UNITARY SOLAR HEATING/COOLING SYSTEM PACKAGE DEVELOPMENT

Progress Report

For Period June 1, 1977 - January 31, 1978

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ABSTRACT

During this period, a 3 ton residential system hardware package has been developed and is operating in an Arkla owned solar house in Evansville. - The Arkla tower-cooled WF36 chiller has been substituted for the evaporatively cooled chiller under development in the package.

The residential software and manufacturing programs are underway.

Only preliminary thinking has been done on the commercial 25 ton program which will soon be getting major attention.

Exhibit I, attached, states the tasks specified in the contract.

In Figure 1 projected task times are shown in solid lines, actual times in dotted lines and completion points by Δ.

Progress to date is as follows:

Task 1 - System Hardware Package

A residential unitary 3 ton system hardware package substituting the Arkla tower cooled WF36 chiller for the intended evaporatively cooled chiller has been developed and will be commercialized in this form during 1978. These requirements are shaping the final configuration of the evaporatively cooled chiller so that it will make up into a similar package.

Figure 2 is a schematic of the package plumbing. The key to unitizing is the "systems tank" which is an above-ground part of the storage system. By including it on a support frame along with the chiller and auxiliary heater, it was then possible to attach all pumps and controls too.

The collector, buried storage tank, domestic water preheater and fan coil are the only externals requiring field interconnections.

The collector/storage drain-down circuit is vented to the atmosphere through a condensing vent which maintains a long column of air as a diffusion barrier to vapor loss yet allows the system to "breathe" with temperature change.

Drain-down is used in the auxiliary heater circuit to avoid freezing and vagrant heat losses when idle.

Drain-down is also used in the generator, domestic water preheater, and fan coil circuits for freeze protection. Undrainable pipes in all circuits contact the warmth of the systems tank as much as possible.

Exhibit II outlines the system controls. Some stated setpoints and differentials may be altered as we gain more field experience.

Task 1 - Oak Meadow Solar House

Figure 3 is an aerial view of the tudor style Arkia solar test home in Evansville. The 48 Revere panels totaling 825 ft² are double glazed with low iron glass ($T = .89/\text{pane}$). The copper absorber plates are treated with a black chrome selective surface of $\alpha = .95$ and $\epsilon = .07$. A latitude tilt of 38° has been chosen.

The house is equivalent to a full two story structure on a 32 x 52 ft. foundation. Six inch studs allow R19 insulation in the walls and the ceiling is R38. A natural draft ridge vent is used along with careful attention to sealing against infiltration. The glass areas are double or triple glazed and protected on the south by 4 ft. overhangs on both stories. South area is 189 ft², north 86 and east 16; no west glass.

Conventional residential load calculation forms indicate a cooling load of 28,000 Btuh and a heating load of 48,000 Btuh.

Figure 4 shows the system hardware package in its garage location. The buried 2500 gallon storage tank is insulated with 6 inches of urethane foam.

The retrofit home has not yet been selected.

Task 1 - Manufacturing Program

Starting January 1, a full time manufacturing engineer has been at work. He has been familiarizing himself with the problems and already has identified several equipment sources who can supply the forming and welding equipment for the shells.

Task 2 - Residential Software Development

Development of a sizing methodology is underway. A visit was made in December to the University of Wisconsin to discuss cooperative efforts with Dr. J. A. Duffie. A consultation visit to Arkia was made by Dr. S. A. Klein in January. It is believed that the reduction of variables effected through standardized hardware will facilitate simplified procedures.

Monitoring of the Oak-Meadow house thermal performance has been in progress since late November via strip chart instrumentation and daily inspection visits. The immediate purpose is to derive system factors for software use.

Task 3 - Commercial 25 Ton Program

Only limited preliminary thinking done to date.

The principal investigator has spent at least 20% of his time on this contract.

Figure 1

Figure 2

Figure 3

Figure 4

EXHIBIT I

The objective of the proposed program is to:

- a. Develop a residential 3 ton unitary system hardware package comprising chiller, controls, fan coil unit, auxiliary heat, storage, domestic hot water preheat and pumps. This package would connect to collectors on the roof and a conventional hot water heater.
- b. Develop application and installation software for the residential system that will assure reliable system performance and accurate forecasting of solar dependency.
- c. Develop system application and installation manuals adapting the Arkla WFB300 25 ton solar chiller to repetitively encountered commercial applications.

