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DEVELOPMENT OF A HIGH TEMPERATURE SOLAR POWERED WATER
CHILLER. VOLUME 4

Phase I Technical Progress Report, September 26, 1977—June 1, 1978

By
Richard A. English

June 1978

Work Performed Under Contract No. EG-77-C-03-1590

Energy Systems Division
Carrier Corporation
Syracuse, New York

MASTER

U.S. Department of Energy

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DEVELOPMENT OF A HIGH TEMPERATURE
SOLAR POWERED WATER CHILLER

VOLUME IV

PHASE I TECHNICAL PROGRESS REPORT
FOR THE PERIOD
SEPTEMBER 26, 1977 - JUNE 1, 1978

RICHARD A. ENGLISH

JUNE 1978

Work performed under Contract EG-77-C-03-1590

ENERGY SYSTEMS DIVISION
CARRIER CORPORATION
CARRIER TOWER
P.O. BOX 4800
SYRACUSE, NEW YORK 13221

MASTER

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1.5 PREDICTED SOLAR SYSTEM PERFORMANCE

The objective of this task was to evaluate the performance of the high temperature solar powered water chiller in a solar system. Three climatic regions were selected for the evaluation which represent significant variations in heating to cooling ratio. Typical multi-family and commercial building constructions were selected for each location, and building load files created using the TRNSYS (Ref. T-5) program. Solar system components were selected on a preliminary basis and simulation models were prepared for each, including the chiller. Component cost and total system cost data were developed for economic trade-off studies.

It is our intention, under this contract, to evaluate various system configurations to determine which best interfaces with the solar driven Rankine unit, both from a performance and economic standpoint. During Phase I, preliminary parametric studies were begun to identify the best type of system and best component sizing for a commercial building in two cities. Some preliminary annual performance data have been obtained and related to conventional equipment performance. The final system configurations will be chosen under Phase II, and seasonal energy usage with and without the solar driven Rankine unit will then be completed for all six city/building selections.

1.5.1 TYPICAL BUILDING LOADS

1.5.1.1 Building Site Selections

Many locations were evaluated as potential sites for use in a computer simulation before settling on three that had both a broad variance of conditions and were representative of climates found in major marketing segments of the United States.

Selected sites were: Phoenix, Arizona; Columbia, Missouri; and New York, New York. These selections presented a wide range of heating to cooling ratios, climatic conditions, and solar availability. New York is typical of conditions experienced in the major northeastern marketing area from Boston to Philadelphia. Columbia is representative of midwestern conditions as might be seen in Kansas City, St. Louis, or Chicago. Phoenix was picked because of its similarity to conditions found in western and southwest marketing areas. Phoenix also presents some weather extremes with regard to high temperatures that allow the Rankine unit and solar system to be examined under operating conditions that would be similar to ARI maximum load test conditions.

1.5.1.2 Building Type Selection

Two building types have been chosen for use in the computer simulation: a low-rise, multi-family residential structure; and a two-story, light-commercial office building. Details of these buildings are attached as Appendix A1.5-1 and A1.5-2. They are based on surveys of common building types found in General Electric and Westinghouse Phase "O" reports (Ref. G-4 and W-6). The buildings have been modified to meet or exceed the minimum recommended energy conservation standards set forth in ASHRAE Standard 90-75R, Energy Conservation in New Building Designs (Ref. A-13).

Since the load varies with the location, and since the cooling unit under study is fixed in size at a nominal 316,500 kJ/hr, the sizes of the buildings will be altered in the different locations from that shown in the Appendix so as to provide the cooling unit a load that approximately matches its capacity.

1.5.2 SOLAR SYSTEM DESIGN FOR SIMULATION

1.5.2.1 Solar Collector Model

Since the system is intended to operate over a range of temperatures entering the Rankine boiler from 121.1°C to 151.6°C, a high performance collector is required. There are several collectors commercially available that could possibly supply the necessary water quantity over the temperature range required (reference Section 1.1.1.6). No attempt, however, has been made to make an actual collector selection based on the best collector available today, as it is felt a completely different generation of collectors will be available when the solar power Rankine chiller is made commercially available. Instead a model has been created which is typical of today's evacuated flat plate collectors.

In establishing collector performance upon which to base the computer study, the following parameters were used:

Collector Slope = Latitude - 10°

Collector Azimuth = 0°

$$\text{Efficiency} = 0.64 - 18.033 \left(\frac{T_i - T_a}{I} \right)$$

where: T_i = temperature fluid entering collector (°C)

T_a = ambient temperature (°C)

I = total insolation $\left(\frac{\text{kJ}}{\text{hr-m}^2} \right)$

We expected costs for this type of collector to approach \$53.80/m² (\$5.00/ft²) within the next five years based on discussions with manufacturers of this type of collector.

Collector areas are to be varied for a given type system, building type and location to allow sufficient data to be determined so optimum collector size for a given system type and location can be established.

Initial computer simulations have been only run with the commercial system. The following areas were used:

TABLE 1.5-1

COLLECTOR SIZING

Type Building	Type System	Location	Collector Area (m ²)
Commercial	Hot Water	New York City	245 282.73 311.69*
		Phoenix	303.42 348.90 384.79*
	Cold Water	New York City	183.43 219.28 233.08*
		Phoenix	227.56 262.04 288.24*
	Storage	New York City	245 282.73 311.69*
		Phoenix	303.42 348.90 384.79*

* Initial Parametric Values

Greater collector area is forecast as being required for the hot water system than the cold water system because of the inefficiency of heat exchanger (HX4) used in the hot water system. This heat exchanger is used in the hot storage system to limit the amount of glycol that has to be added to the system to prevent freezing.

1.5.2.2 Thermal Storage

Two systems are under consideration in this study: (1) one which stores solar heated hot water to be used at some later time to meet the load when solar heated hot water is not directly available; (2) one which stores chilled water produced by the solar driven chiller to be used at some later time to meet the load when cold water from the solar driven chiller is not directly available.

In both instances, the greatest benefits of storage will come in off-peak months when the amount of collector area comes closer to supplying the energy to meet 100% of the load.

Depending on the load characteristics of the application, the chilled water tank will be switched over to store hot water for heating when the sun is not available. For instance, while a commercial application in New York City has a year-round cooling load, there is also a heating load in the months of October through April. In the months of November through March, the heating load exceeds the cooling load. In April, the water in the hot tank should be dumped and the tank refilled with cool water, or measures should be taken to prevent water from the storage tank to be circulated to the chiller until it has cooled down substantially to prevent overloading the chiller. This changeover does not have to be made when going from cooling to heating in November, because the cold water removed would be replaced with city water that was as cold or colder.

In Phoenix, the heating load is small in relation to the cooling load each month, so the cold storage tank remains a chilled water storage tank all year and is not switched to hot storage in the winter.

Cold Storage System

The cooling storage tank has to be sized in relationship to the Rankine chiller's surplus chilled water (over the load) capacity during an off-peak month, and the temperature band over which storage water is to be cooled. The minimum temperature entering the chiller is limited to 7.22°C to prevent freezing. The maximum water temperature at which sufficient cooling can be accomplished with the stored water is 11.11°C . The temperature band then that should be used in calculating the water storage capacity is $11.11^{\circ}\text{C} - 7.27^{\circ}\text{C}$ or 3.89°C . With the surplus capacity available in May, the best apparent chilled water storage capacity is 60.55mm^3 in New York City and 75.7 m^3 in Phoenix. Costs for these tanks are based on Figure 1.5-1.

Fiberglass tanks are ideally suited for storing chilled water because they do not rust or require the addition of inhibitors to prevent rusting. If used to store both hot and cold water, care must be taken to limit the temperature of the hot water storage as the maximum temperature allowed in fiberglass tanks is normally around 65.5°C .

Hot Water Storage System

A 15.14 m^3 tank has been selected for the hot water storage system. A much smaller tank can be used because the range of temperature over which the water is stored is much greater than the 3.89°C of the chilled water system. The storage differential varies from a maximum of 151.67°C to 121.11°C where the water is no longer hot enough to drive the Rankine, 30.56°C .

When selecting hot water tanks that will be exposed to water temperatures up to 160°C , the temperature at which the system starts dumping surplus heat, the pressure developed at those temperatures has to be a consideration in the selection and/or design of the tank. Tanks suitable for these higher pressures also cost approximately 50% more than a comparable sized tank designed to store chilled water, as shown on Figure 1.5-1.

FIGURE 1.5-1

STORAGE TANK COST ESTIMATES

Collector Loop Tank

A third storage tank has been incorporated into the system which may or may not be used. This is a 500 gallon tank in the collector loop. Its purpose is to add thermal mass to the collector loop to make the loop less sensitive to the variances in solar insolation that take place with scattered clouds passing the sun. A 1.93 m³ tank has been selected.

Tanks have been insulated to the insulation schedule shown in Table 1.5-2.

TABLE 1.5-2

TANK INSULATION

Tank	Insulation "R" Value
	$\left(\frac{\text{hr} \cdot \text{m}^2 \cdot \text{C}}{\text{kJ}} \right)$
# 1 Collector Tank	1.153
# 2 Hot Water Storage Tank	1.153
# 3 Chilled Water Storage Tank	0.425

The hot and cold storage systems are so different that separate economic studies will be made for each system and their differing modes of Rankine unit operation.

1.5.2.3 Energy Transport

Two separate systems have been designed. One system involves hot water storage (Figure 1.5-2) and the other, cold water storage (Figure 1.5-3).

Table 1.5-3 is included to show the pump schedule. Piping length and sizes used in determining pump head are shown in Table 1.5-5.

TABLE 1.5-3

PUMP SCHEDULE

Pump Identi- fication	Hot Water Storage System			Cold Storage System		
	Flow Rate kg/hr	Head (kPa)	Power Input (kW)	Flow Rate kg/hr	Head (kPa)	Power Input (kW)
P ₁	26,352	150	1.85	0	0	0
P ₂	13,627	75	0.52	13,627	75	0.52
P ₃	15,774	60	0.58	15,774	60	0.58
P ₄	15,774	60	0.58	—	—	—

Piping is Schedule 40 steel. Pipes are insulated as indicated below:

TABLE 1.5-4

PIPING THERMAL RESISTANCE (kJ/hr · m² · °C)

Collector Loop	0.0025
Boiler Loop	0.0025
Chiller Loop	0.0016

To reduce the amount of glycol that has to be added to the collector loop of a hot storage system, a heat exchanger is normally added between the collectors and the storage tank. This is shown as Heat Exchanger HX4 in Figure 1.5-2. With the addition of the heat exchanger, only the collector loop and not the storage tank has to have glycol added to it to prevent freezing. In the case of a system with a 15.1 m³ hot storage tank as we have initially set up, the quantity of glycol that would have to be added is reduced by 7.55 m³ if a 50% solution were being used to protect the system, and the heat exchanger in place.

FIGURE 1.5-2
HOT STORAGE SYSTEM

FIGURE 1.5 - 3
COLD STORAGE SYSTEM

The addition of the Heat Exchanger, HX4, does impact the system performance by the efficiency of the heat exchanger. The efficiency of the heat exchanger in this system has been improved from 60% with one unit to 75% by adding four identical heat exchangers in a series counterflow configuration. The area of collector required in turn reduces as an inverse function of the improvement in the heat exchanger efficiency.

Upon closer investigation, it may be determined that the best approach to the problem is to eliminate the heat exchanger and pay the penalty for the additional ethylene glycol required by the tank. This would be equivalent to improving the heat exchanger efficiency from 75% to 100%. There is no heat transfer penalty associated with running hot glycol through the boiler, as the heat transfer capacity is presently based on a glycol solution.

In discussing glycol stability with Union Carbide, a glycol manufacturer, they have indicated that inhibitor should be added to the system initially to absorb any of the products formed by the degradation of glycol at 160°C, that might otherwise be harmful to the system. A maintenance program should be scheduled where the glycol is checked on an annual basis and inhibitor added as required. Under these conditions, the glycol should last the life of the equipment. There is no question that inhibitor will have to be added periodically, but its cost will be only a few dollars per kilogram for the material. Whether the heat exchanger is used or not and whether the system is a hot water storage system or a cold water system, the glycol will have to be monitored on an annual basis.

While ethylene glycol (53¢/kg) is suitable, triethylene glycol at 77¢/kg or di-ethylene glycol at 47¢/kg may be a better fluid. This will be investigated in Phase II.

The cold storage computer simulation eliminates the collector-to-boiler loop heat exchanger (HX4) from the simulation by setting the heat exchanger effectiveness to 100%.

A Carrier 25 ton water to air fan coil unit, Model 40RS028, has been simulated for both the space heating and cooling load.

The shell and tube heat exchanger (HX3) used in the cold storage system to transfer heat to the chiller loop for winter heating has an 8.0% effectiveness.

One additional heat exchanger is used in both systems, heat exchanger HX5. Its purpose is to dump surplus heat from the system when present.

1.5.2.4 System Design

The conceptual system base point with respect to components has been shown in Figures 1.5-2 and 1.5-3 for the hot water storage and cold water storage systems respectively.

Hot Water Storage System

By looking at a sketch of the hot water system, Figure 1.5-2, the flow pattern is obvious. Heat from the collectors is transferred directly to the hot storage tank. Hot water required to run the Rankine chiller, or heat the space (depending on the positioning of valve V3) comes from hot storage. This approach has been used instead of that shown in Figure 1.5-4 because it allows simultaneous storage and use of collected heat. It also substantially reduces the amount of heat that previously was being dumped, without increasing the complexity of the controls. Due to the broad temperature range at which the Rankine unit performs, it is not felt there is a performance penalty as a result of not sending the hottest available water directly from the collectors to the Rankine boiler.

When chilled water is required for cooling the space, it is made by either taking hot water from storage (not dependent on whether the sun is shining, but on the storage temperature) and using it to drive the Rankine driven turbine or, in its absence, using the electric motor.

When the hot water in storage is not hot enough to satisfy the heating load in the winter, an electric resistance heater comes on in response to the second stage of the heating thermostat closing.

Cold Water Storage System

Again, the flow is apparent on viewing Figure 1.5-3. Heat goes directly from the solar collectors to the Rankine unit boiler or heat exchanger HX3, depending on the positioning of Valve V3.

Any time hot enough solar heated water is available to drive the Rankine turbine it does. The chilled water produced either goes to the fan coil unit heat exchanger, HX2, or it goes to the chilled water storage tank to be used later when chilled water is not directly available from the chiller. If solar produced chilled water is not available directly from the chiller or from storage, the motor automatically drives the compressor to produce chilled water to meet the load.

In the winter, solar heated hot water can be used to meet the first stage heating requirements directly, or, if desired the cold water storage tank can be changed to a hot water storage tank. If sufficient hot water is not available to meet the load an auxiliary electric heater comes on when the second stage thermostat closes.

It is our intention under this contract to evaluate each system to determine which type system best interfaces with the solar driven Rankine unit, both from a performance and economics standpoint.

FIGURE 1.5-4
HOT STORAGE SYSTEM

This is to be done by varying certain parameters of the system in a computer simulation and then evaluating the results. Items under consideration that affect both the initial cost and the performance of the system are:

1. Collector type
2. Collector area
3. Heat exchangers
4. Flow rates
5. Storage area
6. Insulation

Table 1.5-5 shows estimated installed equipment costs that have been gathered for use in equating each of the two systems. Costs shown do not include costs that are directly related to the collector subsystem or the Rankine unit subsystem. These are shown in Tables 1.5-6 and 1.4-10 respectively.

TABLE 1.5-5

ESTIMATED INSTALLED SYSTEM COSTS

	Hot Water Storage	Cold Water Storage	
1.89 m ³ Tank (T1)	\$1800	\$1800	
Tank Insulation	940	940	
Collector Pump (P1)	1278	—	
Dump Heat Exchanger (HX5)	500	500	
Collector to Boiler Loop			
Heat Exchanger (HX4)	5428	—	
2-Way Valve (V11)	300	300	
Glycol ₃	900	900	
15.1 m ³ Hot Storage Tank (T2)	4700	—	
Tank Insulation	3570	—	
Storage Pump (P4)	1242	—	
Boiler Pump (P3)	1242	1242	
27.8 m Boiler Loop Piping 2"			
Schedule 40 Steel	4392	4392	
Pipe Insulation	1439	1439	
Diverting Valve (V3)	300	300	
Fan Coil Unit (HX2)	4000	4000	
Space Heating Coil (HX1)	1500	1500	
9.3 m Chiller Loop Piping 2"			
Schedule 40 Steel	1465	1465	
Pipe Insulation	300	300	
Circulating Pump (P2)	275	275	
Chilled Water Storage Tank (T3)		<u>Phoenix</u>	<u>New York City</u>
Phoenix (75.7 m ³)		14,000	—
New York (60.06 m ³)		—	11,200
Tank Insulation		5,953	5,091
Diverting Valve (V5)			300
Diverting Valve (V6)			300
Diverting Valve (V7)			300
Diverting Valve (V8)			300
Subtotal Without Collector Subsystem	\$35,571	<u>Phoenix</u> \$40,506	<u>New York City</u> \$36,844

TABLE 1.5-6

ESTIMATED INSTALLED COLLECTOR SUBSYSTEM COSTS

Collector	\$128.00/m ²
Collector Mounting	\$134.50/m ²
3/4" Schedule 40 Steel Piping (Supply and Return Header)	\$ 35.40/m ²
1-1/2" Insulation	\$ 19.15/m ²
Total Subsystem	\$317.05/m ² Installed Collector

The collector price shown above is based on \$53.80/m² OEM cost.

1.5.2.5 Control Strategy

Control strategies used are shown in logic diagrams, Figures 1.5-5 and 1.5-6. The same basic control strategy has been duplicated as closely as possible for each of the two systems so as to be in a better position to make a comparative evaluation of the two systems.

To follow the control logic diagram, one enters at the block labeled "start," and then follows the path from diamond to diamond asking the appropriate type question: Is the differential thermostat " ΔT " sensor $S1 > S2$; is the cooling thermostat " T_C " open or closed; or is the safety control open or closed. A "0" is to be interpreted as a "no" or "open contact," a "1" is "yes" or "closed contact." This will eventually lead to an end point which is called an "operating mode" and is numbered.

Example: Enter the hot storage control logic diagram, Figure 1.5-5, at the starting point, proceed to diamond " T_C " and ask "does the space call for cooling?". If yes, proceed down the leg labeled "1" to the ΔT diamond. Here ask the question, "is differential thermostat sensor $S1$ greater than $S2$?". If yes, sun is indicated and one proceeds down the leg labeled "1" to the "rankine Storage Temp" diamond. The question is asked, "is the storage temperature hot enough to drive the Rankine unit?". If "no," one would follow the "0" leg to the "max collector temp" diamond and ask the question, "is the collector at maximum temperature conditions?". If "no," one follows the "0" leg which terminates at Mode 9. Solar energy is being put into storage and the chiller is being driven from the motor to supply cooling to the space. If maximum collector temperature had been indicated, one would have followed the "1" leg which terminated at Mode 10. Mode 10 is identical to Mode 9 except the surplus heat that is indicated as being present is being dumped, which would occur only if something were to malfunction.

Depending on the conditions existing, the Hot Water Storage System can operate in any one of 35 different modes.

If a Cold Water Storage System were being analyzed, the same procedure would be followed. There are only 31 modes in this system however.

Hot Water Storage System

The hot water storage system collects and stores hot water when sensor $S1$ at the collector is hotter than sensor $S2$ in the hot water storage tank by 2.77°C . During cooling season when the space thermostat calls for cooling, hot water is pumped from storage to the Rankine unit boiler as long as it is hot enough to cause the Rankine turbine to be driven; chilled water produced is sent to the fan coil unit to cool the space. When the water is not hot enough to drive the turbine, an electric motor is energized and drives the chiller compressor directly.

In the winter hot water from storage is pumped to the fan coil unit when the space thermostat calls for heat.

FIGURE 1.5-6
COLD STORAGE SYSTEM - CONTROL LOGIC

Whenever the temperature of the fluid leaving the collector reaches 160°C, maximum conditions (at the collectors) have been reached and surplus heat is dumped from the system.

Chilled Water Storage System

This system runs the chiller utilizing the Rankine turbine any time hot enough solar heated fluid is available. Chilled water produced by the solar driven system is either used to meet the load when the space thermostat requires cooling, or stored in an insulated storage tank. When solar heated hot water is not available to drive the chiller, stored chilled water is circulated to the fan coil unit to handle the load.

When neither the solar heated fluid is hot enough to drive the turbine nor the stored chilled water is cool enough to handle the load, the chiller compressor is motor driven, but only when the space thermostat calls for cooling.

In cooling mode the solar pump starts circulating fluid through the collectors when sensor S1 in the collector exceeds sensor S2 in the supply header by 2.77°C. In the winter the sensor S1 compares the collector temperature to the temperature in the storage tank, sensor S3, to control solar pump operation. This is initiated when an 11.11°C differential exists.

During the heating season, the chilled water tank may be switched over to hot storage if the monthly demand for heating exceeds the demand for cooling. In response to the first stage heating thermostat, heat from the collectors is sent to the fan unit heating coil. Otherwise, solar heat is stored in the storage tank. In this case, if cooling is required, it can only be provided directly without storage from the solar system or by the auxiliary motor. During that part of the year when the storage tank is chilled, heating can only be provided directly from the solar system or by auxiliary heat.

When the chilled water tank is used to store solar heated water, hot water is taken from storage to meet the load when solar heated hot water is not directly available from the collectors. When neither hot water from the collectors nor storage can meet the heating load, a second stage space heating thermostat closes and electric auxiliary heat is energized to handle the load.

Whenever the temperature of the fluid leaving the collectors reaches 160°C, maximum conditions at the collectors have been reached and surplus heat is dumped from the system.

Control settings for the various thermostats shown in mode ladder diagrams, Figures 1.5-5 and 1.5-6, are listed below in Table 1.5-7.

The location of the control in the system is shown in Figures 1.5-7 and 1.5-8.

