Solar House Heating System
Using Reflective Pyramid Optical
Condensing System

PROGRESS REPORT 101-4
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PROGRESS REPORT OF
CONTRACT E(11-1) - 2769
JUNE 1, 1975 - JUNE 1, 1976

Introduction

On June 1, 1975, the Wormser Scientific Corporation entered into a contract, E(11-1)-2769, with ERDA to conduct an experimental program to evaluate solar energy heating and cooling systems employing a pyramidal optics concentrating system. Work on this contract has proceeded with improvements to the initial test installation and instrumentation and evaluation of a newly constructed residence employing an improved version of the concept. The developmental progress made and the test results obtained thus far are summarized below.

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I. Pyramidal Optics Solar Concentrator System

A. Summary of past years accomplishments

1. 472 Westover Road prototype installation

a. Design, installation of 2nd pyramidal optics unit

In order to further substantiate the operational characteristics of the pyramidal optical concentrator, a second prototype unit was designed and constructed in attic space adjacent to the first, at 472 Westover Road in Stamford, Connecticut, the residence of Gerald Falbel, the inventor of the concept. The new unit uses the continuous flap that runs across the south end of the structure as shown in Figure 2. Section and perspective of the new unit are seen in Figures 1 and 3. The new unit has a width of 10 feet, slightly smaller than the older unit, due to space limitations. Since the house is actually oriented several degrees east of south, the eastern side of the unit was placed at right angles to the collecting surface to maximize collection at hours around noon.

b. Design, installation of controls for flap opening and positioning

The pyramidal optics condensing system employs a reflective panel that seasonally tracks the sun, moving from a low angle in December to higher angle in June. The initial concept of controlling the position of this flap by means of photo-electric sensors has not proved feasible due to a lack of definition of the sun's image produced by the reflective material mounted on the flap. A far less complex mechanical control is now in use. The path of the sun through the seasons is well known and predictable. Since the optimum reflective flap position is therefore predictable and identical from year to year, a screw mechanism advancing slowly from December to June was

FIG. 1 SECTION THROUGH PYRAMIDAL SYSTEM #2

PYRAMIDAL OPTICS TEST HOUSE • OPEN

FIG. 3 PERSPECTIVE OF PYRAMIDAL PROTOTYPE

conceived as a simple way to regulate the flap positioning. Each morning the winch lowers the flap until it strikes a limit switch attached to the screw mechanism so that the flap is angled optimally for that day of the year. On June 21 the screw mechanism reaches the upper end of its track, strikes a reversing switch and begins its six-month return journey. The screw mechanism is driven by a small clock motor geared to drive at the desired rate, as shown in Figure 4.

The flap is closed in the event of precipitation to protect the collector components. This action is controlled by a "precipitation sensor" of simple design shown in Figure 5. Two electrical contacts are mounted in close proximity in a small depression of an acrylic plastic base in such a way that precipitation forms a small pool over them. The water, acting as an electrolyte, closes the circuit to the winch and the flap closes. The bottom side of the rain sensor is painted black so that when the sun reappears, the sensor acts like a miniature solar collector and evaporates the accumulated water. When the contacts dry off the flap once again opens to gather more sun energy.

Also in the circuit is a cadmium sulfide cell acting as a sun sensor. This commands the flap to open at sunrise and close at sunset. The sun sensor also detects dry powdery snow (which will not trigger the rain sensor) and will close the flap when a snow layer blocks out the light. The sun sensor operates with an 8 minute delay preventing a passing cloud from activating the control. The signals from the rain sensor are superimposed on this circuitry as shown in Figure 6.

FIG. 4 SCREW CONTROL MECHANISM SCHEMATIC

FIG. 6 FLAP CONTROL CIRCUIT

c. Instrumentation Improvements

Instrumentation improvements were made to upgrade the quality of the performance data. By incorporation of a 20-channel Honeywell recorder the number of parameters that could be monitored was increased. Figure 7 diagrams the measurement system. In addition to the two pyramidal optics units, the prototype experimental installation has an unfocused flat plate collector mounted on the adjacent roof at 50° to the horizontal (the latitude $+ 10^\circ$) to provide a reference for comparative purposes.

Temperature measurements are made by two kinds of sensors, thermistors and thermocouples. Multiple junction thermocouples are used when accurate temperature difference measurements are required, such as across a collector from fluid inlet to fluid outlet. Signal response to temperature is linear for the thermocouples. Thermistors are installed in locations calling for absolute temperature measurements (output versus temperature is shown in Figure 8). Signal response to temperature is calibrated over the range of interest for the thermistors.

