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FORT HOOD SOLAR TOTAL ENERGY PROJECT
TECHNICAL SUPPORT AND SYSTEMS INTEGRATION

Third Semiannual Report, May 1–October 31, 1979

MASTER

February 1, 1980

Work Performed Under Contract No. AC04-78ALO4271

The Aerospace Corporation
Energy and Resources Division
El Segundo, California

U.S. Department of Energy

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FORT HOOD SOLAR TOTAL ENERGY PROJECT
Technical Support and Systems Integration

Fort Hood Solar Total
Energy Project

Third Semiannual Report
1 May 1979 -
31 October 1979

1 February 1980

Prepared by
The Aerospace Corporation
Energy and Resources Division
El Segundo, California 90245

Prepared for
The U.S. Department of Energy
Albuquerque Operations Office

Under Contract DE-AC-04-78-ALO-4271 -

FOREWORD

This report presents a summary of technical support of the Fort Hood Solar Total Energy Project conducted under the Department of Energy, Albuquerque Operations Office (DOE/ALO), Contract No. DE-AC-04-78-ALO-4271. This report is the Third Semiannual Technical Report covering the third six-month period of that contract. Although that six-month period ended 31 October 1979, supporting studies which were underway until 31 December 1979 are documented. That is approximately the date the project was discontinued by DOE.

Responsibility for direction of the Fort Hood project was transferred late in May 1979 to the DOE San Francisco Operations Office (DOE/SAN). Since that time, the project support effort by The Aerospace Corporation has been conducted under the cognizance of Mr. Robert Hughey, Director of the Solar Energy Division, and under the general direction of Dr. S.D. Elliott, Program Coordinator, at DOE/SAN.

This report was prepared by the Energy Projects Directorate of the Energy and Resources Division of The Aerospace Corporation, Mr. S.D. Huffman, General Manager. Mr. J.T. Ator, Project Manager, is the Principal Investigator.

CONTENTS

	<u>Page</u>
FOREWORD	ii
1.0 INTRODUCTION.	1
1.1 Site Location and Description.	1
1.2 Objectives	1
1.3 History	4
2.0 TECHNICAL SUPPORT ACTIVITIES	9
2.1 Reassessment of Energy Loads	9
2.2 Revised System Concept	11
2.3 Plant Sizing Calculations.	15
2.4 Insolation Variation Measurement Planning	24
3.0 REFERENCES.	28

FIGURES

		<u>Page</u>
1.	Location of Fort Hood	2
2.	No. 87000 Troop Housing Complex - Fort Hood, Texas.	3
3.	Program History	5
4.	Design Evolution - Fort Hood Solar Energy Plant	7
5.	Average Daily Thermal Loads for the 87000 Complex	13
6.	Elements of a Central Receiver STES Plant for Fort Hood	14
7.	Simplified Performance Model for Fort Hood Central Receiver STES	16
8.	Available Collector Field Size at Fort Hood	19
9.	Estimates of Peak Parasitic Loads as a Function of Gross Electrical Output	20
10.	Performance Waterfall Diagram for a Fort Hood STES	23
11.	A Representative Map of Cloud Shadows	26
12.	Sites Investigated for an Insolation Variation Experiment	27

TABLES

		<u>Page</u>
1.	Average Daily Energy Required for Hot Water at the No. 87000 Complex	10
2.	Estimated Average Daily Thermal Loads of the No. 87000 Complex	12
3.	Hourly Direct Insolation for Clear Days at Fort Hood, Texas	17
4.	Calculated Peak Performance for a Fort Hood Central Receiver STES	21

1.0 INTRODUCTION

1.1 SITE LOCATION AND DESCRIPTION

The site which had been proposed for the Fort Hood Solar Total Energy System (STES) plant is the No. 87000 Troop Housing Complex at Fort Hood, Texas. The Fort Hood Military Reservation is an area of approximately 400 square miles near Killeen, Texas. It is the home of the U.S. Army III Corps, the First Cavalry Division, the Second Armored Division and various other units with an authorized strength in excess of 40,000 personnel. It ranks second only to Fort Bragg, North Carolina in terms of electricity consumption and has approximately twice as much air conditioning as any other major U.S. military base (Reference 1). Ninety percent of the energy consuming facilities on the reservation are in the eight square-mile Main Post area.

The location of Fort Hood with respect to the cities of Austin and Dallas is shown in Figure 1, and an insert shows the location of the No. 87000 Troop Housing Complex in the eastern portion of the Main Post area. The 87000 Complex, pictured in Figure 2, comprises twenty buildings of contemporary Army design which provide housing, food services, administration, storage, and recreation for approximately 1700 troops.

