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SOLAR HEATING AND COOLING OF BUILDINGS STUDY CONDUCTED FOR DEPARTMENT OF THE ARMY.

VOLUME I: EXECUTIVE SUMMARY AND IMPLEMENTATION PLANS

GENERAL ELECTRIC COMPANY

PREPARED FOR

ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY

JUNE 1974

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SOLAR HEATING AND COOLING OF BUILDINGS STUDY CONDUCTED FOR DEPARTMENT OF THE ARMY

VOLUME I: EXECUTIVE SUMMARY AND IMPLEMENTATION PLANS

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A study of the use of solar energy for the heating and cooling of buildings at Army installations was conducted with two principal objectives: 1) the preliminary design of a solar heating system for retrofitting on an existing building and 2) the evaluation of solar system concepts for the combined heating and cooling of a building in the construction planning phase. A two story administration building at Fort Belvoir, Virginia was selected for the retrofit heating only application and a single story classroom building planned for Fort Huachuca, Arizona was selected for the evaluation of combined solar

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heating and cooling system concepts. In both applications, the solar energy was absorbed by roof mounted, flat-plate collectors, heating a circulating water flow which was collected in large thermal storage tanks until needed.

The preliminary design for the Fort Belvoir building system includes layout and piping interconnection of the solar collectors, the identification and basic sizing of tanks, pumps, valves, etc., the definition of controls, the selection of instrumentation for long-term performance evaluation, and the integration with the existing fan coil units of the building. The selected design uses 3055 square feet of solar collector area and a 4000 gallon thermal storage tank. A systems performance analysis using actual weather data and analytical models for the solar system components and building characteristics indicates that the solar system will provide thirty-nine percent of the seasonal heating load. Reducing the building heating requirements by use of nighttime thermostat setback, reduced nighttime ventilation and storm windows would increase the solar energy contribution to forty-nine percent.

The solar energy system concepts developed for the Fort Huachuca building application include various sizing options, evaluation of roof mounted or building detached solar collector arrangements and the identification of control and interface options. The selected reference system contains 7040 square feet of solar collection area and a thermal storage capacity of 12,000 gallons. A 100 ton lithium bromide-water absorption unit uses hot water supplied from the thermal storage tank and delivers chilled water for cooling purposes. Both the heating and cooling are accomplished by coils located in the air loop of the building. A systems performance analysis predicts that ninety-two percent of the combined heating and cooling requirements of the building can be supplied by this reference system.

Assessments were made of the principal technologies associated with solar collectors, thermal energy storage and cooling by means of solar energy. Implementation plans for follow-on phases describing further design activities, schedules, and cost estimates are provided for both the Fort Belvoir and Fort Huachuca Buildings.

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EXECUTIVE SUMMARY

SOLAR HEATING AND COOLING

OF BUILDINGS STUDY

1.0 INTRODUCTION

During the past decade twenty-four percent of the nation's energy consumption was used for the heating of domestic water and the heating and cooling of buildings. The use of solar energy for this type of consumption, due to its widespread and continuous availability and its clean, non-polluting form, is being increasingly recognized. As a result the U.S. Army initiated this study program to determine the potential application of solar energy for the heating and cooling of Army buildings. The objectives of this program were:

1. To identify a particular Army building suitable for the retrofitting of a solar energy system for heating purposes, and to prepare a preliminary design of the solar energy system.

2. To identify a new Army building presently being planned for construction which is suitable for solar heating and cooling, and to define applicable solar heating and cooling system concepts.

3. To evaluate pertinent solar energy system technologies and assess their impact on the above two applications.

4. To develop implementation plans for the two applications identified above.

This report presents the results of this study program performed by the General Electric Company and the contributors listed in Table 1. The effort was conducted under Contract No. DACA-23-74-C0006 and is reported in two volumes. Volume I (this volume) provides an Executive Summary and Implementation Plans for follow-on phases; Volume II presents the technical study results with supporting appendices.

(1)	NATIONAL CENTER FOR ENERGY MANAGEMENT AND POWER, UNIVERSITY OF PENNSYLVANIA, PHILADELPHIA, PENNSYLVANIA.
(2)	VINOKUR-PACE ENGINEERING SERVICES, INC., JENKINTOWN, PENNSYLVANIA.
(3)	KEAST AND HOOD COMPANY, STRUCTURAL ENGINEERS, PHILADELPHIA, PENNSYLVANIA.
(4)	LAWRENCE G. SPIELVOGEL, INC., CONSULTING ENGINEER, WYNCOTE, PENNSYLVANIA.
(5)	FRIEDMAN AND JOBUSCH, ARCHITECTS AND ENGINEERS, INC., TUCSON, ARIZONA

TABLE 1. STUDY PROGRAM CONTRIBUTORS

2.0 APPROACH

Figure 1 presents a simplified overall program flow diagram. Initially Army installations considered as suitable candidates for the application of solar energy systems were identified. These installations were visited and comparative evaluations of candidate buildings were made. An existing building was selected for the retrofit solar heating system; a new building to be constructed in the near future was selected for the solar heating and cooling system. These selections led to the preliminary design task for the retrofit system and the concept definition task for the new system. Building heating and cooling requirements were analytically determined. Candidate systems were modeled and parametric studies conducted to determine overall performance and to optimize system characteristics. In parallel, technology assessment tasks were conducted which addressed the major technologies associated with solar systems and also provided inputs to the design and concept definition tasks. Implementation plans for the next phase were prepared using the results of the design and concept definition tasks.

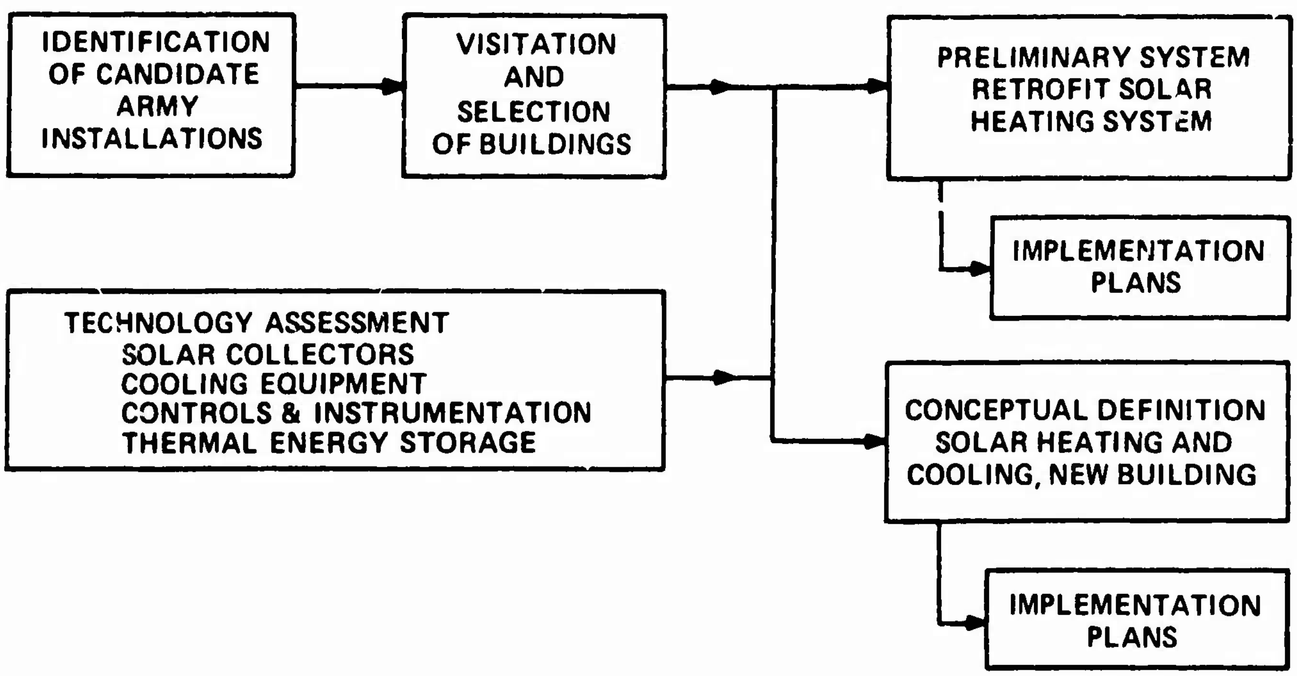
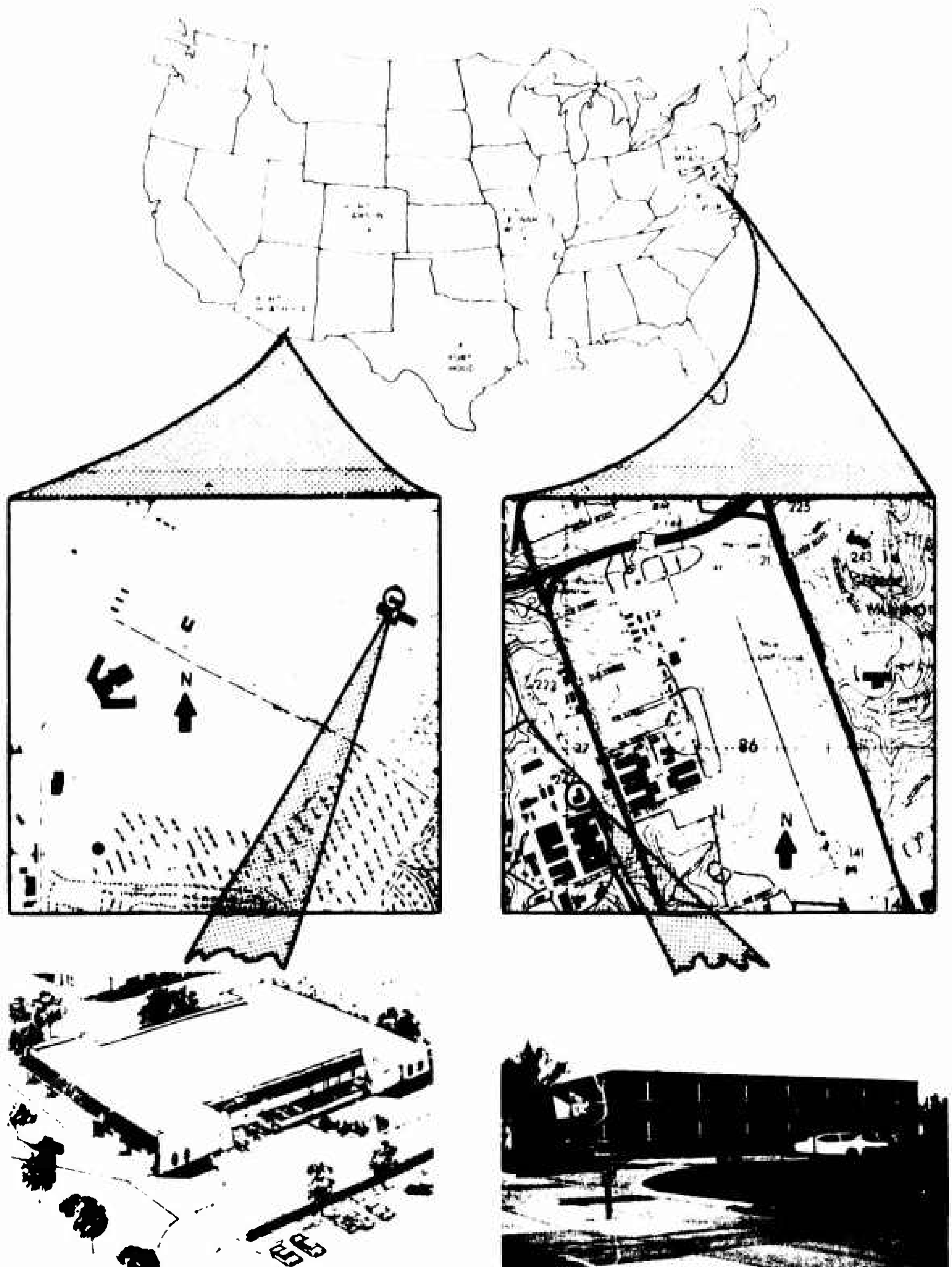


Figure 1. Study Program Approach

SITE AND BUILDING SELECTION



PLANNED CLASSROOM BUILDING

"MECH TECH" ADMINISTRATION BUILDING

Figure 2. Site and Building Selection

3.0 RESULTS

3.1 SITE AND BUILDING SELECTION

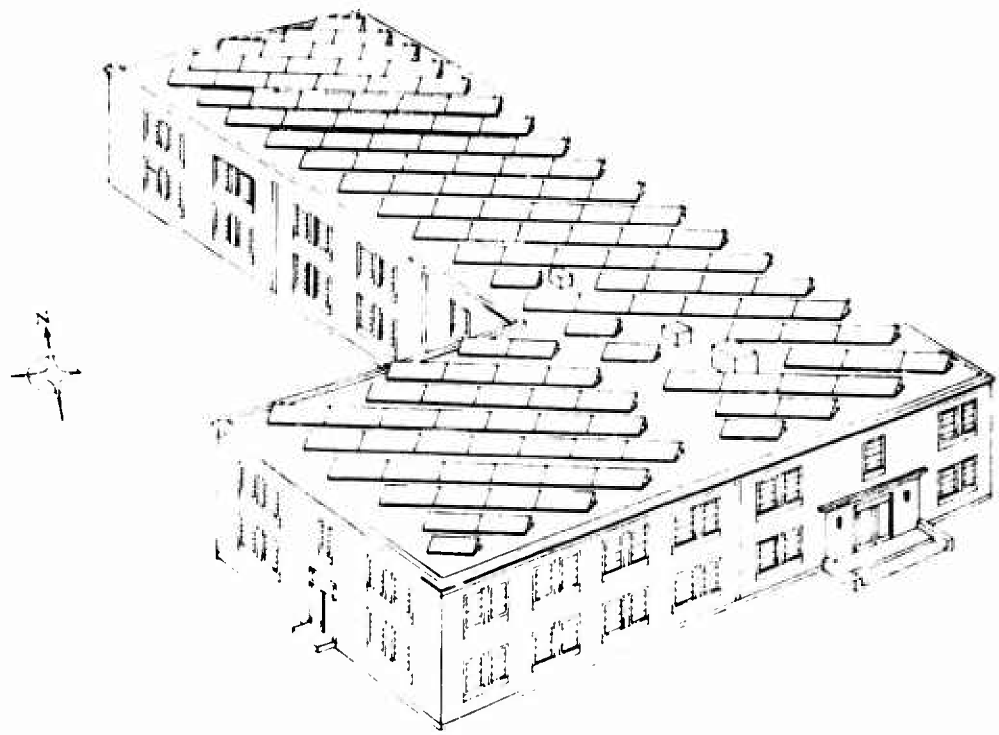
Twenty Army installations were identified as potential sites for building candidates. An initial screening, based mainly on energy savings potential and location, narrowed this group to six sites which included Forts Belvoir, Meade, Leonard Wood, Hood, Carson and Huachuca. Visitations were made to each installation and surveys conducted of possible building candidates. Building types considered included barracks, bachelor officer quarters, administration buildings and classroom buildings. The survey resulted in the compilation of 50 building candidates. The buildings were ranked against a set of selection criteria which included such technical factors as energy savings potential, roof area, and type of heating system, and non-technical factors such as building condition, accessibility and whether the building was typical of many Army buildings. From the assembled data and in consultation with the Army the buildings selected were as follows:

STUDY PURPOSE	LOCATION	DESCRIPTION
RETROFIT HEATING SYSTEM	FORT BELVOIR, VIRGINIA	ADMINISTRATION BUILDING FOR THE DEPARTMENT OF MECHANICAL AND TECHNICAL EQUIPMENT, BUILDING NO. 1425
HEATING/COOLING SYSTEM FOR NEW BUILDING	FORT HUACHUCA, ARIZONA	PLANNED INTELLIGENCE SCHOOL CLASSROOM BUILDING

TABLE A. BUILDING SELECTION

The sites, building locations and pictorial views are shown in Figure 2.

