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SOLAR ENERGY SYSTEM CASE STUDY: TELEX COMMUNICATIONS Blue Earth, Minnesota

September 1984

**U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM**

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SOLAR ENERGY SYSTEM CASE STUDY
TELEX COMMUNICATIONS
BLUE EARTH, MINNESOTA

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MASTER

EXECUTIVE SUMMARY

A study is made of a solar energy system for space heating a 97,000-square-foot office, factory, and warehouse building owned by Telex Communications, Inc. in Blue Earth, Minnesota. The solar system has 11,520 square feet of ground-oriented flat-plate collectors and a 20,000-gallon storage tank inside the building. Freeze protection is by drainback. Solar heated water from the storage tank circulates around the clock throughout the heating season to heating coils in the ducts. The system achieves its design solar fraction, is efficient, and generally reliable, but not cost-effective.

Performance data for the solar system was collected by the National Solar Data Network for three heating seasons from 1978 to 1981. Because of a freeze-up of the collector array in December 1978, the solar system was only partially operational in the 1978-1979 heating season. The data in this report was collected in the 1979-1980 and 1980-1981 heating seasons. Highlights of the performance of the solar system during the above heating seasons are:

- The collector array performance was excellent. The efficiency of the large array was equal to single-panel ASHRAE test results throughout the monitoring period. The operational collector efficiency was 44%. Overall collector efficiency was much lower, only 22%. This is because the collectors did not need to operate full-time in the spring and fall to keep the storage tank hot, and also because the operation of the collector control was conservative to keep the collectors from operating when the possibility of freezing existed. (The collector fluid is water.)
- The solar space heating loop delivered 95% of the collected solar energy to the load (86% through the pipes, nine percent from storage losses). The space heating loop ran continuously throughout the heating season with no minimum temperatures. The temperature of the solar heated water seldom fell below 75°F, but it did circulate at temperatures as low as 58°F after an extended period of cloudy weather.
- There were two major problems encountered with the solar system:
 - Two rows of collectors froze on December 2-3, 1978. Improper heat-taping and insulation of the air vents and vacuum breakers resulted in freezing of these devices under near-zero temperatures, preventing the system from draining.
 - The original hose connections between the internally manifolded collectors slipped frequently due to thermal expansion and contraction, resulting in leaks. This problem was solved by changing the hose to a type with a hump at its midsection which acts as an expansion compensator.

These problems were repaired by the fall of 1979, and have not recurred since then. Maintenance has been confined to the occasional tightening of clamps on the hoses connecting the collector manifolds.

- The design solar fraction was 70% (some documents list a figure of 60%). The measured solar fraction for the two heating seasons combined was 66%. No data was collected in two months that undoubtedly had higher solar fractions.
- The solar system was turned off during the summer months, and stagnation temperatures reached 330°F on the collector absorber plate. The high stagnation temperatures caused no harm.
- The net electrical energy savings from the solar system amounted to 519 million BTU, or 152,000 kwh per season. This is equivalent to \$7,600 saved at the 1980 rate of \$0.05 per kwh. The solar system cost \$460,000 to build in 1977.
- Weather conditions were about equal to the long-term average for Rochester, Minnesota. The average insolation was 1,127 BTU/ft²-day over the three heating seasons from 1978 to 1981. Conditions were often bitterly cold. In January 1979, the temperature dropped below zero on 24 days out of 31, and averaged 0°F for the month.

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SECTION 1

INTRODUCTION

Several of the solar systems monitored by the National Solar Data Network (NSDN) have been selected for "case studies," an in-depth history and analysis. This report is a study of the solar system at Telex Communications, Inc., a large space heating system for a 97,000-square-foot office, factory, and warehouse building in Blue Earth, Minnesota. The solar system was designed by InterTechnology/Solar Corporation of Warrenton, Virginia. Mankato Plumbing and Heating Co. began construction in August 1977.

The solar system is large but not complex, with ten rows of single-glazed black chrome flat-plate collectors (11,520 ft²) mounted on wood trusses and concrete piers four feet off the ground about 200 feet from the building. Freeze protection is by drainback to the storage tank. The drainback is complicated by the fact that the storage tank is higher than the collectors (originally the tank was to be buried at the north end of the array, but cost considerations forced its removal to the building). A sump is used to drain the collectors and a sump pump is used to transfer the water from the sump to the storage tank. The sump and its pump are used throughout the collection. All the solar heated water passes through the sump. The sump was disliked by the design reviewers, who felt that it should be bypassed during normal operation, but the designers rejected the reviewers' advice because they believed the automatic valves necessary to bypass the sump would be an unwarranted complication and might interfere with a reliable drainback. The drainback system was chosen in the first place because of its simplicity and reliability. The drainback system and the sump have proved to be reliable, although there was a freeze-up of two collector rows when these rows did not drain in near-zero weather in December 1978. The cause of the freeze-up was traced to air vents and vacuum breakers that were not properly heat-taped and insulated. Water froze in the vents, and the rows did not drain. When the collectors were repaired, standpipes were installed in the outlet pipes of all ten rows. No drainback problems have occurred since this time (as of the summer of 1984).

The solar heating loop was also quite simple; the load pump ran constantly throughout the heating season, circulating heated water to the load heat exchangers which were in the ducts upstream of the electric resistance heaters. This continuous circulation kept the tank well mixed. The collector water return and heating system supply pipes are located very close to each other at the top of the south end of the tank. This design allows collector return water to circulate directly to the load. There was a load bypass line controlled by the demand of the heating coils; as demand dropped, more water went through the bypass, maintaining a constant pressure at the pump outlet. This scheme worked very well; water circulated constantly through the tank as there was no minimum temperature for circulation. Although the temperature of the solar supply water

fell as low as 58°F after an extended period of cloudy weather, it did not usually go below 75°F. The heat was still useful down to these temperatures because it was warmer than the mixture of room and outside air entering the fan coil units.

In short, the solar system is well designed, simple, and efficient, one of the best performers monitored by the National Solar Data Network (NSDN). However, the system cost \$460,000 to build, and saves less than two percent of that figure per year.

After the monitoring period ended, the system was modified to allow preheating of domestic hot water in the summertime. It is not known whether the savings from this mode of operation are larger than the energy consumed to run the collector pumps in the summer.

SECTION 2

BUILDING DESCRIPTION

2.1 LOCATION

The Telex Communications plant is located in southern Minnesota near the town of Blue Earth, at a latitude of 43.6 degrees north. The plant manufactures tape recorders and other electronic equipment. The 97,000-square-foot building houses administrative offices, assembly areas, and warehouse space. The building is of steel construction with six inches of fiberglass insulation between the steel skins. The design equipment heating load was 2,600 BTU annually, or 3.35 BTU/ft² floor area-heating degree-day. This does not include 2.5 watts/ft² of heat supplied by internal lighting, or internal gains from equipment or people. The design UA coefficient is 7,293 BTU/hr-°F. The storage areas are separated from the manufacturing areas with partitions, and the storage areas are maintained at 55°F, while the work areas are maintained at 68°F during the heating season. During cold weather, the space heating load ranges between nine to 12 million BTU per day. The average number of heating degree-days for the Blue Earth area is approximately 8,000. Heat for the building is provided by electric duct heaters mounted in the air-handling units and electric unit heaters. There is very little hot water demand, since none of the manufacturing operations require hot water.

Figure 1. Telex Communications Building, South View

Because of the use of electric resistance heating, the Telex Communications plant was considered a good choice for a solar heating retrofit. A proposal for a solar system was submitted under the PON-1 Solar Heating and Cooling Commercial Demonstration Program.

in June of 1976, Telex Communications was awarded a contract by ERDA (now the Department of Energy) to construct a solar space heating system. InterTechnology/Solar Corporation began the design of the system in August 1976. Construction of the system by Mankato Plumbing began in August 1977. The system began delivering space heating in February 1978.

2.2 SYSTEM DESCRIPTION

The solar energy system is a retrofit, designed to provide 70% of the annual space heating requirement for the building. Figure 2 is a flow schematic of the Telex Communications solar system. The 11,520-square-foot array of flat-plate collectors is ground-mounted in a field approximately 200 feet east of the building (see Figure 3). The array has 10 rows with 36 four-foot by eight-foot collectors in each row. The 20,000-gallon storage tank is located inside the building. Two 240-gallon-per-minute pumps are used in series to transfer the water from the tank to the collectors, back to a sump, and then from the sump back into the tank. Pre-insulated four-inch copper pipe is buried five feet below-grade to transfer the water to and from the collector field. A pump, with 140-gallon-per-minute capacity, is used to draw the heated water from the storage tank, pass it through the coils in the air-handling units, and then return the water to the storage tank. A second load pump is used as a backup; the two pumps do not run together. The only heat exchangers in the system are the air-to-water coils in the air-handling units. Auxiliary heat is provided by electrical resistance heaters in each air-handling unit and by three electrical space heaters. The air-handling units provide ventilation year-round.

Figure 2. Telex Communications Solar Energy System Flow Schematic

Figure 3. Collector Field

2.2.1 Collection

The solar collectors used on the project are the Mark III model manufactured by InterTechnology/Solar Corporation, Warrenton, Virginia. A total of 360 collectors are used, 10 rows of 36 collectors each. The collectors have nominal four-foot by eight-foot dimensions, giving a gross collector area of 11,520 square feet. The collectors are oriented due south and are tilted at an angle of 58.5 degrees from the horizontal.

Figure 4. Collector Row 5, with Pyranometer

The collector specifications are given below. A black chrome selective absorber coating and water-white glass are used. The black chrome selective coating is electroplated on a nickel-coated aluminum extension. The solar absorptivity and thermal emissivity of the black chrome coating are nominally 0.95 and 0.12, respectively.

Specification 770501
Solar Collector - Medium Temperature
Model Mark III

1. Glazing: Glass, 3/16-inch thick, water-white, single-glazed; transmissivity = 0.91.
2. Glazing Seal: Continuous molded EPDM rubber.
3. Pressure Plate: 18-gauge stainless steel Type 304.
4. Fasteners: 3/4-inch x #10 Truss Head stainless steel sheet metal screws.
5. Frame: 20-gauge galvanized steel, welded corner construction full metal back.
6. Fin Tube Absorber Assembly
 - a. Manifolds: Two, harddrawn, Type M copper tubes, 2-1/2-inch ϕ Nominal.
 - b. Cross Tubes: Eleven harddrawn, Type M copper tubes, 1/4-inch ϕ Nominal.
 - c. Absorber Fins: Eleven Aluminum Extrusions: 0.060-inch x 4.22-inch x 88.125-inch.
 - d. Absorber Coating: Black chrome α 0.95 ϵ 0.12.
7. Manifold Connectors: High temperature formed rubber hose with hose clamps.
8. Insulation: One-inch fiberglass around edges; three-inch fiberglass under absorber.
9. Working Pressure: 50-PSIG; maximum 100-PSIG.
10. Area: 32.0 square feet (47-3/8 inches wide x 97-3/8 inches long x 5-1/4 inches deep overall dimensions).
11. Effective Absorber Area: 29.7 square feet.
12. Mounting Provisions: Consult factory.
13. Dry Weight: 233 pounds.
14. Liquid Volume: 0.318 cubic feet or 19.87 pounds of water.

The water-white glass is specially made with a very low iron oxide impurity content (which gives ordinary glass a greenish cast). The solar transmittance of the water-white glass is 0.90 to 0.91. The slightly rippled pattern in the glass is due to the method of manufacture and has no effect upon its transmittance. The pattern does, however, tend to diffuse the light reflected from the surface of the glass and thus produce a less intense glare.

The InterTechnology/Solar Mark III collector was tested according to ASHRAE Standard 93-77 in 1976 by the University of Connecticut Solar Energy Test Facility. The resulting $F_R(\tau\alpha)$ was 0.75, with an $F_R(U_L)$ of -0.86, based on gross collector area (32 square feet) with a flow rate of 0.33 to 0.40 gpm. The Mark V collector, which is the same as the Mark III except that it is smaller (19-square-foot gross area), was tested by the Florida Solar Energy Center. The results were:

$$F_R(\tau\alpha) : 0.704$$

$$F_R(U_L) : 0.764$$

based on gross area with a flow rate of 0.5 gpm.

In a test performed for the Solar Energy Research Institute, (Reference 1), the results were:

$$F_R(\tau\alpha) : 0.675$$

$$F_R(U_L) : 0.973$$

based on gross area with a flow rate of 0.5 gpm.

The design flow rate was 240 gpm for the array, or 0.667 gpm for a 32-square-foot panel. The measured collector flow rate was about 210 gpm.

The collectors in each row are piped in parallel using the internal manifolds at the top and bottom of each collector. The connections are made inside the collector box using a reinforced silicone "hump" hose and hose clamps. (See Figure 5.) The hump hoses are also bonded to the copper manifolds using a silicone adhesive. Thermal expansion or contraction is absorbed by the hose.

The collectors are supported by a wood structure which is mounted upon poured concrete piers (Figure 6). The concrete piers were poured to varying heights to give a slope to the structure for collector draining. The east side of the structure is approximately 18 inches below the west end, thus allowing the collectors to drain back to the inlet. The system will drain anytime the solar system pump stops. As the water leaves the collectors, air is bled into the system through standpipes located at the upper west end of each row (Figure 7). These standpipes are heat-taped to prevent freezing. Pre-insulated four-inch copper pipe is buried five feet below-grade to transfer the water to and from the collector field.

Figure 5. Collector Hose Connection

Figure 6. Rear of Row 10, Supporting Truss

Figure 7. Collector Return Piping and Standpipes

Because the collectors are located below the level of the storage tank, a sump pit is used to hold the return water from the collectors. A sump pump takes the water out of the sump and returns it to the storage tank. An engine-driven sump pump serves as a backup to the primary sump pump if it fails or if there is an electrical power failure. In addition, there is an overflow to carry water from the sump to the outside if the backup fails. The sump is three feet in diameter and 11 feet deep, with a capacity of about 600 gallons. (See Figure 8.) The collectors and associated piping hold 800+ gallons of water.

Figure 8. Sump Pit and Pump

A formal soils report indicates that the water table fluctuates from the surface down to six feet in depth with the last year's variation ranging from three feet to six feet in depth. The soil material is expansive clay, and the frost depth is reported to be at least five feet. There is a paved parking lot (of about 150 feet in width) between the building and the collector field.

2.2.2 Thermal Storage

Thermal storage for the solar system is provided by a 20,000-gallon water storage tank located inside the building at the east end. The dimensions of the tank are nine feet in diameter by 42 feet long. The tank was constructed from 5/16-inch-thick hot-rolled steel. Insulation for the tank is provided by six inches of fiberglass, giving a total R value of 20.

Figure 9. Storage Tank, Pumps, and Piping

Piping to and from the storage tank is arranged to make full use of the storage capacity of the tank. The solar water return and the heating system supply pipes are located very close to each

other at the top of the south end of the tank. The heating system return water comes back to the tank at the north end. Although the solar pump is physically located at the south end of the tank, it is supplied with water from the bottom of the north end through a four-inch pipe mounted inside the tank. (See Figure 10.)

Figure 10. Storage Tank, Warehouse Area

Because the collectors and associated piping hold a significant quantity of water (800+ gallons), the water level will vary due to the operation of the solar pump. The water level was measured on February 27, 1981, and at that time the volume of water in the tank (collectors full) was calculated to be 18,040 gallons. Make-up water to the tank is automatically supplied by a low- and high-level control. The makeup water is treated by a resin-type water softener. Under normal conditions, the amount of makeup water required by the system should not be large (less than 1,000 gallons/year), since the only way water is normally lost is through evaporation.

2.2.3 Heating

Heating of the plant is accomplished by water-to-air heating coils located in the nine existing air-handling units, and by three water-to-air unit heaters. The water coils in the air-handling units are located upstream from the existing electric heating elements. This location results in more efficient operation of the solar heating system, since the coldest air reaches the water coils first and can thus be preheated before it reaches the electric elements. In this way, the water in the storage tank can be used down to temperatures of 80°F or lower.

Figure 11. Space Heating Ductwork

The operation of each solar hot water coil is controlled by a thermostat located in the area of the plant served by the air-handling unit in which the coil is located. The thermostat actually controls the operation of a two-way valve located in the solar hot water supply line leading to the heating coil. The thermostat and valve are the proportional type. That is, the opening and closing of the valve are controlled by the thermostat in direct proportion to the deviation of the plant air temperature from that set on the thermostat. This proportional action takes place over a $\pm 2^{\circ}\text{F}$ range. Thus, if the thermostat is set at 66°F , the heating valve will be fully closed at 68°F and fully open at 64°F .

If the solar tank temperature is not high enough to provide sufficient heat to meet the requirements of a particular zone, then the temperature of the zone will continue to fall. The electric heating thermostats are set 3°F to 4°F below the solar heating thermostats and will thus turn on the electric heating coils if the tank temperature is too low. Note that, even if the electric heaters turn on, some heat is still being extracted from the solar water coil (since it is upstream from the electric heaters).

Three unit heaters are located in the areas of the plant that are not served by a central air distribution system. These heaters are controlled by standard on-off thermostats. Whenever the space requires heat, the thermostat turns on the unit heater fan. When the heating demand is met, the fan is turned off.

Hot water from the solar storage tanks is supplied to the heating coils by two hot water supply pumps located at the south end of the tank. These pumps are called P2 and P3 on the solar control panel. During the heating season, pump P2 runs continuously. Pump P3 is used as a backup; the pumps do not run together. Water from the hot water supply pump flows not only through the heating coils but also directly back to the tank through a short bypass line. The amount of water passing through the bypass line is controlled by two regulating valves in the bypass line. These regulating valves are controlled so that a constant pressure is maintained at the outlet of the pumps. If the heating coils demand more water, the pressure will fall and the regulating valves will throttle down the flow in the bypass line to maintain the pressure.

Tables 1 and 2 describe the heating coils and unit heaters at Telex Communications, respectively. Table 3 gives the locations and power ratings for the electric heaters.

Table 1. HEATING COIL SCHEDULE
TELEX COMMUNICATIONS

COIL NO.	LOCATION	CFM	AIR		GPM	WATER		CAPACITY (BTU/HR)
			ENTERING TEMPERATURE (°F)	LEAVING TEMPERATURE (°F)		ENTERING TEMPERATURE (°F)	LEAVING TEMPERATURE (°F)	
1	AMU1	8,000	50	80	35	105	90	260,400
2	AMU2	9,200	50	80	40	105	90	300,000
3	AMU3	9,200	50	80	40	105	90	300,000
4	AMU4	3,800	50	80	16	105	90	124,000
5	AMU5	1,200	50	80	5	105	90	39,000
6	AMU6	1,200	50	80	5	105	90	39,000
7	AMU7	2,000	50	80	9	105	90	65,100
8	AMU1A	10,500	50	70	30	105	90	228,000
9	AMU2A	10,500	50	70	30	105	90	228,000

Table 2. UNIT HEATER SCHEDULE
TELEX COMMUNICATIONS

UNIT NO.	SERVICE	CAPACITY (BTU/HR)	CFM	GPM	ENTERING TEMPERATURE (°F)	LEAVING TEMPERATURE (°F)	MOTOR		ELECTRICAL			MODEL NO.
							HP	RPM	VOLTS	HZ	PHASE	
1	Storage	78,000	5,430	12	105	90	0.5	1,140	120	60	1	YU-2620
2	Storage	78,000	5,430	12	105	90	0.5	1,140	120	60	1	YU-2620
3	Storage	78,000	5,430	12	105	90	0.5	1,140	120	60	1	YU-2620

Table 3. ELECTRIC HEATERS

TELEX COMMUNICATIONS

<u>LOCATION</u>	<u>POWER RATING (kw)</u>
Subassembly	22.5
Lunchroom	30.0
East Office	12.5
West Office	15.0
Lobby	5.0
Center Office	10.0
Restroom	3.0
Amp West	34.0
Amp North	34.0
TMS Line East	22.0
TMS Line West	54.0
300 Line	17.6
QC Receiving	30.0
West Building Restrooms	4.0
Shipping Dock	20.0
Receiving Dock	20.0
East Warehouse	30.0
West Building (8)	18.0
North Warehouse (3)	50.0
North Warehouse	20.0
Restrooms	13.0

The total power rating of all the electric heaters at Telex Communications is 720.6 kw.

2.2.4 Controls

The control subsystem governs the operation of the solar system pumps and control valves. The design and installation of the control subsystem was performed by Johnson Controls of Minneapolis according to the specifications of the solar system engineer, InterTechnology/Solar Corporation.

The control panel is located on the east wall of the building adjacent to the solar storage tank. The controls for the solar system pumps, the sump pump, the heating distribution pumps,

and motorized valves are located in this panel. A number of temperature gauges are also provided on the face of the panel to allow the performance of the systems to be monitorized.

The collector control settings are given in the next section, Operational Modes.

The heating control settings are discussed in Section 2.2.3, Heating.

2.3 OPERATIONAL MODES

The system has two modes of solar operation.

Mode 1 - Collector-to-Storage - This mode is entered when the temperature of the collector surface exceeds the water temperature in the water thermal storage by 25°F. Water is circulated from storage through the collectors until the storage temperature reaches 190°F, or until the difference between the collector plate temperature and storage temperature is less than 2°F.

Mode 2 - Storage-to-Space Heating - This mode is controlled by manually preset thermostats. The minimum designed operational temperature in water thermal storage is 100°F, although the control system does not inhibit operation below this temperature. Water is circulated through the heat exchangers and returned to storage until the demand is satisfied. The heating pump normally runs continuously throughout the heating season.

2.4 PIPES

The long underground run of four-inch pipe between the collector field and the storage tank is Rovanco Insul-8, with O-ring coupled copper Type L pipe pre-insulated in the factory with one inch of polyurethane foam, and jacketed with seamless polyvinylchloride (PVC).

2.5 PUMPS

The collector pump is a Bell and Gossett Series 80, size 3x3x9½, centrifugal pump. The collector pump is a seven and one-half horsepower pump, rated at 200 gallons per minute with a head of 80 feet. It is a bronze fitted pump and runs at 1,750 rpm.

The sump pump is an Aurora Model 531, size 4x4x7A. The sump pump is a two-horsepower pump, rated at 240 gallons per minute with a 20-foot head.

The load pumps are Bell and Gossett Series 80, size 2½x2½x9½, centrifugal pumps. These pumps are identical, five-horsepower pumps, rated at 125 gallons per minute with a head of 60 feet. They are bronze fitted, and run at 1,750 rpm.

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SECTION 3

SYSTEM PRELIMINARY DESIGN

3.1 REQUIREMENTS

The Telex Communications office and manufacturing plant in Blue Earth, Minnesota was originally all electrically heated. Because of rising electricity costs following the energy shortage which began in October 1973, Telex Communications looked for an alternative fuel source for space heating. Telex Communications was awarded a contract from the Energy Research and Development Administration (ERDA) to construct a solar space heating system. The solar system was required to supply approximately 75% of the annual space heating load (about 2,600 million BTU) (the domestic hot water load is very small), and to have a 20-year life.

3.2 DESCRIPTION

The retrofit solar energy system was one of those built under the Program Opportunity Notice (PON) program of ERDA. In November 1975, the InterTechnology Corporation (ITC) (now defunct) of Warrenton, Virginia, submitted a proposal to ERDA to design a solar space heating system for Telex Communications.

The original proposal included 20,000 square feet of flat-plate collectors, ground-mounted adjacent to the building, and a 40,000-gallon storage tank buried below the frost line beneath the collectors. The collector fluid was water, with freeze protection derived by automatically draining the collector fluid back to the storage tank when the collector pump stopped. The heated water was to be circulated to heat exchangers at each electric heater location.

Two types of collectors were contemplated, one made by Solar Corporation of America (later merged with ITC to form ITC/Solar) with a selective absorber surface and the PPG collector with a flat-black painted absorber.

3.3 PERFORMANCE ESTIMATES

The performance of the proposed solar system was estimated using an hourly simulation model developed by ITC. The computer program for the simulation of flat-plate solar energy collector performance was based upon detailed heat balance equations for the absorber plate and the cover plates. The analyses were done individually over each month for the geographical location of the solar collector. The weather data required were $\bar{H}$, average daily total radiation (beam + diffuse) on a horizontal surface for the month; t_0 , the average daytime ambient temperature, and $\bar{K}_T$, the fraction of extraterrestrial solar radiation that reaches the

local ground level. Variation of instantaneous solar flux on a horizontal surface over the day, from sunrise to sunset was assumed to be a cosine function such that the flux was zero at sunrise and sunset and maximum at solar noon. The area representing the cumulative energy was $\bar{H}$. The instantaneous value of total solar flux was divided into its beam ($\bar{B}$) and diffuse ($\bar{D}$) components on the basis of $\bar{K}_T$. The beam component $\bar{B}$ was multiplied by a factor (determined by solar declination, tilt angle, and azimuth of solar collector, and solar time), and combined with $\bar{D}$ to get a total instantaneous solar flux on the tilted surface of the collector. The dependence of absorptance-transmittance product on the angle of incidence was taken into account. From the total instantaneous flux, the heat collected per hour was calculated every half hour using detailed heat balance equations for the absorber plate and the cover plates. The storage tank temperature was adjusted according to the solar heat collected and the heating load on the system.

The insolation was varied randomly over the month such that the average was the same as the input value $\bar{H}$.

According to the proposal, the double-glazed selective surface collector used in the performance calculation had an emissivity of 0.4, which is very high for a selective surface, and a reasonable absorptance-transmittance product of 0.75. The results of the calculation are summarized in Table 4.

Table 4. TELEX COMMUNICATIONS PERFORMANCE CALCULATIONS

MONTH	HEATING LOAD* (MMBTU/Month)	HEAT LOAD CARRIED BY SOLAR	
		(MMBTU/Month)	(%)
JAN	514.2	317.4	61.8
FEB	435.1	343.4	78.9
MAR	367.6	344.9	93.8
APR	195.8	195.8	100.0
MAY	90.8	90.8	100.0
JUN	0.0	0.0	*
JUL	0.0	0.0	*
AUG	0.0	0.0	*
SEP	59.6	59.6	100.0
OCT	159.2	159.2	100.0
NOV	319.7	251.6	78.7
DEC	458.4	261.8	57.1
ANNUAL	2,600.2	2,024.7	77.9

Heat supplied by auxiliary = 575.5×10^6 BTU/year.

Collector output = 101,200 BTU/ft²-year.

*Credit has been taken for internal lighting of 2.5 watts per square foot of floor area. The loads have been estimated from the records of actual energy consumption of the building.

The parameters used in the calculations were:

Collector tilt angle	55 degrees
Collector area	20,000 ft ²
Storage size	40,000 gallons

At an energy cost of 3.7¢/kwh, the projected solar system savings were \$21,955/year.