Currently, electricity is supplied to Fort Hood by the Texas Power and Light Company. It provides for all lighting, power, and air conditioning requirements. Energy required for space heating and domestic hot water needs is derived from natural gas supplied by the Lone Star Gas Company.

1.2 OBJECTIVES

Prior to its discontinuance, the Fort Hood STES project was a part of the Department of Energy's Solar Total Energy Program defined in 1976 (Reference 2). The program is concerned with those solar total energy systems that use heat engines or photovoltaic devices to produce electricity (and/or mechanical work) and that apply the low-grade energy rejected by the conversion process to some useful purpose.

The overall objectives of the Solar Total Energy Program are to demonstrate the technical, economic, and institutional feasibility of the solar total energy concept and to promote within appropriate industrial or institutional market sectors a technology which offers the prospect of being economically competitive with other energy sources. An initial step toward achieving the program's goals is to design, build and operate Large Scale Experiments (LSEs) incorporating the solar total energy concept to gain experience with large hardware systems integrated with solar components and to develop the engineering capability required for producing full-scale demonstration projects.

The Fort Hood STES was planned by DOE as one of those Large Scale Experiments. It had been specified by DOE that it be large enough to encounter those engineering problems associated with full-scale applications and to necessitate the use of

Figure 1. Location of Fort Hood

No. 87000 Troop Housing Complex
FORT HOOD, TEXAS

Figure 2

components which are representative of those found in larger systems. Those stipulations resulted in the following general technical design requirements:

- (1) The STES plant shall be sized to supply 100 percent of the peak hourly and daily thermal loads, and to use solar energy to provide on an annual basis at least 50 percent of the thermal loads of buildings being served by the plant.
- (2) Electrical generation capability should be at least in the 200 to 500 kWe range, and there shall be a net positive generation on an annual basis.

1.3 HISTORY

1.3.1 Programmatic History

A programmatic history of the Fort Hood project is depicted in Figure 3. The project began in 1973 with studies funded by the National Science Foundation. In that phase data accumulation on energy loads at Fort Hood and other U.S. military bases and development of an insolation model for the Fort Hood location were begun. Also the feasibility of a variety of solar energy technology approaches to reducing the fossil fuel dependency of military bases was explored, with the Fort Hood site being used as an example. Consistent with solar technology at the time, only distributed collector systems were considered.

In 1975, project cognizance was transferred to the Energy Research and Development Administration (ERDA) which was later to become DOE. In that phase specific attention was given to developing a conceptual solar plant design for Fort Hood, matched to the energy requirements of the No. 87000 Troop Housing Complex. The design contractor, American Technological University (ATU) also procured and operated at West Fort Hood a solar collector test loop using a Sheldahl SLATS (TM) distributed collector module with pressurized hot water serving as a heat absorbing fluid. That effort was followed by a contract to produce a Preliminary Design based on the Conceptual Design arrived at in 1976. ATU was the prime contractor, assisted by Brown and Root.

A combination of project management problems and technical design issues culminated in a redirection by DOE early in 1977. Competitive design studies to seek a more favorable approach were later awarded to TRW and Westinghouse, with ATU acting in a support role to provide site data and military coordination. In September 1977, Westinghouse was selected as the winner of that design competition, with a conceptual design of a STES using parabolic trough collectors (with oil as a heat absorber) and matched to the energy demands of five selected buildings of the No. 87000 complex.

In November 1977, ATU proposed to conduct a preliminary design study along the lines of the new approach, with Westinghouse serving as the design subcontractor. A contract for that effort was awarded in March 1978. Earlier, in December 1977, technical management support to the cognizant DOE field office, Albuquerque Operations Office (ALO), began to be supplied by Aerospace. That role on the Fort Hood project had formerly been assigned to Sandia Laboratories in Albuquerque

Figure 3. Program History

(SLA). SLA management supplied valuable help during the transition period and continued their expert assistance as requested in periodic reviews of the project design.

In November 1978, the ATU/Westinghouse Preliminary Design effort was concluded. It retained the parabolic trough collector field, using paraffinic oil for heat absorption, transfer, and storage. That design was reviewed from both technical and cost standpoints by a DOE-appointed committee. DOE concluded that the design would just barely meet the minimum objectives for the project. Although it met the thermal energy goals (displacing between 50 and 60 percent of the thermal load), it failed to provide a satisfactory level of net electrical generation. Furthermore, it was noted by DOE that experimental systems using sizable parabolic trough collector fields were already in operation at Gila Bend, Arizona and Willard, New Mexico; thus the need for another large experiment using trough collectors was greatly reduced.