RETROFIT
HEATING SYSTEM



SYSTEM CHARACTERISTICS

SOLAR COLLECTORS

- PANEL AREA: 3055 SQUARE FEET
- PANEL SIZE: 38.5 X 96 INCHES
- NUMBER OF PANELS: 130
- ELEVATION ANGLE: 45 DEGREES
- AZIMUTH ANGLE: 11 DEGREES WEST OF SOUTH
- COLLECTOR TYPE: DOUBLE COVER WITH SELECTIVE ABSORBER COATING
- CIRCULATING FLUID: ETHYLENE GLYCOL-WATER MIXTURE

THERMAL STORAGE

- MEDIUM: WATER
- CAPACITY: 4000 GALLONS

ENERGY SAVED

- SPACE HEATING: 4000-5000 GALLONS FUEL OIL PER YEAR
- SUMMER DOMESTIC HOT WATER OPTION: 2000 GALLONS FUEL PER YEAR

Figure 3. Fort Belvoir "Mech-Tech" Building Solar Heating System Installation

3.2 RETROFIT HEATING SYSTEM - FORT BELVOIR MECH-TECH BUILDING

The characteristics of the Mech Tech Building are summarized in Table 2. A heating requirements analysis of the building using a thermal model of the building, and hour-by-hour weather and solar data tapes for the Washington, D.C. area for 1963, a representative year, indicated a heating season requirement of 995×10^6 BTU's.

- TWO STORY, FLAT ROOF, L-SHAPE
- BRICK AND CONCRETE BLOCK
- 15,000 SQUARE FEET FLOOR AREA
- 16 YEARS OLD
- 49 FAN COIL UNITS FOR SUMMER/WINTER OPERATION
- HEATING SYSTEM – STEAM TO HOT WATER CONVERTER FROM CENTRAL FACILITY
- COOLING SYSTEM – CHILLED WATER FROM ON-SITE CHILLER
- OFFICE AREAS, 60 PEOPLE
- USED 0800 TO 1700 HOURS, 5 DAYS A WEEK

TABLE 2. CHARACTERISTICS OF "MECH-TECH" BUILDING

The rooftop solar collector installation for providing a portion of the required heating is shown in Figure 3. A total of 130 collectors are used having a collection area of 3055 square feet. The collectors are 38.5 x 96 inches in size and are oriented at an elevation angle of 45 degrees and an azimuth angle of 11 degrees West of due South. This combination of angles maximizes the amount of solar energy collected. The flat plate collectors consist of a selectively coated absorber plate with integral fluid passages for heat transport and a double glazing of Lexan plastic windows, which entrap the incoming solar flux and minimize reradiation.

A schematic of the recommended solar energy system integrated with the existing heating system is shown in Figure 4. Several variations of this system were evaluated, with this arrangement determined to be the best choice considering performance and complexity. Hot

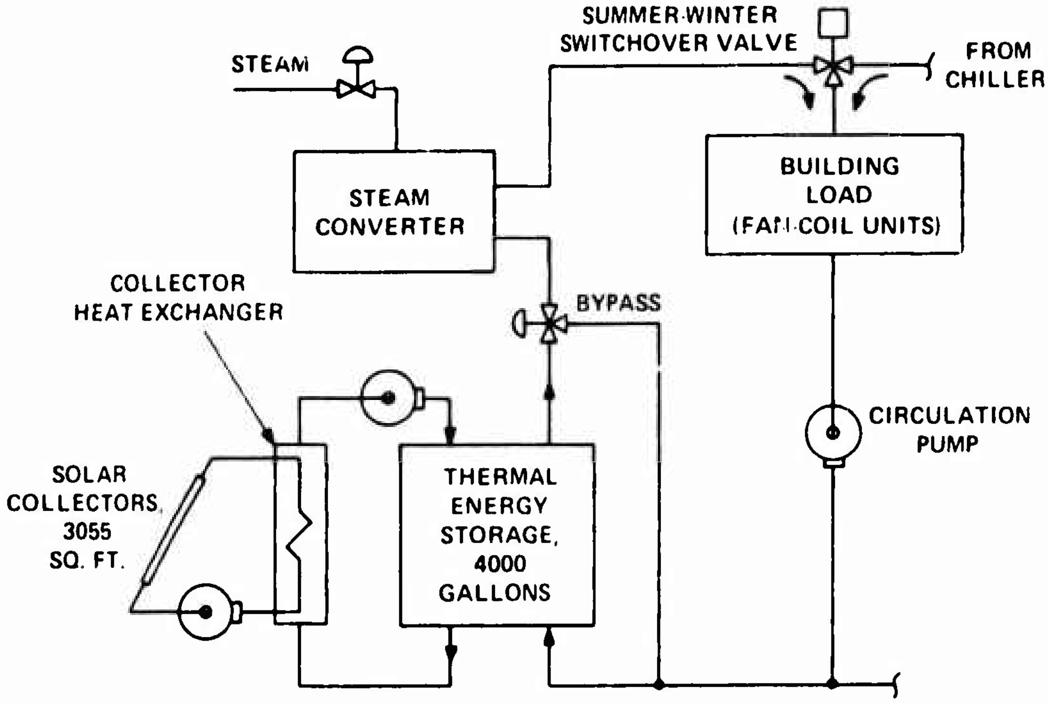


Figure 4. Solar Heating System Schematic

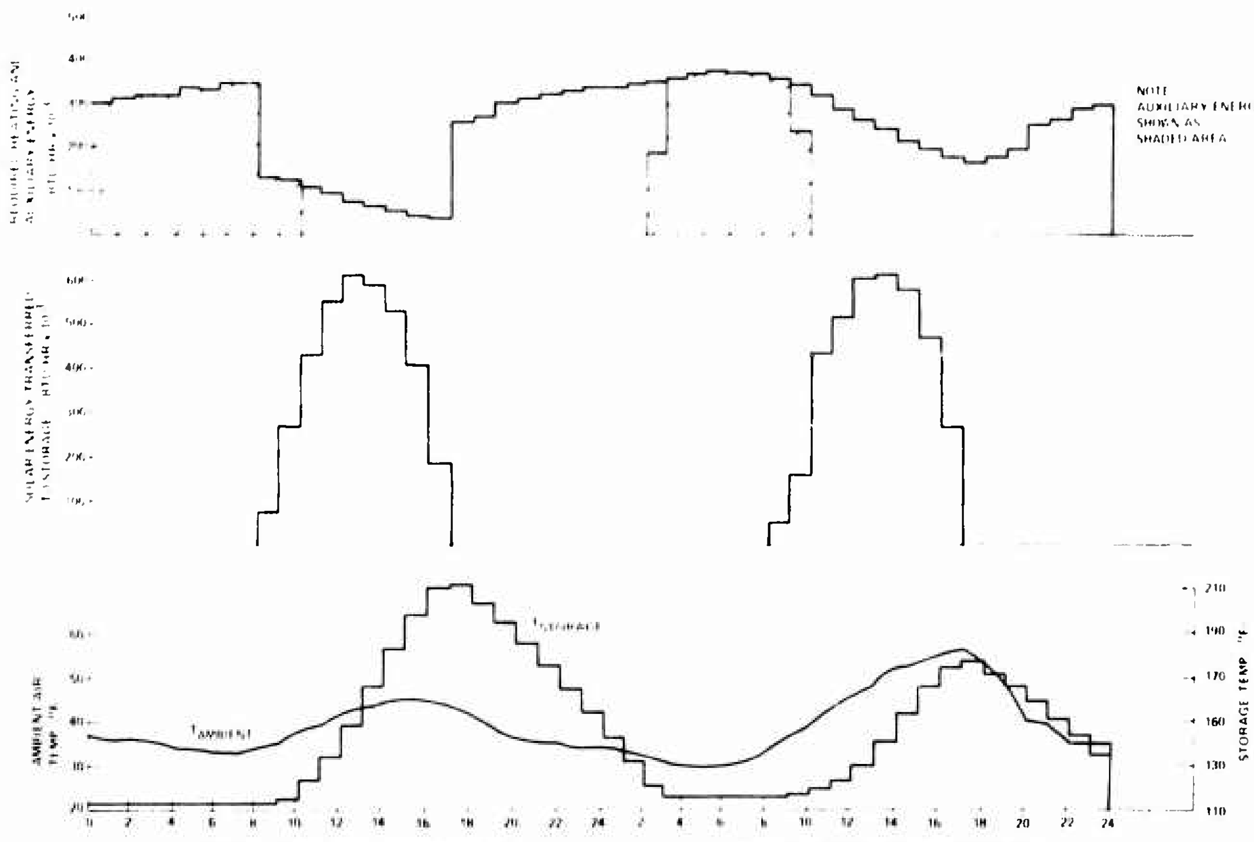


Figure 5. Fort Belvoir Representative Hourly System Performance

fluid (a glycol-water mixture) from the solar collectors is circulated through a heat exchanger whose secondary fluid (water) transports the energy to a 4000 gallon thermal storage tank. Hot water from the tank is circulated through the building fan-coil units. Appropriate bypass controls are used and auxiliary heat supplied from the existing steam converter when needed to provide circulating water at required temperature levels.

Hour-by-hour computer calculations were performed using the system described above together with the hour-by-hour heating requirements analysis described earlier. Figure 5 provides an example of the results in terms of the time-phased energy exchange occurring between the solar collectors, the thermal storage system, the auxiliary heating system and the building heating requirements. A computer summation of the delivered solar energy indicates that the solar system can supply 39 percent of the heating season requirements. The relative contribution of solar and supplemental heating are shown on Figure 6, along with the heating requirements. The solar energy provides an annual savings of 4000 to 5000 gallons of fuel oil. This range in savings is due to the uncertainty in the efficiency of the existing central facilities steam distribtuion system currently in use at Fort Belvoir. Incorporation of energy conserving features, such as storm windows, nighttime temperature setback and reduced nighttime ventilation, reduces the total heating requirement and increases the fraction contributed by solar heating to 48 percent. Extending the system to provide domestic hot water to a nearby barracks complex during the summer could result in an additional savings of 2000 gallons of fuel oil.

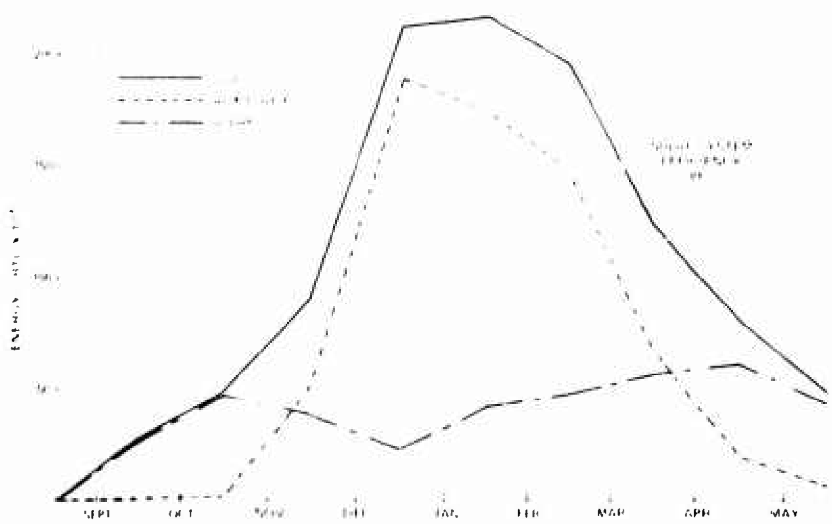


Figure 6. Heating Season Performance Profile

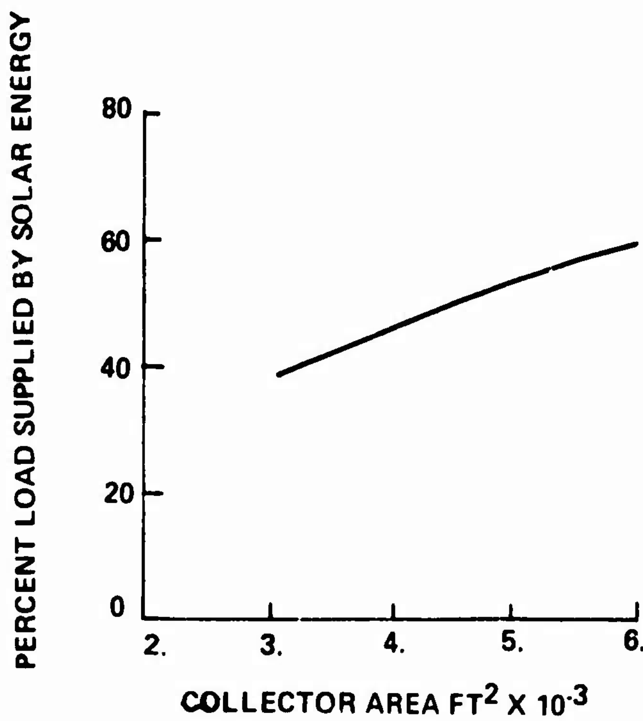
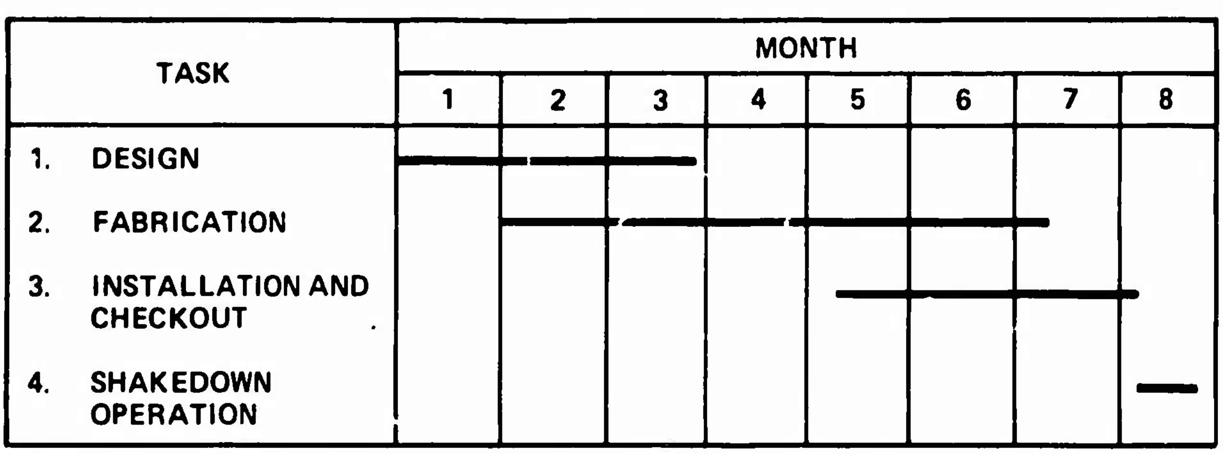