Ten-junction copper-copper constantan thermocouples are used to accurately monitor the temperature rise across each of the flat plate collectors, two of which are located in pyramidal focusing units and one on the unfocused unit. In each case, the inlet water temperature is sensed by a thermistor. As shown in Figure 7, thermistors are used to monitor inlet and outlet water temperatures on both sides of the heat exchanger, inlet and outlet of the domestic hot water storage tank, as well as the outside ambient dry bulb. The flow of the water-

FIG. 7 MEASURING SYSTEM SCHEMATIC

472 WESTOVER RD. STAMFORD, CONNECTICUT

THERMISTOR RESPONSE TO TEMPERATURE

MILLI-VOLTS PER DEGREE FAHRENHEIT

FIG 8 THERMISTOR SIGNAL RESPONSE

ethylene glycol heat transfer fluid is regulated and measured by Bell and Gossett "circuit setters" across which a differential pressure can be read by a Bell and Gossett meter. The flow is derived from a calibration chart. Insolation is measured by a standard Eppley black and white pyranometer mounted at the angle of the unfocused collector.

The data are fed into a Honeywell 20-channel analog chart recorder providing real time display. Full scale deflection of 10 inches corresponds to a 10-millivolt signal. Signal conditioning was required only for the pyranometer where a small resistance was introduced to attenuate full-scale output. (Appropriate calibrations were made).

d. Review of collected data

The pyramidal optics prototype units have been in operation for more than a year and a large amount of data has been collected. There have been minor interruptions due to breakdowns and system modifications, but general predicted performance trends are being substantiated.

Figure 9 is an example of a typical day's output as taken directly from the chart recorder. Analyses have been performed on the data, using the appropriate calibrations.

Figure 10 shows the relationship of the heat collected by the unfocused flat plate collector for a typical winter day compared to the heat collected by the focused system. The focused system collects from two to four times as much heat per square foot of collector as does the unfocused system.

The primary reason for the relatively higher performance of the pyramidal optics system compared to a flat plate system of the same absorber area is the larger amount of solar flux

TYPICAL DAY'S OUTPUT
PYRAMIDAL OPTICS VS. FLAT PLATE UNFOCUSED
DATA FROM 2-12-76

<u>HOOR</u>	<u>9-10</u>	<u>10-11</u>	<u>11-12</u>	<u>12-13</u>	<u>13-14</u>	<u>14-15</u>	<u>Total</u>
Insolation on 50 surface BTU/ft. ²	240	276	294	268	226	158	1462
ΔT focused #2 unit °F	17.5	23.0	27.5	25.0	15.0	1.5	
ΔT unfocused °F	10.5	12.0	12.5	11.5	8.5	3.5	
GPM focused #2	0.65	0.65	0.65	0.65	0.65	0.65	
GPM unfocused	0.47	0.47	0.47	0.47	0.47	0.47	
BTU output #2 focused	4554	5985	7156	6505	3903	390	28493 BTU/day
BTU output unfocused	1976	2258	2352	2164	1599	659	11008 BTU/day

$$\text{BTU output} = (^{\circ}\text{F } T) (\text{GPM}) (\text{MIN/HR}) (\text{LBS/GAL}) (\text{BTU/}^{\circ}\text{F/LB})$$

COMPARISON OF TYPICAL DAY'S OUTPUT
PYRAMIDAL OPTICS VS. FLAT PLATE UNFOCUSED
DATA FROM 2-12-76

	Absorber Area (Ft. ²)	Aperture Area (Ft. ²)	Insolation (BTU/ft. ² /day)	Collector Output (BTU/day)	Ratio	Efficiency Per Ft. ² Absorber(%)	Efficiency Per Ft. ² Aperture(%)
Pyramidal Optics	14.7	50	1462	28493	2.6	130	40
Unfocused Flat Plate	16	16	1462	11008	1.0	47	47

collected by the larger optical aperture and directed to the absorber by the reflective panels. Additional benefits accrue to the focused system. The focused system suffers proportionally less losses from the absorber plate. Any body loses energy by three means: conduction, convection and radiation. These losses are a function of the absorber area and the temperature differences as follows:

Energy lost = Conduction + Convection + Radiation

$$Q_{\text{lost}} = \frac{(k)}{(x)} (A_1) \Delta T_1 + h (A_2) \Delta T_2 + \sigma (F_A) (F_E) (A_3) (T_p^4 - T_{\text{sky}}^4)$$

