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**FORT HOOD SOLAR TOTAL ENERGY PROJECT
VOLUME 1: EXECUTIVE SUMMARY**

Final Report

January 1979

Work Performed Under Contract No. EM-78-C-04-4231

**American Technological University
Killeen, Texas**

U.S. Department of Energy

Solar Energy

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FORT HOOD SOLAR TOTAL ENERGY PROJECT
VOLUME I: EXECUTIVE SUMMARY

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FINAL REPORT
JANUARY 1979

Prepared for

U.S. DEPARTMENT OF ENERGY
DIVISION OF CENTRAL SOLAR TECHNOLOGY
Under Contract No. EM-78-C-04-4321

By

AMERICAN TECHNOLOGICAL UNIVERSITY
Killeen, Texas 76541

With Subcontracting Support From

WESTINGHOUSE ELECTRIC CORPORATION
GEORGIA INSTITUTE OF TECHNOLOGY
HEERY & HEERY, INC.

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FOREWORD

The Fort Hood Solar Total Energy Project is a large-scale experiment which is part of the Department of Energy's Solar Total Energy Program. The project is a military residential application of solar total energy, and is to be installed at Fort Hood's 87000 Troop Housing Complex where it will provide a substantial portion of the electricity, space heating, cooling, and domestic water heating for approximately 700 people.

The preliminary design for the Fort Hood Solar Total Energy System has been completed and is the principal subject of this four-volume report:

- Volume I. Executive Summary
- Volume II. Preliminary Design
- Volume III. Engineering Drawings
- Volume IV. Management Plan

The preliminary design is a mature design as a result of several prior iterations in design criteria and design approach. Hence, it provides a sound point of departure for the subsequent definitive design and construction phases, leading to operational testing early in 1981.

The many persons who have contributed to the project are too numerous to acknowledge individually, but it is appropriate to list several U.S. Army/Corps of Engineers organizations whose cooperation and assistance have made it possible for the Department of Energy and the project team to bring the project to its present state of development:

- Office, Chief of Engineers
- Headquarters, U.S. Army Forces Command
- Headquarters, III Corps and Fort Hood
- Headquarters, Training and Doctrine Command Combined
Army Test Activity
- Fort Worth District, Corps of Engineers
- Fort Hood Directorate of Facilities Engineering
- Headquarters, 6th Cavalry Brigade (Air Combat)
- Headquarters, Atmospheric Sciences Laboratory
- Corps of Engineers Central Texas Area Office
- U.S. Army Communications Command
- Detachment 14, 5th Weather Squadron
- Fort Hood Medical Department Activity
- Fort Hood ASL Meteorological Team

The cooperation and assistance of the Texas Power and Light Company and Lone Star Gas Company are also gratefully acknowledged.

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1.0 INTRODUCTION

This volume summarizes work performed on the Fort Hood Solar Total Energy Project during the period March 1 through October 31, 1978 by American Technological University (ATU) and the subcontractor team: Westinghouse Electric Corporation, the Georgia Institute of Technology, and Heery and Heery, Inc. This work was performed under Department of Energy (DOE) Contract No. EM-78-C-04-04231 administered by DOE's Albuquerque Operations Office with technical support from the Aerospace Corporation. The work was coordinated with the U.S. Army at Fort Hood through the Directorate of Facilities Engineering, and with the Corps of Engineers through the Fort Worth District Office.

STEP Objectives

The Fort Hood Project is part of the U.S. Department of Energy's Solar Total Energy Program (STEP). The STEP Plan (Reference 1) defines a solar total energy system as "an energy system designed to maximize the use of collected solar energy overall by supplying both the low-grade (low-temperature thermal) and high-grade (electrical and/or mechanical) energy needs of selected applications." The program is primarily 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 STEP are to demonstrate the technical, economic, and institutional feasibility of the solar total energy concept and to promote within an appropriate industrial sector a technology which offers the prospect of being economically competitive with other energy sources.

As an initial step toward achieving the program goals, large-scale experimental solar total energy systems will be tested to develop experience with large hardware systems and the engineering capability required for demonstrations. These experiments are to be large enough to encounter those engineering problems associated with full-scale applications and to make use of components which are representative of the larger systems, but small enough to permit evaluation of a number of alternative systems.

Fort Hood Project Objectives

The first large-scale experiment will be a military residential application installed at Fort Hood, Texas. It is to be a solar total energy system with a nominal electric output in the 250-KW range and with a thermal output of approximately 1 to 2 MW_e equivalent. It will be installed in the 87000 Troop Housing Complex at Fort Hood and will supply a substantial portion of the electricity, space heating, space cooling, and domestic hot water heating requirements of several buildings in the complex.

The objectives for this contract period were to perform the preliminary design for the Fort Hood Solar Total Energy System (STES), to carry out a supporting engineering test program, and to conduct a variety of other support activities required for the successful and timely completion of the project. These objectives have been met, and the project team is now ready to perform the definitive design. The construction phase will start in mid-1979 and will be followed by an operational testing phase of approximately two years' duration which will start early in 1981.

Preliminary Design

The preliminary design developed for the Fort Hood STES meets or exceeds the current system design criteria, which are based on the DOE STEP Plan (Reference 1) and more recent guidance from DOE. The system design incorporates several special features which have resulted from careful analysis of alternatives:

- o The collector field outlet temperature is controlled by a simplified feed-forward system which is highly responsive to transient insolation conditions, yet ensures that the maximum allowable temperature will not be exceeded.
- o The low-pressure turbine and/or the absorption air conditioning system may be operated overnight using lower quality heat from an intermediate temperature tank included in the high-temperature thermal storage subsystem.
- o The thermal utilization subsystem includes a dual-use tank for storing heated water for space heating in winter and chilled water for space cooling in summer.