3.4 OPERATING MODE ANALYSIS

The proposed operation of the system was as follows:

Collector-Storage Loop - Whenever the collector plate temperature rises above the storage tank temperature, the comparator (C-1) energizes a timer. This sequence will be called the "startup cycle." The timer then shall operate for a period of five minutes irrespective of C-1 with its contactor closed, thereby energizing the collector pump for a minimum of five minutes. At the end of the five-minute run, the timer shall keep the pump energized unless C-1 indicates that the tank temperature is warmer than the plate temperature. This sequence will be called the "shutdown cycle." At that time, the timer shall reverse its operation and, at the end of another five minutes (assuming C-1 does not call for collection), the timer shall deactivate the collector pump. If C-1 should call for collection during the "shutdown cycle," the timer shall then begin to operate on the previous or "startup cycle" with the exception of rigid adherence to the five-minute delay.

Whenever the pump is operating, the two dump valves shall close. Whenever the pump is de-energized, the valves shall open, draining the collector to the tank.

Space Heating Loop - The performance model assumed that the minimum tank temperature for space heating was 110°F, and the maximum allowable tank temperature was 220°F. It was assumed that, with 110°F or hotter tank water, solar energy could carry the heating load. If the tank temperature was less than 110°F, electrical energy would heat the building. Solar and auxiliary energy would not be used together.

3.5 COST ESTIMATES

The capital cost of the solar system was estimated at \$360,482. The breakdown was:

Solar Collectors	\$210,000
Storage Tank and Insulation	76,000
Structural	25,000
Pumps	2,300
Piping	16,250
Controls	2,500
ITC Design Fee	<u>28,432</u>
TOTAL	\$360,482

3.6 RELIABILITY

The estimated design lives of the subsystems were:

Collector	20 years
Storage	40 years
Heating	20 years
Auxiliary	30 years
Energy Transport	40 years
Controls	30 years

SECTION 4

SUBSYSTEM PRELIMINARY DESIGN

In June 1976, Telex Communications was awarded a contract from the Energy Research and Development Administration (ERDA) to build a solar space heating system. InterTechnology/Solar Corporation began the design in August 1976.

4.1 COLLECTOR

The collector array area in the proposal had been 20,000 square feet. In the first full-fledged preliminary system design, this area was reduced to 14,880 square feet. The design called for 13 rows of collectors, with 36 collectors in 12 of the rows, and 33 collectors in the 13th row, a total of 465 four-foot by eight-foot collectors. The collectors chosen at this stage were the (single-glazed, black chrome) ITC/Solar Mark III collectors that were actually installed in the system. They are fully described in the collection subsystem description, Section 2.2.1. Each row of collectors is supported by 20 concrete piers in two rows of ten. The rows are spaced eight feet, two and one-half inches apart, with the piers 16 feet apart in the row. The piers are 16 inches in diameter, drilled and cast in place to a depth of six feet beneath the surface. The height of the piers varies to produce a slope in the piping. The west end of the array is one foot higher than the east end. The minimum height from ground-level to the bottom of the collectors is about four feet. The frost depth at the site is reported to be at least five feet. Seasonal movements up and down of the structure due to frost heaving could be tolerated provided there was not any excessive differential movement. A soils engineer, Donovan K. Stormore, P.E., of Soil Exploration Company of St. Paul, Minnesota, was asked to consult on the structural design. He recommended the drilled and cast-in-place pier, with a tip elevation below the frost line. He stated that "since the subsurface profile at the site is relatively uniform, large differential movements would not be expected, assuming similar ground-cover conditions over the site."

The collectors are supported by an inclined vertical truss framing system, constructed of treated wood. The design wind load was 20 PSF, corresponding to a wind speed of 90 miles per hour. The wind loading was considered adequate to support snow loads, because the collectors are four feet off the ground and steeply sloped (58.5 degrees). Snow should not stand on the collectors.

4.2 STORAGE

The storage tank designed for the 14,880-square-foot collector array was a buried steel tank with a capacity of 30,000 gallons. The tank was to be 10 feet six inches in diameter and 46 feet long.

It was to be buried at the north end of the collector array, with the top of the tank four feet below-grade. A masonry pit with a 12-inch wall at one end of the tank would contain the collector pump and the two load pumps. Six inches of urethane insulation and a protective coating were specified. All the piping connections (two collectors, two loads, and makeup water) were in one end of the tank, in the masonry pit. There was an internal pipe 38-1/2-feet long running lengthwise about nine inches above the bottom of the tank for the collector supply water. The collector return water came into the pit end of the tank about two-thirds the distance from the bottom. This arrangement should ensure thorough mixing of the collector water with the storage water.

The heating supply water pipe came out of the tank very close to the collector return pipe, allowing a desirable short circuit. The heating return pipe was connected to the tank about one-third the tank diameter from the bottom. The tank was vented to the atmosphere with automatic water makeup. The tank saddles were to be bolted to a concrete pad, using 70 three-quarter-inch anchor bolts with seven-inch embedment.

4.3 HEATING

The solar space heating distribution system design included nine heating coils, located in existing air-handler units upstream of the electric heaters, and three solar unit heaters. Two identical pumps were used in parallel to supply the hot water to the heating coils. Each heating coil had a two-way valve that would partially close during periods of reduced heating demand. This closing would cause a valve that was regulated by the pressure differential between the supply and return lines to open. This pressure differential valve was located in a line bypassing the heating coils as heating demand was reduced. A flow switch in the bypass line would shut off one pump when the flow in the bypass loop was one-half of the total flow. At this point, the pressure differential valve closed, allowing the total flow from one pump to pass through the heating coils. As the heating demand was further reduced, the pressure differential valve would open to bypass some of the flow around the heating coils. If the heating demand increased, the pressure differential valve would close to divert more flow to the heating coils. If the flow in the bypass line fell too low, a second flow switch would activate the other pump.

From the heat exchanger characteristics, it was determined that 70% to 80% of the design heating capacity would be retained if the water flow to the coil were halved. It was concluded that only one pump would be running for the large majority of the total operating hours. The two-pump design also allowed the system to remain in operation if one pump failed.

4.4 PIPING

The piping size and layout are shown in considerable detail in the drawings in Figures C-6, C-7, and C-8 in Appendix C. The underground pipe was to be polytherm, a steel pipe system factory-insulated with one-inch of polyurethane foam, coated with a fiberglass reinforced polyester resin.

4.5 PUMPS

Four pumps were required, a collector pump, two load pumps, and a small sump pump to evacuate water from the masonry pit when necessary. Their characteristics are outlined in Table 5.

Table 5. PUMP SCHEDULE FOR TELEX COMMUNICATIONS

PUMP NO.	SERVICE	GPM	HEAD	RPM	MOTOR HP	TYPE	REMARKS
1	Solar Collectors	300	80	3,500	15	Centrifugal in line	Similar to B&G Series 80
2	Heating Coils	125	110	3,500	15	Centrifugal in line	Similar to B&G Series 80
3	Heating Coils	180	110	3,500	15	Centrifugal in line	Similar to B&G Series 80
4	Sump Pit	5	15	1,725	0.5	Sump Pump	Similar to Aurora Series 510

4.6 CONTROLS

Tank-Collector Operation - Whenever the collector plate temperature would rise 5°F above the storage tank temperature, a comparator, C-1, would energize the collector pump. Once the pump starts, it would stay energized for at least 10 minutes. At the end of 10 minutes, the pump would shut down if the collector temperatures were within 2°F above the tank temperature, otherwise the pump would stay energized. Valve V-1 is a normally open solenoid valve that closes whenever the collector pump is energized.

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SECTION 5
ECONOMIC ANALYSIS

The cost breakdown for the Telex Communications solar system as of January 14, 1977 was as follows:

1. Collectors - 14,880 ft ² -F.O.B. Blue Earth	\$183,551
2. System Design (ITC)	28,675
3. Mechanical & Electrical Work	
a. Cement work including pump house and cradle	81,275
b. Collector support	37,190
c. Tank and insulation	24,095
d. Outside mechanical	111,695
e. Inside mechanical	66,400
f. Electrical	9,150
4. Miscellaneous (performance bond, building permit, rust inhibitor, etc.)	<u>15,000</u>
TOTAL	\$557,031

The contract price was \$459,441, to be paid for by the government (\$350,000) and Telex Communications (\$109,441). In order to get the cost down to the contract price, a number of modifications were made to the solar system. The storage tank and pumps were moved into the building, saving approximately \$50,000. The number of collectors was reduced from 465 to 396 (11 rows of 36, gross area 12,686 square feet). (The collector array was later reduced again; it was built with 10 rows of collectors, with an area of 11,520 square feet.) The storage tank volume was reduced from 30,000 gallons to 20,000 gallons. The collector pump size was reduced from 15-hp to 7.5-hp, but a two-hp pump had to be added. The estimated solar fraction dropped from 80% to 70%.

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SECTION 6

DESIGN REVIEWS AND REVISIONS

6.1 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION DESIGN REVIEW

The National Aeronautics and Space Administration (NASA) reviewed the Telex Communications design in December 1976. The review included civil, structural, architectural, mechanical, and electrical comments. The complete Design Review Comments are included here in Appendix F-1. ITC's structural consultant, Norman C. Pardue, Jr., P.E., "much dismayed and incensed at the quality of the review," wrote a long, detailed rebuttal to the comments, which is also included in Appendix F-2. ITC's comments on the review are included in Appendix F-3. Many of the comments simply asked for more detail or clarification in the specifications. No changes in the design were made as a result of the review.

In order to bring the system cost within the budget, the system was redesigned with an above-grade storage tank near the collector array. This design required considerable complexity to prevent freezing in the case of a power failure. The design finally used, with an indoor storage tank, was the third design.

6.2 FINAL DESIGN REVIEW

A final design review was conducted at Blue Earth, Minnesota on May 4, 1977 with representatives from Telex Communications, Marshall Space Flight Center, InterTechnology, ASHRAE, IBM, the American Institute of Architects (AIA), and Mankato Plumbing and Heating Company in attendance.

The sump was the principal bone of contention at the final design review. When ITC changed the design location of the storage tank from underground to inside the building, the storage tank became higher than the collector field. Because the design depended on drainback for freeze protection, a sump was added to drain the collectors and a sump pump was added to transfer the water from the sump to the storage tank. The sump had a capacity of about 250 gallons. The collectors and associated piping hold about 800 gallons, so a sewer drain one foot below the top of the sump was provided to handle the overflow in case of a power failure. The consensus of those present at the design review (except ITC) was that this design was totally unsuitable. According to the ASHRAE representative, Douglas M. Jardine, P.E., the result would be "constant flooding of the Telex plant, freezing of collectors in the severe climate of southern Minnesota," saying "one year life expectancy may be overly optimistic."

Mr. Jardine and Marshall Space Flight Center (MSFC) made the following recommendations to Telex Communications concerning the sump pit:

1. Enlarge the sump pit capacity from 250 to 860 gallons.
2. Add a three-way valve in the sump pit to bypass the sump in a normal operating mode. The sump pit would be used only for draindown.

ITC did not agree with these recommendations, but the as-built system has a three-foot-diameter sump pit holding about 600 gallons, and there is a gasoline-powered sump pump to empty the sump during power failure.

MSFC and Douglas Jardine were also concerned with the operation of the space heating loop. The design had no low temperature shut-off control on the storage tank for shutting off the space heating pumps when the storage temperature drops below usable loads. The fear was that the storage system could turn into a heat exchanger between the 70°F plant and the 55°F storage areas when the storage tank temperature was low.

ITC felt there was no need for such a control and stated they would not add one. They were as good as their word; no such control was ever added, nor was it needed.

The reviewers were also concerned that there was no freeze protection for the solar coils in the air-handling units. The owner said the fresh air dampers had failed in the past. Apparently, ITC said freeze protection was not needed, while Mankato thought their bid covered such devices. The system was built with freeze protection provided by a low-limit thermostat located just after the hot water coil. If the air temperature falls below 40°F, the fan is turned off, and water flow through the coil is maintained.

Some of the reviewers felt that stratification in the storage tank would cause a decreased solar utilization. ITC claimed stratification would increase solar utilization. Because the load pump ran constantly during the heating season, the tank was never stratified.

SECTION 7
FINAL DESIGN

7.1 SYSTEM DESCRIPTION

Figure 12 is a flow schematic of the Telex Communications solar system. The collectors are mounted in a field approximately 200 feet from the combination office, manufacturing, and warehouse building. The collector array consists of 10 rows with 36 four-foot by eight-foot collectors in each row. The 20,000-gallon storage tank is located inside the building. Two 240-gallon-per-minute pumps are used in series to transfer the water from the tank to the collector, back to a sump, and then from the sump back into the tank. Pre-insulated four-inch copper pipe is buried five feet below-grade to transfer the water to and from the collector field. Two pumps, each with 125-gallon-per-minute capacity, are used to draw the heated water from the storage tank, pass it through the coils in the air-handling units, and then return the water to the storage tank. The only heat exchanger used in this system is the air-to-water coil in the air-handling unit.

Figure 12. Telex Communications System Flow Schematic

The simplicity of a draindown system was used to keep costs low and reliability high. However, the draindown concept in the Telex Communications case is somewhat more complicated than normally encountered. The storage tank is located at a higher elevation than the collectors. As a consequence, a sump was used to drain the collectors and a sump pump was used to transfer the water from the sump to the storage tank. Draining of the collector supply line occurs through an inverted U-tube through siphoning action. Motorized shut-off valves are used to open the U-tube and to shut the flow from the storage tank to the sump. If an air leak should develop at either of the motorized valves, the siphoning action would be precluded. In this case, the collector field will drain, but water would stand in the supply and return lines approximately 18 inches above-grade. A small bleed-line has been included in the design to permit draining of the vertical portions of the supply and return lines. This bleed-line is shown with a manually operated valve near the bottom of the sump in Figure 12. The valve is always open, so some water is bypassed directly into the sump even under normal operation. This bypass is the price one pays for a fail-safe design. The valves are selected so a power failure will result in a draining of the collectors. An engine-driven sump pump is used as a backup to the motorized pump in case of power failure. An overflow drain line is also provided in case both sump pumps fail.

The steel storage tank is phenolic-lined on the inside and covered with six inches of fiberglass on the outside.

The two pumps used to circulate water from the tank to the air-handling units are run simultaneously when heating demand is high. Only one pump is run if the demand is low. Pump operation is controlled by the position of the differential pressure valve shown in Figure 12. The solar system supplies water to the air-handling units down to 100°F.

7.2 KEY DESIGN TRADE-OFFS

The selection of a draindown system represents the most significant design decision. Draindown was selected for its simplicity, low cost, and reliability. With the draindown system, no antifreeze is needed. As a consequence, water treatment is simplified and there is no need for periodic replacement of the heat-transport medium. In addition, there is no need for a heat exchanger between the collector fluid and the storage medium. Problems of pressurization during stagnation conditions are also eliminated. Without draindown, a heat dissipator is required to prevent boiling, scaling, and high pressures in the collector. These problems could persist even with a heat dissipator should there be a power failure. Therefore, draindown, with its inherent reliability, was selected.

Although draindown systems have been built and operated for many years with both aluminum and steel in contact with the fluid, the more conservative route of using copper and silicone hoses was chosen. No steel surfaces will be alternately exposed to water and air during the draindown operation.

The single, water-white glass, black-chrome-coated collector was found to be most cost-effective. Other collectors of lower performance and lower price were considered, but the installed system cost was least for the selected collector.

The InterTechnology/Solar Corporation collector was also selected because it uses an internal manifold. The internal manifold saves approximately 3,000 feet of piping that would otherwise be required. A brief analysis will show the advantages of internal manifolding. For the Telex Communications system, two two-inch lines (on the average) would be required for each collector row. The cost of installed, insulated pipe, complete with contractor's overhead and profit, is approximately \$10 per inch of diameter per foot of length. As a consequence, the supply and return manifolds for the four-foot-side collectors would cost an average of \$160 per collector. This cost is equivalent to \$5.35 per active square foot of collector, or more than 10% of the installed system cost. Since the price of collectors with internal manifolds is approximately the same as that for collectors with external manifolds, the internal manifold is clearly cost-effective.

The disadvantages of the external manifold are increased when the heat losses from the manifolds are included. If two inches of fiberglass insulation are used, the manifolds in effect increase the loss coefficient from the collector by 0.034 BTU/hr-ft²-°F. The loss in efficiency is approximately 1.4% out of the average 44%. As a consequence, approximately three percent more collector area is required to obtain the same array performance. At \$20 per additional square foot, the heat loss from a collector with external manifolds results in an additional equivalent first cost of \$0.60 per net square foot of collector for the same array performance as obtained with internal manifolding.

The primary disadvantage of the internal manifold is the inherent flow imbalance that occurs even with a reverse return. To maintain proper flow balance, the pressure drop from inlet to outlet manifold within a collector should be approximately equal to the pressure drop from beginning to end of the inlet manifold along any row of collectors. The low pressure drop associated with the tubes of a typical collector usually results in a pressure drop through the collector being much less than the pressure drop along the manifold. To provide proper flow balance in the Telex Communications system, an internal distribution tube was placed within the supply and return manifolds. These inner tubes were sealed by silicone hoses so the flow was through the inside of the inner tube, through four 0.1-inch-diameter holes in the inner tube, through the annulus between the inner tube and manifold, and then through the collector tubes toward the outlet manifold. The 0.1-inch-diameter holes were sized to provide the desired pressure ratio and acceptable flow balance.

7.3 LESSONS LEARNED

The following paragraph is from a paper by Frederick A. Costello of InterTechnology Corporation on the Telex Communications solar system design.

"If ITC were to do the design of the Telex Communications system again, the basic decisions pertaining to draindown and internal manifolding would be repeated. The collector choice would also be the same. The primary, unnecessary expenses encountered in this design were due to: (1) the detailed responses to the questions arising in the Critical Design Review; and (2) the redesign necessary to bring the system cost within the budget. The redesigns centered on the location of the storage tank. Originally the storage tank was to be placed below-grade near the collector array. The cost of this arrangement exceeded the budget. The first redesign provided an above-grade tank near the array with a sump tank for draindown. This design required considerable complexity in the use of emergency power to prevent freezing under conditions of adverse weather and electrical power failure. The design finally chosen was the third design developed."

SECTION 8

CONSTRUCTION

8.1 DETAILS AND AS-BUILT CHANGES

The final drawings are presented in Appendix C. A number of details of these drawings reflect changes made during construction or shortly after.

- Sheet A-4:
(Figure C-4) The two-inch by six-inch wood braces on the back of the collectors were added in 1978 to prevent sagging.
- Sheet A-4:
(Figure C-4) The final drawings before construction show the supply pipe rising vertically to the bottom of the truss, rather than angling over. This was changed after the freeze-up.

Figure 13. Collector Supply Piping

- Sheets M-2 and M-3: The system was originally built with a vacuum breaker, an auto air vent, and a pressure relief valve at the outlet of each row. After the freeze-up in December 1978, the vacuum breakers, auto air vents, and pressure relief valves were removed and replaced by three-fourths-inch copper standpipes on each row, plus two-inch copper standpipes on Rows 1 and 10 only.

- Sheet M-2:
(Figure C-7) The collector supply pipe out of the storage tank, pump P-1, and valve V-1 were moved during construction from the location shown in the final design drawings.
- Sheet M-2:
(Figure C-7) The sump is shown on the final drawing as being 24 inches in diameter, but it is actually 36 inches.
- Sheet M-2:
(Figure C-7) The three-fourths-inch collector bypass line shown in the Flow Diagram was originally designed as a one-half-inch pipe.
- Sheet M-5:
(Figure C-10) The gasoline-powered (electric-start) emergency sump pump was originally designed as a battery-powered electric-motor drain pump.

8.2 CONSTRUCTION PHASE

Construction started on August 12, 1977 and was completed February 8, 1978. The project was organized as follows:

- Owner: Telex Communications, Inc.
- Solar Designer, Architect: InterTechnology/Solar Corporation
- Mechanical Engineer: InterTechnology/Solar Corporation
- General Contractor: Mankato Plumbing and Heating
- Subcontractors:
 - Electrical: Electric Service Co.
 - Pipe Insulation: General Pipe Covering
 - Controls: Johnson Controls, Inc.

8.3 COST

In the nine subsections that follow, cost information is provided for the following categories of the solar system:

- Collector Array
- Support Structure
- Piping
- Insulation
- Heating Equipment

- Storage
- Controls
- Electrical Power
- General Construction

In each subsection, descriptions of the category are presented along with the cost components. A tabular presentation of the cost data then follows. All cost data is rounded to the nearest five-dollar increment. The data sources used for each cost item and any unique aspects are discussed along with detailed information related to the basis for the costs. This includes the identification of costs that were either unavailable or impossible to separate from the other categories. The materials and labor columns refer to costs incurred by the general contractor.

8.3.1 Collector Array

The collector array category includes costs associated with the purchase, delivery, handling and mounting, and piping of the collectors. Costs associated with the materials and installation of the structural frame are included in the support structure category. For the Telex Communications project, the collector array was constructed approximately 200 feet from the Telex Communications building. This array consists of 10 rows with 36 collectors in each row, for a total collector aperture area of 10,700 square feet. See Table 6 for collector cost data.

Table 6. COLLECTOR ARRAY CATEGORY COSTS
TELEX COMMUNICATIONS

COMPONENT	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACT
Collectors	\$143,000	0	0	0
Delivery	N/A*	0	0	0
Handling & Mounting	0	0	\$3,045	0
Piping Connections	0	0	2,175	0
SUBTOTAL	\$143,000	0	\$5,220	0
COLLECTOR ARRAY CATEGORY TOTAL COST		\$148,220		

* N/A denotes not available. Delivery costs are included in "Collectors" cost.

- Collector Materials

- Data source - Records of Project Manager
- Cost components - 360 ITC liquid flat-plate collectors, including glazing, enclosures, insulation, and absorber plates. The delivery costs are included in the collector costs to Telex Communications.

- Collector Labor

- Data source - Records of general contractor
- Cost components - Labor required to unload collectors from trucks, mount on support structure, and connect collectors to each other and external piping. Pipefitters and carpenters, with hourly wages of \$11.55 and \$10.72 respectively, installed the collectors.

8.3.2 Support Structure

The support structure category consists of the structural members and subassemblies used to support the collectors. At Telex Communications, the collectors were secured to a frame of treated wood trusses supported on concrete piers. Since initial construction of the support structure, the trusses have sagged considerably and support braces have been added to stop further deformation. The Project Manager feels that angle iron would have been a better choice for the frame than wood. The trusses were prefabricated, pretreated, and delivered to the site by the supplier. See Table 7 for support structure cost data. Figure 13 is a photograph showing the collector support braces and truss.

Table 7 . SUPPORT STRUCTURE CATEGORY COSTS

TELEX COMMUNICATIONS

COMPONENT	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACT
Concrete Piers	0	\$15,345	\$15,605	0
Wood Trusses	0	19,565	5,585	0
SUBTOTAL	0	\$34,910	\$21,190	0
SUPPORT STRUCTURE CATEGORY TOTAL COST			\$56,100	

- Materials
 - Data source - Records of general contractor
 - Cost components - Concrete, reinforcing steel, wood trusses, support braces. The delivery cost for the trusses is included.
- Labor
 - Data source - Records of general contractor
 - Cost components - Excavation and framing for concrete piers, pouring of piers, handling and mounting of trusses on piers, application of support braces to trusses.

Figure 14. Collector Support Braces and Truss

8.3.3 Piping

The piping category includes piping, valves, pumps, and miscellaneous components used to transport the system fluids. All piping labor was performed by plumbers and pipefitters at an hourly rate of \$11.55. In addition, a portion of the system controls cost is

included in the piping valves and labor costs, since they include automatic valves and their installation. These costs could not be isolated from the other piping costs. See Table 8 for piping category costs.

Table 8. PIPING CATEGORY COSTS
TELEX COMMUNICATIONS

COMPONENT	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACT
<u>Exterior</u>				
Pipe & Fittings	0	\$15,760	0	0
Preinsulated Pipe	0	9,205	0	0
Valves	0	1,000	0	0
Balancing	0	0	\$ 1,390	0
Labor	0	0	28,850	0
<u>Interior</u>				
Pipe & Fittings	0	14,330	0	0
Valves*	0	3,155	0	0
Pumps	0	5,055	0	0
Balancing	0	0	1,740	0
Labor	0	0	27,685	0
SUBTOTAL	0	\$48,505	\$59,665	0
PIPING CATEGORY TOTAL COST		\$108,170		

* Includes automatic control valves and installation.

- Materials

- Data source - Records of general contractor
- Cost components - All pipes, fittings, valves, pumps, and miscellaneous hardware employed in the piping system.

- Labor

- Data source - Records of general contractor
- Cost components - Labor required for flow balancing and installation of pipes, fittings, valves, pumps, and other piping hardware, approximately 645 man-days.

8.3.4 Insulation

The insulation category includes all insulation used in the solar system except that used on the hot water storage tank. The major portion of this category is comprised of the interior and exterior piping insulation. All of the insulation work, including that for the storage tank, was performed by a subcontractor. Preinsulated pipe was used for the piping section under the parking lot between the collector array and the building. The cost of this pipe installation is included in the piping category. See Table 9 for insulation category cost data.

Table 9. INSULATION CATEGORY COSTS

TELEX COMMUNICATIONS

COMPONENT	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACT
Exterior Pipe Insulation	0	0	0	\$ 4,290
Interior Pipe Insulation	0	0	0	7,715
SUBTOTAL	0	0	0	\$12,005
INSULATION CATEGORY TOTAL COST		\$12,005		

- Insulation Subcontract

- Data source - Records of general contractor
- Cost components - All labor and materials required for the installation of the insulation, including fiberglass insulation, waterproofing, jacketing, etc. No further cost breakdown could be obtained for the insulation subsystem.

8.3.5 Heating Equipment

The heating equipment category for the Telex Communications solar energy system consists of the water-to-air heating coils used to deliver heat from the storage tank to the conditioned building areas. These coils were installed upstream of the auxiliary electric heating elements in the nine air-handling units and three unit heaters comprising the existing heating subsystem. This arrangement minimized the cost of modifying the distribution system for solar heat and also allows the use of water from storage at 80°F or lower. See Table 10 for heating equipment category cost data.

Table 10. HEATING EQUIPMENT CATEGORY COSTS

TELEX COMMUNICATIONS

COMPONENT	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACT
Heating Coils	0	\$5,370	\$3,075	0
SUBTOTAL	0	\$5,370	\$3,075	0
HEATING/COOLING EQUIPMENT CATEGORY TOTAL COST		\$8,445		

- Materials

- Data source - Records of general contractor
- Cost components - Twelve water-to-air heating coils and associated pipes and fittings

- Labor

- Data source - Records of general contractor
- Cost components - All labor required for the installation of the heating coils, approximately 33 man-days. All work was performed by pipefitters and sheet-metal workers with hourly wages of \$11.55 and \$11.63, respectively.

8.3.6 Storage

The storage category consists of the storage tank, supports, tank insulation, sight gauge, and miscellaneous equipment specifically related to the tank. The 20,000-gallon phenolic-lined steel tank is located on-grade in the mechanical room of the plant. The tank is insulated with six inches of fiberglass that was installed by a subcontractor after the tank was in place. See Table 11 for storage category cost data.

