189	28	42	60	3	34	0
22	1909	1131	34	51	43	3	27	0
23	1895	1554	36	52	83	3	26	0
24	1581	1048	34	49	165	6	29	0
25	1869	1176	27	40	149	5	36	0
26	1961	1199	25	37	160	7	40	0
27	1831	1165	30	41	162	4	36	0
28	128	246	30	34	53	2	34	0
29	1289	915	29	37	110	6	34	0
30	1200	852	31	42	152	7	35	0
31	645	177	23	27	168	9	43	0
SUM	44398	27666	-	-	-	-	999	0
AVG	1432	892	31	43	90	4	32	0

MONTHLY REPORT: TAOS STATE OFFICE BUILDING
FEBRUARY 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMPERATURE DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)	HEAT DEGREE DAYS	COOL DEGREE DAYS
1	1300	17	29	138	6	47	0
2	1951	19	34	50	3	45	0
3	1692	28	42	41	3	34	0
4	1714	30	40	58	7	33	0
5	2109	28	42	51	4	33	0
6	2018	31	43	134	5	34	0
7	2132	30	42	160	7	34	0
8	1935	33	42	167	7	32	0
9	113	32	34	177	6	34	0
10	1548	27	35	184	19	43	0
11	1901	27	39	154	6	40	0
12	2202	30	44	61	4	33	0
13	2201	34	48	48	4	30	0
14	1934	36	53	136	3	26	0
15	1767	38	51	71	4	24	0
16	2084	40	55	49	3	23	0
17	1832	40	54	135	5	25	0
18	1918	42	54	112	5	22	0
19	1621	42	57	92	4	20	0
20	1618	43	57	161	8	20	0
21	914	30	33	199	8	34	0
22	2289	30	43	128	4	33	0
23	2255	38	55	75	4	26	0
24	2266	40	55	116	5	24	0
25	2186	41	58	154	5	24	0
26	1712	40	52	149	9	25	0
27	655	37	46	80	2	28	0
28	1895	39	53	115	4	26	0
SUM	49764	-	-	-	-	850	0
AVG	1777	34	46	133	6	30	0

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MONTHLY REPORT: TAOS STATE OFFICE BUILDING
MARCH 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMPERATURE DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)	HEAT DEGREE DAYS	COOL DEGREE DAYS
1	941	38	43	161	5	25	0
2	1038	37	47	45	4	27	0
3	604	34	36	160	6	30	0
4	668	32	36	176	10	30	0
5	1977	35	46	163	3	27	0
6	1045	33	41	161	6	29	0
7	422	29	32	153	2	33	0
8	1748	34	45	10	4	29	0
9	1411	34	43	29	7	29	0
10	1001	35	43	53	5	27	0
11	825	36	39	22	9	28	0
12	915	36	43	79	3	24	0
13	1796	37	47	57	6	27	0
14	188	33	34	*	4	28	0
15	1876	36	46	76	4	28	0
16	2188	39	51	167	6	27	0
17	1595	35	39	201	15	31	0
18	2231	33	43	140	5	30	0
19	1902	39	53	152	5	26	0
20	653	37	46	177	10	26	0
21	486	34	37	177	13	29	0
22	2133	38	48	121	6	27	0
23	1735	41	52	118	5	23	0
24	1262	41	53	224	9	24	0
25	2167	41	51	164	7	25	0
26	1024	47	56	135	9	20	0
27	1986	44	52	159	14	23	0
28	609	30	33	173	8	35	0
29	1453	38	45	162	6	27	0
30	1767	40	51	180	12	23	0
31	2163	36	44	168	11	28	0
SUM	41811	-	-	-	-	842	0
AVG	1349	37	44	155	7	27	0

