MASTER

PERFORMANCE IMPROVEMENT OF A SOLAR HEATING
SYSTEM UTILIZING OFF-PEAK ELECTRIC AUXILIARY

Semi-Annual Progress Report
for the period June 18, 1979 to December 31, 1979

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ABSTRACT

During the period 18 June, 1979 through December, 1979, a solar assisted heat pump system was designed, installed and operated in the University of Toledo Experimental Solar House. The heat pump system is capable of operating in a wide range of temperatures which is needed in a solar house utilizing off-peak storage from the electric utility. The complete system consists of 584.1 square feet of Libbey-Owens-Ford's flat plate solar collectors, a 5 Horsepower compressor (Victaulic Corp.), an evaporator (Dunham-Bush), a condensor (Dunham-Bush), thermal storage units, and associated equipment.

During the installation and initial operation of the system, numerous aspects of the feasibility of this system design have been evaluated. Many of these aspects point to the potentially improved operating performance of a solar heating system utilizing off-peak storage from the electric utility.

INTRODUCTION

On 17 May, 1979, the U.S. Department of Energy awarded the College of Engineering at the University of Toledo a grant to design, install and test a solar assisted heat pump (capable of operating over a wide range of temperatures) when operated with the University of Toledo Solar House which utilizes off-peak electric auxiliary. This report describes the progress of the project during the first six months.

SCOPE OF INVESTIGATIONS

The objective of this project is to design and build a heat pump suitable for incorporating in a space solar heating system utilizing off-peak storage. It is the objective also to experimentally evaluate the performance of the space solar heating system. The scope of work during the period of the project covered by this report is limited to the following tasks:

1. Find the size of the piston type compressor to be used with an external motor belt drive that is consistent with the evaporator and condenser in the University of Toledo system.
2. Install the new compressor.
3. Determine the appropriate controllers setting for efficient operation.
4. Define appropriate performance indices for system evaluation, and develop the necessary minicomputer software to generate on-line these indices.
5. Determine the solar collector sizing suitable for the house space heating load.
6. Operate the system and perform an initial evaluation.

SIGNIFICANT RESULTS

Project Developments:

During the first six months of the project, all design and installation work on the solar assisted heat pump system to be used with off-peak electric auxiliary was completed, including the data acquisition and control system. Installation of the control system and interfacing of the control instrumentation and the individual components and sensors of the system have been completed and tested for operation.

Evaluation of the performance of the installed system has begun with specific experiments being conducted to measure performance of individual components as well as the complete system. Examples of such tests are measurements of collector efficiency, electric energy consumption, heating load, heat pump coefficient of performance, solar collector circuit coefficient of performance, and percentage of heating load supplied by solar energy.

Technical Developments and Results:

Significant technical developments and results of the project are described below:

(1) Compressor Design and Installation:

The refrigerating capacity and compressor horsepower for a heat pump system using a Victaulic (Lehigh) compressor turning at 544 rpm, working with Freon-12 between a condensing temperature of 172°F and evaporator temperatures of 0°F, 25°F, 50°F, and 75°F were determined. As a further variance, each of these were determined for 150°F, 115°F and 80°F temperatures for the high pressure liquid feed to the throttling valve. The compressor is a piston type with an external motor belt drive. It was installed with the existing evaporator and condenser in the University of Toledo Solar House. The evaporator used is a Dunham-Bush of capacity 21.62 KW (73,800 BTU/hr.), cooling a 50% ethylene glycol water solution by volume. The condenser is also a Dunham-Bush with a capacity of 23.6 KW (80,500 BTU/hr.) at 76.6°C (170°F) condensing temperature.

The heat pump system was then operated separately for two weeks during the month of October 1979. Some refrigerant leaks appeared during that initial test which were corrected. Data collected in general matched the specifications of the system.

(2) Preparing the System for Operation:

During the months of September and October components of the system were checked for operation. Minor leaks were found and corrected. Two expansion tanks were also added in the line. Insulation was checked for any moisture. Rates of flow were recorded in the different sections of the system so that it would be fed to the on-line computer simulation. Pressure levels in the heat pump section were checked to be normal. Temperature sensors and their associated electronics necessary to measure the energy states were assembled and calibrated. Some existing electronic components had to be replaced. In general all instrumentation was checked.

(3) System Performance Indices

The following parameters are calculated each hour by the evaluation software:

- average insolation
- average ambient temperature
- average room temperature
- average solar storage tank A temperature
- average off-peak storage tank B temperature
- energy collected from collector bank A
- energy collected from collector bank B
- energy delivered to the load from air handler
- energy delivered to the heater coils
- time collection circuit is active
- time air handler is active
- time heat coils are active
- time heat pump is active

electrical energy delivered to collection circuit

electrical energy delivered to air handler

energy stored in solar tank A

energy stored in off-peak tank B

The following parameters are calculated daily by the system software:

electrical energy delivered to all of the devices

energy delivered to the load from air handler

energy stored in solar tank A

energy stored in solar tank B

insolation

energy collected from collector bank A

energy collected from collector bank B

energy delivered by the heater coils

energy delivered to the heat pump

energy delivered by the heat pump

heat pump coefficient of performance

average ambient temperature

% of load delivered by solar

% of load delivered by auxiliary

efficiency of collector bank A

efficiency of collector bank B

efficiency of both collectors combined

average load/hour

number of degree days

Monthly Parameters:

total insolation
 average solar collector efficiency
 thermal energy supplied to heat pump
 electrical energy supplied to heat pump
 thermal energy delivered by heat pump
 heat pump coefficient of performance
 electrical energy supplied by electric coils
 thermal energy supplied to heating load
 electrical energy supplied to complete system
 % of load delivered by solar

(4) Collector Sizing:

A preliminary economic feasibility study of solar heating in the Toledo area has been performed. Three main factors were considered in this study. First: the amount of available energy from the sun as determined from a data processing system. Second: the house space heating load. Third: the present and expected future cost of conventional energy. As a result of this study and the constraints imposed on the system by using off-peak storage from the electric utility, thirty (30) flat plate solar collector panels were selected to be used with the heat pump system.