Table 11. STORAGE CATEGORY COSTS

TELEX COMMUNICATIONS

COMPONENT	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACT
Storage Tank	0	\$7,200	\$2,290	0
Tank Insulation	0	0	0	\$4,230
SUBTOTAL	0	\$7,200	\$2,290	\$4,230
STORAGE CATEGORY TOTAL COST		\$13,720		

- Materials

- Data source - Records of general contractor
- Cost components - Tank: 20,000-gallon capacity, 5/16-inch-thick hot-rolled steel, phenolic-lined, cylindrical. No further breakdown of the insulation cost could be obtained.

- Labor

- Data source - Records of general contractor
- Cost components - Unloading, transfer, and setting in place of the storage tank.

8.3.7 Controls

The controls category includes all equipment in the solar energy system installed for the purpose of automatically regulating system operation. The design and installation of the controls of the controls subsystem was performed by a subcontractor in accordance with the specifications of the solar system designer-engineer. However, the control valves were installed by the general contractor and this cost could not be separated from the other piping costs. See Table 12 for the controls category cost data.

Table 12. CONTROLS CATEGORY COSTS

TELEX COMMUNICATIONS

COMPONENT	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACT
Controls Subsystem	0	0	0	\$12,435*
SUBTOTAL	0	0	0	\$12,435
CONTROLS CATEGORY TOTAL COST		\$12,435		

* Automatic valve costs are included in Piping category.

- Controls Subcontract

- Data source - Records of general contractor
- Cost components - Installation and wiring of the collector loop pump, sump pump, heating distribution pumps, and control panel, and wiring of the control valves. No further breakdown of the controls subsystem cost could be obtained.

8.3.8 Electrical Power

The electrical power category includes all components, materials, and labor required to install the power distribution system for the electrical energy needs of the solar system. See Table 13 for the electrical power category cost data.

Table 13. ELECTRICAL POWER CATEGORY COSTS
TELEX COMMUNICATIONS

COMPONENT	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACT
Electrical Subcontract	0	0	0	\$7,370
SUBTOTAL	0	0	0	\$7,370
ELECTRICAL POWER CATEGORY TOTAL COST		\$7,370		

- Electrical Power Subcontract
 - Data source - Records of general contractor
 - Cost components - Labor and materials for power wiring of pumps and other system equipment.

8.3.9 General Construction

The general construction category includes all costs attributable to the solar energy system but not included in other categories. The only building space cost was for the construction of the sump pit, an unusual feature of the Telex Communications system. This pit is necessary for the draindown mode since the storage tank is not below the level of the collector array. Return water from the collectors drains into the pit and is then pumped into the storage tank.

A resin-type water softener was installed to treat the makeup water for the system. See Table 14 for the general construction category cost data.

Table 14. GENERAL CONSTRUCTION CATEGORY COSTS

TELEX COMMUNICATIONS

COMPONENT	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACT
Sump Pit	0	\$4,280	\$1,500	0
Water Softener	0	1,925	0	0
SUBTOTAL	0	\$6,205	\$1,500	0
GENERAL CONSTRUCTION CATEGORY TOTAL COST		\$7,705		

- Materials

- Data source - Records of general contractor
- Cost components - A resin-type water softener and all materials used in construction of the sump pit.

- Labor

- Data Source - Records of general contractor
- Cost components - All labor required for installation of the sump pit.

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SECTION 9
ACCEPTANCE TESTING

9.1 TEST PLAN

The test consisted of operating the system on a clear day and measuring the instantaneous efficiency of the collector array. The collector array efficiency was determined by measuring the total rise in storage temperature for one hour, with no water being circulated from the storage tank to the load. The data acquisition system was used to collect the data using the On-Site Monitor.

The data from the test was plotted as efficiency versus $(T_{in} - T_{amb})/I$. The functional relationship is:

$$\text{Efficiency} = F_R(\tau\alpha) - F_R(U_L) (T_{in} - T_{amb})/I.$$

A range of $F_R(\tau\alpha)$ and $F_R(U_L)$ values that were considered acceptable was prepared. This range is depicted in Figure 15.

Figure 15. Manufacturer's Acceptable $F_R(\tau\alpha)$ and $F_R(U_L)$ Range

9.2 TEST RESULTS

The acceptance test was conducted by the installation contractor, Mankato Plumbing and Heating, in June 1978. The experimentally determined values of $F_R(\tau\alpha)$ and $F_R(U_L)$ fell within the specified range, so the collector installation was considered acceptable. Only two hours of data were used in the acceptance test, one hour from June 9 and one hour from June 26, in 1978. The performance of the collector array during these two hours is plotted in Figure 16, on a standard collector efficiency plot. No line was drawn connecting the two points; rather, it was agreed that the two points agreed with the manufacturer's (ITC's) expected performance data (the line in Figure 16). The point marked in Figure 15 represents the manufacturer's $F_R(\tau\alpha)$ and $F_R(U_L)$ values. The actual test data is shown in Tables 15 and 16.

Figure 16. Collector Array Efficiency During Acceptance Test, June 9 and 26, 1978

The test data taken on the Telex Communications solar heating system appears to closely follow the expected performance data as submitted by InterTechnology Solar Corporation.

Table 15. JUNE 9, 1978 ACCEPTANCE TEST DATA

TELEX COMMUNICATIONS

	TIME	INLET TEMPERATURE (°F)	OUTLET TEMPERATURE (°F)	TEMPERATURE DIFFERENCE (ΔT) (°F)	AMBIENT TEMPERATURE (°F)	INSOLATION (BTU/ft ² -hr)	WIND (mph)
Data Used for Test	12:15	89	107	18	83	247	0.0
	12:25	91	109	18	83	238	2.1
	12:35	94	111	17	83	250	0.0
	12:45	96	114	18	83	256	2.0
	12:55	98	116	18	82	253	0.0
	1:05	100	118	18	84	260	0.0
	1:15	102	120	18	84	256	7.2
	1:25	105	123	18	84	266	0.7
	1:35	107	125	18	83	263	2.1

Inlet water average rate of change in °F/hr = 13°F

Average ΔT = 18°F

Average Ambient Temperature = 83°F

Average Insolation = 251.43 BTU/ft²-hr

Average Inlet Temperature = 96°F

$$\text{Efficiency} = \frac{\Delta T}{T} + \text{Correction Factor of } \frac{9.82 \times 18}{251.43} = 0.70 + 0.09 = 0.79$$

$$\text{Correction Factor} = \frac{\Delta T_{in}}{\Delta T} \times \frac{1}{T} \text{ or } \frac{13}{18} \times \frac{29.7}{251.43} = 0.09$$

$$x = \frac{(96-83)}{251.43} = 0.05$$

Table 16. JUNE 26, 1978 ACCEPTANCE TEST DATA

TELEX COMMUNICATIONS

TIME	INLET TEMPERATURE (°F)	OUTLET TEMPERATURE (°F)	TEMPERATURE DIFFERENCE (ΔT) (°F)	AMBIENT TEMPERATURE (°F)	INSOLATION (BTU/ft ² -hr)	WIND (mph)
1:00	153	*	*	*	247	"
1:10	156	*	*	*	250	16
1:20	158	*	*	*	247	"
1:30	159	*	*	88.9	250	"
1:40	161	*	*	*	253	"
1:50	162	*	*	88.3	250	14
2:00	163	*	*	*	247	"

Average Insolation = 249 BTU/ft²-hr

Average Ambient Temperature = 88.6°F

Total change in 20,000 gallons storage temperature = 8°F

Average Inlet Temperature = 159°F

20,000 × 8.33 × 8 = 1,332,800 BTU/hr

249 × 10,692 ft² = 2,662,308 BTU/hr Efficiency = 0.50

$$x = \frac{(159-89)}{249} = 0.28$$

* Denotes unavailable data.

The collector array efficiency in this test was determined by measuring the total rise in storage temperature for one hour, with no water being circulated through the inside building system. Therefore, all heat being finally collected was being retained in storage.

9.3 SYSTEM STARTUP PROBLEMS

Telex Communications listed the following system startup problems in a memo dated March 13, 1978.

A. Proposed additions that Telex Communications feels should be added to correct or improve the system.

1. The existing fresh air dampers do not close tightly enough and freezestats shut down the blowers twice. Cold air continues to enter the ducts after shutdown, which could freeze the water coils. Mankato Plumbing and Heating has given Telex Communications a bid of \$3,065 to install felt-tipped louvers and replace the ducts.
2. There is no protective device to prevent the collector pump from activating at night. ITC is to review this problem with a possible solution being the addition of a photo cell added to the pump circuit.
3. The wood trusses need strengthening to prevent sagging. Mankato Plumbing and Heating has given Telex Communications a bid of \$2,034 to correct this problem.
4. The present electrical heating system has a night thermostat mode that drops the heating temperature by 10°F. By adding a night mode to the solar system, its efficiency could be improved and its heating time extended. Mankato Plumbing and Heating is to review this addition and give Telex Communications a quote.
5. Telex Communications thinks a water meter should be added to the water softener line. This meter would make it possible to monitor the makeup water and manually recharge the softener, rather than letting the softener recharge at the present six-day cycle. The amount of makeup water thus far has been very low, and recharging the softener only as needed would save on softener salt. Mankato Plumbing and Heating is to give Telex Communications a quote.

B. Items that are the responsibility of ITC

1. At present there are 35-PSI pressure relief valves on each collector row. The rubber connecting hoses will not withstand this amount of pressure, so ITC is to review this problem and give Telex Communications a recommendation. ITC has recommended a change to 15-PSI valves already, but this may be too high yet. Possible standpipes will be reviewed by ITC.

2. Sealing of the collector backs and access plates. ITC has been working on a solution since October of 1977 with no recommendation as yet.
 3. The collector connecting hoses are leaking. ITC to review this problem.
 4. Draindown time is over one-half hour. ITC is to review this and report what conditions would have to be for any damage to occur.
 5. Operating Manual. ITC will have a manual ready one month after all shop material has been supplied by Mankato Plumbing and Heating.
 6. Telex Communications has been experiencing collector shutdown at the height tank temperatures. Johnson Controls installed the collector sensor in the wrong location, with proper location possibly correcting this problem. If this problem continues, Telex Communications will notify ITC for review of a possible fix using a variable controlled valve on the supply line.
- C. Items that are the responsibility of Mankato Plumbing and Heating
1. The high-low water level alarm has not been hooked up to anything. Telex Communications will decide if it is to be hooked up to a telephone line or an audible device installed.
 2. The outside wiring of the heat tapes is temporary and has to be put in the conduit.
 3. An opening is needed to put chemicals into the system. Mankato Plumbing and Heating will install an opening in the sump and a test spigot at the softener.
 4. The tank insulation is not per the specifications. Mankato Plumbing and Heating is to justify the substitution.
 5. The heating pump pressure differential board has not been installed by Johnson Controls as yet. Mankato Plumbing and Heating is to follow-up and expedite.
 6. Sealing of the construction joint on each column remains.
 7. Outside cleanup and dirt leveling under the collectors remain.
 8. Outside painting of the steel remains.

9. The automatic valve (V-1) is leaking, causing the sump to cycle. Mankato Plumbing and Heating is to adjust, repair, or replace.
10. Collector row number six dips, causing a possible low spot. Mankato Plumbing and Heating to review.
11. The collector temperature sensor is located wrong. Mankato Plumbing and Heating is to have the sensor moved to the correct location.
12. The piping is to be marked for type and direction of flow by Mankato Plumbing and Heating.

SECTION 10

SYSTEM THERMAL PERFORMANCE

10.1 SOLAR SYSTEM

After the freeze-up in December 1978, seven of the 10 collector rows were operational. Full operation was restored in the summer of 1979; this section will report in detail the solar system performance in the 1979-1980 and 1980-1981 heating seasons. Data collection closed on August 31, 1981.

The performance of the Telex Communications solar system in the 1979-1980 and 1980-1981 heating seasons is summarized in Tables 17 and 18, respectively. The solar fraction of the heating load was 74% in the 1979-1980 heating season and 59% in the 1980-1981 heating season. The solar fraction in 1980-1981 would have been higher with March included, but the data system was down all of March. The solar fraction for the two seasons combined was 66%, very close to the design solar fraction of 70%. The ITC simulation solar fraction of 79% was based on a collector area of 13,908 square feet; the system was built with 11,520 square feet of collector area.

Table 17. SOLAR SYSTEM THERMAL PERFORMANCE

TELEX COMMUNICATIONS 1979-1980 HEATING SEASON

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED		AUXILIARY ENERGY ELECTRICAL	SOLAR OPERATING ENERGY	TOTAL OPERATING ENERGY	ENERGY SAVINGS ELECTRICAL	SOLAR FRACTION (%)	
			PREDICTED ¹	MEASURED					PREDICTED ¹	MEASURED
NOV	74.5	85.6	64.5	77.7	0.19	7.18	8.97	70.6	82	91
DEC	108	122	77.3	103	2.98	13.2	20.0	89.4	47	84
JAN	80.9	144	72.8	69.6	55.0	13.0	22.0	56.6	29	48
FEB	112	154	112	102	37.5	12.3	17.6	89.6	64	66
MAR	143	153	118	125	12.1	13.4	19.7	112	85	82
APR	70.6	61.3	43.2	53.7	0.95	7.53	9.17	46.1	100	88
TOTAL	587	720	488	531	109	66.6	97.3	464	-	-
AVERAGE	97.8	120	81.3	88.4	18.2	11.1	16.2	77.3	64	74

¹ Predicted performance was determined from a modified f-Chart computer simulation using measured weather, measured subsystem loads, and computed loads as input.

Table 18. SOLAR SYSTEM THERMAL PERFORMANCE

TELEX COMMUNICATIONS
1980-1981 HEATING SEASON

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED	AUXILIARY ENERGY ELECTRICAL	TOTAL OPERATING ENERGY	ENERGY SAVINGS ELECTRICAL	SOLAR FRACTION (%)
OCT	37.0	33.8	32.8	0.01	2.12	31.1	97
NOV	111	127	118	0.40	10.4	110	93
DEC	56.3	147	58.2	72.1	19.5	46.3	40
JAN	152	259	148	95.9	18.7	136	57
FEB	109	233	109	113	15.2	96.3	47
MAR	*	*	*	*	*	*	*
APR	6.50	13.8	13.3	0.10	1.34	11.9	50
TOTAL	471	813	479	281	67.2	432	-
AVERAGE	78.5	133	79.0	46.9	11.2	71.0	59

* Denotes unavailable data.

Collector performance was invariably good; perhaps the pump could have started earlier in the day, but the overall efficiency was one of the best of the NSDN systems.

The solar space heating distribution system also worked well, transferring the collected energy to the load with continuously running pumps. Over the two heating seasons, there were 4,720 million BTU of solar energy incident on the collectors, and 1,009 million BTU, or 21% of the incident energy, went to the loads. For the months of December through February, this fraction was 28% over the two seasons. The main factor limiting the efficiency of the system was the collector control operation. Over the two seasons, only 51% of the incident solar energy fell while the collector pump was running, and even in December through February this figure was only 66% compared to about 80% at most NSDN solar systems.

The flow of energy through the Telex Communications solar system for the period November 1979 through April 1980, and October 1980 through April 1981 (except March 1981) is presented in Figure 17. This Energy Flow Diagram shows the amount of energy collected, transported, stored, consumed, or lost at each point in the system. The number for energy out of storage (916 million BTU) was calculated from storage energy in and tank losses calculated with an empirical storage tank UA. The measured energy out of storage was too large, implying negative tank losses. All the space heating operating energy, and the motor losses from the collector pumps, are assumed to contribute to the space heating load. The losses from the indoor storage tank also contribute to the space heating load. Collector-to-storage piping losses do not contribute to the space heating load; they are warming the soil beneath the parking lot.

* Six million BTU motor losses contributed to space heating load.

Figure 17. Energy Flow Diagram for Telex Communications
1979-1981
(All figures in million BTU)

10.2 PREDICTED VERSUS ACTUAL

A TRNSYS simulation of the Telex Communications solar system was performed by IBM in January 1977. This simulation was the most detailed prediction of the thermal performance that was made, but it modeled the ITC design at that time, which was not the same as the final design. The system that was modeled had a collector area of 13,908 square feet; the system was built with 11,520 square feet of collectors, 17% less area. The modeled storage tank was underground, with a volume of 29,796 gallons, filled with 23,000 gallons of water. The actual tank, inside the building, has a capacity of 20,000 gallons, filled with 18,000 gallons of water. This simulation, which predicted a solar fraction of 90%, was run with no minimum tank temperature. As this model did not reflect the actual as-built system, no further discussion will be presented, but IBM's analysis is included in Appendix E.

The as-built system was modeled using f-Chart Version 5.3. The manufacturer's collector performance parameters, together with measured loads, temperatures, and insolation data were used in this model. The f-Chart model predicted a solar fraction of 64% for the 1979-1980 season; the measured solar fraction was better, 74%.

The building load calculated by the UAC_d method (ASHRAE 1980 Systems, Page 43.8) is presented in Tables 19, 20, and 21 for the 1978-1979, 1979-1980, and 1980-1981 heating seasons, respectively. The agreement between the calculated and measured values is very good for the period December 1978 through March 1979. In this period, very little solar energy was used because of the collector freeze-up in early December 1978. The measured values represent mostly electrical resistance energy, so they should be accurate. This implies that the design UAC_d value of 7,300 BTU/hr-°F is a good value. In the heating season of 1979-1980, the measured values are consistently lower than the design values. In the 1980-1981 winter, the agreement is again good, except for the month of December. This is hard to understand, especially because total electrical usage was actually less in December 1980 than in November 1980. As there was only one indoor temperature sensor in the 97,000-square-foot building, it may be that the building was just a bit cooler in December than in the other months.

Table 19. BUILDING LOAD CALCULATED BY THE UAC_d METHOD

TELEX COMMUNICATIONS
1978-1979 HEATING SEASON

MONTH	BUILDING TEMPERATURE (°F)	AMBIENT TEMPERATURE (°F)	HEATING DEGREE-DAYS (65°F REF)	UA x Cd VALUE (BTU/hr-°F)	DESIGN HEAT LOAD (BTU x 10 ⁶)	MEASURED LOAD (BTU x 10 ⁶)
NOV	74	30	1,050	7,300	184	108
DEC	72	13	1,612	7,300	282	282
JAN	70	0	2,015	7,300	353	351
FEB	70	7	1,624	7,300	285	281
MAR	73	26	1,209	7,300	212	211
TOTAL	-	-	7,510		1,320	1,230
AVERAGE	72	15	1,502	7,300	263	247

Table 20. BUILDING LOAD CALCULATED BY THE UAC_d METHOD

TELEX COMMUNICATIONS
1979-1980 HEATING SEASON

MONTH	BUILDING TEMPERATURE (°F)	AMBIENT TEMPERATURE (°F)	HEATING DEGREE-DAYS (65°F REF)	UA x Cd VALUE (BTU/hr-°F)	DESIGN HEAT LOAD (BTU x 10 ⁶)	MEASURED LOAD (BTU x 10 ⁶)
NOV	71	32	992	7,300	174	85.6
DEC	69	26	1,219	7,300	214	122
JAN	69	16	1,505	7,300	264	144
FEB	68	16	1,427	7,300	250	154
MAR	69	28	1,138	7,300	199	153
APR	73	48	531	7,300	93.0	61.3
TOTAL	-	-	6,812	-	1,193	720
AVERAGE	70	28	1,135	7,300	199	120

Table 21. BUILDING LOAD CALCULATED BY THE UAC_d METHOD

TELEX COMMUNICATIONS
1980-1981 HEATING SEASON

MONTH	BUILDING TEMPERATURE (°F)	AMBIENT TEMPERATURE (°F)	HEATING DEGREE-DAYS (65°F REF)	UA x Cd VALUE (BTU/hr-°F)	DESIGN HEAT LOAD (BTU x 106)	MEASURED LOAD (BTU x 106)
OCT	74	49	485	7,300	85.0	33.8
NOV	73	38	735	7,300	129	127
DEC	66	20	1,391	7,300	244	147
JAN	68	19	1,428	7,300	250	259
FEB	69	21	1,167	7,300	204	233
MAR	*	*	*	*	*	*
APR	73	50	441	7,300	77.3	13.8
TOTAL	-	-	5,647	-	989	813
AVERAGE	71	30	941	7,300	165	136

* Denotes unavailable data.

10.3 SOLAR SUBSYSTEM

10.3.1 Collection

The Telex Communications collector array has 360 panels in ten rows sloped at 58.5 degrees, with a total area of 11,520 square feet. There is a 3/4-inch collector bypass which will drain the vertical portion of the collector-to-storage piping in the event of an air leak in the motorized valves. The flow out of the storage tank is usually 240 gallons per minute. The flow through the collector is less by the amount of bypass flow, which was measured in the spring of 1981 at 26 gallons per minute.

Collection subsystem performance is presented in Tables 22 and 23. Over the two heating seasons, the average collector efficiency was 22%, and the average operational collector efficiency was 44%. To better explain the performance of the collector subsystem, the operation of the collectors on a clear day (January 29, 1981) is presented in Figure 18.

Table 22. COLLECTION SUBSYSTEM PERFORMANCE

TELEX COMMUNICATIONS
1979-1980 HEATING SEASON

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	OPERATIONAL COLLECTOR EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
NOV	320	74.5	23	176	42	1.48	62.9	35
DEC	308	106	34	229	46	3.98	99.6	30
JAN	266	80.9	30	157	52	3.28	80.0	19
FEB	408	112	27	257	44	3.89	102	20
MAR	455	143	31	293	49	4.34	128	32
APR	511	70.6	14	159	44	2.93	59.2	54
TOTAL	2,270	587	-	1,270	-	19.9	531	-
AVERAGE	378	97.8	26	212	46	3.32	88.6	32

Table 23. COLLECTION SUBSYSTEM PERFORMANCE

TELEX COMMUNICATIONS
1980-1981 HEATING SEASON

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	OPERATIONAL COLLECTOR EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
OCT	493	37.0	8	131	28	0.97	35.2	68
NOV	453	111	24	274	41	1.33	105	53
DEC	224	56.3	25	135	42	2.30	55.2	46
JAN	473	152	32	334	45	3.28	152	25
FEB	404	109	27	247	44	4.56	109	25
MAR	*	*	*	*	*	*	*	*
APR	406	6.50	2	*	*	1.19	6.05	57
TOTAL	2,450	471	-	1,120	-	13.6	462	-
AVERAGE	409	78.5	19	224	41	2.27	77.0	46

* Denotes unavailable data.

Figure 18. Plot of Collector Performance, and Absorber Plate, Collector Outlet and Inlet, and Outdoor Temperatures
Telex Communications
January 29, 1981

It was a clear day, with measured insolation first occurring at 7:46 a.m., peaking at 309 BTU/ft²-hr at 12:02 p.m., and dropping back to zero at 5:23 p.m. The total insolation for the day was 1,971 BTU/ft². Solar radiation on the collectors was enhanced by a light snow cover on the ground. The weather was seasonably cold, with an overnight low temperature of -3°F at 7:00 a.m., and a high temperature of 21°F at 3:30 p.m. Winds were lighter than usual, averaging three mph for the day, usually running about seven to 12 mph during the period of collector operation. The collector pump first turned on at 9:38 a.m., when insolation was 206 BTU/ft²-hr. The collector plate temperature was 188°F, and the storage tank temperature was 75°F. The pump could have started earlier, say at 8:56 a.m., with insolation of 145 BTU/ft²-hr and a collector absorber plate temperature of 100°F. At 9:54 a.m., operation had settled down, and, with insolation of 222 BTU/ft²-hr, the collector array inlet temperature was 76°F, and the outlet temperature was 88°F. The flow through the collector array was 220 gallons per minute. The collector efficiency was 52% at this time, with a collector operating point of 0.29. At 12:02 p.m., the peak insolation time, the collector inlet temperature was 97°F, the outlet temperature was 115°F, with a flow rate of 218 gpm. This is a collection rate of 1,880,000 BTU/hr, with insolation of 3,560,000 BTU/hr, or 53% efficiency. The collector outlet temperature peaked at 134°F

at 2:30 p.m. The collector pumps ran steadily until 3:05 p.m., when they cycled off for a couple of minutes, even though insolation was high (210 BTU/ft²-hr) and uninterrupted by clouds. When the pump shut off, the absorber plate temperature was 134°F, and the storage temperature was 126°F. These sensors are not in the same location as the control sensors. The system cycled on and off twice between 3:05 p.m. and 3:20 p.m., and twice more after 3:30 p.m. before shutting down for the day at 3:45 p.m. At this final shutdown time, the absorber temperature was 133°F, then it rose to 165°F at 3:51 p.m. with the pump off. There was still a 7°F rise across the collector array when the pump shut down at 3:45 p.m., with insolation of 168 BTU/ft²-hr. The storage tank temperature was 129°F at shutdown, a rise of 54°F for the day. The operating point at shutdown was 0.65. At this operating point, the collector efficiency should be about 25%, so it was about time for the collectors to shut down. For the day, total collection was 9.12 million BTU, out of 22.7 million BTU incident energy, and 17.7 million BTU incident during collector operation. The overall efficiency was 40%, and the operational efficiency was 52%.

Although the pump could have started 40 minutes earlier, this is very fine performance, and the low ratio of operational incident to total incident energy that shows up in monthly totals is not much in evidence on this day. This problem shows up more on partly cloudy days such as January 23, 1981, discussed in Section 11.2.1.

The operation of the collector array can be seen in Figure 19, a collector efficiency plot for January 1981. The line on the graph is plotted from the manufacturer's ASHRAE test parameter. The measured data falls right on the line, a very good performance for a large array, where the flow must be perfectly balanced in order to achieve design performance.

The flow through the collector array was just about equal to the "rule-of-thumb" value of 230 gpm, or 0.02 gpm per square foot of collector.

Figure 19. Average Collector Efficiency
 Telex Communications
 January 1981

10.3.2 Storage

Thermal storage for the solar system is provided by a 20,000-gallon steel water storage tank inside the building. The tank is nine feet in diameter and 42 feet long, insulated with six inches of fiberglass. Storage performance for the two heating seasons, 1979-1980 and 1980-1981 is presented in Tables 24 and 25. The measured energy out of storage was regularly greater than the measured energy into storage. The measured energy into storage is generally in good agreement with the collected solar energy measurement, but there is no check (other than design heating load - a very rough check) on the measured energy out of storage. The temperature difference between the load supply and return is small, only about 3°F. The accuracy in the sensors is $\pm 0.5^\circ\text{F}$, so the energy out of storage is not a very accurate measurement.

The energy from storage, energy loss, and storage efficiency reported here are calculated values. The values shown were calculated by assuming that the energy into storage (STEI) and the change in stored energy (STECH) were correct, and that storage losses were known. Then the energy out of storage (STEO) = STEI - STECH - STLOSS.