Although innovative in a number of ways, the preliminary design is based largely upon state-of-the-art technology and available components, thus

eliminating the need for costly and time-consuming development programs and their attendant risks.

Final Report

The final report for the period March 1 through October 31, 1978 consists of four volumes. The purposes of this executive summary volume (Volume I) are to

- o Provide an overview of the project and its background
- o Describe the design requirements and approach
- o Summarize the system design and operation
- o Summarize the system performance
- o Describe the major supporting activities
- o Summarize the management plans for subsequent project phases

The full details of the preliminary design and the supporting activities are given in Volumes II and III of the final report. A management plan for the balance of the project is found in Volume IV.

These volumes document the results to date, and provide the basis for continuing with the definitive design and construction of a system that will be a major contribution to the STEP. The development of the Fort Hood STES is also timely in terms of the energy needs of the military, particularly the U.S. Army with its vast amount of floor space requiring heating and cooling. An equally important need exists, however, for the generation of electricity to meet mounting demands at Fort Hood, as well as other military bases. This large-scale experimental system will provide means for assessing solar total energy technology for military, as well as other types of residential, applications and will be a significant step toward future commercialization of such systems.

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2.0 PROJECT BACKGROUND

The Fort Hood Solar Total Energy Project had its origins in 1973, when the Solar Energy Program Manager of the National Science Foundation (NSF) and General Officers from Fort Hood met at ATU to discuss and plan the project. The U.S. Army Corps of Engineers took an active role in the project by assigning a representative to work at NSF to lay the groundwork for military involvement in the solar energy programs. With NSF funding and Fort Hood cooperation, ATU initiated Phase I studies in 1974:

- To assess the energy requirements of Fort Hood
- To set up (with the assistance and cooperation of the U.S. Army Atmospheric Sciences Laboratory Fort Hood Meteorological Team) a station for measuring solar intensity
- To examine the applicability of available technology
- To assess the feasibility of solar energy system applications at Fort Hood

This study effort was concluded in March 1975 and is reported in References 2 through 5.

Phase II, the original conceptual design phase, was planned under the auspices of NSF, but was initiated under the Energy Research and Development Administration (ERDA) when the NSF Solar Energy Programs were transferred to the newly created ERDA organization. This phase, which had the development of the conceptual design for the Fort Hood Solar Total Energy System as its primary goal, began in April 1975 and concluded on November 30, 1976. It included further investigations of solar energy availability and energy requirements at Fort Hood. In addition, an engineering test program was planned, and initial steps were taken toward its implementation. Reference 6 gives the results of this phase.

This original conceptual design served as the point of departure for subsequent design efforts. Based on the design criteria in effect at that time, a 220,000-ft² (aperture) collector field was required. The system

used line focusing solar collectors to heat water to 530°F for producing steam for a turbine-generator set. The turbine exhaust heat was recovered at a lower temperature for space heating and domestic hot water applications.

The 87000 Troop Housing Complex at Fort Hood was selected as the basis for the Phase II conceptual design, and approval of this complex as the installation site was subsequently obtained from the Department of the Army. Consistent with early ERDA direction, the original solar total energy system was a retrofit, leaving in place and making use of existing equipment such as the centrifugal chillers and the steam boilers already installed at the 87000 Complex. This approach led to system size requirements based largely on the high electrical load imposed by operation of the air conditioning, and resulted in a surplus of turbine exhaust heat during the summertime.

The objectives of the project and the system design criteria have been through a number of revisions since the project administration was shifted from NSF to ERDA. The early revisions accompanied several changes in ERDA program management, whereas the later revisions resulted largely from the establishment of the STEP Plan (Reference 1). Following the evolution of firm guidelines, ERDA, in the spring of 1977, redirected the Fort Hood Project to comply with the new guidelines.

The major impact of the redirection was that, instead of developing a preliminary design based upon the original conceptual design, updated conceptual designs reflecting the new ERDA guidelines and design philosophy were developed as a competitive effort by Westinghouse Electric Corporation and TRW, Inc. under concurrent ERDA contracts. ATU provided input data and close support to the design contractors during the competition.

Following the conceptual design competition, ATU was named prime contractor for the project, and Westinghouse Electric Corporation was

selected to perform the preliminary design. The new conceptual design developed by Westinghouse (Reference 7) differed from the original conceptual design primarily in four ways:

- The system was sized to address the thermal energy requirements of five selected buildings within the 87000 Complex.
- Oil rather than water was selected for use as a heat-transfer fluid in the collector field.
- Absorption air conditioning was included.
- Intermediate temperature storage was added to allow overnight operation of the absorption air conditioning.

This new conceptual design formed the basis for the preliminary design now being reported.

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3.0 DESIGN REQUIREMENTS AND APPROACH

The preliminary design for the Fort Hood Solar Total Energy System represents a logical extension of the conceptual design developed by Westinghouse Electric Corporation during the period June 1 through September 30, 1977 (Reference 7). At the beginning of the preliminary design period, the design criteria were updated to reflect the current interpretation of the DOE's overall program plan for solar total energy (Reference 1), and to eliminate certain system sizing and performance inefficiencies that had resulted from following the criteria established for the conceptual design.