By December 1978, DOE Headquarters reached a decision that the ATU/Westinghouse design using troughs should be terminated, and directed DOE/ALO to give consideration to a central receiver collection approach for the Fort Hood application. Subsequently, unsolicited proposals were received to study a central receiver-based STES for Fort Hood, first from an ATU and Westinghouse team, and later from an ATU and McDonnell Douglas Astronautics Company (MDAC) team. The first proposal was deemed to be inadequate. The second proposal was considered acceptable with certain exceptions, and Aerospace recommended that it be funded by DOE.

Late in May 1979, cognizance of the Fort Hood project was transferred from DOE/ALO to the San Francisco Operations Office (SAN), which has programmatic responsibility for central receiver technology and applications development. SAN proceeded to make preparations for procurement negotiations with ATU, but as of the end of the report period a contract to revise the Fort Hood STES design had not been awarded. In mid-December 1979 ATU formally withdrew their proposal and DOE decided to discontinue the project.

1.3.2 Technical Design Review

In parallel with the above review of programmatic history, it is of interest to review the evolution of solar energy plant designs that have been proposed for application at Fort Hood over a five year period. The evolutionary sequence is shown in Figure 4 for the period from 1974 through 1979. It should be noted that the specific application site and numbers of buildings to be served were changed at various times, so that comparisons of designs on the basis of electric rating or collector aperture size would be meaningless in most cases.

The influence of rapid advances made in solar technology through the five year period is evident. By the end of the period, modular flat plate and distributed line focus collection approaches had given way to the central receiver collection concept as the preferred choice for the Fort Hood type of application. The most striking changes in design parameters are seen in the peak temperature of the operating fluid (from 200°F to 850°F) and in collector aperture (from 220,000 ft² to 92,000 ft² for plants serving the full 87000 complex).

	1974 - 1975 (Alternate Design Concepts)		1976	1977	1978	1979 (Proposed)
APPLICATION	No. 30000 TROOP HOUSING COMPLEX	FORT HOOD MAIN BASE	No. 87000 TROOP HOUSING COMPLEX	5 BLDGS OF No. 87000 TROOP HOUSING COMPLEX	5 BLDGS OF No. 87000 TROOP HOUSING COMPLEX	No. 87000 TROOP HOUSING COMPLEX
COLLECTOR TYPE	FLAT PLATE	DISTRIBUTED LINE FOCUS	DISTRIBUTED LINE FOCUS	DISTRIBUTED LINE FOCUS	DISTRIBUTED LINE FOCUS	CENTRAL RECEIVER
HEAT ABSORBING AND TRANSFER FLUID	WATER/ANTI- FREEZE	WATER	WATER	OIL	OIL	MOLTEN SALT OR WATER/STEAM
TOTAL APERTURE (ft ²)	23,200 (each bldg)	6,200,000	220,000	150,000	125,000	92,000
PEAK TEMP (heat abs fluid) (°F)	130 - 200	300	525	550	575	850
MAIN ENERGY STORAGE	WATER	PUMPED WATER	PRESSURIZED HOT WATER	HOT OIL	HOT OIL	MOLTEN SALT (or oil)
POWER CONVERSION MODE	----	HYDROELECTRIC	TURBINE/GEN	TURBINE/GEN	TURBINE/GEN	TURBINE/GEN
ELECTRIC RATING (MW)	0	5	1.33	0.22	0.25	0.5 - 1
THERMAL LOADS MET	HOT WATER, HEATING, AIR COND	AIR COND (via elec chillers)	HOT WATER, HEATING	HOT WATER, HEATING, AIR COND	HOT WATER, HEATING, AIR COND	HOT WATER, HEATING, AIR COND
DESIGN CONTRACTOR	ATU		ATU	WESTINGHOUSE	WESTINGHOUSE	

Figure 4. Design Evolution - Fort Hood Solar Energy Plant

The features listed for a proposed 1979 design are based on calculations using design data published in Reference 3, and from a presentation by McDonnell Douglas Astronautics Company. The proposed design assumes that all 20 buildings of the 87000 complex would be served by the central receiver STES plant. Aerospace calculated that it would require about 92,000 ft² total collector aperture to operate a STES plant with a nominal electrical rating of 0.75 MWe. Although the design is not completed and validated, that amounts to an output of 88 watts per square meter of aperture which may be compared with an output of about 22 watts per square meter for the 1978 parabolic trough design. The technical advantages of the central receiver approach, at least with regard to electrical power generation, thus become readily apparent.

