OPTIMIZING THE PERFORMANCE OF SOLAR-POWERED ABSORPTION COOLING SYSTEMS

by

EUGENIE HAINSWORTH

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Eugenie Hainsworth 1980

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Submitted to the Department of Mechanical Engineering on May 19, 1980 in partial fulfillment of the requirements for the degree of Bachelor of Science in Mechanical Engineering.

ABSTRACT

A definition of an overall coefficient of performance (COP) is proposed to provide a basis for comparing the performance of different solar-powered cooling systems. Two possible systems were proposed to handle a given cooling load, using a concentrating solar collector and different sites and arrangements of absorption chillers was used to calculate the cooling capacity and COP of each system under different operating conditions. While the results indicate that a two-machine system can be made to give a marginally (0.12%) better COP than a single large machine, the difference is so small that it is unlikely that the resulting fuel savings would offset the much larger capital cost of the two-machine system. Further study is recommended for systems using more complex control strategies, and improvements are suggested for some of the simplifying assumptions used in this study.

Thesis Supervisor: Thomas P. Bligh
Title: Associate Professor of Mechanical Engineering

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INTRODUCTION AND BACKGROUND

Cooling Using Solar Energy

Several ways to use solar energy to cool buildings have been proposed and implemented. However, there is no meaningful performance measure to compare various systems; this would be useful to designers of solar cooling systems in choosing among design alternatives. These choices include the principle of operation, the arrangement and sizes of equipment, the control strategy, and the set points for those variables which can be controlled.

In this thesis, an overall coefficient of performance is proposed as a measure of a cooling system's overall efficiency of use of available sunlight. This coefficient is defined as the ratio of the cooling effect produced to the amount of solar energy (insolation) striking the collector.

Absorption Chiller

In a lithium bromide-water (LiBr-H_2O) chiller (Fig.1), the cooling effect is produced by the refrigerant, water, evaporating in the evaporator (A), where the vapor pressure of water is low. This vapor is drawn into the absorber (B), where it is absorbed by the LiBr solution. This

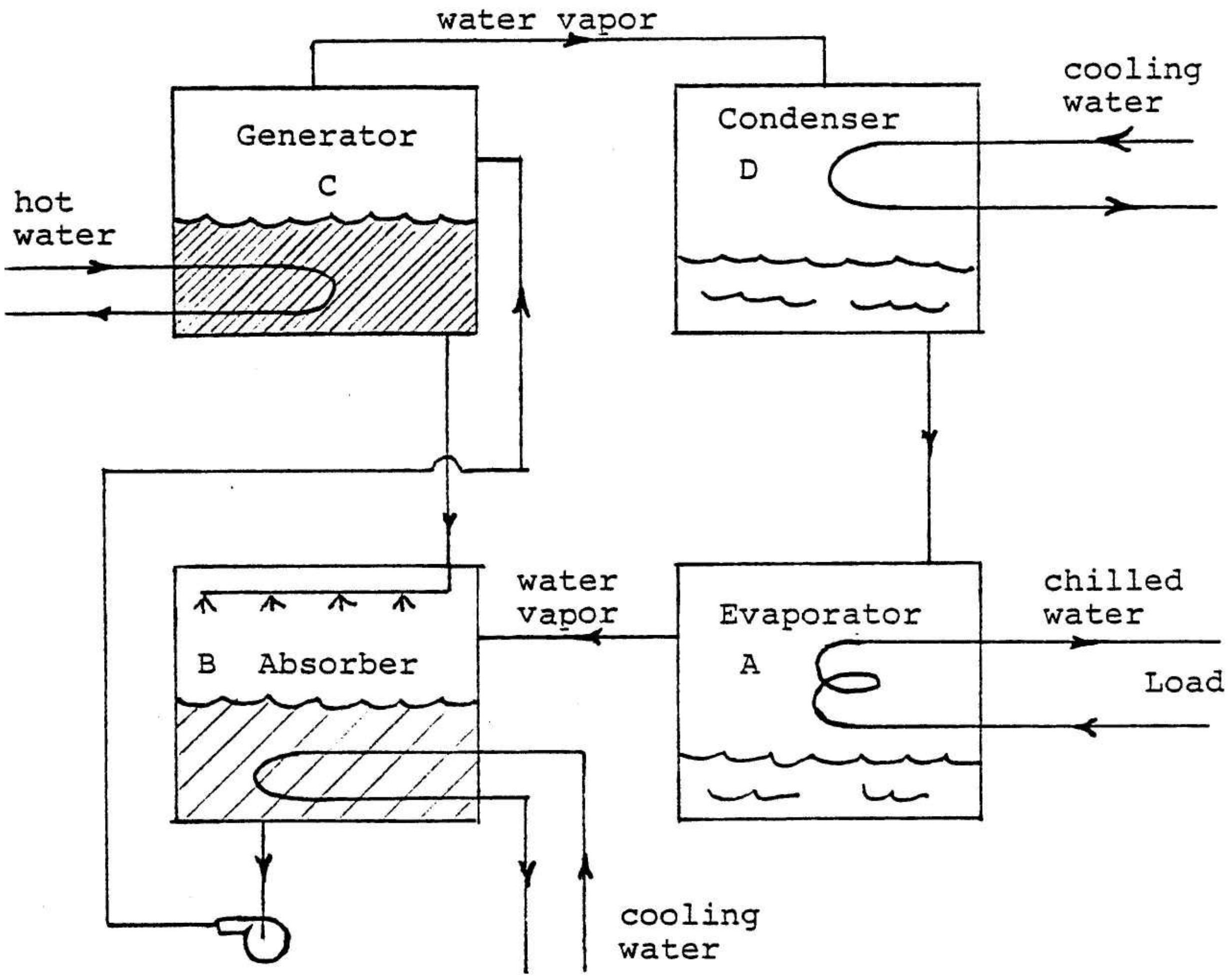

Figure 1.
Absorption chiller - basic cycle schematic.

solution is being diluted continuously by the water it absorbs; it is also being replenished by stronger (more concentrated) LiBr solution from the generator (C). In the generator, the heat from the hot water energy source drives the water out of the LiBr solution. This concentrated solution in the generator is diluted by weaker solution pumped from the absorber. The water vapor driven off then passes to the condenser (D), in which it condenses, and flows to the evaporator, completing the cycle.

At both points in the cycle where water vapor condenses to liquid water (in the absorber, B, and the condenser, D), cooling water coils are used to remove the latent heat released. The cooling water usually runs to the absorber, then to the condenser, and finally to a cooling tower.

Because the pressures in the machine are below atmospheric, the water vaporizes at temperatures below $212^{o}F$.

Performance Criteria

The capacity of an absorption chiller is the maximum cooling effect that it can produce under a given set of conditions. Capacity is usually expressed in tons of cooling where one ton equals 12,000 BTU per hour.

The coefficient of performance (COP) of an absorption chiller is the ratio of the cooling effect produced to the energy input to the generator from the hot water.

The efficiency (η) of a solar collector is the ratio of the energy actually collected, i.e. transferred to the fluid, to the total incident solar energy (insolation).

Solar-Powered Absorption Cooling

If the two components (the absorption chiller and the solar collector) did not affect each other, the performance of the system could be optimized by analyzing each component independently and optimizing its performance. However, the two components are not independent, since the coefficient of performance (COP) and capacity of the absorption chiller and the efficiency of the solar collector all depend on the flow rate and entering and leaving temperatures of the hot water.

The solar collector efficiency is highest at low incoming hot water temperatures (Fig.2). If the absorption chiller is operated at maximum load, its COP peaks at 204^{o} entering hot water temperature (Fig.3). If it is operated at a constant load, its COP is highest at the lowest possible entering hot water temperature for that load (Fig.4).

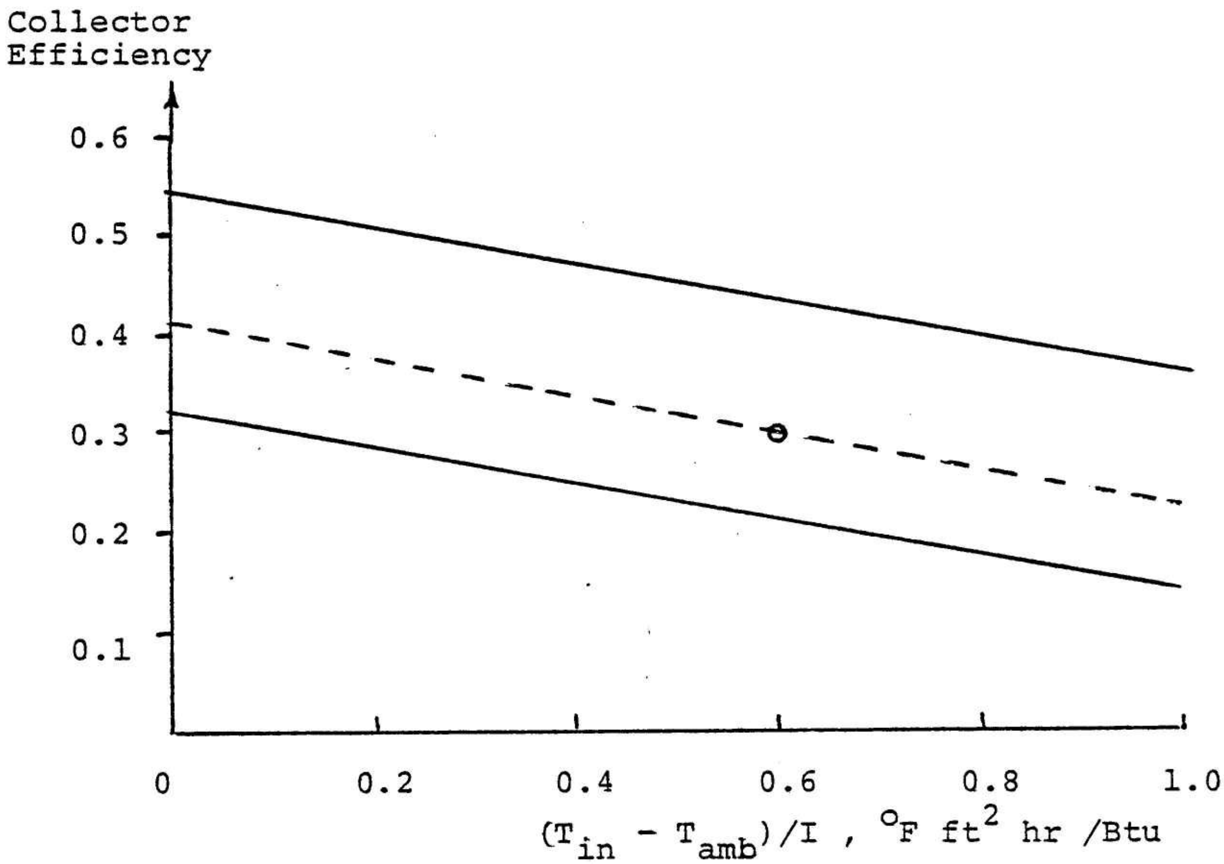

Figure 2.