The design criteria followed during preliminary design require that the Fort Hood Solar Total Energy System:

- Be prototypical of future demonstration plants in the 2-MW_e range
- Supply at least 50 percent of the annual thermal energy load (space heating, cooling, domestic hot water) for five selected buildings of the 87000 Troop Housing Complex
- Provide at least 200 KW for peak shaving of the electrical load of the entire 87000 Complex (synchronous parallel operation)
- Provide 1600 KWH per day on an annual average basis
- Provide thermal storage for extended operation
- Provide fossil fuel backup for self-contained operation

The principal change from the earlier criteria is the requirement to supply 50 percent of the thermal load. This figure was originally 60 percent, but the conceptual design results and subsequent analysis indicated that the solar collector field must be approximately 20-percent larger to provide the 10-percent additional thermal energy displacement. With the revised criterion, a nominal size of 125,000 ft² (aperture) was anticipated for the collector field, whereas a field size of 150,000 ft² was required to meet the conceptual design criterion.

The approach followed during the preliminary design process included these major steps:

- Identification of alternate designs for selected subsystems
- Trade studies to finalize subsystem selections and to establish optimal dimensions, capacities, temperatures, and operating conditions
- Integration of subsystems into overall system design

Using the conceptual design as a baseline, alternative subsystem designs were considered with respect to the system requirements, performance, and cost. Refinement of the subsystem parameters was measured against total system effectiveness. An example of this is the dynamic modeling used to analytically test and compare the feed-forward collector field control system to a more conventional field control system.

Early in the project, a philosophy of utilizing state-of-the-art technology was established. The preliminary design approach continued to follow this philosophy. Specifically, an effort was made to utilize existing technology and component designs to the greatest extent feasible consistent with the overall project goals.

4.0 SYSTEM DESIGN AND OPERATION

A general understanding of the design and operation of the Fort Hood Solar Total Energy System may be gained from the highly simplified block diagram shown in Figure 1. The energy input is from the collector field or, during inclement weather, from an auxiliary oil-fired heater. In normal daytime operation, 550°F heat-transfer oil is pumped to the steam generator producing superheated steam to drive the turbine. During summer, steam is extracted to drive the absorption chiller. Exhaust heat is recovered from the condenser for winter space heating and for domestic water heating year round. Any excess exhaust heat is dissipated by the cooling tower. A common tank is used for summer storage of chilled water and winter storage of heated water.

The Fort Hood STES design and operation may be described in more detail with reference to the diagram shown in Figure 2. This diagram indicates how the major subsystems and components are integrated into the overall system configuration. For clarity, many pumps and details such as valves, feedwater connections, pressurization subsystems and control components, etc., are not included in this diagram. Table 1 gives the more significant system parameters, including capacities, dimensions, temperatures, etc.

The STES has numerous operating modes, and the mode of operation at a particular time depends upon real-time and projected energy demands and energy supply. The operating mode at a particular time depends on many variables that must be considered to obtain the most effective system utilization. The differences among the operating modes are primarily in the temperature levels, the flow paths between the various subsystems, and the particular subsystems in use. The two basic modes of operation are:

- High-Temperature Mode: Oil at 550°F is supplied to the power conversion subsystem to produce superheated steam, and the high-pressure turbine is always operated. The low-pressure turbine and/or absorption chiller are also operated, depending upon the thermal energy requirements.

Figure 1. Simplified Block Diagram of Fort Hood Solar Total Energy System

Figure 2. Schematic Diagram of Fort Hood Solar Total Energy System

TABLE 1

FORT HOOD SOLAR TOTAL ENERGY SYSTEM CHARACTERISTICS AND PARAMETERS

COLLECTOR

TYPE: Parabolic Trough, (~N-S aligned)
 FIELD SIZE: 125,000 ft² (aperture)
 HEAT-TRANSFER FLUID: Sun 21 (paraffinic oil)
 INLET TEMPERATURE: 316°F
 OUTLET TEMPERATURE: 550°F
 PEAK OUTPUT: 16.7×10^6 Btu/hr

AUXILIARY HEATER

TYPE: Oil Fired
 RATING: 5×10^6 Btu/hr

HIGH-TEMPERATURE THERMAL STORAGE

APPROACH: Sensible Heat in Sun 21
 HIGH-TEMP. TANK: 33,662 gal @ 550°F
 INTERMEDIATE-TEMP: 116,771 gal @ 438°F
 LOW-TEMP. TANK: 109,141 gal @ 316°F

STEAM GENERATOR

TYPE: Unfired Three-Stage Counterflow Heat Exchanger
 RATING: High-Temperature--6,000 lb/hr super-heated steam @ 500°F and 315 psia
 Intermediate Temp.--4,012 lb/hr saturated steam @ 298°F and 65 psia

STEAM TURBINE

TYPE: Two Single-Stage Units to Simulate Multistage Turbine
 HIGH-PRESSURE UNIT: 315 psia @ 500°F
 LOW-PRESSURE UNIT: 65 psia @ 304°F

ELECTRICAL GENERATOR

TYPE: Synchronous
 RATING: 250 KW (nominal) @ 480 volts

COOLING SYSTEM

TYPE: Two-stage Absorption
 CAPACITY: 175 tons
 LOAD: 49×10^6 Btu/day (summer day full load)
 STORAGE: 41,000 gal @ 44°F

HEATING SYSTEM

TYPE: Hot Water
 LOAD: 66×10^6 Btu/day (winter day full load)
 STORAGE: 41,000 gal @ 140°F (minimum)

DOMESTIC HOT WATER

LOAD: 20×10^6 Btu/day
 STORAGE: 25,000 gal @ 140°F (maximum)

- Intermediate-Temperature Mode: Oil at 438°F is supplied to the power conversion subsystem to produce saturated steam, and the high-pressure turbine is not operated. The low-pressure turbine and/or absorption chiller are operated, depending upon the thermal energy requirements.