Figure 7. Performance Sensitivity to Collector Area



(ALL SYSTEM MAINTENANCE, REPAIR AND CALIBRATION TO BE PROVIDED BY GE FOR THE FIRST YEAR'S OPERATION)

Figure 8. Fort Belvoir Program Schedule

The maximum number of solar collectors were installed on the roof considering the practical aspects of area occupied by existing equipment and the need for service walkways. The effect on performance of using additional solar collectors, possibly by installing them over areas adjacent to the buildings, is shown on Figure 7.

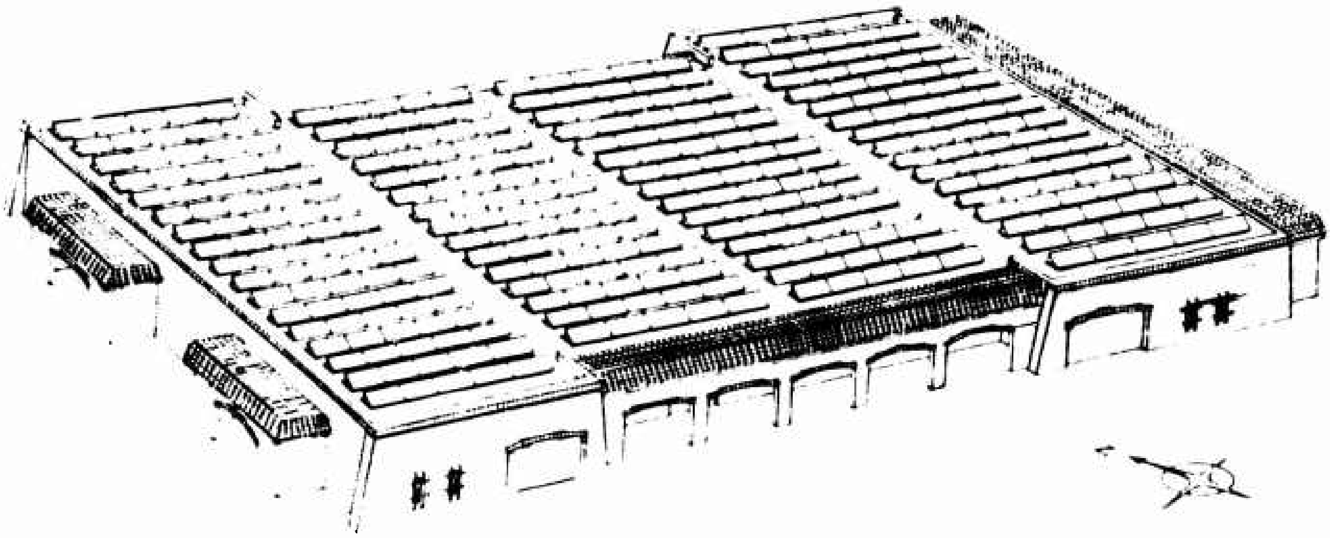
Implementation of this system is recommended. Except for the solar collectors, for which cost savings developments are continuing, the retrofit solar heating system can be implemented with commercially available material and equipment. With a July, 1974 start the system can be installed and operational by January, 1975. This would permit an orderly program and the opportunity to obtain performance data during a portion of the 1974-75 heating season. Figure 8 shows a summary schedule and task breakdown.

The projected cost of implementation is $338,600. Table 3 presents a cost breakdown by task.

TASK	COST ($)
1.0 FINAL DESIGN - INCLUDES FINAL DESIGN OF COLLECTORS, HEATING SYSTEM, CONTROL SYSTEM AND SUPPORT STRUCTURE	51,100
2.0 FABRICATION - INCLUDES COLLECTORS, STORAGE TANKS, HEAT EXCHANGERS, CONTROLS, AND AUXILIARY EQUIPMENT	88,200
3.0 INSTALLATION & CHECKOUT - INCLUDES INSTALLATION OF SUPPORT STRUCTURE, COLLECTORS, PIPING, CONTROLS AND ASSOCIATED EQUIPMENT; AND START UP AND CHECKOUT	121,900
4.0 SYSTEM EVALUATION - INCLUDES DESIGN, FABRICATION AND CHECKOUT OF INSTRUMENTATION; AND THE FIRST YEAR OF DATA COLLECTION, ANALYSIS AND REPORTING	77,400
TOTAL	338,600

TABLE 3. FORT BELVOIR COST SUMMARY

HEATING AND COOLING SYSTEM



SYSTEM CHARACTERISTICS

SOLAR COLLECTORS

- PANEL AREA: 7,040 SQUARE FEET
- PANEL SIZE: 38.5 X 96 INCHES
- NUMBER OF PANELS: 300
- ELEVATION ANGLE: 25 DEGREES
- AZIMUTH ANGLE: 27 DEGREES WEST OF SOUTH
- COLLECTOR TYPE: SINGLE COVER WITH SELECTIVE ABSORBER COATING
- CIRCULATING FLUID: ETHYLENE-GLYCOL-WATER MIXTURE

THERMAL STORAGE

- MEDIUM: WATER
- CAPACITY: 12,000 GALLONS

COOLING EQUIPMENT

- 100-TON ABSORPTION CHILLER (ARKLA)

ENERGY SAVED

- HEATING AND COOLING - 2 MILLION CUBIC FEET OF GAS PER YEAR

Figure 9. Fort Huachuca Basic Officer Course Classroom Building Solar Heating and Cooling System Installation

3.3 HEATING AND COOLING SYSTEM FOR NEW CLASSROOM BUILDING AT FORT HUACHUCA

The characteristics of the classroom building are summarized in Table 4. This building is part of a complex planned for the new academic service school at Fort Huachuca. Using defined occupancy schedules, equipment usage, building characteristics, and heating and cooling requirements, analyses were performed based on a thermal model of the building and hourly weather and solar data for 1963 for the Phoenix, Arizona region. Modifications were introduced for adjusting the data to Fort Huachuca conditions. The building was divided in four zones, and the results produced hour by hour heating and cooling requirements for each zone.

- ONE STORY, FLAT ROOF
- 16,000 SQ. FT.
- REINFORCED CONCRETE SLUMP BLOCK
- ONLY 10% WINDOW AREA
- SPANISH MOTIF
- HOT WATER AND CHILLED WATER FROM CENTRAL FACILITIES PLANT
- ALL CLASSROOMS, EXCEPT FOR MECHANICAL ROOM AND SPACE FOR SMALL TRAINING COMPUTER
- USED 0800 TO 1700 HOURS, 5 DAYS A WEEK
- MAXIMUM OCCUPANCY OF 540 PEOPLE

TABLE 4. CHARACTERISTICS OF BASIC OFFICER COURSE CLASSROOM BUILDING

Both rooftop and detached solar collection systems were studied. The rooftop approach is recommended because of lower losses and is illustrated in Figure 9. A total of 300 collectors are used having a collection area of 7040 square feet. The collectors are 38.5 x 96 inches in size and are in-line with the roof edge at an azimuth of 27 degrees West of South. The in-line arrangement was suitable because the performance of the collectors was insensitive over a wide azimuth range varying from due South. The system optimized for a low angle of 25 degrees because of the dominating demand for cooling and the southern latitude of Fort Huachuca. The solar collectors are similar to those recommended for the Fort Belvoir building except that a single glazing is preferred over a double glazing. The single glazing unit is more cost effective in this operation.

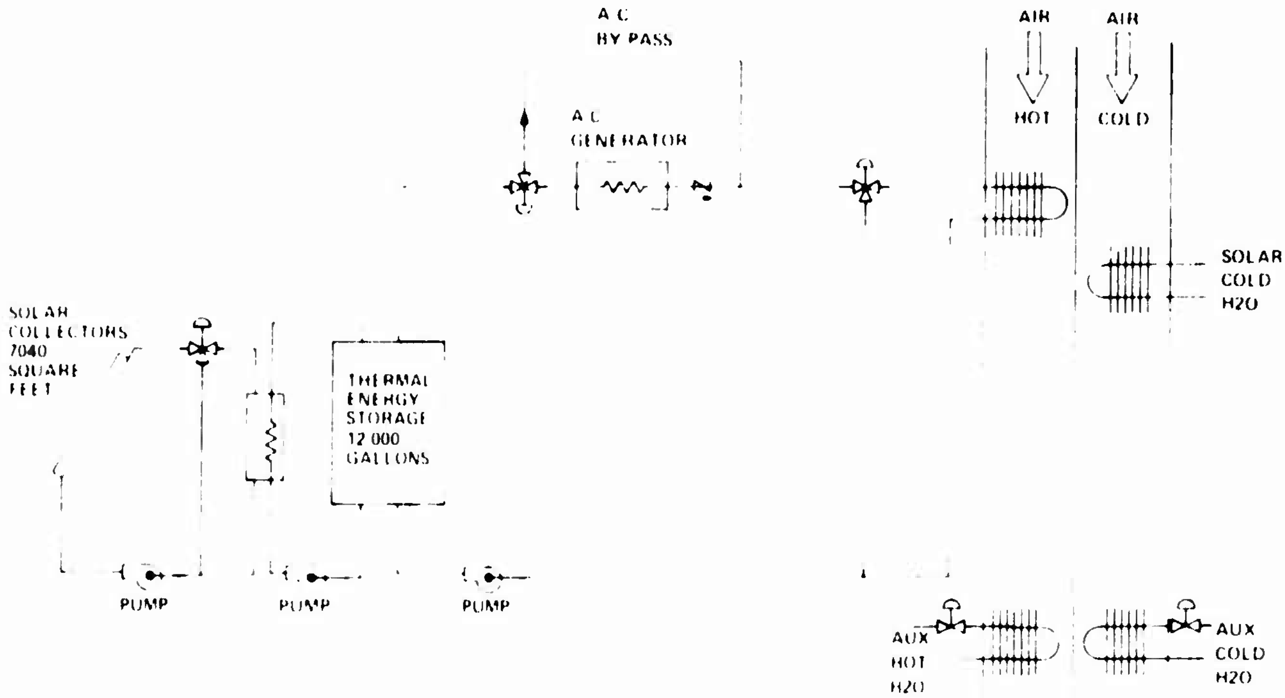


Figure 10. Solar Heating and Cooling System Schematic

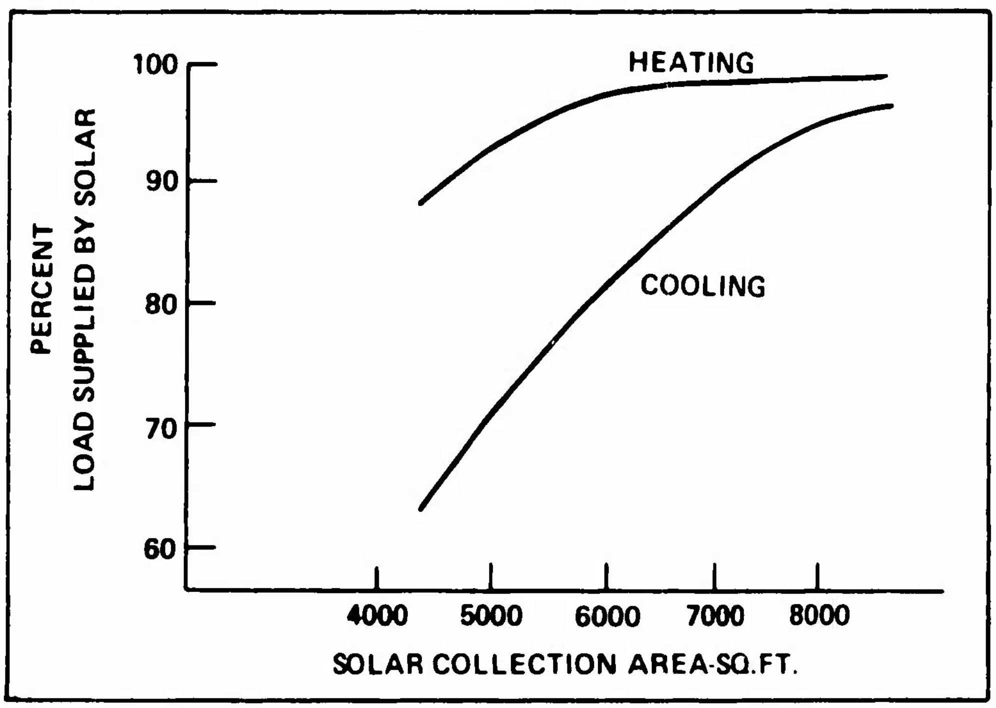


Figure 11. Performance Sensitivity to Collector Area

A diagram of the recommended system concept is shown in Figure 10. The collected solar energy is stored as water sensible heat in a 12,000 gallon thermal storage tank. Heating is provided by circulating water from the thermal storage tank directly through coils in the building air duct system. Cooling is provided by circulating the hot water through a 100 ton absorption chiller which supplies chilled water to coils in the air duct system. Typical results of the parametric studies conducted with the combined heating and cooling requirements with the recommended system are presented in Figure 11. The results indicate that with 7040 square feet of collectors the system can provide 98% of the heating requirements and 90% of the cooling requirements with an annual fuel saving of over 2 million cubic feet of gas (equivalent to 17000 gallons of oil). These studies were performed on an hour-by-hour basis for the entire year since both heating and cooling is desired. Figure 12 shows typical performance results for several days. The studies also considered the use of an economy cycle (using outside air directly for cooling) when feasible.