FIGURE I.5-7
CONTROL LOCATIONS FOR
HOT STORAGE SYSTEM

FIGURE 1.5-8
CONTROL LOCATIONS FOR
COLD STORAGE SYSTEM

TABLE 1.5-7
CONTROL SET POINTS

Open	Close	Control	Setting (°C)	
			Open	Close
0	1	Max Collector T'stat	148.88	154.44
0	1	Rankine Direct T'stat	121.11	126.66
0	1	Rankine Store T'stat	121.11	126.66
0	1	Chilled Water Store T'stat	11.11	10.55
0	1	Max C/W Storage T'stat	62.77	65.55
0	1	T _C Cooling T'stat	24.72	25.55
0	1	TH ₁ 1st Stage Htg T'stat	23.05	22.22
0	1	TH ₂ 2nd Stage Htg T'stat	22.22	21.38
0	1	$\Delta T \ S1 > S2$	1.11	2.77
0	1	$\Delta T \ S1 > S3$	2.77	11.11
0	1	T50°C Hot Water Htg T'stat	50.0	55.0
0	1	Rankine Safeties	--	--

Once the mode of operation for a specific set of conditions is established, the proper modal analysis table (Table 1.5-8 or 1.5-9) can be entered. There is a separate table for both the Hot Water Storage System and the Cold Water Storage System. This will give exact information for any operating mode regarding the position of controls, valves, and the status of motors.

A "0" or "1" in the table indicates if a control is open or closed, if a 3-way valve is in the A-B or A-C position, or if a motor is energized or not. In the case of a control a "0" indicates an open contact and a "1" a closed contact. With a motor, the "0" means the motor is off and a "1" means it's on.

Section 1.5.3.3 describes a new TRNSYS unit that has been developed to take advantage of this table.

TABLE 1.5-8

HOT WATER STORAGE SYSTEM
MODAL ANALYSIS TABLE

MODE NO.	CONTROLS											COMPONENTS																			
	T _C	T _{H1}	T _{H2}	RANKINE STORE T' STAT	RANKINE DIRECT T' STAT	C/W STORE T' STAT	MAX COLLECTOR T' STAT	MAX TANK T' STAT	T _{50°C}	RANKINE SAFETY	ΔT	VALVE V ₁	V ₂	V ₃	V ₄	V ₅	V ₆	V ₇	V ₈	V ₉	V ₁₀	VALVE V ₁₁	TURBINE	MOTOR	FAN	AUX. HTG.	PUMP P ₁	P ₂	P ₃	P ₄	
1	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
2	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
3	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
4	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
5	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
6	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
7	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
8	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
9	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
10	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
11	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
12	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
13	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
14	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
15	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
16	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	0	0	1	0	1	1	1	1
17	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0

TABLE 1.5-9

COLD WATER STORAGE SYSTEM
MODAL ANALYSIS TABLE

MODE NO.	CONTROLS												COMPONENTS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
	T _C	T _{H1}	T _{H2}	RANKINE STORE T'-STAT	RANKINE DIRECT T'-STAT	C/W STORE T'-STAT	MAX COLLECTOR T'-STAT	MAX TANK T'-STAT	T _{50°C}	RANKINE SAFETY	ΔT	HOT/COLD			VALVE	V ₁	V ₂	V ₃	V ₄	V ₅	V ₆	V ₇	V ₈	V ₉	V ₁₀	V ₁₁	VALVE	TURBINE	MOTOR	FAN	AUX. HTG.	PUMP	P ₁	P ₂	P ₃	P ₄																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				

1.5.3 SIMULATION

1.5.3.1 Weather Data

The weather for each individual month is represented by an average day for that month. Hourly average monthly weather data were established by averaging the hourly weather data stored on magnetic computer tapes for each month, for a 10-year period.

National Weather Service (National Oceanic and Atmospheric Administration) data for the following period were used to establish the average values:

Columbia	1965-1974
New York	1965-1974
Phoenix	1955-1964

Twelve different days, each representing the average weather data for a particular month, are used to make up an average year.

A Carrier-developed weather data file condenser and data reader that is compatible with the TRNSYS Program was used to provide the weather data for the building load file. As an example, a copy of the load file for July Phoenix is attached as Appendix A-1.5-4. A TRNSYS Type 9 Data Reader reads the weather data from the building load file into the simulation program for a solar assisted Rankine chiller with hot or cold water storage.

1.5.3.2 Building Loads

Building types were covered in Section 1.5.1.2.

Cooling loads are based on the space cooling thermostat closing at 25.5°C and opening at 24.7°C. Heating loads are based on the first stage thermostat closing at 22.0°C and opening at 23.05°C, and the second stage heating thermostat closing at 21.4°C and opening at 22.2°C. These thermostat settings are consistent with recommendations set forth in ASHRAE Standard 90-75R, Energy Conservation in New Building Design (A-13).

The commercial building is designed so there is only one zone. The multi-family apartment will be designed with multiple zones.

Hourly commercial building load profiles for each average month in Phoenix and New York City have been calculated using the TRNSYS (T5) program. The hourly values for Phoenix for an average July day have been plotted to show a visual representation of the load Figure 1.5-9. This represents the maximum load for the year.

The hourly load values have also been summed for each month and plotted in Figure 1.5-10. Positive numbers have been plotted as cooling loads and negative numbers as heating loads. This curve was useful in establishing when the cold water storage tank should be changed over to store hot water for heating. In New York, the heating load exceeds the cooling load on this particular structure in mid-November. A November winter changeover is selected. In the spring the cooling load starts to exceed the heating load in March.

FIGURE 1.5-9
COMMERCIAL BUILDING AVERAGE HOURLY
LOAD PROFILE FOR JULY

FIGURE 1.5-10
COMMERCIAL BUILDING AVERAGE DAILY
LOAD PROFILE BY MONTH

An April 1st changeover has been selected instead of March 1st, because March has a significant heat load and the load distribution will be such that the sun causes a cooling load during the day and the lack of sun a heating load at night. Solar can be used to run the Rankine chiller during the day and the stored hot water can be used to heat the building at night.

The curve shows that in Phoenix the cooling load so completely dominates year-round that the cold water storage tank should never be used to store hot water for heating purposes.

Loads using average weather data for both the multi-family apartment and for the commercial structure in Phoenix, Arizona; Columbia, Missouri; and New York, New York will be run and used as input to the computer system simulations.

Should building loads and weather data be made available by the Department of Energy for both the multi-family and commercial structures before July 1st, 1978, these data will be substituted for the above described load and weather data.

1.5.3.3 Special TRNSYS Models

The TRNSYS simulation program as supplied by the University of Wisconsin had to be modified to handle the complex systems being evaluated in this Task.

Two proprietary modifications enable the user to employ up to 70 units instead of the normal 50 units, and to provide a file of hourly average monthly weather data for a number of locations. This condensed weather file has been described more completely in Section 1.5.3.1.

Two special units were added under this contract to handle the complex system control logic in a simple manner, and the Rankine chiller model. These are briefly described below and an abstract of the master controller appears in Appendix A-1.5-3.

TRNSYS Master Controller

The TRNSYS master controller was designed to provide a simple, but powerful, means of controlling the operating states of a TRNSYS model. The problem is easily illustrated with the following example. Consider a system with seven control signals, such as thermostat outputs; nine two-state devices to be controlled, such as valves (open/closed), pumps, fans, heat supply units (on/off); and 12 operating modes (each mode is a unique configuration of on/off, open/closed settings for the system components). This rather simple system has, nonetheless, 128 possible states, and would normally require nine boolean functions of seven variables.

The master controller avoids the need for complex boolean functions, yet requires a table of only $3n$ elements, where n is the number of operating modes. In the example, with 12 modes, this would be 36 elements. The advantage over the use of a direct look-up method which would require $2^m \cdot 2$ elements where m is the number of input signals, is not so great in the example (256 table elements); but if one had 12 input signals and 30 modes (still a rather small number), the comparison would be 90 to 8192 table elements.

The master controller achieves its simplicity by interpreting each input signal as a digit in a binary number. Then, by means of a masking operation, the input set is mapped onto the smallest binary integer in the class of integers associated with a particular state. (There are n such integers.) This integer is then used to reference the set of output control signals for the given state.

The table entries are easily generated from the decision tree path for each state by noting the control elements involved (i.e., which thermostats) and their settings.

TRNSYS Rankine Chiller

The TRNSYS solar-assisted chiller unit was developed to model the operation of the Rankine cycle chiller under study. A three-dimensional table, interpolated linearly, describes the performance of the unit for varying outside ambient air temperature, varying entering boiler water temperature and varying entering

chiller water temperature. Each table element is a vector of six data; boiler energy input, chiller energy output; motor, fan and pump power draw (kW) and a threshold indicator to allow for abrupt shifts between turbine-only operation and motor-only operation.

A parallel copy of the unit was used as an indicator of the mode, motor or turbine, in which the unit operated, or would operate, under the current ambient air, entering boiler water, and entering chiller water temperature.

This unit has also been used to model other electric and heat driven air conditioners for comparative evaluations under this task.

1.5.3.4 Solar System Simulation Model

A single solar system simulation model comprised of the elements for both a hot water storage system and cold water storage system has been structured for use with the University of Wisconsin TRNSYS (Ref. T-5) computer program. The elements required for this dual approach are shown in Figure 1.5-11.

The system shown appears more complex than either system is in reality, because valves required for TRNSYS modeling are not actually required in either the hot or cold water storage system.

To make the composite system shown in Figure 1.5-11 into the cold storage system shown in Figure 1.5-3, V1, V2, V4, V9, and V10 are permanently positioned in the "0" position. This bypasses both the hot storage tank, pump P4, and heat exchanger HX1. Since valves V1, V2, V9, V10 are permanently positioned, each can be replaced by a straight pipe. Heat exchanger HX5 is eliminated from the system by setting its efficiency equal to 100%. Pump P1 and Pump P3 are treated as a single pump equal to Pump P3.

To make the composite system shown in Figure 1.5-11 into a hot water storage system, Figure 1.5-2, the following permanent valve positioning is required: Valves V1, V2, V4, V9, V10, V12 put to their "1" position and Valves V5, V6, V7 and V8 to their "0" position. This eliminates them from the system and bypasses the cold water storage tank and heat exchanger HX3. The hot water system has only two control valves, Valve V3 and Valve 11.

Sixty data points are calculated and recorded hourly, including temperatures, insolation rates, power and heat quantities. These points are identified on the composite system shown on Figure 1.5-12 as alpha-numerics. Thirty-three values are summed daily, monthly, and yearly. These points are identified for the cold water storage system on Figure 1.5-13 and for the hot water storage system on Figure 1.5-14.

One of the very interesting aspects of the computer model provided by the Master Controller unit, is a separate printout of the operating modes encountered during each time step. This is helpful in determining if the model has been set up properly. Also, a mode map can be drawn to make a visual representation of how the system operates through a given time period. Changes in the modes become apparent when parameters or set points are changed.

The solar simulation model uses an input file of previously prepared hourly building load data, and solar insolation data to compute the system operation on an hourly basis. For instance, in the cooling mode, with parameters set to define the system components, the TRNSYS Program reads the input file and calculates the temperature of the solar heated fluid available to the Rankine unit. The Rankine unit will then read the chiller capacity, motor watts or Rankine cycle input, etc., from the performance tables. The cooling effect on the building will then result in a room temperature change which may or may not satisfy the thermostat set point. One factor in this regard which should be noted is that the use of an input load file reflects the effect of a fixed room temperature on the load and not a variable temperature as in a real situation.

FIGURE 1.5-11
COMBINED HOT AND COLD STORAGE SYSTEMS FOR COMPUTER MODELING

FIGURE 1.5-12
COMBINED HOT AND COLD STORAGE SYSTEMS FOR COMPUTER MODELING
POINTS CALCULATED HOURLY

UNITS

H = SPECIFIC HUMIDITY, KG MOISTURE/KG AIR
I = INSOLATION, KJ/HR·M²
Q = HEAT QUANTITIES KJ/HR
T = TEMPERATURE °C
W = KILOWATTS

FIGURE 1.5-13
COLD STORAGE SYSTEM
DAILY, MONTHLY & SEASONAL SUMMARY ITEMS

FIGURE 1.5-14
HOT STORAGE SYSTEM
DAILY, MONTHLY, & SEASONAL SUMMARY ITEMS

1.5.3.5 Preliminary Simulation Results

Actual system simulations began in Phase I with the parametric system study. Due to the complexity of the solar system model, a great deal of effort was expended in debugging and accuracy checking. Only a few preliminary results have been obtained for the parametric study. These are important, however, in establishing the order of magnitude of expected results, indicating trends, and as examples of some of the methodology which will be used to complete the parametric study.

The parametric system study was begun using the initial parameters, such as size, capacity, heat quantities, power consumption and flow rates shown in Table 1.5-10. The Rankine cycle data used are given in Table 1.4-14 and represent the intermediate level of R-113 Rankine cycle performance obtained with the unoptimized design and the vaneless diffuser compressor.

Annual runs were made for both the hot and cold storage systems in the Phoenix and New York City commercial buildings. Collector areas were varied downward in two steps from the initial values as shown in Table 1.5-1. Important annual summary results for these runs are shown in Table 1.5-11.

A base line run for each location has been made by simulating the performance of a standard commercially available air cooled water chiller (Carrier Model 30GA030, data given in Table 1.1-10) in place of the solar powered Rankine unit in both locations. The annual power usage of the conventional unit from these simulations is shown on Table 1.5-11 as "Total Base Unit Watts." It is used to determine the annual power savings by subtracting from it the "Total Solar Watts Input" for each system and location.

Hourly, 60 data points are calculated and recorded. These are temperatures, insolation rates, power inputs, and heat quantities. They are those items that vary with respect to weather, the time of year, the time of day and the available insolation. The points at which these calculations are made are shown in Figure 1.5-12 of the composite system with each print identified by an alpha-numeric designation.

The type of data that can be derived from the hourly summary is shown in Figure 1.5-15. Here the average daily building load for the month of July in Phoenix is shown. It is item 59 from the summary and is identical to the curves previously presented as Figure 1.5-9. Its load profile is identical to that shown in Appendix A-1.5-4. 288.24 m² of collector are used. Superimposed on this curve is the chiller output (Item 51), the Rankine boiler heat input (Item 22) and the solar energy collected (Item 2). When the chiller is shown in operation but has no corresponding boiler heat input, it is being driven by the motor to meet the building load. When the chiller is being run by the turbine, any surplus capacity, as indicated by the cross-hatched area, is put into cold water storage for later use.

TABLE 1.5-10

COMPONENT PARAMETERS

Pumps and Fans

P ₁	26352 kg/hr	1.85 kW
P ₂	13627 kg/hr	0.52 kW
P ₃	15774 kg/hr	0.58 kW
P ₄	15774 kg/hr	0.58 kW
Fan	20412 kg/hr	3.28 kW

Heat Exchangers

HX1	19314.89 kJ/hr °C	
HX2	11715.71 kJ/hr °C	
HX3	8% Effectiveness	
HX4	75% Effectiveness	100% C/W System
HX5	8% Effectiveness	

Tanks

	<u>Size</u>	<u>Loss</u>
Tank 1	1.892 m ³	7.4 kJ/hr °C
Tank 2	5.10 m ³	45.73 kJ/hr °C
Tank 3	60.56 m ³ N.Y.C.	197.96 kJ/hr °C
Tank 3	75.7 m ³ Phoenix	231.44 kJ/hr °C

Pipes

Pipe Loss	
Collector Loop	75.65 kJ/hr °C
Boiler Loop	57.70 kJ/hr °C
Chiller Loop	28.8 kJ/hr °C

Collectors

Collector Efficiency Parameter Has Previously Been Covered in Section 1.5.2.1 Along with Collector Areas.

FIGURE 1.5-15
COLD WATER STORAGE SYSTEM

Thirty-three values are summed daily, monthly and yearly. These are shown in Figure 1.5-13 and 1.5-14. Monthly load data and solar driven cooling performance have been extracted from these calculations for a commercial structure in Phoenix with 227.6 m² collector and a cold water storage system. The values have been plotted in Figure 1.5-16 and show the ratio of solar performance to load on a monthly basis.

Some of the annual summary items have been tabulated in Table 1.5-11. Even though the work is preliminary, some observations can be made that are of interest.

The % annual cooling load handled by the solar-driven, Rankine machine varies from 69% to 86%. The percent of the load handled increases as the collector area increases.

While the COP of the solar driven, Rankine unit varies from 0.91 in New York City to 0.78 in Phoenix, it does not appear to vary too significantly with the type system used, hot water storage vs. cold water storage. The reduced COP in the hotter Phoenix area is due to the increased energy input required at the high outdoor Phoenix temperatures.

The COP of the unit when motor driven varies from 5.4 in New York City to 4.0 in Phoenix. As collector is added the COP increases slightly. The reason for the decrease in COP from New York City to Phoenix is again due to the operation at higher head pressures and required greater power input when operating at the elevated outdoor temperatures. When more collector is added, less motor operation is required during the hot daylight hours and the COP increases. The fact that most of the motor operation occurs in the non-daylight hours accounts for the unusually high COP's shown. Annual unit COP's for the system are shown to be close to 1.0.

The total annual system kWh are shown, as are the pump kWh. The ratio of pump watts to total watts for the hot water system is significantly higher (22-34%) than the same ratio for a cold water storage system (8-17%). This is due to the use of more and larger pumps in the hot water system. Since pump power is such a large factor in the operation of the Hot Water System, pump selection and component pressure drop will be re-evaluated.

The amount of heat dumped by the dump heat exchangers as a result of 160°C temperature being reached at the collectors varies from 5.7% of the total collected to 25.6%. The percent dumped by the Cold Water System is an appreciably greater % than the hot water storage system. This is because provisions have been made to store hot water in the Hot Water Storage System so logically less dumping should occur. When 18 to 25.6% of the heat collected is dumped in a system where only 69 to 73% of the total load is handled by solar, there are indications that the possibility exists to improve the ability to utilize this waste heat or certainly minimize the amount by changing some of the parameters of the system.

FIGURE 1.5 -16

TABLE 1.5-11

PRELIMINARY SIMULATION RESULTS

Units	New York						Phoenix					
	Hot Storage			Cold Storage			Hot Storage			Cold Storage		
	Collector Area m ²											
	245	282.73	311.69	183	219.28	233.08	303.42	348.9	384.29	227.56	262.04	288.24
Total Cooling Load (kJ x 10 ⁶)	550	555	550	554	547	547	1119	1119	1119	1123	1125	1121
Total Supplied by Solar Rankine Cooling (%)	72.8	78.6	83.1	74.8	78.8	80.3	78.3	82.5	85.9	69.0	72.8	73.6
Total Supplied by Motor Cooling (%)	27.2	21.4	16.9	25.2	21.2	19.7	21.7	17.5	14.1	31.0	27.2	26.4
COP of Motor Driven System	5.460	5.473	5.490	5.360	5.428	5.431	4.076	4.137	4.151	4.225	4.324	4.275
COP of Solar Rankine Driven System	0.910	0.910	0.913	0.907	0.906	0.906	0.816	0.796	0.788	0.811	0.793	0.789
Annual Total Unit COP	1.106	1.045	1.000	1.167	1.113	1.098	0.998	0.940	0.902	1.106	1.044	1.033
Pump kWh x 10 ²	95.6	94.8	92.1	38.0	37.9	39.2	123.3	122.8	122.8	45.5	46.2	45.7
Total Solar kWh Input (kWh x 10 ²)	280.9	269.4	254.3	240.4	226.8	225.7	561.9	539.1	519.3	549.3	526.3	525.6
Total Base Unit kWh Input (kWh x 10 ²)	754.8	754.8	754.8	754.8	754.8	754.8	1240.5	1240.5	1240.5	1240.5	1240.5	1240.5
Annual kWh Saved (kWh x 10 ²)	473.9	485.4	500.5	514.4	528.0	529.1	678.6	701.4	721.2	691.2	714.2	714.9
Heat Dumped as % Collected	5.7	11.2	13.3	12.3	15.0	18.3	8.6	13.3	17.4	18.1	22.6	25.6
Total Solar System Cost (\$ x 10 ³)	150.5	162.4	171.6	132.0	143.6	148.0	168.4	183.4	194.6	149.9	160.8	169.1

Once a set of calculations has been run using the initially established parameters shown in Table 1.5-1 and 1.5-10, it should be studied, then the decision should be made as to which parameter to vary next and then another set of calculations run.

As changes are made to the system, changes in system costs should also be reflected. System costs have been included in summary Table 1.5-11.

Parameters should be varied for both the Hot Water Storage System and the Cold Water Storage System until an optimized system is determined. By optimized, it is meant that combination of components that results in the lowest owning and operating costs.

For each location a run has been made with Carrier Model 30GA030 (a standard commercially available, air-cooled chiller) performance inserted into the TRNSYS Model in place of the solar driven Rankine unit used throughout the study. The results of the impact that the solar powered system has on reducing annual operating costs can be seen by comparing it directly to the required annual cost of a standard system for the two locations.

The preliminary owning and operating cost curves shown in Figures 1.5-17 for Phoenix and 1.5-18 for New York City are based on "total solar kWh input" and "total solar system cost" given in Table 1.5-11. The comparisons of both hot water storage systems and cold water storage systems are made against varying collector areas. The operating cost curves have been extrapolated from the minimum collector values at which the calculations were made to the operating cost of the conventional chiller (30GA030) for the zero collector area point.

Operating cost is based on the present worth of the fuel used over a 20 year period at an 8% discount rate and a 6% real fuel escalation rate. These are values recommended in Reference D-8, DOE FACILITIES SOLAR DESIGN HANDBOOK. Owning cost is the annualized value of the system first cost. No maintenance costs are included. The owning and operating cost is the summation of the two individual cost curves. All costs have been plotted as equivalent uniform annual costs based on a 20 year capital recovery factor at the 8% discount rate.

These plots show a distinct advantage for the cold water storage system. This preliminary result may change as further refinements are made in calculating pump power, which is substantially larger in the hot water storage system. The minimum value of the owning and operating cost curves, which occurs at around 100 m² on both systems, in both cities, is not as low as the conventional system. The conventional system first cost in this case is only the conventional chiller selling price, Table 1.4-8. These preliminary results will improve through system changes which reduce dumping losses, reduction of pump work in the hot storage system, and through expected improvement in the performance level of the Rankine chiller as indicated in Section 1.4.5.9.