* = UNAVAILABLE DATA

MONTHLY REPORT: TAOS STATE OFFICE BUILDING
APRIL 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMPERATURE DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)	HEAT DEGREE DAYS	COOL DEGREE DAYS
1	2078	44	57	186	8	24	0
2	1229	49	60	135	11	18	0
3	277	36	36	167	15	27	0
4	976	33	38	189	15	32	0
5	2039	36	48	114	6	27	0
6	1977	45	57	150	8	20	0
7	1995	51	60	172	14	16	0
8	1942	48	58	170	11	18	0
9	1914	50	62	169	7	18	0
10	1890	53	67	132	9	12	0
11	1861	52	63	158	8	13	0
12	1221	50	61	153	7	17	0
13	1142	52	59	28	7	11	0
14	414	43	44	29	20	23	0
15	1023	45	51	191	4	19	0
16	1649	53	61	172	5	11	0
17	1780	56	70	46	5	10	0
18	574	51	60	132	5	11	0
19	1686	50	60	156	6	14	0
20	1765	51	62	171	8	15	0
21	1508	52	65	168	8	14	0
22	1689	50	63	52	10	13	0
23	1681	50	61	158	6	15	0
24	1588	56	68	121	5	9	0
25	1556	60	72	111	6	6	0
26	1495	54	66	134	10	9	0
27	1498#	49#	59#	143#	9#	*	*
28	1498#	49#	59#	143#	9#	*	*
29	1498#	49#	59#	143#	9#	*	*
30	1498#	49#	59#	143#	9#	*	*
SUM	44943	-	-	-	-	486	0
AVG	1498	49	59	142	9	16	0

* = UNAVAILABLE DATA; # = <40% VALID DATA

MONTHLY REPORT: TAOS STATE OFFICE BUILDING
MAY 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMPERATURE DEG F	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)	HEAT DEGREE DAYS	COOL DEGREE DAYS
1	758#	54#	62#	151#	7#	*	*
2	758#	54#	62#	151#	7#	*	*
3	758#	54#	62#	151#	7#	*	*
4	758#	54#	62#	151#	7#	*	*
5	758#	54#	62#	151#	7#	*	*
6	758#	54#	62#	151#	7#	*	*
7	758#	54#	62#	151#	7#	*	*
8	758#	54#	62#	151#	7#	*	*
9	758#	54#	62#	151#	7#	*	*
10	758#	54#	62#	151#	7#	*	*
11	758#	54#	62#	151#	7#	*	*
12	758#	54#	62#	151#	7#	*	*
13	758#	54#	62#	151#	7#	*	*
14	867	56	67	152	8	5	0
15	881	51	62	162	8	13	0
16	334	42	43	178	6	20	0
17	589	42	46	170	8	21	0
18	1047	52	60	70	4	12	0
19	1052	55	62	42	6	11	0
20	692	57	60	83	12	8	0
21	874	53	59	179	12	13	0
22	935	52	62	180	10	15	0
23	810	53	65	44	7	11	0
24	805	54	62	317	6	10	0
25	760	57	68	200	4	9	0
26	830	61	73	183	5	5	0
27	786	64	75	192	6	1	0
28	555	57	66	105	6	6	0
29	414	53	60	64	8	13	0
30	656	54	59	24	6	11	0
31	779	56	70	172	5	8	0
SUM	23516	-	-	-	-	333	0
AVG	759	54	62	146	7	11	0

* = UNAVAILABLE DATA; # = <40% VALID DATA

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

The Taos State Office Building passive solar energy system operated consistently throughout the reporting period without any major system problems or changes. The building was occupied on normal working days throughout the period. The building construction was completed in March 1978 and the solar system has been in operation since January 1979. The data communication system has been in operation since mid-September 1980. Periods of data communication problems during the report period are listed below.

December 5-8, 13-15	SDAS down
April 27	SDAS down

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 fuel 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/μ2
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: JANUARY 1981
SITE SUMMARY: TAOS STATE OFFICE BLDG

	CONVENTIONAL UNITS
GENERAL SITE DATA:	
INCIDENT SOLAR ENERGY	105.844 MILLION BTU
	44398 BTU/SQ.FT.
COLLECTED SOLAR ENERGY	62.326 MILLION BTU
	38777 BTU/SQ.FT.
AVERAGE AMBIENT TEMPERATURE	31 DEGREES F
AVERAGE BUILDING TEMPERATURE	72 DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY	0.60
ECSS OPERATING ENERGY	1.034 MILLION BTU
STORAGE EFFICIENCY	106.30 PERCENT
EFFECTIVE HEAT TRANSFER COEFFICIENT	* BTU/DEG F-SQ FT-HR
TOTAL SYSTEM OPERATING ENERGY	1.034 MILLION BTU
TOTAL ENERGY CONSUMED	119.948 MILLION BTU