Table 24. STORAGE SUBSYSTEM PERFORMANCE

TELEX COMMUNICATIONS
1979-1980 HEATING SEASON

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE (CALCULATED)	ENERGY FROM STORAGE (MEASURED)	CHANGE IN STORED ENERGY	STORAGE ¹ EFFICIENCY (%)	AVERAGE STORAGE TEMPERATURE (°F)	LOSS FROM STORAGE (CALCULATED FROM EMPIRICAL UA)
NOV	62.9	68.7	73.0	-14.9	86	135	9.09
DEC	99.6	97.8	117	-3.04	95	98	4.89
JAN	80.0	66.7	82.2	10.4	96	82	2.83
FEB	102	94.4	105	0.21	93	122	7.46
MAR	128	118	133	2.42	94	118	7.46
APR	59.2	42.2	45.5	5.56	81	158	11.5
TOTAL	531	487	556	0.71	-	-	43.2
AVERAGE	88.6	81.2	92.6	0.12	92	119	7.20

¹ Based on calculated energy from storage.

Table 25. STORAGE SUBSYSTEM PERFORMANCE

TELEX COMMUNICATIONS
1980-1981 HEATING SEASON

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMPERATURE (°F)	EFFECTIVE HEAT LOSS COEFFICIENT (BTU/hr-°F)	LOSS FROM STORAGE
OCT	35.2	19.4	2.41	62	170	0.13	13.4
NOV	105	107	-12.5	90	152	0.13	10.8
DEC	55.2	55.0	-3.01	94	86	0.10	3.21
JAN	152	141	3.48	97	116	0.06	7.03
FEB	109	102	-0.15	94	123	0.14	7.02
MAR	*	*	7.52	*	*	*	*
APR	6.05	4.59	-7.22	-44	136	0.12	8.68
TOTAL	462	429	-9.47	-	-	-	50.1
AVERAGE	77.0	71.5	-1.35	91	131	0.12	8.35

* Denotes unavailable data.

The storage losses, STLOSS, were calculated from the measured temperature decay after April 19, 1980, when no energy was put into or taken out of the tank. The storage temperature was 185°F on April 19, 1980, and slowly declined over a period of months. (On May 31, 1980, storage temperature was 116°F.) The temperature of storage should decline exponentially, according to:

$$e^{(-A \times \text{Time}) / R \times C_p \times \text{Mass}}$$

where: A = Area of tank = 1,314 square feet

R = R-value of insulation

C_p = Specific heat of water = 1

Mass = Mass of water in storage = 20,000 x 8.335 =
166,700 lbs.

An R-value of 7.6 gave the best fit to the decay curve. This value is considerably lower than the R-value of 20 which should nominally be available from six inches of fiberglass.

Using the R-value of 7.6, the storage loss was calculated from:

$$\text{STLOSS} = A \times (\text{TST} - \text{TB}) / R$$

where: TST = Measured storage temperature

TB = Temperature of building. (The temperature of the storage tank room is 5°F to 10°F cooler than the temperature measured during the winter.)

The energy from storage was then calculated from this empirical storage loss, and the measured values of the solar energy entering into and departing from the storage tank.

The plot of storage temperatures for January 29, 1981, Figure 20, shows that there was little stratification in the tank. The load pump runs throughout the heating system, keeping the tank well mixed.

Figure 20. Plot of Storage Temperatures
Telex Communications
January 29, 1981

10.3.3 Heating

The space heating performance for the Telex Communications solar system is presented in Table 26 for the 1979-1980 heating season, and in Tables 27a and 27b for the 1980-1981 heating season. The performance is consistent in the amount of solar energy used from season to season, and the solar fraction is about equal to the design value (and better than the f-Chart prediction). The solar fraction undoubtedly would have been higher in the second season if March were included, but the data collection system was not functioning during March 1981.

The value of solar energy used for space heating is actually the amount of solar energy that goes into the storage tank from the collectors plus (minus) depletion of (addition to) stored energy. Once in the tank, all the energy will heat the building. As explained in the storage performance section (10.3.2), the measured energy going to the space heating load was larger than the energy into storage, so there is no reason to suspect large pipe losses in the space heating distribution system. The plot of heating load and storage temperatures (Figure 20) shows the small temperature difference between the load supply and return. The supply temperature is equal to the well-mixed storage tank temperature, with the return 3°F or 4°F lower. Note the sharp drop in the return temperature at 5:00 a.m. when the heat is turned up. The solar energy appears to be utilized well at storage temperatures as low as 76°F.

Table 26. SPACE HEATING SUBSYSTEM PERFORMANCE

TELEX COMMUNICATIONS
1979-1980 HEATING SEASON

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	ENERGY CONSUMED				TOTAL OPERATING ENERGY	SOLAR FRACTION (%)	BUILDING TEMPERATURE (°F)
		SOLAR	AUXILIARY THERMAL	AUXILIARY ELECTRICAL	SOLAR OPERATING ENERGY			
NOV	85.6	77.7	0.19	0.19	5.70	7.49	91	71
DEC	122	103	2.98	2.98	9.25	16.0	84	69
JAN	144	69.6	55.0	55.0	9.73	18.7	48	69
FEB	154	102	37.5	37.5	8.38	13.7	66	68
MAR	133	125	11.1	12.1	9.08	15.3	82	69
APR	61.3	53.7	0.95	0.95	4.60	6.24	88	73
TOTAL	770	511	109	109	46.7	77.6		
AVERAGE	120	88.8	18.1	18.1	7.79	12.9	74	70

Table 27a. SPACE HEATING SUBSYSTEM PERFORMANCE

TELEX COMMUNICATIONS
1980-1981 HEATING SEASON

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	CONTROLLED DELIVERED ENERGY	TOTAL SOLAR ENERGY USED	TOTAL AUXILIARY THERMAL USED	SOLAR FRACTION OF LOAD (%)	BUILDING TEMPERATURE (°F)	AMBIENT TEMPERATURE (°F)
OCT	33.8	19.4	32.8	0.01	97	74	49
NOV	127	107	118	0.40	93	73	38
DEC	147	127	90.2	73.1	40	66	20
JAN	259	239	148	95.9	57	68	19
FEB	233	214	109	113	47	69	21
MAR	*	*	*	*	*	*	*
APR	13.8	4.75	13.3	0.16	96	73	50
TOTAL	813	712	479	281	-	-	-
AVERAGE	135	119	79.8	46.9	59	71	30

* Denotes unavailable data.

Table 27b. SPACE HEATING SUBSYSTEM PERFORMANCE

TELEX COMMUNICATIONS
1980-1981 HEATING SEASON
(Continued)

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	MEASURED SOLAR ENERGY USED	SOLAR ENERGY LOSSES TO LOAD	TOTAL OPERATING ENERGY	SOLAR SPECIFIC OPERATING ENERGY	AUXILIARY ELECTRICAL FUEL	HEATING DEGREE DAYS
OCT	33.8	19.4	13.4	0.79	0.72	0.01	485
NOV	127	107	10.8	8.08	6.27	0.40	735
DEC	147	55.0	3.21	16.2	9.55	72.1	1,391
JAN	259	141	7.03	14.1	9.24	95.9	1,425
FEB	233	102	7.02	11.3	7.80	113	1,167
MAR	*	*	*	*	*	*	*
APR	13.8	4.59	8.68	0.15	0.15	0.16	441
TOTAL	813	429	50.1	50.6	33.7	281	5,644
AVERAGE	135	71.5	8.35	8.44	5.62	46.9	941

* Denotes unavailable data.

10.3.4 Parasitics

Measured values of the Telex Communications operating energy for the 1979-1980 and 1980-1981 heating seasons are presented in Tables 28 and 29. The solar system used 66.6 million BTU of operating energy in the period November 1979 through April 1980, and 47.4 million BTU in the period October 1980 through February 1981, plus April 1981.

The components which use operating energy are:

Collector Pump (7.5-hp Bell & Gossett centrifugal pump)	}	6.7 kw
Sump Pump (2-hp Aurora sump pump)		
Heating Load Pump (5-hp Bell & Gossett centrifugal pump)		3.7 kw
Distribution Blowers in Air-Handler Units 5, 6, and 7		5.4 kw each
Solar Heater with 5-kw blower		

The three pairs of air handler units known as 1-2, 3-4, and 8-9 run year-round for ventilation, so they are not included. They are each 10.8 kw.

Table 28. SOLAR OPERATING ENERGY

TELEX COMMUNICATIONS
1979-1980 HEATING SEASON

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR-UNIQUE)	SHS OPERATING ENERGY (SOLAR)	TOTAL SOLAR OPERATING ENERGY
NOV	1.48	5.70	7.18
DEC	3.98	9.25	13.2
JAN	3.28	9.73	13.0
FEB	3.89	8.38	12.3
MAR	4.34	9.08	13.4
APR	2.93	4.60	7.53
TOTAL	19.9	46.7	66.6
AVERAGE	3.32	7.79	11.1

Table 29. SOLAR OPERATING ENERGY

TELEX COMMUNICATIONS
1980-1981 HEATING SEASON

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR-UNIQUE)	SHS OPERATING ENERGY (SOLAR)	TOTAL SOLAR OPERATING ENERGY
OCT	0.97	0.72	1.69
NOV	1.33	6.27	7.60
DEC	2.30	9.55	11.9
JAN	3.28	9.24	12.5
FEB	4.56	7.80	12.4
MAR	*	*	*
APR	1.19	0.15	1.34
TOTAL	13.6	33.7	47.4
AVERAGE	2.27	5.62	7.89

* Denotes unavailable data.

The solar energy Coefficient of Performance (COP) is presented in Tables 30 and 31. The COP provides a numerical value for the relationship of solar energy used or collected and the energy required to deliver or collect it (higher COP equals greater efficiency). The solar COP for the two heating seasons combined was 8.86. The collection subsystem COP was high in both Novembers because the collector pump was throttled down, pumping at a reduced flow rate and consuming less power per hour of collection.

Table 30. COEFFICIENT OF PERFORMANCE

TELEX COMMUNICATIONS
1979-1980 HEATING SEASON

MONTH	SOLAR ENERGY SYSTEM	COLLECTION SUBSYSTEM	SPACE HEATING SOLAR
NOV	10.8	54.6	13.6
DEC	7.76	29.8	11.1
JAN	5.35	26.8	7.15
FEB	8.30	31.2	12.2
MAR	9.32	35.7	13.8
APR	7.12	26.1	11.7
WEIGHTED AVERAGE	7.96	32.2	11.4

Table 31. COEFFICIENT OF PERFORMANCE

TELEX COMMUNICATIONS
1980-1981 HEATING SEASON

MONTH	SOLAR ENERGY SYSTEM	COLLECTION SUBSYSTEM	SPACE HEATING SOLAR
OCT	19.4	38.2	26.9
NOV	15.5	83.4	17.1
DEC	4.9	24.5	5.8
JAN	11.8	46.3	15.3
FEB	8.8	23.8	13.0
MAR	*	*	*
APR	9.9	5.5	30.6
WEIGHTED AVERAGE	10.1	34.6	12.7

* Denotes unavailable data.

10.4 ENERGY SAVINGS

Energy savings for the Telex Communications solar system are presented in Tables 32 and 33. The total for the two heating seasons was 895 million BTU. Additional savings were realized, but not measured because of data system problems in October 1979 and March 1981. If values for October 1980 and March 1980, respectively, are substituted, the projected savings would be 1,040 million BTU, or 519 million BTU/season. This is equivalent to 152,100 kwh of electricity saved per season. This is equivalent to \$7,605 saved at the 1980 rate of \$0.05 per kwh. Built in 1977 at a cost of \$460,000, the solar system will not pay for itself quickly.

Table 32. ENERGY SAVINGS
TELEX COMMUNICATIONS
1979-1980 HEATING SEASON
(All values in million BTU)

MONTH	SOLAR ENERGY USED	SPACE HEATING ELECTRICAL	ECSS OPERATING ENERGY	NET ENERGY SAVINGS ELECTRICAL
NOV	77.7	72.0	1.48	70.6
DEC	103	93.4	3.98	89.4
JAN	69.6	59.8	3.28	56.6
FEB	102	93.5	3.89	89.6
MAR	125	116	4.34	112
APR	53.7	49.1	2.93	46.1
TOTAL	531	484	19.9	464
AVERAGE	88.4	80.7	3.32	77.3

Table 33. ENERGY SAVINGS
TELEX COMMUNICATIONS
1980-1981 HEATING SEASON
(All values in million BTU)

MONTH	SOLAR ENERGY USED	SPACE HEATING ELECTRICAL	ECSS OPERATING ENERGY	NET ENERGY SAVINGS ELECTRICAL
OCT	32.8	32.1	0.97	31.1
NOV	118	111	1.33	110
DEC	58.2	48.6	2.30	46.3
JAN	148	139	3.28	136
FEB	109	101	4.56	96.3
MAR	*	*	*	*
APR	13.3	13.1	1.19	11.9
TOTAL	479	445	13.6	431
AVERAGE	79.8	74.2	2.27	71.9

* Denotes unavailable data.

10.5 ENVIRONMENTAL CONDITIONS

Weather conditions for the winters of 1978-1979, 1979-1980, and 1980-1981 are presented in Tables 34, 35, and 36. The insolation values are measured in the plane of the collector, which faces due south with a tilt of 58.5 degrees. The long-term insolation values are modeled to represent insolation on a tilted surface by a TRNSYS-type radiation processor, from SOLMET long-term horizontal values. Long-term temperatures and horizontal insolation values are based on the historical record for Rochester, Minnesota, which is about 75 miles east and 25 miles north of Blue Earth. Insolation was close to, but somewhat above, the long-term average in all three seasons. One would expect the insolation values in the winter to be higher than the long-term average, due to reflection from the persistent snow cover, which would have more effect on our measurements at a 58.5 degree tilt than on the long-term horizontal values. The long-term program uses a 20% enhancement for ground reflection. The winter of 1978-1979 was especially bitter, with far below normal temperatures. Both 1979-1980 and 1980-1981 were warmer than the long-term average.

Table 34. WEATHER CONDITIONS

TELEX COMMUNICATIONS 1978-1979 HEATING SEASON

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT ² -DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		WIND SPEED (MPH) MEASURED
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	
OCT	1,201	1,289	48	50	527	485	*
NOV	766	889	30	33	1,050	972	7
DEC	945	734	13	19	1,612	1,429	8
JAN	1,159	938	0	13	2,015	1,615	8
FEB	1,562	1,207	7	17	1,624	1,347	7
MAR	1,084	1,331	26	28	1,209	1,153	10
TOTAL	-	-	-	-	8,037	7,001	-
AVERAGE	1,120	1,065	21	27	1,340	1,167	8

* Denotes unavailable data.

Table 35. WEATHER CONDITIONS

TELEX COMMUNICATIONS
1979-1980 HEATING SEASON

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT ² -DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		WIND SPEED (MPH) MEASURED
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	
NOV	927	899	32	33	992	972	8
DEC	848	734	26	19	1,219	1,429	7
JAN	746	938	16	13	1,505	1,615	9
FEB	1,223	1,207	16	17	1,427	1,347	7
MAR	1,275	1,331	28	28	1,138	1,153	9
APR	1,478	1,335	48	45	531	615	8
TOTAL	-	-	-	-	6,812	7,131	-
AVERAGE	1,083	1,072	28	26	1,135	1,189	8

Table 36. WEATHER CONDITIONS

TELEX COMMUNICATIONS
1980-1981 HEATING SEASON

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT ² -DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		WIND SPEED MEASURED (MPH)
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	
OCT	1,380	1,289	49	50	485	485	7
NOV	1,311	889	40	33	735	972	5
DEC	627	734	20	19	1,391	1,429	7
JAN	1,325	938	19	13	1,425	1,615	7
FEB	1,252	1,207	21	17	1,167	1,347	10
MAR	*	*	*	*	*	*	*
APR	1,175	1,335	50	45	441	615	9
TOTAL	-	-	-	-	5,644	6,463	-
AVERAGE	1,178	1,065	33	30	941	1,077	8

* DENOTES UNAVAILABLE DATA.

SECTION 11

OPERATIONAL HISTORY

11.1 SYSTEM

System construction began in August 1977, and was substantially complete by December 1977. The system startup problems as of March 1978 are listed in Section 9.3. The system has a space heating load only, so it was not used in the summer of 1978. The system was operated a short time each day on September 25-28, 1978, in preparation for the coming heating season. The storage tank temperature was raised from 81°F to 152°F. The solar heating system began continuous operation on October 1, 1978, and energy collection commenced on October 5, 1978. From this time, through the summer of 1984, the only major operational problems were a freeze-up in December 1978, and problems with slipping hose connections that were substantially solved in the summer and early fall of 1979.

Over the weekend of December 2 and 3, 1978, a freeze-up occurred which was discovered on Monday, December 4. The freeze-up was confined to the lower headers of Rows 7 and 10 (Row 1 is the southernmost row). There was no evidence of freezing in any of the other eight rows. The computer listing of the system performance data showed no unusual behavior other than some cycling of the collector pump, which was to be expected because of the marginal insolation conditions which prevailed over that weekend.

The Telex Communications system relies on the draining of the collectors for freeze protection. To relieve the vacuum caused by the draining water, air vents and vacuum breakers were installed at the outlet of each row. They were specified to be heat-taped and insulated. A close inspection of the air vents and vacuum breakers showed that under near-zero temperatures the heat tape was not keeping these devices above freezing. This problem was due partly to the lack of tight contact between the heat tape and the bodies of the vents and breakers and partly to the lack of insulation around the vent holes.

It was not clear, though, how nonoperative air vents and vacuum breakers could have led to the freezing of only two rows out of 10. The entire system would drain if any of the 10 sets of air vents and vacuum breakers operate, because all the rows are connected in parallel. The actual draindown time was established by test at less than 10 minutes. It was also found that sections of the pipe and valves that contained ice due to incomplete draining could be cleared in a few minutes after the system pump started.

While the freeze problem was being investigated, it was decided to run the system under manual control to eliminate short cycling. The system (eight rows) was then operated through the month of

December only on clear days. On January 1, 1979, the system was started up and it was noticed that the absorber plate temperature on Row 5 remained high. Upon investigation, it was found that the bottom manifold of this row was frozen. Examination of the previous day on which the system operated revealed no abnormalities. At a meeting in January it was decided to install standpipe vents at each row as well as at the north and south ends of the return header. These standpipes were to be heat-taped and insulated. Also, piping on the supply side was changed to steeper slope. This work was carried out in February and the system was placed into operation with seven rows on February 25 with no further freeze problems.

The problem with the slipping hoses is discussed in Section 11.2.3.

11.2 COLLECTION SUBSYSTEM OPERATIONAL HISTORY

11.2.1 Operation

The Telex Communications collector array has operated efficiently throughout its history. Performance monitoring began on April 7, 1978. In April 1978, the overall collector efficiency was 42% for the month. Efficiency was good throughout the monitoring period. Overall collector efficiency was 27% in February 1981, with 44% operational collector efficiency. This was the last full month of monitored operation. Telex Communications says the collectors have produced the continued expected quantity of heat through the subsequent heating seasons.

Early in the history of the Telex Communications solar system, in July 1978, there was some concern that the collector pump might accidentally turn on at night, which would be disastrous in the winter. Johnson Controls quoted a price of \$1,063 for a photocell and aquastat to prevent this, and Telex Communications decided it was not worth the cost. On October 20, 1978, the collector control failed, and the collector pump ran all night. It was not cold enough to damage the array. Johnson Controls found the problem to be a bad collector control temperature sensor. Telex Communications requested a backup safety to prevent a recurrence. The problem has not recurred.

The operation of the collection subsystem on a typical clear day was described in detail in Section 10.3.1, Collection subsystem. It was pointed out in that section that the collector pump runs for a smaller fraction of the time when the sun is shining than in most of the NSDN-monitored solar systems. To illustrate, the operation of the solar system on a partly cloudy day, January 23, 1981, is described.

January 23 was a mild day for January, with an overnight low of 18°F and a daytime high temperature of 54°F at 2:25 p.m. The collector pump first turned on at 9:38 a.m., with an absorber plate temperature of 207°F, storage temperature of 128°F, and insolation

of 220 BTU/ft²-hr. At 9:58 a.m., insolation dropped to 115 BTU/ft²-hr, the absorber plate temperature declined to 130°F, the storage temperature was still 128°F, and the collector shut off. This seems reasonable for the collector to shut off, with the absorber plate within 2°F of storage, but, on the clear day, January 29, 1981 (see Figure 18 on Page 58), the collector did not turn on until the absorber plate was more than 50°F warmer than storage. The collector pump came on again at 10:15 a.m., when the storage temperature was 129°F, the absorber plate temperature was 158°F, and insolation was 184 BTU/ft²-hr. The pump cycled on and off more than a dozen times on that day. Some of the cycling appears to be unnecessary; for example, at 2:21 p.m., the pump switched off for four minutes when insolation fell to 190 BTU/ft²-hr, the absorber plate temperature went to 153°F, while storage was at a temperature of 146°F. There was still a +6°F temperature rise across the collectors when the pump shut off. For the day as a whole, there were 16.5 million BTU of incident solar energy, but the collector pump ran while only 9.1 million BTU were incident. Of this, 3.8 million BTU were collected.

The collector operation is characterized by very efficient collection, but a tendency to be oversensitive to clouds, starting later and shutting off sooner than necessary for optimum efficiency. The designers wanted to err on the side of safety, because a freeze-up could happen quickly if the pump came on when insolation was too low, but some efficiency was lost as a result. The loss in efficiency is not large, though, considering the system produces more solar energy than f-Chart predicts.

The flow equalization tubes in the collector manifolds were removed in July 1979, because Telex Communications feared the tubes had or might contribute to freezing because of the flow restriction. Theoretically, this should imbalance the collector flow, and lead to low flow in the middle of the rows, but no adverse effect upon performance has been detected. Thermography did not reveal any flow imbalance, either.

11.2.2 Collector Controls

The collector pump is set to turn on when the absorber plate temperature exceeds the storage temperature by 25°F, and to turn off when this difference falls to 2°F. This setting was apparently maintained throughout the history of the Telex Communications solar system. For details of the operation of the collectors under the control settings, see the previous section, 11.2.1, and also Section 10.3.1.

On October 20, 1978, approximately five million BTU of energy were rejected by the collectors when the collector pump ran all night. After this problem was discovered, the collector pump was operated manually. The problem was a bad collector control sensor, which was replaced on November 1, 1978, and automatic operation was restored.

From the beginning of the heating season in October 1980 until November 19, 1980, the collector pump was operated manually, and with a timer, because the controller had failed. It was repaired November 19, 1980.

11.2.3 Collector Reliability and Maintainability

The collector freeze-up in December 1978 was discussed in Section 11.1. The only other problem concerned the hoses joining the collectors. The collectors are internally manifolded with 2½-inch headers. Connections from collector to collector were initially made with a reinforced silicone rubber hose. Because of the length of the row (144 feet) and the large temperature range to which the manifolds would be exposed, there could be changes in the length of the row of up to $\pm$ two inches due to thermal expansion and contraction. It was anticipated that the silicone hoses would be capable of absorbing this movement. In the actual installation, however, it was found that the axial forces could be transmitted down the manifolds to the hose that was clamped with the weakest pressure. This hose would then slip on the manifold, eventually resulting in a leak.

The solution was the change all the hoses to a different type. The new hose has a single "hump" at its midsection which allows it to act as an expansion compensator. The new hump hose is also constructed of silicone rubber and is capable of withstanding the 350°F-400°F stagnation temperatures that the absorber reaches. As a further precaution against leaks, the hoses were bonded to the copper manifolds using a primer and silicone adhesive. An unlined hose clamp was also used. The installation of the hoses took place in the summer and early fall of 1979.

After this repair, the hoses still slip occasionally, but it is not a major problem. The hose clamps must be retightened several times a year. This job takes about two hours.

11.2.4 Maintenance and Repairs - Collector

There is no regular maintenance required for the solar collectors. During extremely cold weather, the standpipe openings must be inspected for ice buildup. Any ice buildup must be removed. Repairs were discussed in Sections 11.1 and 11.2.3.

11.3 STORAGE SUBSYSTEM OPERATIONAL HISTORY

11.3.1 Operation

Storage water (which is also collector water and load water) is treated automatically by a Culligan Mark 512 Automatic Water Conditioner. The treatment includes a rust inhibitor, C-70,

composed mostly of nitrite, borate, and MBT. The dosage used is 1,500 ppm, with a low level of 1,000 ppm. Chemical treatment M-25 at a level of 60 ppm is used to control algae, bacteria, and fungi. A chemical analysis of the water is presented in Table 37.

Table 37. STORAGE WATER CHEMICAL ANALYSIS

TELEX COMMUNICATIONS
FEBRUARY 4, 1981

<u>CHEMICAL/PHYSICAL PROPERTY</u>	<u>ANALYSIS</u>
Water Content by KF* (%)	97.6
pH	9.1
Reserve Alkalinity	2.2
Specific Gravity	1.003
Ash (%)	0.22
Sodium (mg/liter)	940
Copper (mg/liter)	0
Iron (mg/liter)	1
Silicon (mg/liter)	2
Aluminum (mg/liter)	0
Calcium (mg/liter)	11
Magnesium (mg/liter)	5
Zinc (mg/liter)	1
Boron (mg/liter)	200
Chlorides (mg/liter)	6
Sulfates (mg/liter)	490
Ethylene Glycol (%)	0
Propylene Glycol (%)	0

* Karl Fischer method.

There is an automatic water makeup system to replace water lost through leaks, evaporation, and sump overflows. From system startup to February 1979, 4,340 gallons of makeup water were added. In the 1980-1981 heating season, about 200-300 gallons of makeup water were added per month.

11.3.2 Controls

There are no controls on the storage subsystem.

11.3.3 Reliability and Maintainability

There were no failures, nor was maintenance required, other than the addition of rust inhibitor.

11.3.4 Maintenance and Repairs

None.

11.4 HEATING SUBSYSTEM OPERATIONAL HISTORY

11.4.1 Operation

The solar heating loop always operated continuously throughout the heating season. As explained in the system description, there is always flow (130-165 gallons per minute) out of the storage tank, but the flow to the load is bypassed more as the heating demand decreases. The bypass operation was not monitored by the NSDN, which measured only the flow out of the storage tank, and the supply and return temperatures. There was no minimum tank temperature for circulation to the load, and the water was (very rarely) circulated at a temperature as low as 58°F after an extended period of cloudy weather. Below about 64°F (depending on the time of day, etc), return water would be as warm or warmer than the supply water. The storage tank was usually much warmer than 64°F (the lowest storage temperature in January 1981 was 76°F), and the storage tank got as hot as 167°F in January 1981, when the average daytime temperature was 41°F.

The maximum rate of solar energy delivered by the storage tank was about 800,000 BTU/hour, representing 165 gallons per minute flow with a 10°F temperature drop. For short periods (five to 10 minutes) a 16°F temperature drop was occasionally recorded.

The two space heating load pumps never ran together, but one was used as a backup for the other. The pumps were alternated periodically to even out the wear.

11.4.2 Heating Subsystem Controls

The operation of the controls was described in Section 2.2.3. Instrumentation was not extensive enough to determine how the controls actually operated during the monitoring periods.

11.4.3 Reliability and Maintainability

The space heating pumps have had no failures.