Where Q_{lost} = Energy lost

K = thermal conductivity of supporting material

x = thickness of supporting material

A_1 = area of supporting material of absorber plate

ΔT_1 = temperature difference across supporting material

h = film coefficient

A_2 = surface area of convector/absorber

ΔT_2 = temperature difference of air and convecting absorbing surface

σ = Steffen-Boltzman constant

F_A = configuration factor

F_E = emmisivity factor

A_3 = surface area of radiator absorber

T_{sky} = temperature of sky

T_p = temperature of radiating plate

As noted the convection and radiation surfaces are identical with the absorbing surface. The supporting area of the absorber plate is equal to or smaller than the absorbing plate surface. From the above relationship it may be observed that energy losses are directly proportional to absorber surface areas. In the

pyramidal optics system the absorber surface area is a fraction of the collection area, compared to an unfocused system. Energy losses from the system are correspondingly smaller.

This expectation of reduced temperature dependance is verified by the curves shown in Figure 11, in which efficiencies are plotted against the temperature difference from the plate to the ambient air (x axis values are divided by the insolation to permit comparisons at different levels of solar energy). The slope of the unfocused flat plate curve is much steeper than the focused system curve showing that the performance of the unfocused plate is more severely affected by plate-ambient temperature differences.

e. Difficulties and problems

Data collection was somewhat hampered by the existance of two tall trees which in December and January cast shadows at very low sun angles. These shadows appeared as dips in the data curves, for which adjustments were made.

Some difficulty was experienced with circulation pumps. Sizing and seizing problems largely have been solved through use of higher temperature rating pumps. However, the performance data obtained to date is limited to a temperature differential $T=100^{\circ}\text{F}$. Future tests at higher temperature differentials are planned.

2. Delaware House Fully Enclosed Pyramidal Optics System

a. House description

The prototype P.O. system in Stamford, Connecticut is

PYRAMIDAL OPTICS VS. FLAT COLLECTOR

WORMSER SCIENTIFIC CORPORATION

FIG. 11

an open system with the absorber plate and reflective surfaces exposed to the outside ambient conditions.

By enclosing the optical system as shown in Figure 12 it was determined that several advantages would be gained.

1. Performance improvements would be realized with the absorber plate in a protected inside environment and convective and conductive losses reduced.
2. Longevity and performance of reflector and absorber surfaces would be enhanced because of protection from the elements.
3. The materials and construction details of internal piping and mechanisms would not need to be weather resistant.
4. Anti-freeze solution would no longer be a requirement with the system in a freeze-protected environment.

A ranch style home with 1,400 sq. ft. of floor space was constructed by the Better Homes Company of Delaware at Rehoboth, Delaware incorporating a full-sized pyramidal optics solar collection unit in the attic space. Wormser Scientific acted as solar systems design consultant. The dwelling as far as architectural design and appearance is a conventional, medium cost, speculative house not unlike many in the immediate neighborhood. Plan and outside view, Figs. 13 and 14, illustrate that the impact on the aesthetics of the house by the solar system is minimal.

WINTER APERTURE: $10' \times 10' = 100 \text{ FT}^2$
 COLLECTOR: $3' \times 8' = 24 \text{ FT}^2$
 GEOM. GAIN: 4.16
 NET GAIN: 3.33
 NET APERTURE: 80 FT^2

PYRAMIDAL OPTICAL SYSTEM - WITH WINDOW

FIG. 13 PYRAMIDAL OPTICS SOLAR HOUSE, DELAWARE

DELAWARE SOLAR HOUSE

SCALE 1/8" = 1'-0"

FIG. 14

In order to minimize energy consumption through heat losses in winter and heat gains in summer, the following special energy conservation features were incorporated in the Delaware home.

The exterior wall insulation consists of $3\frac{1}{2}$ " of foil faced fiberglass bats ($R=11$) augmented by $\frac{3}{4}$ " of styrofoam rigid sheet ($R=3$) on the outside which minimizes infiltration in addition to improving insulation.

The ceiling has 10" of loose rockwool ($R=30$) while the floor area has 4" of fiberglass ($R=12$) over a crawl space.

The windows are dual glazed throughout. The exterior doors are metal with urethane cores.

Heat loss estimates were made independently by three professional engineers resulting in a heat loss estimate of 32,000 BTU/hr $\pm$ 2,000 BTU/hr for 0°F outside temperature and 68°F inside temperature.

Usual construction procedures call for far less insulating material, typically 3 inches in the walls, 6 inches in the ceiling with limited use of insulated sheathing or glazing. The increased insulation reduces the heat losses from the structure by approximately $\frac{1}{2}$. This amount of heat loss reduction reduces the solar equipment requirement by many times the investment in insulation and dual glazing.