NOTE: Although the following development took place after the period covered by this report, it is pertinent to note that an RFP was issued by DOE/SAN in February 1980, entitled "Conceptual Design of a Solar Cogeneration Facility," which requested proposals, among other categories, for solar central receiver cogeneration of electricity and thermal energy for space conditioning and service hot water at a military base. If selected, such a proposal could represent a follow-on to the work described in this report.

2.0 TECHNICAL SUPPORT ACTIVITIES

2.1 REASSESSMENT OF ENERGY LOADS

In preparation for a contracted effort to revise the 1978 Fort Hood STES design to incorporate a central receiver collection system, a new set of design requirements was drafted in July 1979 (Reference 4). Those requirements addressed a design which would still take into account only five buildings of the No. 87000 complex for purposes of a thermal energy load for the STES. It thus repeated the net thermal energy output requirements developed during the 1978 ATU/Westinghouse study.

At a project planning meeting hosted by DOE/SAN August 7-8, 1979, attended by DOE, Aerospace, ATU, and MDAC, it was agreed to treat the entire No. 87000 complex of buildings as a thermal load for the re-designed STES. If cost or field size limitations should prevent that, the STES design would of course be scoped downward. This increase in the number and types of buildings to be served by the STES necessitated a re-evaluation of the thermal energy loads to be accommodated.

During a visit to the 87000 complex in October, data were obtained from Fort Hood personnel on:

- (1) Range of fluctuation in occupancy level of the barracks buildings
- (2) Number and steam usage characteristics of cooking and washing appliances in the Food Services building
- (3) Typical head counts for meals served at the Food Services building.

From these new data, estimates were made of the average hot water loads as a function of barracks occupancy. Also, estimates were made of the amount of steam used in the Gymnasium and the Food Services buildings. For thermal load estimation, that amount was added in with the hot water load. The results are summarized in Table 1. It is seen that the hot water demand of the total complex can vary from 21.6×10^6 Btu/day to a maximum of 71.6×10^6 Btu/day.

Reference 5 reported a relationship between the combined hot water/space heating loads and heating degree-days, derived from flow and temperature measurements made of the steam condensate return from the five buildings selected for thermal load purposes. That relationship was used to prepare space heating load estimates for those five buildings by subtracting out the hot water loads. The resultant heating loads, treated as a function of heating degree-days, were used with U.S. Weather Bureau data for heating degree-days to calculate the heating loads for the five selected buildings. They were then extrapolated to estimates for the entire 87000 complex on the basis of heated floor space.

Reference 5 also presents a relationship between cooling loads and cooling degree-days which was derived from August measurements of the chilled water return line from the five selected buildings. That was used with the Reference 5 data on

Table 1. Average Daily Energy Required for Hot Water at the No. 87000 Complex

<u>BUILDING TYPE</u>	<u>BUILDING NUMBER</u>	<u>NORMAL OCCUPANCY WINTER</u>	<u>NORMAL OCCUPANCY SUMMER</u>	<u>MAX</u>	<u>MIN</u>
.....5 SELECTED BUILDINGS.....					
BARRACKS	87012	7.0	4.8	10.2	2.9
	87013	5.4	3.7	7.8	2.1
	87015	7.0	4.8	10.2	2.9
ADMINISTRATION AND STORAGE	87014	-	-	-	-
	87016	-	-	-	-
	SUBTOTAL	19.4	13.3	28.2	7.9
.....REMAINDER OF 87000 COMPLEX.....					
BARRACKS	87007	5.4	3.7	7.8	2.1
	87020	7.0	4.8	10.2	2.9
	87021	5.4	3.7	7.8	2.1
	87027	7.0	4.8	10.2	2.9
ADMINISTRATION AND STORAGE	87004	-	-	-	-
	87011	-	-	-	-
	87019	0	-	-	-
BRIGADE HQ	87005	-	-	-	-
DISPENSARY	87006	-	-	-	-
BRANCH PX	87008	-	-	-	-
BATTALION HQ	87003	-	-	-	-
	87009	-	-	-	-
GYM	87010	1.2	1.2	1.7	0.9
FOOD SERVICE FACILITY	87017	3.9	3.9	5.7	2.8
CENTRAL ENGINEERING FACILITY	87018	-	-	-	-
	87000 COMPLEX TOTAL (10 ⁶ Btu)	49.3	35.4	71.6	21.6

cooling degree-days for the summer months to estimate the cooling loads for the five selected buildings as a basis for preliminary calculations. Those were extrapolated to the total 87000 complex on the basis of air conditioned floor space.