(5) System Operation

During the month of November, 1979 the solar heating system was operated using the high temperature heat pump. The heat pump is used to transfer energy from the solar collection storage tank to the auxiliary storage tank, keeping the fluid temperature in the solar collectors tank as low as practically possible, thus increasing the collectors efficiency.

The average temperature for this month was 7.85°C (46°F). This is compared with a 3.9°C (39°F) average based on a ten year average for Toledo. Insolation for this month was $21,922 \text{ BTU/ft}^2$ (69 KWH/m^2) compared with a ten year average of $26,100 \text{ BTU/ft}^2$ (82 KWH/m^2). The heat pump compressor consumed an average 55.6 KWH/day (correction was made for wrong controller setting during which the electric heating coils came on). Average energy supplied to all auxiliary pumps and air handler fan was 23 KWH/day . Percent of space heating load supplied by solar was determined to be 70.5% (electric energy supplied to pumps and air handler fan was not included). The solar collection coefficient of performance, which is defined as the ratio of energy at the load point from solar origin to the electric energy supplied to auxiliary pumps and fan, was measured to be 4.22 . Average of 23 KWH/day of electric supply energy produced an average of 96.7 KWH/day of net usable energy of solar source.

The highest daily average heat pump coefficient of performance (C.O.P.) observed was 3.81 , and the lowest was 1.59 . The monthly average C.O.P. was 2.37 . The monthly average solar collectors efficiency was measured to be 34.5% , and that does not include the waste energy collected on cloudy days. During cloudy days the heat pump was able to maintain the solar collector storage at relative low temperatures (between -7°C (19°F) to 0°C (32°F)), thus forcing the solar collectors pump to operate and store waste energy from the ambient. If the waste energy collected is included, the average collectors efficiency is estimated to be 53% .

(6) System Potential:

The use of a high temperature solar assisted heat pump in a system utilizing off peak storage from the electric utility instead of a

conventional direct solar heating system design would:

(a) Allow the flat plate solar collectors to operate at a much higher efficiency (53% for November 1979 compared to 13% for November 1978).

(b) Minimize the thermal energy losses from the solar collectors storage tank.

(c) Allow the solar collectors during the cloudy days to act as heat exchangers to supply the heat pump evaporator with the necessary energy, thus permitting the solar assisted heat pump to act as an efficient conventional heat pump when solar energy is not available.

(d) Greatly improve the average coefficient of performance of the heat pump over the conventional one. Average C.O.P. during November 1979 was 2.34.

(e) Eliminate the compressor overheating problem (by using a piston type compressor with an external motor belt drive) encountered in a conventional heat pump operated at high temperatures needed for off-peak storage.

(f) Help create a much more uniform temperature in storage tanks, thus allowing better system control.

(g) Reduce considerably the electrical resistance heating usage as a backup (November data indicates that the coils were on zero time).

(h) Tremendously increase the percent of heating load supplied by solar energy (70.5% for November 1979).

(i) Make the effective solar portion supplied to the heating load higher than the measured since the auxiliary energy will be primarily at off-peak rates. The effective solar portion supplied to the heating load is expected to exceed 80% for November 1979.

(j) Permit the usage of the same system as a cooling one.

COMPLIANCE WITH GRANT REQUIREMENTS

So far all work has been on schedule according to the time table proposed. Preliminary data are very encouraging and indicates that the system is doing what it was designed for. Two problems during the system operation did arise: the severe mechanical vibrations generated by the piston type compressor and the high sensitivity of the system efficiency on the controllers setting. A request for renewal of the grant will provide for a full heating and cooling season test with some potential modifications.

PERCENTAGE OF TIME OR EFFORT OF PRINCIPAL INVESTIGATOR

During the period July 1, 1979 to December 31, 1979, the principal investigator devoted approximately 50 percent of his time to the project. It is anticipated that he will devote 35 percent of his time for the remainder of the project (from January 1, 1980 to June 30, 1980).

TECHNICAL PUBLICATIONS

Technical publications arising as a result of the project include:

1. "Performance Evaluation of a Solar House Utilizing a High Temperature Heat Pump", A. H. Eltimsahy, R. G. Molyet, and R. L. Barnes, submitted for presentation at the American Section of the International Solar Energy Society 1980 Annual Meeting in Phoenix, Arizona.
2. "An Optimally Controlled Solar Heating System Utilizing a Dual Source Heat Pump", A. H. Eltimsahy, and R. G. Molyet, submitted for presentation at the American Section of the International Solar Energy Society 1980 Annual Meeting in Phoenix, Arizona.
3. "A Solar House Utilizing a High Temperature Solar Assisted Heat Pump and Off-Peak Storage", A. H. Eltimsahy, to be presented at the Industrial Power Systems Department (of the Institute of Electrical and Electronics Engineers) Meeting in Houston, Texas, May 1980.