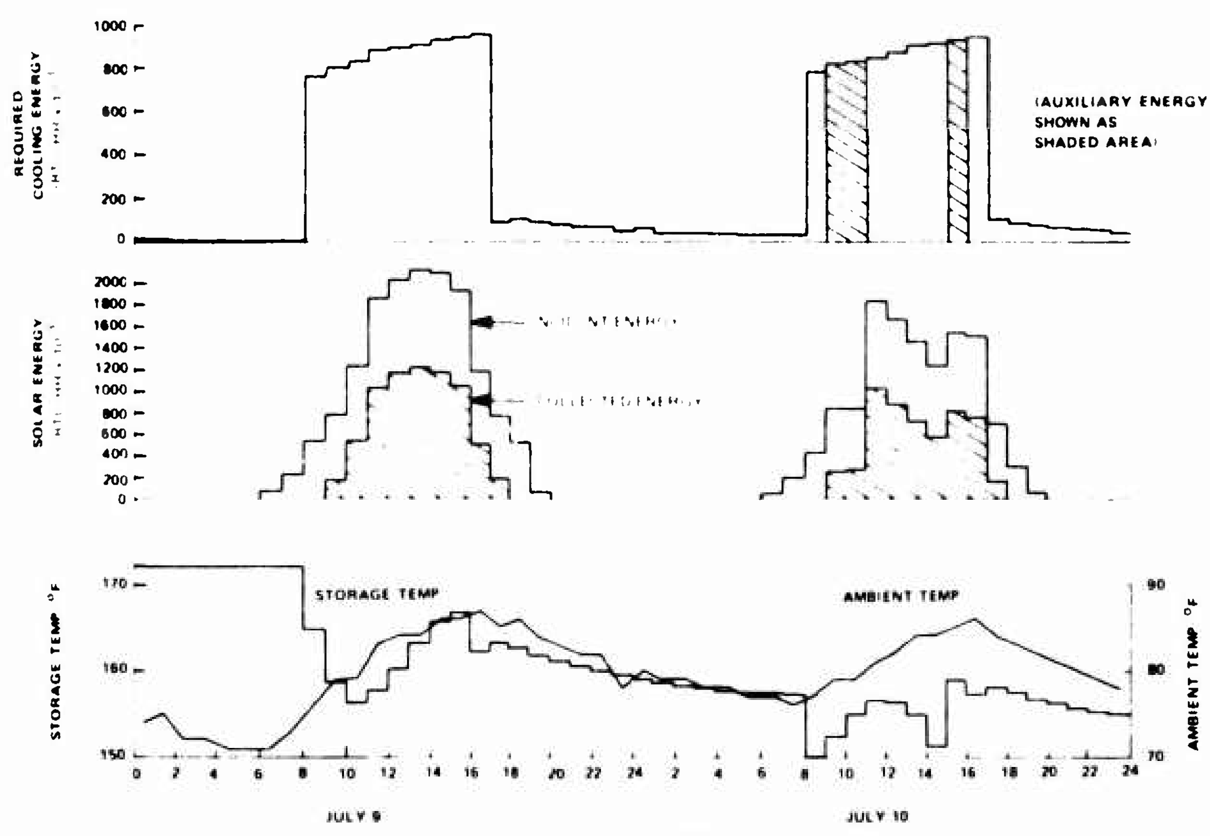


Figure 12. Fort Huachuca Representative Hourly System Performance

HEATING AND COOLING SYSTEM

Incorporation of a solar heating and cooling system into this academic classroom building is recommended. Except for the solar collectors, for which cost savings developments are continuing, the system can be implemented with commercially available material and equipment. The program should proceed into the preliminary design in phase with the schedule for design and construction of the building as shown in the schedule and task summary presented in Figure 13. Building completion and solar system operational dates will coincide. This would be in early 1976.

The projected incremental costs for implementation of the solar heating and cooling system is $465,000. Table 5 presents a cost breakdown by task.

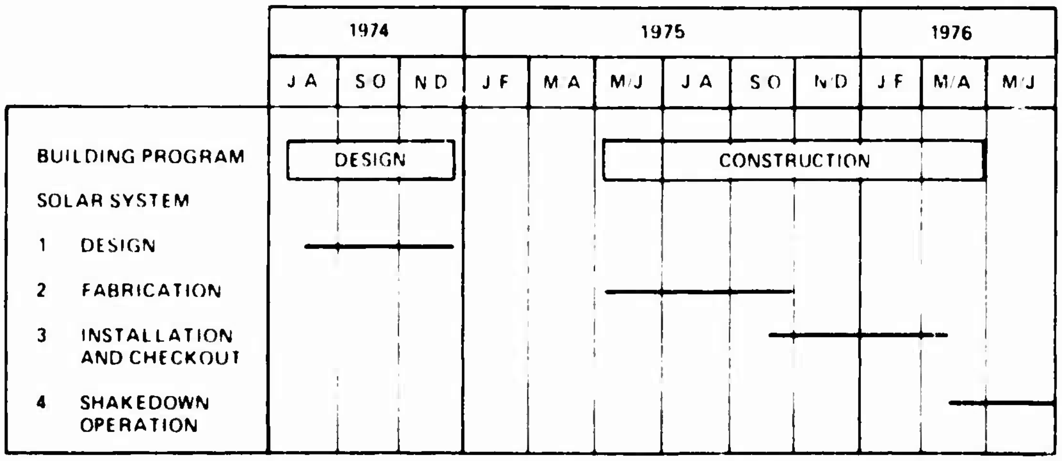


Figure 13. Fort Huachuca Program Schedule

TABLE 5. FORT HUACHUCA COST SUMMARY

TASK		[illegible]
1. [illegible]	INCLUDES FINAL DESIGN OF COLLECTORS, HEATING AND COOLING SYSTEMS, CONTROL SYSTEMS, SUPPORT STRUCTURE AND INCREMENTAL BUILDING [illegible] COSTS FOR CHANGES TO BASIC BUILDING DESIGN.	[illegible]
2. FABRICATION	INCLUDES COLLECTORS, CHILLER, COOLING TOWER, STORAGE TANKS, HEAT EXCHANGERS, CONTROLS AND [illegible] EQUIPMENT	165,000
3. INSTALLATION & CHECKOUT	INCLUDES INSTALLATION OF SUPPORT STRUCTURE, COLLECTORS, PIPING, CONTROLS AND ASSOCIATED EQUIPMENT. INCREASED COSTS OF THE CONSTRUCTION CONTRACTOR AND START-UP AND CHECKOUT	[illegible]
4. SYSTEM EVALUATION	INCLUDES DESIGN, FABRICATION AND CHECKOUT OF INSTRUMENTATION AND THE FIRST YEAR OF DATA COLLECTION, ANALYSIS AND REPORTING	89,000
TOTAL		4[illegible],000

3.4 TECHNOLOGY ASSESSMENT

Solar Collectors

Both analytical and empirical data support the selection of flat plate solar collectors for collecting solar energy for the heating and cooling of buildings. The basic design consists of 1 or 2 glass or clear plastic glazing covers over an absorber plate as shown in Figure 14. A selective absorber coating is preferred because it limits the amount of reradiation resulting in better performance as shown in Figure 14b.

Figure 14c shows the collector design currently being recommended by the General Electric Company.

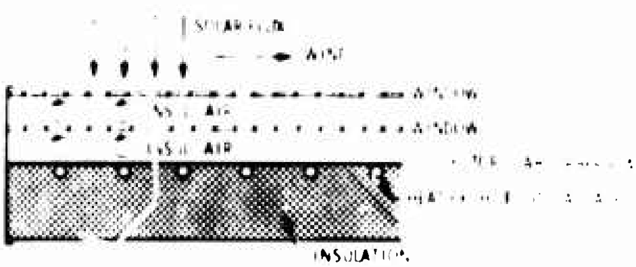


Figure 14a. Basic Solar Collector Design

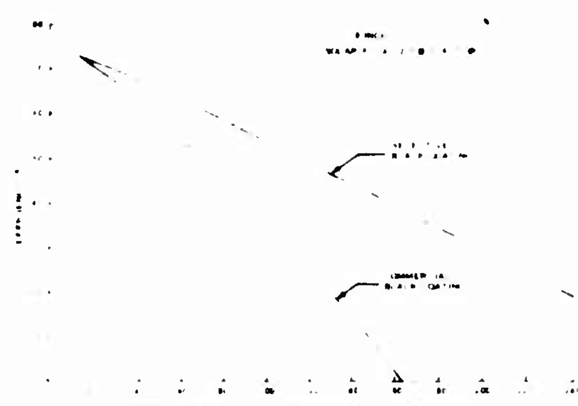


Figure 14b. Effect of Absorber Coating on Collector Efficiency

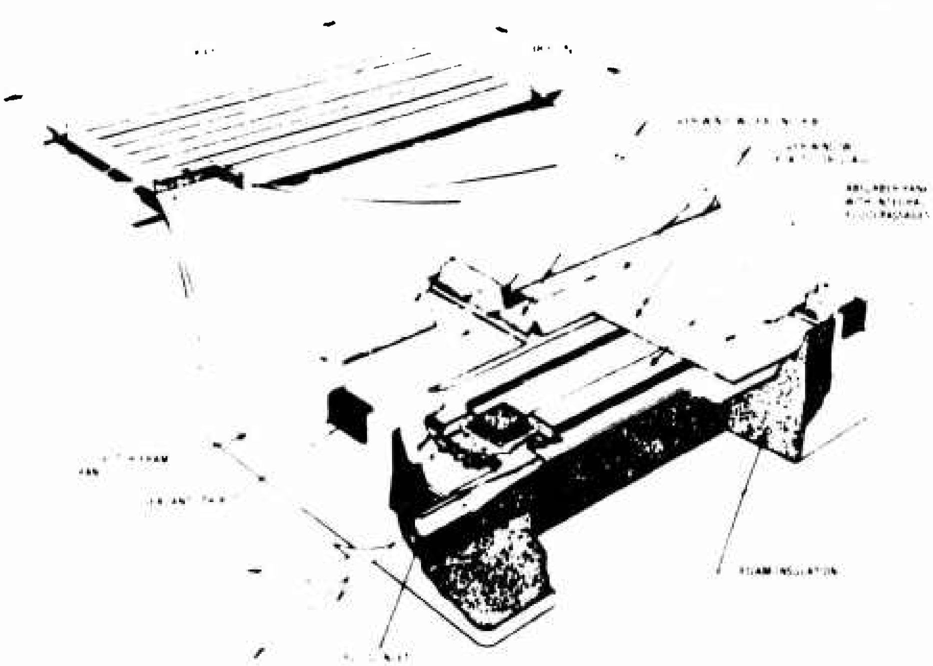


Figure 14c. General Electric Production Solar Collector Used in NSF Boston School Project

Similar collectors were recently installed on a Boston school as shown in Figure 15 under a grant provided by the National Science Foundation. A photograph of a single four foot by eight foot collector on a test stand is shown in Figure 16.

Current individual small batch production runs cost on the order of $20 per square foot. It is anticipated that volume production will reduce these costs to $5 per square foot.

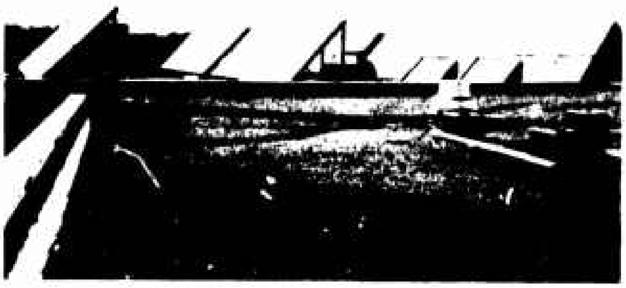


Figure 15. Boston School Solar Collector Installation

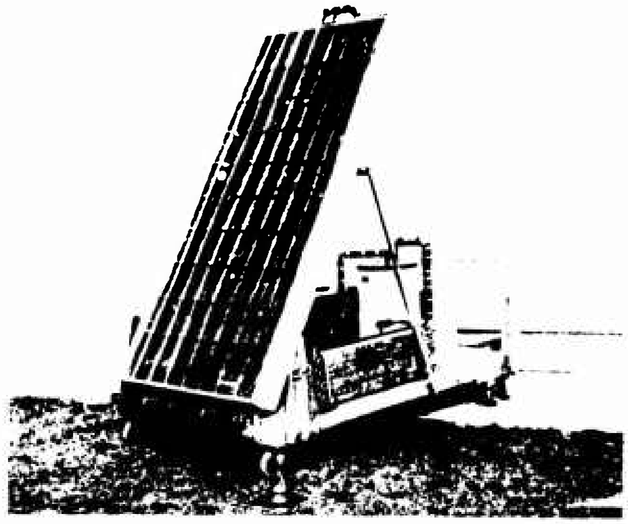


Figure 16. Test Collector

Cooling Equipment

The results of this technology assessment clearly show that the only candidate for cooling equipment available within the schedules of the Fort Huachuca project is the water fired gas absorption refrigeration system. Specifically, a 100 ton lithium-bromide/water unit manufactured by Arkla is recommended.

Thermal Storage

Although considerable work has been performed on numerous materials, water appears the most practical as an energy storage medium. One concept which holds some promise consists of a slurry of coated paraffin particles in water. The particles provide the necessary heat transfer surface, a stumbling block with many approaches. Also, paraffin is a relatively inexpensive material. Such factors as long term stability are yet to be determined.