Installation Site

The Fort Hood STES is to be installed at Fort Hood's 87000 Troop Housing Complex. The 87000 Complex is a group of 20 buildings of contemporary Army design located at the eastern extremity of the main post at Fort Hood. This set of buildings provides housing, food services, administration, storage, and recreation for a brigade-size complement of troops (approximately 1,700). Table 2 lists the buildings which make up the 87000 Complex and identifies the five buildings selected as the thermal load for the STES. The floor area of the five selected buildings (156,556 ft²) represents over one-third of the floor area of the entire complex.

Figure 3 is a photograph of a scale model of the STES installed at the 87000 Complex. The collector field is at the right, and the balance of the system (storage tanks, STES building, etc.) is immediately to the left of the collector field. The entire 87000 Complex lies across the street to the left of the STES.

The 87000 Complex and its existing electrical and mechanical systems are not disturbed by the addition of the STES. The thermal output (space heating, cooling and domestic hot water) is interfaced with the existing systems at the mechanical room of each of the five buildings served by the STES, and the electrical output is synchronized with and operates in parallel with the existing electrical system for the entire complex. Thus, consistent with the experimental nature of the system, it may be shut down temporarily for adjustments or modifications without interfering with normal activities within the 87000 Complex.

Collector Field

As may be seen in Figures 2 and 3, the collector field consists of three subfields. It utilizes a novel feed-forward control concept which maintains the outlet temperature of the heat-transfer oil (Sun 21) near the design point (550°F), and minimizes perturbations caused by partial cloud

TABLE 2
87000 TROOP HOUSING COMPLEX DATA

BUILDING TYPE	BUILDING NUMBER	FLOOR AREA (ft ²)
2 Module Barracks	87007	31,698
4 Module Barracks	87012*	43,264
3 Module Barracks	87013*	31,698
4 Module Barracks	87015*	42,264
4 Module Barracks	87020	42,264
3 Module Barracks	87021	31,698
4 Module Barracks	87022	42,264
4 Co. Adm. & Stor.	87004	18,818
5 Co. Adm. & Stor.	87011	25,168
3 Co. Adm. & Stor.	87014*	14,162
5 Co. Adm. & Stor.	87016*	25,168
4 Co. Adm. & Stor.	87019	18,818
Brigade HQ	87005	9,840
Dispensary	87006	4,073
Branch PX	87008	4,696
2 Bn HQ & Clrm	87003	12,381
2 Bn HQ & Clrm	87009	12,381
Gym	87010	21,956
Food Service	87017	15,695
Central Energy	87018	3,327
Total		450,633

*Buildings selected for the STES thermal load.

Figure 3. Scale Model of Fort Hood Solar Total Energy System and 87000 Complex

cover or other changes in solar intensity. In principle, this is achieved by partial recirculation of some of the oil during poor insolation conditions. When good insolation conditions might otherwise cause the design point to be exceeded, 316⁰F-oil from thermal storage is blended with the heated oil prior to circulation through the final section of the collector field.

Flow through the three subfields is basically serial, but alternate flow paths provide flexibility in controlling the temperature of the heat-transfer oil. A feed-forward path provides for conditioning the inlet temperature of the subfields, and paths to the intermediate-temperature thermal storage tank are provided to allow storage of partially heated oil during insolation periods too poor to achieve the design outlet temperature. Finally, a recirculation path achieves the proper outlet temperature during low and intermediate insolation conditions.

The collector field is comprised of parabolic trough concentrating collectors. Each subfield is composed of 28 parallel strings, or rows, of individual collector modules whose receivers are connected serially. The rows are approximately north-south aligned (17 degrees east of north) for effective utilization of the available land area without realignment of surrounding streets. The total aperture (active area) of the collector field is approximately 125,000 ft², and the land area occupied by the collector field is approximately eight acres.

The collectors are mounted on concrete foundations, and the land area occupied by the collector field has a base course of gravel and a single penetration consisting of oil and aggregate to provide a surface which will be serviceable for the duration of the operational testing phase. The collector field is gently sloped to a bermed catch basin at the southeast corner to control runoff water from collector cleaning operations and to contain any oil leakage that might occur.

The normal inlet temperature to the collector field is 316⁰F and the outlet temperature is 550⁰F. An auxiliary oil-fired heater is included to permit operation of the STES in certain modes during periods when sufficient heat

is not available from the collector field. The auxiliary heater heats 316°F oil from the low-temperature tank to 438°F for storage in the intermediate-temperature tank of the thermal storage subsystem, or to 550°F for high-temperature system operation. The auxiliary heater could well be located further "downstream" in a commercialized version of the system, but placing it before the high-temperature thermal storage subsystem permits additional flexibility which is desirable for this initial experimental system.

High-Temperature Thermal Storage

The high-temperature thermal storage subsystem involves three tanks, as shown schematically in Figure 2. All three tanks are constructed of carbon steel and are upright cylinders, as depicted to the south of the STES building in Figure 4. The upper tank is at the field exit temperature (550°F) and serves primarily as a buffer and for peaking operations. It has an active capacity of 33,662 gallons and, when fully charged, it is capable of operating the system at the same rate as the collector field under good insolation conditions for a period of approximately one and one-half hours.