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	N.A.	100.421	N.A.	100.421 MILLION BTU
SOLAR FRACTION	N.A.	79	N.A.	79 PERCENT
SOLAR ENERGY USED	N.A.	63.956	N.A.	63.956 MILLION BTU
OPERATING ENERGY	N.A.	1.034	N.A.	1.034 MILLION BTU
AUX. THERMAL ENERGY	N.A.	36.464	N.A.	36.464 MILLION BTU
AUX. ELECTRIC FUEL	N.A.	36.464	N.A.	36.464 MILLION BTU
AUX. FOSSIL FUEL	N.A.	N.A.	N.A.	N.A. MILLION BTU
ELECTRICAL SAVINGS	N.A.	N.A.	N.A.	3.387 MILLION BTU
FOSSIL SAVINGS	N.A.	106.594	N.A.	106.594 MILLION BTU

SYSTEM PERFORMANCE FACTOR: 0.80
INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 3.88

* = 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: JANUARY 1981
SITE SUMMARY: TAOS STATE OFFICE BLDG

SI UNITS

GENERAL SITE DATA:

INCIDENT SOLAR ENERGY	111.665 GIGA JOULES
	504178 KJ/SQ.M.
COLLECTED SOLAR ENERGY	65.754 GIGA JOULES
	440346 KJ/SQ.M.
AVERAGE AMBIENT TEMPERATURE	-1 DEGREES C
AVERAGE BUILDING TEMPERATURE	22 DEGREES C
ECSS SOLAR CONVERSION EFFICIENCY	0.60
ECSS OPERATING ENERGY	1.091 GIGA JOULES
STORAGE EFFICIENCY	106.30 PERCENT
EFFECTIVE HEAT TRANSFER COEFFICIENT	* W/SQ M-DEG K
TOTAL SYSTEM OPERATING ENERGY	1.091 GIGA JOULES
TOTAL ENERGY CONSUMED	126.545 GIGA JOULES

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	N.A.	105.944	N.A.	105.944 GIGA JOULES
SOLAR FRACTION	N.A.	79	N.A.	79 PERCENT
SOLAR ENERGY USED	N.A.	67.474	N.A.	67.474 GIGA JOULES
OPERATING ENERGY	N.A.	1.091	N.A.	1.091 GIGA JOULES
AUX. THERMAL ENG	N.A.	38.470	N.A.	38.470 GIGA JOULES
AUX. ELECTRIC FUEL	N.A.	38.470	N.A.	38.470 GIGA JOULES
AUX. FOSSIL FUEL	N.A.	N.A.	N.A.	N.A. GIGA JOULES
ELECTRICAL SAVINGS	N.A.	N.A.	N.A.	3.574 GIGA JOULES
FOSSIL SAVINGS	N.A.	112.457	N.A.	112.457 GIGA JOULES

SYSTEM PERFORMANCE FACTOR: 0.80

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 3.88

* = 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: TAOS STATE OFFICE BLDG JANUARY 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	83	3.609	2.022	1.587	N	0.289	0.342	2.979	3.320	90
2	63	3.672	2.063	1.609	O	0.630	0.760	2.282	3.042	75
3	74	3.746	2.084	1.663	T	0.334	0.680	2.732	3.412	80
4	71	3.390	1.860	1.530		0.320	0.776	2.294	3.070	75
5	71	3.573	1.917	1.656	A	0.768	0.859	1.947	2.806	88
6	64	4.012	2.210	1.803	P	0.676	0.937	2.398	3.336	77
7	65	3.835	2.064	1.771	P	0.760	1.397	1.679	3.075	77
8	63	3.948	1.997	1.951	L	0.718	1.529	1.701	3.230	77
9	65	3.759	2.109	1.650	I	0.680	0.968	2.112	3.080	80
10	93	3.724	1.966	1.759	C	0.247	0.000	3.478	3.478	100
11	93	3.563	2.014	1.548	A	0.246	0.000	3.317	3.317	100
12	77	3.579	1.981	1.598	B	0.727	0.932	1.920	2.852	93
13	59	3.845	2.018	1.827	L	0.685	1.688	1.472	3.160	70
14	62	3.937	2.189	1.748	E	0.630	1.035	2.272	3.307	73
15	69	3.893	2.185	1.708		0.645	1.058	2.191	3.249	81
16	49	3.589	1.867	1.721		0.854	1.733	1.002	2.735	61
17	63	3.277	1.692	1.586		0.445	1.766	1.066	2.832	72
18	71	3.243	1.773	1.470		0.348	2.045	0.850	2.894	78
19	58	3.987	2.120	1.867		0.805	2.418	0.764	3.182	70
20	64	4.486	2.267	2.220		0.593	1.688	2.206	3.894	74
21	70	4.038	2.237	1.800		0.741	1.173	2.124	3.297	83
22	62	3.704	2.098	1.606		0.662	0.864	2.178	3.042	76
23	76	3.623	2.066	1.557		0.637	0.489	2.497	2.986	92
24	92	3.749	1.994	1.755		0.250	0.053	3.446	3.499	98
25	84	4.190	2.179	2.011		0.296	0.348	3.546	3.894	91
26	57	4.687	2.333	2.354		0.791	1.570	2.326	3.896	70
27	66	4.039	2.224	1.815		0.684	1.149	2.207	3.355	77
28	61	3.454	1.861	1.593		0.958	1.701	0.795	2.496	74
29	56	4.109	2.057	2.052		0.895	1.993	1.221	3.214	71
30	53	4.060	1.967	2.093		0.756	1.965	1.339	3.304	63
31	64	4.592	2.076	2.516		0.424	2.548	1.621	4.168	72
SUM	-	118.914	63.489	55.425	N.A.	18.493	36.464	63.956	100.421	-
AVG	68	3.836	2.048	1.788	N.A.	0.597	1.176	2.063	3.239	79
PFRV	0.8548	0.9933	0.9933	0.9933	N.A.	0.9933	0.9933	0.9933	0.9933	0.8548