In order to accomodate the solar collection system the height of the attic was increased to $10\frac{1}{2}$ ' at the center using 10/12 (or 40°) slopes on the attic side walls.

An oversize utility room 14'x16' was added to the house to accomodate the storage tank for the solar system, in addition to space for laundry equipment, and a stair to the

DELAWARE HOUSE HEAT LOSS CALCULATION

"U" VALUES

WALL

Outside air	0.17
5/8" plywood	0.77
3/4" beadboard	2.68
3 1/2" R-11	11.00
1/2" gypsum	0.45
inside air	0.68
R =	15.75
U =	0.063

CEILING

inside air	0.61
1/2" gypsum	0.45
10" R-30	30.00
outside air	0.61
R =	31.67
U =	0.032

ATTIC ROOF

inside air	0.62
1/2" gypsum	0.45
5 1/2" mineral wool	18.00
1/2" plywood	0.62
shingles	0.44
outside air	0.17
R =	20.30
U =	0.049

FLOOR

Outside air	0.25
3 1/2" R-11	11.00
3/4" air space	1.01
1/2" subfloor	0.62
1/2" finish floor	0.62
carpet & pad	1.23
inside air	0.92
R =	15.65
U =	0.064

WINDOWS

3/16" double glazing	
U =	0.69

Doors

Urethane filled	
U =	0.40

ATTIC END WALL

outside air	0.17
5/8" plywood	0.77
3/4" beadboard	2.68
3 1/2" R-11	11.00
inside air	0.68
R =	15.30
U =	0.065

HEAT LOSS CONTINUED

SURFACE AREAS

Window	142 sq. ft.
wall	1104
floor	1040
man door	40
ceiling	1264
utility slab	
perimeter	60
den ceiling in attic	442
end wall in den	130
building volume	11776 cubic feet

DESIGN CONDITIONS

Outside temperature = 15°F 97½% ASHRAE
 Inside 68°F
 ΔT 53°F

Wall	(.063)(1104)(53) =	3686
floor	(.064)(1040)(53) =	3472
windows	(.69)(142)(53) =	5192
man door	(.40)(40)(53) =	848
ceiling	(.032)(1264)(28) =	1133
den ceiling	(.049)(442)(53) =	1147
end wall	(.065)(130)(53) =	448
Sensible Heat Subtotal		<u>15926</u>

INFILTRATION $H = 0.018$ (air volume)(air changes) T
 1.3 air changes/hr.
 = (0.018)(11776)(1.3)(53)
 = 14600

TOTAL HEAT LOSS AT DESIGN CONDITIONS

15926 BTUH conduction loss
 14600 BTUH infiltration loss
30500 BTUH TOTAL FOR BUILDING

den in the attic, the auxiliary heat pump system, the hot water tank as well as space for monitoring and recording equipment.

Description of Solar Energy Collection System

A schematic section through the solar collection optical system used in the Delaware house is given in Figure 15. The optical system consists of a window $12\frac{1}{2}'$ in slant height by $34'$ in total width. The window is made up of 13 sheets of extruded acrylic plexiglass $32'' \times 156'' \times 0.100''$. These are mounted on double $2'' \times 6''$ rafters as shown in the photograph (Figure 16). The plexiglass is reinforced using $\frac{1}{2}''$ horizontal mylar straps spaced $18''$ vertically apart. The 40° rear attic slope is lined with reflective mylar, applied to gypsum wall board. The stationary portion of the floor $6'9''$ in depth is $\frac{3}{8}''$ plywood lined with reflective mylar, while the movable portion of the reflector is made of $\frac{1}{2}''$ plywood applied over a frame. The movable reflector is counterweighted and moved from a 8° elevation above horizontal in winter (Dec. 21) to a 42° elevation above horizontal in summer (June 21) by an automatically programmed small clock motor and screw mechanism as shown in Figure 17. The two ends of the $34'$ wide pyramidal reflector are also lined with reflective material applied to $\frac{1}{2}''$ plywood.