Nighttime operation is from the 116,771-gallon intermediate tank which accumulates the partially heat-depleted Sun 21 heat-transfer oil circulated through the steam generator during the daytime. At night during summer, this 438°F oil is circulated through the boiler to produce saturated steam at 298°F and 65 psia to drive the absorption chiller. At night during the winter, the saturated steam is routed to the second (low-pressure) turbine stage to produce electricity and to provide exhaust heat for space heating. At the end of a normal night's operation, all of the oil is accumulated in the 109,141-gallon low-temperature tank at 316°F, ready for recirculation through the collector field the next day.

Power Conversion Subsystem

All input energy to the system, whether from the collector field, auxiliary heater, or high-temperature storage, flows through at least two stages of

Figure 4. STES Building, Storage Tanks and Collector Field

the three-stage steam generator. The steam generator includes a preheater and a combination evaporator (boiler) and superheater. Sun 21 heat-transfer oil at 550°F is circulated through the steam generator to produce up to 6,000 pounds per hour of 500°F superheated steam at 315 psia for normal operation. For operation from intermediate storage, Sun 21 heat-transfer oil at 438°F is circulated through the evaporator and preheater stages to produce up to 4,000 pounds per hour of saturated steam at 298°F at 65 psia. In both modes, the feedwater is at approximately 290°F.

The steam generator is part of the power conversion subsystem which also includes the steam turbines, electrical generator, and condenser as major components. Two single-stage steam turbines are operated in concert in a manner representative of a two-stage turbine with steam extraction. (Extraction steam, rather than lower quality exhaust steam, is required for effective operation of the absorption chiller.) The first turbine--called the high-pressure turbine--operates on superheated steam, whereas the low-pressure turbine may be operated either on the exhaust from the high-pressure turbine or on saturated steam from the steam generator.

Clutches and a reduction gear allow the electrical generator to be driven by both turbines or by the low-pressure turbine alone, depending upon the mode of operation. The synchronous generator has a maximum gross output of 247 KW when the system is operated with 550°F oil supplied to the steam generator. This is reduced to 77 KW when operating from intermediate storage (438°F oil). The electrical output is 135 KW when operating the absorption chiller at peak capacity. When intermediate storage is used for nighttime space cooling, the electrical generator may not be operated at all, depending upon the cooling demand.

The condenser, although a conventional component of a steam turbine-generator system, is of special significance because it is one of the two major links which make the Fort Hood System a solar total energy system rather than simply a solar electric generation plant. (The other link is the extraction steam which drives the absorption chiller.) The condenser is capable of condensing and cooling 5,234 pounds of saturated steam at 4.9

psia to condensate at 156.4°F when supplied with 253 gpm of 100°F cooling water, which leaves the condenser at 140°F. This water serves as the heat source for space heating and domestic water heating. When there is no requirement for this extracted heat, the condenser may be operated at a reduced pressure, using 68°F cooling water for increased electrical production. In this case, the excess heat is rejected to the atmosphere by the cooling tower.

Thermal Utilization Subsystem

An insulated storage tank with a useful capacity of 25,000 gallons provides stratified storage for water heated to a minimum of 140°F by the condenser. Hot water from this tank is circulated through a heat exchanger to heat domestic water for the barracks buildings of the 87000 Complex, whose thermal energy requirements are addressed by the STES.

During winter, excess heat available from this storage tank may also be used for space heating. However, additional hot water for space heating is stored in a second stratified tank which is designed for dual use. It has a useful capacity of 41,000 gallons and is used for storing chilled water during the cooling season. Both the 25,000- and 41,000-gallon tanks may be seen behind the STES building in Figure 4.

A two-stage absorption machine chills water for air conditioning the five selected buildings of the 87000 Complex. It has a nominal capacity of 175 tons when driven by steam at approximately 300°F and 63 psia as provided by the STES. When operating in the high-temperature mode, this steam is extracted between the two turbine stages. When operating from the intermediate tank of the high-temperature thermal storage subsystem, saturated steam of similar quality is provided directly from the evaporator stage of the steam generator.

In addition to being able to operate overnight from intermediate storage, provisions are included for storage of excess chilled water which may be produced in the daytime. Specifically, the dual-use 41,000-gallon storage tank described above permits following the space cooling loads of the five buildings while the absorption chiller operates at a relatively constant level.

In addition to the thermal energy needs of the five selected buildings of the 87000 Complex, the system serves the thermal energy needs of the STES building.

Instrumentation and Control

The instrumentation and control system may be characterized as a state-of-the-art digital based system. With exception of the solar collector field, control at the individual subsystem and component level employs conventional techniques. However, the overall control system must handle the many complex interactions among the various subsystems required for effective energy management. The collector field, as described earlier, employs a novel feed-forward control scheme which is well suited for the response times associated with large collector fields.

The instrumentation and control subsystem is comprised of a master computer, localized microprocessors, instrumentation, input/output devices and control actuators. The master computer includes a real-time operating software system and an operator control console. This subsystem provides for the startup, shutdown, and operation of the system in its various modes.

The instrumentation and control subsystem provides for remote automatic control of all subsystems. It also permits manual control of all subsystems except the collector field, even in the event the master computer is inoperative. Energy management, including automatic system operational mode selection, is provided by the master computer. The operational modes are selected to adjust the system output to correspond to real-time and projected loads.

In addition to instrumentation necessary for control purposes, this subsystem includes instrumentation for measuring and logging key data relating to system performance. This feature is essential to the operational testing phase of this large-scale experiment.