3.5 IMPLEMENTATION PLAN SUMMARIES

Summaries of the Implementation Plans described later in this volume are as follows:

- Fort Belvoir Building

  The system can be installed including instrumentation, by January, 1975, with a July 1974 start date. This would permit actual operation during the latter half of the 1974/75 heating season. A task and schedule summary is shown in Figure 8. A more detailed breakdown is presented in the Implementation Plan section. The projected cost to implement the recommended system is $338,600. A breakdown by task is shown in Table 3.

- Fort Huachuca Building

  A recommended schedule for the Fort Huachuca project is shown in Figure 13. It requires initiation within the next two months (July or August 1974) in order to be in phase with the planned design and construction of the new building complex at Fort Huachuca. This would result in an operational system by the summer of 1976. A more detailed task breakdown is presented in the Implementation Plan section. The projected incremental cost to implement the recommended system is $465,000. A cost breakdown by task is presented in Table 5.

In developing the implementation plans for the two systems identified in this study, it was considered useful to formulate a logical future plan for Army solar system applications, and to evaluate how other programs now underway or due to be started in the near future can impact and provide possible support for the Army program. Consequently a multiphase program illustrated in Figure 17, was formulated which extends over a four to six year period. As shown, the first phase is the study presented in this report and the next phase (Phase 2) is the implementation of the retrofitted solar heating system and the installing of a solar heating and cooling system in a new building.

The Phase 2 demonstrations will provide the practical experience and actual on-site performance for both systems. The results of these demonstrations will lead to the next phase (Phase 3) which would involve the selection of several demonstration units representing a variety of building types at Army installations at several different geographical locations. The actual implementation of these systems and the resulting operational experience would then permit the "mapping" of the relative benefits of the solar systems. This would identify the types of systems and buildings in specific locations of the country showing economic or energy savings advantages, and would enable the Army to establish a priority for the application of solar systems. The final phase (Phase 4) would be the actual widespread implementation according to the priority established as a result of the experience of the preceding phases.

IMPLEMENTATION PLAN

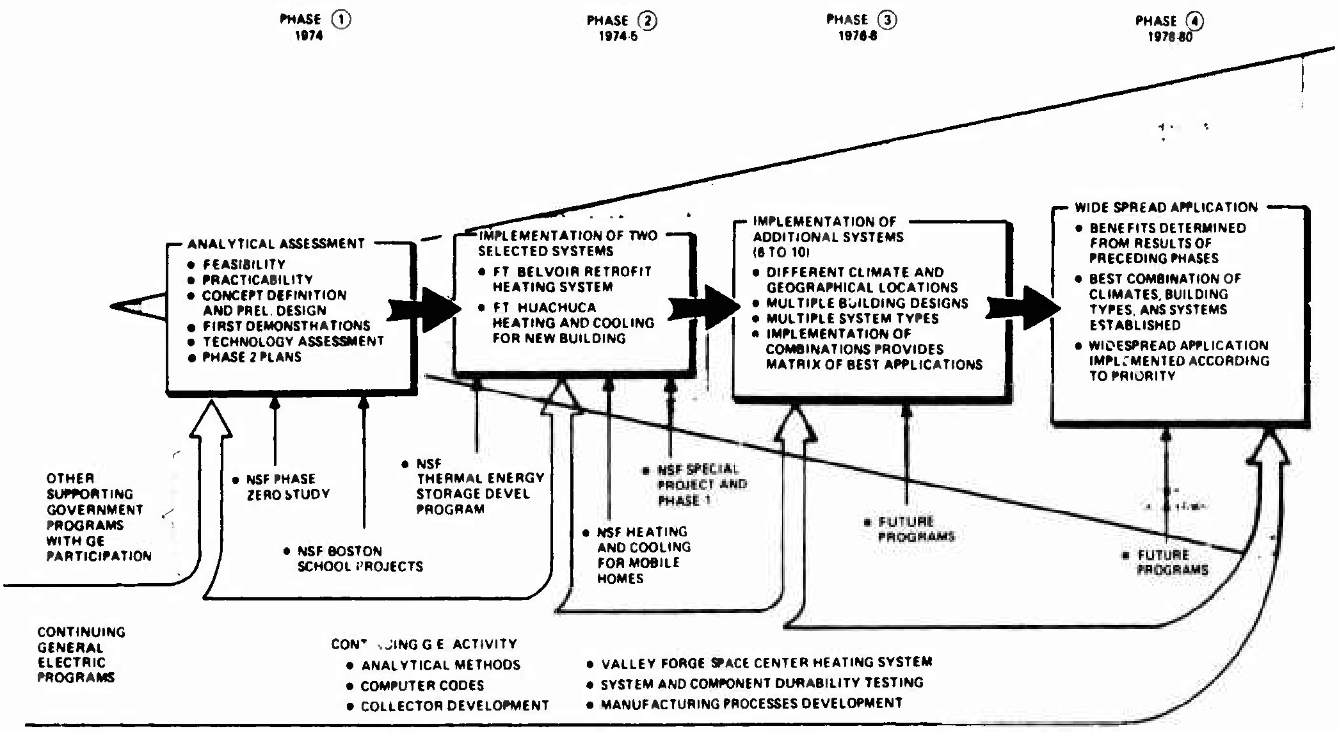


Figure 17. Army Program for Application of Solar Heating and Cooling of Buildings

Figure 17 also indicates that other programs, both those underway at GE and those due to be started in the near future, support the Army program. In the category of programs presently underway, the National Science Foundation (NSF) Phase 0 Study addresses the requirements, the system types, the marketing aspects, social and environmental factors, and the costs of solar systems. It also includes the planning of subsequent phases and evaluates means for stimulating the widespread application of these solar systems. GE is one of three Phase 0 contractors. The NSF school program resulted in the actual fabrication and installation of a solar heating systems in four schools. GE was the contractor for a school in Boston, Massachusetts. The GE in-house programs have concentrated on the development of analytical methods and computer codes, and on the development of flat plate solar collectors. All of these efforts have already contributed significantly to making the results of this Phase 1 Army program more meaningful.

In the category of upcoming programs two grants from NSF will provide benefits to the Army follow-on phases. One concerns the feasibility of a paraffin-water slurry as a practical thermal energy storage media, and the other concerns the design and construction of a solar heating and cooling system for a mobile home. Plans for expanded GE in-house efforts include component development and durability evaluation, manufacturing processes development, and the retrofit of a solar heating system to one wing of the main GE Space Center building. General Electric also anticipates working on Phase 1 of the NSF study and participating in other special projects.

Results available from other programs and applicable to this type of system will also be utilized, such as the results and experiences of the other NSF Phase 0 studies and school programs.

CONCLUSIONS

4.0 CONCLUSIONS

The principal conclusions resulting from this Phase 1 study are as follows:

1. A solar energy heating system for the Fort Belvoir Mech-Tech Building can provide 39 percent of the space heating requirements, can save 4000 to 5000 gallons of fuel oil annually, and can be in operation by January 1975. It would cost approximately $338,600. Implementation of this system will provide the practical experience of retrofitting a new technology system. Real performance data as well as maintenance and operational experience will be obtained.

2. A solar energy heating and cooling system for the Fort Huachuca classroom building can provide 90 percent of the cooling requirements and 98 percent of the heating requirements for an annual fuel savings of over 2 million cubic feet of natural gas. It can be installed at a cost of $465,000 and be operational for the 1976 summer cooling season. Implementation of this system will provide the practical experience of designing and constructing a solar heating and cooling system into a new building. Real performance data as well as maintenance and operating experience will be obtained.

3. The study produced a methodology for analyzing the performance of solar heating and cooling systems. With the definition of key building parameters and the availability of hour-by-hour weather and solar data, the methodology can be applied to a wide range of building types, operating conditions, and geographical regions.

4. Although the buildings studied differed widely in characteristics and geographical location there were a number of significant commonalities of design, e.g., the type and arrangement of solar collectors, the type of thermal storage and certain aspects of control. This result indicates the potential for standardization.

5. Except for solar collectors, for which cost-saving developments are continuing, the design of the solar heating and cooling system can be implemented using commercially available hardware.

5.0 RECOMMENDATIONS

The recommendations resulting from this study are:

1. The follow-on phase for the Fort Belvoir building involving detailed design, construction and operation should be initiated as soon as practicable to accommodate both an orderly program and the opportunity to obtain performance data during a portion of the 1974-75 heating season. If a later start appears necessary, incorporation of the domestic water heating feature would permit its evaluation during the spring and summer of 1975. Evaluation of the heating system would then occur during the following winter.

2. Definition of the Fort Huachuca system should proceed into preliminary design in phase with the schedule for design and construction of this classroom building. The design should be based on the rooftop concept described in the body of this report. However, if further consideration of the central solar farm approach for Fort Huachuca is desired, then a more in-depth study of this specific approach should be made and its features compared with the features of the individual rooftop systems. This was beyond the scope of this study.

3. Broad system studies should be undertaken to determine the extent that the Army should utilize solar energy for heating and cooling of buildings. Such studies should be performed in parallel with the Phase 2 demonstration phase to: (a) determine the nature of Phase 3 demonstrations; (b) provide a basis for planning the future role of solar energy utilization; and (c) assemble data relative to Army installations regarding types of heating and cooling systems used, the types of building construction, generalized heating and cooling requirements, usage and availability of fuels for heating and cooling of buildings, and weather and solar energy availability data.

4. Additional development is needed in the following areas to facilitate the widespread application of solar systems:

   (a) Improved materials and manufacturing techniques that will lead to greater durability, higher efficiency, and decreased cost for solar collectors.

   (b) Improved coefficients of performance (COP) for absorption or other types of cooling equipment that are compatible with the temperatures of solar systems.

   (c) Cost-saving innovations relative to installation and mounting of collectors, piping, heat exchangers, controls, and auxiliary equipment.

   (d) Roof integrated solar collectors, i.e., collectors that provide roofing functions (prevention of water entry, insulation, etc.) in addition to collecting solar energy.

IMPLEMENTATION PLAN
RETROFIT HEATING SYSTEM FOR FORT BELVOIR
MECH-TECH BUILDING

PROGRAM IMPLEMENTATION PLAN
RETROFIT HEATING SYSTEM

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A. INTRODUCTION

This program will provide a solar energy heating system to augment the existing system on the Administration Building for the Department of Mechanical Technical Equipment at Fort Belvoir, Virginia. The proposed system is expected to provide from thirty to fifty percent of the heat required during a typical heating season. It will consist of an array of 130 flat plate solar collectors mounted on the roof of the building. A water/ethylene glycol fluid circulating through the collectors will provide heat to a heat exchanger which in turn will provide hot water to a thermal energy storage (TES) tank and the existing fan coil units in the building. The fan-coil units currently use hot water in the same temperature range as that available from the solar collectors, however to increase the effectiveness of the solar system, a somewhat lower modulated water temperature will be used. A thermal energy storage tank of 4000 gallons capacity will be used to store excess solar energy for use during periods when direct collection is insufficient to supply the heating demand. Control and modulating valves and an integrated control system will complete the interface between the existing and the solar energy systems so that heating can be supplied from either or both systems to meet the heating load demands. Instrumentation will be provided to monitor system performance and allow an evaluation of the total energy usage and that portion supplied by the solar heating system.

The system will be optimized to provide the maximum practical heating using roof mounted flat plate collectors in conjunction with thermal energy storage (TES).

B. SCOPE

This plan defines a program for the final design, procurement, fabrication, installation and operation of a solar heating system to be installed on an existing Army building. It includes an implementation schedule and an estimate of the costs for each of the major program tasks. The program is planned as a follow-on to Army Contract DACA 23-74-C0006 for "The Development of a Solar Heating and Cooling System."

C. SCHEDULE

The solar heating retrofit program has been structured to minimize total elapsed time while allowing it to be conducted in an orderly manner. With a go-ahead by July 1, 1974, the system can be operational by the end of January, 1975 so that a performance evaluation can be made during the remaining portion of the heating season. The detailed design will be accomplished

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on a short time cycle since it will follow directly from the analysis and preliminary design which was accomplished during Phase I of the program. Some overlap is planned between the detailed design, fabrication and installation phases of the program to permit a smoother total program flow. Long lead items will be identified midway through the detailed design effort to allow orders to be placed for deliveries that are compatible with the fabrication and assembly needs. Building modifications will be started during the hardware fabrication cycle so that installation can begin as soon as hardware becomes available. Collector installation will be phased with building modification and hardware fabrication such that collectors will be shipped and installed in batches as the structure is completed and collectors are delivered. This approach results in schedule overlaps, but allows a more efficient total application of effort as can be seen in the case of the collectors where the last batches are being fabricated while earlier lots are already being installed.

The planned program schedule, with elapsed time shown in months from Program go-ahead, is shown in Figure 1. Key program milestones are defined.

D. COST SUMMARY

The cost of retrofitting the Fort Belvoir Mech-Tech Building with a solar heating system was evaluated. The cost to perform the effort as defined by this implementation plan is projected to be $338,600. This cost is exclusive of the optional decorative fascia, exterior stairs to the roof, or domestic hot water heating which would comprise an additional $58,600. The elements of this cost, in accordance with the task definitions, are as follows:

Task 1.0	FINAL DESIGN	$ 51,100
Task 2.0	FABRICATION Solar Collectors, 3055 sq. ft. @ $17.70/sq. ft. Auxiliaries (TES, heat exchanger, pumps, valves, shipping containers, controls, and other costs) $34,100	$ 88,200
Task 3.0	INSTALLATION & CHECKOUT	$121,900

Task 4.0	SYSTEM EVALUATION Instrumentation (design, fabrication and installation) $53,600 Data Collection & Analysis $17,400 Reporting $6,400		$ 77,400
TOTAL			$338,600

OPTIONAL ITEMS

Decorative Fascia	$32,600
Stairs to Roof	6,500
Domestic Hot Water Heating	19,500
Total	$58,600

1.0 FINAL DESIGN

Final system definition, analysis and detailed design will be accomplished under this task. It will also include that effort required for direction, monitoring and control of the program.

1.1 PROGRAM DEFINITION AND SYSTEM DESIGN

Program objectives and design parameters have been defined based on the data generated under the phase I program.