Noon-hour efficiency of Suntec SLATS concentrating solar collector (from Bligh and Ramsey, 1978).

The solid lines (for different average cloudiness) and one data point for an average July day were given. The dotted line was assumed as the efficiency characteristic for July.

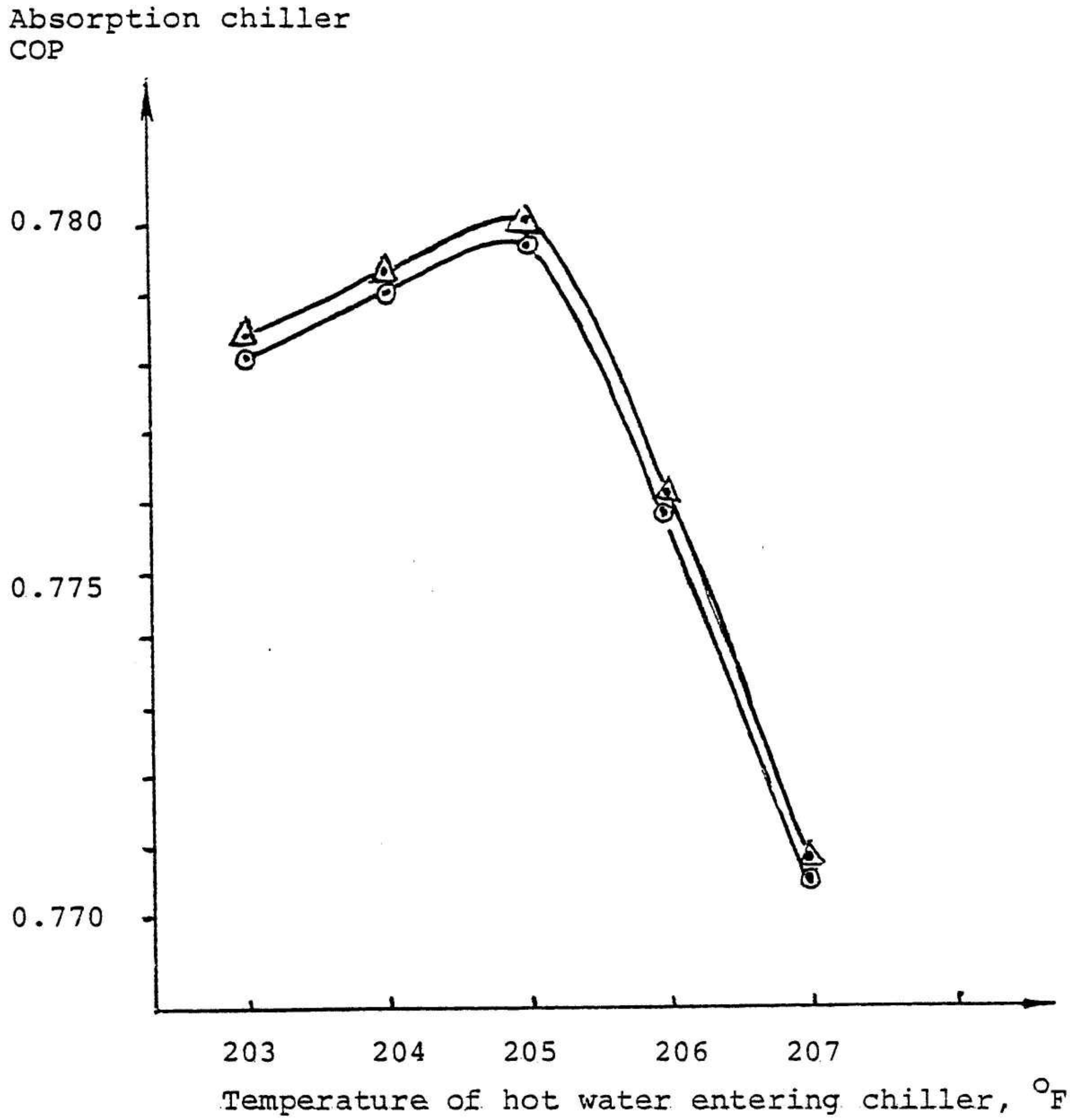

Figure 3.
Absorption chiller COP as a function of inlet temperature for operation at maximum load.

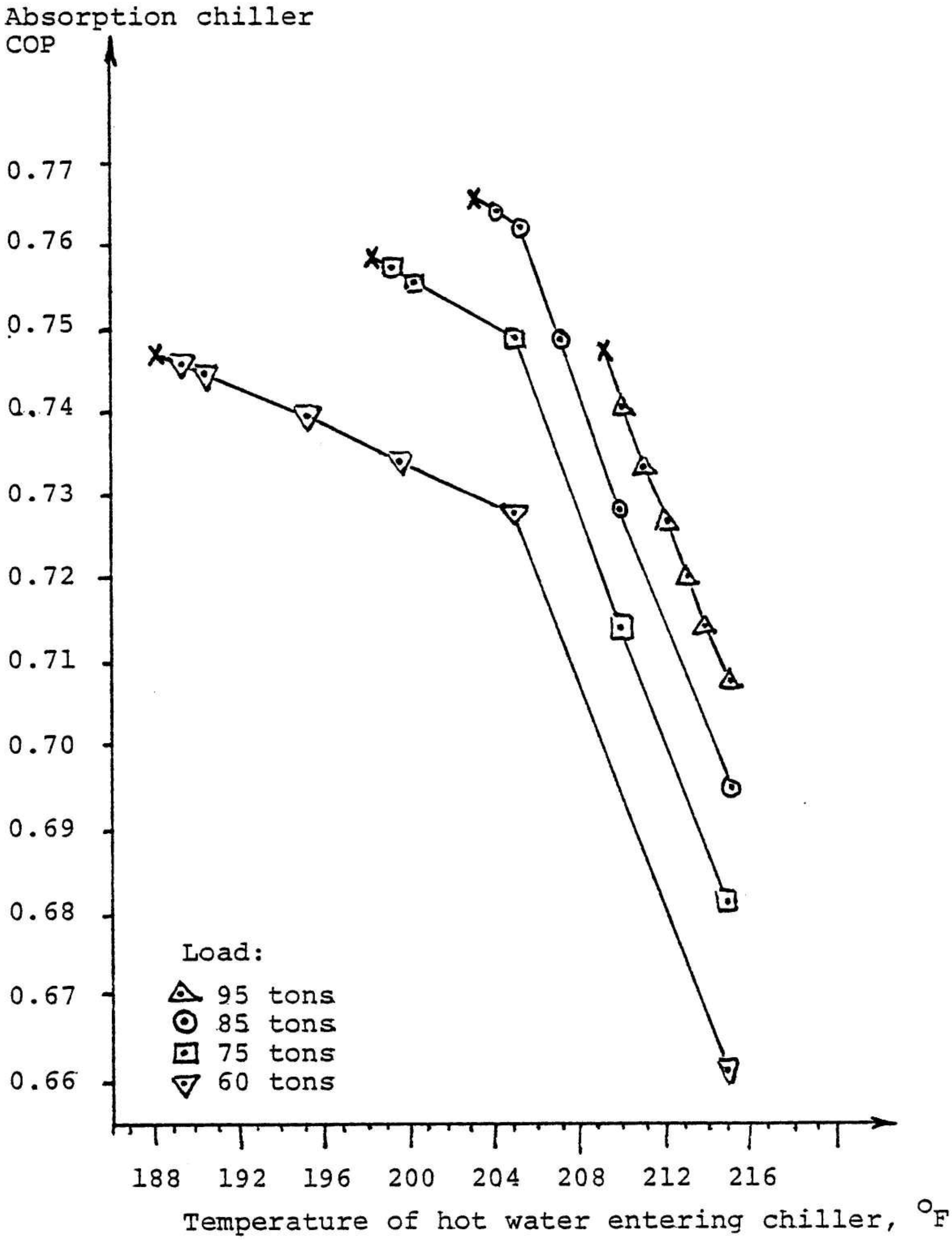

Figure 4.

Absorption chiller COP as a function of inlet temperature for operation at constant load (148-ton machine).

X indicates lowest temperature in recommended design range.

Because the criteria for optimizing the performance of the absorption chiller and the solar collector conflict, more detailed analysis is needed to determine the best operating point for a complete system.

Auxiliary Firing Strategy

During periods of low solar energy input, i.e. early morning or late afternoon and cloudy days, extra energy must be added to the system so that it can handle the cooling load. This can be done by heating the water in the collector/absorption chiller loop, either with locally available steam or by burning fossil fuel.

However, this will raise the temperature of the water returning to the solar collector, thereby lowering the collector efficiency.

An alternate strategy is to use two or more smaller absorption chillers, each handling part of the total cooling load. During periods of low sun, one or more of the machines could be operated entirely by the auxiliary heat source, while the other(s) could be operated entirely by solar energy.