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5.0 SYSTEM PERFORMANCE

Performance calculations for the Fort Hood Solar Total Energy System include state points (i.e., temperatures, flow rates, etc., at all critical points in the system, while under steady-state conditions in each of the various operating modes) and annualized performance calculations. The state-point performance data, described in detail in Section 4.2 of Volume II, establish the thermodynamic validity of the system design, and set the specifications for various system components. The annualized performance calculations, summarized below, give a more comprehensive view of the system's capabilities.

The annualized performance calculations are based on the following data and assumptions:

- Hour-by-hour solar availability and meteorological data for the representative year
- Mechanical availability of 85 percent (i.e., the system is capable of being operated 85 percent of the time)

The calculations were performed with the Solar Utilization Program (SUPR) developed by Westinghouse and described in Section 4.3 of Volume II.

The primary measure of system performance is the extent to which the design criteria are met. The principal criterion in this regard is that the Fort Hood STES should supply at least 50 percent of the annual thermal energy (space heating, cooling, and domestic hot water) requirements of five selected buildings of the 87000 Complex. Detailed performance calculations indicate that 57 percent of the annual thermal energy requirements would be supplied by the present system design. Moreover, by utilization of the oil-fired auxiliary heater to supplement the heat collected by the solar collector field, the system has the capability of supplying 100 percent of the thermal load of the five buildings.

The electrical system has the capability to produce 248 KW (gross) of electricity, as compared to the objective of 200 KW minimum. The projected daily average gross electrical output is 1,380 KWH over a one-year period. This average can probably be increased to the 1,600-KWH target by refinements in operating strategy.

The overall performance of the STES may also be expressed in terms of annualized energy displacement (i.e., the impact on the amount of energy required from conventional sources). The energy displacement analysis considered:

- Electricity displaced by the STES electrical generator output
- Electricity displaced by use of STES absorption chilling in lieu of the present electrical chilling
- Natural gas displaced by use of STES turbine exhaust heat for space heating and domestic hot water

Although the STES electrical output is actually fed into the electrical distribution system for the entire complex, the electricity displacement was computed as though the STES electricity output was applied directly toward the requirements of the five selected buildings of the 87000 Complex.

Table 3 summarizes the results of the energy displacement analysis. The total gas consumption with and without STES indicates that 57 percent of the thermal energy required for space heating and domestic hot water is supplied by STES. The electrical displacement data given in Table 3 indicate that, if the STES electrical output were indeed applied against the equivalent electrical requirements of the 87000 Complex, the system would displace 41 percent of the electrical requirements. However, it should be emphasized that most of the electrical displacement results from the STES absorption chilling which is applied directly to the five selected buildings, whereas the net STES electrical output is actually applied to the 87000 Complex as a whole.

TABLE 3

STES ENERGY DISPLACEMENT FOR FIVE SELECTED BUILDINGS
OF THE 87000 TROOP HOUSING COMPLEX

MONTH	GAS CONSUMPTION (MCF)*		ELECTRICITY CONSUMPTION (KWH)	
	WITHOUT STES	WITH STES	WITHOUT STES	WITH STES
January	2,797	1,203	59,597	35,869
February	1,994	857	53,453	33,411
March	1,806	777	58,075	31,730
April	1,026	441	48,728	35,088
May	930	400	50,353	43,873
June	900	387	204,755	49,108
July	930	400	240,598	63,669
August	930	400	236,859	59,659
September	900	387	205,117	59,298
October	1,046	450	50,353	51,553
November	1,567	674	55,683	43,850
December	2,413	1,038	57,408	39,168
TOTAL	17,239	7,414	1,320,979	546,276

*MCF = 1,000 ft³ = 10⁶ Btu

As an adjunct to the performance calculations, an annual energy balance was prepared and is given in Figure 5. It indicates the disposition of the 26,628 MMBtu total input into the Fort Hood STES from the solar collector field and the auxiliary oil heater. The input/output of each major system component and the output supplied to each of the thermal loads are indicated in parentheses. Thermal losses from major components and from interconnecting piping and equipment are also indicated.

The thermal and gross electrical output of the STES is 17,304 MMBtu and 1,711 MMBtu, respectively. This results in an overall system efficiency of 71 percent. Taking the electrical parasitic load of the STES into account reduces the overall efficiency to 66 percent.

Twenty-nine percent of the input energy from the collector field and auxiliary heater is not applied toward satisfying the load requirements. Instead, it appears in the form of heat rejected by the condenser cooling tower (15 percent or 3932 MMBtu), and thermal losses occurring throughout the system (14 percent or 3681 MMBtu). It should be noted that 5,947 MMBtu of the 11,780 MMBtu rejected from the absorption chiller cooling tower represents the air conditioning load and is not a part of the 26,628 MMBtu of input energy.

Figure 5. Annual Energy Balance of the Fort Hood Solar Energy System

6.0 SUPPORTING ACTIVITIES

The development of the preliminary design for the Fort Hood Solar Total Energy System was accompanied by a number of supporting studies. Some of these, such as solar collector evaluation studies and trade studies, provided important inputs to the design. Others, such as solar availability analyses and system load measurements, either substantiated data being used for design purposes or indicated where possible revisions may be required in the future. Also closely connected with the design effort was a reliability assessment, static testing of the collector heat transfer fluid, and planning of a solar/meteorological station. Another supporting activity was the planning and initial steps toward implementation of the Pilot Test Array (PTA)--the equivalent of one complete row of the collector field. It was to have been tested prior to installation of the entire field. However, the PTA was cancelled because of budgetary constraints.