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

MONTHLY REPORT: TAOS STATE OFFICE BLDG JANUARY 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	4.128	4.123	2.975	49	0.721
2	4.001	3.996	2.262	49	0.565
3	4.011	4.008	2.772	49	0.691
4	2.688	2.609	1.859	48	0.692
5	3.654	3.573	2.137	51	0.585
6	4.109	4.100	2.510	45	0.611
7	2.201	2.087	1.168	38	0.531
8	3.892	3.814	2.026	47	0.520
9	4.214	4.210	2.345	49	0.557
10	3.878	3.868	3.334	46	0.860
11	3.537	3.532	3.118	41	0.881
12	2.659	2.640	1.616	42	0.608
13	4.282	4.278	1.898	46	0.443
14	4.331	4.326	2.441	45	0.564
15	3.984	3.979	2.178	44	0.547
16	0.469	0.328	0.100	37	0.214
17	0.288	0.033	0.480	28	1.667
18	1.590	1.510	0.835	37	0.525
19	4.301	4.221	1.560	37	0.363
20	4.638	4.635	2.672	41	0.576
21	4.877	4.874	1.939	42	0.398
22	4.551	4.545	2.347	51	0.516
23	4.519	4.515	2.612	52	0.578
24	3.768	3.739	3.139	49	0.833
25	4.455	4.426	3.447	40	0.774
26	4.674	4.637	2.367	37	0.506
27	4.364	4.361	2.305	41	0.528
28	0.304	0.109	-0.092	34	-0.302
29	3.073	3.012	1.392	37	0.453
30	2.862	2.859	1.438	42	0.503
31	1.539	1.422	1.146	27	0.745
SUM	105.844	104.367	62.326	-	-
AVG	3.414	3.367	2.011	43	0.589
PFRV	0.9933	0.9933	0.9933	0.9933	0.0000