OUTLINE OF APPROACH

Using the two strategies discussed above, two systems were proposed to handle a given cooling load. The overall coefficient of performance was used as a basis for comparison to determine which system makes greater use of the available solar energy.

System # 1

One large absorption chiller handles the entire cooling load. Auxiliary heat is added to the collector loop as needed to maintain the load (Fig. 5).

System # 2

Two small absorption chillers share the load, not necessarily equally. When there is insufficient solar energy to maintain the load, one machine is fired with auxiliary heat, while the other remains on 100% solar operation for as long as possible (Fig.6). When it is no longer possible to operate one machine entirely on solar, then both machines must be fired with auxiliary heat.

For both systems, at some low level of insolation, the collector panel will lose more heat to the air than it gains from the sunlight. At this point the collector

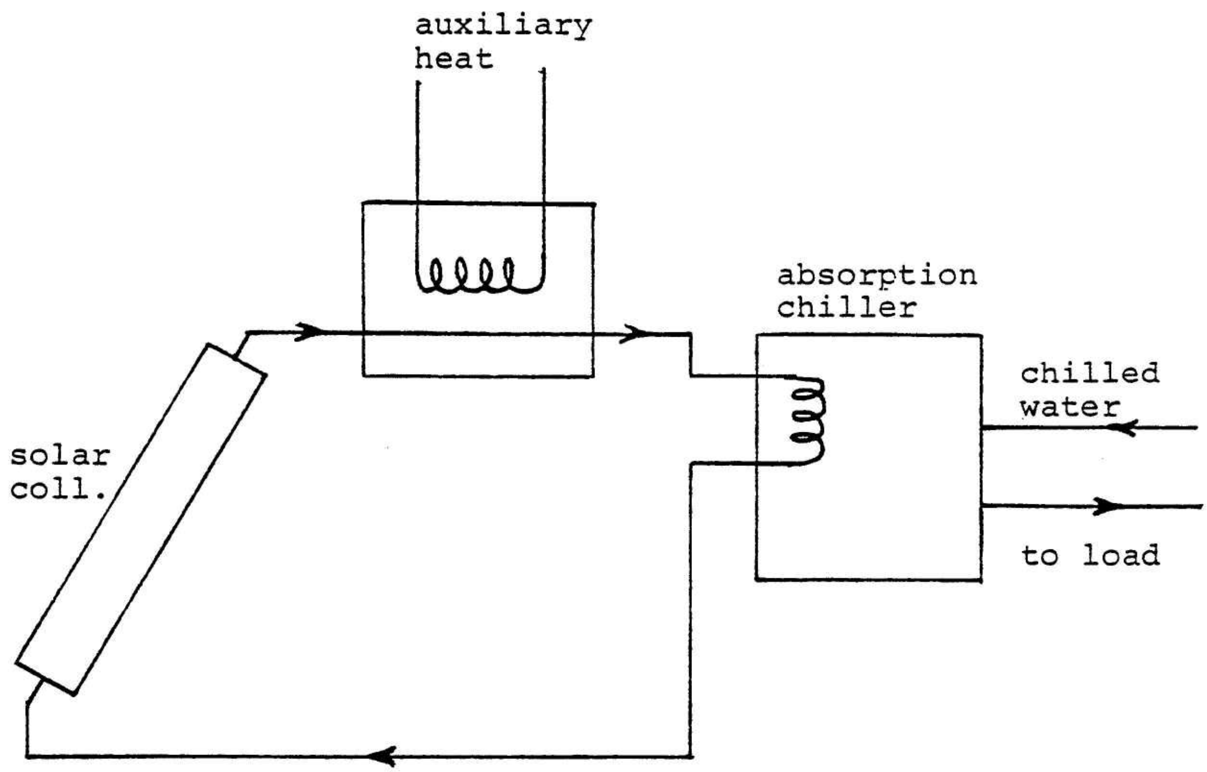

Figure 5.

System #1: one large absorption chiller handles the entire load.

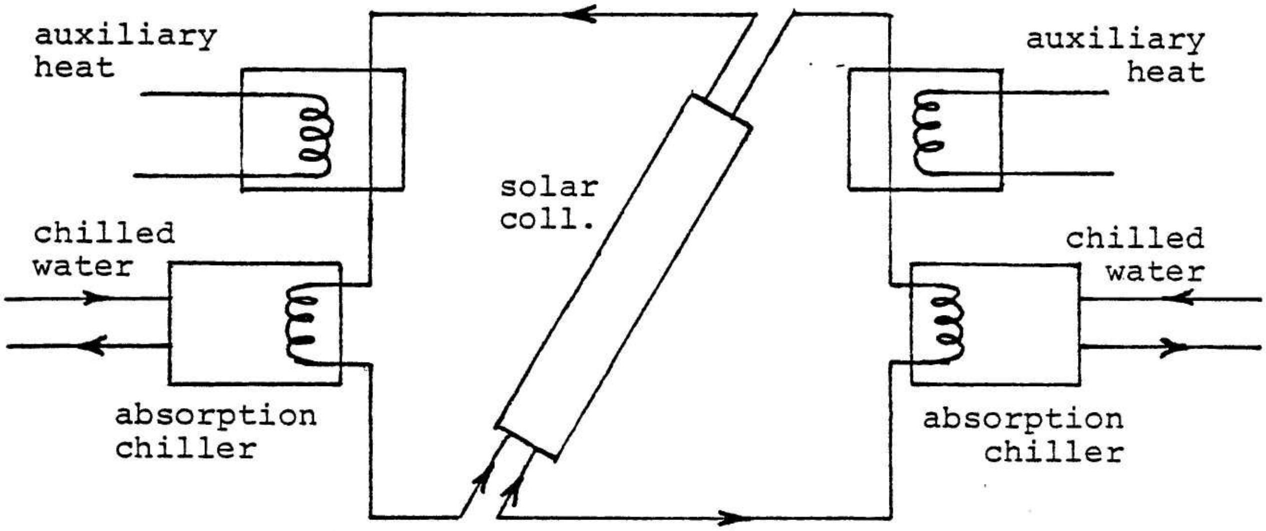

Figure 6.

System #2: two small absorption chillers share the load.

loop is disconnected from the chiller, which then operates on 100% auxiliary firing.

Overall Coefficient of Performance

To measure the efficiency of a system's overall performance, an overall coefficient of performance was defined as the ratio of the cooling effect provided by solar energy to the available solar energy incident on the collectors:

$$COP_o = \frac{L}{IA}$$

where COP_o = overall coefficient of performance

L = cooling load, BTU/hr

I = insolation, BTU/hr ft^2

A = collector area, ft^2

If the system is not operated on 100% solar, i.e., it is partially fired by auxiliary heat, then the cooling effect provided by solar energy is not the entire cooling load handled by the machine. In this case, the cooling provided by solar energy is defined as the total cooling provided by the system (solar and auxiliary firing) times the fraction of the energy used which was provided by solar:

$$COP_o = \frac{L\left(\frac{u_s}{u_{aux} + u_s}\right)}{IA}$$

where u_s = solar energy collected and used

u_{aux} = energy used from auxiliary source

Without this factor, it would appear from the definition of COP_o that for a system operating on solar and auxiliary heat, the COP_o could be raised (indicating more efficient use of solar energy) by decreasing insolation or the collector area, thus decreasing the solar energy input. However, for a given load, decreasing the solar energy input requires increasing the energy input from the auxiliary source. Including the energy-use fraction in the definition of the COP_o takes this effect into account.

Although it appears from this revised definition that decreasing the amount of auxiliary energy added will raise the COP, this is not true: decreasing the auxiliary energy added will also decrease the load that the machine can handle.

For the system of two machines, one on solar operation only and one partly on auxiliary firing, the overall COP can be expressed as:

$$COP_o = \frac{L_1 + L_2\left(\frac{u_{s2}}{u_{aux2} + u_{s2}}\right)}{IA}$$

where the subscript 1 refers to the machine using solar energy only, and the subscript 2 refers to the machine using solar and auxiliary firing.

When both machines must be operated at least partially by auxiliary heat, the overall COP is

$$COP_o = \frac{L_1\left(\frac{u_{s1}}{u_{aux1} + u_{s1}}\right) + L_2\left(\frac{u_{s2}}{u_{aux2} + u_{s2}}\right)}{IA}$$

A computer was used to find the optimimum operating point of each system at different values of insolation (sunlight incident on the collector), and to calculate the overall coefficient of performance.

Computer Program

The computer program uses data for the Trane Company's low temperature input absorption chillers (Trane, 1977) and for a Suntec Slats concerning solar collector (Bligh and Ramsey, in progress). For the absorption chillers, the computer program uses the limits of Trane's recommended capacity design range as absolute limits. This is conservative; the machines can be operated at higher loads than this computer program will allow.

Approximate equations were fitted to the curves and charts used in the Trane design procedure. In some ranges, these equations can give values that differ by up to 5% from the values read from the graphs. While better curve-fits would improve this, several small errors (1% and less) in reading the raphs can also cause larger errors (e.g., 8%) in quantities computed later. In this case, accuracy could be significantly improved by obtaining the original data for the curves from Trane and fitting more accurate equations.

COMPARISON OF THE TWO SYSTEMS

Details of the Two Systems

Both systems were designed to handle a constant cooling load of 150 tons. The collector area was chosen as the minimum necessary to supply 100% of the energy requirements for 1 hour of the day, based on data for an average July day in Minnesota (Fig. 4).

The following variables were held constant throughout the analysis:

Ambient temperature	78°F
Cooling water inlet temperature	85°F
Chilled water flowrate	300 gpm
Chilled water leaving temperature	45°F

This is only a first approximation analysis: for a real system, both the load and the ambient temperature vary during the day. The cooling water inlet temperature is a function of the ambient temperature and the relative humidity.

The chilled water flowrate and leaving temperature are held constant by the absorption chiller; the temperature of the returning chilled water varies as the load varies. Changing this set point will change the required cooling water flowrate and cooling tower temperature drop.