FIGURE 1.5 - 17
SOLAR SYSTEM ANNUAL OWNING & OPERATING COSTS
AS A FUNCTION OF COLLECTOR AREA
COMPARING HOT & COLD STORAGE
IN PHOENIX, ARIZONA

FIGURE 1.5 - 18
SOLAR SYSTEM ANNUAL OWNING & OPERATING COST
AS A FUNCTION OF COLLECTOR AREA
COMPARING HOT & COLD STORAGE
IN NEW YORK CITY

One of the other very interesting aspects of the computer model as set up is that it not only prints out an hourly summary of 60 values but it also indicates when the system shifts to different operating modes. This is helpful in determining if the model has been set up properly. Also, a mode map can be drawn to make a visual representation of how the system operates. Changes in the modes become apparent when parameters are changed, or the same system is operating in different months. Tables 1.5-11 and 1.5-12 show a hot water storage system in New York City in August and October with 311.69 m² of collector. Figure 1.5-5 should be referred to, to determine what type of system operation is actually indicated by the various mode numbers.

TABLE 1.5-11. MODE MAP - AUGUST HOT WATER STORAGE SYSTEM, NEW YORK CITY, 311.69 m² COLLECTOR

HOURS	MODES*															
	MINUTES															
	3.75	7.5	11.25	15.0	18.75	22.5	26.25	30.0	33.75	37.5	41.25	45.0	48.75	52.5	56.25	60.0
0-1	17															
1-2	17															
2-3	17			15												
3-4	15						17									
4-5	17															
5-6	17															
6-7	17			13			17	18	17	18	17	9	15	9		15
7-8	9												18			
8-9	18															
9-10	18						1									
10-11	1															
11-12	1													18		
12-13	18											1				
13-14	1															
14-15	1															
15-16	1															
16-17	1															
17-18	1	18	17	18	17	18	17	18			17				11	
18-19	11															
19-20	11											17				
20-21	17															
21-22	17			11												
22-23	15							17							15	
23-24	17															

* Refer to Figure 1.5-5

TABLE 1.5-12. OCTOBER HOT WATER STORAGE SYSTEM, NEW YORK CITY, 311.69 m² COLLECTOR
MODES*

HOURS	MINUTES															
	3.75	7.5	11.25	15.0	18.75	22.5	26.25	30.0	33.75	37.5	41.25	45.0	48.75	52.5	56.25	60.0
0 - 1	17															
1 - 2	17															
2 - 3	17															
3 - 4	17															
4 - 5	17															
5 - 6	17															
6 - 7	17															
7 - 8	17					18			17	18	17	18	17	18		17
8 - 9	18	17	18													
9 - 10	18													9	1	
10 - 11	1											18				
11 - 12	18															
12 - 13	18				1											
13 - 14	1					18										
14 - 15	18									1						
15 - 16	1												18		17	18
16 - 17	17	18	17	18	17	18			17							
17 - 18	17	11														
18 - 19	11			17												
19 - 20	17															
20 - 21	17					11										
21 - 22	11	17														
22 - 23	17															
23 - 24	17															

* Refer to Figure 1.5-5.

1.6 DESIGN EVALUATION

1.6.1 ENVIRONMENTAL ASSESSMENT

The three aspects of this design which have potential impact on the environment are manufacturing, installation and service, and operation. The conceptual design described in previous sections is similar in all respects to current conventional air conditioners. It is our opinion that the proposed design will not introduce any new, environmentally significant factors, and that by following the technology, codes and standards now regulating the design, manufacture, service and operation of conventional equipment, an environmentally safe product will result.

Design. The proposed unit will be designed in detail under Phase II in accordance with the safety codes and standards applicable to conventional air conditioning equipment. These codes include:

UL 465 (Ref. U-1) and UL 465A (Ref. U-2), which are safety standards covering construction, protection of service personnel, performance, and outdoor use of Unitary Air Conditioning Equipment.

ANSI B9.1 (Ref. A-9) which is a safety code for mechanical refrigeration covering the design, construction and application of refrigerant containing systems.

ASME Boiler Code, Sec. VIII (Ref. A-14) which is a safety code for design and construction of unfired pressure vessels.

Manufacturing. Environmentally significant manufacturing processes, typical of the metal fabrication trade, which will be used to produce the proposed unit are: welding and brazing, degreasing and other metal preparation, painting, leak testing and charging. Carrier complies with all OSHA, EPA or other applicable federal and local regulations for these processes. Where Carrier has determined that the regulations are not adequate, more stringent in-house standards are in force. No new processes are foreseen for the manufacture of the proposed unit.

Pressure vessels will be tested in accordance with ANSI B9.1 (Ref. A-9) and ASME Sec. VIII (Ref. A-14). The refrigerant containing system will be leak tested to a sensitivity of 1/100 ounce/year. Quality performance tests will assure efficient operation.

Installation and Servicing. Installation and servicing will follow procedures presently established for conventional outdoor, air cooled, air conditioners. The completely factory assembled package design will minimize the installation requirements. No new techniques will be required for installation of this design.

The proposed refrigerants are either R-113 or R-114. Both are classified under ANSI B9.1 in safety group 1, for non-flammable, non-toxic refrigerants. Under the U.L. code classification, R-113 is in group 4-5 and R-114 is in group 6 (Ref. A-6).

The chilled water and solar water circuits will be charged with inhibited water or glycol solutions. Installation and Service Instructions will be required to specify proper handling and disposal techniques, as well as identify environmentally safe products for use.

Operation. The noise level of the chiller package will be the sum of the turbo/compressor and air handler noise. The turbo/compressor noise will consist of a relatively high frequency distribution which can readily be attenuated, by acoustic treatment, including absorptive materials and isolation devices. We believe that the resultant sound power level will be equivalent to that of conventional hermetic compressors. The sound power level of the air noise can be controlled to an acceptable level through careful arrangement and selection of the components. The sound power level of the unit will be measured and rated according to ARI Standard 270-75, (Ref. A-10). The resulting rating will be a single number, the Sound Rating Number (SRN). It is anticipated that the SRN of the proposed unit will be in line with conventional air cooled air conditioners of the same heat rejection capacity (i.e., about 50 tons equivalent).

Many communities and municipalities have enacted ordinances to limit sound produced by outdoor air conditioning equipment. These ordinances generally specify the legal limit of sound power level and the point of measurement, such as the property line. The SRN can be used to determine the sound power level at any distance, per the methodology of ARI Standard 275-69 (Ref. A-11). Therefore, the placement of the equipment and employment of any sound attenuation devices can be determined prior to installation in order to obtain an acceptable sound power level at the specified measuring location.

Thermal pollution is not considered to be significantly different than with conventional air cooled air conditioning equipment. Heat will be rejected only to air, at a temperature rise of approximately 15°F. Air discharge will be upwards, away from people, plants, or windows. It should be pointed out that the reject heat is a combination of processed solar heat and building heat gain, with insignificant new energy added.

Fluorocarbon Emissions. The working fluid chosen for this cycle is a fully halogenated hydrocarbon. There is concern regarding possible ozone depletion in the earth's upper atmosphere and its relationship, if any, to emission of the type of fluorocarbon chosen for this cycle. There is considerable scientific uncertainty regarding the ozone-depletion theory.

Furthermore, fluorocarbon emissions from building cooling equipment in the United States represent less than one percent of total worldwide emissions. Nevertheless, Carrier Corporation has been working on refrigerant containment for several years, and some emission reduction has been achieved. As a manufacturer, Carrier Corporation will continue to accept the responsibility to reduce emissions wherever practically and economically feasible. Emission-reduction investigations are underway in the areas of product design, manufacturing and service.

With respect to the project at hand, several emission-reduction practices will be followed in the development of the proposed design. Emissions will be controlled through the following:

1. Hermetic design of turbo/compressor and all other refrigerant containing vessels.
2. Factory assembled, charged, and tested package design, which assures integrity of the system and eliminates charging procedures in the field.
3. Thorough factory leak testing of complete system at a high level of sensitivity.
4. Use of leak testing fluids other than fully halogenated hydrocarbons, or use of methods which reclaim the leak test fluid.
5. Incorporation of valves and devices in the design that provide means for servicing without loss of charge.
6. Development of servicing techniques and procedures that will reduce emissions.

1.6.2 ASSESSMENT OF OWNER'S COST

1.6.2.1 Expected Equipment Life

The former Energy Research and Development Administration (ERDA) developed a document, "Life Cycle Costing, Emphasizing the Energy Conservation," which lists the "Average Useful Life" (AUL) of various types of energy conservation equipment. The following AUL values were taken from the list.

<u>Equipment</u>	<u>AUL (years)</u>
Centrifugal Chillers	20
Centrifugal Compressors	20
Centrifugal Liquid Chilling Systems	20-30
Condensers Remote Air Cooled	12
Electric Motors	20-25
Turbines (Steam)	10-30
Liquid Coolers - Horizontal Shell & Tube	30
Boilers	20-25
Float Regulators - Low Pressure Ammonia	30
Fans	20

The expected life for the proposed Rankine cycle water chiller equipment is 25 years except for the air cooled condenser coils, fans and motors which are exposed to commercial outdoor atmospheres. These components, depending on the degree of outdoor air contamination (pollution), may need to be replaced during the 25 years. In reasonably clean atmospheres and with motor relubrication, these components could be expected to have a 25 year life also.

1.6.2.2 Service and Maintenance Requirements

The proposed solar Rankine cycle chiller requires no special service or maintenance over that expected for standard air cooled liquid chillers. The following planned service checklist outlines items that should be checked on a regular basis.

Cooler - Liquid Suction Heat Exchanger

1. Check all auxiliary components such as chilled liquid circulating pump, liquid flow switches, pump contactor, chilled water safety thermostat, etc.
2. Check condition of circulating chilled liquid.

Condenser Coils

1. Check condenser coil condition.
2. Remove dirt, lint and other materials from coil surfaces.

Condenser Fans and Motors

1. Check motor bearings for wear and lubrication.
2. Check motor housings for signs of corrosion.
3. Check fan blades for tightness and alignment.
4. Remove accumulated dirt and other materials from blades.

Turbine-Compressor-Motor

1. Check general operation and condition.
2. Check boiler, exhaust, head and suction pressures.
3. Check noise and vibration.
4. Check for loose bolts.

Refrigerant Circuit

1. Check system for refrigerant leaks.
2. Check refrigerant charge.
3. Check operation of refrigerant controls.
4. Check insulation vibration, noise.
5. Check for noncondensables.

Controls

1. Check thermostat operation.
2. Check operation of contactors (starters).
3. Check operation of relays.
4. Check operation of pressure and temperature limit switches.
5. Check all wiring from disconnect switch to unit including fuses.
6. Check operation of solenoid and/or modulating valves.
7. Check operation of cooler expansion valve.

Water Circuits

1. Check for water leaks.

The technical knowledge and service expertise required by the proposed Rankine cycle equipment is the same as required by refrigeration and air conditioning equipment. A good refrigeration service mechanic with experience working on centrifugal compressors would be well qualified for service work on the proposed equipment. Some training on the service and operation of high speed centrifugal compressors and turbines, as well as the variable speed compressor motor and power supply, should be provided.

1.6.2.3 Quality Control Requirements

One of the major advantages of a completely packaged refrigeration machine is the reduction in installation quality control requirements. All of the critical assembly operations can be performed in the factory where dirt, moisture, noncondensables, leaks, misalignment, mis-wiring and other sources of potential failure can be continuously monitored by quality control inspectors. The manufacturing quality control requirements will be more demanding than those required for normally produced centrifugal liquid chiller equipment.

The high speed turbo/compressor unit with its gas bearings will not have the tolerance for particulate dirt that conventional machines have. Therefore, there will need to be new techniques used in processing parts and assembling components and systems to assure cleanliness. In addition, the thermal stability of R-113 at elevated temperatures may be adversely affected by residue oils, and all parts will have to be oil free at the time of assembly.

Equipment assembled in one package ready for operation can be operated as a complete assembly in the manufacturer's test facilities prior to shipment to the field. This final factory operating test has been very successful in eliminating manufacturing errors of packaged equipment and is one of the main reasons for the success and growth of packaged equipment during the past years.

Packaged equipment, including the proposed solar Rankine chiller, requires a minimum of installation quality control requirements. The refrigeration system of the proposed package is factory charged and sealed. The turbo/compressor and controls will have been operated and checked out. It is only necessary to make the final electrical and water connections.

Only a check for shipping damage, loose electrical connections and control settings will be necessary prior to equipment start-up.

1.6.2.4 10-Year Service Costs

There are four main types of service contracts used by heating and air conditioning dealers and contractors. These four types are:

1. Full Maintenance Contract - One annual fee covers all expenses (labor, parts).

2. Inspection and Labor Contract - One annual fee covers all labor for inspection, maintenance and breakdown repair. The cost of parts is paid for by the customer.
3. Inspection Contract - One annual fee covers the labor required for inspections. Repairs are recommended. The cost of repair labor and parts is paid for by the customer.
4. Time and Material Agreement - Customer agrees to pay for all labor, material and parts used to restore or maintain equipment after such work is requested by the customer and has been performed.

For this study, the service costs were figured on the basis of Carrier's Planned Service Contract Pricing Guide. A full-maintenance type contract was assumed. Labor rates vary considerably from one part of the country to another so three different base wage rates were used: \$7.50, \$10.00 and \$12.50. The base wage equals the serviceman's wage plus all fringe benefits.

Two other assumptions were made in arriving at the contract price. First, Carrier's Contract Pricing Guide does not cover Rankine cycle equipment. The proposed 25 ton unit's size is similar to a 50 ton vapor compression unit. Secondly, the controls, condensate pump, and related parts would make the unit similar in complexity to a heat pump system. Therefore, the contract calculation was based on a 50 ton multi-compressor heat pump and indoor air handler system factors with six inspections per year. A sample of the contract calculation is given in Appendix A-1.6.

The results of the calculations for a ten-year period are shown on Figure 1.6-1. The Pricing Guide is designed to give the service agency a 50% gross margin. A review of actual service contracts show that because of competitive pressures and particular job requirements, real prices may actually be 75% of the Pricing Guide.

It should be emphasized that this calculation is based on a 50 ton unit because that most nearly approximates a 25 ton Rankine cycle. The resulting contract will, therefore, be nearly double the price expected for a 25 ton conventional machine.

1.6.2.5 Installation Requirements

The proposed solar Rankine chiller is self-contained and requires only electrical power supply connections, conditioned space thermostat connection, solar water collection system connection and chilled water system connection. The chilled water flow rate and the solar collection system flow rate to the boiler required are 60 gpm and 75 gpm respectively. A 100 ampere, 230 volt, three-phase electrical service connection is required to power the condenser fan motors, the compressor, and the condensate pump motor. Chilled water temperature and limit control signals must be provided.

FIGURE 1.6 -1

10 YEAR SERVICE CONTRACT PRICES

NOTE: COST OF SOLAR COLLECTION
AND STORAGE SYSTEM SERVICE
NOT INCLUDED. CONTRACT PRICE
INCLUDES ONE 25 TON AIR HANDLER.

With the exception of rigging which would be equal to a 50 ton air cooled chiller, and the solar collection and storage system, the cost of installation of the proposed equipment would be the same as installation costs for a 25 ton air cooled chiller unit. There may be some additional expense in mounting the proposed package; however, the loading per square foot of floor or roof area is less than a 25 ton air cooled chiller package.

1.7 CONCLUSIONS

1.7.1 CHILLER PACKAGE DESIGN

1. A conceptual design of a 25 ton high temperature solar powered water chiller has been developed which will operate at rated conditions with an overall COP in excess of 0.80. This design is based on an air cooled Rankine driven vapor compression cycle using a single working fluid and a high speed turbo/compressor. The compressor will be directly driven by an electric motor for auxiliary operation.
2. The estimated selling price of the conceptual design is on a par with currently available equipment installed to provide the same functions (i.e., air cooled solar cooling with electric auxiliary energy). The selling price can be expected to drop substantially as the design matures and moves into regular production.
3. The unitary package design of this concept is similar to conventional air cooled chiller packages. It can be shipped, handled, and installed in a similar manner. Required service and maintenance technology will be similar.
4. The physical size of the 25 ton Rankine driven water chiller package will be approximately the same as a 50 ton conventional chiller package, because the size is dominated by the air cooled condenser which must reject the heat of the vapor compression cycle as well as the Rankine cycle.
5. The conceptual design will introduce no new environmentally significant manufacturing processes, service and installation technology, or operating conditions, compared to conventional packaged air cooled water chillers.

1.7.2 CYCLE SCREENING TESTS

1. Screening tests have shown that the combination of a liquid suction heat exchanger and a regenerator in this high temperature cycle produce a greater OCOP improvement than expected from the sum of the individual improvements.
2. Screening tests have shown that arranging the vapor compression cycle condenser upstream of the Rankine condenser in this high temperature cycle can provide a substantial improvement in OCOP when compared with a common condenser.

1.7.3 TURBO/COMPRESSOR CONCLUSIONS RESTATED FROM THE MTI REPORT, SECTION 1.3

1. R-114 gives better turbo/compressor performance than R-113, because of lower mach numbers and better turbine and compressor matching.
2. The compressor was characterized by high mach numbers and low impeller tip speeds for both R-113 and R-114. These conditions lead to a high reaction impeller design with inlet guide vanes.
3. For R-113, the initial turbine speed selection resulted in low turbine efficiency. The rotational speed was increased to improve turbine efficiency at a sacrifice in compressor efficiency due to high mach numbers at the inducer.
4. The induction type motor best meets the prototype design requirements. However, for the long term, a permanent magnet motor is a design worth considering.
5. Both tilting pad and foil type gas bearings will give acceptable performance for both journal and thrust applications. Rotor dynamic analysis on the shaft assembly was found to be within a favorable range for both bearing types and no instability problems are expected.
6. Turbo machine costs, excluding the motor, were found to be within target objectives.
7. A vaned diffuser has been designed for the R-113 compressor which improves the chiller OCOP and widens the operating ambient range of the chiller between surge and choke at a constant solar water temperature. A vaned diffuser in a compressor stage normally produces higher efficiency at the expense of a limited flow range. The effect on the solar chiller system of a wider pressure ratio range, in this instance, allows a wider range of condensing pressures.

1.7.4 SELECTION OF A WORKING FLUID

1. R-113 is the selected working fluid, based on performance and thermal stability.
2. R-113 has been shown to produce equal or better performance than other common refrigerants examined when considering both the cycle OCOP and the pump work input.
3. The literature shows that R-113 should have acceptable thermal stability at 300°F in an oil free system if the heated compounds are constructed of a single material such as steel. None of the refrigerants examined as working fluids would have acceptable stability in the presence of oil, and R-11 stability data are not acceptable without oil.
4. Although the turbine/compressor performance is better with the R-114 design than the R-113 design because of better matching characteristics and lower mach numbers, the overall system performance with R-113 is 25% better than with R-114. The poorer turbine/compressor performance is more than offset by the superior thermodynamic cycle OCOP and the low pump work of R-113.
5. Due to the subatmospheric pressure of R-113 in the evaporator and condenser, an air purge system will be required.

1.7.5 Off-Design Characteristics

1. A computer program has been written to simulate the off-design performance of a dual loop Rankine cycle with specified heat exchanger, turbine, and compressor performance.
2. Off-design performance maps have shown that there is a direct relationship between the minimum supply water temperature to the Rankine cycle and the outdoor ambient temperature. This relationship can be employed to control the turbo/compressor operation. The flexibility of this control concept will allow a choice of a cooling capacity characteristic ranging from constant and independent of outdoor ambient to a capacity which varies directly with ambient and which tends to match the building load line.
3. The significant increase in OCOP predicted for lower outdoor temperatures will result in a high seasonal OCOP, which will more than offset the efficiency penalty associated with high collector temperatures, when compared with low temperature solar absorption systems.

1.7.6 MOTOR OPERATION

1. Off-design compressor performance maps indicate that a variable speed compressor drive is required because of the small pressure ratio available at one speed compared with the wide pressure ratio range required over the expected air cooled operating conditions.
2. A key problem with this design concept is the anticipated high cost of the power supply and speed control electronics required by all of the variable speed motor types examined. This cost is also a direct function of the power level needed at high outdoor temperature conditions and/or under starting conditions to overcome static bearing friction.
3. Motor horsepower and cooling capacity will increase as speed is increased to meet high pressure ratios at warmer outdoor conditions. This characteristic requires a larger motor, but results in a machine which tends to parallel the building load line.
4. The predicted EER of the electric motor driven compressor is about 50% better than for conventional motor compressor equipment primarily due to the oversized condenser available when the Rankine cycle is not operating.

1.7.7 FEED PUMP

1. Due to a lack of commercially available pumps which would meet the design objectives for the boiler feed pump, two alternate conceptual pump designs have been developed which will meet the objectives of first cost, efficiency, and NPSH.

1.8 RECOMMENDATIONS

- 1.8.1 It is recommended that the R-113 design be selected for the Phase II design effort.
- 1.8.2 The turbo machine rotating assembly should be supported on tilting pad journal bearings and a foil thrust bearing.
- 1.8.3 The turbo machine and motor costing study should be extended into Phase II in order to verify base line costs and complete the evaluation of motor and bearing options.
- 1.8.4 A bench test program to verify turbo machine performance before incorporation in the chiller system should be developed.
- 1.8.5 The prototype turbo machine should be designed with variable geometry and other features which will give the greatest latitude in test development.
- 1.8.6 It is recommended that the gerotor pump with liquid refrigerant bearings be designed for the prototype chiller with an open drive. This will minimize development costs and allow more complete testing of the pump concept prior to application of a hermetic motor.
- 1.8.7 It is recommended that R-113 thermal stability tests be conducted at the earliest date during Phase II in order to confirm the choice of R-113 under the specified conditions with the proposed materials. The recommended test comprises a series of runaround systems to evaluate more than one variable and allow early sampling for a preliminary evaluation before the end of Phase II.
- 1.8.8 It is recommended that a water cooled condenser also be designed for the prototype in order to facilitate testing. This could also be tested in a series arrangement with the air cooled condenser to develop data on heat reclaim operation.
- 1.8.9 The solar system simulation program should be carried through to completion in Phase II. It is recommended that data from load and weather tapes supplied by DOE be used only for the final economic analysis. It is also recommended that DOE provide the economic parameters required for this analysis in order to obtain uniform evaluations from all contractors. These would include fuel costs, fuel escalation factors, discount rates and tax incentives for the localities of the tapes.
- 1.8.10 It is recommended that instrumentation, materials, and other items required for construction of the test facility and prototype under Phase III which are determined to be long lead time purchases be ordered during Phase II as necessary.

