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SOLAR HEATING AND COOLING SYSTEMS DESIGN AND DEVELOPMENT - QUARTERLY REPORT

Prepared by

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16. ABSTRACT

This program calls for the development and delivery of eight prototype solar heating and cooling systems for installation and operational test. Two heating and six heating and cooling units will be delivered for single-family residences, multiple-family residences and commercial applications. Lennox Industries, Marshalltown, Iowa, and Barber Nichols Engineering Company, Arvada, Colorado, are supporting Honeywell in subcontractor roles. This document describes the progress of the program during the fifth program quarter, 1 July 1977 to 30 September 1977.

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QUARTERLY SUMMARY
(Edited for Release)

This period was dominated by two intense activities: 1) the preparation for and conduct of Prototype Design Review on our first two single-family residences and 2) initiation and development of a way to solve ERDA's concerns on our cooling subsystems.

The prototype Design Review for the William O'Brien site was held on July 25; approval to proceed with hardware fabrication was obtained. The system design was well received with only a few questions presented for clarification of design.

The Prototype Design Review for the New Castle, Pennsylvania, site was held on August 24; approval to proceed with hardware fabrication was obtained.

ECPs have been submitted for installation costs at William O'Brien State Park and for New Castle, Pennsylvania. The ECPs (002 and 003) have been approved, and contracts were let to the site owner for installation. Construction work has started at the William O'Brien site. Construction at the New Castle site is expected to start mid October.

A site review meeting was held in September at the multi-family residence heating and cooling site at Kansas University. Agreement was reached, and verbal commitment given to proceed with the site-specific design.

The three-ton cooling subsystem design and development work has been halted due to anticipated program redirection. Work is continuing on the 25-ton system with fabrication of the first two units well underway.

The Lennox program management team has been reassigned. Fabrication of hardware will be in Carrollton, Texas supervised by Lennox personnel assigned to the 404 project. All major testing will be completed at Marshalltown.

Lack of approved sites is still a major concern. The list of candidates is adequate. However, selecting technically suitable sites and getting the owner to agree to absorb the installation costs is very time consuming.

ANALYSIS AND INTEGRATION

Analysis of the New Castle, Pennsylvania SFR heating site was completed in preparation for the PDR held in August. Results of the analysis were reported in the PDR document.

Analysis of the Lawrence, Kansas, MFR heating and cooling site is being reinvestigated to determine effects of inclusion of the 25-ton air conditioner with an unloading, multi-cylinder compressor into the analysis model.

The baseline 25-ton cooling configuration includes a 25-ton compressor driven by a 20-horsepower motor/generator and a 20-horsepower design point Rankine engine. The inclusion of an unloading compressor in the simulator results in an apparent shift from a 20-horsepower Rankine engine to some horsepower less than 20 as the optimal engine size for maximum solar contribution.

Figure 1 shows the simulated cooling results for the Kansas site at various design engine output powers. The figure indicates that a design output power of 10 horsepower provides the greatest solar cooling contribution in this location. The shift from an engine sized for design power requirements of the air conditioner to a smaller sized engine is due mainly to the cooling load being less than design capacity of the air conditioner. Correspondingly, the unloading compressor will require less power.