Task-1: Contractor will develop a residential unitary system hardware package comprising an evaporatively cooled chiller, controls, auxiliary heat (gas or oil), heat storage, domestic water pre-heat and pumps. This package would connect to collectors on the roof and a fan coil unit in the conditioned space and a conventional water heater.

The collectors would not be part of the package and could be of any manufacture meeting the specification of copper tubes, self draining and performance at least equal to double glazed selective surface flat plate designs. This could include evacuated tube and concentrating types.

The fan coil unit would be mated to the system package through special related design features favorable to part-load operation.

Phases to completion are as follows:

- a. Design prototype systems.
- b. Build prototype package.
- c. Test prototype on Arkla Engineering building.
- d. Install systems on two test homes.
- e. Refine design.
- f. Manufacturing engineering study on how to build chiller which would put on paper a plant layout for a 900/year facility.
- g. Experiment with manufacturing techniques critical to the unique features of the evaporatively cooled chiller and verify during building of 4 chillers.

- h. Build 2 improved packages and 2 additional chillers from production type cooling.
- i. Test 2 on actual residences: one new and one retrofit in Evansville. In the prototype stage the tower cooled Arkla WF36 chiller would be used. The improved package would use the evaporatively cooled chiller.

Task 2: Contractor will develop the complementing application and installation software. Personnel involved shall participate in the system field testing, visit other installations, evaluate available sizing techniques, and employ the supporting services of ERDA recommended system analysts. The goal of this effort will be to approach the simplicity typical of current system hardware package.

Phases to completion:

- a. Monitor prototype system testing.
- b. Calculate system heating/cooling solar dependency for different collector types and geographical locations.
- c. Devise tentative sizing strategy maximum cooling solar dependency.
- d. Monitor improved system field testing.
- e. Visit other solar cooling installations.
- f. Finalize manuals.

Task 3: Contractor will identify repetitively encountered commercial heating/cooling applications and proceed to develop reliable system designs with the Arkla 25 ton WFB300 solar chiller as the core. System development activities should include visits to existing installations and laboratory testing of chiller unitized with prescribed essential peripheral hydronic and control hardware. Sizing and solar dependency forecasting software would be developed with subcontracted help from ERDA recommended system analysts.

Phases to completion:

- a. Visit existing commercial size solar installations.
- b. Identify repetitively encountered solar applications.
- c. Devise system design.

- d. Test chiller with essential prescribed peripheral hardware in laboratory to establish part-load performance.
- e. Conduct sizing and solar dependency analysis.
- f. Finalize installation and application manuals.

The deliverables are:

- Phase 1 - Two installed operating unitary residential systems. Two additional evaporatively cooled chillers. A plant layout of a 900/year manufacturing facility.
- Phase 2 - Application and installation manuals written on this residential system of HVAC industry users.
- Phase 3 - System application and installation manuals adapting the Arkla 25 ton solar chiller, WFB300, to repetitively encountered commercial applications.

Contractor shall perform the aforementioned work in general accordance with the program schedule set forth as Figure 1 in the Contractor Proposal (ERDA No. P7700721 - Revised) dated May 17, 1977.

EXHIBIT IICONTROL OF SOLAR SYSTEMA. Thermostat

1. Cool - Heat - Off Positions
2. Fan - Auto and On Positions
3. Located in living space and controlled by occupants

B. Collector1. Solar Commander - Differential Thermostat

- a. The control supplies solid state switching, thermistor sensors and circuit isolation both input and output. It is supplied with a manual pump switch having "Off", "Auto", "On" positions, power pilot indicator light and pump cycling indicator light. It operates on 115V - 50 - 60 HZ and has switching capacity of 3.5 amps inductive.
- b. The thermistor sensor located at the collector is rated at 400°F and the thermistor sensor located at the storage tank is rated at 300°F.
- c. The performance of the commander is nearly linear between 120°F and 220°F.
- d. Water is moved from the storage tank through the collectors and back into the systems tank by a Gorman Rupp 115V 1/3 H.P. pump. The pump is caused to start when the collector temperature is 15°F + 3 above the storage tank temperature and is stopped when the temperature difference falls to 5° + 3°. The commander supplies 115V power to the coil of the collector pump relay.
- e. The maximum allowed temperature of water in the storage tank will fall in the 200°F range. When this temperature is reached, power to the collector pump is broken and is re-established when storage tank temperature falls to 190°F to 195°F.