The effort under this task will finalize the overall system design and consist of the following subtasks:

- review and approval of final system design, including collector design and instrumentation definition
- definition of operating parameters and prediction of performance characteristics
- monitor, control and report on program performance through funding control, financial reports, contract accounting and contractual documentation
- provide the customer with information on program status and progress, to include program meetings with him
- review and approval of subcontractor agreements and liaison during fabrication and installation

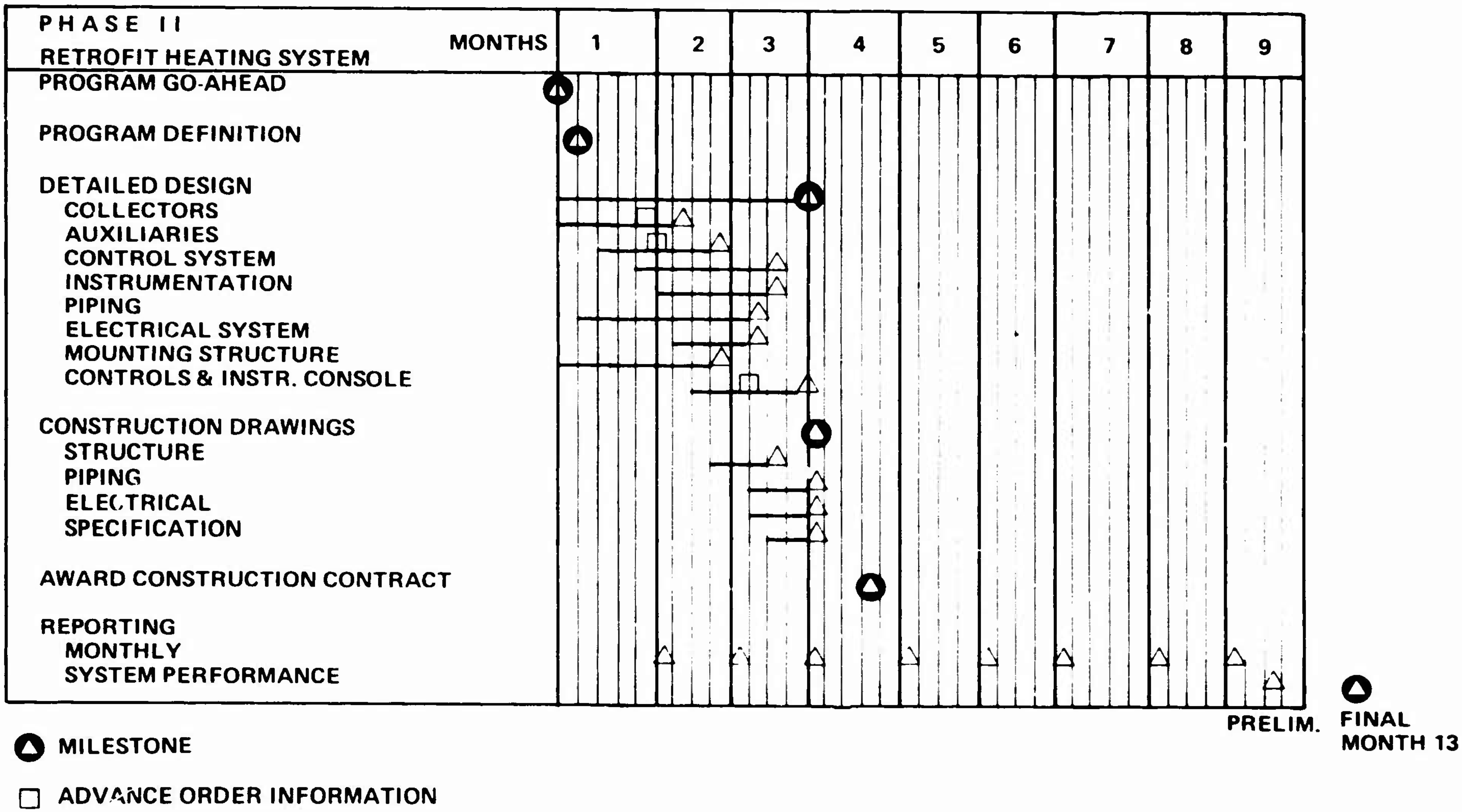

Figure 1. Program Schedule

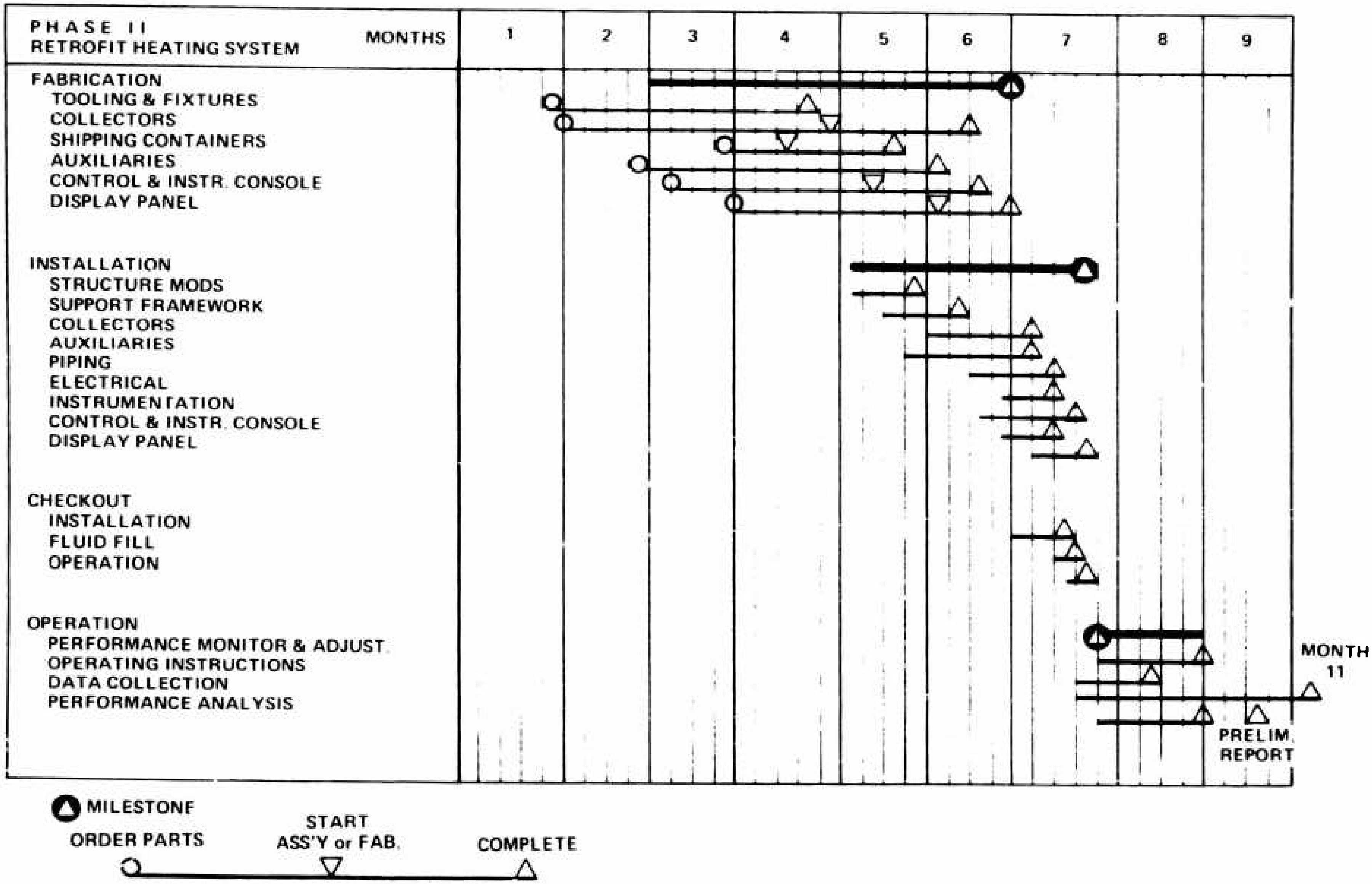

Figure 1. Program Schedule (cont)

- definition of a heating system, based on the phase I preliminary design that will satisfy the program objectives and design parameters
- sufficient analysis of the system to provide a prediction of its performance
- evaluation of the design tradeoffs required to integrate the solar heating system with the existing building structure and heating system.

1.1.1 HEATING SYSTEM

Prepare a detailed heating system design to meet the system operating parameters. Select system components from standard production hardware and define their integration into the total system. These components will consist of piping, valves, thermal energy storage, expansion tanks, heat exchangers and pumps. The following effort will be required:

- thermal analysis of system
- analysis of flow parameters, pressure drops and pumps capacities
- system definition to simplify maintenance and minimize single point failure modes
- detailed piping drawings specifying pump capacities, pipe sizes, insulation, valve types and capabilities
- detailed definition of heat exchangers, expansion tanks, and thermal energy storage tank
- design of electrical power connection with the existing system including wiring schematics.

1.1.2 CONTROL SYSTEM

The control system will be finalized and designed to operate in a completely automatic mode with a minimum of manual setting or maintenance. The basic control functions will be operated from a control panel housed in a console with the instrumentation system. The control system will be analyzed for its ability to perform under the full range of system operating conditions, to minimize transients and eliminate loop instability. It will make maximum use of the control signals generated by the existing system and will be completely integrated with it. Definition of the control system will be as follows:

- logic diagram of control system defining control and switchover points
- analysis of each operating mode

- detailed design of control panel
- definition of the interconnection with the existing control system and operating components of the solar energy system, including pneumatic system schematics
- analysis of failure modes and maintenance troubleshooting procedures

1.1.3 STRUCTURE

The structure to support the collectors will be kept to an absolute minimum. The collectors themselves will have sufficient integrity to be supported by fittings on their corners. The mounting details will be integrated with the architect engineer and general contractor who are selected to perform the equipment installation. This task will consist of:

- detailed design of the mounting structure including roof tie-in
- analysis of the existing structural system and its ability to support the collectors and auxiliary equipment
- technical liaison with the subcontractors
- integration and detailed design of the support and tie-in of all elements of the system (piping, pumps, tanks, cable runs, etc.) with the structure
- subcontractor assistance in design of related subsystems
- preparation of construction documents for review and use in construction.

The subcontractor design effort which will be required to support other tasks will be included in this task.

1.2 COLLECTOR DESIGN

A final collector design will be generated. This design will be based on the preliminary definition formulated under the phase I contract. It will be compatible with the overall system design. The collector performance will be analyzed and optimized for this particular application within the constraints of manufacturing capability and cost effectiveness. The following specific tasks will be accomplished:

- Definition of:
  - pan and internal structure
  - insulation
  - absorber panel and coating
  - window configuration and attachment

- piping interface
- structure interface and mounting

- Preparation of final design drawings for the collectors including the features listed above.
- Analysis of the collector performance for the complete range of operating and off-design conditions.
- Definition of configuration required during non-operating periods, i.e. continuous water circulation, covers, convective air cooling, etc.

2.0 FABRICATION

This task will cover the procurement, fabrication and assembly associated with the solar collectors, auxiliary equipment such as heat exchangers and TES tanks, and the control panel. Support will be provided as follows for all subtasks:

- coordinate and supervise hardware activities
- develop schedules and expedite hardware
- provide shipping, receiving and transportation support
- provide production control support.

2.1 COLLECTORS

- Procure material.
- Fabricate collectors.
- Conduct acceptance test.
- Fabricate shipping containers and ship collectors to building site.
- Fabricate and/or procure tooling and fixtures required for fabrication and assembly.
- Procure hose and fittings to interconnect collectors.

2.2 AUXILIARY EQUIPMENT

This subtask will cover the procurement and fabrication of specific auxiliary equipment which is not supplied by the general contractor under the installation task. It will consist of:

- the collector heat exchanger
- thermal energy storage tank
- ethylene glycol for the fluid loop.

3.0 INSTALLATION AND CHECKOUT

Integration of the solar heating system into the existing building will be accomplished under this task. It will cover all general contractor effort which is required for the total program. Subcontractors will be involved in a number of the subtasks, however, the effort described will cover the total scope and not necessarily differentiate between who will do a particular item.

The scope of the subcontracted effort will be established and support provided during selection and negotiation. Subcontractor and site representative technical liaison and interfaces will be maintained through appropriate direction, monitoring and control.

3.1 STRUCTURE

The structural modifications will consist primarily of attaching a mounting structure to the existing roof to support the collectors and roof mounted auxiliary equipment. To accomplish this the following effort, including material, will be required:

- anchor attachments to structural roof panels
- procure and install support framework for collectors and auxiliary equipment both on the roof and in the equipment room
- install walkways and work platforms on the roof as required including material
- weatherproof roof around all installations
- install outside stairway for roof access
- install facing at roof edges.

3.2 COLLECTORS

The collectors will be structurally self supporting with mounting brackets attached to their corners. The mounting and interconnecting of the collectors with flexible hose will complete the collector installation.

- mount collectors on support structure
- interconnect collectors with flexible hose.

3.3 PIPING, ELECTRICAL & AUXILIARY EQUIPMENT

The procurement and installation of all piping, wiring and auxiliary equipment will be accomplished under this task, along with the installation of the specific auxiliary equipment to be supplied under Task 2.2. This effort will consist of:

- procurement and installation of all pipe, fittings, valves, meters, gages and pumps required for interconnection of the elements of the solar heating system and tie-in with the current system
- electrical wiring, including material, meters and controls, of the total system and tie-in to the existing electrical system
- insulation and burial of the TES tank
- insulation of the piping runs
- supply and installation of instrumentation conduit
- modification of the pneumatic control system to accommodate the solar heating system.

3.4 CHECKOUT, FILL, OPERATIONAL VERIFICATION

In process monitoring will be performed to verify proper fabrication and installation. The total system will be checked for:

- proper valve installation
- conformance of control valves and pump switches to control system logic
- leak tightness prior to fill with operating fluid.

The collector loop of the system will be filled with an ethylene glycol/water solution and systematically vented. The remaining loops and the TES will be filled with water to operational levels.

After the system is filled, operation will be verified for all control modes. A complete checklist will be prepared for use during this verification which will include checks of the following:

- flow rates
- pressure drops
- pump performance

- control functions
- interlocks
- instrumentation readout
- system temperatures
- recording equipment

4.0 SYSTEM EVALUATION

An instrumentation system will be provided to evaluate solar heating system performance.

The operation of the heating system will be monitored on a full time basis for a month after initial operational verification. During this time period data formats and operating instructions will be finalized. An initial analysis of system performance will be made. For the remainder of the heating season the system will be monitored directly only on a periodic basis with day to day operation and data collection turned over to the normal maintenance personnel.