On October 24, 1978, a hydronic heating coil froze and burst, flooding the west building. There was about \$1,000 worth of damage caused by the flooding.

The burst coil was a result of improper integration between the solar space heating subsystem and the vapor compression air conditioning system. When the outside temperature was 40°F, the air conditioner came on and then the outside vents opened. The cold air caused the freeze stat to cut the blower off, but the air conditioner continued to run. The freeze stat also caused the room thermostat valve to fail closed, so warm water was not circulating through the solar heat coil. This coil, which is only 12 inches from the air conditioner, froze and burst.

11.4.4 Maintenance and Repair

To correct the above problem, the following actions were taken:

- The room thermostat valves were changed to fail open.
- The air conditioning and heating were interlocked so they would not run simultaneously.
- The freeze stat sensor was allowed to close the outside damper.

At the same time, the air mix controller was moved from downstream of the solar coil to upstream of the solar coil. In the old location, the controller had called for too much outside air, resulting in a waste of solar heat.

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SECTION 12

ECONOMIC ANALYSIS

12.1 DESIGN

The original design estimated cost of the Telex Communications solar system was \$360,482. The breakdown of this estimate is presented in Section 3.5. This estimate proved to be too low and was raised to \$557,031. (The contract price was \$459,441, so design changes were made to reduce the price.) A discussion of these matters is found in Section 5.

12.2 CONSTRUCTION

Detailed subsystem construction cost analysis is presented in Section 8.3. The total system cost is presented in Table 38.

No allowance has been made for general Overhead and Profit (OH&P) or General and Administrative (G&A) costs. It is important to note that at Telex Communications, subcontractors were significant participants in the system construction. All subcontract costs listed below and in Section 8 include the subcontractors' OH&P. The labor and materials breakouts presented in Section 8 and Table 38 represent the costs incurred by the general contractor directly.

Table 38. TOTAL SYSTEM CONSTRUCTION COST SUMMARY
TELEX COMMUNICATIONS

CATEGORY*	TELEX COMMUNICATIONS	MATERIALS	LABOR	SUBCONTRACTS	TOTAL
Collector Array	\$143,000	None	\$ 5,220	None	\$148,220
Support Structure	None	\$ 34,910	21,190	None	56,100
Piping**	None	48,505	59,665	None	108,170
Ductwork	None	None	None	None	None
Insulation	None	None	None	\$12,005	12,005
Heating/Cooling	None	5,370	3,075	None	8,445
Storage	None	7,200	2,290	4,230	13,720
Controls**	None	None	None	12,435	12,435
Electrical Power	None	None	None	7,370	7,370
General Construction	None	6,205	1,500	None	7,705
SUBTOTAL	\$143,000	\$102,190	\$92,940	\$36,040	\$374,170
TOTAL COST			\$374,170***		

* For a complete description of items in each category, see Section 8.

** Automatic control valve costs are included in the piping category costs.

*** Does not include overhead and profit or general and administrative costs for the general contractor

In order to standardize solar system cost analysis, the NSDN Solar Project Cost Report series added a standard percentage of 25% for overhead and profit to general contractor bare costs and 10% to all subcontract costs. This brings the Telex Communications solar system construction cost with overhead and profit to \$462,305. In addition, the cost of the system design was \$28,675. The contract total cost was \$552,136 including instrumentation, and \$525,728 not including instrumentation. The difference, \$34,748, between the construction and design cost and the contract total represents startup costs and instrumentation changes. The Department of Energy's share of the cost was \$409,066.

12.3 SYSTEM STARTUP

- The existing fresh-air dampers did not close tightly enough to prevent the water coils from freezing. The ducts were replaced and felt tipped louvers installed at a cost of \$3,065.
- Wood braces were added to the collector support trusses at a cost of \$2,034.
- The repairs to the system because of the freeze-up cost in excess of \$24,000.
- Adding heat-taped, insulated, 3/4-inch and two-inch standpipes and moving the balancing and gate valves to vertical pipes cost about \$3,000.
- Repairing the freeze-damaged collector rows cost an estimated \$10,800.
- Repairing the flexible hoses and clamps cost \$3,885 for materials plus \$5,000 in labor. The cost of heat-taping the outside valves and modifying the control system could not be determined.

12.4 OPERATION AND MAINTENANCE

No cost figures are available, but the system has been relatively trouble-free since the freeze-up, with maintenance consisting of occasional tightening of collector hose clamps and maintaining the concentration of rust inhibitor.

12.5 SUBSIDIES AND INCENTIVES

The Department of Energy paid \$409,066 of the contract total of \$525,728.

SECTION 13

REFERENCES

1. Kirkpatrick, D.L., Flat-Plate Solar Collector Performance Data Base and User's Manual, SERI/STR-254-1515, July 1983.
- *2. National Solar Data Network, SOLAR/0003-80/17, January 1980, Vitro Laboratories, Silver Spring, Maryland
- *3. Solar Project Description, Telex Communications, Inc., July 1979, Mueller Associates, Inc.
- *4. Solar Project Cost Report, Telex Communications, Inc., July 1979, Mueller Associates, Inc.
- *5. Solar Energy System Performance Evaluation, Telex Communications, November 1979 through April 1980, SOLAR/2033-80/14, Vitro Laboratories, Silver Spring, Maryland.
- *6. Solar Performance Bulletin, Telex Communications, November 1979 through April 1980, SOLAR/2033-80/16, Vitro Laboratories, Silver Spring, Maryland.

*Copies of these reports may be obtained from Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37831.

APPENDIX A
NATIONAL SOLAR DATA NETWORK
PROGRAMMATIC INFORMATION

APPENDIX A

NATIONAL SOLAR DATA NETWORK PROGRAMMATIC INFORMATION

One of the principal objectives of the National Solar Heating and Cooling Demonstration Program established by the National Solar Heating and Cooling Demonstration Act of 1974 was the collection and evaluation of solar information, and its dissemination to potential users. In order to achieve this objective and to ensure that all related activities are conducted uniformly, the National Solar Data Program, including the National Solar Data Network (NSDN), was established.

Approximately 5,000 residential and commercial solar demonstration sites have been established since the inception of the National Solar Heating and Cooling Demonstration Program. Approximately 150 of these sites were instrumented and included in the National Solar Data Network.

The Department of Energy (DOE) had responsibility for the solar energy program; however, other government agencies were significantly involved. Those agencies include the Department of Housing and Urban Development, the National Aeronautics and Space Administration, the Department of Defense, the National Bureau of Standards, Argonne National Laboratory, and the Department of Health, Education and Welfare. State and local governments, portions of the private sector, and other groups within DOE were active participants.

The National Solar Data Program had a major goal to collect and analyze data from solar sites throughout the United States to enable determination of solar energy system performance. Specifically, the data which is generated and collected in support of this program is used to:

1. Improve the general knowledge and understanding of the performance and operating characteristics of solar energy systems.
2. Develop definitive solar energy system performance criteria.
3. Provide a basis for component and system improvements.
4. Estimate the economic importance of solar energy systems in reducing the consumption of conventional fuels.

The National Solar Data Network provided data to meet this major goal. Accurate, consistent, and orderly data was obtained from a variety of solar energy systems, located in many buildings and exposed to differing climatic conditions. The data was collected, organized, maintained and analyzed at a central point assuring consistent system analysis and performance evaluation.

Figure A-1. Schematic Diagram of the NSDN Teleprocessing Network

To meet the goals and objectives of the National Solar Data Program, the National Solar Data Network was operated for the Department of Energy by Vitro Corporation. The network concept was based on automatic collection of data from remote solar sites and transmission of this data to a central computer facility. Thus, the National Solar Data Network was developed to gather, convert, transfer, and analyze solar system data using six basic steps (see Figure A-2).

1. Evaluate each site and its instrumentation requirements.
2. Select sensors and personalize standardized data acquisition equipment in order to meet specific site requirements.
3. Install and check out instrumentation on site.
4. Retrieve automatically collected site data over the telephone network on command from a central computer facility.
5. Process data in centrally located computers; this includes error checking, performance evaluation computations, and data base maintenance.

6. Analyze data received and document this analysis in a standard report format for distribution.

Figure A-2. Instrumentation, Monitoring and Analysis Process

The following discussion will define each step in detail

Site Evaluation

First, a careful study of the solar energy system design of each demonstration site was conducted. Using detailed information supplied by the solar system designer and the site contractor, the system and its environment was investigated to establish performance evaluation equations and associated site monitoring instrumentation requirements. The details of the site instrumentation were documented in the Instrumentation Installation documents generated for each solar site. (See Figure A-3.)

Figure A-3. Site Study - Generates Instrumentation Requirements and Performance Evaluation Equations

Performance evaluation factors were determined using the energy balance concept. Simply stated, energy entering a system (or subsystem) is equal to the sum of energy leaving the system, energy accumulated in the system, energy transferred through thermal leakage, and conversion inefficiency. As stated in the Instrumentation Program, the sensors selected were those necessary to accurately and economically determine this energy balance.

Performance factors were used to:

1. Determine fossil fuel and electrical energy savings resulting from use of solar energy for space heating, space heating, space cooling, and hot water systems.

2. Determine total heating, cooling, and hot water thermal energy demands and the fraction of each supplied by solar energy.
3. Measure solar energy system efficiency for converting available solar energy into useful thermal energy.
4. Measure thermal performance of major subsystems or components and thermal interactions between collector array, storage, and energy conversion equipment.
5. Measure occupant's energy usage by means of parameters such as temperature level maintained and hot water demand.
6. Determine major system operational characteristics and degradation over life of the demonstration.
7. Obtain records of incident solar radiation and other pertinent site environmental parameters that affect system performance over life of the site.

Personalization of Standard Equipment

The second step was to select sensors and personalize the standard data acquisition equipment to meet the requirements specified in the Instrumentation Program. Sensors were selected from a standardized set of sensors which has been established to ensure compatibility with the Site Data Acquisition Subsystem (SDAS) and to minimize software development. The SDAS is a microprocessor-controlled electronic unit, which collects data from the sensors, stores the data, and on command transmits it to the central facility. (See Figures A-4 and A-5.) The scanning process, data treatment procedure, and other functions of the SDAS are directed by a microprogram, which was custom developed for each SDAS, according to the Instrumentation Program for a specific site. Additional personalization was provided through unique wiring of the SDAS and its associated junction-box (see Figure A-6), as described in the sensor Installation Plan. Figures A-7 through A-11 show some of the sensors employed to monitor a solar Domestic Hot Water system.

Figure A-4.
SDAS Unit mounted
on wall. A micro-
terminal is used
to obtain sensor
measurements for
on-site tests.

Figure A-5.
SDAS without cover
reveals internal
power supply, tape
recorder and arith-
metic processor.

Figure A-6.
SDAS with the associated
electrical junction box.
Equipment was normally
wall-mounted in area
easily accessible.

Figure A-7.
Eppley Pyranometer mounted
in the plane of the solar
collectors

Figure A-8.
Electrical power sensor
with current sensor coil
used to monitor opera-
tional energy.

Figure A-9.
Resistance Thermal Devices (RTD) were used to provide accurate temperature measurements. Stainless steel thermal wells were threaded into pipes and house the RTDs.

Figure A-10.
Hersey totalizing flow meters provide flow rate data for variable flow loops. Not shown, Ramapo flowmeters used for constant flow rate loops.

Figure A-11.
WeatherMeasure wind speed and direction vane and ambient air temperature sensor were particularly important on Passive Solar Sites.

On-Site Installation and Checkout

The third step was the installation and checkout of the SDAS and the sensors. The site contractor installed the supplied sensors in accordance with specific installation procedures and verified that the wiring was correct before the SDAS is connected. Sensors were connected to the SDAS through a junction-box, which was wired according to the Installation Plans and attached to the SDAS by standard interface cables. The SDAS was connected to the National Solar Data Network through a telephone interface installed by the local telephone company. Figure A-12 depicts a typical junction-box properly wired to reduce line losses and to allow easy access for trouble shooting.

Figure A-12. The junction-box was mounted on a plywood sheet mounted on masonry wall. Wires were terminated with crimped terminals and attached to terminal boards.

After the SDAS has been installed, checkout procedures were initiated to verify correct local operation of the sensors and data acquisition equipment. Portable monitors were used to obtain a direct readout in Engineering Units of the system measurements and thereby verify that the solar system and SDAS are performing correctly.

The final checkout step was to verify correct transmission of the data to the Central Data Processing System (CDPS).

Retrieval Over Telephone Network

After the site data acquisition equipment had been installed and checked out, data retrieval began. Data was transferred from the on-site SDAS to the Central Data Processing System (CDPS) using the standard commercial telephone network. Each SDAS scanned sensor inputs every five minutes and stored the raw data on a cassette tape. The Communications Processor, IBM System 7, at the CDPS, automatically called each SDAS daily. The SDAS identified itself and then rewound and played back the data sorted on its cassette tape. The Communications Processor received the data, performed error checking and formatting operations, and passed the data to a data storage tape. The SDAS cassette tape was then rewound and proceeded to gather new data. The data storage tape was transferred to the main computer, IBM 3033, for processing.

Analysis and Reporting

The energy balance method of systems analysis was used to evaluate the performance of solar systems. Figure A-13 illustrates this process. By carefully monitoring the energy flow patterns throughout the system, this method not only provided a measure of efficiency for each major component, but it also provides a built-in check of the instrumentation.

Each of the NSDN solar sites was analyzed on a monthly basis. Data collected daily was integrated and performance factors were generated using customized software. Figure A-14 is a summary page for the month of March for one NSDN site. The purpose of this page was to provide the reader with all of the pertinent information regarding the solar system's performance without burdening the reader with details. The remainder of the monthly report contains daily statistics, which could be used to explain operational anomalies. In addition to the monthly reports, the solar analysts also received plots of specific sensor values on a daily basis. This enabled the analysts to detect problems as they occur.

Seasonal reports were also prepared for each of the NSDN sites at the end of the solar system's load season. Since the performance of an individual system was based upon a large number of uncontrollable variables, the evaluation of a system over a larger time horizon was frequently preferable. The seasonal reports provided the same information as a monthly report, however, the conclusions may be drastically different than an individual monthly analysis. The reports also acted as a better check of the system's performance since most systems were designed to operate efficiently over a long time horizon, not a given month.

* Six million BTU motor losses contributed to space heating load.

Figure A-13. Energy Flow Diagram for Telex Communications
1979-1981
(All figures in million BTU)

CONVENTIONAL UNITS				
GENERAL SITE DATA:				
INCIDENT SOLAR ENERGY				473.070 MILLION BTU
				41065 BTU/SQ.FT.
COLLECTED SOLAR ENERGY				180.087 MILLION BTU
				15632 BTU/SQ.FT.
AVERAGE AMBIENT TEMPERATURE				19 DEGREES F
AVERAGE BUILDING TEMPERATURE				68 DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY				0.32
ECSS OPERATING ENERGY				4.556 MILLION BTU
STORAGE EFFICIENCY				96.63 PERCENT
EFFECTIVE HEAT TRANSFER COEFFICIENT				0.065 BTU/DEG F-SQ FT-HR
TOTAL SYSTEM OPERATING ENERGY				18.677 MILLION BTU
TOTAL ENERGY CONSUMED				294.638 MILLION BTU
SUBSYSTEM SUMMARY:				
	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	N.A.	260.584	N.A.	260.584 MILLION BTU
SOLAR FRACTION	N.A.	58	N.A.	58 PERCENT
SOLAR ENERGY USED	N.A.	150.170	N.A.	150.170 MILLION BTU
OPERATING ENERGY	N.A.	14.121	N.A.	18.677 MILLION BTU
AUX. THERMAL ENERGY	N.A.	95.875	N.A.	95.875 MILLION BTU
AUX. ELECTRIC FUEL	N.A.	95.875	N.A.	95.875 MILLION BTU
AUX. FOSSIL FUEL	N.A.	N.A.	N.A.	N.A. MILLION BTU
ELECTRICAL SAVINGS	N.A.	150.170	N.A.	145.614 MILLION BTU
FOSSIL SAVINGS	N.A.	N.A.	N.A.	N.A. MILLION BTU
SYSTEM PERFORMANCE FACTOR:		0.68		
INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS:			0.81	

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

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, NOVEMBER 1981.
SOLAR/D004-81/18
READ THIS BEFORE TURNING PAGE.

Figure A-14. Monthly Report: January 1981
Site Summary: Telex Communications

Comparative reports were also prepared periodically for classes of solar systems. A single comparative report may be based on 20 or more domestic hot water or space heating systems for the purpose of highlighting the effectiveness of systems in a particular environment or under specific load conditions or to identify system components which consistently operate well.

APPENDIX B
PRELIMINARY DESIGN DRAWINGS

DIMENSION FACTOR 1.945

SYMBOL LIST

SV	SHUT OFF VALVE
GV	GLOBE VALVE
AV	AUTOMATIC AIR VENT
CAV	COMB. AUTO. AIR VENT/VACUUM BREAKER
PD	PIPE DOWN
PU	PIPE UP
SW	SOLAR WATER SUPPLY
SR	SOLAR WATER RETURN
HW	HOT WATER SUPPLY
HR	HOT WATER RETURN
PDV	PRESSURE DIFFERENTIAL VALVE
HC	HEATING COIL
PQ	PRESSURE DROP
UH	UNIT HEATER
WG	WATER GAUGE

$$110 \text{ FT} \times 62.43 \text{ lb/ft}^3 = 6867 \text{ lb/ft}^3$$

$$2307 \text{ PSI/FT} + 14.7 = 2321.7 \text{ PSI/FT}$$

$$2321.7 \text{ PSI/FT} \times 144 \text{ in}^2/\text{ft}^2 = 49.6916 \text{ lb/in}^2$$

$$\text{Total Pump hp} = \frac{Q \cdot \Delta H}{3960} = \frac{260 \text{ gpm} (111 \text{ FT})}{3960} = 7.22$$

$$\text{P.R. hp} = \frac{180 \text{ gpm} (110 \text{ FT})}{3960} = 5$$

$$\text{S.E.C. hp} = \frac{125 \text{ gpm} (110 \text{ FT})}{3960} = 3.472$$

FLOOR PLAN
SCALE: 1/32" = 1'-0"

TYPICAL HOT WATER
COIL PIPING CONNECTIONS
SCALE: NOT TO SCALE

TYPICAL SOLAR COLLECTORS

COMBINATION AUTO. AIR VENT/VACUUM BREAKER (TYP. FOR ALL COLLECTOR ROWS)

1/2" CONNECTION TO COLLECTOR MANIFOLD (TYPICAL)

1/2" CONNECTION TO COLLECTOR MANIFOLD TYP. FOR ALL ROWS

NAME OF PROJECT	REV	DESCRIPTION	DATE	SHEET TITLE	JOB NO.	DATE	INTERTECHNOLOGY CORPORATION	SHEET NO.
TELEX COMMUNICATIONS INC.				FLOOR PLAN AND DETAILS	107-354	1987	107 MAIN ST. WARRENTON, OREGON 97146	M-1

Figure B-1. Preliminary Design Drawing
Telex Communications
Floor Plan and Collector Array Layout

Figure B-2. Preliminary Design Drawing
 Telex Communications
 Flow Diagram, Collector Row, Storage Tank,
 Piping

APPENDIX C
FINAL DRAWINGS

TELEX COMMUNICATIONS, INC.

DRAWING INDEX

ARCHITECTURAL STRUCTURAL

- A-1 COVER SHEET
- A-2 PIER LAYOUT, DETAILS, & FRAMING PLAN
- A-3 COLLECTOR SUPPORT DETAILS
- A-4 COLLECTOR ROW ELEVATION
- A-5 STORAGE TANK PLAN & SECTIONS

MECHANICAL

- M-1 FLOOR PLAN, GENERAL NOTES
- M-2 SECTIONS & FLOW DIAGRAM
- M-3 DETAILS & SCHEDULES
- M-4 DETAILS
- M-5 DETAILS

E-1 ELECTRICAL

BLUE EARTH, MINNESOTA

GENERAL NOTES

1. General:
 - A. Do not scale drawings. All indicated dimension shall govern.
 - B. Engineer's approval must be secured for all substitutions.
2. Site:
 - A. Precautions shall be taken to prevent erosion as required by local Soil Conservation District and Codes.
 - B. All elevations on the drawings are based on a survey performed by Balton and Menk, Inc., Engineers, Farmonth, Minnesota.
 - C. Datum point to be used for all site layout work and elevations will be that used by Balton and Menk, Inc., Engineers, Farmonth, Minnesota for survey performed by them; filed January 25, 1968 No. 1250.
 - D. Contractor shall be thoroughly familiar with the soil report and take all necessary precautions in order to assure that drilled-in-place concrete piers are installed properly with minimal hazard to laborers. Care should be exercised in excavating for piers. Excavation wall stability and ground water could be a problem. Place concrete as soon as possible after excavating. See soil report for amplification. Consultation with soil Engineer may be desired.
3. Design:
 - A. Wind load = 20 PSF
 - B. Dead load = 10 PSF
 - C. Allowable soil stresses and densities per Soil Exploration Company report. For complete details see report.
 1. Allowable bearing @ piers = 2000 PSF
 2. Allowable bearing @ tank = 2000 PSF
3. Passive pressure = overburden pressure + 2X cohesion (1000 PSF)
4. Materials:
 - A. For complete details see specifications.
 - B. Concrete: f'_c = 3000 psi compressive strength at 28 days.
 - C. Reinforcing bars: ASTM Grade 40
 1. All bar lengths are not drawn to scale. No splices of reinforcement shall be made except as detailed or authorized by the Engineer.
 2. Detail bars in accordance with A.C.I. Manual of Standard Practice for Detailing Reinforced Concrete Structures (ACI 315) and A.C.I. Building Code Requirements for Reinforced Concrete (ACI 318), latest editions.
 3. Provide all accessories necessary to support reinforcing at positions shown on the drawings.
 - D. Lumber:
 1. Unless otherwise noted lumber to be Douglas Fir Larch, studs-grade, preservative treatment per specifications.
 2. Metal hardware, nails and anchor bolts to be galvanized steel.
 3. 6 x 8 wood beam to be cut to and length to have bolt and nail holes prebored prior to pressure treatment per specification.
5. Construction:
 - A. All dimensions and conditions shown on drawings shall be field verified by the contractor and any discrepancy shall be reported to the Engineer prior to proceeding with fabrication or construction.
 - B. All concrete shall be thoroughly vibrated to prevent honeycombing.
 - C. Cast-In-Place Concrete Piers:
 1. For complete details see specifications.
 2. Concrete piers to be drilled in place, true in diameter and depth with no caving in of soil or ground water present. Steel cages and concrete to be placed as soon after drilling as possible to prevent disturbance to soil. In all cases, piers shall have full bearing at tip elevation. Remove all loose soil at bottom of pier shaft. Dewatering of shaft will be required if excessive water is present. Engineer should be consulted if excessive ground water present.
 3. Forms shall not be removed until 7th day after placement of concrete. Solar structure shall not be placed on drilled in place concrete piers until 14th day after placement of concrete.
 - D. Cast-In-Place Concrete Storage Tank Slabs
 1. Concrete slabs for water tank shall have been in place 7 days prior to installing tank. Do not fill tank with water until 14th day after concrete has been placed.
 2. Verify all wiring through floor and walls with mechanical and electrical requirements.
 3. Compaction (backfill) where required shall be 95% of Standard Proctor per soils report.
- E. Rough Carpentry:
 1. All lumber shall be clean cut so as to produce a finished appearance.
 2. All metal hardware including nails shall be painted after installation with two coats of weather resistant sealant and paint. Paint shall seal joints between metal hardware and wood surfaces so that moisture does not penetrate between surfaces. Color to be selected by owner.
6. Inspections:

Required inspections to be made by Engineer (48 hours notice shall be given Engineer prior to required inspections):

 1. Prior to pouring any concrete the Engineer shall inspect placement of reinforcing steel for conformance with plans and specifications.
 2. Forty-eight hours after installation of first row of solar collector structures the engineer shall inspect to assure conformance with plans and specifications.
 3. Concrete pump pit shall be inspected after removal of forms and prior to backfilling.
 4. Forty-eight hours after complete solar collector structure (with solar collectors in place) is erected the Engineer shall be called for inspection.

INTERTECHNOLOGY CORPORATION

100 MAIN STREET
WARRENTON, VIRGINIA 22186 USA

SHEET NO

A-1

Figure C-1. Final Drawing
Telex Communications
Site/Key Plan, General Notes

C-1

Figure C-2. Final Drawing
Telex Communications
Solar Heating System
Pier Layout, Framing Plan, and Details

NAME OF PROJECT SOLAR HEATING SYSTEM TELEX COMMUNICATIONS, INC. BLUE EARTH, MINNESOTA	REV.	DESCRIPTION	DATE	SHEET TITLE COLLECTOR SUPPORT DETAILS	JOB NUMBER 00040	SCALE AS NOTED	INTERTECHNOLOGY CORPORATION 100 MAIN STREET WARRENTON, VIRGINIA 22186, U.S.A.	SHEET NO. A-3
	NONE	ISSUED FOR REVIEW				DRAWN BY M.H. & J.G.		
	A	PER NASA 90% REVIEW COMMENTS	3/9/77		DATE 27 Oct 76	APPROVED BY		

Figure C-3. Final Drawing
Telex Communications
Solar Heating System
Collector Support Details

Figure C-4. Final Drawing
Telex Communications
Solar Heating System
Typical Row Elevation and Details

Figure C-5. Final Drawing
Telex Communications
Solar Heating System
Storage Tank Plan and Sections

SYMBOL LIST

	Gate Valve
	Globe Valve
	Motorized Valve
	Balancing Valve
	Check Valve
	Butterfly Valve
	Union
	Automatic Air Vent
	Combination Automatic Air Vent/Vacuum Breaker
	Strainer
	Pipe Anchor
	Pipe Up
	Pipe Down
	End Cap for Pipe
	Direction of Flow
	Thermostat
	Solar Water Supply
	Solar Water Return
	Hot Water Supply
	Hot Water Return
	Heating Coil
	Unit Heater
	Gallons Per Minute
	Feet Per Minute
	Revolutions Per Minute
	Cubic Feet Per Minute
	Total Dynamic Head
	Entering Air Temperature
	Leaving Air Temperature
	Entering Water Temperature
	Leaving Water Temperature
	Water Gauge
	Pressure Differential Valve
	Pressure Drop
	Expansion Loop
	American Air Filter
	NORMALLY OPEN
	NORMALLY CLOSED

GENERAL NOTES

1. ALL THERMOSTAT LOCATIONS SHALL BE COORDINATED WITH EXISTING THERMOSTATS AND WITH THE PLANT MANAGER BEFORE INSTALLATION.
2. MAKE-UP WATER SUPPLY CONNECTION SHALL BE MADE IN STRICT ACCORDANCE WITH LOCAL CODES WITH A BACKFLOW PREVENTER AND PRESSURE REDUCING VALVE.
3. ONLY LONG RADIUS ELBOWS SHALL BE USED ON ALL PIPES.
4. BOTH SUPPLY AND RETURN WATER MAINS TO COLLECTOR SHALL ALWAYS SLOPE TOWARDS THE PIT.
5. ALL VALVES, AIRVENTS AND VACUUM BREAKERS OUTSIDE THE BUILDING SHALL BE HEAT TRACED TO PREVENT FREEZING.
6. ANCHOR UNDERGROUND PIPE AT ALL CHANGES IN DIRECTION AND AS RECOMMENDED BY THE PIPE MANUFACTURER. ANCHOR COLLECTOR SUPPLY PIPE AT ALL VERTICAL CONNECTIONS.