The tabulation of all thermal load estimates for the complex, in terms of the average daily demand for each month of the year, is provided in Table 2. A graph showing the annual profile for the average load and its constituent parts is shown in Figure 5. The marked impact of the Fort Hood energy conservation policy of shutting off heating and air conditioning during April, May and October is dramatically shown. The thermal load is essentially the domestic hot water load for those months. Ironically, if a solar total energy system were installed, its annual performance figures would very likely be enhanced if heating and air conditioning were made available during those months.

2.2 REVISED SYSTEM CONCEPT

In anticipation of a redesign effort on the Fort Hood STES application by an industrial contractor using the central receiver approach, Aerospace reviewed the results of the First Small Power System Experiment, Engineering Experiment No. 1 (EE No. 1) Phase I study documented by MDAC in Reference 3. That study was done under the direction of DOE and was managed by the Jet Propulsion Laboratory (JPL).

The objectives of that Phase I study were: (1) select preferred system concepts for each of three program durations, (2) complete conceptual designs for each of three system concepts, (3) provide sensitivity data over a plant rating range between 0.5 and 10 MWe and an annual capacity factor range of zero storage to 0.7, (4) prepare detailed Phase II plans and cost proposal (for three versions of EE No. 1), (5) prepare Phase III program and cost estimates (three versions of EE No. 1), and (6) recommend preferred EE No. 1 program.

The development was addressed in the JPL study by MDAC as a Task 1 effort, followed by sensitivity analyses in Task 2. The results of Task 1 provide a useful data base for configuring a central receiver system design for Fort Hood. It was decided that the design developed for a 3.5-year program duration incorporated the technologies most applicable to Fort Hood project needs with the exception that "second generation" heliostats could be used in the design. In July 1979 MDAC reviewed Fort Hood site-specific data contained in Reference 5 and earlier project documentation and developed initial recommendations for a design approach for a central receiver STES at Fort Hood. Their recommendations were presented to DOE and Aerospace in August 1979.

After reviewing the results of the JPL/MDAC EE No. 1 study and the above MDAC recommendations a baseline design concept for the Fort Hood STES application was prepared, which is presented schematically in Figure 6. Tentative technology choices in various subsystem areas are as follows:

Table 2. Estimated Average Daily Thermal Loads of the No. 87000 Complex

	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>	<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>
HOT WATER	49.3	49.3	45.8	42.4	38.9	35.4	35.4	35.4	38.9	42.4	45.8	49.3
HEATING	112.3	95.2	74.9	0	0	0	0	0	0	0	75.9	100.7
AIR CONDITIONING	0	0	0	0	0	104.6	104.6	104.6	104.6	0	0	0
TOTAL (10 ⁶ Btu)	161.6	144.5	120.7	42.4	38.9	140	140	140	143.5	42.4	121.7	150

Assumptions: 1. Normal occupancy of barracks.
2. Air conditioning load is the same each month.

Figure 5. Average Daily Thermal Loads for the 87000 Complex

Figure 6. Elements of a Central Receiver STES Plant for Fort Hood

Collectors	-	MDAC "Second generation" heliostats with 49 m ² reflective surface
Receivers	-	Cavity-type, conical shaped
Heat Absorbing and Storage Medium	-	Molten salts
Working Fluid for Power Conversion	-	Water/steam
Turbine Generator	-	Back pressure, extraction type
Air Conditioning	-	Absorption chiller

It is recognized that a detailed conceptual design exercise including subsystem trade studies might change the above choices for reasons of improved performance, reduced cost, or lower technical risk.

2.3 PLANT SIZING CALCULATIONS

2.3.1 Assumptions and Design Parameters

A preliminary investigation of plant sizing for a central receiver STES at Fort Hood was performed, with the following assumptions:

- (1) Collector field size is constrained by the shape and dimensions of the "Yellow Ribbon Recreation Park" area located east of the 87000 complex and bounded by Battalion Avenue, Redbud Drive, Martin Drive, and the future Central Avenue.
- (2) The plant should be capable of displacing, with solar energy, at least 50 percent of the annual thermal energy load of the 87000 complex.

The design parameters assumed for a central receiver STES for Fort Hood are summarized in Figure 7 and Table 3. Figure 7 presents a simplified performance model based on the 1.0 MWe 3.5-year duration Experimental System design presented in Reference 3. Table 3, presents the Fort Hood hourly direct insolation values for clear days at the winter and summer solstices based on data in Aerospace files.