4.1 INSTRUMENTATION

4.1.1 INSTRUMENTATION DEFINITION

The instrumentation system will be designed to provide performance and operating data for monitoring and evaluation. It will incorporate both real time display and recording of desired data. Instrumentation readout and recording equipment will be included in a console with the control system. A panel will be provided to display performance parameters that are technically significant and of general interest to visitors. This panel will be located in a prominent easily accessible area, and may be either remote or integrated with the instrumentation console depending on the console's location.

System data to be generated will include:

- calculation of the amount of energy collected by the solar energy system
- calculation of the amount of energy delivered to the building for heating
- calculation of energy savings through solar heating
- diagnostic systems data to evaluate the performance of all major components such as heat exchangers, thermal energy storage tank, etc.

This will be accomplished by measuring:

- temperatures
  - at selected collector inlets and outlets
  - at the inlet and outlet of fluid loops, heat exchangers, thermal energy storage tank, etc.

- internal to the thermal energy storage
- at other major components

- flow rates through all fluid loops
- pressure and pressure drops
- system control events and operating modes
- solar insolation
- air temperature
- wind direction and velocity
- humidity or wet bulb temperature

In addition, direct reading thermometers, pressure gages, and flow meters will be installed at meaningful locations in the system to be used during initial installation and checkout and ultimately for display and demonstration of operation.

The effort under this tasks will consist of:

- definition of instrumentation required
- detailed instrumentation console design including display and recording capability
- specification of the location of sensors
- preparation of detailed instrumentation system schematics and cable runs.

4.1.2 CONSOLE FABRICATION & CHECKOUT

This task includes:

- procurement of components for control and instrumentation console and display panel
- assembly of console and display panel
- performance of functional console checkout
- procurement of instruments for monitoring temperature, pressure, flow rate, solar insolation and weather.

4.2 SYSTEM OPERATION

4.2.1 PERFORMANCE MONITORING AND ADJUSTMENT

The performance of the system will be monitored under the range of operating conditions encountered in day-to-day operation. Adjustments will be made as required to:

- maximize performance
- maintain balanced flow through system

- minimize pressure surges
- equalize temperatures throughout the collector banks
- verify response to all control modes

This effort will be on a continuing basis during the first month of operation and then on an intermittent basis for the remainder of the heating season.

Particular emphasis will be placed on the automatic operation of the system so that a schedule may be established for monitoring and adjustment.

It is anticipated that physical monitoring of the system by Army maintenance personnel will be required on a twice weekly basis. This monitoring will consist of verification that operation is within prescribed limits based on control panel readouts, a check of system components for leakage or other visible evidence of malfunctions, replacement of charts, chart annotation, and a data log entry of observations. Any system maintenance, repair or calibration that is required during the initial year of operation will be performed by the contractor. All components with the exception of the solar collectors are standard commercially available items. Normal service or part replacement is expected to be obtainable.

4.2.2 OPERATING INSTRUCTIONS

A set of instructions will be formulated for operating the system. They will include a standard performance checklist and periodic maintenance schedule. The intent of these instructions will be to insure a routine check of the more vital characteristics of the system, insure continued system operation, and gather and annotate system operational data.

4.2.3 DATA COLLECTION

Automatic recording equipment will be provided for most of the system data. A few data points such as tank water levels and visual observations such as cloud cover will be recorded manually as part of the normal system operation. The manually recorded data, some record annotation, checks of recorder operation and replacement of charts will be incorporated into the system operating instructions. After the first month of full time monitoring and data collection this effort is planned to be performed by normal maintenance personnel with periodic checks of performance during which the accumulated data will be collected.

4.3 PERFORMANCE ANALYSIS AND REPORTING

A monthly letter progress report will be issued each month during the conduct of the program. At the completion of the design phase this report will include the results of the design and analysis efforts.

An initial report of system performance will be provided after the first month of operation. This report will include a description of the checkout, fill, operational verification and operating parameters. Subsequent monthly reports will provide a summary of operating data and will highlight any outstanding events. Two months after the end of the heating season in May a final report will be issued analyzing system performance and providing a comparison with the initial performance predictions.

IMPLEMENTATION PLAN
HEATING AND COOLING SYSTEM FOR NEW BUILDING
AT FORT HUACHUCA

PROGRAM IMPLEMENTATION PLAN
HEATING AND COOLING SYSTEM

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A. INTRODUCTION

This program will define a solar energy system to provide heating and cooling for the Basic Officer Course Classroom Building to be constructed at Fort Huachuca, Arizona. This definition will include a final trade-off study to optimize the system. The program will also encompass the final design, fabrication, installation, checkout and initial operation of the system.

The proposed system will consist of a 7040 square foot array of flat plate solar collectors, a thermal energy storage tank of 12,000 gallons, a nominal 100 ton absorption air conditioner and associated cooling tower, heat exchangers, piping and control for integration with the basic building heating and air conditioning system. The heat transfer medium will be an ethylene glycol-water solution, circulated through the solar collectors and then to the other system components.

The solar energy system components will be designed for installation during the building construction and will be completely integrated with the conventional HVAC system. This system integration will be done during the building design phase. The solar system will be capable of supplying 85 to 100 percent of the total heating and cooling requirements depending on the building usage and seasonal weather characteristics.

Instrumentation will be provided to monitor system performance and allow an evaluation of the energy supplied by the solar system in actual operation. The control panel will be mounted in the instrumentation console which will also provide a visual display of the system operation.

B. SCOPE

This plan defines a program for the analysis, design, procurement, fabrication, installation and operation of a solar energy system to provide heating and cooling for a building to be constructed at Fort Huachuca, Arizona. It includes an implementation schedule and a cost projection for the total program. The program is planned as a follow-on to Army Contract DACA 23-74-C0006 for "The Development of a Solar Heating and Cooling System."

C. SCHEDULE

The solar heating and cooling program will be scheduled to be compatible with the design and construction schedule for the new buildings at Fort Huachuca. The preliminary design will include system trade-offs and analysis leading to system definition and will phase each element into detailed design as soon as it can be defined. The detailed design will be completed on a time cycle compatible with the building design. Long lead items will be ordered at the start of the fabrication cycle so that fabrication and assembly can proceed on an orderly basis to insure that all hardware associated with the solar system will be available as needed during building construction. Collectors will be shipped to the construction site in batches and installation will be coordinated so that piping, controls and power interconnections can be accomplished in conjunction with overall building schedules. Final checkout of the system, installation and checkout of instrumentation and display consoles, and operational verification will be accomplished during the final HVAC installation so that best utilization of the diverse people involved may be realized.

It is planned to have the system operational coincident with building completion. Operation will be monitored during the cooling season and the following heating season. An initial report of system performance will be issued after the first month of operation. The evaluation of system performance will be reported in two parts, the first for cooling system performance and the second for heating system performance, two months after the end of the respective seasons.

The planned program schedule is shown in Figure 1, key program milestones are identified. This program should be initiated in August, 1974, in order to proceed in an orderly fashion and be compatible with the planned schedule of design and construction of this Basic Officer Course Classroom Building.

D. COST SUMMARY

The cost of incorporating a solar heating and cooling system in the new building at Fort Huachuca was evaluated. The cost to perform the effort, (above the cost of the building with conventional heating and cooling systems) as defined by this implementation plan, is projected to be $465,000. This cost assumes that the structural, mechanical and electrical construction costs will be accomplished during the building construction and the two efforts will be completely integrated. This estimate also takes into account the fact that a similar project for the heating part of the system will have preceded this effort at Fort Belvoir and some hardware, such as the instrumentation and control console, will require only tailoring to this system's requirements including the addition of air conditioning. In the event that this is the only solar energy project undertaken an additional cost of twelve thousand dollars would be incurred.

The elements of the projected costs to accomplish the effort defined by this implementation plan are as follows:

Task 1.0 FINAL DESIGN	$ 86,000
Solar heating & cooling system $80,000 Incremental building A/E costs $6,000	
Task 2.0 FABRICATION	$165,000
Solar collectors, 7040 sq. ft. @ $12/sq. ft. Air conditioner and cooling tower $33,000 Auxiliaries (TES, heat exchangers, controls, shipping containers and other costs) $47,000	
Task 3.0 INSTALLATION & CHECKOUT	$125,000
Solar system installation and checkout $35,000 Engineering support during construction $8,000 Incremental construction contractor cost $82,000	
Task 4.0 SYSTEM EVALUATION	$ 89,000
Instrumentation (design, fabrication, checkout & installation) $55,000 Data collection & analysis $25,000 Reporting $9,000	
TOTAL	$465,000

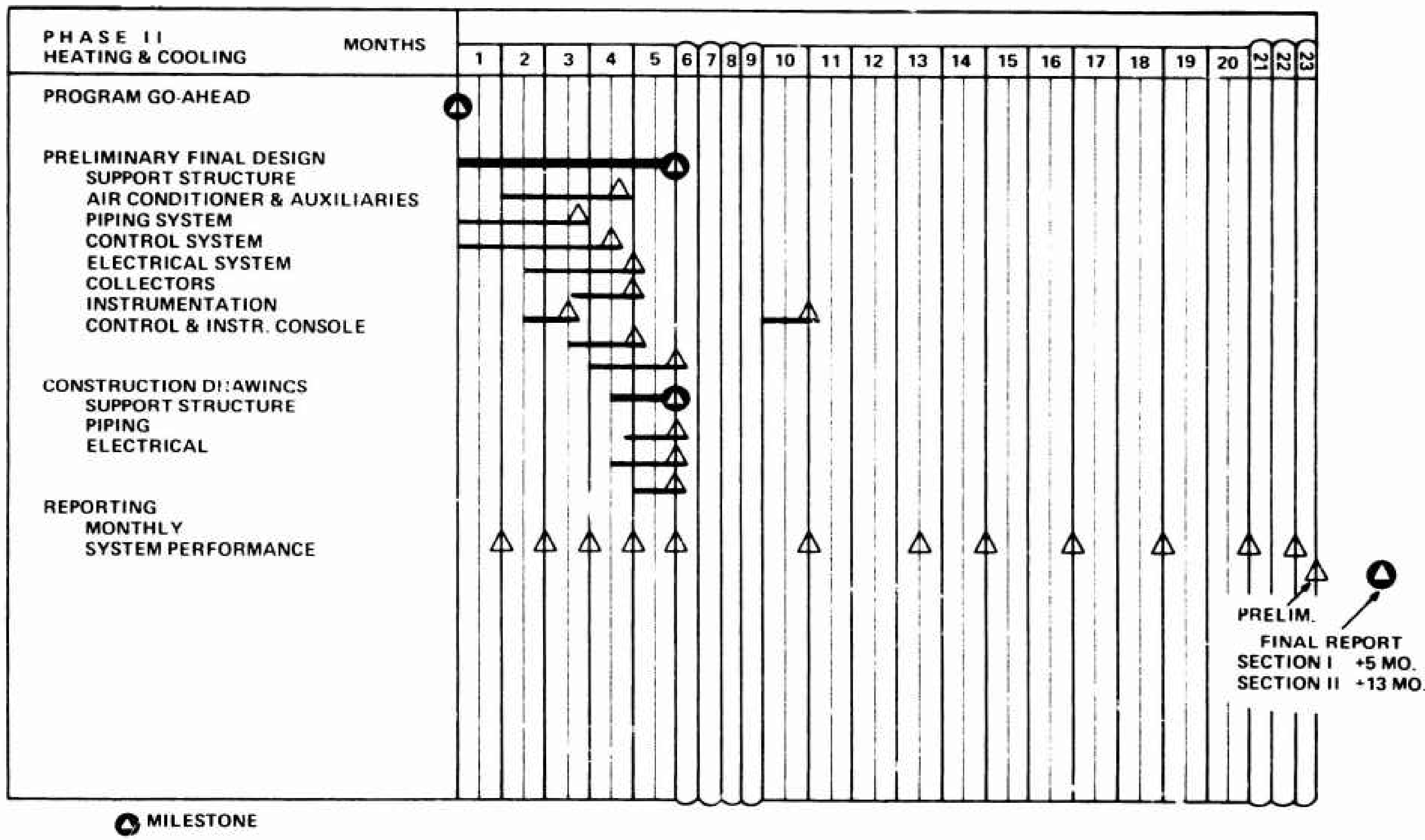

Figure 1. Program Schedule

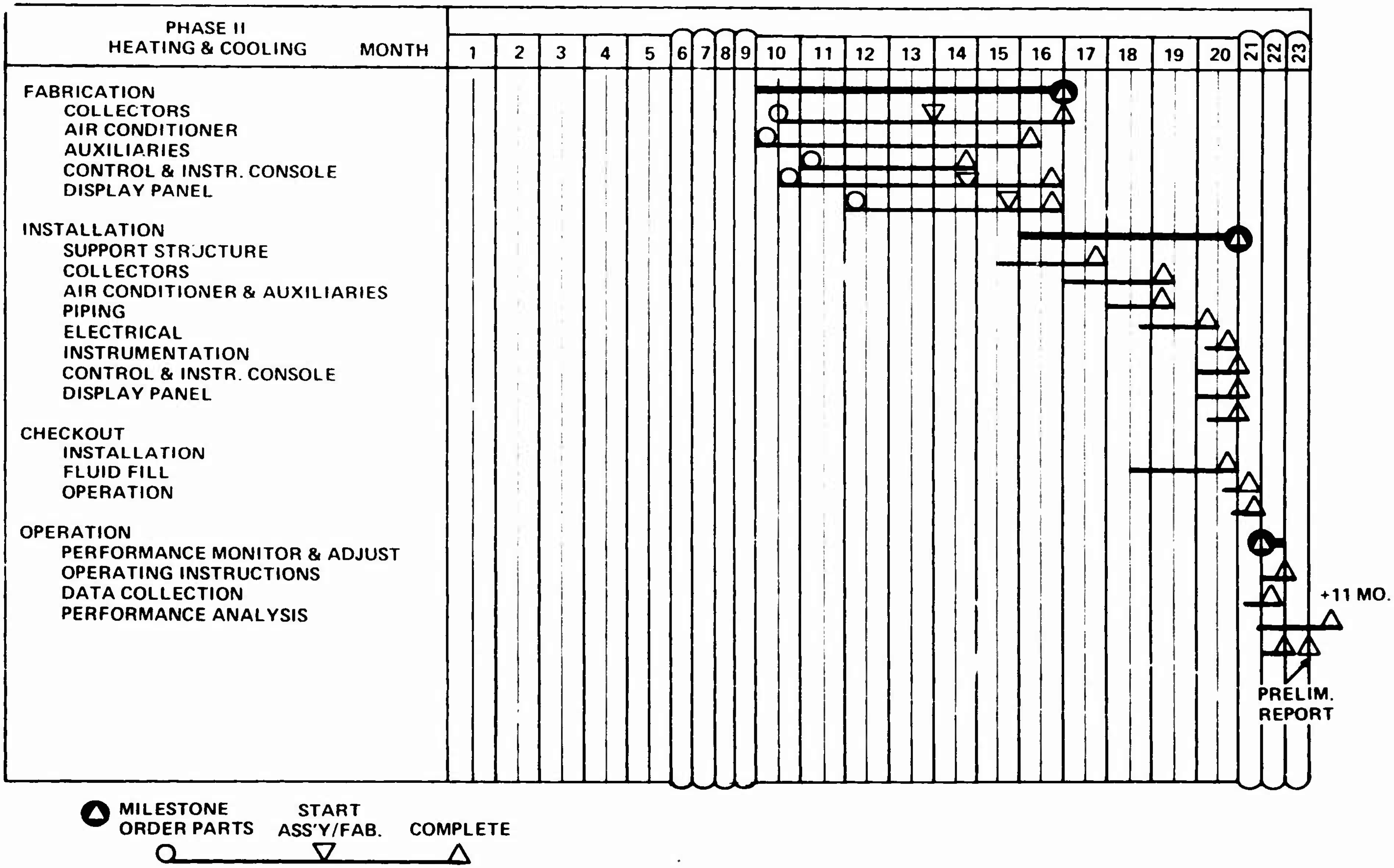

Figure 1. (Continued) Program Schedule

1.0 FINAL DESIGN

The design effort will be accomplished in two complementary overlapping phases which will encompass preliminary and final design. The preliminary design effort will provide the trade-off analyses leading to final system definition. This definition will form the basis for detailed hardware and system design which will be started as each element of the total system is defined. The detailed design will be the basis from which construction drawings can be prepared for integration into the overall building definition. The collector design will be reviewed just prior to initiating fabrication to incorporate any changes that have evolved since the detailed design was originally completed.