The four $3' \times 8'$ flat plate collectors are mounted in a single continuous row at an angle of 70° to the horizontal. The collectors consist of $22'' \times 96'' \times 0.40''$ copper Rollbond finished with Enthone selective black coating having an absorptivity of 0.90 and a emissivity of 0.12. The $22''$ wide

GROSS W. OF WINDOW 34.67' PY. 1-DAL OPTICS DESIGN REVISION
 NET GLASS WIDTH-RAFTERS SUBTRACTED 31.42'

MONTH	WIDTH	HEIGHT NORMAL TO RADIATION	APERTURE NORMAL
DEC.	31.42'	11.08'	348 SQ. FT.
JAN.	31.42	10.08	317
FEB.	31.42	8.42	265
MAR.	31.42	6.58	207
APR.	31.42	4.00	126
MAY	31.42	4.25	134
JUNE	31.42	4.33	136

MONTH	HEIGHT OF WINDOW @ 40°	APERTURE AT 40° SOUTH
DEC.	12.17	382
JAN.	10.83	340
FEB.	8.50	267
MAR.	6.50	204
APR.	4.08	128
MAY.	4.53	144
JUNE	4.75	149

DELAWARE HOUSE - 39° N.

FIG. 16 WINDOW CONSTRUCTION

DELAWARE SOLAR HOUSE

SECTION THRU PYRAMIDAL OPTICS SOLAR SYSTEM

MOVING REFLECTOR IN WINTER POSITION - 10°

SCALE $3/8" = 1'$

FIG. 17

copper Rollbond is extended on each side by a 5" width .017" copper sheet with a $\frac{1}{4}$ " I.D. copper tube (Sunworks-Enthone) to make for a total collector dimension of 32"x96" as shown in Figure 18.

The collectors were initially equipped with a single layer of ASG white tempered crystal glass. Preliminary tests have indicated that improved performance is obtained without glazing on the collectors.

The system is designed to provide maximum collection of sunlight in the winter months. A tabulation of the geometrical aperture and gain and the net aperture and gain with an average reflection efficiency of 80% is given below:

APERTURE OF SOLAR COLLECTION SYSTEM AS A FUNCTION OF SEASON

<u>Season</u>	<u>Geom. Aperture</u> ft. ²	<u>Geom. Gain</u>	<u>Net Aperture</u> ft. ²	<u>Net Gain</u>
Winter	348	4.07	278	3.26
Spring/Fall	207	2.43	166	1.95
Summer	136	1.59	109	1.27
Flat plate collector 4'x8'x32" = 85.3 ft. ²				1.1

A calculation of the amount of solar energy collected on month by month basis (based on insolation data from the nearest station recording solar data which is Seabrook, NJ, at a distance of less than 40 miles) vs. heating energy required is given below in Table I.

b. Description of the heating system

The heating system combines the assets of the solar collectors with the advantages of a water-to-air heat pump. A schematic of the system is shown in Figure 19. The solar energy is stored as hot water in an 800-gallon precast concrete tank, waterproofed by a butyl rubber bladder. Fully insulated,

FIG. 18 COPPER FLAT PLATE COLLECTOR 3' X 8' (WITHOUT GLAZING)

TABLE I

Month	Total Heat Load $\times 10^6$ BTU	Solar Input $\times 10^6$ BTU	Supplemental Required With Solar Alone BTU $\times 10^6$	Solar/Heat Pump Output $1.6 \times$ Solar Input BTU $\times 10^6$	Supplement Required With Solar/Heat Pump BTU $\times 10^6$	Estimated Storage Tank Temperature Range ° F
Jan.	12.8	5.0	7.8	8	4.8	50°- 80° J
Feb.	11.6	3.7	7.9	5.9	5.7	50°- 80° F
March	9.5	3.8	5.7	6.1	3.4	50°- 80° M
April	5.8	2.3	3.5	3.7	2.1	50°- 80° A
May	2.7	2.7	-	-	-	80° M
June	1.5	2.7	(1.2)	-	-	100°+ J
July	1.4	2.6	(1.2)	-	-	100°+ J
Aug.	1.4	2.5	(1.1)	-	-	100°+ A
Sept.	2.0	3.6	(1.6)	-	-	100°+ S
Oct.	4.7	4.6	0.1	-	-	80° = O
Nov.	8.2	5.3	2.9	8.5	(0.3)	50°- 100° N
Dec.	<u>12.1</u>	<u>4.8</u>	<u>7.3</u>	<u>7.7</u>	<u>4.4</u>	50°- 80° D
	73.7	43.6	35.2	39.9	20.4*	

Percentage Furnished By
Solar Without Heat Pump

$$\frac{73.7 - 35.2}{73.7} = 52\%$$

Percentage Furnished By
Solar With Heat Pump

$$\frac{73.7 - 20.4}{73.7} = 72\%$$

*Does not include
heat pump power
consumption.