The sizes of the machines used for the two systems were selected to be the smallest that could handle the given load (150 tons for system #1, 75 tons for each of the two machines of system #2) while operating as close as possible to maximum absorption chiller COP for that load (Fig. 8). A 256-ton machine for system #1 and two 129-ton machines for system #2 were selected.

The collector size, 28,000 square feet, was chosen to be the minimum and necessary to supply all of the energy needed by the absorption chiller(s) to provide 150 tons of cooling at an insolation of 257 Btu/hr ft^2, which is the insolation one half hour each side of solar noon (see Fig. 7).

For system #2 (two machines, one operating on 100% solar for as long as possible), each machine uses 14,000 square feet of the collector at solar noon. As the amount of insolation decreases, the load that the all-solar machine can handle decreases, dropping below 45 tons. When the insolation drops low enough, 2,000 square feet of collector can be switched from the partially auxiliary-fired machine to the all-solar machine. The insolation must be low enough that the all-solar machine can use all of the solar energy from the increased collector area without operating over its design limit load for that inlet

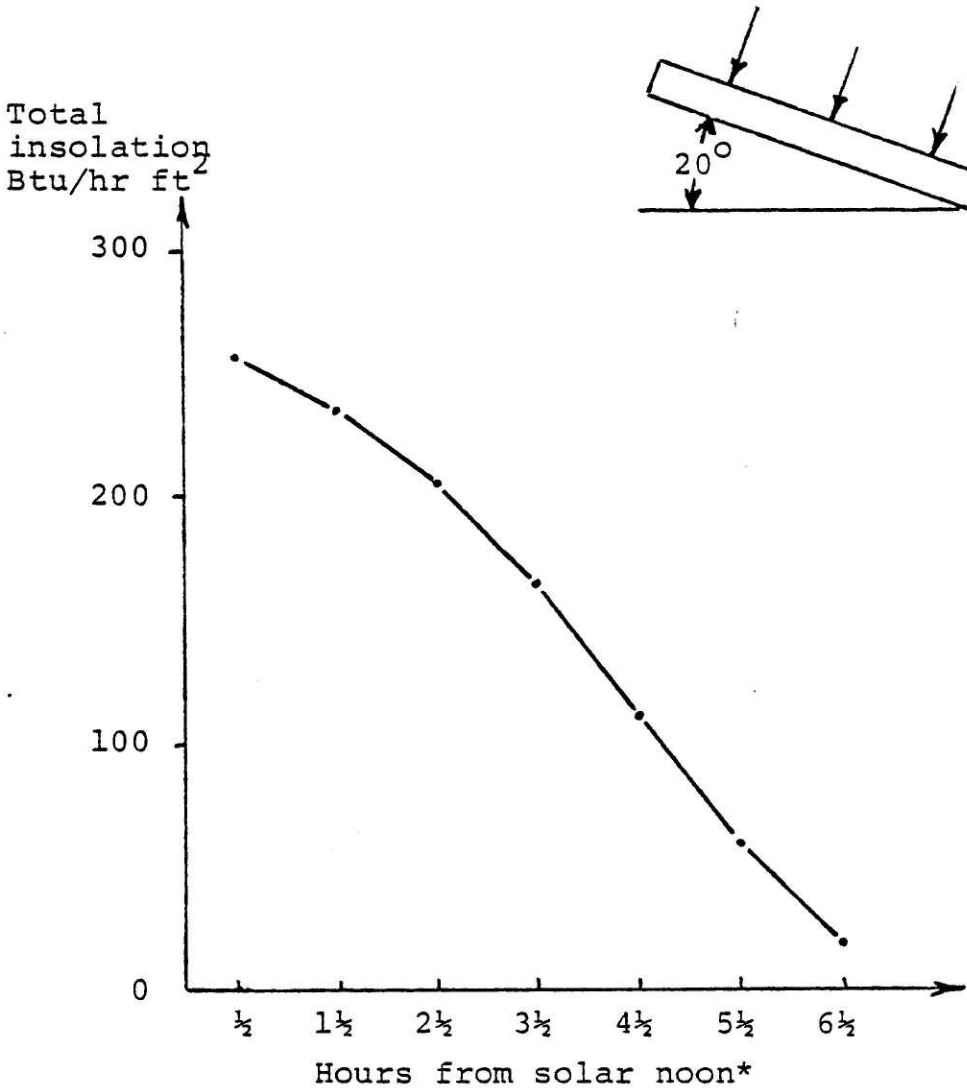

Figure 7.

Variation of insolation with time of day.

Average data for July, collector tilted at 20°, conditions in the St. Cloud - Twin Cities area, Minnesota (Bligh and Ramsey, in progress).

*This curve is assumed to be symmetrical about solar noon.

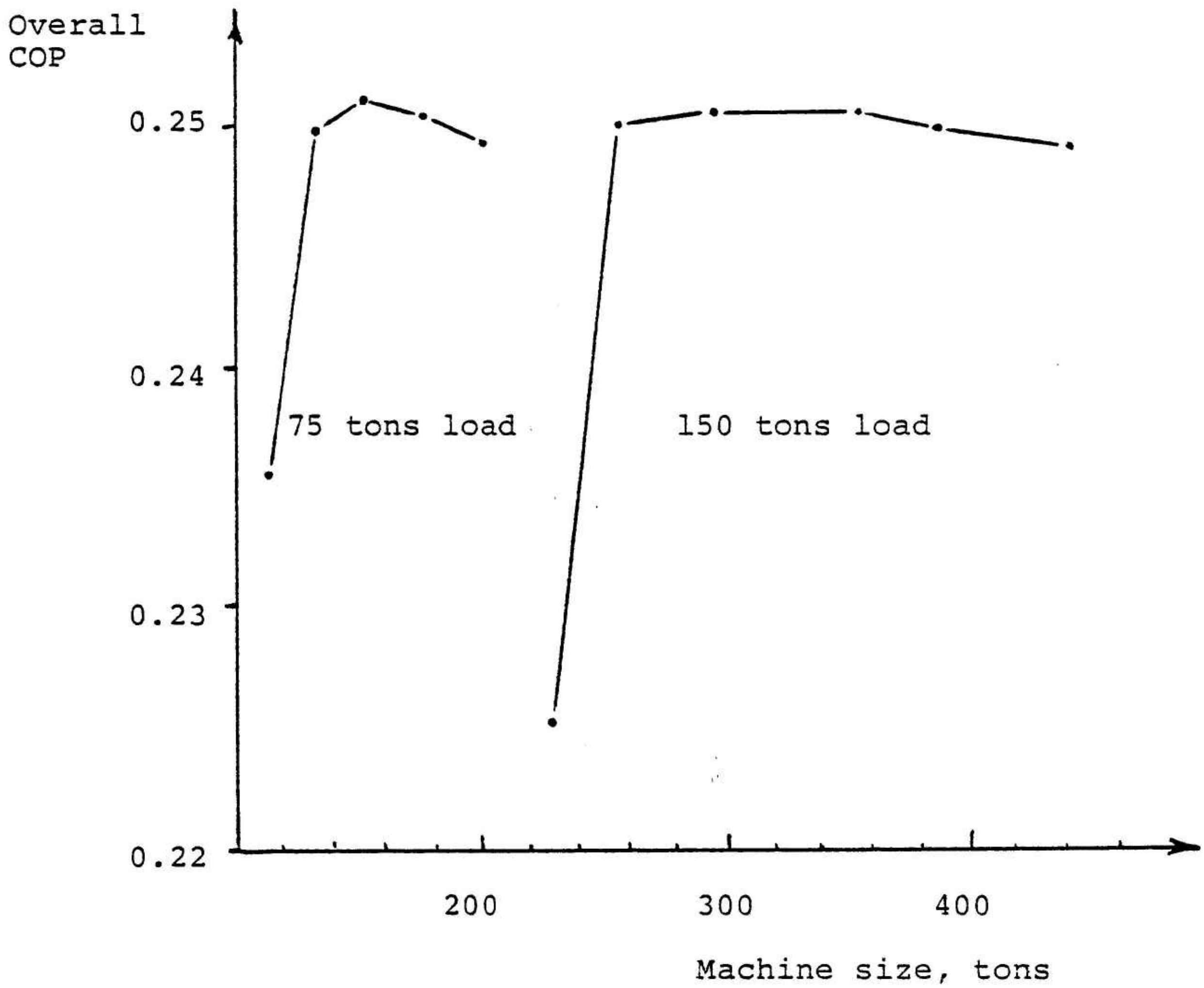

Figure 8.

Noon-hour overall COP of systems using different sizes of machines. The circled points represent the machines selected.

temperature. The machine could operate at a higher load if the inlet temperature were raised, but this lowers the absorption chiller COP: in effect, the chiller can use more energy in part because it is wasting more.

This strategy of switching 2000 ft^2 increments of collector area produces the curve of load as a function of insolation shown in Fig. 9 for the all-solar machine.

When the all-solar machine is handling less than 75 tons of the load, the second, partially auxiliary-fired machine must handle more than 75 tons. This can be done either by operating the machine at a higher inlet temperature, which raises its design limit load but lowers its COP, or by using a bigger machine which can handle the same load at a lower inlet temperature. Both of these strategies were examined and compared with system #1 (one large machine).

Calculation of Coefficients of Performance

The overall COP defined earlier can be evaluated for each system at any given value of insolation. This is an instantaneous COP, since the insolation varies continuously with time (see Fig. 7).