FLOOR PLAN
SCALE: 1/32" = 1'-0"

NAME OF PROJECT SOLAR HEATING SYSTEM TELEX COMMUNICATIONS, INC. BLUE EARTH, MINNESOTA	REV. DESCRIPTION DATE	DESCRIPTION DATE	DATE	SHEET TITLE FLOOR PLAN, GENERAL NOTES AND SYMBOL LIST	JOB NUMBER 00040	SCALE AS SHOWN DRAWN BY T.W.A.	APPROVED BY		INTERTECHNOLOGY CORPORATION 100 MAIN STREET WARRENTON, VIRGINIA 22186, U.S.A.	SHEET NO. M-1
---	-----------------------------	---------------------	------	---	---------------------	---	-------------	--	---	-------------------------

Figure C-6. Final Drawing
Telex Communications
Solar Heating System
Floor Plan and Collector Array Layout C-6

PUMP SCHEDULE										
PUMP NO.	SERVICE	PERFORMANCE DATA				CONSTRUCTION DATA		NPSH AVAIL.	NPSH REQD.	MANUFACTURER
		GPM	TDH FT.	RPM	MOTOR H.P.	TYPE	PUMP			
1	SOLAR COLLECTORS	240	55'	1750	7 1/2	CENTRIFUGAL	IN LINE	8'	4'	AURORA SERIES 380
2	HEATING COILS	125	60	1750	#	CENTRIFUGAL	IN LINE	8'	3'	" " "
3	HEATING COILS	125	60	1750	"	CENTRIFUGAL	IN LINE	6'	2'	" " "
4	SUMP PIT	240	20	1750	2	SUMP PUMP		6'	4'	" " 530
5	SUMP PIT	240	20	3600	1 1/2	SUMP PUMP		6'	4'	" " 530

HEATING COIL SCHEDULE										
COIL NO.	LOCATION	CAP. CFM	AIR			WATER			MAX FACE VELOCITY IN FPM	
			EAT °F	LAT °F	P.D. IN. WG	GPM	EWT °F	LWT °F		
HC-1	UNIT-1	8000	50	80	.5	55	105	90	2	600
HC-2	UNIT-2	9200	50	80	.5	40			2	600
HC-3	UNIT-3	9200	50	80	.5	40			2	600
HC-4	UNIT-4	3800	50	80	.5	16			2	600
HC-5	UNIT-5	1200	50	80	.5	5			2	600
HC-6	UNIT-6	1200	50	80	.5	5			2	600
HC-7	UNIT-7	2000	50	80	.5	9			2	600
HC-8	UNIT-1A	10500	50	70	.5	30			2	600
HC-9	UNIT-2A	10500	50	70	.5	30			2	600

UNIT HEATER SCHEDULE												
UNIT NO.	SERVICE	CAP. MDH	CFM	GPM	FWT °F	LWT °F	MOT. DATA		ELECTRICAL DATA			REMARKS
							MHP	RPM	VOLTS	HZ	PHASE	
1	STORAGE	78	5430	12	105	90	1/2	1140	120	60	1	SIMILAR TO A.A.F. NO. YU-2620
2	STORAGE	78	5430	12	105	90	1/2	1140	120	60	1	SIMILAR TO A.A.F. NO. YU-2620
3	STORAGE	78	5430	12	105	90	1/2	1140	120	60	1	SIMILAR TO A.A.F. NO. YU-2620

NAME OF PROJECT SOLAR HEATING SYSTEM TELEX COMMUNICATIONS, INC. BLUE EARTH, MINNESOTA	REV.	DESCRIPTION	DATE	SHEET TITLE DETAILS AND SCHEDULES	JOB NUMBER 00040	SCALE AS SHOWN	INTERTECHNOLOGY CORPORATION 100 MAIN STREET WARRENTON, VIRGINIA 22186, U.S.A.	SHEET NO. M-3
						DRAWN BY T.W.A.		
					DATE APRIL 20, 1977	APPROVED BY		

Figure C-8. Final Drawings
Telex Communications
Solar Heating System
Details and Schedules

END SEAL FOR PIPE ENTERING PIT
SCALE: NONE

END SEAL FOR UNDERGROUND PIPE ENTERING BLDG.
SCALE: NONE

PIPE CAP FOR UNDERGROUND PIPE
SCALE: NONE

EXP. LOOP SCHEDULE..

LOOP NO.	PIPE SIZE IN.	W FEET	H FEET
1	3	3	6
2	4	5	8
3-11	1 1/2, 2, 2 1/2, 3	1	2

UNDERGROUND PIPE-ANCHOR
SCALE: NONE

TEMP. SENSOR MOUNTING DETAIL
FOR 4" PIPE AND STORAGE TANK
SCALE: NONE

COLLECTOR PIPE SUPPORT DETAIL
SCALE: NONE

DISPLAY PANEL
SCALE: NONE

37" HIGH x 24" WIDE x 9" DEEP
PANEL SIMILAR TO
HONEYWELL NO. 15753275-001

NAME OF PROJECT	REV.	DESCRIPTION	DATE	SHEET TITLE	JOB NUMBER	SCALE AS SHOWN	INTERTECHNOLOGY CORPORATION	SHEET NO.
SOLAR HEATING SYSTEM TELEX COMMUNICATIONS, INC. BLUE EARTH, MINNESOTA				DETAILS	00040	DRAWN BY T.W.A.		M-4
					DATE APRIL 20, 1977	APPROVED BY	100 MAIN STREET WARRENTON, VIRGINIA 22186, U.S.A.	

Figure C-9. Final Drawing
Telex Communications
Solar Heating System
Underground Collector Pipe Details
and Display Panel

- NOTE:
1. ALL PIPE TO EXTEND A MINIMUM OF 9" BEYOND THE SURFACE OF THE TANK.
 2. ALL PIPE SMALLER THAN 2 1/2" SHALL BE THREADED PIPE.

STORAGE TANK DETAIL
SCALE: 1/4"=1'-0"

NOTE: THE UNIT SHALL AUTOMATICALLY TURN ON WHENEVER THE WATER LEVEL IN THE PIT RISES TO 6" BELOW DRAIN PIPE.

EMERGENCY SUMP PUMP DETAIL
SCALE: NONE

NAME OF PROJECT	REV.	DESCRIPTION	DATE	SHEET TITLE	JOB NUMBER	SCALE AS SHOWN	INTERTECHNOLOGY CORPORATION	SHEET NO.
SOLAR HEATING SYSTEM TELEX COMMUNICATIONS, INC. BLUE EARTH, MINNESOTA				DETAILS	00040	DRAWN BY T.W.A.	100 MAIN STREET WARRENTON, VIRGINIA 22186, U.S.A.	M-8
					DATE APRIL 20, 1977	APPROVED BY		

Figure C-10. Final Drawings
Telex Communications
Solar Heating System
Storage Tank and Emergency Sump
Pump Details

APPENDIX D

CONTRACT PRICING PROPOSAL FROM THE
INTERTECHNOLOGY CORPORATION PROPOSAL
November 26, 1975

APPENDIX D

CONTRACT PRICING PROPOSAL FROM THE INTERTECHNOLOGY CORPORATION PROPOSAL November 26, 1975

C.1. Cost

a) Funding Summary

- 1) Estimated total project cost, including solar energy portion; \$345,050
- 2) Estimated total equivalent project cost with conventional energy equipment, \$0. The project and all conventional equipment is existing.
- 3) Difference = solar system cost: \$345,050
- 4) Payback = solar system cost ÷ fuel cost savings/year - 15.7 years
- 4.a) If the required instrumentation were not considered the payback period could be reduced to 15 years.

5. Since other costs are involved in the solar system such as design fees, instrumentation, monitoring personnel, and personnel to accompany visitors through the site, the amount of initial cost to the owner (as indicated above) will increase the expected payback period. Therefore, it is suggested that the government provide the major portions of the construction monies and the owner will provide the dollars (minus the cost of money to obtain them) equivalent to a payout period of five years. It is understood here that this contract shall be negotiated with the government and that financial ideas expressed herein are not firm but merely suggestive of the owner's feelings. Future discussions with the proper government agency will define a financially practical and equitable solution.

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D-4

CONTRACT PRICING PROPOSAL
(RESEARCH AND DEVELOPMENT)

Office of Management and Budget
Approval No. 29-1-018

This form is for use when (i) submission of cost or pricing data (see FPR 1-3.807-3) is required and (ii) substitution for the Optional Form 59 is authorized by the contracting officer.

PAGE NO.

NO. OF PAGES

NAME OF OFFEROR InterTechnology Corporation		SUPPLIES AND/OR SERVICES TO BE FURNISHED for Telex Communications, Inc.	
HOME OFFICE ADDRESS 100 Main Street		Feasibility Study, Tradeoff Studies, Engineering, Construction, Inspection, Test & Analysis of System	
WARRENTON, VIRGINIA 22186			
DIVISION(S) AND LOCATION(S) WHERE WORK IS TO BE PERFORMED		TOTAL AMOUNT OF PROPOSAL \$ 28,431	GOVT SOLICITATION NO. DSE 75-2

DETAIL DESCRIPTION OF COST ELEMENTS

1. DIRECT MATERIAL (Itemize on Exhibit A)	EST COST (\$)	TOTAL EST COST	REFERENCE
a. PURCHASED PARTS			
b. SUBCONTRACTED ITEMS			
c. OTHER — (1) RAW MATERIAL			
(2) YOUR STANDARD COMMERCIAL ITEMS			
(3) INTERDIVISIONAL TRANSFERS (At other than cost)			
TOTAL DIRECT MATERIAL			
2. MATERIAL OVERHEAD (Rate % XS base =)			
3. DIRECT LABOR (Specify)	ESTIMATED HOURS	RATE/HOUR	EST COST (\$)
Feasibility study-tradeoffs, solar engineering	350	9.57	3349
Construction documents and construction	638	10.53	8540
Cost & System performance Analysis	320	10.53	3369
TOTAL DIRECT LABOR			15,258
4. LABOR OVERHEAD (Specify Department or Cost Center)	OH RATE	X BASE =	EST COST (\$)
	1.5	15,258	22,887
TOTAL LABOR OVERHEAD			22,887
5. SPECIAL TESTING (Including field work at Government installations)		EST COST (\$)	
TOTAL SPECIAL TESTING			
6. SPECIAL EQUIPMENT (If direct charge) (Itemize on Exhibit A)		EST COST (\$)	
7. TRAVEL (If direct charge) (Give details on attached Schedule)		EST COST (\$)	
a. TRANSPORTATION 10 man trips @ 180		1800	
b. PER DIEM OR SUBSISTENCE 20 days @ 36		720	
TOTAL TRAVEL			2,520
8. CONSULTANTS (Identify—purpose—rate)		EST COST (\$)	
TOTAL CONSULTANTS			
9. OTHER DIRECT COSTS (Itemize on Exhibit A)	Computer Time	750	
TOTAL DIRECT COST AND OVERHEAD			26,157
10. GENERAL AND ADMINISTRATIVE EXPENSE (Rate % of cost element No.)			
11. ROYALTIES			
TOTAL ESTIMATED COST			26,157
12. FEE OR PROFIT			2,274
TOTAL ESTIMATED COST AND FEE OR PROFIT			28,431

ERDA DSE 75-2

TYPE: NAME AND TITLE

SIGNATURE

NAME OF FIRM

DATE OF SUBMISSION

26 November 1975

COST EL NO.

ITEM DESCRIPTION (See footnote 5)

EST COST (\$)

☒ YES ☐ NO (If yes, identify below.)

NAME AND ADDRESS OF REVIEWING OFFICE AND INDIVIDUAL

TELEPHONE NUMBER/EXTENSION

11. WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS PROPOSED CONTRACT?

☐ YES ☒ NO (If yes, identify on reverse or separate page)

III. DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT?

☒ YES ☐ NO (If yes, identify.): ☐ ADVANCE PAYMENTS ☒ PROGRESS PAYMENTS OR ☐ GUARANTEED LOANS

IV. DO YOU NOW HOLD ANY CONTRACT (Or, do you have any independently financed (IR&D) projects) FOR THE SAME OR SIMILAR WORK CALLED FOR BY THIS PROPOSED CONTRACT?

☐ YES ☒ NO (If yes, identify.):

V. DOES THIS COST SUMMARY CONFORM WITH THE COST PRINCIPLES SET FORTH IN AGENCY REGULATIONS?

☒ YES ☐ NO (If no, explain on reverse or separate page)

See Reverse for Instructions and Footnotes

OPTIONAL FORM 60 (10-71)

APPENDIX E

THERMAL PERFORMANCE MODELS
TRNSYS SIMULATION OF ORIGINAL DESIGN
OF TELEX COMMUNICATIONS SOLAR SYSTEM
AT BLUE EARTH, MINNESOTA
BY IBM CORPORATION

APPENDIX E
THERMAL PERFORMANCE MODELS
TRNSYS SIMULATION OF ORIGINAL DESIGN
OF TELEX COMMUNICATIONS SOLAR SYSTEM
AT BLUE EARTH, MINNESOTA
BY IBM CORPORATION

D62-77-1001
1/5/77

1.0 SUMMARY AND CONCLUSIONS

This study was undertaken to assist MSFC in evaluating the ITC proposal to incorporate solar heating in an existing manufacturing building at Blue Earth, Minnesota; specifically, to determine the percent solar contribution to building heating and to validate the contribution claimed by ITC.

All simulations were made using TRNSYS with Madison, Wisconsin, design year weather information from the University of Wisconsin. Appropriate modifications were made in the temperature profile to match the peak heating season loads given by ITC.

The ITC claim of 79% appears to be conservative, since IBM results show 90% (SIM #1, Table 1) for a comparable situation (no tank minimum temperature). The primary difference is in the solar energy collected. IBM used the collector data generated in the University of Connecticut test of the Solar Corporation of America collector with a black chrome absorber plate coating. Corresponding data values used by ITC were not available to IBM during the study.

Solar contribution (as determined by IBM) reduces to 77% as the minimum useful tank temperature is increased to 115°F (SIM #3); a minimum temperature of 100°F produced a solar contribution of 82%. It was also determined that with sufficiently high minimum tank temperatures (e.g., 100°F), only the small (106 GPM) circulation pump is required. The exact temperature at which the larger pump is required was not determined. Such a determination is beyond the scope of this study. Maximum solar contribution is obtained with no minimum tank temperature, and, for this situation, both pumps are required. However, it is possible that economic analyses may determine that the extra pump power required may exceed the benefit derived from solar at some minimum temperature and that, therefore, a tank temperature control should be installed.

	PDR ANALYSIS UPDATE	TRNSYS SIM #1	TRNSYS SIM #2	TRNSYS SIM #3	
Tank Minimum Temperature Cutoff Level	None	None	100	115	⁰ F
Solar Energy Available	---- (81.5)*	53.0 (77.6)	53.0 (77.6)	53.0 (77.6)	10 ⁸ KJ
Solar Energy Collected	---- -----	16.7 (20.0)	15.4 (18.6)	14.4 (17.7)	10 ⁸ KJ
Collector Efficiency	---- -----	31.6 (25.8)	29.0 (24.0)	27.3 (22.7)	%
Heating Load	15.8	17.3	17.3	17.3	10 ⁸ KJ
Solar Energy Applied to Heating	12.5	15.7	14.2	13.3	10 ⁸ KJ
Auxiliary Energy Required	3.3	1.7	3.1	4.1	10 ⁸ KJ
Heat Lost Due to Tank Over Temperature	0.5 (2.8)	1.1 (4.1)	1.1 (4.1)	1.1 (4.1)	10 ⁸ KJ
Average Storage Temperature	---- (78)	52.6 (66.7)	57.2 (70.0)	60.8 (72.5)	⁰ C
Tank Loss	---- (.308)	.143 (.266)	.154 (.278)	.163 (.287)	10 ⁸ KJ
Percent Solar	79	90	82	77	%

* Parenthetical values represent 12 month values; all others represent September through April values.

Table 1. Telex Building Solar System Performance Analysis Summary

Manual startup and shutdown of the solar heating system is planned for the beginning and end of the heating season. Such an operational mode leaves heating during spring and fall transition periods to the auxiliary system. IBM recommends that an economic analysis of control and operational costs of alternative operational modes be made for (1) leaving the circulation pump on year-round, (2) automatic control of circulation pump when heating load present, and (3) manual control during heating season (current system).

A potential collector pump oscillation problem should also be investigated. IBM was unable to determine the location of the temperature probes of the pump differential controller. Depending on the specific locations, the pump "on" and "off" criteria may be incompatible; i.e., marginal insolation and ambient temperature conditions sufficient to start the pump may be insufficient to continue its operation, resulting in an oscillation. The exact locations should be determined and controller setpoints determined for non-oscillatory operation.

2.0 ASSUMPTIONS AND RATIONALE

This section details the assumptions and approximations made in modeling the Telex solar system and the rationale behind each. Assumptions are divided into three categories below: (1) Weather and Loads; (2) System; and (3) Controls.

2.1 WEATHER AND LOADS

Weather data (including insolation) used was derived from the University of Wisconsin design year for Madison, Wisconsin. Insolation at Madison and Blue Earth, Minnesota, is approximately the same according to Bennett's¹ graphical data. This is further supported by the "solar energy available" data in Table 1, where the annual values differ by approximately 5%. Temperatures at Madison were significantly altered (by 3.67°C lower) in order to better match heating loads in the peak heating season of December through February. As a consequence, heating loads (by following the Madison seasonal variation) are modeled larger than the ITC model during the months of March and April. Heating loads were assumed to be zero from May 1 through August 28. The IBM approximation produces a larger total load than ITC (by 9%), but this results in a more conservative estimate while still providing good agreement in high load periods.

The load dependence on ambient temperature is shown in Figure 1. It was derived by plotting the September through April monthly load data given in the ITC analysis of 9/22/76 against Rochester, Minnesota, ambient temperatures and fitting a straight line to the points. The load function implies that heat is required if the ambient temperature is less than 20.38°C (68.7°F) and that the overall loss coefficient of the building is 13847 KJ/hr-°C. This setpoint differs from the setpoints given by ITC (65°F, 55°F, and 50°F in the various zones) but produces the same heating loads. A single zone was used in the TRNSYS model since no finer-resolution load data was available. Likewise, no economizers or night setback thermostats were modeled.

¹ Bennett, Iven. "Monthly Maps of Mean Daily Insolation for the United States", *Solar Energy*, 9 (3): 145-158

HEATING LOAD VS. $(65^{\circ}\text{F} - T_{\text{AVG}})$
FOR ROCHESTER, MINN.
FROM 09/22/76 DATA

TELEX BUILDING
BLUE EARTH, MINN.

FIGURE 1. HEATING LOAD VS. AMBIENT TEMPERATURE

2.2 SYSTEM

The present storage tank design is one of 29,796 gallons capacity filled to 23,000 gallons. As a simulation artifice, a 23,000 gallon tank with the same wetted area was chosen for the model to provide a full tank with the same energy loss rate. The tank was assumed to be isothermal. As a first approximation, the tank environment was chosen as the annual average temperature at Rochester (6°C, 42.8°F). Tank temperature was limited to 99°C due to the large atmospheric vent on it and the 1000 ft. elevation of Blue Earth. Energy lost due to boiling was tracked and is shown in Table 1.

Tank-to-building piping was assumed lossless in the model, since a supplemental analysis showed that less than 0.2% of the usable energy collected is lost in the piping.

The auxiliary resistance heating capacity was chosen to meet the building loss at the ASHRAE 2 1/2% Rochester temperature (-25°C). Since this system currently meets the entire heating load, its capacity is always sufficient to supplement the solar contribution to 100% of the load, and its exact capacity is thus not significant to the model. The value chosen is 625,000 KJ/hr.

The heat transfer coefficient of the duct heat exchangers was determined from inlet and outlet temperatures and flow rates given in the mechanical drawings. Assuming a crossflow heat exchanger, the effectiveness was determined to be 0.55, which implies a UA of 129,566 KJ/hr-°C at the rated conditions. Given this, the model computed effectiveness for all other flow conditions.

Building capacitance was chosen to be 450,000 KJ/°C to provide a stable simulation with a step size of 0.25 hour. That is, maximum solar combined with auxiliary heat was not sufficient to cause a building temperature rise of more than 2°C/hr or 0.5°C/step. In this way, the simulation could not "skip over" a control regime in one time step, and simulation stability was enhanced.

Building temperature was limited to 25.56°C (78°F) to simulate the effects of the cooling system. No energy penalty was assessed for this.

2.3 CONTROLS

The load profile (Figure 2) is equivalent to a heating setpoint of 20.38°C (68.7°F). Therefore, the first stage heating (solar) is selected when the building temperature falls below that point. Second stage (auxiliary) heating is selected when the building temperature falls 10° (1.8°F) below the first stage setpoint; however, solar heating is also continued. The second stage setpoint is 19.38°C (66.9°F).

Selection of the tank to heat exchanger flow rate in the real system is a trial-and-error function, which may step through several flow rates before determining the proper one. This produces transients in flow and temperature distribution which do not occur in the model. The model instantaneously selects the minimum flow rate (of the set 106, 154 or 260 GPM) which meets the heating load.

Collector flow logic in the real system is maintained at the last selected state (OFF or ON) for 10 minutes before another switch is allowed. The simulation models this as 15 minutes (one step size) in order to simplify the model logic. This makes a minimal difference over a year simulation since, in general, the collector comes on once per day and goes off once per day.

A tank minimum temperature cutoff for the heat exchanger flow was modeled in the simulation. At the time the study was performed, some consideration was being given to such a control in the real system. In addition, ITC studies assumed a 100°F minimum, although, apparently, no control logic was used to enforce it. In order to assess the impact of such a control, it was left as a study parameter, and Table 1 indicates the effects of its variation.

FIGURE 2. HEATING LOAD COMPARISON

APPENDIX A

TRNSYS MODEL DESCRIPTION

A.0 INTRODUCTION

The TRNSYS model used in this Telex study is shown in schematic form in Figure A-1. Water heated by the collector is pumped into a storage tank when the collector/tank temperature difference is greater than 5 °F. Flow continues until the difference is less than 2 °F. A relief valve limits the tank temperature to less than 210°F. When a heating load is present, water is pumped from the tank into a water/air duct heat exchanger at one of three flow rates (106, 154 or 260 GPM) dependent on the amount of heating required. The fan circulates air through the duct heat exchanger across the auxiliary resistance heating and through the building. First stage heating from the solar storage tank is activated at 68.7°F; second stage heating from the auxiliary, at 66.9°F. Since a heating load was available only for a single zone, the building was treated as a single zone with a single composite duct heat exchanger, fan and auxiliary heat source.

The model used in this study is shown in information flow form in Figure A-2. Each unit in the simulation is grouped into a loop and discussed below. Solution order of the units is indicated in the figure by the numbers on the left side of each unit.

A.1 HEATING LOAD PROFILE

Units 12 and 16 generate the heating load. Unit 12 is a building model with a capacitance of 450,000 KJ/C°, a heat loss coefficient of 13847 KJ/hr-C° and no internal heat gain. The heating load is given by the equation

$$Q_H = 13847 \frac{\text{KJ}}{\text{hr-C}^\circ} (20.38^\circ\text{C} - T_A)$$

where T_A is the external ambient temperature. Unit 16 prevents summer room overheating by simulating cooling at a level of 25.56°C (78°F). Energy required for this is not accounted in the heating system.

TELEX BUILDING SOLAR
SYSTEM M-200
(FIGURE A-1)

Programmer: R. K. FIERI Prog No.: FIGURE A-2 Date: 10/27/74 Page:
Chart ID: Chart Name: TELEVISION SYSTEM Program Name:

A.2 COLLECTOR LOOP AND CONTROL

Units 1, 2, 3, 5, 6 and 31 comprise the collector loop and its control. Unit 1 reads design year weather data from Madison, Wisconsin, and reduces the ambient temperature by 3.67°C (6.61°F) to approximate Blue Earth, Minnesota, weather. Unit 2 transforms horizontal insolation data to that incident on a collector facing due south at a latitude of 43.6°N and tilted at 58.5° to the horizontal. The collectors (Unit 3) use water as a heat transfer medium and are modeled with an efficiency factor (F') of 0.96, a loss coefficient (U_L) of $20.1 \text{ kJ/m}^2\text{-hr-}^{\circ}\text{C}$, an absorptance (α) of 0.94, and a cover transmittance (τ) of 0.90. The total collector array area is 1292.1 m^2 . The collector pump (Unit 5) has a capacity of 53384 kg/hr (235 GPM) and is controlled by Unit 6. The pump is activated if the temperature differential between the collector outlet and the storage tank is greater than 2.78°C (5°F). Subsequent deactivation occurs when the differential falls below 1.11°C (2°F). The minimum activation/deactivation time interval is 15 minutes. A relief valve (Unit 31) is placed in the loop to limit simulated tank temperatures to boiling at 1000 ft. altitude (99°C , 210.2°F). Water in the collector flows through hot storage to complete the loop.

A.3 HOT STORAGE

Unit 4 models a water-filled, 87.1 m^3 (23,000 gallon) tank with a height of 7.8 m. The heat loss coefficient is $0.409 \text{ kJ/hr-m}^2\text{-}^{\circ}\text{C}$. It is assumed to be an isothermal (fully-mixed) tank in a constant ambient temperature of 6°C (42.8°F). The simulation requires that the tank be full; thus the modeled dimensions are different from the actual tank dimensions (a capacity of 29,796 gallons). The modeled tank has a capacity of 23,000 gallons and the same wetted surface area as the actual tank.

A.4 HEATING LOOP

The heating loop consists of a water loop (Units 8, 9, 14, 20, 21 and 30) and an air loop (Units 10, 13 and 15). The water loop pumps water from the hot storage tank (Unit 4) through a duct heat exchanger (Unit 9) and back via a pump (Unit 8) modulatable to levels of 105, 154, and 260 GPM.

The air loop blows air through the heat exchanger (Unit 9) across auxiliary resistance heating (Unit 10), through the building (Unit 12) and back via a composite fan (Unit 13) with 125825 kg/hr capacity. Operation of this is under control of a two-stage thermostat (Unit 15).