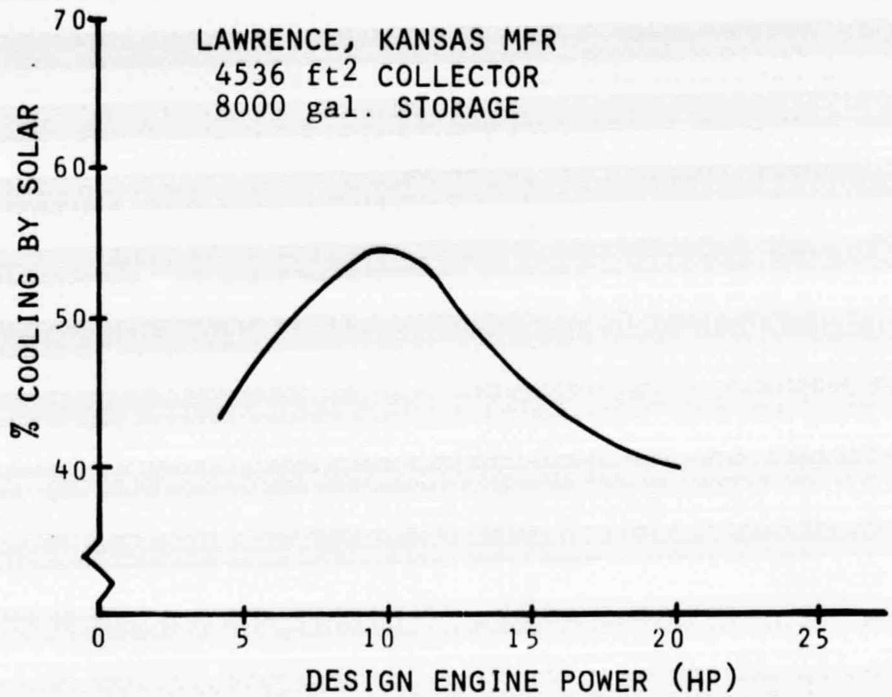

Figure 1. Percent versus Design Engine Power

Additional studies are underway to determine if thermal performance pheonmena is site and load profile specific. Studies are also being done to find possible system configuration alternatives that will maintain high solar contribution while reducing parasitic energy consumption.

COLLECTOR SUPPORT STRUCTURE

Honeywell has under development a collector support structure that could be applicable in a majority of ground- and roof-mounted sites throughout the United States. It is expected to be assembled in the field without skilled steelworkers and provides easy mounting of collectors and headers resulting in reduced collector field material and installation costs.

By changing member sizes only, our current structural configuration will support collector arrays with the following variations:

- Collector slopes from 10° to 60°
- Various collector row lengths, two collectors high
- Ground- or roof-mounted and capable of interfacing with a majority of roof supports in the U. S.
- Various wind and snow loading conditions
- Capability to accommodate future collector dimensional changes

Some of the specific criteria used in the design is as follows:

- Structure must withstand a 90-mph wind from any direction and a 50 lb/ft^2 snow load
- Design must be compatible with American Institute of Steel Construction (AISC), Uniform Building Code (UBC), and other applicable codes
- Field assembly should be accomplished with bolt-together sections; the goal is no field welding or drilling and minimal need of heavy installation equipment
- Simple collector-to-structure and insulated header-to-structure interface
- Structural members should be finished to resist corrosion and be aesthetically acceptable

Alternate design fabrication approaches were reviewed. Two of those rejected were:

- On-site fabrication of the entire support structure using standard steel shapes, which has been used in past solar installations. This requires site-specific load calculations, a complete structural design with consideration of collector sizes and installation requirements, and skilled welding labor in the field.

- Shop fabrication of support modules (each supporting 4 or 6 collectors), using standard steel members. The units must be shipped to the site. Preliminary design revealed the weight and size of modules might require special lifting and installation equipment. It also indicated a limitation in accommodating collector dimensional variations.

The approach selected does not have the deficiencies noted above, particularly the field assembly and application flexibility.

This approach will be tested in a support structure to be assembled next quarter at the Honeywell solar test lab. This structure will support an array of 30 collectors at an angle of 45°. The purpose is to 1) identify problem areas, 2) determine a recommended assembly sequence, 3) verify the labor time estimates by Unistrut, and 4) make modifications that refine the overall design.

Collector Qualification Tests

The qualification test on the Lennox Collector was successfully concluded during this quarter.

Residential Heating System Verification

The William O'Brien system has been verified to the requirements of the Interim Performance Criteria. A verification report is in production.

SPACE HEATING AND AUXILIARY HEATING

Work Accomplished

During the past quarter, the subsystem effort was phased out of the design and development mode and was directed toward hardware fabrication and shipment. Detailed drawings are being finalized and installation, operation and maintenance manuals are being compiled.

Residential Subsystems

The cabinet of the solar space heating coil was modified to accommodate a drain pan.

The single-family heating only components for William O'Brien State Park were shipped in September. Work continues on the heat pump components required at New Castle. The hardware is assembled and tested. The results were acceptable. Drawings of the solar coil (CW3-45) and the purge coil (HAWI-130) were completed. The I.O.M. manuals for the CW3-45 are complete.

Com... rcial Subsystems

Vibration Test -- As mentioned in previous reports, a new blowers/motor mounting frame was designed to accommodate the solar coil in the modified commercial unit. The following conclusions were based on vibration tests previously reported and on visual observations:

- Phase angle between the blowers rotation and vibration at any point on the frame was unsteady. In such case, it becomes difficult to balance the system dynamically.
- The load distribution on the vibro absorbers was not uniform. The vibro absorber nearest the motor was overloaded and, hence, could soon fatigue and fail.
- The weld joining the bearing support to the bearing frame could fail under fatigue.
- With an unbalance of 150 grains on each wheel and without any unbalance on the wheels, the maximum peak velocities were 0.768 and 0.257 in./sec., respectively.