A daily COP can be defined as the ratio of the total cooling provided by solar energy to the total amount of

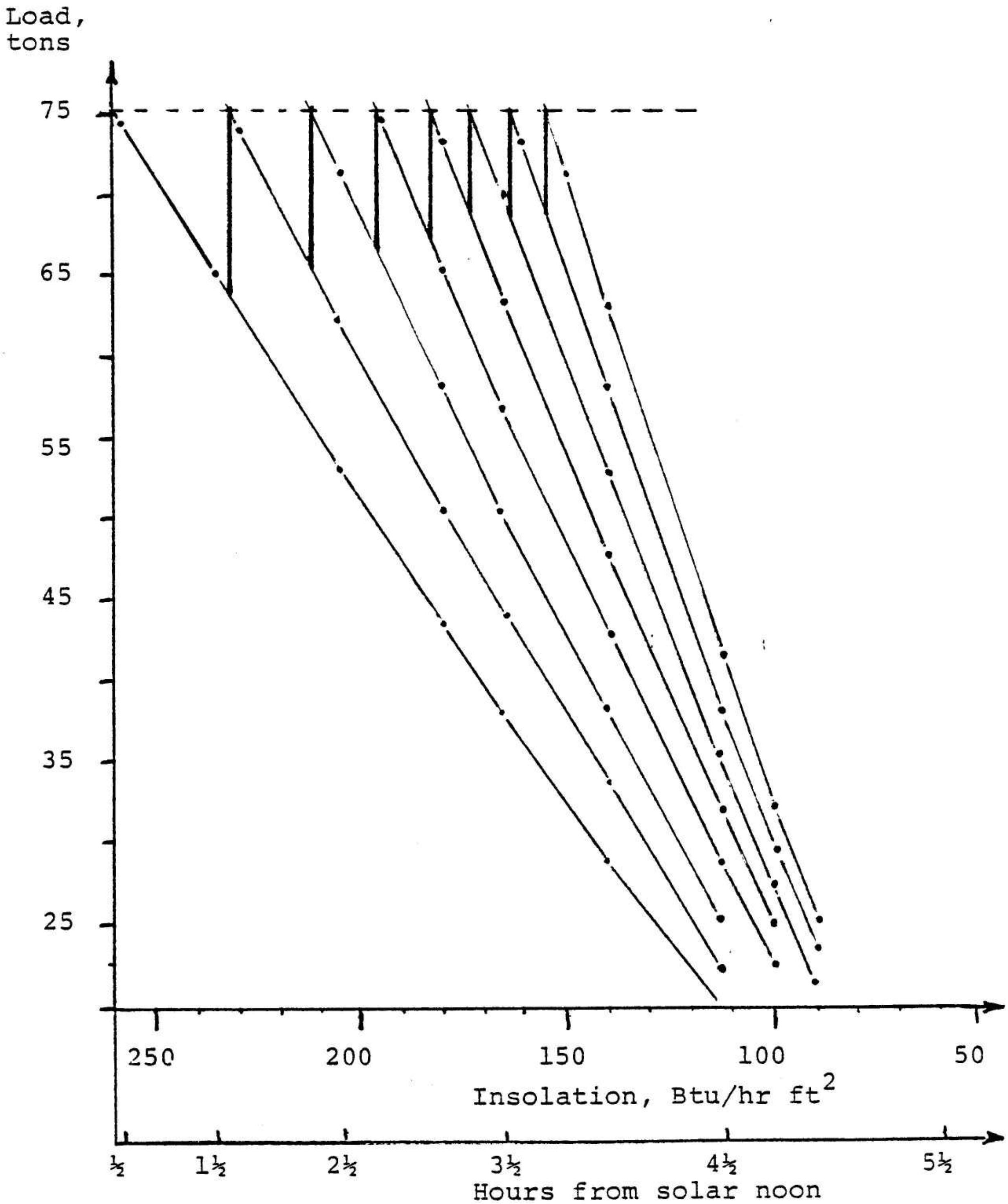

Figure 9.

Load handled by the all-solar machine of system #2.

solar energy that struck the collector for one day.
This is approximated by

$$COP_{day} = \frac{\sum_I \left(\frac{u_s}{u_{aux} + u_s} \right)_I L_I \, \Delta t_I}{\sum_I \left[I \cdot A \right]_I \Delta t_I}$$

where the subscript I indicates that the term is evaluated at insolation I , and Δt_I is the length of time for which there was that amount of insolation.
For a two-machine system, this definition is modified:

$$COP_{day} = \frac{\sum_I \left[\left(\frac{u_s}{u_{aux} + u_s} \right)_1 L_1 + \left(\frac{u_s}{u_{aux} - u_s} \right)_2 L_2 \right] \Delta t_I}{\sum_I \left[I \; A \right]_I \Delta t_I}$$

where the subscripts 1 and 2 refer to the two different machines.

This daily COP was evaluated using increments of insolation of 5 Btu/hr ft^2, which corresponds to a Δt of 1.1 to 2.7 minutes. The results are shown in Table 1 for system #1 and for four variations of system #2. Each of these variations has a different auxiliary-fired machine; the numbers in parentheses are the size (in tons) and the inlet temperature of the auxiliary-fired machine. The inlet temperatures were chosen as the mininum possible for a load of 86.25 tons, since the smallest load the all-solar

Table 1. Daily COP of each system

System	COP_{day}
#1	0.213
#2a (129, 212°F)	0.206
#2b (148, 204°F)	0.211
#2c (174, 196°F)	0.211
#2d (200, 191°F)	0.211

machine handles is 63.75 tons (see Fig. 9). The minimum possible temperature for a given load gives the maximum absorption chiller COP (see Fig. 4).

Improved Collector Efficiency Model

For all of the previous calculations, the collector efficiency was assumed to be the noon-hour efficiency (Fig. 2).

Actually, the collector efficiency is also a function of the insolation (Fig. 10). If this dependence is included in the previous calculations, the curve of load vs. insolation changes (Fig. 11), and the predicted daily COP's for all of the systems are lower (Table 2).

Previous calculations assumed that after the point at which both machines of system #2 needed auxiliary firing, all 28,000 square feet of the collector remained connected to the first, all-solar machine. If all 28,000 square feet are switched over to the second machine, the results (Table 3) show that system #2d now has a higher daily COP than system #1.

If the collector area is distributed partly to each machine during the low-sun period, the value for the daily COP will lie somewhere between the two extremes for one machine or the other having all 28,000 square feet (Fig. 12).

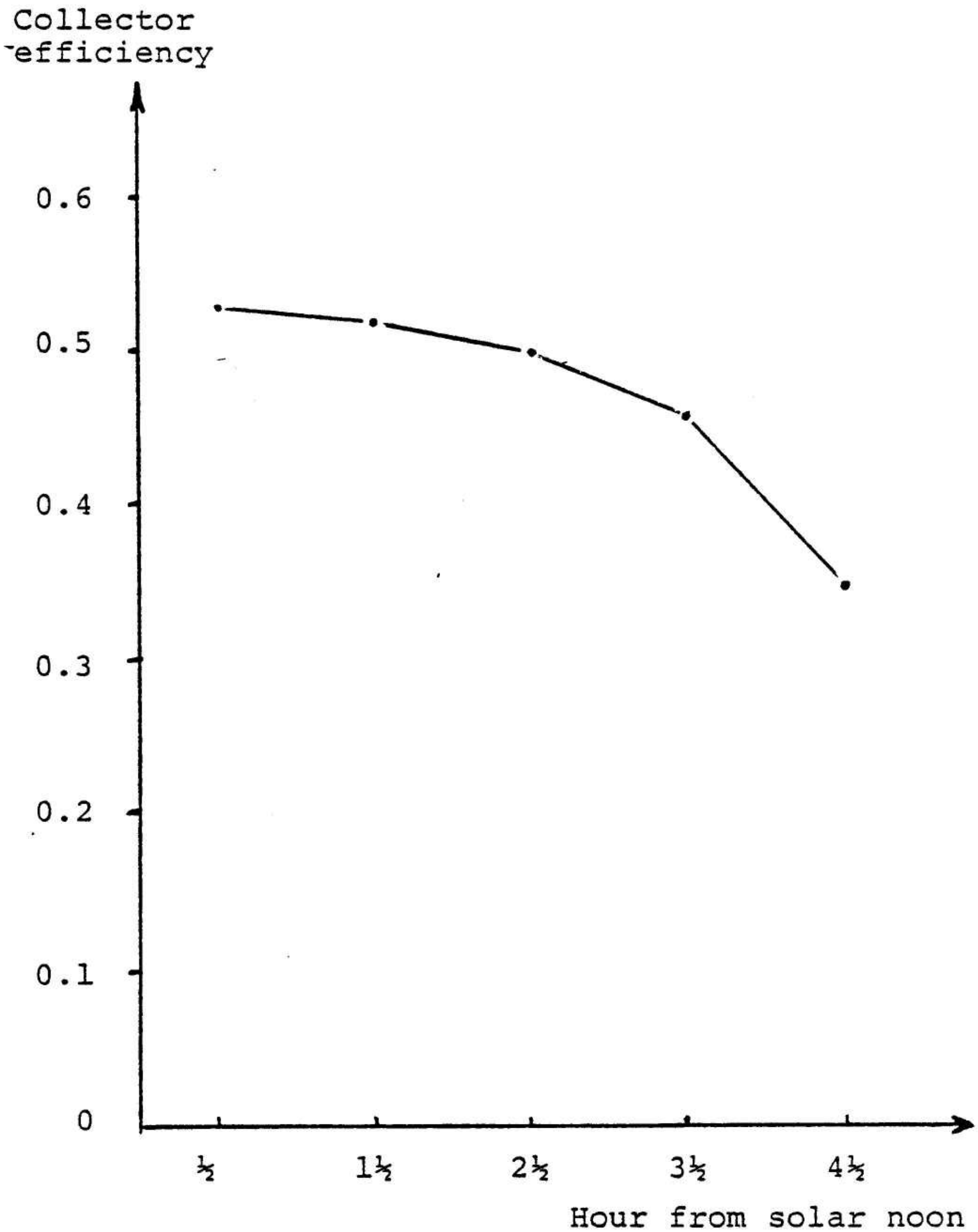

Figure 10.

Variation of collector efficiency with time of day, for Suntec SLATS concentrating collector tilted at 20°, July.