DELAWARE SOLAR HOUSE
SOLAR SYSTEM - AUXILIARY SYSTEM
INTERFACING

LEGEND

HE	WATER TO AIR HEAT EXCHANGER
RH	RESISTANCE HEAT 'BACK-UP'
⊙	PRESSURE GAUGE
⊗	VALVE
P	CIRCULATING PUMP
⊞	TEMPERATURE SENSORS
+	CIRCUIT SETTER
⊥	RELIEF VALVE

this tank will hold:

$$\begin{array}{rcl} (800 \text{ gal.}) (8.34 \text{ \#/gal.}) (1 \text{ BTU/\#/\text{F}}) (100^{\circ}\text{F}) & = & 660,000 \text{ BTU} \\ (7000 \text{ \# concrete}) (0.2 \text{ BTU/\#/\text{F}}) (100^{\circ}\text{F}) & = & \underline{140,000 \text{ BTU}} \\ & & 800,000 \text{ BTU} \end{array}$$

Building heat losses for an average winter day have been computed to be 32,000 BTUH at design conditions of 68°F inside, 0°F outside. Once fully charged, the storage tank represents 3 average days storage capacity.

Since the solar collectors are located inside an insulated attic structure and thus protected against freezing and the collectors and all related plumbing are made of copper, deionized and purified water without antifreeze or inhibitors is used as the heat transfer medium.

The water-to-air heat pump can supply heat to the dwelling using the solar-heated water down to a temperature of 50°F at high coefficients of performance. If the storage is further depleted, resistance heating in the duct is available as a back-up system. Summer cooling is also provided by the heat pump.

Operation of the solar system is fairly simple. The collector water circulation pumps begin pumping when the collectors reach a temperature 10°F above the storage and turn off at storage temperature. A Rho-Sigma differential temperature control is used.

Whenever the storage tank temperature is above 90°F water from the top of the storage tank is pumped using a 1/6 H.P. pump through a 6-row water-to-air heat exchanger in the plenum of the duct system just above the heat pump (see Fig. 19). The heat is distributed using the centrifugal blower

in the heat pump developing air flow of 900 C.F.M. Thus, whenever the tank temperature is above 90°F, which will be the case when the solar heat input exceeds the heat demand for several days, the home heat will be supplied 100% by the solar system. The only power consumption then will be that of the water circulating pumps and blower. As shown in Table I, this condition is expected to prevail most of the time, except for the months of December, January and February.

For periods of time when the heat demands of the house exceed the heat supplied by the solar system over a period of several days, a water-to-air heat pump has been provided as an auxiliary heating system. Whenever the temperature in the storage tank drops below 90°F, water from the storage tank is supplied to the water-to-air heat pump where the heat is upgraded in a freon compression-expansion cycle.

The heat pump operates satisfactorily with water temperatures ranging from 95°F to 50°F. It has a coefficient of performance (C.O.P.) of 2.9 at 90°F and 2.5 at 50°F, which means that 66% of the heating energy is supplied by solar-heated water at 90°F with 34% supplied by electricity; while at a water temperature of 50°F 60% of the heating energy is supplied by the solar-heated water with 40% supplied by electricity. The use of the water-to-air heat pump extends the utilization of solar heat to considerable lower temperature levels than would otherwise be possible and improves the overall performance of the solar system as shown below. When the temperature of the storage is below 50°F, resistance duct heating

carries the heating needs of the dwelling.

The heat pump is controlled by a two-stage thermostat in the living room. The first stage brings on the direct solar coil or heat pump. If further heat is required, the second stage brings on the resistance heating. It is expected that resistance heating will be used infrequently.

A diagram of the control system is shown in Figure 20. The control sequences are shown on this diagram.

The hot water consumption for a family of four is estimated at 75 gallons/day at a temperature of 130°F. If the average temperature of well water is assumed to be 55°F, the energy for hot water is as follows:

$$75 \text{ gal} \times 8.3 \text{ lbs/gal} \times 30 \times 75^\circ\text{F} = 1.4 \times 10^6 \text{ BTU}$$

Table I shows that this amount of energy is available from the solar system at all times.

The hot water system is integrated with the house heating system. A 60 gallon galvanized steel tank is suspended near the top of the 800 gallon storage tank and will thus assume the temperature of the storage tank. When the temperature of the storage tank is above 140°F the hot water will be tempered to 140°F in an automatic mixing valve. When it is below 125°F the hot water will be further heated in a glass lined conventional hot water tank as shown in Figure 19.

c. Description of instrumentation

The instrumentation of the Delaware house is similar to the instrumentation used at the prototype installation at 472 Westover Road in Stamford. Figure 21 outlines the basic instrumentation arrangement. Ten-junction thermocouples positioned across each of the four collectors monitor the temperature rise

SEQUENCE OF CONTROL OPERATIONS
DELAWARE SOLAR HOUSE

Any time temperature at collector as indicated by thermistor sensor T-1 exceeds temperature at bottom of storage tank as indicated by thermistor sensor T-2 the differential thermostat (Rho Sigma Model 102) actuates the relay to operate collector circulation pump P-1.