Many related activities reflected the system design rather than directly contributing to it. These included a health and safety assessment, an environmental impact assessment, life-cycle cost and economic analyses, and information dissemination. All of these studies are presented in appropriate detail in Sections 5.0 and 6.0 of Volume II, and some of the key studies are briefly summarized below.

Solar Collector Evaluation

The collector evaluation tasks included development of models for performance prediction, analysis of collector performance using these models, and, based on the modeling and analyses, determination of the most useful test data, along with appropriate procedures for obtaining the required data. The recommendations regarding performance testing were particularly relevant to the PTA (which, as mentioned above, was cancelled), but they will still serve useful purposes, such as evaluating tests or test plans proposed by potential collector suppliers.

The performance modeling had as its objectives the provision of:

- A sound collector model for the overall system as modeled in the SUPR program
- Analytic tools to support the collector procurement process

Emphasis was placed on performance modeling of parabolic trough concentrating collectors--the type selected during conceptual design for the Fort Hood STES. Mathematical relationships, including optical and thermodynamic performance, were formulated and programmed. Inclusion of geometric effects such as end losses and shading by adjacent collectors was an important part of the modeling because of the impact of these effects on collector field design.

Trade Studies

Trade studies are an important part of the design process in that they are one mechanism by which data and information are developed for use in choosing among alternatives and selecting optimum temperatures, sizes, etc. Formal trade studies conducted during preliminary design included:

- Insulation and pumping power tradeoffs
- Oil stability/handling/temperature limits
- Solar collector orientation analysis
- Solar collector spacing and string length
- Domestic hot water temperature
- Steam pressure level
- Oil versus oil/rock thermal storage
- Thermal storage sizing

These trade studies are described in detail in Section 5.5 of Volume II, and their results are reflected in the preliminary design of the Fort Hood STES.

Solar Availability

It is necessary to specify the amount of solar energy available as a function of time over a representative one-year period in the Fort Hood area in order to design the system to meet the performance requirements. Hour-by-hour normal incidence solar intensities, temperatures, cloud conditions, etc. were developed during earlier contract periods based upon limited data taken at Fort Hood and a model which correlates solar radiation with climatological variables. An ancillary task of the preliminary design effort was to develop an updated representative year to verify the original representative year, or to replace it if necessary.

Two lines of approach were employed. In one, the Georgia Institute of Technology compared the representative year data with other data for the same general geographic area and demonstrated that the data were compatible. This study is described in Section 5.4 of Volume II. The other approach, pursued by ATU and described in Section 6.1 of Volume II, involved the construction of a new representative year based upon the more extensive measured solar radiation data now available for Fort Hood (data for almost four years, as compared to the less than two years available for developing the original representative year).

Detailed comparisons between the new and original representative years indicated no differences that were considered significant in view of the statistical nature of the processes involved. Therefore, it was concluded that, for continuity, the original representative year data should continue to be used for design purposes.

Load Measurements

The size of the Fort Hood Solar Total Energy System is based on calculated thermal energy loads for five selected buildings of the 87000 Troop Housing Complex. Because of their significance, it is important that these

calculated load data be validated by actual measurements. Thus a program of measurements initiated during the prior contract period has been continued. Extensive measurements of electricity consumption at the 87000 Complex were initially included, but these have been curtailed now that it has been established that the electrical output of the STES will be synchronized with and fed into the existing electrical distribution system instead of being applied directly toward satisfying the requirements of specific buildings.

The thermal load measurements for the five selected buildings include:

- Space heating
- Domestic hot water
- Space cooling

The thermal requirements of these buildings are presently met by steam and chilled water supplied by separate branch lines from a central energy facility which serves the 87000 Complex. Since all five buildings are on the same branch lines, their collective thermal loads are measured at a common location. The instrumentation provides for measuring the temperatures of the steam supply and condensate return and the temperatures of the chilled water supply and return. Also measured are the steam pressure and condensate return volume and flow rate, and the chilled water flow rate.

Since the steam supply is the heat source for both domestic hot water and space heating, these two uses may be delineated only by season. Measurements initiated February 25, 1978, and continued through the end of the heating season (March 23) indicated that the combined loads were compatible with the calculated loads, although these dates covered such a small portion of the heating season that the comparison cannot be considered conclusive. Subsequent steam measurements represent hot water consumption and line losses only. Data through August 1978 indicate that the domestic hot water load drops considerably during the summer and may,

at times, be as little as one-third of the design load. The load appears to be cyclical, and further measurements are required for resolution. If these trends are confirmed, the STES operation strategy may be refined to obtain higher electrical generation efficiency.

Measurements of the space cooling loads were initiated on June 7, 1978, but, for various reasons, the data obtained prior to July 30 are not considered valid. Although too limited to be considered conclusive, the space cooling data obtained during the month of August tend to support the calculated loads.

Heat-Transfer-Fluid Tests

Trade studies conducted during the conceptual design (Reference 7) resulted in the selection of Sun 21 heat-transfer oil for use in the collector field and the high-temperature thermal storage subsystems of the Fort Hood STES. However, little was known about the stability and makeup requirements of Sun 21 at the operating temperatures involved (550°F). For this reason, the available test data have been reviewed, and additional static testing has been performed. The tests were planned under the Fort Hood Project but were conducted as part of a test program by Sandia Laboratories (Livermore) under separate DOE funding.