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APPENDIX A-1.1

PHYSICAL SPECIFICATIONS FOR
COMMERCIAL 25 and 50 TON AIR COOLED WATER CHILLERS

Physical data and dimensions

VLT 30	GA		030	GB		
	020	025		040	045	055
APPROX OPER WT (lb)	5695	2913	3270	3780	4350	4940
R-22 OPER CHARGE (lb)	55.0	57.2	63.0	40.2	50	65
COMPRESSOR, Type	Reciprocating Semi-hermetic					
06E* Circuit 1	B250	C250	C275	B250	B250	J275
Circuit 2				B250	F275	F275
Cyl/Compr	4	5	6	4	5	6
Oil/Compr (pt)	14	19	19	14	18	19
CONDENSER FANS	Propeller, Direct Drive					
No. ...Diam (in.)	3...28	3...30		4...26	6...26	
Rpm		1140			1080	
Total Airflow (cfm)	418,200	475,200	28,200	25,000	39,000	
COND COIL, No. ...Fins/in.)		1...12.4		3...17.7	2...17.5	3...15.5
Rows/Coil (deep)		3		2		3
Face Area (sq ft)			47.6			114
COOLER, No. ...Type	1...Shell and Tube					
Refrig Circuits	2					
Net Water Volume (gal.)	11.2			18.8	15.3	
Maximum Design Working Press. (psig)	Refrigerant Side - 235 Water Side - 250					
WATER CONN (in.)						
Inlet and Outlet	3 FPT			3 MPT		
Drain	1 FPT			¾ MPT		

*Unloaders: A,F = none; B,J = one; C = 2.

	30GA		
	020	025	030
A	12-10 $\frac{3}{4}$		
B	5-4 $\frac{1}{2}$	5-4 $\frac{1}{2}$	6-2 $\frac{3}{8}$
C	4-4 $\frac{1}{2}$	2-4 $\frac{1}{2}$	3-1 $\frac{1}{8}$
D	4-4 $\frac{1}{2}$	3-1 $\frac{1}{2}$	4-10
E	3-7 $\frac{5}{8}$		
F	3-7 $\frac{5}{8}$	3-8 $\frac{1}{4}$	4-7 $\frac{1}{2}$
G	0-2 $\frac{3}{8}$		
H	0-8 $\frac{7}{8}$		
J	2-5 $\frac{1}{4}$		
K	4-5 $\frac{1}{4}$		
L	5-6 min		

- 6 - 1-in. FPT Water Drain
 - 7 - 5/8-in. Diameter Hole for Floor Mounting - 6 Legs
 - 8 - 1/2-13 Thd for Lifting Eyebolt - 4 Holes
 - 9 - 115-1-60 Receptacle Box
- RP** - Removable Pane

30GB040,045,055

TOP VIEW

Overhead Clearance
Must Be Unrestricted

COOLER END VIEW

SIDE VIEW

Clearance for service and airflow.

DIMENSIONS (ft-in.)

UNIT 30GB		040	045	055
LENGTH	A	13-7/8	13-8	
CABINET WIDTH	B	7-0		
OVERALL WIDTH (Base Channels)	C	7-6		
OVERALL HEIGHT	D	4-9	5-8	
MOUNTING HOLES C (Width)	E	7-3		
MOUNTING HOLES C (Length, inner)	F	8-2	10-0	
MOUNTING HOLES C (Length, outer)	G	10-7	12-5	
LIFTING HOLES C	H	8-4	11-3	
HEIGHT TO POWER CONNECTION	J	7-8	4-8	4-8
HEIGHT TO CONTROL POWER CONNECTION	K	7-2	3-5	
HEIGHT TO WATER NOZZLES C	L	1-9		
WATER NOZZLES BETWEEN C	M	0-4		
WATER NOZZLE LOCATION C	N	2-8		

WEIGHT DISTRIBUTION

UNIT 30GB	APPROX OPER WT (lb)	SUPPORT POINT			
		1	2	3	4
040	3780	1261	1261	629	629
045	4350	1395	1395	700	700
055	4940	1546	1546	924	924

*4 Fans on 30GB040

APPENDIX A-1.2-1

ESD COMPUTER PROGRAM ABSTRACT

ESD COMPUTER PROGRAM ABSTRACT

Title ESDT004 . RANK06 . FORT

System TSO

Language FORTRAN IV

Purpose: This program is designed to calculate cycle performance of a dual loop turbo-Rankine cycle driven centrifugal compression chilled water cycle. The program has (3) three Regenerator configuration options open to the user. Refrigerant properties are computed using the RDC Refrigerant Properties program RDCI699C. Refrigerants which currently are available are: R11, R12, R22, R113, R114, R500, R502, R13B1 and R13. In order to handle a wet expansion refrigerant or a super critical cycle, the option is open both to specify the boiler pressure as well as the saturated temperature, and to specify super-heat. The computation is on a per ton basis (with the exception of wheel sizing).

Inputs: Input data is set up in a separate data set named RANK6 . DATA. This data is set up as a NONUM data set, free format, with commas between inputs. There are 29 inputs. Definitions are as follows:

1. NREF , refrigerant number; i.e., 12
2. TB , saturated boiling temperature, °F, for ordinary cycles.
3. TCRC saturated condensing temperature of the Rankine cycle condenser F. Both condensers are in series with the refrigeration condenser on the entering air side.

4. TCAC saturated condensing temperature of the refrigeration cycle condenser F.
5. TE saturated evaporator temperature F.
6. TSUB Subcooling produced by both condensers F
7. TSUP Evaporator superheat
8. PB Boiler pressure, PSIA. This is an option to assist in describing the vapor condition entering the expander for a super-critical cycle. If PB set = 0, the pressure is calculated using TB as the saturated vapor temperature. If PB is set to a specific value, the condition entering the expander is based upon PB and TB (or TB + SUPHT).
9. SUPHT Superheat added in the boiler F. This is an option which is necessary for wet expansion refrigerants to prevent condensation in the turbine. It can be set = 0 for dry expansion refrigerants.
10. TSOL Solar water temperature entering the boiler. By specifying this temperature, the program will compute LMED and UA in the boiler and preheater sections, knowing GPMS.
11. GPMS Solar water flow per ton: GPM/TON.
12. TAIR Ambient air temperature entering the condenser. By specifying this temperature the program will compute LMED and UA in both condensers which are in series, knowing CFM.
13. CFM Air flow through the condensers in series, per ton CFM/TON.

14. CWT Chilled water temperature leaving the chiller.
By specifying this temperature, the program will compute
UA and LMED for the chiller, knowing GPMCW.
15. GPMCW Chilled water flow rate per ton GPM/TON.
16. ETAEXP Adiabatic expansion efficiency of the turbine,
decimal.
17. ETACOM Adiabatic compression efficiency of the compressor,
decimal.
18. ETAPUM Total efficiency of the boiler feed pump,
decimal.
19. LOSS Mechanical losses assigned to the drive
between the turbine and compressor, decimal.
20. ETALSH Heat exchanger effectiveness of the liquid
suction heat exchanger, decimal. This heat exchanger
is required for wet compression refrigerants to provide
enough superheat at the compressor suction to avoid
condensation. This superheat can be recovered in the
regenerator.
21. PLSH Pressure drop of vapor between the chiller and
compressor suction, PSI. This would be primarily the
pressure drop of the liquid suction heat exchanger plus
the line losses.
22. ETANX Heat exchange effectiveness of the regenerator,
decimal. It is computed differently for each optional
configuration (see 3).
23. PREG Pressure drop of vapor between the turbine
exhaust and its condenser, and/or between the compressor
discharge and its condenser, psi. These pressure drops

are primarily regenerator pressure drop plus any line losses.

24. Z A user option for the Regeneration Configuration

(-1) = Regenerator only exchanges heat between the compressor discharge gas and the liquid return to the boiler.

(+1) = Regenerator only exchanges heat between the turbine exhaust gas and the liquid return to the boiler.

(0) = Regenerator exchanges heat between both hot gas stream and the liquid returning to the boiler. It assumes a mixed condition for purposes of simplified calculation.

25. TON Unit capacity in tons. Only used to compute wheel sizes.

26. NST Specific speed of turbine , RPM.

27. DST Specific diameter of turbine , inches.

28. NSC Specific speed of compressor , RPM.

29. DSC Specific diameter of turbine , inches.

A data input sheet is attached.

Description of Cycle

For explanatory purposes, Fig. 1 shows a typical cycle on R114, using the following input: NREF=114, TB = 273, TCRC = 123, TCAC = 111.5, TE = 40, TSUB = 5, TSUP = 1, PB = 0, SUPHT = 0, TSUL = 300, GPMS = 2.5, TAIR = 95, CFM = 1560, CWT = 45, GPMCW = 2.5, ETAEXP = .8, ETACOM = .775, ETAPUM = .5, LOSS = 0, ETALSH = .7, PLSH = 0, ETAHX = .8, PREG = 0, Z = 0; state points are labeled as they show in the printout. (Not all state points are printed out.) Mass flow of the Rankine cycle is based on the work output of the turbine equaling the work input of the compressor for one ton of cooling.

$$(i.e. \text{ MRC} = \frac{W_e}{W_T} * M_{12000})$$

Description of Heat Exchangers

<u>Boiler</u>	Fig. 2 shows a temperature/energy diagram for the heat exchange between refrigerant and solar water. Nomenclature used in program is underlined.
<u>Condenser</u>	Fig. 3 shows the temperature/energy diagram for the two condensers in series. Nomenclature used in the program is underlined.
<u>Chiller</u>	Fig. 4 shows the temperature/energy diagram for the evaporator/chiller.
<u>LSHX</u>	Fig. 5 shows the temperature/energy diagram for the liquid suction heat exchanger. The formula used for effectiveness is given on the diagram with all computer labels underlined.

NO. 340R-L210 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH

BY _____ DATE _____
CHKD. BY _____ DATE _____

SUBJECT FIG. 2
TEMPERATURE ENERGY DIAGRAM
FOR RH4 COILER

SHEET NO. _____ OF _____
JOB NO. _____

BY _____ DATE _____
CHKD. BY _____ DATE _____

SUBJECT FIG 3
TEMPERATURE-ENERGY DIAGRAM
FOR R114 CONDENSERS

SHEET NO. _____ OF _____
JOB NO. _____

BY _____ DATE _____
CHKD. BY _____ DATE _____

SUBJECT FIG 4
TEMPERATURE-ENERGY DIAGRAM
R114 EVAPORATOR/CHILLER

SHEET NO. _____ OF _____
JOB NO. _____

BY _____ DATE _____
CHKD. BY _____ DATE _____

SUBJECT FIG 5 SHEET NO. _____ OF _____
TEMPERATURE / ENERGY DIAGRAM JOB NO. _____
R114 LIQUID-SUCTION HEAT-X

$$E_{TALSH} = \frac{T_{10} - T_{101}}{T_{72} - T_{101}}$$

$W_{Cp} LIQUID > W_{Cp} VAPOR$

BY _____ DATE _____
CHKD. BY _____ DATE _____

SUBJECT FIG 6
TEMPERATURE/ENERGY DIAGRAM
R114 REGENERATOR

SHEET NO. _____ OF _____
JOB NO. _____

Regeneration Fig. 6a, b and c shows the temperature/energy diagrams for the three types of regenerator used in the program as a user option. The formulas for effectiveness are also given.

Operation A special executive program, RANK1 . CLIST, has been set up to compile and link the program RANKØ6 . FORT. A copy is attached. Procedure is as follows:

1. Edit input data set RANK6 . DATA
2. Execute CLIST by the following command from the READY mode:

EX RANK1 . CLIST

3. Run RANKØ6 by the following command from the READY mode:

LIMIT SECONDS(Ø3)

4. For new input data, re-edit RANK6 per item (1) above.

RANK06

DATA INPUT SHEET

NONUM DATA SET ~ FREE FORMAT SPACED BY COMMAS

NAME: RANK6.DATA

LINE NREF _

1

	,
--	---

2

TB	,	TCRC	TCAC	TC	TSUB	TSUP	PB	SUPHT
	,		,		,		,	

3

TSOL	GPMS	TAIR	CFM	CWT	CPMCW
	,		,		,

4

ETAEXP	ETACOMP	ETAPUM	LOSS
	,		,

5

ETALSH	PLSH	ETAHX	PREG	Z
	,		,	

6

TON	NST	DST	NSC	DSC
	,		,

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Figure A-1
SIMPLIFIED FLOW SCHEMATIC
DUAL LOOP, RANKINE HEAT ENGINE DRIVEN COMPRESSION WATER CHILLER

LAST RANK 6.DAT

PARAM06.DAT

```

00010      DEFINE FILE 11(10,80,U,IREF)
00020      25 READ *,NREF,
00030      $      TB,TCRC,TCRC,TE,TSUB,TSUP,PS,SUPHT,
00040      $      TSOL,GPM5,TAIP,CFM,CWT,GPMCN,
00050      $      ETAEXP,ETACOM,ETAPUM,ALOSS,
00060      $      ETALSH,PLSH,ETAHX,PREG,Z,
00070      $      TON,NST,DST,MSC,DSC
00080      CALL NRNN(NREF)
00090      T7 = TCRC-TSUB
00100      T72 = TCRC-TSUB
00110      T2 = TB + SUPHT
00120      IF (PB) 31,31,32
00130      31 PB = SPXX(TB)
00140      32 CALL PTUH(PB,T2,U2,H2)
00150      PCRC = SPXX(TCRC)
00160      PCRC = SPXX(TCRC)
00170      U5 = SUMX(TCRC,PCRC)
00180      H5 = HUXX(TCRC,PCRC,U5)
00190      U51 = SUMX(TCRC,PCRC)
00200      H51 = HUXX(TCRC,PCRC,U51)
00210      H7 = HLXX(T7)
00220      H72 = HLXX(T72)
00230      D7 = DLXX(T7)
00240      U7 = 1/D7
00250      S2 = EUXX(T2,U2)
00260      P4 = PCRC + PREG
00270      CALL PSHT(P4,S2,H4,T4)
00280      11 QB1 = H2 -H7
00290      QW = (H2 -H4)*ETAEXP
00300      H6 = H2-QW
00310      12 CALL PHUT(P4,H6,U6,T6)
00320      GO TO 10
00330      20 QP = .18509*U7*(PB - PCRC)/ETAPUM
00340      ETAT1 = QW/QB1
00350      IF (Z) 16,17,18
00360      16 T13 = T12 - (T12-T7)*ETAHX
00370      U13 = SUMX(T13,PCRC)
00380      H13 = HUXX(T13,PCRC,U13)
00390      QHX1 = H12-H13
00400      H1 = H7+QHX1
00410      T1 = T7 + QHX1/U7
00420      T121 = T13
00430      DT4 = T121-T7
00440      DT5 = T12-T1
00450      DTHX2 = (DT4-DT5)/ALOG(DT4/DT5)
00460      DTHX3 = 0
00470      UAHX2 = QHX1 * WRF/DTHX2
00480      UAHX3 = 0
00490      IF (DT4-DT5) 51,52,52
00500      51 APHX2 = DT4
00510      APHX3 = 0
00520      GO TO 53
00530      52 APHX2 = DT5
00540      APHX3 = 0
00550      53 QHX2 = QHX1*WRF