Water-to-air heat coil pump P-2 operates when two stage room thermostat T-3 calls for heat and tank thermostat T-4 indicates top of tank is above 90°F.

When temperature at top of tank drops below 90°F, relay for pump P-2 will be de-energized and relay for pump P-3 (hot water supply for heat pump) will be energized simultaneously with heat pump heating cycle.

If water temperature in supply loop to heat pump drops below 60°F 4KW circulation heater will provide boosting of supply water temperature up to 80°F.

If storage tank temperature should drop below 40°F, relay for pump P-3 (water supply to heat pump) shall be de-energized by tank temperature sensor T-5 and both stages of the backup electric duct heater shall be supervised by the room thermostat.

During cooling cycle the single stage cooling side of room thermostat T-3 shall control the compressor operation of the heat pump and pump P-3 relay (COOL). Pump P-3 relay shall cycle the evaporative cooler whenever the compressor is in operation.

CONTROL DIAGRAM
DELAWARE SOLAR HOUSE

FIG 21 DELAWARE HOUSE MEASURING SYSTEM

from collector inlet to outlet. The temperature at the collector inlet is detected by a thermistor. Other temperatures recorded are the attic ambient dry bulb, outside ambient dry bulb, the tank temperature, water temperatures entering and exiting the heat pump, and air temperatures in the house heat supply duct.

Electrical consumption measurements are being made with the cooperation of the Delmarva Power Company, who have supplied recording meters for four parts of the load, the heat pump, the domestic hot water heater, the resistance heater, and the solar system pumps and controls. The total building consumption is recorded on a fifth recording meter. These consumptions are recorded on magnetic tapes which are read and analyzed by the Delmarva Power personnel who report the readings to Wormser Scientific monthly. A sample of this data is shown in Table 2. Solar radiation is measured by an Eppley pyranometer mounted at the angle of the window aperture. The outputs of the thermocouples, thermistors and pyranometer are wired to a 20-channel Honeywell chart recorder for analog readout in real time.

System Performance Prediction

A performance prediction for the overall system has been prepared based on the following parameters: heat loss computations for the house prepared by three independent experts agreeing to better than 10%, Degree Day data on Wilmington, Delaware from ASHRAE publications, insolation data from U.S. Weather Bureau station at Seabrook, New Jersey a distance of 40 miles, efficiency data on pyramidal optics unit based on 18 months of test data obtained on prototype unit located in Stamford, Connecticut, performance on water-to-air heat pump

	1	2	3	4	5	6	7	8	9	10	11	12
3 25 75 200 AM KA										.53	1.27	1.5-
AV KA	.66	.90	.66	.66	1.19	.52	1.54	2.04	4.01	1.02	.46	.15
DAILY LOAD FACTOR	.180					4.01						
3 25 75 200 AM KA	.79	1.92	1.01	1.31	1.13	1.41	1.33	3.31	.77	1.35	.46	1.20
AV KA	.58	.41	.51	.43	.83	1.52	.54	2.53	.63	.39	.22	.52
DAILY LOAD FACTOR	.315					3.31						
3 25 75 200 AM KA	1.56	1.05	.88	1.16	.97	1.43	.92	3.71	.79	.87	.54	.55
AV KA	.57	.90	1.00	.94	.71	.81	.41	.25	.25	1.13	.25	.19
DAILY LOAD FACTOR	.240					3.71						
3 27 75 200 AM KA	.15	.55	.90	.94	1.79	.97	1.26	1.34	1.66	2.67	.46	.57
AV KA	.66	1.35	1.34	.64	.56	.5	.55	.30	.30	.46	.32	1.20
DAILY LOAD FACTOR	.320					2.67						
3 28 75 200 AM KA	.38	.22	.21	.15	.51	.36	1.42	1.15	3.75	1.51	.83	.49
AV KA	1.38	.55	.73	1.53	.72	2.41	.31	2.15	1.98	.92	.59	.6-
DAILY LOAD FACTOR	.285					3.75						
3 29 75 200 AM KA	1.05	1.00	2.13	1.49	1.35	1.45	1.68	1.85	2.31	.92	.92	1.69
AV KA	.61	.51	.55	.61	.43	.27	2.67	1.12	.94	1.64	1.65	1.13
DAILY LOAD FACTOR	.441					2.67						
3 30 75 200 AM KA	1.65	1.10	1.45	1.25	1.84	1.95	1.39	3.04	1.19	1.00	1.13	.89
AV KA	1.72	.69	.69	.57	.55	.90	1.50	3.00	3.53	.43	1.35	.92
DAILY LOAD FACTOR	.383					3.53						
3 31 75 200 AM KA	1.34	1.72	1.40	1.00	1.40	1.21	1.33	3.09	1.33	1.14	1.18	1.50
AV KA	1.31	1.62	1.29	1.17	1.00	1.35	2.15	1.03	1.32	1.41	1.47	1.23
DAILY LOAD FACTOR	.450					3.09						