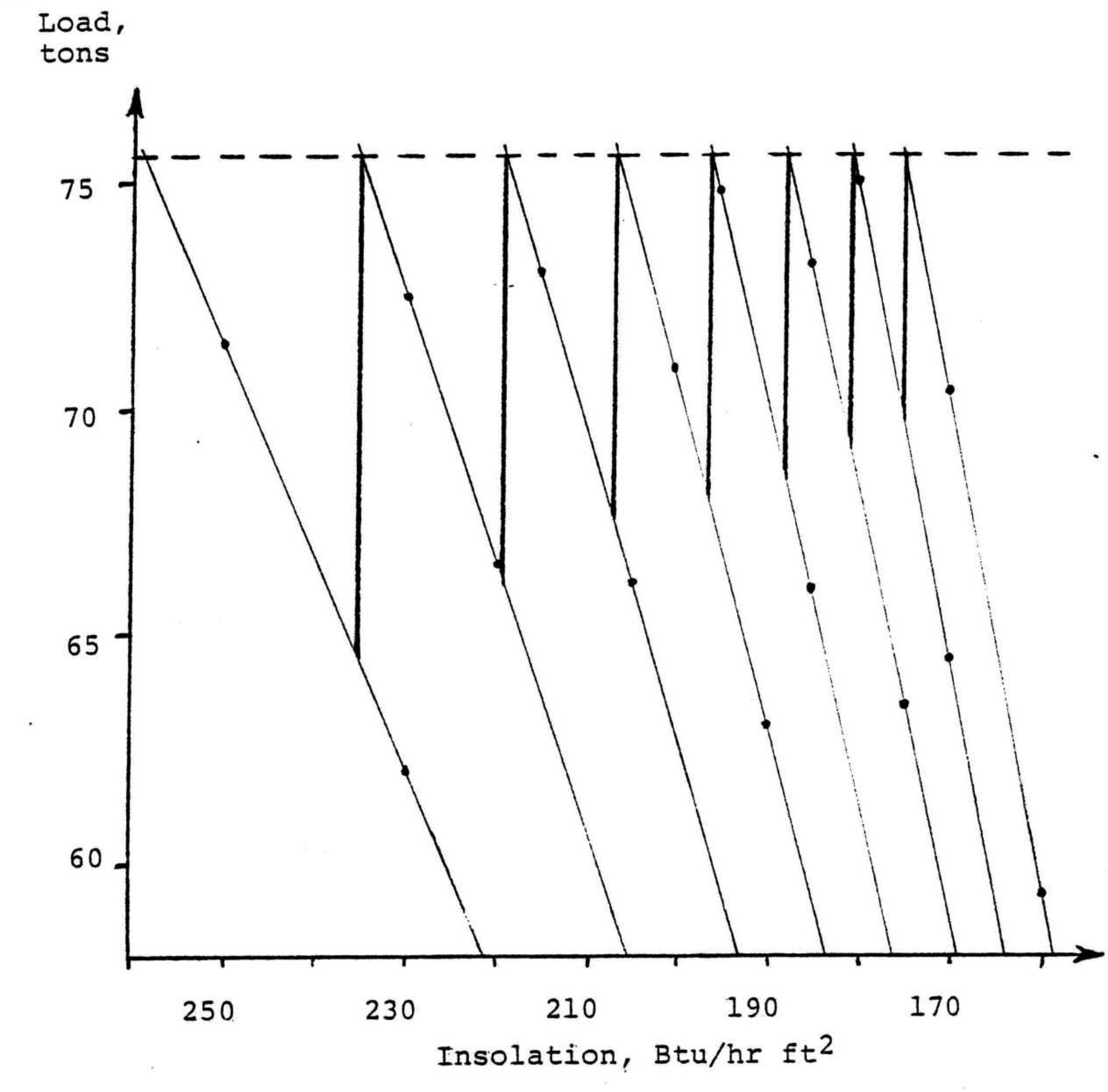

Figure 11.

Load handled by the all-solar machine of system #2, using corrected collector efficiency equations.

Table 2. Daily COP of each system, using corrected collector efficiency

System	COP_{day}
#1	0.185
#2a (129, 212°F)	0.179
#2b (148, 204°F)	0.183
#2c (174, 196°F)	0.183
#2d (200, 191°F)	C.183

Table 3. Daily COP of System #2, using corrected collector efficiency and switching solar collector to second machine during low-sun period

System	COP_{day}
#2a (129, 212^{o}F)	0.176
#2b (148, 204^{o}F)	0.182
#2c (174, 196^{o}F)	0.184
#2d (200, 191^{o}F)	0.185

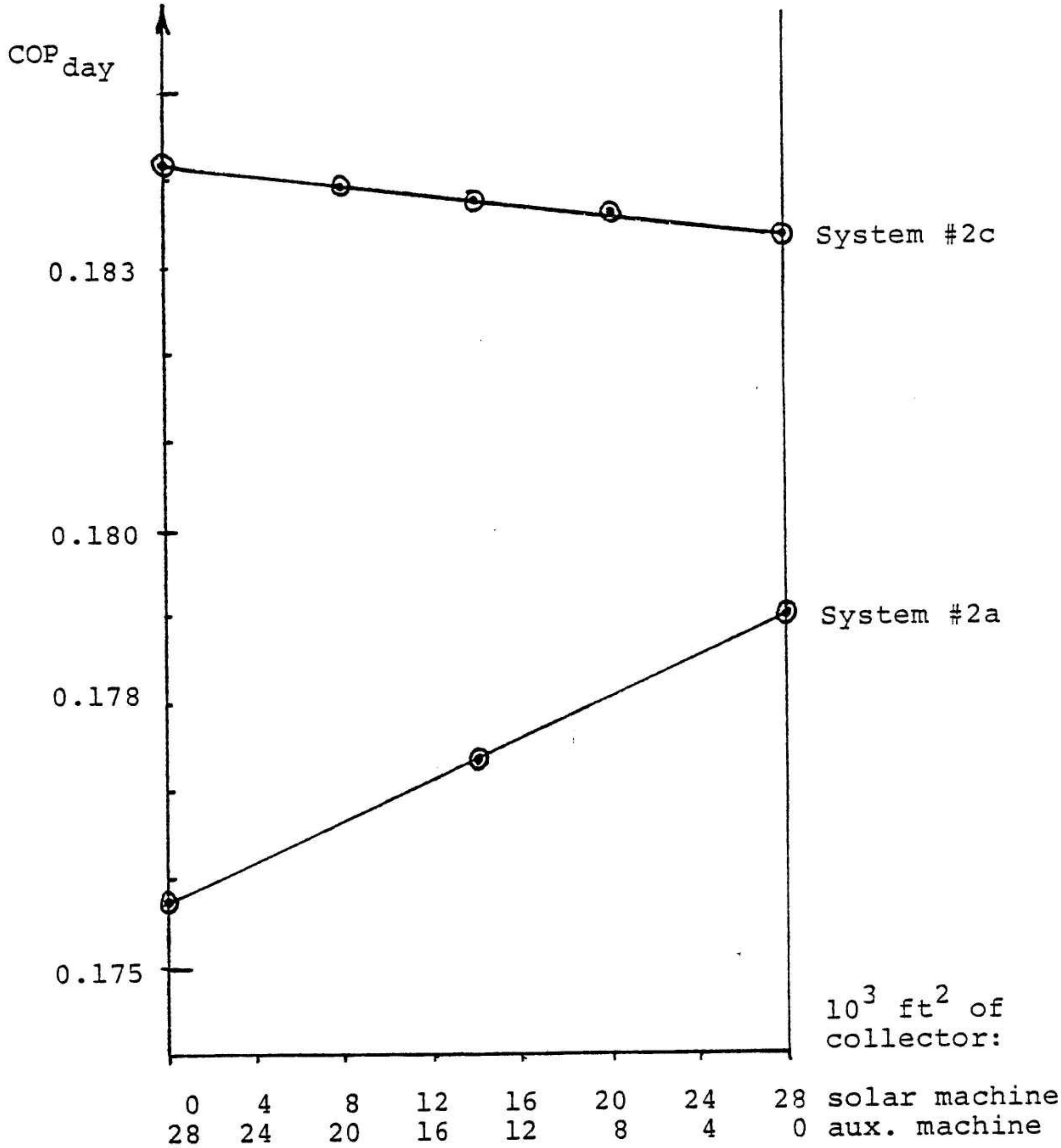

Figure 12.

Daily COP of system #2 as a function of how the collector is distributed during low-sun periods.

DISCUSSION OF RESULTS

The two-machine system can be made to have a higher daily COP than a single large machine, however, this difference is small, only 0.12%. The two-machine system will have a much higher capital cost, both for the absorptions chillers and for the collector-switching controls, valves, and piping. Therefore, it should show significantly better performance than the single large machine in order to be considered a better design choice.

There are many effects which were not taken into account in this study.

1. Load

   The load was assumed to be constant. However, the load actually varies over the day, peaking sometime in the early afternoon. It is not obvious without further study whether or not including this effect would improve the daily COP's calculated here.

2. Ambient temperature

   The ambient temperature was held constant at 78°F. However, the ambient temperature also varies over the day, peaking in the early afternoon. Higher temperatures will improve the collector efficiency, and thus the instantaneous overall COP, in the early afternoon. Lower temperatures in the morning and late afternoon will decrease the overall COP during these periods.

Differences in ambient temperature and relative humidity will also affect the temperature of the cooling water coming from the cooling tower.

3. Transients

The data for the Trane machines used here was intended for use in selecting a machine for a given application and thus describes steady-state operating points. The two-machine system requies both machines to vary their loads up and down as often as twice an hour. Because the absorption chillers will have internal lags in responding to increased energy input, the calculations done in this study may be inaccurate for the two-machine system.