```

```

00560      QHX3 = 0
00570      CONDR = (H13-H7)*WRF
00580      CONDR = (H6-H7)*WRC
00590      GO TO 19
00600 18      T13 = T6-(T6-T7)*ETAHX
00610      U13 = SUXX(T13,PCRC)
00620      H13 = HUXX(T13,PCRC,U13)
00630      QHX1 = H6-H13
00640      H1 = H7+ QHX1
00650      T1 = T7 + QHX1/CP
00660      T61 = T13
00670      DT6 = T61-T7
00680      DT7 = T6-T1
00690      DTHX3 = (DT6-DT7)/ALOG(DT6/DT7)
00700      DTHX2 = 0
00710      UAHX3 = QHX1*WRC/DTHX3
00720      UAHX2 = 0
00730      IF (DT6-DT7) 46,47,47
00740 46      APHX3 = DT6
00750      APHX2 = 0
00760      GO TO 48
00770 47      APHX3 = DT7
00780      APHX2 = 0
00790 48      QHX3 = QHX1*WRC
00800      QHX2 = 0
00810      CONDR = (H12-H7)*WRF
00820      CONDR = (H13-H7)*WRC
00830      GO TO 19
00840 17      T82 = T7+(T12-T7)*ETAHX
00850      T83 = T7+(T6-T7)*ETAHX
00860      WF1 = WRF/(WRC+WRF)
00870      WF2 = WRC/(WRC+WRF)
00880      H82 = HLXX(T82)
00890      H83 = HLXX(T83)
00900      QHX2 = WF1*(H82-H7)
00910      QHX3 = WF2*(H83-H7)
00920      QHX1 = QHX2+QHX3
00930      T1 = T82*WF1+T83*WF2
00940      H1 = HLXX(T1)
00950      H61 = H6-QHX3
00960      CALL PHUT(PCRC,H61,U61,T61)
00970      H121 = H12-QHX2
00980      CALL PHUT(PCRC,H121,U121,T121)
00990      DT4 = T121-T7
01000      DT5 = T12-T82
01010      DT6 = T61-T7
01020      DT7 = T6-T83
01030      DTHX2 = (DT4-DT5)/ALOG(DT4/DT5)
01040      DTHX3 = (DT6-DT7)/ALOG(DT6/DT7)
01050      UAHX2 = QHX2*WRF/DTHX2
01060      UAHX3 = QHX3*WRC/DTHX3
01070      IF (DT4-DT5) 43,44,44
01080 43      APHX2 = DT4
01090      APHX3 = DT6
01100      GO TO 45
01110 -4      APHX2 = DT5
01120      APHX3 = DT7

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01130      45 CONDRC = (H12-H72-QHX2)*WRF
01140      CONDRC = (H6-H7-QHX3)*WRC
01150      QHX2 = QHX2*WRF
01160      QHX3 = QHX3*WRC
01170      19 QB2 = H2-H1
01180      ETAT2 = QW/QB2
01190      EXPRAT = PB/P4
01200      GO TO 30
01210      10 T101 = TE + TSUP
01220      T10 = T101 + (T72-T101)*ETALSH
01230      PE = SPXX(TE)
01240      P10 = PE-PLSH
01250      U101 = SUXX(T101,PE)
01260      H101 = HUXX(T101,PE,U101)
01270      U10 = SUXX(T10,P10)
01280      H10 = HUXX(T10,P10,U10)
01290      S10 = EUXX(T10,U10)
01300      P11 = PCAC+PREG
01310      TL = T7-10
01320      HL = HLXX(TL)
01330      CP = (H7-HL)/10
01340      T71 = T7-(H10-H101)/CP
01350      H71 = HLXX(T71)
01360      CALL PSHT(P11,S10,H11,T11)
01370      13 QC = (H11-H10)/ETACOM
01380      H12 = H10 + QC
01390      14 CALL PHVT(P11,H12,U12,T12)
01400      15 COMRAT = P11/P10
01410      QE = H10-H7
01420      COP = QE/QC
01430      WRF = 12000/QE
01440      QCOMP = QC*WRF/2545
01450      WRC = (1+ALOSS)*QCOMP * 2545/QW
01460      GO TO 20
01470      30 H14 = HLXX(TB)
01480      QHX = QHX1*WRC
01490      QBSENS = (H14-H1)*WRC
01500      SHF = QBSENS*100/(WRC*QB2)
01510      HX = QHX*100/(WRC*QB1)
01520      COMPHD = (H11-H10)*778
01530      EXPHD = (H2-H4)*778
01540      OLSHX = (H10-H101)*WRF
01550      SONICU = SOXX(P10,H10)
01560      QCOND = CONDRC + CONDR
01570      QBOIL = QB2*WRC
01580      COPQV2 = 12000/QBOIL
01590      QPUMP = QP*WRC/2545
01600      DISPLC = WRF*U10/60
01610      DISPLP = WRC*U7/60
01620      DISPLE = WRC*U6/60
01630      ST = NST*EXPHD**(.75/(DISPLE*TON/60)**.5
01640      DT = DST*12 *(DISPLE*TON/60)**.5/EXPHD**(.25
01650      SC = NSC*COMPHD**(.75/(DISPLC*TON/60)**.5
01660      DC = DSC*12*(DISPLC*TON/60)**.5/COMPHD**(.25
01670      TA1 = TAIR+ CONDRC/(1.08*CFM)
01680      TA2 = TA1+CONDRC/(1.08*CFM)
01690      DTOR = (TA1-TAIR)/ALOG((TCAC-TAIR)/(TCAC-TA1))

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```
01700      DTORC = (TA2-TA1)/ALOG((TCRC-TA1)/(TCRC-TA2))
01710      UACR = CONDR/DTORC
01720      UACRC = CONDR-ITCRC
01730      APCR = TCRC-TA1
01740      APCRC = TCRC-TA2
01750      QBOILR = QBOIL-QSENS
01760      T14 = TB
01770      T21 = TSOL-QBOILR/(500*GPMS)
01780      T22 = T21-QSENS/(500*GPMS)
01790      DTPRHT = ((T22-T1)-(T21-T14))/ALOG((T22-T1)/(T21-T14))
01800      DTBOIL = ((TSOL-T2)-(T21-T14))/ALOG((TSOL-T2)/(T21-T14))
01810      UAPRHT = QSENS/DTPRHT
01820      UABOIL = QBOILR/DTBOIL
01830      FINCH = T21-T14
01840      QEVAP = 12000.0
01850      ECNT = CWT + QEVAP/(500*GPMCN)
01860      DTEVAP = (ECNT-CWT)/ALOG((ECNT-TE)/(CWT-TE))
01861      UAEVAP = QEVAP/DTEVAP
01870      APEVAP = CWT-TE
01880      DT1 = T71-T101
01890      DT2 = T72-T10
01900      DTLHX = (DT1-DT2)/ALOG(DT1/DT2)
01910      UALHX = QLSHX/DTLHX
01920      IF (DT1-DT2) 40,41,41
01930      40 APLHX = DT1
01940      GO TO 42
01950      41 APLHX = DT2
01960      42 WRITE (6,50) NREF
01970      WRITE (6,60) TB
01980      WRITE (6,61) TSOL,GPMS
01990      WRITE (6,70) TCRC
02000      WRITE (6,72) TCAC
02010      WRITE (6,71) TAIR,CFM
02020      WRITE (6,80) TE
02030      WRITE (6,81) CWT,GPMCN
02040      WRITE (6,90) TSUB
02050      WRITE (6,100) TSUP
02060      WRITE (6,110) ETAEXP
02070      WRITE (6,120) ETAPUM
02080      WRITE (6,130) ETALHX,PREG
02090      WRITE (6,140) ETACOM,ALOSS
02100      WRITE (6,141) ETALSH,FLSH
02110      WRITE (6,142) SUPHT
02120      IF (Z) 33,34,35
02130      33 WRITE (6,143)
02140      GO TO 36
02150      34 WRITE (6,144)
02160      GO TO 36
02170      35 WRITE (6,145)
02180      36 IF (PB) 37,37,38
02190      38 WRITE (6,146) PB
02200      37 WRITE (6,150)
02210      WRITE (6,160) PB
02220      WRITE (6,170) PC
02230      WRITE (6,180) T6
02240      WRITE (6,360) WRC
02250      WRITE (6,370) CONDR
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02260      WRITE (6,390) QBOIL
02270      WRITE (6,440) QHX
02280      WRITE (6,470) HX
02290      WRITE (6,450) QBSSENS
02300      WRITE (6,460) SHF
02310      WRITE (6,190) U2
02320      WRITE (6,200) U6
02330      WRITE (6,210) EXPRAT
02340      WRITE (6,430) DISPLE
02350      WRITE (6,490) EXPHD
02360      WRITE (6,215) ETAT1
02370      WRITE (6,220) ETAT2
02380      WRITE (6,400) QPUMP
02390      WRITE (6,420) DISPLF
02400      WRITE (6,421) NST,ST
02410      WRITE (6,422) DST,DT
02420      WRITE (6,240)
02430      WRITE (6,250) PE
02440      WRITE (6,260) T12
02450      WRITE (6,330) WRF
02460      WRITE (6,340) QCOMP
02470      WRITE (6,350) CONDR
02480      WRITE (6,270) U10
02490      WRITE (6,280) U12
02500      WRITE (6,290) COMRAT
02510      WRITE (6,410) DISPLC
02520      WRITE (6,480) COMPHD
02530      WRITE (6,700) SONICV
02540      WRITE (6,300) COP
02550      WRITE (6,301) QLSHX
02560      WRITE (6,302) NSC,SC
02570      WRITE (6,303) DSC,DC
02580      WRITE (6,310)
02590      WRITE (6,315) COPOU2
02600      WRITE (6,380) QCOND
02610  50  FORMAT (///,' SPECIFIED CYCLE PARAMETERS FOR DUAL LOOP, R',I
4)
02620  60  FORMAT ( ' 1. SATURATED BOILER TEMPERATURE, F      = ',F6.1)
02630  61  FORMAT ( ' 2. SOLAR TEMP. & FLOW, F & GPM/TON    = ',
02640      $      F6.1,5X,F6.3)
02650  70  FORMAT ( ' 3. RANKINE CYCLE SAT. COND. TEMP., F    = ',F6.1)
02660  72  FORMAT ( ' 4. AIR/CON CYCLE SAT. COND. TEMP., F    = ',F6.1)
02670  71  FORMAT ( ' 5. CONDENSER AIR TEMP: & FLOW, F & CFM = ',
02680      $      F6.1,5X,F6.1)
02690  80  FORMAT ( ' 6. SATURATED SUCTION TEMPERATURE, F    = ',F6.1)
02700  81  FORMAT ( ' 7. CHILLED WATER TEMP. & FLOW, F & GPM= ',
02710      $      F6.1,5X,F6.3)
02720  90  FORMAT ( ' 8. CONDENSER SUBCOOLING, F              = ',F6.1)
02730 100  FORMAT ( ' 9. EVAPORATOR SUPERHEAT, F              = ',F6.1)
02740 110  FORMAT ( ' 10. EXPANDER EFFICIENCY                  = ',F6.3)
02750 120  FORMAT ( ' 11. FEED PUMP EFFICIENCY                 = ',F6.3)
02760 130  FORMAT ( ' 12. REGENERATOR, EFFY. & PSI LOSS      = ',
02770      $      F6.3,5X,F6.3)
02780 140  FORMAT ( ' 13. COMPRESSOR, EFFY & MECH. LOSS      = ',
02790      $      F6.3,5X,F6.3)
02800 141  FORMAT ( ' 14. LIQ-SUCT HX ,EFFY & PSI LOSS        = ',
02810      $      F6.3,5X,F6.3)

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002820 142 FORMAT ( ' 15. BOILER SUPERHEAT = ', F6.1)
002830 143 FORMAT ( ' 16. REGEN TYPE -1, USES COMPRESSOR FLOW ')
002840 144 FORMAT ( ' 16. REGEN TYPE 0, USES COMBINED FLOW ')
002850 145 FORMAT ( ' 16. REGEN TYPE +1, USES EXPANDER FLOW ')
002860 146 FORMAT ( ' 17. BOILER PRESS., SPECIFIED, PSIA = ', F6.1)
002870 150 FORMAT ( '//, ' CALCULATED RANKINE CYCLE PERFORMANCE ')
002880 160 FORMAT ( ' 1. BOILER PRESSURE, PSIA = ', F6.1)
002890 170 FORMAT ( ' 2. CONDENSER PRESSURE, PSIA = ', F6.1)
002900 180 FORMAT ( ' 3. EXPANDER EXHAUST TEMPERATURE, F = ', F6.1)
002910 360 FORMAT ( ' 4. RANKINE CYCLE MASS FLOW, LB/HR-TON = ', F10.3)
002920 370 FORMAT ( ' 5. RANK CONDENSER REJECTION, B/HR-TON = ', F10.3)
002930 390 FORMAT ( ' 6. RANKINE BOILER INPUT, B/HR-TON = ', F10.3)
002940 440 FORMAT ( ' 7. REGENERATOR HEAT EXCHANGE, B/HR-TON = ', F10.3)
002950 470 FORMAT ( ' 8. PERCENT REGENERATOR HEAT = ', F6.3)
002960 450 FORMAT ( ' 9. BOILER SENSIBLE HEAT, B/HR-TON = ', F10.3)
002970 460 FORMAT ( ' 10. PERCENT SENSIBLE HEAT = ', F6.3)
002980 190 FORMAT ( ' 11. SPECIFIC VOLUME, EXPANDER INLET, CFP = ', F10.3)
002990 200 FORMAT ( ' 12. SPECIFIC VOLUME, EXPANDER OUTLET, CFP = ', F10.3)
003000 210 FORMAT ( ' 13. EXPANDER PRESSURE RATIO = ', F10.3)
003010 430 FORMAT ( ' 14. EXPANDER DISPLACEMENT, CF/MIN-TON = ', F10.3)
003020 490 FORMAT ( ' 15. EXPANDER ADIABATIC HEAD, FT-LBS/LB = ', F10.3)
003030 215 FORMAT ( ' 16. THEO. CYCLE EFFICIENCY, W/O HX = ', F6.3)
003040 220 FORMAT ( ' 17. ACTUAL CYCLE EFFICIENCY, W/HX = ', F6.3)
003050 400 FORMAT ( ' 18. FEED PUMP WORK INPUT, HP/TON = ', F10.3)
003060 420 FORMAT ( ' 19. FEED PUMP DISPLACEMENT, CF/MIN-TON = ', F10.3)
003070 421 FORMAT ( ' 20. TURBINE SPEED AT ', I3, ' NS = ', F10.
3)
003080 422 FORMAT ( ' 21. TURBINE DIA. AT ', F5.2, ' DS, INCHES = ', F6
.3)
003090 240 FORMAT ( '//, ' CALCULATED REFRIGERATION CYCLE PERFORMANCE ')
003100 250 FORMAT ( ' 1. EVAPORATOR PRESSURE, PSIA = ', F6.1)
003110 260 FORMAT ( ' 2. DISCHARGE TEMPERATURE, F = ', F6.1)
003120 330 FORMAT ( ' 3. REFRIGERANT MASS FLOW, LB/HR-TON = ', F10.3)
003130 340 FORMAT ( ' 4. COMPRESSOR WORK INPUT, HP/TON = ', F10.3)
003140 350 FORMAT ( ' 5. REFRIG CONDENSER REJECTION, B/H-TON = ', F10.3)
003150 270 FORMAT ( ' 6. SPECIFIC VOLUME, SUCTION, CF/LB = ', F10.3)
003160 280 FORMAT ( ' 7. SPECIFIC VOLUME, DISCHARGE, CF/LB = ', F10.3)
003170 290 FORMAT ( ' 8. COMPRESSOR PRESSURE RATIO = ', F10.3)
003180 410 FORMAT ( ' 9. COMPRESSOR DISPLACEMENT, CF/MIN-TON = ', F10.3)
003190 480 FORMAT ( ' 10. COMPRESSOR ADIABATIC HEAD, FT-LB/LB = ', F10.3)
003200 700 FORMAT ( ' 11. SONIC VELOCITY COMPRESSOR INLET, F/S = ', F10.3)
003210 300 FORMAT ( ' 12. REFRIGERATION COP = ', F6.3)
003220 301 FORMAT ( ' 13. LSHX HEAT EXCHANGE, B/HR-TON = ', F10.3)
003230 302 FORMAT ( ' 14. COMPRESSOR SPEED AT ', I3, ' NS = ', F10.
3)
003240 303 FORMAT ( ' 15. COMPRESSOR DIA. AT ', F5.2, ' DS, INCHES = ', F6
.3)
003250 310 FORMAT ( '//, ' CALCULATED OVERALL CYCLE PERFORMANCE, /TON ')
003260 315 FORMAT ( ' 1. OVERALL COP, W/O PUMP = ', F6.3)
003270 380 FORMAT ( ' 2. TOTAL CONDENSER REJECTION, B/HR-TON = ', F10.3,
003280 $ '////////')
003290 WRITE (6,500)
003300 WRITE (6,510) T71,PCAC,H71
003310 WRITE (6,520) T1,PB,H1
003320 WRITE (6,530) TB,PB,H14
003330 WRITE (6,540) T2,PB,H2,U2,S2
003340 WRITE (6,550) T4,P4,H4,S2

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00350 WRITE (6,550) TCRC,PCRC,H5
00360 WRITE (6,570) T6,P4,H6,U6
00370 WRITE (6,580) T7,PCRC,H7,U7
00380 WRITE (6,590) T101,P3,H101
00390 WRITE (6,600) T10,P10,H10,U10,S10
00400 WRITE (6,610) T11,P11,H11,S10
00410 WRITE (6,620) T12,P11,H12,U12
00420 WRITE (6,630) TCRC,PCRC,H51
00430 500 FORMAT ( ' STATE POINT',4X,'T',9X,'P',9X,'H',9X,'U',9X,'S')
00440 510 FORMAT ( ' 71 ',3F10.3)
00450 520 FORMAT ( ' 1 ',3F10.3)
00460 530 FORMAT ( ' 14 ',3F10.3)
00470 540 FORMAT ( ' 2 ',5F10.3)
00480 550 FORMAT ( ' 4 ',3F10.3,10X,F10.3)
00490 560 FORMAT ( ' 5 ',3F10.3)
00500 570 FORMAT ( ' 6 ',4F10.3)
00510 580 FORMAT ( ' 7 ',4F10.3)
00520 590 FORMAT ( ' 101 ',3F10.3)
00530 600 FORMAT ( ' 10 ',5F10.3)
00540 610 FORMAT ( ' 11 ',3F10.3,10X,F10.3)
00550 620 FORMAT ( ' 12 ',4F10.3)
00560 630 FORMAT ( ' 51 ',3F10.3,///)
00570 WRITE (6,690)
00580 WRITE (6,710)
00590 WRITE (6,720) QHX3,DTHX3,UAHX3,APHX3
00600 WRITE (6,730) QHX2,DTHX2,UAHX2,APHX2
00610 WRITE (6,740) QLSHX,DTLSHX,UALSHX,APLSHX
00620 WRITE (6,750) QBOILR,DTBOIL,UABOIL,PINCH
00630 WRITE (6,760) QBSENS,DTPRHT,UAPRHT,PINCH
00640 WRITE (6,770) CONDR,DTCR,UACR,APCR
00650 WRITE (6,780) CONDR,DTCR,UACR,APCR
00660 WRITE (6,790) QEVAP,DTEVAP,UAEVAP,APEVAP
00670 690 FORMAT ( ' HEAT EXCHANGER ',4X,'HEAT',9X,'LMED',7X,
00680 $ 'UA',9X,'APPROACH')
00690 710 FORMAT ( ' BTU/HR-TON',6X,'DEG F',
00700 $ 4X,'BTU/HR-F-TON',4X,'DEG F')
00710 720 FORMAT ( ' REGENERATOR,EXPANDER ',4F12.3)
00720 730 FORMAT ( ' REGENERATOR,COMPRESSOR',4F12.3)
00730 740 FORMAT ( ' LIQUID-SUCTION HEAT-EX',4F12.3)
00740 750 FORMAT ( ' BOILER SECTION ',4F12.3)
00750 760 FORMAT ( ' PREHEATER SECTION ',4F12.3)
00760 770 FORMAT ( ' CONDENSER, RANK. CYCLE',4F12.3)
00770 780 FORMAT ( ' CONDENSER, REFR. CYCLE',4F12.3)
00780 790 FORMAT ( ' EVAPORATOR/CHILLER ',4F12.3)
00790 END
READY

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APPENDIX A-1.2-2

REFRIGERANT SELECTION MATRIX

D R A F T

REFRIGERANT SELECTION MATRIX

1.1 General

In order to give consideration to unrelated parameters in the selection of a refrigerant for use in the SAC 3 chiller system, points were subjectively assigned for each parameter. In order to give a particular parameter its due weight with respect to all others, a weighting system was used. Each parameter was weighted and then assigned a relative rating number of 0 to 10.

The major groups of parameters and their assigned points follow in the table below:

Reliability	400
First Costs	400
Acceptance	100
Development Costs	100
Operating Power Costs	<u>350</u>
Total	1,350

2.1 Reliability

2.2.1 Safety Environment

1. Fire Explosion	100
2. Toxicity	150
3. Environment	20
4. Operational Pressures	20
5. Refrigerant Stability	100
6. Effect on Materials	<u>10</u>
	400 points

2.2.2 Fire Explosion-Toxicity Data - ASHRAE Handbook of Fundamentals 1972

Chapter 14, Page 253.

Refrigerant	ANSI-B9.1 Safety Code Group	Toxicity		Explosive-Fire	
		UL Group Classification	Selection Rating 0-10	Explosive Limits in Air	Selection Rating 0-10
R-11	1	5	6	Non-Flam.	10
R-12	1	6	8	"	10
R-113	1	4-5	5	"	10
R-114	1	6	8	"	10

Group 6 - Gases or vapors up to 20% no apparent injury.

Group 5 - Less toxic than 6 but more than 4.

Group 4 - Gases or vapors up to 2-1/2% no apparent injury.

2.2.3 Environment Data

		Selection Rating 0-10
R-11	CCl_3F	2
R-12	CCl_2F_2	2
R-113	$\text{CCl}_2\text{FCClF}_2$	2
R-114	$\text{CClF}_2\text{CClF}_2$	2

2.2.4 Operational Pressures

	P_{critical}	Evap.	Cond.	Boiling	Selection Rating 0-10
R-11	639.5	7.0	33.0	231.0	6
R-12	596.9	51.7	172.3	700.0	2
R-113	498.9	2.7	15.4	131.7	4
R-114	473.0	15.1	62.7	383.4	6

2.2.5 Refrigerant Stability

	%/yr @ 300 "A"	"R"	Selection Rating 0-10
R-11	0.716	-123.2	*
R-12	0.066	6.8	7
R-113	0.084	3.2	3
R-114	0.071	5.8	6

Bases for Selection Rating

2.2.6 Effect on Materials - Data per ASHRAE Handbook of Fundamentals (1972)

Chapter 14, page 254.

	Linear Swell, Percent		Plastic Swelling			Selection Rating 0-10
	Bunan	Neoprene	Polyethylene	Polyvinyl Chloride	Poly Styrene	
R 11	6	17	6.7	0	*	2
R-12	2	0	0.4	0	-0.1	6
R-113	1	3	2.3	0	-0.2	4
R-114	0	2	0.6	0.1	-0.2	6

2.2.7 Summary Reliability

	R-11	R-12	R-113	R-114
Fire Explosion	100	100	100	100
Toxicity	90	120	75	120
Environment	4	4	4	4
Operational Pressures	12	4	8	12
Refrigerant Stability	*	70	30	60
Effect on Materials	2	6	4	6
TOTAL	208*	304	241	272

3.1 First Costs

3.1.1 General

In estimating the effect on costs with respect to refrigerant, the following points were assigned to each group.

1.	Collector	300
2.	Compressor	10
3.	Heat Transfer Surface	73
4.	Expander	10
5.	Condensate Pump	5
6.	Cond. Fan Motor	<u>2</u>
	TOTAL	400 points

3.1.2 Collector

Refrigerant	Cycle	"R"	Selection Rating 0-10
R-11	0.714	10.56	10
R-12	0.532	3.28	3
R-113	0.707	10.28	10
R-114	0.611	6.44	6

$$R = 40(\overline{\text{PERF}}) - 13$$

3.1.2 Compressor

	<u>Suction Line Connect</u>	<u>Speed</u>	<u>Wheel Diam. Inches</u>	<u>Selection Rating 0-10</u>
R-11	1.06	38,280	4.04	8
R-12	0.75	74,720	1.87	6
R-113	1.89	21,640	6.50	7
R-114	1	39,630	3.26	8

3.1.3 Heat Transfer Surface

	<u>ft² outside/ton</u>				<u>ft² inside/ton</u>			
	<u>Evaporator</u>	<u>Condenser</u>	<u>Boiler & Preheater</u>		<u>Evaporator</u>	<u>Condenser</u>	<u>Preheater</u>	<u>Boiler</u>
			<u>Preheater</u>	<u>Boiler</u>				
R-11	10.5	328.4	3.32	10.72	2.96	16.26	2.84	3.02
R-12	8.6	616.7	4.513	3.06	2.42	30.54	3.86	0.86
R-113	17.6	464.4	5.99	12.12	4.96	23.00	5.12	3.41
R-114	10.6	459	6.74	15.58	2.99	22.73	5.76	4.39
SR	3.55	20.193	1.17	3.55	3.55	20.193	1.17	3.55

	<u>Evap. Preheat Boiler</u>	<u>Condenser</u>	<u>Total Surface</u>	<u>"SR" Ratio Total Surface to R-11</u>	<u>"R" Selection Ratio 0=10</u>
R-11	8.82	16.26	25.08	1.00	10.0
R-12	6.96	30.54	37.58	1.50	6.7
R-113	13.49	23.00	36.49	1.45	6.9
R-114	13.14	22.73	35.87	1.43	7.0

$$R = 10 \left(\frac{1}{SR} \right)$$

3.1.4 Expander

Refrigerant	Inlet Line Coun	Inlet Press	Speed	Wheel Diameter, in.	R Selectic Ratio 0-10
R-11		231	49,320	2.42	6
R-12		700	59,015	1.59	6
R-113		132	33,760	3.35	7
R-114		383	45,050	2.18	6

3.1.5 Condensate Pump

Ref.	Flow #/hr	v ft ³ /#	Displace Vol ft ³ /hr	hp/ton	Selection Ratio 0-10
R-11	216	0.011	2.38	0.07	10
R-12	408	0.013	5.304	0.41	4
R-113	231	0.011	2.54	0.04	10
R-114	338	0.012	4.06	0.18	5

3.1.6 Cond. Fan Motors

Ref	Coil ΔP	Air BHP/ton	R
R-11	0.128	0.06	10
R-12	0.242	0.12	5
R-113	0.181	0.09	7.5
R-114	0.176	0.09	7.5

Note: See Condenser Surface Cal for Data

3.1.7 Summary First Costs

	<u>R-11</u>	<u>R-12</u>	<u>R-113</u>	<u>R-114</u>
Collector	300	90	300	180
Compressor	8	6	7	8
Heat Transfer Surface	73	49	50	51
Expander	6	6	7	6
Condensate Pump	5	2	5	3
Cond. Fan Motors	2	1	1	1
TOTAL	<u>394</u>	<u>154</u>	<u>370</u>	<u>249</u>

4.1 ACCEPTANCE

1. Serviceability	10
2. Noise and Vibration	30
3. Size - Weight	30
4. Installation Costs	<u>30</u>
	100

4.1.1 SERVICEABILITY

	Availability Experience	High Pressure	Evap. Press	Selection Ratio 0 - 10
R-11	8	7	3	6
R-12	8	2	8	6
R-113	8	7	3	6
R-114	6	5	5	5

4.1.2 NOISE AND VIBRATION

Refrig.	Comp. Speed	Turbine Speed	Cond. Pump HP	Cond. Fan HP	Selection Ratio 0 - 10
R-11	38,280	49,320	.07	.06	8
R-12	74,720	59,015	.41	.12	5
R-113	21,640	33,760	.04	.07	10
R-114	39,630	45,050	.18	.09	7

4.1.3 SIZE - WEIGHT

Refrig.	Total Surface	Selection Ratio
R-11	23	10
R-12	38	5
R-113	30	8
R-114	36	6

4.1.4 INSTALLATION COSTS

Assume no difference at 25 points each.

4.1.5 SUMMARY ACCEPTANCE

	R-11	R-12	R-113	R-114
Serviceability	6	6	6	5
Noise and Vibration	24	15	30	21
Size - Weight	30	15	24	18
Installation Costs	25	25	25	25
Total	85	61	85	69

5.1 DEVELOPMENT COSTS

Assume no difference in development costs for the four refrigerants. Use 75 points each.

6.1 OPERATING COSTS

Based on operating cost savings = 400 points for \$2,300 worth of savings or about a 4 to 1 ratio of first costs to operating cost savings.

Yearly operating costs based on 2,628 hours of cooling operation per year (30% of time unit on).

6.1 OPERATING COSTS (cont'd.)

	Cond. Pump	Fan Power	Total Power	"C" Estimated Yearly Costs Electrical	Points	"R" Selection Ratio 0 - 10
R-11	.07	.06	.13	\$ 532	308	8.8
R-12	.41	.12	.53	2,170	21	0.60
R-113	.04	.07	.11	450	322	9.2
R-114	.18	.09	.27	1,105	207	5.9

Equation for Points

$$\text{Points} = \left(\frac{2300 - C}{2300} \right) (400)$$

$$R = \text{Points}/35 \quad \text{or} \quad \text{Points} = 35(R)$$

7.1 REFRIGERANT SELECTION MATRIX

	Relative Weight	R-11	R-12	R-113	R-114
Reliability	400	208*	304	241	272
First Costs	400	394	154	370	249
Acceptance	100	85	61	85	69
Development Costs	100	75	75	75	75
Operating Costs	400	308	21	322	207
Total	1,400	1,070*	615	1,093	872

* Refrigerant not stable at the operating temperatures of the cycle compared.

APPENDIX A-1.4-1

BASIS FOR PRODUCTION VOLUME ESTIMATES

APPENDIX

A 1.4 BASIS FOR PRODUCTION VOLUME ESTIMATES

ARI Industry Shipments data were analyzed for 25 ton unitary equipment and 25 ton water chillers. Projections were made to the year 1982. Historically, 25 ton unitary equipment represents approximately 3% of all sizes of unitary equipment, while 25 ton chillers represent approximately 6-1/2% of all sizes of chillers. Figure A 1.4-1 plots ARI shipment data from 1970 to 1982, for 25 ton unitary and 25 ton chillers.

Considering that any one manufacturer will ship only a fraction of the total, and that solar equipment will be some fraction of those shipments, then 5 to 10% of the 25 ton unitary business would be a reasonable goal at the outset. Further, if only one size solar unit was available initially, it would be in competition with more sizes and a larger share of the total unitary business than just the 25 ton business, and tend to raise the volume. On this basis, we assumed a single manufacturer production level will be 10% or 500 per year for cost estimating purposes.

INDUSTRIAL ACTUAL AND PROJECTED SHIPMENTS OF 25 TON UNITARY AND CHILLERS 1970-1982

NOTE:

HISTORICALLY, 25 TON UNITARY
REPRESENTS APPROX 37.5% OF ALL
UNITARY, AND 25 TON CHILLERS
REPRESENTS APPROX 65% OF ALL
CHILLERS

UNITARY SHIPPED

10000

8000

6000

4000

2000

1000

500

0

TOTAL 25 TON
UNITARY

ACTUAL ← → PROJECTED

TOTAL 25 TON
CHILLERS; AIR-WATER
COOLERS

70 1 2 3 4 5 6 7 8 9 80 1 2

1977

YEAR

APPENDIX A-1.4-2

RANK1Ø, DUAL LOOP RANKINE CYCLE SIMULATION

Variable List

Input Variables

1. NREF Refrigerant number; i.e., 113
2. TB Initial guess of saturated boiling temperature, °F
3. TC Initial guess of saturated condensing temperature, °F
4. TE Initial guess of saturated evaporating temperature, °F
5. TSUB Subcooling produced by the condenser, °F
6. TSUP Evaporator superheat, °F
7. TSUPHT Boiler superheat, °F
8. TSOL Solar water temperature entering the boiler, °F
9. GPMS Solar water flow rate per ton, gpm/ton
10. TAIR Ambient air temperature entering the condenser, °F
11. CFM Air flow through the condensers in series, per ton, cfm/ton
12. CWT Chilled water temperature leaving the chiller, °F
13. GPMCN Chilled water flow rate per ton, gpm/ton
14. ETAEXP Initial guess of expander adiabatic efficiency
15. ETACOM Initial guess of compressor adiabatic efficiency
16. ETAPUM Pump adiabatic efficiency
17. ALOSS Mechanical losses assigned to the drive between the turbine and compressor
18. ETALSH Initial guess of liquid suction heat exchanger effectiveness
19. PVLSH Pressure drop of liquid suction heat exchanger, vapor side, psi
20. PLLSH Pressure drop of liquid suction heat exchanger, liquid side, psi
21. ETAHX Initial guess of regenerator effectiveness
22. PREG Pressure drop in the regenerator
23. DELT Convergence tolerance for heat exchanger heat rates
24. UAHX Overall surface heat transfer coefficient for the regenerator, Btu/hr°F
25. UALSHX Overall surface heat transfer coefficient for the liquid suction heat exchanger, Btu/hr°F
26. UAPRHT Overall surface heat transfer coefficient for the preheater, Btu/hr°F
27. UABOIL Overall surface heat transfer coefficient for the boiler, Btu/hr°F
28. UACR Overall surface heat transfer coefficient for the condenser, Btu/hr°F
29. UAEVAP Overall surface heat transfer coefficient for the evaporator, Btu/hr°F
30. TONS Initial guess of chiller capacity, tons
31. PCOND Pressure drop in condenser, psi
32. TDELT Convergence tolerance for heat exchanger saturation temperatures, °F
33. DELTON Convergence tolerance for chiller capacity, tons
34. IRUN Run number
35. IMO, IDAY, IYR, Month, day and year of run
36. FPHIC Flow parameter scale factor for compressor
37. TTPHIT Choked turbine scale factor
38. VANED R-114 compressor diffuser type 0-vaneless
1-vaned

Output Variables

1.	QBOILR	Boiler heat rate, Btu/hr
2.	QBOIL	Combined boiler/preheater heat rate, Btu/hr
3.	QPRHT	Preheater heat rate, Btu/hr
4.	FPRHT	Percent of QBOIL attributed to the preheater
5.	QHX	Regenerator heat rate, Btu/hr
6.	ETAHX	Regenerator effectiveness
7.	WRC	Rankine cycle refrigerant flow rate, lb m/hr ton
8.	EXPRAT	Turbine expansion ratio
9.	ETAT2	Rankine cycle efficiency
10.	QPUMP	Refrigerant pump power, hp
11.	ETAEXP	Turbine adiabatic efficiency
12.	TPHIT	Turbine flow parameter
13.	QEVAP	Evaporator capacity, Btu/hr
14.	TONS	Evaporator capacity, tons
15.	QLSHX	Liquid suction heat exchanger heat rate, Btu/hr
16.	QCOMP	Compressor power required, hp
17.	COMRAT	Compression ratio
18.	TPHIC	Compressor flow parameter if scale factor was equal to 1
19.	COP	Vapor compression cycle's coefficient of performance
20.	WRF	Vapor compression cycle refrigerant flow rate, lb m/hr ton
21.	ETALSH	Liquid suction heat exchanger effectiveness.
22.	ETACOM	Compressor adiabatic efficiency
23.	ATPHIC	Compressor flow parameter
24.	QCOND	Condenser heat rejection rate, Btu/hr
25.	OCOP	Overall combined cycle coefficient of performance
26.	TB	Boiler saturation temperature, °F
27.	TC	Condenser saturation temperature, °F
28.	TE	Evaporator saturation temperature, °F
29.	TSOL2	Solar water temperature at boiler outlet, °F
30.	TSOL3	Solar water temperature at preheater outlet, °F
31.	ECWT	Entering water temperature to chiller, °F
32.	TA	Air temperature at condenser outlet, °F
33.	SPEED	Percent of turbine design point speed
34.	FLOS	Surge line flow parameter at specified shaft speed
35.	FLOC	Choke line flow parameter at specified shaft speed

Listing of RANK10