TABLE II

based on manufacturer's test data.

Table I shows the following: the heat and hot water requirements are fully met by the solar assisted heat pump system except for periods during January, February and March. During these months the resistance heaters in the heating plenum will operate to supplement during periods of extended cloudiness.

It is estimated that the solar system would furnish 52% of the energy requirement to a heating system without a heat pump. With the heat pump which can utilize lower temperature solar output the estimated percentage of solar contribution is 72% (see Table 1).

d. Review of data collected

As with most construction projects, this one was not without delays. Adjustments to the system are still being made to optimize the system's performance. Performance data collected thus far starting in March indicate that the system is performing near predicted levels for this season. The pyramidal optics concentrator is designed to produce maximum heat collection in the winter months when the requirement is greatest. Analysis of winter operation next season will indicate more fully the performance of the system.

e. System de-bugging

A few problems were encountered during the initial startup of the system. Several pumps had to be relocated due to a negative head problem. Other pumps had to be exchanged from circulating types to self priming types to avoid startup problems when the system is drained down.

Air lockups developed randomly within the collectors.
This required careful venting and some collector modifications.
The air lock and venting problem is not completely solved yet.
The currently used collectors with horizontal water passages
will be replaced with collectors with vertical water passages.

APPLICATION OF PYRAMIDAL OPTICS
SYSTEMS IN OTHER GEOGRAPHICAL
LOCATIONS

Experience accumulated in the construction of the full scale Rehoboth, Delaware Pyramidal Optics installation has been applied in the modification of a solar heated 4-unit town house condominium in Columbia, South Carolina. Fig 22 is an illustration of the building which consists of two two-story end units of 2500 sq. ft. living area each and two three-story units of 1600 sq.ft. each in the middle. Prior to introducing solar heating, a general energy conservation and upgrading effort has been made to reduce heat losses and gains by 45%.

Two pyramidal optics assemblies similar to those used in the Delaware house previously described are installed in the two-story end units. It has been possible to incorporate these units with minimum effect on the architectural style of the units, which was one of the principle ground rules laid down by the developers of this 400-unit condominium located on Lake Murray outside Columbia, South Carolina. As shown schematically in figure 23, hot water from the two collector assemblies is supplied to a single 2500-gallon concrete storage tank. Four water-to-air heat pumps and four domestic hot water booster tanks in each townhouse are supplied from this single thermal storage tank. The distribution in each townhouse is similar to that used in the Delaware house, i.e., direct solar heating is used when the tank temperature is above 90⁰ F and the heat pump is employed at temperatures below 90⁰F and as low as 50⁰F.

SOLAR HEAT-PUMP SYSTEM - FOUR TOWN HOUSE CONDOMINIUM

FIG. 22

SYSTEM DESIGN
WORMSER SCIENTIFIC CORP.

YACHT COVE
COLUMBIA, S.C.

Through use of only two collector assemblies and a single central storage, the system is cost effective and is estimated to pay for itself in seven to ten years at present fuel costs. The South Carolina installation offers an opportunity to better understand and predict the performance of the pyramidal optics concentrating system in that operation at the South Carolina latitude and climate will provide valuable new data for analysis. It is hoped that funds for data aquisition and analysis will be included under the proposed extension of the original contract.

INTERIM CONCLUSIONS AND RECOMMENDATIONS

A more comprehensive set of conclusions and recommendations will be included in the final report on the contract. The following interim conclusions and recommendations are made at this time.

1. It has been shown in several practical examples such as the Delaware ranch house and the four townhouse condominium at Yacht Cove, South Carolina that the Pyramidal Optics System lends itself to easy architectural integration and has minimum affect on the appearance of the dwelling.

2. Full evaluation of performance requires continuation of testing of the Delaware installation and instrumentation and testing of the South Carolina townhouse unit.

3. Evaluation of the cost effectiveness of the system requires further analysis of the costs incurred in these first installations and estimation of future costs.