2.3.2 Peak Performance Calculations

An estimate was made of the maximum size heliostat field which could be installed in the area east of the 87000 complex described above. By overlaying on a scaled map of that area the outlines of the largest north-oriented heliostat field which could reasonably be accommodated, leaving room for security fencing, etc., it was possible by numerical integration to calculate the maximum available field area. For the field configuration, an optimized field layout designed for a small central

ALL OPERATING MODES

$$Q_1 = \gamma \left(\text{INTERCEPTED DIRECT INSOLATION} \right)$$

$$Q_2 = 0.60 Q_1 \text{ (peak)}$$

$$Q_2 = 0.57 Q_1 \text{ (annual average)} \quad \left\{ \begin{array}{l} \text{INCLUDES EFFECTS OF} \\ \text{STEADY STATE AND} \\ \text{TRANSIENT LOSSES} \end{array} \right.$$

TOTAL ENERGY MODE

$$Q_3 = 0.73 Q_2$$

$$Q_4 = 0.27 Q_2$$

PURE THERMAL MODE

$$Q_3 = Q_2$$

$$Q_4 = 0$$

Figure 7. Simplified Performance Model for Fort Hood Central Receiver STES
(Based on JPL/MDAC EE No. 1,3.5 Yr Design)

Table 3. Hourly Direct Insolation for Clear Days at Fort Hood, Texas
(W/m²)

<u>SOLAR HOUR ENDING AT:</u>	<u>SUMMER SOLSTICE (June 21)</u>	<u>WINTER SOLSTICE (Dec 21)</u>
7 AM	478	—
8	660	—
9	765	616
10	816	848
11	835	934
12 PM	839	951
1	839	951
2	835	934
3	816	848
4	765	616
5	660	—
6	478	—

receiver system was taken from Reference 6. The envelope containing the largest such field outlines the shaded area in Figure 8. The total area of the heliostat field envelope was calculated to be 29,000 m².

Estimates of the maximum value "fill factor", or the ratio of total reflective surface area of the heliostats to the area contained in the envelope, range from 0.25 to 0.30. If a fill factor of 0.30 is assumed, the total heliostat area that can be utilized in the field represented in Figure 8 is 8700 m², which would require 178 Second Generation heliostats. For a fill factor of 0.25, the total heliostat area would be 7250 m², requiring only 148 Second Generation heliostats.

It should be noted that subsystem efficiencies listed in Figure 7 are for a central receiver plant dedicated only to generating electricity, e.g., for peak shaving or utility repowering applications. The total energy application at the Fort Hood site can make use of a high percentage (estimated between 70 and 80 percent) of the thermal energy in the exhaust steam from the turbine generator. However in so doing, it will incur a much higher electrical parasitic load than is characteristic of the purely electric generating plant. A review of the 1978 Fort Hood STES design in Reference 5 shows that the parasitic load can use as much as 31 percent of the gross electrical output during the cooling season and 21 percent during the heating season. A major share of the parasitic load in those cases is attributed to operation of pumps associated with the air conditioning and heating subsystems.

A graph showing a summary of estimates of the parasitic loads for central receiver system designs is presented in Figure 9. It is noted that the advanced-technology commercial designs by MDAC (Reference 3) all have parasitic load estimates below ten percent of gross electrical output. The range of parasitic load values to be encountered in a central receiver STES at Fort Hood was calculated based on extrapolations from Reference 5. The results are shown in the shaded area in Figure 9.

A summary table showing electric generation performance levels that might be expected of a central receiver STES at Fort Hood at noon at the winter solstice clear day condition is presented in Table 4, for a range of heliostat field Fill Factors of 0.25 to 0.30.

The conclusion is that the peak gross electrical output to be expected at the winter solstice design conditions is about 0.94 MWe, with net delivered power of 0.78 MWe under peak thermal load conditions. Occasionally, with hot water storage tanks topped off, and the heating load temporarily satisfied, parasitics will drop, allowing the net generation to climb to 0.83 MWe.

Similar calculations for the summer solstice conditions on June 21, with the parasitic loads associated with the cooling season, result in a peak gross electric generation of 0.81 MWe, with a net generation of 0.59 MWe during peak air-conditioning loads.

* By assuming a relocation of Martin Drive on the eastern boundary of the site, as was considered in an earlier design study (Ref. 7), a heliostat field envelope containing at least 34,000 m² can be accommodated.