This task will also include the effort required for direction, monitoring and control of the program, as well as, technical liaison and interfacing with subcontractors and site representatives.

1.1 SYSTEM DEFINITION

A thermal analysis will be performed to determine system performance in conjunction with the conventional system for both heating and cooling modes. Analysis of the following system parameters will be accomplished to define final design requirements:

- collector performance
- structural loads
- fluid loop sizing and flow
- control interface

Overall program definition will be established based on the design requirements formulated under the preliminary design effort. The program manager will direct overall program activities and monitor and control program performance. The effort under this task will consist of:

- final definition of operating parameters and performance characteristics
- final definition of collector location, quantity, orientation and elevation angle
- monitoring, control and reporting on program performance through funding control, financial reports, contract accounting and contractual documentation
- provide the customer with information on program status and progress, to include program meetings with him

- review and approve subcontractor agreements and provide liaison during fabrication and installation.

Detailed design for a heating and cooling system that satisfies the preliminary design requirements will be made including performance prediction analyses of the system. Trade-offs will be made to evaluate the integration of the solar heating and cooling system with the proposed conventional systems including site and structural considerations.

1.1.1 HEATING SYSTEM

A detailed heating system design, integrated with the conventional system to meet the system operating parameters will be prepared. System components will be selected from standard production hardware and integrated into the total system. These component will consist of piping, valves, thermal energy storage, expansion tanks, heat exchangers and pumps. The following effort will be required:

- thermal analysis of system
- analysis of flow parameters, pressure drops and pump capacities
- system definition to simplify maintenance and minimize single point failure modes;
- detailed piping drawings specifying pump capacities, pipe sizes, insulation, valve types and capabilities
- detailed definition of heat exchangers, expansion tanks, and thermal energy storage tank
- design of electrical power connection with the existing system including wiring schematics.

1.1.2 COOLING SYSTEM

A detailed cooling system design which integrates an absorption air conditioner and cooling tower with the proposed building cooling system will be prepared. Cooling system components will be selected from standard production hardware which best utilize the available energy. This will require the following effort:

- analysis of performance characteristics to optimize system operation and control
- thermal analysis of system and specification of air conditioner and associated hardware
- evaluation of flow parameters to establish pressure drops, pump capacities and overall integration of components

- preparation of detailed piping drawings, for interconnection of components, specifying pump capacities, pipe sizes, insulation and valves
- design of electrical power connection with the existing system including wiring schematics.

1.1.3 CONTROL SYSTEM

The control system will be designed to operate in a completely automatic mode with a minimum of manual setting or maintenance. The basic control functions will be operated from a control panel housed in a console with the instrumentation system. The control system will be analyzed for its ability to perform under the full range of system operating conditions, to minimize transients and eliminate loop instability. It will make maximum use of the control signals generated by the conventional system and will be completely integrated with it. Definition of the control system will be as follows:

- logic diagram of control system defining control and switchover points
- analysis of each operating mode
- detailed design of control panel
- definition of the interconnection with the proposed control system and operating components of the solar energy system, including wiring schematics
- analysis of failure modes and maintenance troubleshooting procedures.

1.1.4 STRUCTURE

The support structure for the collectors will be kept to an absolute minimum. The collectors themselves will have sufficient integrity to be supported by fittings on their corners. The mounting details will be integrated with the architect engineer and general contractor. The location of the collectors will have been determined during the preliminary design. The basic structure on which the collector support structure is mounted will be considered to exist as an integral part of a building or central station. This task will provide only for collector support structure and will consist of:

- detailed design of the support structure including basic structure tie-in
- analysis of the proposed structural system and its ability to support the collectors, air conditioning and auxiliary equipment
- technical liaison with the subcontractors

- integration and detailed design of the support and tie-in of all elements of the system (piping, air conditioner, water tower, pumps, tanks, cable runs, etc.) with the basic structure
- subcontractor assistance in design of related subsystems
- preparation of construction documents for review and use in construction.

All subcontractor design support will be included in this task even though it may relate to other associated activities.

1.2 COLLECTOR DESIGN

The effort under this task will be limited to design modifications required for this application. It is expected that these would be primarily in the areas of piping and mounting interfaces. This effort will be split into two parts, the first to be accomplished during the detailed design and the second just prior to the start of production, in order to incorporate any innovations that have evolved as a result of continuing collector development.

Collector performance will be analyzed and their integration into the system optimized for this particular application. The following tasks will be accomplished as a part of this effort:

- definition of piping and mounting interface
- analysis of collector performance for the complete range of applicable operating and off-design conditions
- modification of collector drawings as required.

2.0 FABRICATION

This task will cover the procurement, fabrication and assembly associated with the solar collectors, air conditioner, auxiliary equipment such as the water tower, heat exchangers and TES tanks, and the control and display consoles. Support will be provided as follows for all subtasks:

- coordinate and supervise hardware activities
- develop schedules and expedite hardware
- provide shipping, receiving and transportation support
- provide production control support.

2.1 COLLECTORS

- Procure material
- Fabricate collectors
- Conduct acceptance test
- Fabricate shipping containers and ship collectors to building site
- Procure fittings to interconnect collectors.

2.2 AIR CONDITIONER AND AUXILIARY EQUIPMENT

This subtask will cover the procurement or fabrication of the absorption air conditioner and specific auxiliary equipment which is not supplied by the general contractor under the installation task. The auxiliary equipment will consist of:

- the cooling tower
- the collector heat exchanger
- thermal energy storage tank
- ethylene glycol for the fluid loop.

3.0 INSTALLATION AND CHECKOUT

Integration of the solar heating and cooling system into the proposed location will be accomplished under this task. It will cover the additional general contractor effort which is associated with the solar heating and cooling system. Subcontractors will be involved in a number of the subtasks.

The scope of the subcontracted effort will be established and support provided during selection and negotiation. Subcontractor and site representative technical liaison and interfaces will be maintained through appropriate direction, monitoring and control.

3.1 STRUCTURE

The effort under this task will consist primarily of attaching a support structure to the basic structure to mount the collectors, air conditioner and auxiliary equipment. To accomplish this the following effort, will be required:

- procure and install support structure for collectors and auxiliary equipment including the air conditioner and other items in the equipment room
- Procure and install walkways and work platforms as required.

3.2 COLLECTORS

The collectors will be structurally self supporting with mounting brackets attached to their corners. The mounting and interconnecting of the collectors with supplied fittings will complete the collector installation.

- mount collectors on support structure
- interconnect collectors with fittings supplied.

3.3 PIPING, ELECTRICAL & AUXILIARY EQUIPMENT

The procurement and installation of all piping, wiring and auxiliary equipment will be accomplished under this task, along with the installation of the air conditioner and specific auxiliary equipment to be supplied under Task 2.2. This effort will consist of:

- procurement and installation of all pipe, fittings, valves, meters, gages and pumps required for interconnection of the elements of the solar heating and cooling system and tie-in with the proposed conventional system
- electrical wiring, including material, meters and controls, of the total system and tie-in to the proposed electrical system.

- insulation of the TES tank
- insulation of the piping runs
- supply and installation of instrumentation conduit
- interconnection with the proposed control system.

3.4 CHECKOUT, FILL OPERATIONAL VERIFICATION

Inspection will be performed to verify proper fabrication and installation. The total system will be checked for:

- proper valve installation
- conformance of control valves and pump switches to control system logic
- leak tightness prior to fill with operating fluid.

The collector loop of the system will be filled with an ethylene glycol/water solution and systematically vented. The remaining loops and the TES will be filled with water to operational levels.

After the system is filled, operation will be verified for all control modes. A complete checklist will be prepared for use during this verification which will include checks of the following:

- flow rates
- pressure drops
- pump performance
- control functions
- interlocks
- instrumentation readout
- system temperatures
- recording equipment.

4.0 SYSTEM EVALUATION

An instrumentation system will be provided to evaluate the performance of the solar heating and cooling system.

The operation of the heating and cooling system will be monitored on a full time basis for a month after initial operational verification. During this time period data formats and operating instructions will be finalized. An initial analysis of system performance will be made. For the remainder of the cooling season and the following heating season the system will be monitored directly only on a periodic basis with day to day operation and data collection turned over to the normal maintenance personnel.

4.1 INSTRUMENTATION

4.1.1 INSTRUMENTATION DEFINITION

The instrumentation system will be designed to provide performance and operating data for monitoring and evaluation. It will incorporate both real time display and recording of desired data. Instrumentation readout and recording equipment will be mounted in a console with the control system. A panel will be provided to display performance parameters of general interest to visitors. This panel will be located in a prominent easily accessible area, and may be either remote or integrated with the instrumentation console depending on the console's location.

System data to be generated will include:

- calculation of the amount of energy collected by the solar energy system
- calculation of the amount of energy delivered to the building for heating or cooling
- calculation of energy savings through use of solar energy
- diagnostic systems data to evaluate the performance of all major components such as absorption air conditioner, water tower, heat exchangers, thermal energy storage tank, etc.
- solar insolation and weather.

This will be accomplished by measuring:

- Temperatures
  - at selected collector inlets and outlets
  - at the inlet and outlet of each air conditioner fluid loop

- at the inlet and outlet of other fluid loops, heat exchangers, thermal energy storage tank, water tower, etc.
- internal to the thermal energy storage
- at other major components

- flow rates through all fluid loops
- pressure and pressure drops
- system control events and operating modes
- solar insolation
- air temperature
- wind direction and velocity
- humidity or wet bulb temperature.

In addition, direct reading thermometers, pressure gages, and flow meters will be installed at meaningful locations in the system to be used during initial installation and checkout and ultimately for display and demonstration of operation.

The effort under this task will consist of:

- definition of instrumentation required
- detailed instrumentation console design including display and recording capability
- specification of the location of sensors
- preparation of detailed instrumentation system schematics and cable runs.

4.1.2 CONSOLE FABRICATION AND CHECKOUT

This task includes:

- procurement of components for instrumentation console and display panel
- assembly of console and display panel
- performance of a functional console checkout
- procurement of instruments for monitoring temperature, pressure, flow rate, solar insolation and weather.

4.2 SYSTEM OPERATION

4.2.1 PERFORMANCE MONITORING AND ADJUSTMENT

The performance of the system will be monitored under the range of operating conditions encountered in day-to-day operation. Adjustments will be made as required to:

- maximize performance
- maintain balanced flow through the system
- minimize pressure surges
- equalize temperatures throughout the collector banks
- verify response to all control modes.

This effort will be on a continuing basis during the first month of operation and then on an intermittent basis for the remainder of the cooling and the following heating season.

Particular emphasis will be placed on the automatic operation of the system so that a schedule may be established for monitoring and adjustment.

It is anticipated that physical monitoring of the system by Army maintenance personnel will be required on a twice weekly basis. This monitoring will consist of verification that operation is within prescribed limits based on control panel readouts, a check of system components for leakage or other visible evidence of malfunctions, replacement of charts, chart annotation, and a data log entry of observations. Any system maintenance, repair or calibration that is required during the initial year of operation will be performed by the contractor. All components with the exception of the solar collector are standard commercially available items. Normal service and part replacement is expected to be available. Any service of the Arkla unit should also be available. They are a nationwide company.

4.2.2 OPERATING INSTRUCTIONS

A set of instructions will be formulated for operating the system. They will include a standard performance checklist and periodic maintenance schedule. The intent of these instructions will be to insure a routine check of the more vital characteristics of the system, insure continued system operation, and gather and annotate data.

4.2.3 DATA COLLECTION

Automatic recording equipment will be provided for most of the system data. A few data points such as tank water levels and visual observations such as cloud cover will be recorded manually as a part of the normal system operation. The manually recorded data, some record annotation, checks of recorder operation and replacement of charts will be incorporated into the system operating instructions. After the first month of full time monitoring and data collection this effort is planned to be performed by normal maintenance personnel with periodic checks of performance during which the accumulated data will be collected.

4.3 PERFORMANCE ANALYSIS AND REPORTING

A monthly letter progress report will be issued each month during the design phase of the program and a bimonthly report for the remainder of the program. At the completion of the design phase this report will include the results of the design and analysis efforts.

An initial report of system performance will be provided after the first month of operation. This report will include a description of the checkout, fill, operational verification and operating parameters. Subsequent monthly reports will provide a summary of operating data and will highlight any outstanding events. Two months after the end of the cooling season in September the first section of the final report will be issued analyzing cooling system performance and providing a comparison with the initial performance predictions; this will be supplemented at the end of the following heating season in May with a second section analyzing system performance in a heating mode.