In the water loop, the heat exchanger is crossflow water/air with an overall heat transfer coefficient of 129566 KJ/hr- $^{\circ}$ C. Pump control is by three logical functions: (1) minimum tank temperature (Unit 20); (2) heating load requirement modulator (Unit 14); and (3) summer cutoff (Unit 30). These three functions are AND'ed by Unit 21 to provide a final modulated pump control signal. The minimum tank temperature control disables the pump if the tank temperature falls below the set point (values of 0 $^{\circ}$ C (32 $^{\circ}$ F), 19.38 $^{\circ}$ C (66.88 $^{\circ}$ F), 37.78 $^{\circ}$ C (100 $^{\circ}$ F), and 46.11 $^{\circ}$ C (115 $^{\circ}$ F) were used as study parameters). The modulator selects the minimum flow rate necessary to meet the heating load via the heat exchanger; it selects full on if all rates are insufficient. During the 120 day period from May 1 through August 28, the summer cutoff disables the pump completely.

In the air loop, the auxiliary heater is sized to provide a 50 $^{\circ}$ temperature rise in the absence of solar assist at the ASHRAE 2 1/2% temperature for Rochester, Minnesota (-25 $^{\circ}$ C). This is supplied by a heater capacity of 629125/KJ/hr. First stage heating (solar only) is selected by the thermostat when room temperature falls below 20.38 $^{\circ}$ C (68.7 $^{\circ}$ F) by activating the fan. Second stage heating (resistance) is activated in addition to that available from solar if room temperature falls below 19.38 $^{\circ}$ C (66.9 $^{\circ}$ F).

APPENDIX F
DESIGN REVIEW COMMENTS

- Appendix F-1. NASA Design Review Comments
on InterTechnology Corpora-
tion's Original System
Design (December 20, 1976)
- Appendix F-2. Reply to NASA Review Comments
Letter from Norman C. Pardue, Jr.
Consulting Civil Engineer
- Appendix F-3. Reply to NASA Review Comments
by InterTechnology Corporation

APPENDIX F-1

NASA DESIGN REVIEW COMMENTS
ON INTERTECHNOLOGY CORPORATION'S
ORIGINAL SYSTEM DESIGN
(DECEMBER 20, 1976)

DESIGN REVIEW COMMENTS

PROJECT: SHAC

BLUE EARTH, MINN

PAGE 1 of 3

OF REVIEW:

DATE:

NAME:

12-20-76

CADDY

FACILITIES OFFICE

☐ ARCHITECT☐ MECHANICAL☐ CIVIL☒ STRUCTURAL

OTHER _____

☐ ELECTRICALDRAWING NO.
OR SPEC. PARA.

COMMENTS

ACTION

CALCS
P. 12, 17

(Not Initiated as being checked)

CALCS for design of concrete piers do not address forces due to frost heaving. Per soils report these uplift forces are significant!

NEED 17' OF
CONCRETE TO
DEVELOP STRESS

P. 14

CALCS differ from dwg in member selection.

$\frac{1}{4}$ for $2 \times 4 = 64 > 50 \Rightarrow$ no good

per AITC 4-3.

FROM AN ASSUMPTION OF TOWER CONSTRUCTION

Member $U_{5/4} f_c = 173 > F_c' = 140$ N.G.

(will check
and provide
new results)

P. 17

Horiz. shear calc has a 16% overstress even with wind allowance.

EXCESS STRESS ALLOWABLE

P. 19

Good practice to embed A.B. to develop bolt strength.

P. 20

A.B. req'd to secure tank - Allowable bond stress = 160 psi instead of 220 psi $\Rightarrow$ 89 bolts are req'd vs. 65 as stated

P. 22

Slab re-steel $M_{max} = 27.58'K$ vs. $25.88'K$. #7 @ 7" o/c be used.

Dwgs do not reflect what is originally calculated.

P. 24

$M_2 = 8.88'K$ vs. $12.18'K \Rightarrow$ ~~max~~ ~~temp~~ ~~max~~

~~max~~ ~~temp~~ ~~max~~ $A_s \approx 0.96 \text{ in}^2/\text{ft} \approx 6.5 \text{ in}^2/\text{ft}$

CALL OUT #5 @ 10" o/c

DESIGN REVIEW COMMENTS		PROJECT: SHAC Blue Earth, Minn.		PAGE 2 OF 3
TYPE OF REVIEW:		DATE: 12-20-76		NAME: Caddy
☒ FACILITIES OFFICE ☐ OTHER _____		☐ ARCHITECT ☒ CIVIL ☐ ELECTRICAL ☐ MECHANICAL ☒ STRUCTURAL		

ITEM	DRAWING NO. OR SPEC. PARA.	COMMENTS	ACTION
8.	CALCS P. 25	SLAB design $\rightarrow W = \frac{8}{12}(150) + 2\frac{1}{4}'(125)$ $W = 381$ vs. 230 ?	
9.	SPECS Excav., filling, & grading. P. 3.06 B. 2.	Should read, "... bring to within 5% below or above ..."	Corrected
10.	P. 2.07 A.	Capacity of Water Storage Tank is not shown on the drawings.	
11.	P. 2.07 B. 6. ref: 2.03 B. P. 5-4 3.05. D. P. 15-31	Details of tank insulation and particularly the protective coating (Hypalon) should be <u>more</u> specific. Where is the end-point for the Hypalon? All exposed metal below grade should be protected with an asphaltic coating (i.e. saddles, anchor bolts, etc.) Which hypalon coating is desired?	ASPH. COATING W/ BE REWORK
12.	P. 3.07 p. 2-15	Is grading req'd @ the site? None shown on the dwgs.	
13.	P. 2.01. B. 1. P. 3-19	Concrete to be used in wall? NOT SPECIFIED	

DESIGN REVIEW COMMENTS		PROJECT: SHAC Blue Earth, Minn.	PAGE 3 OF 3
TYP. OF REVIEW:		DATE: 12-21-76	NAME: Caddy
☒ FACILITIES OFFICE ☐ OTHER _____		☐ ARCHITECT ☒ CIVIL ☐ ELECTRICAL	☐ MECHANICAL ☒ STRUCTURAL
ITEM	DRAWING NO. OR SPEC. PARA.	COMMENTS	ACTION
14.	<u>SPECS</u> TP 3.05 B. P. 15-30	Specs conflict with drawings as to slab thickness. SPEC - 12, DWG 18	
15.	TP 3.07 B. P. 15-35	(MM) designation of pipe insulation	
16.	GENERAL SPEC	No Electrical Specs	
17.	<u>DWGS</u> A-4	Detail tank saddles (1/2" thick 18" wide)	SADDLES TO BE PROVIDED WITH SADDLES
18.	A-4	Show sand bedding & backfill for tank.	NEEDS to
19.	A-4	SHIP - 1/2" thick 18" wide	answered
19.	A-5	West End Elevation - weight of LG" welded to WG x 8.5.	IDENTIFY WEIGHT
20.	A-2	Pipe Trench Detail — piping should be located below the frost zone (i.e. 5')	
21.	A-2	Concrete Piers, Section 2 — If variability of pier depth is anticipated, Contractor's bid should have unit cost for additional depth.	
22.	Calcs General	Calcs do not address snow drifting!	

DESIGN REVIEW COMMENTS		PROJECT: SHAC BLUE EARTH, MINN.		PAGE 1 OF 1
TYPE OF REVIEW:		DATE: 12-20-76	NAME: JERRY SIMPSON	
☒ FACILITIES OFFICE ☐ OTHER <u>1</u>		☒ ARCHITECT ☐ CIVIL ☐ ELECTRICAL ☐ MECHANICAL ☐ STRUCTURAL		
ITEM	DRAWING NO. OR SPEC. PARA.	COMMENTS	ACTION	
1.	A-3	Connection details as shown permit water to stand in contact with structural wood members; conducive to rot.		
2.	General	Insulation details - INVESTIGATE SURFACE	NOT TAR OVER	
3.	"	P.E. Stamp req'd.		

F-1-4

DESIGN REVIEW COMMENTS		PROJECT: SHAC FOR TELEX COM. 1. BLUE EARTH, MINN.	
TYPE OF REVIEW:		DATE: 12-20-76	PAGE 1 OF 2 NAME: <i>Scrip</i>
☒ FACILITIES OFFICE ☐ OTHER _____		☐ ARCHITECT ☐ CIVIL ☐ ELECTRICAL	
		☒ MECHANICAL ☐ STRUCTURAL	

ITEM	DRAWING NO. OR SPEC. PARA.	COMMENTS	ACTION
1.	M-1	Typical Hot Water Coil Piping Connections — Piping arrangement should include a 3-way by-pass valve.	
2.	"	Show details of expansion loops. INCLUDE LENGTH OF RUNS	
3.	"	Show detail of underground piping (i.e. insulation detail, etc.)	
4.	"	Detail anchor supports to control or accomodate pipe expansion and contraction.	
5.	M-2	System Flow Diagram — show valve controllers.	
6.	"	SECTION 1 — Expansion and contraction for collector piping?	
7.	"	SECTION 1 — Detail @ supply header from storage tank to waterproof insulation.	
8.	"	SECTION 2 Detail 2 — Locate manhole in storage tank required by spec. TP 2-07 p. 15-9	

DESIGN REVIEW COMMENTS		PROJECT: SHAC BLUE EARTH, MINN.		PAGE 2 OF 2
TYPE OF REVIEW:		DATE: 12-20-76	NAME: SERIP	
☒ FACILITIES OFFICE ☐ OTHER _____		☐ ARCHITECT ☐ CIVIL ☐ ELECTRICAL ☒ MECHANICAL ☐ STRUCTURAL		
ITEM	DRAWING NO. OR SPEC. PARA.	COMMENTS	ACTION	
9.	M-2	Detail 2 — Specify appropriate code(s) for tank fabrication; call out fittings; call out tank material; show welding details.	BID MAT will BE SPECIFIED.	
10.	"	SECTION 3 — Piping in pump pit should be arranged to permit access for maintenance, etc.		
11.	M3	INLINE PUMP CONN. DETAIL — What is the intention of the pressure gauge? Differential press. or linepress.? The Detail as drawn does not conform to spec. TP 2.05 B.I. p.15-7 (i.e. split case, flexible connectors, etc.)		
12.	"	DETAIL 1 — flex elbow from return header to collector is poor configuration.		

DESIGN REVIEW COMMENTS		PROJECT:		PAGE 1 OF 1	
TYPE OF REVIEW:		DATE:		NAME:	
		12-22-76		Keller	
☒ FACILITIES OFFICE ☐ OTHER _____		☐ ARCHITECT ☐ CIVIL ☒ ELECTRICAL ☐ MECHANICAL ☐ STRUCTURAL			
ITEM	DRAWING NO. OR SPEC. PARA.	COMMENTS	ACTION		
1.	E-1	All panel boards to have <u>equipment</u> ground bus in direct contact with panel enclosure.	METAL FRAME GROUND, NEC PROVIDES SIZING GREEN INSULATION		
2.	"	All power circuits to have equip. ground wire (green color insulation) run in feeder conduit.			
3.	"	How far for the 2" PVC empty conduit?			
4.	"	Locate power source panel on plan & give distance.			
5.	"	U.H. #3 — "... with 2 #12 ANG & 1 #12 G in 3/4" C.			
6.	"	Where is main distribution panel? How far? Does 100A 3p C.B. exist in panel?			
7.	"	Identify panel for source of pwr. How far?			
8.	"	LP Note — Rewrite — "Install a new 70A 3p CB in exist 100A 3p space & connect feeder."			
9.	Symbol List	☐ - disconnect switch, no fuse, furnish integral part of unit heater. NEEDED TO DEFINE TEMP CONTROL ON HEATERS			

APPENDIX F-2

REPLY TO NASA REVIEW COMMENTS

Letter dated January 16, 1977
from Norman C. Pardue, Jr., P.E.
Consulting Civil Engineer
Manassas, Virginia

to

Dr. Fred Costello, P.E.
Chief Engineer
InterTechnology Corporation
Warrenton, Virginia

NORMAN C. PARDEE, JR., P.E.
CONSULTING CIVIL ENGINEER
6819 BEN. LONGSTREET'S LANE
MANASSAS, VIRGINIA 22110
(703) 754-4254

January 16, 1977

Re: Telex Communications, Inc.
Blue Earth, Minnesota
Solar Heating System Project
ERDA contract no. E(49-18)2376

Dr. Fred Costello, P.E.
Chief Engineer
InterTechnology Corporation
Warrenton, Virginia 22186

Dear Fred:

As ITC's structural consultant, I have reviewed the structural portion of the NASA design review comments. I find most of the comments to be extremely fallacious and misleading. In many instances the review comments show a lack of sound, practical engineering judgement and an inability to read either the calculations or design drawings. There are gross errors in fact regarding what is purported to be in the calculations and design drawings. I am much dismayed and incensed at the quality of the review and the professional ethics of the NASA men involved for not giving me or ITC the courtesy of a phone call for clarifications on questions that they had prior to issuing a formal review report to your client (Telex). And, I can well appreciate your concern about misplacing your trust in me when fallacious comments, such as these, are made about my calculations and professional judgement. The damage of such mendacity has been done and no rebuttle, however effective, is as potent as the initial charges. Fortunately, our relationship is such that I hope these review comments will not adversely affect the goodwill I have enjoyed up til now.

NASA certainly has performed no detailed review analysis and design of the structural portion of the project. It appears that the reviewers merely flagged areas in the design and calculations where in my judgement negligible overstressing was permissible and noted as so. (I will explain later in this letter the rationale behind such judgements.) In other instances, the reviewers cite as faults design situations that do not exist. For instance, item 3 of the review comments cites page 17 of the calculations for overstress in horizontal shear of a notched beam. Casual review of the design drawings by the design reviewers would have revealed to them that no such situation exists. This calculation was a determination of the stresses that existed at an earlier time in the course of the calculations when notching of the diagonal 2X6 struts was considered to accommodate joist hangers. This idea was later dismissed, partially because of the calculation of the overstress. Calculations by their very nature are not static, but

reflect the engineer's continuing evaluation and judgement. Another instance of such gross misrepresentation is found in review comment item 4 where the design reviewers cite page 19 of the calculations for using $3/4"$ anchor bolts in the concrete piers. These being, they claim, oversized bolts. Casual review of the calculations and design plans will reveal no mention of $3/4"$ anchor bolts in the concrete piers. The calculations call for $1/2"$ anchor bolts with 6" embedment as do the design plans. The most blatant example of poor practical engineering judgement is illustrated in the design review comment item 1 where the design reviewers cite a 17 foot deep concrete pier as possibly being required. A good size high rise building, I suspect, could be supported on such a foundation. I sincerely question the qualifications of the design reviewers. A registered, professional civil or structural engineer with experience in design would not even suggest a 17 foot deep pier, nor would such a qualified individual misinterpret or misrepresent the situations cited above. Further, it dismayed me that the reviewers did not question more pertinent design criteria such as the active and passive soil pressure or the soil density. These criteria are not found in the soils report, but were requested of Mr. Donovan Stormoe over the phone by me and later documented in a letter (attached). It also dismayed me that the reviewers did not catch the errors in the calculations that I was aware of but had not corrected due to their insignificance. There are many other such fallacious statements which I will cover later in this letter.

It is my feeling that ITC must rebut item by item these pernicious comments as not only is my professional reputation at stake, but ITC's as well. However, before I rebut each item I would first like to elaborate on the nature of structural calculations in the field of civil engineering and what is required of engineering judgement.

Among the major responsibilities of the consulting structural engineer is to provide his client with a structure that serves the client's needs, is economical, and is not hazardous to health or life. In performing those functions he draws on many years of education and experience to solve design problems. Particularly important for developing a solution for structural designs are calculations and design plans (or sketches). It would be extremely misleading to assume that the structural engineer analyses or designs every item of a design through manipulation of numbers, formulas and code requirements. Many of the things considered by the practicing engineer never get down on the paper. Other considerations are so obvious to the practicing engineer that he may merely cite his reasoning as "by inspection." Long beams, for instance, will probably be more critical in bending rather than in shear. An experienced structural engineer may likely not show a calculation for the shear stress, or only once for one beam and not for other similar beams. Likewise, by experience a practicing engineer will not show computations for a solution to a situation in which by experience the engineer knows beforehand the proper solution. I am referring here to item 14 of the mechanical section of the design review.

The test of the structural design is not the amount of calculations performed or their rigid computational accuracy. All structural designs by their very nature are models, and as such are subject to variations in modeling as performed by each structural engineer. The true test is the reasonableness of the engineer's approach, and the ultimate solution: does it perform its function? Throughout all of this the structural engineer must

exercise his professional judgement. Codes, for all their value, are merely one measure of a structure's adequacy and in many instances the codes are inadequate or grossly severe (see the 1976 Engineering News-Record article on Henry Degenkolb, Consulting Structural Engineer). Situations and codes invariably call upon the engineer to exercise his rational judgement based on his experience. Examples of some areas that require such judgements are determination of what constitutes lateral support for a beam or what constitutes fixity for a column. Further, in the course of a design the structural engineer may come across a member that is slightly overstressed. It is at that type of situation where the designer must reflect on the design philosophy, load assumptions, safety factors, modeling, computational accuracy, as well as, the real world situation in determining whether to accept the member or reject it. This type of judgement can only be done by an engineer who has thoroughly absorbed the design philosophy and computations. Typically, a structural engineer may comment that he will be more conservative in designing columns than in designing beams, thus reflecting his appreciation of the relative importance of these members. The foregoing, by way of illustration, constitutes in a small way what is meant by "engineering judgement."

Engineering judgement initially requires adopting a design philosophy. It would be clarifying here to state that I was consulted to design an economical structure that would have at least a twenty year life. This was ITC's major concern regarding the structure (in addition to its practical functioning). This design philosophy is totally justified, as solar energy systems are costing much more than the commonly advertised \$20 per square foot of collector area. Experience indicates that costs in the neighborhood of between \$40 and \$80 per square foot are more likely. At these costs, it has been explained to me, solar energy may not prove competitive with other conventional energy sources. With this in mind, I opted for wood as the structural material. Treated wood easily has a twenty year life; it is easily constructed and maintained; and, is one of the least expensive structural materials. Likewise, when Mr. Stormoe, the soils engineer, reported requiring a bell footing at the end of the concrete pier, I questioned him on his design philosophy. I explained to him that the cost of such a foundation would be excessive and unjustified. I told him that we could tolerate seasonal movements of the structure up and down provided we did not get excessive differential movement. I again questioned him about a foundation curb. He discouraged the curb idea citing that water would freeze under such a footing and subject the structure to differential heaving. Understanding our requirements of an inexpensive, but functional foundation that would not be exposed to differential heaving, he recommended a drilled and cast-in-place concrete pier with a tip elevation below the frost line. (During the course of our conversation, Mr. Stormoe mentioned that he had been recently involved in the foundation requirements for airport runway lamps which require no movement and that the bell footing was a carry over from his design philosophy on the previous project. He felt that if movement could be tolerated, then certainly a bell footing was an excessive requirement.) Attached is a copy of a letter from Mr. Stormoe documenting this, as well as, the active and passive soil pressures and soil density.

REBUTTAL OF DESIGN REVIEW COMMENTS

ITEM:

1. I have checked these calculations. There is no code requirement that I know of that require calculations to be initialed as being checked. To be sure, many consulting offices may require this of their employees. In some offices this may be very rigorous; in others very lax. In some offices merely the approval of the chief engineer is required on the final design. In any event, these structures are not of such complexity (nor a hazard to life) to warrant a rigorous independent check by another structural engineer. A consultant, such as myself, rigorously reviews his own designs prior to the formal submission for construction bids or building permits. It is understood by ITC that I should be consulted again for complete document review prior to issue for bids or building permits.

The concrete piers do not address forces due to frost heave as we can tolerate seasonal movement of the structure, so long as it is not differential movement. The soils engineer was consulted concerning this. See his attached letter and the body of this letter for further amplification.

2. I do not see any discrepancy between the members selected in the calculations and as shown on the drawings. The reviewers may have outdated prints.

In regard to the L/d ratio comment citing the A.I.T.C. requirement that L/d for simple columns be equal or less than 50 ($L/d \leq 50$), let it be understood that this is an area in which engineering judgement must prevail. When computing the stresses in the members, I did not feel it warranted to comply with the L/d requirement since the allowable stresses computed for the 2X4's was based on

$$F_c = \frac{0.3E}{(L/d)^2}$$

which reduces allowable stress inversely as the $(L/d)^2$ ratio increases. And, in addition, I felt that my design loads in the critical reversal condition were excessive. The large compressive force in U₅L₄ (175 lbs.) is the result of a wind load from the back of the collectors. I computed this load at 1.75 times the wind load from the front of the collectors to account for wind suction. If one reviews the Uniform Building Code (UBC, 1976 ed.) section 2311.c. one will find that it states "Roofs of unenclosed buildings, roof overhangs . . . or similar structures unenclosed on one or more sides shall be designed to withstand upward pressures equal to one and one-fourth times those values set forth in Table No. 23-F." A copy is attached. This is merely one of the considerations I made while considering the use of 2X4's. Additional considerations that I took into account were the function of the structure and the consequences of its failure. As for the function, there is no hazard to life should the structure fail; the loading condition would be extremely unlikely and temporary in nature; and, in any event, the truss plates provide some fixity for the member U₅L₄. Also, the UBC wind table might allow a 15 psf design load in this area of Minnesota. See attached charts. We have checked with the local building department and they require a 20 psf

design wind load, but they might concede that lowering the wind load requirement for this structure would be in order. Nevertheless, let us review the design considering 20psf wind load. Let us first reduce reversal forces in proportion to the UBC requirements. Let us, also, in view of the incorrect loading of the truss, correct the applied loads. I had been aware of this error earlier, but have not changed the computations to reflect it because the error is inconsequential to the final design. I was dismayed that with all that was considered by the reviewers that they had not cited this.

Wind from the right: see calculation page 13

$$W_2 = -1.25 \times 80 = -100 \text{ plf}$$

$$\sum M^P = 0 = -100 \times 8^2/2 + 40 \times 80 \times 2.06 - 8.25B_y$$

$$B_y = -308 \text{ lbs.}$$

$$B_{\text{thrust}} = -360 \text{ lbs.}$$

With the corrected truss forces let us consider the capacity of the members. As I mentioned earlier the $L/d \leq 50$ requirement I felt under certain circumstances warranted being neglected when in the judgement of the engineer the structure will perform adequately for its function. Remember that this structure is not a building. Armed with this design review's questioning my judgement concerning the sizing of the members for the truss, I decided to call outside independent agencies for their requirements. I particularly wanted information on simple wood column fixity and the basis of setting an arbitrary L/d ratio for wood columns regardless of loading conditions and fixity. It seemed unreasonable to me that 2X4 columns lightly loaded or temporarily heavily loaded should be required to conform to a maximum length of 6.25 feet. In fact if one reads the A.I.T.C. section 4-3 cited by the design reviewers, it states in the second and third paragraphs justification for the use of engineering judgement:

"The procedures presented have been found to be the methods most suited to the particular member or system in question; however, other methods may be used if substantiated by tests or sound engineering principles.

"The examples are illustrative only. In actual design, all the conditions which might be expected to have a bearing on the ability

of the member or structure to support all anticipated loads safely should be considered."

To settle the question I called Mr. Bob Hewit, Director of Engineering of the National Forest Product Association (NFPA), Washington, D. C. which publishes the National Design Specification for Stress-Grade Lumber and Its Fastenings. I explained to him the information I was looking for and he recommended the following USDA report: "Test of Large Timber Columns and Presentation of Forest Product Laboratory Column Formula" by Newlin and Cahagan (technical bulletin #167, 1930). This may be obtained at P.O. Box 5130, Madison, Wisconsin or possibly from the government printing office. I asked whether this would apply to small columns and he indicated that it would. A discussion of the L/d ratio limitation would be found there. I then explained in more detail the specifics of my problem of trying to determine an effective L for a 2X4 compression member in a wood truss citing the temporary nature of the loads and the fixity at the connections as ample justification for using a 2X4 of an L/d ratio greater than 50. He then pointed out the NFPA is in the process of revising their code requirements concerning the L/d ratio statement to include a provision for the engineer's judgement in determining fixity at the connections. This has been a source of controversy among engineers. Some maintain that no allowance can be made. Others maintain that an allowance for fixity can be made. Mr. Hewit indicated that the original intention was for the engineer to apply his judgement and that this new code is being revised to clear up the controversy. I asked if the A.I.T.C. will concur in their new code, and he informed me that one of the directors of the NFPA sits on the board of the A.I.T.C. and they are revising their code likewise. Hewit also offered that the Canadian Code already reflects this pending change and that there have been many instances of 2X4's being used in situations as columns with effective lengths over 6.25 feet; however, he imagined that the applied loads were low. He then recommended that I talk with Mr. Bob Spangler, Managing Director of the Truss Plate Institute, Washington, D.C. regarding column fixity provided by truss plate connectors. Mr. Spangler told me that the Truss Plate Institute's design specifications allow an effective L factor of .8 for compression members in a truss, and that certainly there are 2X4's in compression used in trusses that are longer than 6.25 feet. He volunteered that actual studies by an independent testing agency found that the effective L factor to be more in the range of .7. Based on these discussions and my professional judgement, I do not feel that there should be any concern for the adequacy of the truss as designed. See attached specifications.

Now, in this light, let us examine the truss members again. Certainly, there are members whose L/d ratio exceed 50, and there are possibly members whose effective L/d ratio exceed 50, but are the stresses in the members significant.

U₅L₅:

$$f_c = \frac{P}{A} = \frac{914}{5.25} = 174 \text{ psi}$$

$$F_c = \frac{0.3E}{(L'/d)^2} = \frac{.3 \times 1.5 \times 10^6}{(.8 \times 92/1.5)^2} = 186.9 \text{ psi} > f_c - \text{ok}$$

$$KL/d = .8 \times 92/1.5 = 49 < 50 - \text{ok}$$

Note: this does not include a 1/3 increase in stress due wind loading.

∴ Use 2X4 DFL - studs grade

U₅L₄:

$$f_c = \frac{P}{A} = \frac{602.59}{5.25} = 114.8 \text{ psi}$$

$$F_c = \frac{0.3E}{(L'/d)^2} = \frac{.3 \times 1.8 \times 10^6}{(.8 \times 94/1.5)^2} = 215 \text{ psi} > f_c - \text{ok}$$

$$KL/d = .8 \times 94/1.5 = 50.13 \approx 50 - \text{say ok}$$

Note: this does not include a 1/3 increase in stress due wind loading.

∴ Use 2X4 DFL - No. 1 grade

Other members in the truss can likewise be justified, especially in view of their considerably lower loadings.

Please note that in the original calculations U₅L₄ was not stressed to 173 psi as was purported in the design review comments. Again they have misread and misinterpreted the calculations.

3. As noted in the body of this letter, a situation with horizontal shear in a notched beam does not exist. The review comment is fallacious in its import.
4. This comment is erroneous in stating that it is good practice to embed anchor bolts to develop bolt strength. See response to item 5 below. It is also erroneous in stating that I called for 3/4" ϕ anchor bolts for the piers, nor is this indicated anywhere in the drawings. I call for 1/2" ϕ anchor bolts with 6 inches of embedment to resist tension.
5. Typically, anchor bolts are not designed to develop concrete bond stress nor bolt stress. This is the type approach used to develop deformed reinforcing bars (rebars). An anchor bolt is not a rebar. Typically, anchor bolts are designed with concrete shear strength as the mode of failure to be avoided. When designing anchor bolts the structural engineer has several alternatives. I will only mention two here. Theoretical design of anchor bolts is quite complex and generally not warranted except in sophisticated structures requiring likewise design calculations. Most structural engineers will refer to a building code like the UBC. See Table No. 26-G, "Allowable Shear and Tension on Bolts" (attached).