4. Collector

Solar collectors have lower efficiencies at higher water temperatures, as shown in Fig. 2. This effect was not very significant in the systems examined: the overall COP was more sensitive to the absorption chiller COP than to the collector efficiency. However, if a solar collector was used which was more sensitive to temperature, i.e., if Fig. 2 had a steeper slope, the effect of the collector efficiency would be more important. Flat plate collectors do have a steeper slope of η vs. $\Delta T/I$ and thus the results shown here cannot be generalized to systems using flat plate collectors.

5. Variation of insolation

The variation of insolation over the day (Fig. 7) was assumed to be symmetric about solar noon. In fact, average insolation is greater in the morning because there are more clouds in the afternoon. Actual weather data could be used to generate a more accurate average curve of insolation vs. time. In this case, the daily COP would have to be calculated for the whole day rather than for a half day as done here.

CONCLUSIONS AND RECOMMENDATIONS

While the results of this study indicate that a two-machine system can be made to give a marginally (0.12%) better daily COP than a single large machine, the difference is so small that it is unlikely that the resulting fuel savings would offset the much larger capital cost of the two-machine system.

The two-machine system's daily COP could be improved if the inlet temperature of the second machine were varied so that the machine would operate always at the optimum temperature for the load required at that moment. This strategy would be valuable for both systems when handling a fluctuating load.

Another possible strategy would be to keep the inlet temperature constant and artificially maintain the load at the maximum possible load for that temperature by chilling more water than necessary. The excess chilled water could be stored for use during low-sun periods or during the night.

Further study is recommended to determine how much improvement in daily COP is possible by using the above strategies.

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2. Bligh, T. P., and Ramsey, J. W., "Solar Heating and Cooling for an Underground Building at the University of Minnesota", Proceedings of the Second Solar Heating and Cooling Commercial Demonstration Program Conference, U.S. Dept. of Energy, San Diego, Dec. 1978.

3. The Trane Company, "Single-Stage Absorption Cold Generators for Low Temperature Input", July 1977, The Trane Company, La Crosse, WI.

Special thanks to the Trane Company for answering questions and for providing the data from which the computer programs were written.

APPENDIX A. COMPUTER PROGRAMS

List of programs and descriptions

List of variables used in the programs

Simplified flowcharts

Actual programs

These programs are stored on a diskette belonging to Professor Bligh. The computer used was a Digital Equipment MINC.

Since these listings, SCOOL5, SCOOL6, and SCOOL7 have been modified to include the variation of collector efficiency with time of day.

List of programs and descriptions

SCOOL1 Given the enterning hot water temperature, entering cooling water temperature, leaving chilled water temperature and flowrate, and load, this program selects the required machine size, then calculates the hot water temperature leaving the chiller, hot water flowrate, cooling water flowrate and temperature rise, and COP.

SCOOL2 Same as SCOOL1, except that you choose the machine size. The program tells you the maximum design load; you then choose the load.

SCOOL4 Finds the necessary collector area for 100% solar operation at a given load, hot water temperature, and insolation. Efficiency of the collector is not corrected for variation over the day.

SCOOL5 Finds the amount of auxiliary heat necessary to support a given load, with a given insolation, collector area, and hot water temperature.

SCOOL6 Iterates to find the maximum load for 100% solar operation.

SCOOL7 Finds the daily COP for one large machine, and for a two-machine system where the all-solar machine is a #3 (129-ton) size operating at an inlet temperature of 204°F.

SC5
SC6
SC7 SAME AS SCOOL5, SCOOL6, and SCOOL7, respectively, except that the efficiency of the collector is not corrected for variation over the day.

Data files

M.DAT

Data for each machine:

Column	Contents
1	size (tons)
2	lowest chilled water flowrate for which there is data
3	higher chilled water flowrate for which there is data
4	slope of flow factor vs. chilled water flowrate
5	intercept of flow factor vs. chilled water flowrate
6	lowest operating ratio for which there is data
7	highest operating ratio for which there is data
8	crossover point if there are two lines for cooling water flowrate vs. operating ratio; 200 if there is only one line
9	slope of cooling water flowrate vs. operating ratio (low end if there are two lines)
10	intercept of cooling water flowrate vs. operating ratio (low end if there are two lines)

11	slope of cooling water flowrate vs. operating ratio (high end)
12	intercept of cooling water flowrate vs. operating ratio (high end)
13	pump power, kilowatts

N.DAT

Backup, same as M.DAT

G.DAT

Data to find the design condition correction factor D as a function of chilled water temperature T3.

Column	Contents
1	crossover point T3
2	low end slope
3	low end intercept
4	high end slope
5	high end intercept

Each row represents a cooling water temperature from 65 to 95°F in increments of 5°F.

H.DAT

Backup, same as G.DAT

P.DAT

Data for the energy input rate y as a function of bad ratio R2, where $y = A\ (R2-v)^2 + B$

Column	Contents
1	A
2	v
3	B

Each row represents a different value of heat source correction factor H from .20 to .70 in steps of .10

Q.DAT

Backup, same as P.DAT

List of variables used in the programs

A	Available tons
C	Specific hear-densing factor
D	Design condition correction factor
E	Evaporator tons
E8	Instantaneous overall COP
E9	Efficiency of solar collector
F	Flow correction factor
F1	Flag for which machine
F2	Flag for whether auxiliary firing is being used
F9	Increment for insolation
H	Hear source correction factor
I	Machine number
I9	Insolation
JO	Index for loop
K	Index which tells whether to repeat or end
L	Load
L1	Maximum load
L9	Load for second machine of a two-machine system
N	Nominal tons
Q1	Chilled water flowrate
Q2	Cooling water flowrate
Q3	Hot water flow
R	Operating ratio
R2	Load ratio

S8 Collector area for first machine of a two-machine system

S9 Collector area

T0 Temperature of hot water leaving collector

T1 Hot water temperature entering the chiller

T2 Entering cooling water temperature

T3 Leaving chilled water temperature

T4 Hot water temperature leaving the chiller

T5 Cooling water temperature rise

T9 Ambient temperature

u Auxiliary energy used

u2 Solar energy used

v Reciprocal of time internal

v1, v2 Fraction of load handled by solar energy

y Heat input rate

z COP of chiller

SCOOL1

```
Input  T1, T2, T3, Q1, L
Find T4 and H from T1
Find I from L, H, data files
 ------------------------------------------
| Find D from T2, T3, I, data files        |
| Find A from H, D, I                      |
| Find F from Q1, I, data files            |     Basic
| Find E from F, A                         |     absorption
| Find R from L, E                         |     chiller
| Find Q2 from I, R, data files            |     calculations
| Find R2 from L, I                        |
| Find y from H, R2, I, data files         |
| Find C from T1, T4                       |
| Find Q3 from y, C, T1, T4, L             |
| Find T5 from L, y, Q2                    |
| Find z from y                            |
 ------------------------------------------
Print out I, z, Q3, T4, Q2, T5
```

SCOOL2

Input T1, T2, T3, Q1, I

Find T4 and H from T1

Caculate maximum load L1

Print L1

Input L

Basic absorption chiller calculations
(see SCOOL1 for details)

Print z, Q3, T4, Q2, T5

SCOOL4

Input T1, L, T2, T3, Q1, I, I9, T9, S9

Find maximum load L1

If L > L1, set L equal to L1

Basic absorption chiller calculations
(see SCOOL1)

Find E9 from T4, T9, I9

Find S9 from T1, T4, C, Q3, E9, I9

Print z, L, L1, Q3, T4, Q2, T5, S9, E9, overall COP

SCOOL5

Input T1, I9, L, T2, T3, Q1, I, T9, S9

Find maximum load L1

If L > L1 then set L equal to L1

Basic absorption chiller calculations
(see SCOOL1)

Find E9, T0, U, U2:

- Find E9 from T4, T9, I9
- Find T0 from E9, I9, S9, C, Q3, T4
- Find a new value for C from T0, T4
- Go back and find a new T0 (loop 5 times)
- Print T0
- Find U from Q3, C4, T1, T0; Print U
- Find U2 from Q3, C, T0, T4; Print U2

Print solar used/total used

Print Z,L, L1, Q3, T4, Q2, T5, S9, E9

Find E8 from U, U2, L, I9, S9; Print E8

SCOOL6

Input I9, L, S9, T2, T3, Q1, I, T9

Find maximum load L1

If L > L1 then input a new value for L

Basic absorption chiller calculations
(see SCOOL1)

Find E9, T0, u, u2
(see SCOOL5)

Print T1, Z, L, L1, Q3, T4, Q2, T5, E9

Find E8 from u, u2, L, I9, S9

If u < 0 or u > 2, then change L and repeat

If 0 < u < 2, stop.

SCOOL7

Input F9

Initialize I9, S8, T9, T2, T3

→ Decrease I9 by F9

If I9 $\le$ then stop.