2. Collector High Limits

A high limit control located on the back side of the collector plate is used to interrupt power to the collector pump when the plate temperature rises to 275°F and re-establishes power when the temperature falls to 245°F. This is done by making or breaking the electrical power to the 24V coil of a DPDT relay. One set of NO contacts of the relay opens at temperatures above 275°F thus breaking the 115V power to the collector pump.

3. System High Limit

The system high limit aquastat senses the temperature in the systems tank. When the temperature of the systems tank reaches 205°F, it breaks the power to the coil of the system relay thus stopping the collector pump. When the temperature falls to 200°F the switch closes and re-establishes power to the relay coil.

C. Auxiliary Heater

1. The Solar Commander determines if there is enough solar energy available to start the collector pumps. If there is not, the auxiliary heater controls are allowed to control the performance of the auxiliary heater supplying heat for the systems tank.
2. The control of the temperature level in the systems tank is done by two aquastats, one for the cooling mode and one for the heating mode. The cooling mode aquastat causes the auxiliary heater to keep the water temperature in the system tank between 184°F and 189°F while the heating mode aquastat causes the auxiliary heater to maintain a water temperature in the systems tank between 130°F and 135°F. Both aquastats have adjustable temperature set points as well as adjustable differential temperature setting.
3. An ambientstat sensing outside ambient temperature determines which aquastat is in control of the auxiliary heater. If the ambient is 75°F or above and down to 72°F, the cooling mode ambientstat is in control. If the ambient temperature is 72°F or below and up to 75°F, the heating mode aquastat is in control. The set point of this control is adjustable.
4. The auxiliary heater is equipped with its own set of operating and safety controls, all in series.
 - a. Pilot safety control shuts off main gas and pilot gas if pilot flame goes out.
 - b. High limit control senses the water temperature leaving the auxiliary heater and shuts off the gas valve at 200°F and opens it at 185°F. Control is adjustable.
 - c. Flow switch allows the gas valve to open after water flow through the heater has been established. This is important since the boiler drains when the circulating pump stops.
5. The basic control sequence is as follows:
 - a. If the Solar Commander cannot detect sufficient solar radiation, the auxiliary heater contacts of the systems relay are closed. The ambientstat selects cooling or heating mode, if systems tank temperature is not high enough to satisfy the aquastat, the R-G circuit of the heater is completed, and the 1/12 H.P. 115V Grundfos circulating pump is started by the closing of the contacts of the auxiliary heater relay. Water flow is established, the gas valve opens and burners are ignited. At the same time, power is supplied to the heating element of a time delay relay. The contacts of the TOR are in parallel with the contacts of the auxiliary heater relay and provide extension of power for the heater circulating pump on shut down of the heater for a period of two minutes. Heat input to the systems tank will continue until the controlling aquastat is satisfied and then the heater will be shut off.

D. Cooling Mode

1. The room thermostat control must be moved to the cooling position and the dial set to demand cooling. The thermostat and aquastat are used to complete the R-Y circuit of the WF-36 for cooling. The switch of the aquastat sensing the temperature of the water in the systems tank is in series with the room thermostat; therefore, the cooling mode cannot be started unless the hot water temperature is 178°F. The aquastat opens the circuit when the water temperature falls to 178°F and closes it when the temperature rises to 182°F.
2. The W-36 control box provides unit operating and safety controls as well as power and connection points for the system operating relays. During the cooling cycle, the following relays located in the systems control box are actuated:

- a. Cooling tower relay
- b. Generator control relay
- c. Cooling control relay
- d. Fan coil relay
- a. Cooling Tower Relay

The cooling tower relay contacts supply power for the operation of the cooling tower pump, Gorman-Rupp 230V 1/3 H.P., and fan, 230V 1/3 H.P. Upon demand, the pump and fan start and run until the cooling load is satisfied and the thermostat or aquastat breaks the R-Y circuit. Temperature of the cooling water in the tower sump is monitored by a sump aquastat. When the temperature falls to 76°F, the fan is stopped. It is brought back on when the temperature rises to 80°F. The contacts of the cooling tower relay are in series with a disconnect switch which is supplied and installed by the contractor in the field. The electrical disconnect should be installed near the cooling tower.