```

00010      DEFINE FILE 11(10,80,U,IREF)
00020      READ *,NREF,
00030      $    TB,TC,TE,TSUB,TSUP,TSUPHT,
00040      $    TSOL,GPMS,TAIR,CFM,CWT,GPWCW,
00050      $    ETREXP,ETACOM,ETAPUM,ALOSS,
00060      $    ETALSH,PULSH,PLLSH,ETAHX,PREG,
00070      $    DELT,UAHX,UALSHX,UAPRHT,UABOIL,UACR,UAEVAP,
00080      $    TONS,PCOND,TDELT,DELTON,
00090      $    IRUN,IMO,IDAY,IYR,FPHIC,TPPHIT,UANED.
00100      CALL NNN(NREF)
00110      TON1=TONS
00120      ETREX1=ETREXP
00130      ETAC01=ETACOM
00140      CL=1.
00150      CH=1.
00160      CC=1.
00170      CB=1.
00180      CE=1.
00190      CT=1.
00200      CLS=1.
00210      TB2=TB
00220      TC2=TC
00230      TE2=TE
00240      T1=0.
00250      T1=0.
00260      BAL=0.
00270      NBAL=0
00280      500 CONTINUE
00290      BAL=BAL+1.
00300      NBAL=NBAL+1
00310      BBAL=BAL/2.
00320      NNBAL=NBAL/2
00330      TC1=TC
00340      TB1=TB
00350      TE1=TE
00360      ETLSH1=ETALSH
00370      ETAHX1=ETAHX
00380      GO TO 41
00390      402 TE1=TE
00400      TE=TE1
00410      401 TB1=(TB+TB1)/2.
00420      TB=TB1
00430      40 TC1=(TC+TC1)/2.
00440      TC=TC1
00450      CT=CT+1.
00460      41 T7=TC-TSUB
00470      PC=SPXX(TC)
00480      P5=PC+PCOND
00490      P15=P5
00500      IF(UAHX.LE.0.) PREG=0.
00510      P4=P5+PREG
00520      P11=P4
00530      P6=P4
00540      P12=P4

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00550      P13=P4
00560      T5=STXX(P5)
00570      U5=SUXX(T5,P5)
00580      H5=HUXX(T5,P5,U5)
00590      H7=HLXX(T7)
00600      T2=TB+TSUPHT
00610      P3=SPXX(T2)
00620      U2=SUXX(T2,P3)
00630      H2=HUXX(T2,P3,U2)
00640      S2=EVXX(T2,U2)
00650      H14=HLXX(T3)
00660      T14=TB
00670      CALL PSHT(P4,S2,H4,T4)
00680      T101=TE+TSUP
00690      P101=SPXX(TE)
00700      IF (UALSHX.LE.0.) T10=T101
00710      IF (UALSHX.LE.0.) PULSH=0.
00720      IF (UALSHX.LE.0.) ETALSH=0.
00730      P10=P101-PULSH
00740      IF (T10) 1,1,2
00750      1 T10=T101+(T7-T101)*ETALSH
00760      2 U101=SUXX(T101,P101)
00770      H101=HUXX(T101,P101,U101)
00780      U10=SUXX(T10,P10)
00790      H10=HUXX(T10,P10,U10)
00800      S10=EVXX(T10,U10)
00810      CALL PSHT(P11,S10,H11,T11)
00820      QC=(H11-H10)/ETACOM
00830      H12=H10+QC*(1.+ALOSS)
00840      CALL PHUT(P12,H12,U12,T12)
00850      COMRAT=P12/P10
00860      TL=T7-10.
00870      HL=HLXX(TL)
00880      CP=(H7-HL)/10.
00890      IF (CLS.NE.1.) GO TO 112
00900      110 H71=H7
00910      H71I=H71
00920      GO TO 111
00930      105 CLS=CLS+1.
00940      112 QLSH=(H10-H101)*WRF
00950      IF (UALSHX.LE.0.) QLSH=0.
00960      H71I=H71
00970      H71=H7-QLSH/(WRF)
00980      T71=T7-QLSH/((WRF)*CP)
00990      P71=PC-PLLSH
01000      IF (UALSHX.LE.0.) P71=PC
01010      111 QE=H101-H71
01020      WRF=12000./QE
01030      QCOMP=QC*WRF*TONS/2545.
01040      D7=DLXX(T7)
01050      U7=1./D7
01060      QW=(H2-H4)*ETAREXP
01070      H6=H2-QW
01080      CALL PHUT(P6,H6,U6,T6)
01090      WRC=(1.+ALOSS)*QC*WRF/QW
01100      H13=(H12*WRF+H6*WRC)/(WRF+WRC)
01110      DH71=ABS(H71I-H71)
01120      TOL71=(DH71/H71)*100.
01130      IF (CLS.EQ.1..OR.TOL71.GT.DELT) GO TO 105
01140      IF (UAHX.LE.0.) ETAXX=0.
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01150      CALL PHUT(P13,H13,U13,T13)
01160      IF(T1) 3,3,4
01170      3 T1=T7+(T13-T7)*ETAHX
01180      4 H1=HLXX(T1)
01190      QHX=WRC*(H1-H7)
01200      H15=H13-QHX/(WRF+WRC)
01210      CALL PHUT(P15,H15,U15,T15)
01220      IF(UAHX.LE.0.) GO TO 450
01230      CP1=(H1-H7)/(T1-T7)
01240      450 CONTINUE
01250      QB2=H2-H1
01260      QB2IL=QB2*WRC*TONS
01270      QBSENS=(H14-H1)*WRC*TONS
01280      QB2ILR=(H2-H14)*WRC*TONS
01290      QLSHX=QLSH*TONS
01300      QHX1=QHX*TONS
01310      QCOND=(H15-H7)*(WRF+WRC)*TONS
01320      QEVAP=12000.*TONS
01330      IF (UALSHX.LE.0.) GO TO 16
01340      17 DT1=T71-T101
01350      SOS1=1.
01360      IF(DT1.LE.0.) WRITE(6,100) SOS1
01370      DT2=T7-T10
01380      SOS2=2
01390      IF(DT2.LE.0.) WRITE(6,100) SOS2
01400      DTLSHX=(DT1-DT2)/ALOG(DT1/DT2)
01410      QLSHX2=UALSHX*DTLSHX
01420      IF (QLSHX2-QLSHX*(1.+DELT)) 14,14,15
01430      14 IF (QLSHX*(1.-DELT)-QLSHX2) 16,16,15
01440      15 QLSHX=(QLSHX+QLSHX2)/2.
01450      DELSHX=QLSHX/UALSHX
01460      T10=T10+(DTLSHX-DELSHX)
01470      U10=SUXX(T10,P10)
01480      H10=HUXX(T10,P10,U10)
01490      H71=H7-(H10-H101)
01500      T71=T7-(H7-H71)/CP
01510      CL=CL+1.
01520      GO TO 17
01530      16 CONTINUE
01540      IF(UAHX.LE.0.) GO TO 11
01550      13 DT4=T15-T7
01560      SOS3=3.
01570      DT5=T13-T1
01580      SOS4=4.
01590      DT4I=(T15+T13)/2.
01600      DT5I=(T7+T1)/2.
01610      DTHX=DT4I-DT5I
01620      QHX2=UAHX*DTHX
01630      IF (QHX2-QHX1*(1.+DELT)) 10,10,11
01640      10 IF (QHX1*(1.-DELT)-QHX2) 12,12,11
01650      11 QHX1=(QHX1+QHX2)/2.
01660      IF(UAHX.LE.0.) QHX1=0.
01670      H15=H13-QHX1/((WRC+WRF)*TONS)
01680      CALL PHUT(P15,H15,U15,T15)
01690      H1=QHX1/(WRC*TONS)+H7
01700      IF(UAHX.LE.0) T1=T7
01710      IF(UAHX.LE.0.) GO TO 12
01720      T1=T7+(H1-H7)/CP1
01730      CH=CH+1.
01740      GO TO 13

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01750      12 CONTINUE
01760      23 T21=TSOL-QBOILR/(500.*GPM5)
01770      T22=T21-QBSSENS/(500.*GPM5)
01780      IF(T14.GE.T21) T14=T21-.01
01790      SOS5=5.
01800      IF((T22-T1).LE.0.) WRITE(6,100) SOS5
01810      SOS6=6.
01820      IF((TSOL-TB).LE.0.) WRITE(6,100) SOS6
01830      DTPRHT=((T22-T1)-(T21-T14))/ALOG((T22-T1)/(T21-T14))
01840      DTBOIL=((TSOL-TB)-(T21-T14))/ALOG((TSOL-TB)/(T21-T14))
01850      QTOT=QBOILR+QBSSENS
01860      QTOT2=UAPRHT*DTPRHT+UABOIL*DTBOIL
01870      IF(QTOT2-QTOT*(1.+DELT)) 18,18,19
01880      18 IF(QTOT*(1.-DELT)-QTOT2)20,20,21
01890      19 TB=TB-(QTOT-QTOT2)/((UABOIL+UAPRHT)*2.)
01900      GO TO 22
01910      21 TB=TB+(QTOT2-QTOT)/((UABOIL+UAPRHT)*2.)
01920      22 T2=TB+TSUPHT
01930      PB=SPXX(T2)
01940      U2=SUXX(T2,PB)
01950      H2=HUXX(T2,PB,U2)
01960      S2=EUXX(T2,U2)
01970      H14=HLXX(TB)
01980      T14=TB
01990      QB2=H2-H1
02000      QBOIL=QB2*WRC*TONS
02010      QBSSENS=(H14-H1)*WRC*TONS
02020      SHF=QBSSENS*100./QBOIL
02030      QBOILR=(H2-H14)*WRC*TONS
02040      CB=CB+1.
02050      GO TO 23
02060      20 CONTINUE
02070      27 TA=TAIR+QCOND/(1.08*CFM)
02080      DTC1=T7-TAIR
02090      DTC2=T5-TA
02100      SOS7=7.
02110      IF(DTC1.LE.0.) WRITE(6,100) SOS7
02120      SOS8=8.
02130      IF(DTC2.LE.0.) WRITE(6,100) SOS8
02140      DTCR=(DTC1-DTC2)/ALOG(DTC1/DTC2)
02150      QCOND2=UACR*DTCR
02160      IF(QCOND2-QCOND*(1.+DELT)) 24,24,25
02170      24 IF(QCOND*(1.-DELT)-QCOND2) 26,26,25
02180      25 QCOND3=QCOND
02190      DELCON=QCOND3/UACR
02200      T7=T7-(DTCR-DELCOM)
02210      TC=T7+TSUB
02220 C  ASSUME H15-H7 DOES NOT VARY MUCH WITH PRESS,USE SAME QCOND
02230      CC=CC+1.
02240      GO TO 27
02250      26 CONTINUE
02260      33 ECNT=CNT+QEVAP/(500.*GPMCW)
02270      TCW1=ECNT-TE
02280      TCW2=CNT-TE
02290      SOS9=9.
02300      IF(TCW1.LE.0.) WRITE(6,100) SOS9
02310      SOS10=10.
02320      IF(TCW2.LE.0.) WRITE(6,100) SOS10
02330      DTEVAP=(TCW1-TCW2)/ALOG(TCW1/TCW2)
02340      QEVAP2=UAEVAP*DTEVAP

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02350 C    ASSUME SUPHT IN FLOODED COOLER NOT SIGNIFICANT FOR DTEVAP
02360      IF (QEVAP2-QEVAP*(1.+DELTA))30,30,31
02370      30 IF (QEVAP*(1.-DELTA)-QEVAP2)32,32,31
02380      31 TE=TE-(QEVAP-QEVAP2)/(UAEVAP*2.)
02390 C    ASSUME TONS CONSTANT FOR THIS ITERATION
02400      CE=CE+1.
02410      GO TO 33
02420      32 CONTINUE
02430      IF (TC.LT. (TC1-TDELTA).OR.TC.GT. (TC1+TDELTA)) GO TO 40
02440      IF (TB.LT. (TB1-TDELTA).OR.TB.GT. (TB1+TDELTA)) GO TO 401
02450      IF (TE.LT. (TE1-TDELTA).OR.TE.GT. (TE1+TDELTA)) GO TO 402
02460      PHIT=MRC*(T2+460.)**.5/(PB*3600.)
02470      PHIC=MRF*(T10+460.)**.5/(P10*3600.)
02480      TPHIT=PHIT*TONS
02490      TPHIC=PHIC*TONS/FPHIC
02500      ATPHIC=PHIC*TONS
02510      EXPRAT=PB/P6
02520      COMRAT=P12/P10
02530      IF (NREF.EQ.114) GO TO 750
02540      IF (VARED.EQ.1.) GO TO 791
02550      SPEED=49.640854*COMRAT-6.8966733*COMRAT**2+4.8063214*TPHIC
02560      $+.36910227*COMRAT**3+.43645545D-02*TPHIC**3-3.9063458*TPHIC*
02570      $COMRAT+.65464123*TPHIC*COMRAT**2-.035841316*COMRAT**3*TPHIC
02580      $+.19012101*TPHIC**2-.020666998*COMRAT*TPHIC**2-11.188171
02590      ETACOM=-.038236016*TPHIC+.001571198*SPEED*TPHIC
02600      $-.004414132*TPHIC**2-.80214901D-06*SPEED**3
02610      $+.36115868D-03*SPEED+.73226555
02620      GO TO 795
02630      791 SPEED=-2.1890225*COMRAT*TPHIC-.01877252*COMRAT**2*TPHIC**2+
02640      $.14957566D-03*TPHIC**3-3.1701447*COMRAT**2-.21440066*
02650      $COMRAT*TPHIC**2+.71320934*TPHIC*COMRAT**2+.79918471D-02*
02660      $TPHIC**3*COMRAT-.13495259*COMRAT**3+29.6013*COMRAT+
02670      $.52496209*TPHIC**2+2.3811324*TPHIC+10.682561
02680      ETACOM=.13776620D-03*TPHIC**5+1123.0762*ALOG (TPHIC)-
02690      $.27962557D-08*SPEED**5-13.526584*SPEED*ALOG (TPHIC)+
02700      $.11515565*(SPEED-100.)**2-11.0779*TPHIC**2-
02710      $.54027705D-03*TPHIC*SPEED**2+30.433321*SPEED*TPHIC**.5
02720      $+.10224163*SPEED*TPHIC**2-.12349022*SPEED**2+
02730      $.68265586D-06*SPEED**4+448.83442*TPHIC-.15341009D-02*
02740      $SPEED*TPHIC**3-.75810083D-02*TPHIC**4-2614.6447*TPHIC**.5
02750      $-4.9345875*TPHIC*SPEED+.30588910*TPHIC**3+863.57416
02760      795 CONTINUE
02770      TPHIT2=.065851817*EXPRAT-.70576625D-06*SPEED**3
02780      $-.37994856D-03*SPEED*EXPRAT-.010958649*EXPRAT**2
02790      $+.88975668D-03*EXPRAT**3-.24278706D-04*EXPRAT**4
02800      $+.44840648D-05*EXPRAT*SPEED**2-.11235189D-06*EXPRAT**2*SPEED
02810      $+.15297192D-03*SPEED**2-.0123372*SPEED+.57105446
02820      IF (TTPHIT.NE.0.) TPHIT2=TTPHIT
02830      ETAEXP=-.45256894D-04*EXPRAT**4+.11998145D-04*SPEED*EXPRAT**
02840      $3+.34251545D-07*SPEED**4+.0014180358*SPEED**2
02850      $+.89071936D-03*EXPRAT**3+.58462175D-05*EXPRAT*SPEED**2
02860      $+.79280863D-02*EXPRAT**2+.0042738345*SPEED*EXPRAT
02870      $-.44081447D-03*SPEED*EXPRAT**2-.22211429*EXPRAT
02880      $-.12202305D-04*SPEED**3-.077552288*SPEED+2.5145707
02890      GO TO 751
02900      750 CONTINUE
02910      SPEED=68.983025*COMRAT-12.617353*COMRAT**2+11.798707*TPHIC
02920      $+.12415542*COMRAT**3-12.159303*TPHIC*COMRAT-1.4773474*
02930      $COMRAT*TPHIC**2+.31632237*COMRAT*TPHIC**3