Figure 8. Available Collector Field Size at Fort Hood

Figure 9. Estimates of Peak Parasitic Loads as a Function of Gross Electrical Output

Table 4. Calculated Peak Performance for a Fort Hood Central Receiver STES
12:00 Noon, December 21

	<u>ASSUMED FILL FACTOR</u>		
	<u>0.250</u>	<u>0.275</u>	<u>0.300</u>
TOTAL HELIOSTAT AREA (m ²)	7250	7975	8700
POWER INCIDENT ON COLLECTORS (MW _t)	6.89	7.58	8.27
POWER ABSORBED BY RECEIVER (MW _t)	4.82	5.31	5.79
GROSS ELECTRICAL OUTPUT (MW _e)	0.78	0.86	0.94
NET ELECTRIC OUTPUT (MW _e) (heating season)	0.63	0.70	0.78

2.3.3 Input Energy Required to Meet Thermal Displacement Objective

As stated above, one of the objectives of the Fort Hood STES experiment was to displace, with solar energy, at least 50 percent of the annual thermal load (heating, air conditioning, hot water). The annual thermal load for the 87000 complex can be derived from the average daily load estimates given in Table 2. The result is 4.18×10^{10} Btu, so the minimum thermal load displacement objective is 2.09×10^{10} Btu.

The annual average-day value of direct normal insolation at Fort Hood from Reference 10, is 4.62 kWh/m^2 . Multiplication by 365 days results in an annual total of 1.686 MWh/m^2 , or $5.75 \times 10^6 \text{ Btu/m}^2$ per year. For a field of 8700 m^2 aperture, that results in 5.0×10^{10} Btu, or 14.7 GWh annual energy incident on the heliostats.

A performance waterfall diagram for a Fort Hood central receiver STES based on the JPL/MDAC EE No. 1 technology is shown in Figure 10. It shows the ratio of thermal energy delivered to the power conversion subsystem (PCS) to be about 0.57 of the annual direct insolation intercepted by the heliostat field, or 8.35 GWh. That is equivalent to 2.85×10^{10} Btu, which, if it were fully utilized in thermal form, would displace 68 percent of the annual thermal load derived above. For the solar plant to function as a total energy system, however, a portion of the energy available at the output of the steam generator must be allocated to electrical power generation.

2.3.4 Input Energy Required for Electric Power Generation

For purposes of illustration let it be assumed that a minimum electric power production objective for the Fort Hood central receiver STES is equivalent to an average generation of 0.500 MWe (gross) for eight hours each day or 1460 MWe per year. Using the turbine-generator efficiency listed in Figure 7, that would require at least 1.85 MW_t power flow from the steam generator to the turbine. Then, on an annual basis, the electrical production objective assumed above would require a total of

$$1.85 \text{ MW}_t \times 8 \text{ hrs} \times 365 \text{ days} = 5402 \text{ MWh}_t$$

to be supplied by the steam generator. That is equivalent to 1.84×10^{10} Btu of required input energy to the turbine.

2.3.5 Combined Input Energy Requirements

At rated efficiency, 73 percent of the steam introduced in the turbine in the central receiver STES design (Figure 7) is made available as thermal energy at the turbine exhaust. Therefore, in generating the assumed electricity objective of 1460 MWe per year, 73 percent of 1.84×10^{10} Btu, or 1.34×10^{10} Btu would be provided for thermal utilization. Based on the 5-building STES design described in Reference 5, 18 percent of the annual thermal energy provided via turbine exhaust and turbine bypass was ultimately rejected through the condenser cooling tower, and 2 percent was expended in thermal losses in the heating, cooling, and domestic hot water subsystems. Using that as a guide, one can conservatively estimate that 80 percent

Figure 10. Performance Waterfall Diagram for a Fort Hood STES

of the available thermal energy in the present case or 1.07×10^{10} Btu can be allocated to thermal loads.

That can be applied toward the annual thermal energy displacement objective as follows:

$$\begin{array}{r} 2.09 \times 10^{10} \text{ Btu (thermal objective)} \\ - 1.07 \times 10^{10} \text{ Btu (via turbine exhaust)} \\ \hline 1.02 \times 10^{10} \text{ Btu (still needed)} \end{array}$$

It follows that the minimum annual energy required at the output of the steam generator to meet the combined thermal and electrical objectives stated above is 1.02×10^{10} Btu plus 1.84×10^{10} Btu, or 2.86×10^{10} Btu.

2.3.6 Minimum Required Collector Field Aperture

The above results may be used to estimate the minimum required aperture of the heliostat field, as follows:

$$Q_{\text{st.gen.}} = (0.57) (I_{\text{annual}}) (A)$$

where

$$Q_{\text{st.gen.}} = \text{Total energy required from steam generator in one year, in Btu}$$

$$I_{\text{annual}} = \text{Total annual direct insolation available, in Btu/m}^2$$

$$A = \text{Total field aperture, m}^2$$

$$\text{then } A = \frac{Q_{\text{st.gen.}}}{(0.57) (I_{\text{annual}})}$$

$$A = \frac{2.86 \times 10^{10} \text{ Btu}}{(0.57) 5.75 \times 10^6 \text{ Btu/m}^2}$$

$$A = 8726 \text{ m}^2$$

That aperture corresponds closely to the 0.300 Fill Factor case in Table 4. It thus appears that reasonable minimum performance objectives for Fort Hood can be met with a heliostat field that can be fitted into the available site boundaries, using EE No. 1 technology from the 3.5 year program in the JPL/MDAC study.