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

MONTHLY REPORT: TAOS STATE OFFICE BLDG JANUARY 1981

SPACE HEATING SUBSYSTEM I

DAY OF MONTH (NBS ID)	SPACE HEATING LOAD MILLION BTU (Q402)	CONTROLLED DELIVERED ENERGY MILLION BTU	TOTAL SOLAR ENERGY USED MILLION BTU (Q400)	TOTAL AUXILIARY THERMAL USED MILLION BTU (Q401)	SOLAR FRACTION OF LOAD PCT (N400)	ELECT ENERGY SAVINGS MILLION BTU (Q415)	FOSSIL ENERGY SAVINGS MILLION BTU (Q417)	BLDG TEMP DEG F (N406)	AMB TEMP DEG F (N113)
1	3.320	N	2.979	0.342	90	N	4.964	73	35
2	3.042	O	2.282	0.760	75	O	3.804	73	34
3	3.412	T	2.732	0.680	80	T	4.553	74	34
4	3.070		2.294	0.776	75		3.823	72	35
5	2.806	A	1.947	0.859	88	A	3.245	73	37
6	3.336	P	2.398	0.937	77	P	3.997	73	30
7	3.075	P	1.679	1.397	77	P	2.798	72	28
8	3.230	L	1.701	1.529	77	L	2.834	73	34
9	3.080	I	2.112	0.968	80	I	3.519	74	33
10	3.478	C	3.478	0.000	100	C	5.796	72	33
11	3.317	A	3.317	0.000	100	A	5.528	71	31
12	2.852	B	1.920	0.932	93	B	3.201	71	30
13	3.160	L	1.472	1.688	70	L	2.454	72	33
14	3.307	E	2.272	1.035	73	E	3.786	73	30
15	3.249		2.191	1.058	81		3.651	73	30
16	2.735		1.002	1.733	61		1.669	71	29
17	2.832		1.066	1.766	72		1.776	68	27
18	2.894		0.850	2.045	78		1.416	68	29
19	3.182		0.764	2.418	70		1.274	71	28
20	3.894		2.206	1.688	74		3.676	72	27
21	3.297		2.124	1.173	83		3.539	73	28
22	3.042		2.178	0.864	76		3.630	73	34
23	2.986		2.497	0.489	92		4.161	74	36
24	3.499		3.446	0.053	98		5.743	72	34
25	3.894		3.546	0.348	91		5.909	71	27
26	3.896		2.326	1.570	70		3.876	72	25
27	3.355		2.207	1.149	77		3.678	73	30
28	2.496		0.795	1.701	74		1.324	72	30
29	3.214		1.221	1.993	71		2.035	72	29
30	3.304		1.339	1.965	63		2.232	72	31
31	4.168		1.621	2.548	72		2.701	70	23
SUM	100.421	N.A.	63.956	36.464	-	N.A.	106.594	-	-
AVG	3.239	N.A.	2.063	1.176	79	N.A.	3.439	72	31
PFRV	0.9933	N.A.	0.9933	0.9933	0.8548	N.A.	0.9933	0.9933	0.9933

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

MONTHLY REPORT: TAOS STATE OFFICE BLDG JANUARY 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 MILLIO BTU	AVG STORAGE TEMP DEG F	AVG BLDG TEMP DEG F
1	4.128	2.979	2.975	1.052	1.056	-0.004	84	73
2	4.001	2.282	2.262	0.991	1.011	-0.020	84	73
3	4.011	2.732	2.772	1.049	1.009	0.040	84	74
4	2.688	2.294	1.859	0.552	0.987	-0.435	82	72
5	3.654	1.947	2.137	1.030	0.840	0.190	81	73
6	4.109	2.398	2.510	1.121	1.010	0.112	83	73
7	2.201	1.679	1.168	0.400	0.910	-0.510	80	72
8	3.892	1.701	2.026	1.037	0.712	0.325	80	73
9	4.214	2.112	2.345	1.160	0.926	0.234	82	74
10	3.878	3.478	3.334	0.913	1.057	-0.143	83	72
11	3.537	3.317	3.118	0.776	0.975	-0.199	81	71
12	2.659	1.920	1.616	0.605	0.909	-0.304	79	71
13	4.282	1.472	1.898	1.230	0.804	0.426	80	72
14	4.331	2.272	2.441	1.106	0.936	0.169	82	73
15	3.984	2.191	2.178	0.962	0.974	-0.012	83	73
16	0.469	1.002	0.100	0.006	0.907	-0.901	78	71
17	0.288	1.066	0.480	0.008	0.594	-0.586	73	68
18	1.590	0.850	0.835	0.264	0.279	-0.015	71	68
19	4.301	0.764	1.560	1.286	0.490	0.796	74	71
20	4.638	2.206	2.672	1.218	0.752	0.466	79	72
21	4.877	2.124	1.939	1.300	1.485	-0.185	82	73
22	4.551	2.178	2.347	1.158	0.989	0.169	84	73
23	4.519	2.497	2.612	1.144	1.029	0.115	85	74
24	3.768	3.446	3.139	0.832	1.139	-0.307	84	72
25	4.455	3.546	3.447	0.977	1.075	-0.099	83	71
26	4.674	2.326	2.367	1.052	1.012	0.041	82	72
27	4.364	2.207	2.305	1.060	0.961	0.098	83	73
28	0.304	0.795	-0.092	0.036	0.922	-0.887	79	72
29	3.073	1.221	1.392	0.694	0.523	0.172	76	72
30	2.862	1.339	1.438	0.679	0.580	0.099	78	72
31	1.539	1.621	1.146	0.175	0.649	-0.475	76	70
SUM	105.844	63.956	62.326	25.872	27.503	-1.630	-	-
AVG	3.414	2.063	2.011	0.835	0.887	-0.053	80	72
PFRV	0.9933	0.9933	0.9933	0.9933	0.9933	0.9933	0.9933	0.9933