In item no. 4 above I call for a 1/2" ϕ anchor bolt with 6" embedment. The UBC allows a 950 lbs. tension load in a 1/2" ϕ A.B. with 4" embedment.

With inspection for proper placement, that value may be increased 100% which is 1900 lbs., and considering that such loading is due to wind, we can allow a 1/3 increase which is 2527 lbs > 2100 lbs - ok.

Now let us consider the design review comment that 89 anchor bolts are required versus ITC's 65 to secure the tank. Consider one thing first, it is highly unlikely that this tank will be buried and not contain liquid; thus no buoyancy effect. If the condition should occur it will only be of short duration. Referring to UBC Table No. 26-G we find that 3/4" ϕ anchor bolts with 5" embedment are good for load of 2250 lbs. each. If the engineer inspects the bolts for proper placement, the allowable load may be increased 100% to 4500 lbs. each. If one considers the temporary nature of the loading a 1/3 increase should be allowed. Then due to the temporary nature of the loading, the capacity of the bolt would be in the range of 5985 lbs. each.

$$\text{No. A.B. req'd.} = \frac{\text{buoyancy force}}{\text{bolt capacity}} = \frac{311\text{k}}{5.985\text{k/bolt}} = 52 \text{ bolts.}$$

In actual fact ITC's design provides for 70 anchor bolts with 7" embedment (2" longer than the UBC minimum). This is perfectly adequate.

The other method a structural engineer might use to design anchor bolts would be similar to the design method found in the Prestressed Concrete Institute Design Handbook for Precast and Prestressed Concrete, figure 6.1.12 (attached) where formulas and theory are developed for tension capacity of weld headed studs in concrete. As I stated earlier anchor bolts are not rebar and actually have, at the very least, a head which contributes to the development of a shear cone in the concrete similar to a weld headed stud. Illustration:

6. The slab rebar as designed are adequate. The design reviewers must have an old print, because I recall a drafting error in which the draftsmen mistakenly indicated the temperature rebars as the main rebars. The rebars as shown on page 22 of the calculations are correct and the latest drawing reflects this. The main rebars are #5@3 1/2" o.c. The difference in moments as computed by the design reviewers versus the moments I computed is insignificant. One engineer's model may be more or less accurate than another's. Who is to say which? The fact of the matter is that #5@3 1/2" o.c. provide more steel per foot (1.05 sq. in./ft.) than either #7@7" o.c. (1.03 sq.in./ft.) or #7@7 1/2" o.c. (0.96 sq. in./ft.) as suggested by the design reviewers. #5@3 1/2" o.c. get better distribution and I am certainly not going to reduce the area of steel that I feel is required.
7. Again the difference in moments computed by the design reviewers and myself is insignificant. ITC's moment is greater and the calculations

call for #6@5 $\frac{1}{2}$ " o.c. The reviewer again flags the fact that the drawing of the wall at the center line location indicates #5@5 $\frac{1}{2}$ " o.c. failing to notice that the wall in the drawing is a 12" wall while the wall in the calculations is a 9" wall. The reviewer may not have had the addendum to the calculations, but missing such an obvious discrepancy certainly casts doubt in my eyes as to his credentials. A copy of the structural calculation addendum is attached.

8. The design reviewers here flag the uniform load over the pump pit slab maintaining the W=381 plf vs. ITC's 230 plf. Part of what has happened here is that my calculations reflect only a 1'-6" ground cover over the slab. After the computations, unknown to me, it was decided to increase the cover to 2'-4". Nevertheless, it will be shown that the slab design is adequate. (Notice that the reviewer did not include a live load on the slab. This is certainly unrealistic.) It should also be noted that the slab was designed for simple bending ($M=WL^2/8$, unrestrained rotation at the supports) which is not totally realistic, but is conservative and in line with engineering judgement. The slab has definite continuity at the walls:

$$W = .67 \times 150 + 40 + 2.25 \times 125 = 421.25 \text{ plf}$$

$$\text{actual span} = 9'$$

$$M_u = 1.4 \times WL^2/12 \text{ (due to continuity at the supports)}$$

$$= 1.4 \times 421.25 \times 9^2/12 = 3.98^k < 4.02^k - \text{actual moment capacity}$$

9. I do not have a copy of the specifications and therefore cannot comment, except to say that it is understood by ITC that I have complete design review privileges and that any discrepancies will be corrected.
10. No comment required.
11. I have not been involved in the selection of the protective coating and expect others at ITC to respond.
12. Site grading is not required as the site is level.
13. See 9 above.
14. See 9 above. An 18" slab is required.
15. See 9 above.
16. Not my area of responsibility.
17. Typically, tank saddles are not designed by consultants but by the vendor. It is the vendor's responsibility to provide adequate and properly designed saddles.
18. Sand bedding and backfill are not required and represent an additional and unwarranted expense. We intend to lay the tank on undisturbed

soil and backfill with the excavated soil. Sand is likely to compress, whereas the undisturbed soil is likely not to. What is the rationale behind this?

19. C6X8.2

20. I question the validity of this requirement. My feeling is that provided the pipe is well insulated (I do not know if this is case) there is little reason to require the pipe at a lower elevation. At any rate, let us check with soils engineer.

21. Variability of the pier depth is not anticipated. See soils engineer's attached letter.

22. Snow drifting should be a minimal problem since the bottom of the solar collectors is 4 feet above grade. Snow will not stand on the collectors and if it should, the design loads based on wind loadings would be adequate. One does not apply simultaneously wind loads and snow loads under these design circumstances.

Architectural:

1. The wood is pressure treated per the specifications and it is highly unlikely that the wood will rot due to standing in water accumulated on the top of the piers.
2. I have not been consulted in this area.
3. A P.E. stamp is not required until the final design for submission to the building department. Preliminary designs are rarely (almost never) stamped by a registered engineer.

Mechanical:

I will respond in this area only where I have had involvement.

14. This is an area where past experience and engineering judgement prevail. I have had lengthy experience in the support of piping with Bechtel Corporation's Refinery and Chemical Division and based on this experience I determined that 24 foot spacing would be adequate. Attached is a copy of a design standard used by Bechtel in determining how often to support piping. Note that they cite past experience in justifying the deflection of the piping. If the reviewer is concerned about the bending stresses, shear stresses and deflection, it would be a simple matter for him to perform a moment distribution and find a criteria by which to judge the adequacy or inadequacy of the spacing. If my memory serves me well the piping sizes we are concerned here with are between 2"Ø and 4"Ø. I will have to review the piping drawings to see if there is any reasonable concern.

I would like to restate that prior to this design being submitted formally for bids and the building permit that I should be consulted to review that portion of the design plans and specifications that directly relate to my specialty. In addition I should like to review the bid package

for proper contractual arrangements to assure that the contractor complies with the design and specifications. During the course of preparing this rebuttle, I have notice additional minor changes I would like to consider, and I will discuss these details with you at a later date.

In conclusion, I would like to assure you, your client and the NASA design reviewers that in my judgement there is nothing substantively in error with the structural design for this project. Further, from what I have seen in these review comments, I do not feel that NASA is qualified or in a position to judge the structural design for this project. We (ITC), I feel, have taken an in depth look at this project, and it is obvious to me that NASA has not.

Again, fallacious comments as made by the design reviewers have no place in a formal professional review of this nature. Many of the problems the reviewers have had in reviewing the calculations and drawings could have been cleared up with a simple courtesy phone call. I am not certain about a violation of professional ethics, but it is definitely suspect. I intend to contact the American Society of Civil Engineers for their opinion. I certainly feel that I and ITC are owed a formal apology for such pernicious comments to Telex prior to our being consulted.

The reviewers and Telex should rest easy since this design is still subject to our review (and revision) which has been much more substantive than NASA's review, and particularly in view of the fact that we are ultimately responsible for the design and not NASA.

If I can be of further assistance to you in this matter, please do not hesitate to call. Should the NASA reviewers wish to contact me, I may be reached at the following numbers: 202-872-8688 (days) or 703-307-9190 (evenings). Please note my new address at

75 S. Reynolds St, G120
Alexandria, Virginia 22304

Very truly yours,

Norman C. Pardue, Jr. P.E.
CONSULTING ENGINEER

Attachments: as noted

APPENDIX F-3

REPLY TO NASA REVIEW COMMENTS
BY INTERTECHNOLOGY CORPORATION

ARCHITECTURAL/STRUCTURAL COMMENTS

We are limiting our remarks to NASA review comments on architectural and structural to items 11, 13 and 16, of the structural review, and 1 and 2 of the architectural review. Our structural consultant has adequately answered the other items. NASA should refer to the attached letter for these remarks. We are, however, adding some additional comments to his answers on items 5, 19 and 20.

<u>ITEM</u>	<u>REMARK</u>
5	Inspection will be requested per Section 03300, para. 3.01 A-2 of the specification, so the higher loading cited by the consultant apply.
11	See Sheet M-2, Section- 3 for the end points of the hyplon protective Coating. Corrosion protection for the exposed metals to be buried can be found in Section 15600, para. 2.07 B-4 of the specifications.
13	"Footings" in Section 03300, para. 2.01 B-1 should read "Pit Walls". This will be corrected in the 100% submission.
14	Specification should read 18 inch. This will be corrected in the 100% submission.
15	The dimension in millimeter (0.40) will be added.
16	No Comment required.
19	Weight will be indicated on drawings at 100% submission.
20	Pipes from the storage tank to the building will be buried at 5' below grade, the collector supply and return piping will remain at 3'-0" below grade, and will be so indicated on the drawings for the 100% submittal.

ARCHITECTURAL

- 1 In addition to the remark of our consultant, the amount of standing water on top of the piers at any given time will be insignificant.
- 2 NASA's comment includes the necessary reply.
- 3 Drawings shall be stamped on application for building permit.

MECHANICAL COMMENTS

- 1 We disagree with the comments. We recommend the 2 way valve as designed for the following reasons:
 - a) Two-way valves allow only that quantity of water to flow through the underground supply and return mains which is actually required by the heating coils to satisfy the building heat load. The rest of the water is by-passed around the pump in the pit.
 - b) Reduced flow in several hundred feet of underground pipe reduces heat losses from pipes. The controls are designed such that our pump can be automatically shut down during prolonged periods of reduced heating loads.
 - c) Reduced flow also results in reduced pipe friction losses which means savings in pumping horse power.
 - d) Two-way valves cost much less in material as well as installation costs.
- 2 Expansion loops have been sized according to the charts provided by the manufacturer of the specified pipe (Perma-Pipe) and the charts given in the Carrier Pipe Design Manual.
- 3 Comment withdrawn by NASA
- 4 We will provide an anchor support detail in our 100% submission.
- 5 In standard HVAC design practice only a description of control sequence is provided. A control diagram can be prepared if requested by the client.
- 6 High temperature flexible hose is not sensitive to ultra-violet sun rays. As NASA noted, the flexible hose accomodates expansion and contraction.
- 7 Comment withdrawn by NASA.
- 8 We will locate the manhole on our drawings.

- 9 Tank material is called out in specifications section 2.07 page 9. We did not call out fittings because we were waiting for Instrumentation design from NASA so that all fittings can be called out together.
- 10 The piping in the pit has been designed to permit easy maintenance. The contractor is also required to submit shop drawings for all work. We plan to make necessary revisions at that time.
- 11 Specification Section 2.05 page 7 does not call for flexible connectors. It calls for flexible coupling between pump and motor. The words "Split Case" will be deleted from specifications.
- 12 All pipe penetrations will be added to the drawings in 100% submission.
- 13 According to the manufacturer, conduit at all the elbows is slightly oversized to accomodate pipe expansion. We will also call this out in our specifications. See structural comments.

ELECTRICAL COMMENTS

- 1 See Electrical specifications para. 1.07 grounding systems.
- 2 Same as item 1.
- 3 Same trench as for line shall be used.
- 4 We will comply in next submission.
- 5 Wire is oversized because of the long run from Panel board. Panel board will be shown in the next submission.
- 6 We will comply and show the panel in next submission.
- 7 We will comply and show the panel in next submission.
- 8 We do not understand the necessity of changing our wording.
- 9 We will comply. The heater is electric.
- 10 We will change to 200 watts.
- 11 Yes.

APPENDIX G
TECHNICAL SPECIFICATIONS

APPENDIX G
TECHNICAL SPECIFICATIONS

Collectors:	InterTechnology/Solar Corp. Mark III
Storage:	Arrow Tank and Engineering Corp.
Controls:	Johnson Controls
Underground Pipe:	Rovanco Insul-8
Pumps - Collector:	Bell & Gossett 80 - 3x3x9½ 7½ hp
- Load (2):	Bell & Gossett 80 - 2½x2½x9½ 5 hp
- Sump:	Aurora 531 - 4x4x7A 2 hp
- Emergency Sump:	Peabody Barnes 151CU-1 3x3
Collector Flow Balancing:	Bell & Gossett Circuit Setters
Floating Coils:	McQuay 5WH,5WS
Unit Heaters:	McQuay UDH
Flow Switches:	McDonnell FS4-3, FS4-3-20
Heating Control:	Penn Controls M80J Proportional Motor Activator
	Penn Controls V90AA 2-Way Single Seat Globe Valves
Water Treatment:	Culligan Mark 512
Valves V-1, V-2	Johnson Controls VB 3752, VB3970 with VA3200 Electro-Hydraulic Valve Activator
Shut-Off Valves on Collector:	Milwaukee Bronze Gate Valves
Supply Lines	
Space Heating Valves:	Gate - Milwaukee
	Balance - Rockwell Plug
	Check - Milwaukee

APPENDIX H
PERFORMANCE FACTORS AND SOLAR TERMS

APPENDIX H

PERFORMANCE FACTORS AND SOLAR TERMS

The performance factors identified in the site equations (Appendix C) by the use of acronyms or symbols are defined in this appendix. Section 1 describes general acronyms used in this report. Section 2 includes the acronym, the actual name of the performance factor, and a short definition.

Section 3 contains a glossary of solar terminology, in alphabetical order. These terms are included for quick reference by the reader.

Section 1. General Acronyms

Section 2. Performance Factor Definitions and Acronyms

Section 3. Solar Terminology

SECTION 1

GENERAL ACRONYMS

ATCE	Auxiliary Thermodynamic Conversion Equipment.
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 degree Fahrenheit. One BTU is equivalent to 2.928×10^{-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.
TCE	Thermodynamic Conversion Equipment.

SECTION 2

PERFORMANCE FACTOR DEFINITIONS AND ACRONYMS

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
ASTECH	Change in Energy Stored in Cold Storage	Change in stored energy in cold storage during specific time period.
ASTEFF	Cold Storage Efficiency	Ratio of the sum of energy supplied to cold storage and the change in cold storage energy to the energy removed from cold storage.
ASTEI	Energy Delivered to Cold Storage	Amount of energy delivered to cold storage from the load.
ASTE0	Energy from Cold Storage	Amount of energy removed from cold storage by the chiller
ASTLOSS	Cold Storage Loss	Total energy losses from the cold storage subsystem.
ATCECOP	Auxiliary Cooling Subsystem Coefficient of Performance	The ratio of the auxiliary cooling subsystem load to thermal or electrical energy input.
ATCEI	Auxiliary Cooling Subsystem Thermal Energy Input	Equivalent thermal energy supplied as a fuel source to the auxiliary thermodynamic conversion equipment.
ATCEL	Auxiliary Cooling Load	Thermal energy removed from the air being cooled by the auxiliary thermodynamic conversion equipment.
ATCEOPE	Auxiliary Thermodynamic Conversion Equipment Operating Energy	Energy required to support the operation of the auxiliary thermodynamic conversion equipment; e.g., pumps, fans, etc.

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
ATCERJE	Auxiliary Rejected Energy	Amount of energy intentionally rejected from thermodynamic conversion equipment as a by-product of its operation.
ATST	Average Cold Storage Temperature	Average temperature of the cold storage medium.
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.
* BL	Building Load	Sum of heat conducted through the building walls and ceilings, and heat convected through cracks, doors, and windows as air infiltration.
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.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
CAT	SCS Auxiliary Thermal Energy	Amount of thermal energy supplied to the SCS by the auxiliary equipment. For vapor compression units, it is CAE multiplied by compressor efficiency.
CDD	Cooling Degree-Days	A rough measure of the cooling requirement. This performance factor is the difference between the mean daily temperature, TAVE, and 65°F. If the mean is 65°F or less, cooling degree-days are zero.
CDE	Controlled Delivered Energy	Space heating intentionally delivered by the space heating subsystem including solar and auxiliary. This does not include heat losses from electric motors, pipes, storage, and other equipment.
* 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.
CLEF	Collection Subsystem Efficiency	Ratio of the energy collected to the total energy incident on the collector array.
CLEFOP	Operational Collection Subsystem Efficiency	Efficiency when there is fluid in the collector loop.
CLS	Solar Energy Contribution to Cooling Load	The portion of the total cooling load which was satisfied by solar energy.

* Primary Performance Factor

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
COPE	SCS Operating Energy	Amount of electrical energy required to support the SCS operation (fans and pumps) which is not intended to directly affect the thermal state of the subsystem.
COPE1	Solar-Specific Operating Energy	The operating energy necessary to the functioning of the solar energy portions of the SCS.
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.
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	Percentage of the SCS load which is supported by solar energy.
CSOPE	ECSS Operating Energy	Amount of energy used to support the ECSS operation (e.g., fans, pumps, etc.) which is not intended to affect directly the thermal state of the subsystem.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
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 SCS loads.
EHL	Equipment Heating Load	Amount of energy supplied to the space heating subsystem equipment: solar, auxiliary thermal, operating energy converted to heat, and losses from the space heating equipment which contribute to heating (the building heating load less internal gains).
GENOPE	Power Generation Operating Energy	The electrical energy required to operate the ECSS and Rankine subsystems when they are in the power generation mode.
HAE	SHS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SHS to be converted and applied to the SHS load.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
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 thermal energy provided to the SHS by the auxiliary SHS.
HDD	Heating Degree-Days	A rough measure of the heating requirement. This performance factor is the difference between the mean daily temperature and 65°F. The mean is the average of the minimum and maximum temperatures for a given day. If the mean is 65°F or more, heating degree-days are zero.
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).
HOPE1	Solar-Specific SHS Operating Energy	Operating energy necessary to the functioning of the solar energy portions of the SHS.
HOURLCT	Record Time	Count of hours elapsed from the start of 1977.
HSE	Solar Energy to SHS	Amount of solar energy delivered to the SHS, including thermal losses from solar heated fluids.
HSEL	Solar Energy Losses to Load	Solar energy losses from storage and other equipment which heat the conditioned space.
HSEM	Measured Solar Energy to SHS	Solar energy intentionally delivered to SHS by the distribution network. Does not include solar energy losses which also sometimes contribute to space heating.

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
* HSFR	SHS Solar Fraction	Percentage of the SHS load which is supported by solar energy
* 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 Consumed	Amount of heated water delivered to the load from the HWS excluding tempering water.
HWCSMA	Tempered Hot Water Consumed	Amount of heated water delivered to the load from the HWS including tempering water.
HWDM	Hot Water Demand	Total energy required to raise the hot water used from the supply water temperature to the hot water temperature
HWDSFR	HWS Solar Fraction of Demand	Percentage of the "hot water demand" which is supplied by solar energy.
* HWL	Hot Water Subsystem Load	Amount of energy supplied to the HWS.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
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.
HWOPE1	Solar-Unique HWS Operating Energy	"Operating energy" necessary to the functioning of the solar energy portions of the HWS.
HWSE	Solar Energy to HWS	Amount of solar energy delivered to the HWS.
HWSE1	Solar Energy to Preheat Tank	The amount of solar energy input to a preheat tank.
* HWSFR	HWS Solar Fraction	Percentage 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.
LINLOS	Recirculation Loop Losses	Thermal energy losses due to recirculation of hot water in a large building loop.
OUTVC	Cooling Produced	Space cooling provided by the air conditioner, energy removed from the conditioned space.
PARA	Rankine Parasitic Power	Amount of auxiliary electrical energy supplied per unit time to the refrigerant pump and the Rankine subsystem controls.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
PRELOS	Preheat Tank Losses	The difference between the input solar energy to a pre-heat tank and the output solar energy to the HWS tank. This includes losses and changes in internal energy.
PWRGEN	Rankine Power Generated	Amount of electrical energy per unit time produced by the motor generator from the shaft power of the gas turbine.
PWRSVE	Rankine Power Generation Savings	The net output of the Rankine engines when operating in the power generation mode.
RANKOUT	Rankine Turbine Output	Mechanical energy developed at the output shaft of the Rankine engine gas turbine. Includes energy losses in the gearbox. This shaft output can drive a motor generator or an air conditioning compressor.
REFF	Rankine Thermal Efficiency	The ratio of RANKOUT to RSE. This percentage was developed from laboratory experimental data taken from gas turbines operating under typical conditions at the solar sites.
RELH	Relative Humidity	Average outdoor relative humidity at the site.
ROPE	Rankine Operating Energy	Amount of electrical energy required to support the Rankine system. Includes energy for boiler feedwater pumping, cooling tower pumping, cooling tower fan and parasitics.
RSCAE	Rankine Auxiliary Electric Used	Amount of auxiliary electrical energy supplied to the motor generator for driving the air conditioning compressor.

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
RSCOP	Rankine Coefficient of Performance	The ratio of useful energy provided by the Rankine subsystem including the associated air conditioner to the operating and auxiliary energy input to the subsystem. Specifically, it is $(OUTVC + PWRGEN)/(RSCAE + ROPE)$.
RSE	Rankine Solar Energy Used	Amount of solar energy supplied to boil the refrigerant which drives the Rankine cycle gas turbine.
RSRJE	Rankine Energy Rejected	Amounts of energy intentionally rejected through the cooling tower from the Rankine condenser and air conditioning condenser.
* 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.
* SEL	Solar energy to Load Subsystems	Amount of solar energy supplied by the ECSS to all load subsystems.
SEOP	Operational Incident Solar Energy	Amount of solar energy incident upon the collector array when the collector loop is active.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
* SFR	Solar Fraction of System Load	Percentage of the system load which was supported by solar energy.
SSSR	System Solar Savings Ratio	The ratio of the sum of the solar contributions to the system load minus the solar-specific system operating energy to the total system load.
STECH	Change in ECSS Stored Energy	Change in ECSS stored energy during specific 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.
STLOSS	Storage Loss	Total energy losses from the storage subsystem.
STOCAP	Storage Capacity	The volumetric storage capacity of the storage subsystem.
STPER	Effective Heat Transfer Coefficient	The overall heat transfer coefficient for the hot solar storage tank as measured for the month: ratio of storage loss to product of outside tank area, temperature difference across insulation, and number of hours in the month.
SYSCOP	System Coefficient of Performance	The ratio of the total solar energy delivered to the load to the sum of the solar operating energies.
* SYSL	System Load	Energy required to satisfy all desired temperature control demands at the output of all subsystems.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
* 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.
SYSOPE1	Solar System Operating Energy	Operating energy that is specifically used for the solar components of the system.
* 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.
TANKV	HWS Heat-up Energy	The energy required to heat all the water in the HWS tank from the cold water supply temperature to the hot water outlet temperature.
TAVE	Average Daily Temperature	The average daily temperature as defined by the National Weather Service; i.e., the average of the minimum and maximum temperatures for a given day.
* TB	Building Temperature	Average temperature of the air in the controlled space of the building.
TCECOP	TCE Coefficient of Performance	Coefficient of performance of the thermodynamic conversion equipment, typically, the ratio of equipment load to thermal energy input.
TCEI	TCE Thermal Input Energy	Equivalent thermal energy which is supplied as a fuel source to thermodynamic conversion equipment.
TCEL	Thermodynamic Conversion Equipment Load	Controlled energy output of thermodynamic conversion equipment.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
TCEOPE	TCE Operating Energy	Amount of energy required to support the operation of thermodynamic conversion equipment (e.g., pumps and fans).
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.
TRANKC	Rankine Condensing Water Temperature	Temperature of the heat transfer fluid at the inlet to the condenser of the gas turbine subsystem.
TRANKS	Rankine Solar Water Temperature	Temperature of the heat transfer fluid at the inlet to the refrigerant boiler of the gas turbine.
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.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
* 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.
WDIR	Wind Direction	Average wind direction at the site.
WIND	Wind Velocity	Average wind velocity at the site.

* Primary Performance Factor

SECTION 3
SOLAR TERMINOLOGY

Absorptivity	The ratio of radiation absorbed by a surface to the total radiated energy incident on that surface.
Active Solar System	A system in which a transfer fluid (liquid or air) is circulated (by pump or fan) through a solar collector.
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.
Array	An assembly of a number of collector elements, or panels, into the solar collector for a solar energy system.
Auxiliary Energy	In solar energy terminology, the energy supplied to the heating 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 supplemental in nature but does not have the auxiliary system as an origin; e.g., energy supplied to the space heating load from the external environment by a heat pump.
Auxiliary Energy Subsystem	In solar energy terminology, the auxiliary energy system is the conventional heating and/or cooling equipment used as a supplement or backup to the solar system.
Backflow	Reverse flow.
Backflow Preventer	A valve or damper installed in a pipe or duct to prevent reverse flow of the fluid.
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.
Collection Subsystem	The assembly of components that absorbs incident solar energy and transfers the absorbed thermal energy to a heat transfer fluid.
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 Conversion Efficiency	Ratio of thermal energy output to solar energy incident on the collector array.
Concentrating Solar Collector	A solar collector that concentrates the energy from a larger area onto an absorbing element of smaller area.
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 mean daily temperature is <u>above</u> 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.
Drainback	Automatic draining of the collector array and piping to storage each time the collector pump shuts off.
Draindown	A system equipped with automatic or manual valves which 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 the system heat transfer fluid expands and contracts to prevent excessive pressure from developing and causing damage.
F-Chart	A computer program developed by the University of Wisconsin Solar Energy Laboratory, which calculates solar heating system performance and economics.
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 reradiated from the panel is trapped within the collector

Flat-Plate Collector (Continued)	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 terminology, 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 mean daily temperature is <u>below</u> 65°F.
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
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{T_i - T_a}{I}$, under steady-state conditions (see Operating Point).

Instantaneous Efficiency Curve

A plot of solar collector efficiency against operating point, $\frac{T_i - T_a}{I}$, (see Operating Point).

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 heating or cooling requirements.

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 earth's 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_i), and outside ambient temperature (T_a). The operating point is defined as:

$$\frac{T_i - T_a}{I} \left(\frac{^{\circ}\text{F} \times \text{hr} \times \text{ft}^2}{\text{BTU}} \right)$$

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 reradiates little of it as thermal radiation.
Sensor	A device used to monitor a physical parameter of 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, η_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 which 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.