2.4 INSOLATION VARIATION MEASUREMENT PLANNING

In connection with technical management activities on the Barstow 10 MWe Pilot Plant Project, Aerospace investigated small scale temporal and spatial characteris-

tics of the insolation at Barstow, California, adjacent to the future location of the pilot plant. A 12-month series of measurements was made at that site using a grid of pyranometers connected to a digital recording system. The results of those observations are published in Reference 8.

Those observations revealed situations where cloud shadows smaller than the collector field will exist. Such shadows may move so rapidly that they cause problems in the thermal control of fluid flowing behind the receiver's absorbing surfaces. The data were prepared in the form of detailed cloudy-event scenarios for use in control system simulation studies by the pilot plant Solar Facility Design and Integration contractor. Figure 11 is a sample of the insolation variation map derived for one such event.

Inasmuch as a similar but smaller collector field would be needed for the conceptualized Fort Hood STES, which might introduce difficulties in plant control, it appeared that measurements similar to those at Barstow should be made at Fort Hood. The Barstow results are not directly transferable to the Fort Hood project because of differences in geometric scale of the collector fields (requiring different spatial resolution in the cloud data) and marked differences in climate of the two regions.

In October 1979 a trip was made to Fort Hood to survey possible sites and explore logistics for an insolation variation experiment. The nominal area needed for such an experiment was determined to be 500 ft x 500 ft. The principal criteria used for site evaluation were physical security, availability of a clear sky view, availability of electrical power, and site preparation needed (fencing, etc.).

The assistance and cooperation of personnel from the Fort Hood Directorate of Facilities Engineering, the Corps of Engineers, and ATU were obtained in locating potential sites. Locations of the four sites determined to be worth considering are shown on the map in Figure 12, and are identified as:

Site 1	87000 Barracks Complex
Site 2	Hood Air Field
Site 3	West Fort Hood
Site 4	ATU Campus

All of the above were determined to be usable, with certain qualifications. Site 4 would be applicable only if ATU would be on contract to DOE for system design studies so that local experiment maintenance could be provided by them. Of the other three, Site 1 is the best choice, assuming necessary fencing could be erected for protection of the equipment used in the experiment.

The instrumentation and cabling used in the Barstow insolation variation measurement experiment were made available as of 1 November 1979 for use at Fort Hood or elsewhere.

- SITE: BARSTOW, CA
- DATE: 8 AUGUST 1978
- SCALE: "1" - 5% OF AVAILABLE DIRECT SOLAR RADIATION;
"10" - 95% OF AVAILABLE DIRECT SOLAR RADIATION

PATTERN
VELOCITY: 10 m / sec

Figure 11. A Representative Map of Cloud Shadows

Figure 12. Sites Investigated for an Insolation Variation Experiment

1. "Solar Energy Program for U.S. Army Installations," Phase I Report, Vol. I, Electricity and Natural Gas Consumption at Fort Hood, American Technological University, March 31, 1975.
2. "Solar Total Energy Program Plan," Sandia Laboratories, Report SAND76-0167, July 1976.
3. "Phase I of the First Small Power System Experiment (Engineering Experiment No. 1)," Final Technical Report, Vol I through V, McDonnell Douglas Astronautics Company, May 1979.
4. "Design Requirements for the Fort Hood Solar Total Energy System Large Scale Experiment" (Draft), July 1979, prepared by The Aerospace Corporation for DOE, Albuquerque.
5. "Fort Hood Solar Total Energy Project," Final Report, Vol. I through IV, American Technological University, January 1979.
6. "Definition of Two Small Central Receiver Systems," Final Report, R.J. Holl, McDonnell Douglas Astronautics Company, January 1978 (Sandia No. SAND78-7001).
7. "Solar Total Energy - Large Scale Experiment, Fort Hood, Texas," Preliminary Design, First Design Review Report, Westinghouse Electric Corporation, May 18, 1978.
8. "Measurements of Insolation Variation Over a Solar Collector Field," C.M. Randall, M.E. Whitson, Jr., and B.R. Johnson, The Aerospace Corporation, ATR-79(7747)-2, 30 December 1978.