- b Generator Control Relay

The generator control relay brings on the 1/12 H.P. Grundfos 115V 1/12 H.P. circulating pump and the Barber-Colman generator control valve and control module. The BC generator control valve is a three-way valve and is moved by a proportional hydraulic actuator having the spring return feature. The position of the valve is governed by a solid state BC controller which senses chilled water temperature leaving the absorption chiller. The sensor is a 1000 OHM wire resistor. The controller is calibrated to allow full hot water flow to the generator at chilled water temperature leaving the unit down to 43°F. At 40°F chilled water temperature, the hot water flow is by-passed around the generator and back to the systems tank. At temperatures between 43°F and 40°F, the flow is approximately proportional between the extremes mentioned. Calibrations of the controller as follows:

- (1) Calibrating the AT-8122-01 set point adjuster to the TP-8101-404 controlled.
Reverse acting output

- (a.) Remove the internal sensor from TP-8101-404 and set dial at 70°F. This is done at the factory. This is the neutral point on controller. Place internal brown wire on #3 terminal (3°F throttling range).

- (b.) Remove dial now from the TP-8101-404. This is done at the factory.
- (c.) Attach a V.O.M. set on D.C. volts between blue and yellow leads, after wiring between set point adjuster, controller, and controlled device (valve) have been made.
- (d.) Attach a decade bridge or 1000 OHM sensor between terminals #7 and #8 on TP-8101-404.
- (e.) When attaching the decade bridge set the OHMS to correspond to 43°F water and for the known sensor. The sensor will have been calibrated at 55°F. Subtract 26 OHMS from this reading (2.20 OHMS/1°F).
- (f.) (1) Adjust the knob on the remote set point adjuster to deliver 6 V.D.C.
 (2) Loosen set screw in knob and move knob until arrow is at 43°F mark on temperature indicating plate. Then re-tighten set screw.
 (3) Decrease OHMS by 6 or 7 on decade bridge. The D.C. volts should increase to 9.
- (g.) If a 1000 OHM sensor is used instead of decade bridge, follow steps (a) (b) and (c). Next immerse sensor in 43°F water bath for several minutes. Now proceed with 1 and 2 of step f. Next reduce water temperature to 40°F. D. C. volts should go to 9.

c. Cooling Control Relay

The cooling control relay contacts brings on the fan coil pump and supplies power for the chilled water by-pass valve. The fan coil water pump is a Grundfos 115V 1/12 H.P. pump and if necessary, more than one can be used by piping the pump in series and by electrically wiring them in parallel. The chilled water by-pass valve is used to cause chilled water to flow around a fix part of the fan coil when the temperature of the chilled water supplied to the coil reaches 49°F. It re-establishes flow through the entire coil when the temperature falls to 46°F. With this action, we can assure that a reduced load is presented to the WF-36 thus allowing the unit to keep the chilled water temperature in a range that will cause latent removal. High loads; high cooling water temperature or low temperature generator hot water will cause the capacity of the unit to be reduced. The chilled water by-pass valve is a 3-way valve with a 115V operator.

d. Fan Coil Relay

The fan coil relay contacts supply power for the fan coil blower motor, 115V 1/3 H.P. A switch at the room thermostat can be set to cause the blower to run continuously, or the blower can be caused to come on when cooling is required and shut off when the load is satisfied.

3. 3-Way By Pass Valve - Heating - Cooling

The 3-way by-pass valve is manufactured by Barber-Colman and has a two position hydraulic actuator with spring return feature.

In the cooling mode, the valve remains in the de-energized position and the chilled water flow is from the WF-36 evaporator to the fan coil tank.

Note: The unit evaporator does not drain during the cooling mode.