The support frame of the blowers/motor mounting frame was modified, and three out of five absorbers were relocated. The modification of the mounting frame and the relocation of the vibro mounts helped in two respects: the phase angle between the blower rotation and the vibration at any point on the frame became steady; and the load distribution on the vibro absorbers became more uniform. The stiffness of bearing support and the length of the weld joining the bearing support to the bearing frame were increased. This removed the possibility of the failure of bearing support or of the weld under fatigue.

Vibration tests were conducted on the modified frame. The vertical accelerations were measured at seven different locations and at three different blower speeds; i. e., 772, 857, and 978 rpm, with and without unbalance on the wheels. The vibration levels were higher, but the system could be easily balanced.

The following additional tests were successfully completed:

1. Hot and Cold Spots Tests
2. Motor Temperature Tests
3. Limit Control Tests
4. Blower Capacity Tests
5. Condensate Control

ENERGY TRANSPORT SUBSYSTEM

The energy transport module for the William O'Brien site has been built according to the design described in Quarterly Report 4. Components were selected, and design refinements were made in the plumbing layout and cabinetry to more readily accommodate both the function and fabrication of the ETM. Refinements include:

- Re-routing of plumbing connections, resulting in the collector supply/return lines entering through adjacent openings in the cabinet

- Re-arrangement of some hydronic components to insure maintenance accessibility and to more readily accommodate the S. D. A. sensors

- **Use of additional valves to provide a more flexible and thorough means of flushing the collectors and the heat exchanger**

- **Reinforcing the cabinet base plate and divider; use of pump shock mounts for added sound insulation**

Testing of the ETM using the hydronic test stand has begun. The testing will verify that Interim Performance Criteria and operating parameters described in Quarterly Report 4 are met. These include:

- Leak test and component pressure test or verification (1-1/2 times system pressure relief valve setting)

- Operational check of pumps, valves, and hydronic specialties

- Verification of pressure drop and flow rate capabilities of the ETM

- Temperature readings of the cabinet interior and its surface exterior

- Verification that internal ETM wiring adheres to applicable electrical codes

Testing of the first ETM and assembly and testing of the second unit (for New Castle) shall be completed early next quarter.

Heat Exchanger Analysis

The design of a new configuration for the heat exchanger surface has been completed, and analysis is underway to compare the results of heat transfer and pressure drop tests from an economical and practical viewpoint. Assessment of the data will be based on a comparison figure that determines the suitability of the heating surface with regard to heat transfer and pressure drop for given fluid properties.

Thermal Performance -- The conditions used in the design and testing of the heat exchanger were similar to the expected operational conditions of the solar system. Present thermal performance results indicate a close agreement with the analytical predictions.

With 23 ft^2 of overall heat transfer area and a constant heating fluid flow rate of 12.0 gpm at 140°F, the amount of heat transferred varied between 60,000 and 70,000 Btu/hr depending on the heated fluid flow rate and the mode of operation. For example, in the storage charging mode, with a secondary flow rate of 10.0 gpm at 115°F, the heat gained amounted to 70,000 Btu/hr with an effectiveness of 0.60. In the direct heating mode the effectiveness increased to 0.68, while the rate dropped to 60,000 Btu/hr with the decrease of flow rate to 8.0 gpm.

Pressure drop measurements correlate favorably with the analytical predictions and remain at 3.0 Lbf/in^2 in the critical mode of direct heating.

COOLING

Residential Cooling Subsystem

The three-ton system redesign and development program has been defined and the ECP to implement it is in preparation. Development of the existing three-ton system has been stopped.

The primary objective of the redirected effort is to design and develop a marketable single-family cooling subsystem consistent with Lennox manufacturing capabilities and techniques. To achieve this objective, it is first necessary to formulate a design configuration that accomplishes a more detailed set of objectives relative to the present single-family cooling subsystem:

- Reduce production costs
- Reduce the package size and weight
- Eliminate the cooling tower
- Develop a single-package condensing unit
- Improve system performance
- Reduce maintenance requirements and
- Provide standard Lennox quality and reliability consistent with the advanced design nature of this equipment

Multi-Family and Commercial Cooling Subsystem

Rankine Cycle/Air Conditioning -- The first 25-ton subsystem is in assembly at Barber Nichols. All plumbing is complete with the exception of the RC boiler and the AC suction/liquid line interchanger. The boilers that were shipped to Barber Nichols were contaminated. They have been sent back to Dunham-Bush for cleaning. Tests of the system will be completed by the end of November.