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02940 $+4.5367493*TPHIC*COMRAT**2-.47134062*TPHIC**2*COMRAT**2
02950 $+2.6356325*TPHIC**2-.12666728*TPHIC**3-25.085921
02960 ETACOM=-.94666797D-03*SPEED**2+.06024264*TPHIC
02970 $-.20552353*TPHIC**2+.9543032D-02*SPEED*TPHIC
02980 $+.05246098*SPEED-.014407291*TPHIC**3-.22056883D-03*SPEED
02990 $*TPHIC**3+.43429845D-02*SPEED*TPHIC**2-.15703041D-03*
03000 $TPHIC*SPEED**2+.68047524D-05*SPEED**3+.19169167D-02*TPHIC**
03010 $4-.93248951D-08*SPEED**4-.45791125
03020 TPHIT2=.11467318*EXPRAT-.64707192D-07*SPEED**3-.033620841*
03030 $EXPRAT**2+.62314907D-05*EXPRAT*SPEED**2-.38453414D-06*
03040 $SPEED**2*EXPRAT**2-.16625217D-03*EXPRAT**4-.22971277D-03*
03050 $SPEED*EXPRAT+.40707329D-02*EXPRAT**3-.73195562D-05*
03060 $SPEED**2+.17085645D-03*SPEED+.043039529
03070 IF(TTPHIT.NE.0.) TPHIT2=TPHIT
03080 ETAXP=.10721918D-07*SPEED**4+.95084828D-05*EXPRAT*SPEED**2
03090 $-.23973293D-02*SPEED*EXPRAT**2-.14225485D-02*EXPRAT**4
03100 $-.28650827*EXPRAT-.26635997D-05*SPEED**3+.014501325*SPEED*
03110 $EXPRAT+.12271506D-03*SPEED*EXPRAT**3+.022146503*EXPRAT**3
03120 $-.073046053*EXPRAT**2-.27441706D-02*SPEED+.83982270
03130 751 CONTINUE
03140 IF(BBAL.NE.NNBAL) GO TO 500
03150 DTONS=(TPHIT-TPHIT2)/(2.*TPHIT2)
03160 IF(ABS(DTONS*TONS).LE.DELTON) GO TO 600
03170 TONS=TONS*(1.-DTONS)
03180 GO TO 500
03190 600 CONTINUE
03200 IF(NREF.EQ.114) GO TO 752
03210 IF(VANED.EQ.1) GO TO 792
03220 FLOS=.37678571D-02*SPEED**2-.43225*SPEED+.15542857D+02
03230 FLOC=.21428571D-03*SPEED**2+.149*SPEED-2.9257143
03240 GO TO 753
03250 792 FLOS=.35089286D-02*SPEED**2-.381375*SPEED+13.041429
03260 FLOC=.12625D-02*SPEED**2-.040367857*SPEED+4.6631429
03270 GO TO 753
03280 752 CONTINUE
03290 FLOS=.91785714D-03*SPEED**2-.10123571*SPEED+4.0591429
03300 FLOC=.4625D-03*SPEED**2-.039996429*SPEED+3.5065714
03310 753 CONTINUE
03320 FHX=QHX1*100./(QHX1+QBOILR)
03330 COPOU2=12000.*TONS/QBOIL
03340 QPUMP=.18509*U7*WRC*TONS*(PB-P7)/(ETAPUM*2545.)
03350 DISPLP=WRC*U7/60.
03360 ETAT2=QW/QB2
03370 COP=QE/QC
03380 DEL=DELT*100
03390 ETAXX=(T1-T7)/(T13-T7)
03400 ETALSH=(T10-T101)/(T7-T101)
03410 UUC=SUXX(TC,PC)
03420 SCI=EUXX(TC,UUC)
03430 SC=SCI-HEXX(TC)/(TC+460.)
03440 CP7=(HLXX(TC)-HLXX(T7))/(TC-T7)
03450 S7=CP7*ALOG((T7+460.)/(TC+460.))+SC
03460 S15=EUXX(T15,U15)
03470 S6=EUXX(T6,U6)
03480 S12=EUXX(T12,U12)
03490 UU14=SUXX(T14,PB)
03500 S14I=EUXX(T14,UU14)
03510 S14=S14I-HEXX(T14)/(T14+460.)
03520 S13=EUXX(T13,U13)
03530 UUE=SUXX(TE,P101)

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03540      DHLE=HEXX(TE)
03550      HUE=HUXX(TE,P101,UUE)
03560      X9=1.-((HUE-H71)/DHLE)
03570      SFG9=DHLE/(TE+460.)
03580      SU9=EUXX(TE,UUE)
03590      SF9=SU9-SFG9
03600      S9=X9*SFG9+SF9
03610      CP14=(H14-H1)/(T14-T1)
03620      S1=CP14*ALOG((T1+460.)/(T14+460.))+S14
03630      IF(T1.NE.T7) CP8=(H7-H1)/(T7-T1)
03640      IF(T1.EQ.T7) CP8=0.
03650      S8=CP8*ALOG((T7+460.)/(T1+460.))+S1
03660      S5=EUXX(T5,U5)
03670      S101=EUXX(T101,U101)
03680      CPP=(H71-H7)/(T71-T7)
03690      S7P=CPP*ALOG((T71+460.)/(T7+460.))+S7
03700      U71=1./DLXX(T71)
03710      S71=-U71*144.*(P71-PC)/((T71+460.)*778.26)+S7P
03720      SPB=QBOILR/((TSOL+T21+920.)/2.)
03730      SPC=QCOND/((TA+TAIR+920.)/2.)
03740      SPE=QEVAP/((CWT+920.+ECWT)/2.)
03750      SPPH=QSENS/((T22+T21+920.)/2.)
03760      DSYS=-((TAIR+460.)*(SPB-SPC+SPE+SPPH)/TOMS
03770      SPCND=(S7-S15)+(H15-H7)/((TA+TAIR+920.)/2.)
03780      DCOND=(TAIR+460.)*(WRC+WRF)*SPCND
03790      DTURB=WRC*(TAIR+460.)*(S6-S2)
03800      DCOMP=WRF*(TAIR+460.)*(S12-S10)
03810      DMIX=(TAIR+460.)*(-WRC*S6-WRF*S12+(WRC+WRF)*S13)
03820      DRESUP=(TAIR+460.)*(S15-S13)
03830      DRESUP=DRESUP*(WRC+WRF)
03840      DPUMP=(TAIR+460.)*(S3-S7)*WRC
03850      DRELIO=(TAIR+460.)*(S1-S8)
03860      DRELIO=DRELIO*WRC
03870      DEVAP=((S101-S9)-(H101-H71)/((CWT+ECWT+920.)/2.))
03880      DEVAP=DEVAP*WRF*(TAIR+460.)
03890      DPRHT=(S14-S1)-((H14-H1)/((T21+T22+920.)/2.))
03900      DPRHT=DPRHT*(TAIR+460.)*WRC
03910      DBOIL=(S2-S14)-((H2-H14)/((TSOL+T21+920.)/2.))
03920      DBOIL=DBOIL*(TAIR+460.)*WRC
03930      DLSHXL=S71-S7
03940      DLSHXL=DLSHXL*(TAIR+460.)*WRF
03950      DLSHXS=S10-S101
03960      DLSHXS=DLSHXS*(TAIR+460.)*WRF
03970      DVALUE=(TAIR+460.)*(S9-S71)*WRF
03980      DREGEN=DRELIO+DRESUP
03990      DLSHX=DLSHXS+DLSHXL
04000      FITRB=DTURB/DSYS
04010      FDCMP=DCOMP/DSYS
04020      FIDND=IDCOND/DSYS
04030      FMIX=DMIX/DSYS
04040      FREGEN=DREGEN/DSYS
04050      FPUMP=DPUMP/DSYS
04060      FEVAP=DEVAP/DSYS
04070      FPRHT=DPRHT/DSYS
04080      FBOIL=DBOIL/DSYS
04090      FLSHX=DLSHX/DSYS
04100      FVALUE=DVALUE/DSYS
04110      50 FORMAT (///,'
04120      51 FORMAT ('
ENERGY SYSTEMS DIVISION')
RUN NO.',I3,'; DATE',I2,'/'

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04130      $      12,' ',12)
04140      52 FORMAT(//,' RANK10 DUAL LOOP RANKINE TURBO-COMPRESSOR CYCLE
')
04150      53 FORMAT(' WITH COMMON CONDENSER AND REGENERATOR ')
04160      799 FORMAT(' ALSO A VANED DIFFUSER COMPRESSOR ',/)
04170      54 FORMAT(//,' INPUT PARAMETERS: REFRIGERANT R',I4,
04180      $      ' CONVERGENCE TOLERANCES',F6.2,' %',F6.3,' F',F6.3,'
TONS')
04190      55 FORMAT('      TSOL      GPM5      TAIR:      CFM',
04200      $      '      CNT      GPMCN')
04210      56 FORMAT('      TSUB      TSUP      TSUPHT      ETAPUM',
04220      $      '      ALOSS')
04230      57 FORMAT('      PREG      PULSH      PLLSH')
04240      58 FORMAT('      UAHX      UALSHX      UAPRHT      UABOIL
UACR',
04250      $      '      UAEVAP')
04260      59 FORMAT(//,' INITIAL VALUES:')
04270      60 FORMAT('      TB      TC      TE      ETREXP',
04280      $      '      ETACOM')
04290      61 FORMAT('      ETALSH      ETAHX      TONS')
04300      62 FORMAT(///,' CALCULATED PERFORMANCE:')
04310      63 FORMAT(' RANKINE CYCLE:')
04320      64 FORMAT('      QBOILR      QBOIL      QPRHT      FPRHT',
04330      $      '      QHX      ETAHX')
04340      65 FORMAT('      WRC      EXPRAT      ETAT2      QPUMP',
04350      $      '      ETREXP      TPHIT')
04360      66 FORMAT(//,' COMPRESSION CYCLE:')
04370      67 FORMAT('      QEVAP      TONS      QLSHX      QCOMP',
04380      $      '      COMRAT      TPHIC')
04390      68 FORMAT('      COP      WRF      ETALSH      ETACOM',
04400      $      '      ATPHIC')
04410      69 FORMAT(//,' OVERALL CYCLE:')
04420      70 FORMAT('      QCOND      QOOP      TB      TC',
04430      $      '      TE')
04440      71 FORMAT('      TSOL2      TSOL3      ECNT      TA')
04450      76 FORMAT(///,' ITERATION COUNTERS:')
04460      77 FORMAT('      CL      CH      CC      CB      CE',
04470      $      '      CT      CLS')
04480      97 FORMAT(7F7.1)
04490      72 FORMAT(//,' CYCLE STATE POINTS:')
04500      73 FORMAT(' NUMBER      TEMPERATURE      PRESSURE      ENTHALPY',
04510      $      '      VOLUME      ENTROPY')
04520      661 FORMAT(//,' COMPRESSOR SURGE ')
04530      662 FORMAT(//,' CHOKED COMPRESSOR ')
04540      663 FORMAT('      SPEED      TPHIC      ',
04550      $      'FLOS      FLOC      ')
04560      78 FORMAT('      1      ',3F12.3,12X,F12.3)
04570      79 FORMAT('      14      ',5F12.3)
04580      80 FORMAT('      2      ',5F12.3)
04590      81 FORMAT('      4      ',3F12.3,12X,F12.3)
04600      82 FORMAT('      5      ',5F12.3)
04610      83 FORMAT('      6      ',5F12.3)
04620      84 FORMAT('      7      ',3F12.3,12X,F12.3)
04630      85 FORMAT('      71      ',5F12.3)
04640      86 FORMAT('      8      ',3F12.3,12X,F12.3)
04650      87 FORMAT('      9      ',5F12.3)
04660      88 FORMAT('      101      ',5F12.3)
04670      89 FORMAT('      10      ',5F12.3)
04680      90 FORMAT('      11      ',3F12.3,12X,F12.3)
04690      91 FORMAT('      12      ',5F12.3)