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

MONTHLY REPORT: TAOS STATE OFFICE BLDG JANUARY 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	83	64	77	74	80	80	12	35	49	4.128	84
2	82	65	76	74	79	80	11	34	49	4.001	84
3	85	65	77	75	82	81	13	34	49	4.011	84
4	81	65	76	74	78	79	13	35	48	2.688	82
5	84	64	75	73	83	81	12	37	51	3.654	81
6	84	64	75	73	83	80	11	30	45	4.109	83
7	82	64	75	73	78	78	12	28	38	2.201	80
8	83	64	74	75	81	80	11	34	47	3.892	80
9	85	64	75	73	82	80	9	33	49	4.214	82
10	82	63	76	73	79	80	11	33	46	3.878	83
11	81	62	76	73	79	78	11	31	41	3.537	81
12	84	60	75	72	82	77	12	30	42	2.659	79
13	84	62	73	76	84	80	10	33	46	4.282	80
14	82	64	76	73	80	80	8	30	45	4.331	82
15	85	64	76	73	82	82	10	30	44	3.984	83
16	83	65	76	74	79	77	11	29	37	0.469	78
17	80	61	73	73	71	72	12	27	28	0.288	73
18	81	60	71	75	76	73	13	29	37	1.590	71
19	85	58	73	75	82	79	12	28	37	4.301	74
20	87	61	75	75	84	82	9	27	41	4.638	79
21	87	62	75	76	84	79	9	28	42	4.877	82
22	84	64	76	75	84	80	8	34	51	4.551	84
23	87	64	77	75	86	82	8	36	52	4.519	85
24	83	63	78	75	81	81	9	34	49	3.768	84
25	85	61	77	75	82	81	8	27	40	4.455	83
26	87	60	76	78	84	81	7	25	37	4.674	82
27	86	63	76	75	83	80	8	30	41	4.364	83
28	78	65	77	74	77	76	11	30	34	0.304	79
29	83	64	74	73	77	79	13	29	37	3.073	76
30	84	63	74	74	83	79	10	31	42	2.862	78
31	82	62	75	76	75	75	10	23	27	1.539	76
SUM	-	-	-	-	-	-	-	-	-	105.844	-
AVG	87	58	75	74	81	79	10	31	43	3.414	80
PFRV	N.A.	N.A.	0.9933	0.3333	0.3333	0.3261	0.9933	0.9933	0.9933	0.9933	0.9933

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

MONTHLY REPORT: TAOS STATE OFFICE BLDG JANUARY 1981

ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ.FT (Q001)	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	1732	946	35	49	N	69	3	27	0
2	1678	946	34	49	O	54	4	27	0
3	1683	948	34	49	T	60	4	29	0
4	1127	778	35	48		54	3	27	0
5	1533	908	37	51	A	135	5	26	0
6	1724	988	30	45	P	48	3	32	0
7	923	715	28	38	P	47	3	33	0
8	1633	988	34	47	L	26	7	30	0
9	1768	1012	33	49	I	43	3	27	0
10	1627	965	33	46	C	46	5	29	0
11	1484	905	31	41	A	23	2	33	0
12	1115	796	30	42	B	0	2	35	0
13	1796	1058	33	46	L	42	5	30	0
14	1817	1061	30	45	E	54	3	31	0
15	1671	1027	30	44		44	3	34	0
16	197	384	29	37		206	3	36	0
17	121	268	27	28		0	1	37	0
18	667	532	29	37		0	1	32	0
19	1804	1039	28	37		239	5	34	0
20	1946	1150	27	41		309	7	37	0
21	2046	1189	28	42		60	3	34	0
22	1909	1131	34	51		43	3	27	0
23	1895	1154	36	52		83	3	26	0
24	1581	1048	34	49		165	6	29	0
25	1869	1176	27	40		149	5	36	0
26	1961	1199	25	37		160	7	40	0
27	1831	1165	30	41		162	4	36	0
28	128	246	30	34		53	2	34	0
29	1289	915	29	37		110	6	34	0
30	1200	852	31	42		152	7	35	0
31	645	177	23	27		168	9	43	0
SUM	44398	27666	-	-	-	-	-	999	0
AVG	1432	892	31	43	N.A.	90	4	32	0
PFRV	0.9933	0.9933	0.9933	0.9933	N.A.	0.980	0.993	N.A.	N.A.

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

*U.S. GOVERNMENT PRINTING OFFICE: 1981-740-145/2477