The outline for the I. O. M. manuals is complete. Detailed drawings of the system continue to be produced at Lennox.

SITE DATA ACQUISITION SUBSYSTEM

The SDAS plans for the William O'Brien and New Castle sites have been reviewed by NASA/MSFC and IBM, with several changes and additions requested. This will require change orders to the installation contractors, which are being prepared by the site architects.

CONTROL SUBSYSTEM

Detailed design of the parallel solar-heat pump system control panel for the New Castle site has been completed in cooperation with Honeywell Residential Division and Lennox. The control panel will be installed in the Energy Transport Module.

SITE ACTIVITY

Kansas University

A site/system coordination meeting was held at Kansas University (KU) on 28 September 1977. The Kansas University site preparation costs were reduced from $34, 860 to $25, 000. This figure is acceptable to KU and go-ahead has been given, pending review of the NASA contract.

To be ready to accept hardware by 15 March 1978, Kansas University must complete the site preparation this year. It was agreed in the site coordination meeting to move the PDR date to 14 January 1978 in Minneapolis. Detailed site design and documentation preparation is in progress at Honeywell, B/N and Lennox.

North Carolina Status

The state of North Carolina is dedicated to finding a site for a 75-ton installation. Initial investigations of a Sampsen County medical clinic and a Wayne Community College educational building have been rejected for schedule and load mismatch, respectively. Drawings for additional buildings are on the way.

New Castle, Pa.

Fixed price bids for the New Castle site have been received by the owner. The low bids and the architect's fees for the solar heating and SDAS installation were submitted to NASA/MSFC in the form of an ECP. Work at the site is scheduled to begin in October with the current time schedule remaining unchanged.

William O'Brien

The ECP (002) covering the installation costs for the SFR heating-only system at William O'Brien State Park has been approved. A contract was let to the State of Minnesota Department of Natural Resources for the installation; construction was started in mid September. Figures 2 and 3 are photos of this SFR showing the east and south exposures. The trench for the collector support structure can be seen in Figure 2. Figure 3 shows the south wall where the collectors will be installed on a lean-to structure. The equipment covered by the tarps is the solar collectors and the auxiliary and space heating units.