Several samples of Sun 21 are being held at temperatures of 500°F, 550°F and 600°F for a total of 3,000 hours. Some of the samples include carbon or stainless steel such as might be used in piping or storage tanks. Test data for the samples held at 600°F through August 31, 1978 (1,920 hours), show appreciable weight loss (approximately 0.005 percent per hour) and indicate that the presence of steel does not alter the loss rate significantly. No weight loss has been observed at 500°F, and based on the limited preliminary data, a weight loss of less than one percent per year (2,920 operating hours) is expected for a bulk temperature of 550°F. Chemical analyses of the samples will be performed at the end of the test period (3,000 hours).

Environmental Impact Assessment

An updated draft environmental impact assessment was prepared for the Fort Hood STES. It briefly describes the project goals, present system design,

and potential areas of environmental concern. This assessment is organized in the format prescribed by DOE and, therefore, contains the following elements:

- Description of proposed action
- Description of existing environment
- Potential environmental impacts during construction, operation, and site restoration
- Coordination effected
- Description of alternatives

Based on information presently available, the following conclusions were reached:

- The proposed Fort Hood Solar Total Energy Project is considered to be an action of vital importance to the National Solar Energy Development Program, although in relation to other projects (such as nuclear and space), it does not involve a major commitment of resources.
- An environmental impact statement is not required for the proposed action. There will be only limited additional air pollution and noise during the construction and site restoration phases. No destruction of archaeological or historic sites is involved. No disruption of wildlife habitats is anticipated. No increase in urban congestion should result. No critical effects on the health and safety of persons living in the area of the proposed action are expected, although there are potential health and safety considerations for workers involved in the construction, operation/maintenance, and site restoration activities. These limited impacts may be mitigated by effective control and monitoring efforts. Finally, no undesirable land use patterns are expected, and no consequences adverse to the environmental goals of the National Environmental Policy Act would result.

Information Dissemination

Since one purpose of STEP is to promote the solar total energy concept as well as solar energy technology in general, information dissemination has been a significant ancillary task during this contract period. Toward this

end, a brochure describing the Fort Hood Solar Total Energy Project was developed, a model depicting the system installed at the 87000 Troop Housing Complex was constructed, a set of 48 colored slides was prepared, and approximately 40 groups (including government, military, professional, civic, academic and foreign organizations) were briefed on the project during this contract period.

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7.0 PROJECT PLANNING

Statements of work, task schedules, long-lead item procurement plans, and cost estimates have been prepared for the next phase of the project--definitive design. Summaries of the subsequent construction phase tasks and schedules have also been prepared and are given in Volume IV, Management Plan. A preliminary plan for the final phase of the project--testing--has also been developed, and its outline is included in Volume IV.

Schedule

After completion of this preliminary design phase on October 31, 1978, a 10-month definitive design phase is planned. This will be followed by a 16-month construction period, with system completion scheduled for January 1981. After initial startup, the system will be operated in an experimental mode for 2 years, during which time numerous tests will be conducted and data will be collected and analyzed. These phases of the project are shown in Figure 6.

PHASE	1978	1979	1980	1981	1982
PRELIMINARY DESIGN
DEFINITIVE DESIGN
CONSTRUCTION
OPERATION

Figure 6. Project Schedule

Definitive Design Phase Tasks

Definitive design efforts have already been initiated for the instrumentation and control subsystem and the turbine-generator, long lead items requiring early procurement. The balance of the equipment specifications and procurement documents will be completed in the next phase. Technical support activities will continue as well as site coordination and information dissemination. Major definitive design phase tasks are summarized below.

- Project Management and Control
 - Project management
 - Planning and control
 - Site interface and coordination
- Project Technical Support
 - Site specific data analyses (energy loads, solar availability, soils characteristics)
 - Commercialization and economic analyses
 - Integrated logistics support
 - Environmental, health, and safety analyses
 - Information dissemination
 - Training requirements
- System Design
 - Site preparation
 - Solar collector subsystem
 - Power conversion subsystem
 - Heating and cooling subsystem
 - Instrumentation and control
 - Operation and maintenance
 - System integration

The subsystem design tasks will include final development and issue of piping and instrumentation diagrams, subsystem description documents, and measurement requirement lists. Foundation requirements will be developed, equipment and materials specifications will be detailed, and operation and maintenance manuals will be prepared.

REFERENCES

1. "Solar Total Energy Program Plan," Sandia Laboratories, Report SAND76-0167 (July 1976).
2. R.L. French and A.A.J. Hoffman, "Solar Energy Program for U.S. Army Installations, Vol. I, Electricity and Natural Gas Consumption at Fort Hood," American Technological University Phase I Report (March 1975).
3. A.A.J. Hoffman, D. Rapp, and CPT J.D. Crews, "Solar Energy Program for U.S. Army Installations, Vol. II, Availability of Solar Energy at Fort Hood," American Technological University Phase I Report (March 1975).
4. R.L. French, LTC A.J. Cates, D. Rapp, and A.A.J. Hoffman, "Solar Energy Program for U.S. Army Installations, Vol. III, Solar Thermal Conversion System Concepts for Fort Hood," American Technological University Phase I Report (March 1975).
5. A.A.J. Hoffman and R.L. French, "Solar Energy Program for U.S. Army Installations, Vol. IV, Executive Summary," American Technological University Phase I Report (March 1975).
6. R.L. French, A.A.J. Hoffman, and D. Rapp, "ATU/Fort Hood Solar Total Energy Project, Phase II Final Report for the Period April 1975 - November 1976; Conceptual System Design," American Technological University Report No. ORO/4924 - 76/01 (April 1977).
7. "Final Technical Progress Report: Solar Total Energy Large Scale Experiment, Phase II," Westinghouse Electric Corporation Advanced Energy Systems Division, (September 1977).