4. WF-36 Control Box

The WF-36 control box contains a high limit control which senses the condenser temperature and two low temperature controls which sense the temperature of the flash chamber. At 115°F, the high limit control breaks the power to the coil or the circulating pump relay of the WF-36 which in turn breaks the power to the solution pump relay, the cooling control relay and the generator control relay. The switch closes when the condenser temperature falls to 100°F and re-establishes power to the above relays. The low temperature control opens the circuit when the temperature of the flash chamber falls to 34°F. As a result, the coil of the No. 1 cooling tower relay is de-energized thus breaking the power to the solution pump relay, the generator control relay, and the No. 2 cooling tower relay. The circuit is re-established when the flash chamber temperature rises to 40°F. The second low limit control or flash chamber control closes the circuit to the unit solution by-pass valve when the flash chamber falls to 37°F and opens the circuit when the temperature rises to 40°F. When the valve is energized, salt solution is caused to by pass the absorber.

E. Heating Mode :

1. The room thermostat control must be moved to the heating position and the dial set to demand heating. The room thermostat is used to complete the R-W circuit of the WF-36 for heating thus actuating the following relays which are located in the systems tank control box :

- a. Heating Control Relay;

- b. Fan Coil Relay;

- a. Heating Control Relay;

Upon demand, power is supplied to the coil of the heating control relay and the heater element of a time delay relay.

"B" contacts of the relay start the fan coil pump and (or pumps).

"A" contacts supply power for the 3-way Heating and Cooling valve. This valve moves to its No. 2 position thus causing the hot water to flow from the WF-36 evaporator to the systems tank. The three-way valve requires approximately 60 seconds to move to the No. 2 position and when de-energized, it takes 20 seconds to move back to the No. 1 position. Since it is desirable to drain the WF-36 evaporator when the heating load is satisfied, the contacts of the time delay relay have been placed in parallel with the "A" contacts of the heating control relay thus providing for an extension of power to the 3-way heating and cooling valve for four minutes. This time period is sufficient to allow draining.

- b. Fan Coil Relay

The fan coil relay contacts close thus starting the fan motor at the air handler. When the load is satisfied, the fan continues to run until the coil temperature falls to 100°F. This extension of power is provided by a temperature control which senses the coil temperature. Its contacts are in parallel with the relay contacts and closes the electrical circuit when the heat exchange temperature is 130°F and opens it when it falls to 100°F.

F. Domestic Water Pre-Heater - Differential Thermostat

- a. The control supplies solid state switching, thermistor sensors and circuit isolation both input and output. It is supplied with a manual pump switch having "Off", "Auto", "On" positions; power pilot indicator light and pump cycling indicator light. It operates on 115V - 50 - 60 HZ and has a switching capacity of 3.5 amps inductive.
- b. One thermistor is located on the outlet domestic water line from the pre-heater and the other thermistor is located in the systems tank. Both thermistors are rated at 300°F.
- c. The performance of the differential thermostat is nearly linear between 80°F and 180°F.
- d. Hot water is moved from the systems tank through the pre-heater heat exchanger back to the system tank by Grundfos 115V 1/20 H.P. pump. The pump is caused to start when the temperature of the systems tank is $15^{\circ}\text{F} + 3^{\circ}$ above the domestic water outlet of the pre-heater and stops the pump when that difference falls to $5^{\circ}\text{F} + 3^{\circ}$. The differential thermostat supplies 115V power to the pump.
- e. The maximum allowed temperature of the domestic water leaving the pre-heater is $160^{\circ}\text{F} + 5^{\circ}\text{F}$. When this temperature is reached, power to the pre-heater is broken and is re-established when it falls to 145°F .

G. General:

The controls of the solar package are housed in three main control boxes and several small junction boxes. One main control box is located on the WF-36 and it contains the safety and operating controls of the WF-36 and source of power for the operating relays. Two main control boxes are located on the systems tank. One box contains controls and relays, while the other contains only the main current limiting disconnect and six individual current limiting disconnects. Power supplied to the control boxes should be 230V 60 HZ with a neutral wire. Since power to the main disconnect is "back fed" into the individual disconnects, the source should contain a disconnect or a current-limit disconnect.

FRED BAUER
12/15/77