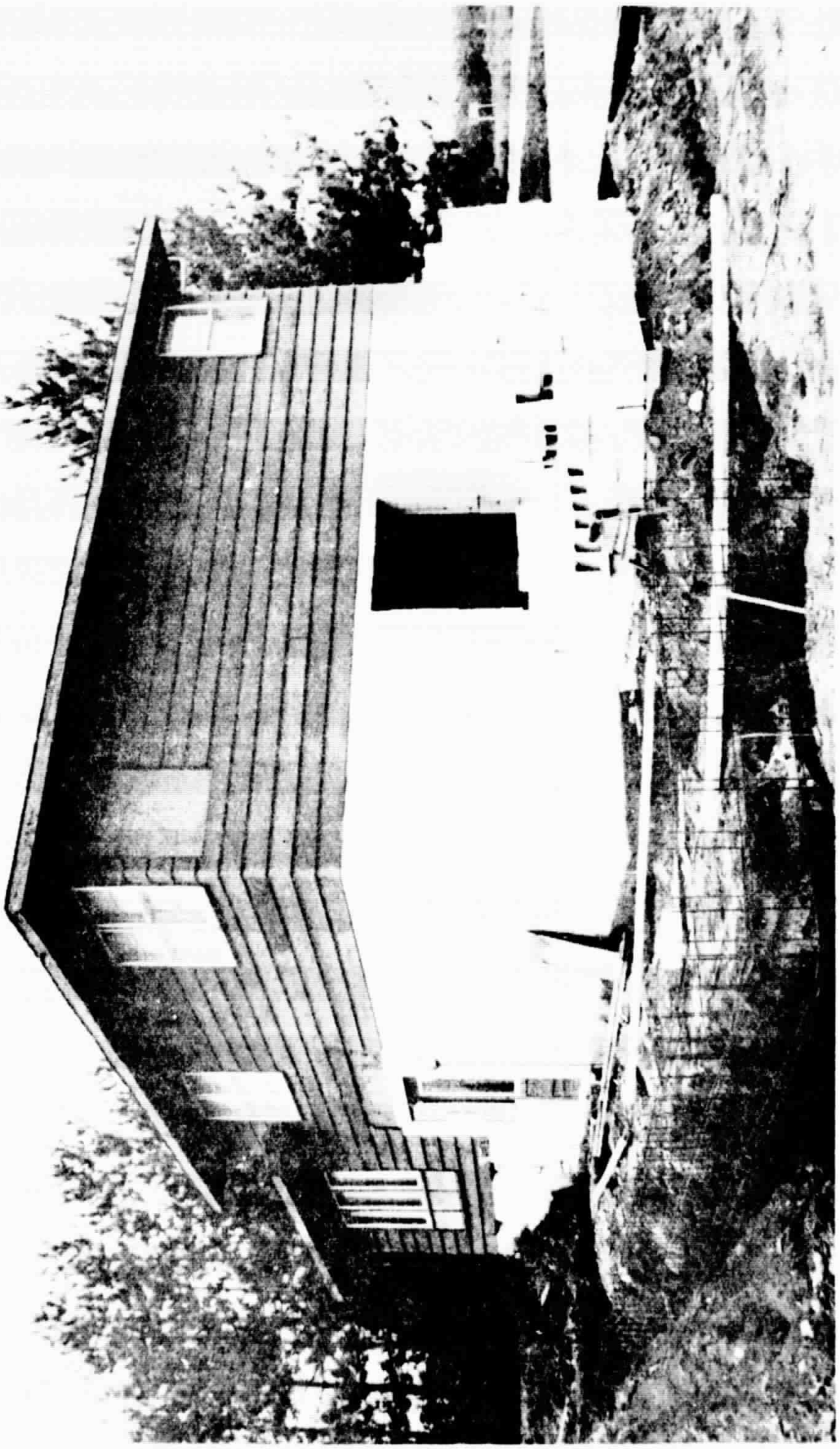

Figure 2. East Exposure SFR at William O'Brien State Park

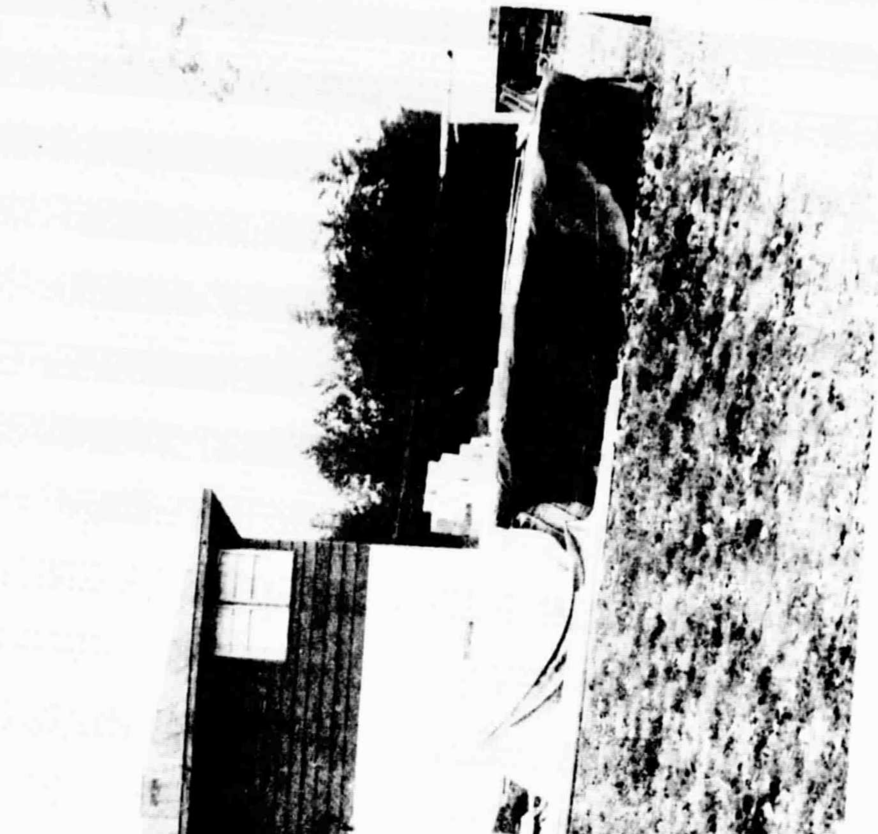

Figure 3. South Exposure SFR at William O'Brien State Park

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