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04700      92 FORMAT( ' 13      ',5F12.3)
04710      93 FORMAT( ' 15      ',5F12.3)
04720     100 FORMAT(6F12.3)
04730     101 FORMAT(5F12.3,F12.4)
04740      WRITE(6,100) DSYS,DCOND,DTURB,DCOMP,DMIX,DREGEN
04750      WRITE(6,100) DPUMP,DEVAP,DPRHT,DBOIL,DLSHX,DVALUE
04760      WRITE(6,100) FDCND,FDTRB,FDCMP,FMIX,FREGEN
04770      WRITE(6,100) FPUMP,FEVAP,FPRHT,FBOIL,FLSHX,FVALUE
04780      WRITE(6,50)
04790      WRITE(6,51) IRUN,IMO,IDAY,IYR
04800      WRITE(6,52)
04810      WRITE(6,53)
04820      IF(UANED.EQ.1.) WRITE(6,799)
04830      WRITE(6,54) NREF,DEL,TDELT,DELTON
04840      WRITE(6,55)
04850      WRITE(6,100) TSOL,GPMS,TAIR,CFM,CWT,GPMCM
04860      WRITE(6,56)
04870      WRITE(6,100) TSUB,TSUP,TSUPHT,ETAPUM,ALOSS
04880      WRITE(6,57)
04890      WRITE(6,100) PREG,PULSH,PLLSH
04900      WRITE(6,58)
04910      WRITE(6,100) UAHX,UALSHX,UAPRHT,UABOIL,UACR,UAEVAP
04920      WRITE(6,59)
04930      WRITE(6,60)
04940      WRITE(6,100) TB2,TC2,TE2,ETAEX1,ETAC01
04950      WRITE(6,61)
04960      WRITE(6,100) ETLSHI,ETAHXI,TON1
04970      WRITE(6,62)
04980      WRITE(6,63)
04990      WRITE(6,64)
05000      WRITE(6,100) QBOILR,QBOIL,QBSENS,SHF,QHX1,ETAHX
05010      WRITE(6,65)
05020      WRITE(6,101) WRC,EXPRAT,ETAT2,QPUMP,ETAEXP,TPHIT
05030      WRITE(6,66)
05040      WRITE(6,67)
05050      WRITE(6,101) QEVAP,TONS,QLSHX,QCOMP,COMRAT,TPHIC
05060      WRITE(6,68)
05070      WRITE(6,100) COP,WRF,ETALSH,ETACOM,ATPHIC
05080      WRITE(6,69)
05090      WRITE(6,70)
05100      WRITE(6,100) QCOND,COPOU2,TB,TC,TE
05110      WRITE(6,71)
05120      WRITE(6,100) T21,T22,ECWT,TA
05130      IF(TPHIC.GE.FLOS.AND.TPHIC.LE.FLOC) GO TO 700
05140      IF(TPHIC.GE.FLOS) GO TO 660
05150      WRITE(6,661)
05160      GO TO 700
05170     660 WRITE(6,662)
05180     700 WRITE(6,663)
05190      WRITE(6,100) SPEED,TPHIC,FLOS,FLOC
05200      WRITE(6,76)
05210      WRITE(6,77)
05220      WRITE(6,97) CL,CH,CC,CB,CE,CT,CLS
05230      WRITE(6,72)
05240      WRITE(6,73)
05250      WRITE(6,78) T1,PB,H1,S1
05260      WRITE(6,79) T14,PB,H14,U14,S14
05270      WRITE(6,80) T2,PB,H2,U2,S2
05280      WRITE(6,81) T4,P4,H4,S2
05290      WRITE(6,82) T5,P5,H5,U5,S5
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05300      WRITE(6,83)  T6,P6,H6,U6,S6
05310      WRITE(6,84)  T7,PC,H7,S7
05320      WRITE(6,85)  T71,P71,H71,U71,S71
05330      WRITE(6,86)  T7,PB,H7,S8
05340      WRITE(6,87)  TE,P101,H71,U9,S9
05350      WRITE(6,88)  T101,P101,H101,U101,S101
05360      WRITE(6,89)  T10,P10,H10,U10,S10
05370      WRITE(6,90)  T11,P11,H11,S10
05380      WRITE(6,91)  T12,P12,H12,U12,S12
05390      WRITE(6,92)  T13,P13,H13,U13,S13
05400      WRITE(6,93)  T15,P15,H15,U15,S15
05410      END
```

APPENDIX A-1.5-1

PARAMETERS OF A TYPICAL LOW RISE MULTIFAMILY RESIDENTIAL STRUCTURE
THAT COMPLIES WITH AHSRAE STD. 90-75R
"ENERGY CONSERVATION IN NEW BUILDING DESIGN"

APPENDIX A1.5-1

PARAMETERS OF A TYPICAL LOW RISE MULTIFAMILY RESIDENTIAL STRUCTURE
THAT COMPLIES WITH ASHRAE STD. 90-75R
"ENERGY CONSERVATION IN NEW BUILDING DESIGN"

A. DESCRIPTION

16 Apartments/Building

2 Stories

880 ft² per apartment

Slab foundation with 24" of insulation around perimeter having an
R of at least 4.35 $\frac{\text{F}\cdot\text{hr}\cdot\text{ft}^2}{\text{Btu}}$

Flat roof with mansard treatment for maximum collector area.

B. DIMENSIONS

Depth 32'

Width 30'

Floor Height 8'

Hall 8' x 10'

Overhang, Front 24", back 24", end 24"

Windows Front 48 ft² single strength

Back 40 ft² single strength

35 ft² double glazed door

Overhang 16" above windows

C. CONSTRUCTION

1.	Exterior walls, lower	Brick	3.5"
		Fiberboard	0.5"
		Fiberglass	3.5"
		Drywall	0.5"
2.	Exterior walls, upper	Asphalt Shingle	0.3"
		Plywood	0.375"
		Air Space	0-24"
		Fiberboard	0.5"
		Fiberglass	3.5"
		Drywall	0.5"
3.	Interior walls	Drywall	0.625"
		Drywall	0.625"

4. Roof	Built up roofing	0.25"
	Plywood	0.5"
	Fiberglass	6"
	Drywall	0.5"
5. Floor, lower	Carpet	0.75"
	Concrete	3.5"

D. MISCELLANEOUS - LOADS PER APARTMENT

Infiltration 1 air change/hour

<u>Time</u>	<u>People</u>	<u>Evaporation</u> <u>lbH₂O/hr</u>	<u>Electric</u> <u>Btu/hr</u>
12-8 a.m.	3	0	450
8 a.m.-6 p.m.	1	0.8	550
6 p.m.-12 a.m.	3	0.5	2,300

APPENDIX A-1.5-2

PARAMETERS FOR A TYPICAL LOW RISE COMMERCIAL OFFICE
THAT COMPLIES WITH ASHRAE STD. 90-75R
"ENERGY CONSERVATION IN NEW BUILDING DESIGN"

APPENDIX A1.5-2

PARAMETERS FOR A TYPICAL LOW RISE COMMERCIAL OFFICE
THAT COMPLIES WITH ASHRAE STD. 90-75R
"ENERGY CONSERVATION IN NEW BUILDING DESIGN"

A. DESCRIPTION

Single Zone
2 Story
Flat Roof, 2' Parapet
Slab building

B. DIMENSIONS

Width 74'
Depth 74'
Height/Floor 11'
No Overhang
Windows, 20% of Each Wall

Single Strength, metal casement with storm windows or other appropriate treatment to get U to 0.54 or less.

C. CONSTRUCTION

Exterior Walls

Face Brick	4"
Concrete Block	8"
Furring	2"
2" Insulation	
Drywall	0.5

Roof

Built-up roofing	0.375"
Insulation	3"
Metal Deck	
Air Space	2'
Acoustic Tile	0.5"

Floor

Slab Concrete	4" with 24" of insulation around perimeter having an R of at least $4.5 \frac{\text{F}\cdot\text{hr}\cdot\text{ft}^2}{\text{Btu}}$
---------------	---

(NOTE: None required in Phoenix.)

D. MISCELLANEOUS LOADS

Infiltration		1 Air Change/hour	
<u>Time</u>	<u>People</u>	<u>Evaporation</u> <u>lb H₂O/hr</u>	<u>Electric</u> <u>Btu/hr</u>
12-8 a.m.	0	0.5	6,000***
8 a.m.-6 p.m.****	55	2.0	130,900*
6 p.m.-12 a.m.	5	0.5	13,000**

* 3.5 w/ft²

** 10% of max.

*** 5% of max.

**** 8-6 Diversity Factor

People 0.9

Lights 0.85

APPENDIX A-1.5-3

TYPE 42 MASTER CONTROLLER/TABLE LOOK-UP

TYPE 42 MASTER CONTROLLER/TABLE LOOK-UP

General Description

The need for a single unit designed to handle the logical control of a system becomes quite evident when modeling systems of even moderate size. TYPE 15 algebraic units are rather limited in their ability to model complex control operations, and the difficulty in determining when the system is in a particular state or mode, and the cause of the transition into or out of that state is immense. Mode 1 of the TYPE 42 master controller/table look-up unit provides a simple, efficient means of setting up to 19 (but easily extended) output control signals, such as for pumps, auxiliary heaters, fans, flow diverters, etc., from 10 (but easily extended to 32) input control signals, such as from thermostats. The Mode 1 operation also allows for the printing of the current simulation time, iteration step, input signal array, and output signal array whenever the state of the system changes. Since a table look-up procedure is the basis for the Mode 1 operation, Mode 2 allows the modeler to take advantage of this fact and utilize the unit as a simple table look-up unit, similar in effect to a TYPE 14 forcing function unit, except that the table values are stored on a file instead of as parameters, and no interpolation is performed. The unit in Mode 2 also requires an exact match between the search argument and the table. This unit might be used to determine an energy consumption value that changes for discrete values of say 1 through 9, of some input function or variable such as system state or compressor output level (in the latter case, a type 15 unit would be needed to scale the output and select a value of 1 through 9).

Mode 1 Set-up

While perhaps not the most elegant or sensible, the following model of a residential heating system will be used to illustrate the Mode 1 set-up procedure.

4.42-2

The system has eight states or modes of operation:

- (1) Null
- (2) Heat pump to load
- (3) Heat pump to storage
- (4) Storage to load
- (5) Heat pump to load and auxiliary heater
- (6) Storage to load and auxiliary heater
- (7) Heat pump to load with defrost and auxiliary heater if previously called for
- (8) Heat pump to storage with defrost

Note that state (7), a heat pump defrost state, requires the auxiliary heater to remain on only if it was previously on, as would occur when switching from states 5 or 6 to state 7, but remain off when switching from state 3 to state 7. The control functions for the various units for each state are:

State	Heat Pump	Pump	Fan	Aux. Htr.	Valve 1	Valve 2	Valve 3	Valve 4	Valve 5
1	off	off	off	off	—	—	—	—	—
2	on	off	on	off	off	on	off	on	on
3	on	off	off	off	on	off	on	on	on
4	off	on	on	off	off	on	on	off	off
5	on	off	on	on	off	on	off	on	on
6	off	on	on	on	off	on	on	off	off
7	on	off	on	previous	off	on	off	on	on
8	on	off	off	off	on	off	on	on	on

4.42-3

The following logic tree determines the state of the system.

Clearly, no single thermostat alone controls a particular system element, and the setting of some thermostats are, at times, irrelevant for determining the system state. In Mode 1, the TYPE 42 unit will set the appropriate on/off output signals for each of the nine states as determined by the on/off signals from the six thermostats and controllers. In order to generate the appropriate logic table for the unit, first construct an input table and an output table as shown below. For the input table each row corresponds to the settings, zero or one, of each decision point (diamond in the above logic tree) encountered when tracing the path from the start of the logic tree to the state. If a decision point is not encountered, the corresponding table entry is blank. For state 3, T_1 , T_3 , T_5 , and T_6 are encountered, with settings of 0, 0, 0, and 1, respectively. If there is more than one path to a state, add an additional state for each path. The control settings will be the same as for the original state. In the example, states 9 through 12 were added, having output settings corresponding to states 1, 7, 5, and 2, respectively.

4.42-4

The output table identifies the on/off control settings for each unit. If the setting for a particular unit is irrelevant, as, for example V_2 in Mode 1, the table entry should be assigned an arbitrary value of 1 or zero. If the setting for a unit is to remain as set in the previous state, the table entry is marked with an asterisk, as is the case for the auxiliary heater in Mode 7. Note the insertion of state 0. State 0 is the default state, should the actual settings of the control inputs not determine a valid state. One could consider one state as the default state, such as state 1, and enter it as the default state (and omit the first row of the tables below). However, by explicitly recognizing all states, a logical error is easily spotted if the default state is entered. Normally, one would print out the states as they are entered (see below) and/or set the output control signals to cause an easily identified system malfunction.

Input Table						State	Output Table									
T_1	T_2	T_3	T_4	T_5	T_6											
						0	1	1	0	1	1	1	1	1	1	1
0					0	1	0	0	0	0	0	0	0	0	0	0
1	0			0	0	2	1	0	1	0	0	1	0	1	1	1
0		0		0	1	3	1	0	0	0	1	0	1	1	1	1
1	0		1		1	4	0	1	1	0	0	1	1	0	0	0
1	1			0	0	5	1	0	1	1	0	1	0	1	1	1
1	1		1		1	6	0	1	1	1	0	1	1	0	0	0
1				1	0	7	1	0	1	*	0	1	0	1	1	1
0		0		1	1	8	1	0	0	0	1	0	1	1	1	1
0		1			1	9	0	0	0	0	0	0	0	0	0	0
1			0	1	1	10	1	0	1	*	0	1	0	1	1	1
1	1		0	0	1	11	1	0	1	1	0	1	0	1	1	1
1	0		0	0	1	12	1	0	1	0	0	1	0	1	1	1
							HP	P	F	H_x	V_1	V_2	V_3	V_4	V_5	

4.42-5

After the input and output tables have been drawn up, corresponding mask tables, if required, must be generated.

If there are no asterisks in the output table and no blanks in the input table, the number of entries per element (parameter 3) will be two, and mask tables are not needed. If there are blanks in the input table, an input mask table is required. If there are asterisks in the output table, both an input mask and output mask table are required (parameter 6 is set to the number of mask tables plus two). The mask tables are generated in the following manner: Make a copy of the table, converting all ones and zeros to one, and all blanks and asterisks to zero. The mask tables should have no blanks. For the example:

<u>Input Mask Table</u>						<u>State</u>	<u>Output Mask Table</u>									
T ₁	T ₂	T ₃	T ₄	T ₅	T ₆											
0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
1	1	0	0	1	1	2	1	1	1	1	1	1	1	1	1	1
1	0	1	0	1	1	3	1	1	1	1	1	1	1	1	1	1
1	1	0	1	0	1	4	1	1	1	1	1	1	1	1	1	1
1	1	0	0	1	1	5	1	1	1	1	1	1	1	1	1	1
1	1	0	1	0	1	6	1	1	1	1	1	1	1	1	1	1
1	0	0	0	1	1	7	1	1	1	0	1	1	1	1	1	1
1	0	1	0	1	1	8	1	1	1	1	1	1	1	1	1	1
1	0	1	0	0	1	9	1	1	1	1	1	1	1	1	1	1
1	0	0	1	1	1	10	1	1	1	0	1	1	1	1	1	1
1	1	0	1	1	1	11	1	1	1	1	1	1	1	1	1	1
1	1	0	1	1	1	12	1	1	1	1	1	1	1	1	1	1
							HP	P	F	E _x	V ₁	V ₂	V ₃	V ₄	V ₅	

4.42-6

The final step in generating the table required by the TYPE 42 Mode 1 unit is to encode the input, output, and mask tables in hexadecimal (base 16 numbers) and create a FORTRAN format record.

The encoding into hexadecimal is done as follows: Group the entries for each table by four, from right to left (but not altering the sequence), converting any blanks in the input table and asterisks in the output table to zero. For the example:

<u>(State)</u>	<u>Input</u>	<u>Output</u>	<u>Input Mask</u>	<u>Output Mask</u>
0	00 0000	1 1011 1111	00 0000	1 1111 1111
1	00 0000	0 0000 0000	10 0001	1 1111 1111
2	10 0000	1 0100 1011	11 0011	1 1111 1111
3	00 0001	1 0001 0111	10 1011	1 1111 1111
4	10 0101	0 1100 1100	11 0101	1 1111 1111
5	11 0000	1 0110 1011	11 0011	1 1111 1111
6	11 0101	0 1110 1100	11 0101	1 1111 1111
7	10 0010	1 0100 1011	10 0011	1 1101 1111
8	00 0011	1 0001 0111	10 1011	1 1111 1111
9	00 1001	0 0000 0000	10 1001	1 1111 1111
10	10 0011	1 0100 1011	10 0111	1 1101 1111
11	11 0001	1 0110 1011	11 0111	1 1111 1111
12	10 0001	1 0100 1011	11 0111	1 1111 1111

Hexadecimal encoding is done by substituting a hexadecimal digit for each group for each table. If a group has less than four bits, the missing high order (left side) bits are assumed to be zero(i.e., 10 would be 0010). The substitution table is:

<u>Binary</u>	<u>Hex</u>	<u>Binary</u>	<u>Hex</u>
0000	0	1000	8
0001	1	1001	9
0010	2	1010	A
0011	3	1011	B
0100	4	1100	C
0101	5	1101	D
0110	6	1110	E
0111	7	1111	F

4.42-7

The first line of the output table, 1 1011 1111, would be converted to LBF. The following table shows how the table would look, including the format record, when stored on file. The first column is from the input table, the second column is from the output table, and the last two columns are from the input and output mask tables, respectively, and may not always be present.

(Z2,10X,Z3,9X,Z2,10X,Z3)			
00	LBF	00	LFF
00	000	21	LFF
20	14B	33	LFF
01	117	2B	LFF
25	OCC	35	LFF
30	16B	33	LFF
35	OEC	35	LFF
22	14B	23	LDF
03	117	2B	LFF
09	000	29	LFF
23	14B	27	LDF
31	16B	37	LFF
21	14B	37	LFF

This table would be stored on a file, identified by the logical unit number specified by parameter 2. The format is identical to a FORTRAN FORMAT statement except for the omission of a statement number and "FORMAT", and continuation to a second record is not allowed. The use of Z format type for hexadecimal integers is similar to the I Type format for decimal integers.

Parameter 3 specifies the number of table entries, excluding the format record (13 for this example). Parameter 6 specifies the number of outputs, which equals the number of bits in the unencoded output table. In the example, it is 9.

If desired, the TYPE 42 Mode 1 unit will print out system state information each time it changes. It will print the time, iteration step, table entry position, starting from zero (if the states are entered in the table sequentially, as was done in the example, it will correspond to the state number), the input argument before masking (i.e., the inputs to the unit encoded in hexadecimal), the output argument, and the output argument mask. The latter three are encoded in hexadecimal. Use the above table to decode. For the example, the following output might be printed:

9.000. 2 ENTRY= 7 I=00000036 O=0000014B M=000001DF

4.42-8

Decoding the three hexadecimal numbers and ignoring leading zeros, yields: 11 0110, 1 0100 1011, and 1 1101 1111, respectively. The inputs indicated that T_1 , T_2 , T_4 , and T_5 were set at 1, the others at zero.

It is apparent from the input of 11 0110 that state 7 should be selected since, when T_2 and T_4 are ignored (input table was blank for T_2 and T_4 for state 7), the resulting input would be 10 0010, the entry in the input table for state 7. The output is a copy of the output table except for any outputs corresponding to a zero in the mask (the "M" field). Note that the sixth position from the right is a zero. This indicates that the 6th output, even though the 6th bit (from the right) in the output ("O") field is zero, could have actually been set to 1. It will actually have the setting, one or zero, from the previous state. In the example, if the state previous to state 7 were state 6, output 6 would be one.

The final set-up step is to assign the inputs and outputs for the unit. Inputs must be assigned from right to left as shown in the input table. In the example, input 1 would be T_6 , input 2 would be T_5 , etc.

Outputs are in the right to left order as shown on the output table. Output 1 is thus V_5 , output 2 is V_4 , etc.

To extend the number of outputs, simply replicate the TYPE 42 unit, substituting the additional output table and output mask table for the new outputs. To extend the number of inputs, use one or more TYPE 15 units to generate the number 1,

$$2 = \sum_{i=10}^n V_i 2^{i-10}, \quad i \geq 10 \quad n \leq 32$$

where i is the i th input and V_i is the value, 1 or 0, of the i th input, and input 2 to the 10th input of the TYPE 42 unit.

Mode 2

In mode 2, the first element of each table entry (except the first entry) is searched for a match with the input value. (Normally, with only one input to the unit, and that being input 1, no complications arise. However, if inputs 2 or higher are used, they are first raised to 2^{i-1} , where i is the i th input, and then summed with input 1 to form the search argument.) Outputs 1 through n are set to the values of elements 2 through n of the selected table entry, where n is specified by parameter 3. As in mode 1, parameter 4 specifies the number of table entries and the first record on the file specifies the input format with a FORTRAN format (see discussion under mode 1 set up. Use I type format instead of Z type). Note that since all inputs are

4.42-9

truncated to integers (before summing), they may need to be scaled and rounded by a type 15 unit. Also, all table entries must be integers. Parameter 6 is provided to scale all outputs. If no scaling of outputs is done, parameter 6 must be set to 1.

Mathematical Description

An integer table search argument, S, is generated:

$$S = \sum_{i=1}^m \text{INT}(I_i) \cdot 2^{i-1}$$

where,

m = number of inputs
 I_i = ith input
 INT = integer conversion function

Note that for Mode 1, if the values of the inputs are one or zero, as they would normally be, the search argument is the binary number represented by writing the values of the inputs in reverse order. For Mode 2, which would normally have only one input, that one input is left unchanged, except to be converted to an integer, the table is searched, $i = 2, 3, 4, \dots, n$:

$$i' = \begin{cases} 1 & \text{if } S = T_{i,1} \wedge T_{i,3} \quad (\text{mode} = 1 \text{ and } l \geq 3 \text{ only}) \\ 1 & \text{if } S = T_{i,1} \wedge T_{i,3} \quad (\text{mode} = 1 \text{ and } l \geq 3 \text{ only}) \\ 1 & \text{if } S = T_{i,1} \quad (\text{mode} = 2 \text{ or mode} = 1 \text{ and } l = 2 \text{ only}) \\ 1 & \text{if } S = T_{i,1} \quad (\text{mode} = 2 \text{ or mode} = 1 \text{ and } l = 2 \text{ only}) \end{cases}$$

Where $T_{i,j}$ is the jth element of the ith table entry and l is the number of elements per table entry (parameter 3).

The outputs, O_j , are generated as follows for $j = 1, 2, 3, \dots, n$:

$$O_j = \begin{cases} \text{REM} \frac{T_{i',3} \wedge T_{i',4}}{2^{n-j}} & \text{if mode} = 1 \text{ and } n = 4 \\ \text{REM} \frac{T_{i',3}}{2^{n-j}} & \text{if mode} = 1 \text{ and } n \leq 3 \\ T_{i',j+1} \cdot F & \text{if mode} = 2 \end{cases}$$

4.42-10

and

$$O_{n+1} = i' - 1$$

where REM is the remainder function. (Because of rounding errors, division is not actually performed. A bit manipulation technique is used instead.)

It should be noted that in Mode 1, outputs 1 through n, when written in reverse order, represent a binary integer.

TRANSYS Component Configuration

<u>Parameter No.</u>	<u>Description</u>
1	Mode - 1 for controller 2 for table look-up
2	LU _{in} - logical unit number for file containing logic table entries.
3	l - number of elements per table entry
4	N - number of table entries (exclude format record, include default entry).
5	1STICK - Number of TYPE 42 calls in time step before outputs "stick" (see discussion of Parameter 1 for TYPE 8).
6	J - Number of output signals (Mode 1) F - Table multiplication factor. Since the table must be entered as integers, the outputs can be scaled with this parameter (Mode 2).
7	LU _{out} - Logical unit number for status output (Mode 1 only).
8	t _s - Starting time for output on LU _{out} (mode 1 only)
9	t _e - Ending time for output on LU _{out} (mode 1 only)

4.42-11

Input Number

Description

1	I_1	- Input control signal (Mode 1) - Search argument (Mode 2)
k	I_k	- Control signal k (Mode 1)

Output Number

Description

1	O_1	- Output control signal (Mode 1) - Table element 2 (Mode 2)
k	O_k	- Output control signal k (Mode 1) - Table element k+2 (Mode 2)
j+1	$i'-1$	- Table entry selected

Information Flow Diagram

INPUTS - up to 10
 OUTPUTS - up to 20
 PARAMETERS - 9 (Mode 1) 6 (Mode 2)
 DERIVATIVES - 0

PARAMETERS

1. Mode
2. LU_{in}
3. l
4. N
5. $lSTICK$
6. J (Mode 1)
 F (Mode 2)
7. LU_{out} (Mode 1)
8. t_s (Mode 1)
9. t_e (Mode 1)

APPENDIX A-1.5.4

DAILY LOAD PROFILE EXAMPLE

APPENDIX A-1.5.4

DAILY LOAD PROFILE EXAMPLE

<u>Hour</u>	<u>Average Hourly Building Load kJ</u>	<u>Ambient D.B. °C</u>	<u>Ambient W.B. °C</u>	<u>Outdoor Specific Humidity kg H₂O kg Air</u>	<u>Average Inso- lation kJ</u>	<u>Internally Generated Moisture kg</u>
48.0000	1.3210+05	3.0500+01	1.9890+01	1.0160-02	0.0	9.9640-01
49.0000	1.2180+05	2.9560+01	1.9720+01	1.0330-02	0.0	9.0050-01
50.0000	1.1240+05	2.8720+01	1.9500+01	1.0380-02	0.0	8.0460-01
51.0000	1.0390+05	2.8000+01	1.9280+01	1.0390-02	0.0	7.0870-01
52.0000	9.5470+04	2.7220+01	1.9110+01	1.0500-02	0.0	6.1280-01
53.0000	8.7950+04	2.6610+01	1.8940+01	1.0540-02	0.0	5.1690-01
54.0000	8.3260+04	2.6390+01	1.8890+01	1.0540-02	3.0170+02	4.2100-01
55.0000	8.8340+04	2.7780+01	1.9500+01	1.0780-02	1.0190+03	4.2040-01
56.0000	1.0000+05	2.9890+01	2.0220+01	1.0860-02	1.7720+03	4.1970-01
57.0000	1.6910+05	3.1890+01	2.0780+01	1.0790-02	2.4370+03	4.1910-01
58.0000	1.9530+05	3.3560+01	2.1170+01	1.0630-02	2.9560+03	4.1850-01
59.0000	2.1810+05	3.4940+01	2.1440+01	1.0450-02	3.3050+03	4.1790-01
60.0000	2.3730+05	3.6220+01	2.1610+01	1.0160-02	3.4320+03	4.1720-01
61.0000	2.5250+05	3.7280+01	2.1780+01	9.9570-03	3.3380+03	4.1660-01
62.0000	2.6370+05	3.8280+01	2.2000+01	9.8620-03	3.0170+03	4.1600-01
63.0000	2.7060+05	3.8940+01	2.2060+01	9.6670-03	2.4960+03	1.2840+00
64.0000	2.7190+05	3.9330+01	2.2110+01	9.6670-03	1.8200+03	1.1880+00
65.0000	2.7060+05	3.9170+01	2.1890+01	9.6670-03	1.0580+03	1.0920+00
66.0000	2.6700+05	3.8670+01	2.1670+01	9.2270-03	3.2810+02	9.9640-01
67.0000	2.0970+05	3.7440+01	2.1390+01	9.3390-03	0.0	9.0050-01
68.0000	1.9020+05	3.5610+01	2.1000+01	9.5540-03	0.0	8.0460-01
69.0000	1.7350+05	3.3830+01	2.0670+01	9.8300-03	0.0	7.0870-01
70.0000	1.6020+05	3.2560+01	2.0390+01	9.9800-03	0.0	6.1280-01
71.0000	1.4890+05	3.1500+01	2.0220+01	1.0190-02	0.0	5.1690-01
72.0000	1.3530+05	3.0500+01	1.9890+01	1.0160-02	0.0	4.2100-01

NOTE: Above load profile is for the commercial building during July in Phoenix.

APPENDIX A-1.6

SERVICE CONTRACT PRICING

CONTRACT PRICING GUIDE

- 487 -

Customer _____

Address _____

Date _____ By _____

INSTRUCTIONS

- 1 Circle Serviceman Base Wage and extend factor to Column "A".
- 2 Circle all System Considerations that apply and extend corresponding factors to Column "A".
- 3 Total all factors in Column "A".

Convert the total factor from No. 3 to dollars using table on reverse side of this form. This is the Full Maintenance Base Price. To find the base price for other type contract, determine your best multiplier and follow formula given. Suggested multipliers are shown.

List any additional charges.

Total the contract base price with Additional Charges for Total Contract Price.

Make	Model No.	Serial No.	Make	Model No.	Serial No.

	Base Wage	Factor	Base Wage	Factor	Column "A"
1 BASE WAGE	\$3.50	1.079	\$ 9.50	1.491	
	\$4.00	1.146	\$10.00	1.505	
EQUALS	\$4.50	1.204	\$10.50	1.519	
SERVICEMAN'S	\$5.00	1.255	\$11.00	1.531	
BASE WAGE	\$5.50	1.301	\$11.50	1.544	
PLUS	\$6.00	1.342	\$12.00	1.556	
ALL FRINGE	\$6.50	1.380	\$12.50	1.568	1.505
BENEFITS	\$7.00	1.415	\$13.00	1.580	
	\$7.50	1.431	\$13.50	1.591	
	\$8.00	1.447	\$14.00	1.602	
	\$8.50	1.462	\$14.50	1.613	
	\$9.00	1.477	\$15.00	1.623	
2 SYSTEM CONSIDERATIONS			Full Maintenance Factor		
	1		1.778		
	2-3		1.813		
	4-5		1.903		
	7.5		2.000		
	10		2.097		
	15		2.217		
COMPRESSOR	20		2.301		
SIZE	25		2.380		2.623
(Tons)	30		2.439		
25 TON CHILLER	40		2.544		
PLUS RANKINE	50		2.623		
SYSTEM	60		2.699		
	75		2.785		
	100		2.881		
	125		2.964		
	Applied DX		0.041		0.041
	Chilled Water		0.041		
TURBINE-COMPRESSOR	Waste Water		0.021		
	Tower or Evap		0.079		
	Multiple Compr		0.061		0.061
OTHER	Steam Coil		0.021		
ELEMENTS	Gas Heat		0.061		
	Oil Heat		0.079		0.176
EXTRA CONTROLS	Heat Pump		0.176		
	Electric Heat		0.035		
	Process		0.079		
	2		0.845		
	4		0.903		
NO. OF INSPECTIONS	6		1.000		1.000
	9		1.114		
	12		1.204		
	24		1.301		
	0-1		0.544		
AGE IN YEARS	2-5		1.000		1.000
	6-8		1.061		
	9-11		1.114		
3 TOTAL FACTOR					6.406

CONTRACT BASE PRICE

FULL MAINTENANCE BASE PRICE

From next page for 6.406 Full Factor
\$2550

INSPECTION & LABOR BASE PRICE

[Full Maintenance Base Price x Multiplier (.65 to .75)]

\$

INSPECTION BASE PRICE

[Full Maintenance Base Price x Multiplier (.45 to .60)]

\$

ADDITIONAL CHARGES

Air Handling Units over one _____ number of units x \$ _____ each.

\$

Filters

_____ number of filters x \$ _____ each

\$

Water Treatment

\$

Equipment Inaccessibility

\$

Make of Equipment

\$

Special Controls

\$

Travel time beyond normal miles

\$

Miscellaneous charges

\$

Total Additional Charges

\$

Add Contract Base price

\$

Subtotal

\$

Tax

\$

TOTAL CONTRACT PRICE

\$ 2550

Deductions for multiple units in a single location. 5% off BASE PRICE for each additional system.

Only discount the number of systems that can be inspected in one day.

Note: Price based on all work being done during normal working hours.

TERMS OF PAYMENT (In Advance)

- ☒ Yearly
☐ Semi-Annually
☐ Quarterly
☐ Other

\$ 2550
\$
\$
\$

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