Do for each of the 3 machines:

Set values of L, Q1, I, S9, F1

Basic absorption chiller calculations (see SCOOL1)

Find E9, T0, u2, u (see SCOOL5)

Find time interval $\frac{1}{v}$

Add to numerator and denominator running totals v(1, F1) and v(2, F1)

When calculations have been done for all 3 machines, decrease I9 and repeat

```
1 REM Absorption chiller program
2 REM Procedure from Trane catalog supplement
3 REM This program finds machine size and hot water flowrate, given
4 REM entering temperature and load.
11 PRINT "** indicates extrapolated data"
20 OPEN "M.DAT" FOR INPUT AS FILE #1
30 DIM #1,M(21,13)
40 OPEN "G.DAT" FOR INPUT AS FILE #2
50 DIM #2,G(7,5)
60 OPEN "P.DAT" FOR INPUT AS FILE #3
70 DIM #3,P(6,3)
100 PRINT  \ PRINT
115 REM input variables
120 PRINT "Entering hot water temperature (160-260 F)"; \ INPUT T1
130 PRINT "Entering cooling water temperature (65-95 F)"; \ INPUT T2
140 PRINT "Leaving chilled water temperature (40-60 F)"; \ INPUT T3
150 PRINT "Chilled water flow (130-1700 GPM)"; \ INPUT Q1
160 PRINT "Load (20-1250 tons)"; \ INPUT L
200 REM Determine heat source correction factor H
201 REM  and leaving hot water temperature T4
210 LET T4=(T1+30.9)/1.21
215 IF T4<158.5 THEN PRINT "** Hot water temperature low."
220 IF T4>239 THEN PRINT "** Hot water temperature high."
230 IF T4<205 THEN LET H=(1.36*T4-205.4)/100 \ GO TO 300
240 LET H=(.99*T4-129.6)/100
300 REM Select machine size
301 REM Find nominal tons N
302 PRINT "H= ";H
320 LET N=L/H
321 PRINT "N= ";N
325 LET I=1
330 IF N<=M(I,1) THEN  GO TO 410
335 IF I=21 THEN PRINT "No machine big enough." \ GO TO 950
340 LET I=I+1
345 GO TO 330
360 REM I is the number of the machine
400 REM Determine available tons A
405 REM Find design condition correction factor D, from subrot
```

```
410 GO TO 2000
415 LET A=M(I,1)*H*D
416 PRINT "D= ";D
417 PRINT "A= ";A
425 REM Find flow correction factor F
429 PRINT "I= ";I
430 IF Q1<M(I,2) THEN PRINT "** Low chilled water flow."
435 IF Q1>M(I,3) THEN PRINT "** High chilled water flow."
440 LET F=(M(I,4)*LOG10(Q1)+M(I,5))/100
441 PRINT "F= ";F
445 REM Find evaporator tons E
450 LET E=A*F
455 REM Find condenser operating ratio R
460 LET R=L/E
461 PRINT "R= ";R
465 REM Find cooling water flow Q2
470 IF R<M(I,6) THEN PRINT "** Low operating ratio."
475 IF R>M(I,7) THEN PRINT "** High operating ratio."
480 IF R>M(I,8) THEN  GO TO 495
485 LET Q2=10^(M(I,9)*10^R+M(I,10)) \ GO TO 500
495 LET Q2=10^(M(I,11)*10^R+M(I,12))
500 REM Find hot water flowrate Q3
501 REM Find load ratio R2
502 LET R2=L/M(I,1)
505 REM Find energy input rate Y, from subrot
510 GO TO 3000
520 REM Find specific heat-density factor C
525 LET C=(-.0642857)*(T1+T4)+510.171
530 LET Q3=Y*L/(T1-T4)/C
600 REM Find cooling water temperature rise T5
605 LET T5=L*(12000+Y)/(500*Q2)
610 REM Find COP Z (Cooling/energyinput)
620 LET Z=12000/Y
900 REM Outputs
905 PRINT "Machine size = ";M(I,1);" tons,"
910 PRINT "COP = ";Z \ PRINT
915 PRINT "Hot water flow = ";Q3;" GPM"
```

```
920 PRINT "Leaving hot water temperature = ";T4;" F"
925 PRINT "Cooling water flow = ";Q2;" GPM"
930 PRINT "Cooling water temperature rise = ";T5;" F"
935 PRINT  \ PRINT
950 PRINT "Again? (1 = yes, 2 = no)"; \ INPUT K
960 IF K=1 THEN  GO TO 100
970 IF K<>2 THEN  GO TO 950
990 CLOSE
995 GO TO 4000
2000 REM Subrot to find design condition correction factor D
2010 REM Check limits
2015 IF T2<=90 THEN  GO TO 2025
2020 IF T3<45 THEN PRINT "*** Cooling water too hot." \ GO TO 950
2025 REM Find the nearest temperatures for which there's data
2030 LET T6=T2/5-12
2035 LET G1=INT(T6)
2040 IF G1<1 THEN LET G1=1
2045 IF G1>6 THEN LET G1=6
2050 LET G2=G1+1
2052 IF G1=2 THEN LET G1=1
2053 IF G2=2 THEN LET G2=3
2055 LET S1=(G1+12)*5
2060 LET S2=(G2+12)*5
2065 REM Calculate D for each
2070 IF T3>G(G1,1) THEN  GO TO 2085
2075 REM Lower end
2080 LET D1=G(G1,2)*T3+G(G1,3) \ GO TO 2095
2085 REM Upper end
2090 LET D1=G(G1,4)*T3+G(G1,5)
2095 IF T3>G(G2,1) THEN  GO TO 2110
2100 REM Lower end
2105 LET D2=G(G2,2)*T3+G(G2,3) \ GO TO 2120
2110 REM Upper end
2115 LET D2=G(G2,4)*T3+G(G2,5)
2120 REM Interpolate
2125 LET D=(T2-S1)*(D2-D1)/(S2-S1)+D1
2130 GO TO 415
```

```
3000 REM Subrot to find energy input rate Y
3005 IF H<.2 THEN PRINT "** Low hot water temperature."
3010 IF H>.7 THEN PRINT "** High hot water temperature."
3015 LET H1=.1*INT(H*10)
3020 IF H1<.2 THEN LET H1=.2
3025 IF H1>.6 THEN LET H1=.6
3030 LET H2=H1+.1
3035 LET B1=H1*10-1
3040 LET B2=H2*10-1
3045 LET Y1=P(B1,1)*(R2-P(B1,2))^2+P(B1,3)
3050 LET Y2=P(B2,1)*(R2-P(B2,2))^2+P(B2,3)
3060 REM Interpolate
3065 LET Y=((H-H1)*(Y2-Y1)/(H2-H1)+Y1)*1000
3066 PRINT "Y= ";Y
3090 GO TO 525
4000 END
```

```
1 REM Absorption chiller program
2 REM Procedure from Trane catalog supplement
3 REM Modified to keep machine size constant
4 REM Given the entering hot water temperature, this program
5 REM   determines the max.load, and the COP and flowrate at
6 REM  a load that you choose.
11 PRINT "** indicates extrapolated data"
20 OPEN "M.DAT" FOR INPUT AS FILE #1
30 DIM #1,M(21,13)
40 OPEN "G.DAT" FOR INPUT AS FILE #2
50 DIM #2,G(7,5)
60 OPEN "P.DAT" FOR INPUT AS FILE #3
70 DIM #3,P(6,3)
75 PRINT "Do you need the list of machine #'s and sizes (1=yes,2=no)";
80 INPUT CO
85 IF CO<>1 THEN  GO TO 100
90 FOR C1=1 TO 21
92 PRINT C1;" : ";M(C1,1);" tons"
95 NEXT C1
100 PRINT  \ PRINT
115 REM input variables
120 PRINT "Entering hot water temperature (160-260 F)"; \ INPUT T1
125 IF K=3 THEN 170
130 PRINT "Entering cooling water temperature (65-95 F)"; \ INPUT T2
140 PRINT "Leaving chilled water temperature (40-60 F)"; \ INPUT T3
150 PRINT "Chilled water flow (130-1700 GPM)"; \ INPUT Q1
165 PRINT "Machine # "; \ INPUT I
170 PRINT
200 REM Determine heat source correction factor H
201 REM  and leaving hot water temperature T4
210 LET T4=(T1+30.9)/1.21
215 IF T4<158.5 THEN PRINT "** Hot water temperature low."
220 IF T4>239 THEN PRINT "** Hot water temperature high."
230 IF T4<205 THEN LET H=(1.36*T4-205.4)/100 \ GO TO 300
240 LET H=(.99*T4-129.6)/100
300 REM Determine maximum load
365 LET L=M(I,1)*H
```

```
366 PRINT "Maximum load= ";L
370 PRINT "What load do you want"; \ INPUT L
380 PRINT
400 REM Determine available tons A
405 REM Find design condition correction factor D, from subrot
410 GO TO 2000
415 LET A=M(I,1)*H*D
425 REM Find flow correction factor F
430 IF Q1<M(I,2) THEN PRINT "** Low chilled water flow."
435 IF Q1>M(I,3) THEN PRINT "** High chilled water flow."
440 LET F=(M(I,4)*LOG10(Q1)+M(I,5))/100
445 REM Find evaporator tons E
450 LET E=A*F
455 REM Find condenser operating ratio R
460 LET R=L/E
465 REM Find cooling water flow Q2
470 IF R<M(I,6) THEN PRINT "** Low operating ratio."
475 IF R>M(I,7) THEN PRINT "** High operating ratio."
480 IF R>M(I,8) THEN  GO TO 495
485 LET Q2=10^(M(I,9)*10^R+M(I,10)) \ GO TO 500
495 LET Q2=10^(M(I,11)*10^R+M(I,12))
500 REM Find hot water flowrate Q3
501 REM Find load ratio R2
502 LET R2=L/M(I,1)
505 REM Find energy input rate Y, from subrot
510 GO TO 3000
520 REM Find specific heat-density factor C
525 LET C=(-.0642857)*(T1+T4)+510.171
530 LET Q3=Y*L/(T1-T4)/C
600 REM Find cooling water temperature rise T5
605 LET T5=L*(12000+Y)/(500*Q2)
610 REM Find COP Z (Cooling/energyinput)
620 LET Z=12000/Y
900 REM Outputs
905 PRINT "Machine size = ";M(I,1);" tons,"
910 PRINT "COP = ";Z \ PRINT
915 PRINT "Hot water flow = ";Q3;" GPM"
```

```
920 PRINT "Leaving hot water temperature = ";T4;" F"
925 PRINT "Cooling water flow = ";Q2;" GPM"
930 PRINT "Cooling water temperature rise = ";T5;" F"
935 PRINT  \ PRINT
950 PRINT "Again? (1 = yes, 2 = no)"; \ INPUT K
960 IF K=1 THEN  GO TO 100
965 IF K=3 THEN 100
970 IF K<>2 THEN  GO TO 950
990 CLOSE
995 GO TO 4000
2000 REM Subrot to find design condition correction factor D
2010 REM Check limits
2015 IF T2<=90 THEN  GO TO 2025
2020 IF T3<45 THEN PRINT "*** Cooling water too hot." \ GO TO 950
2025 REM Find the nearest temperatures for which there's data
2030 LET T6=T2/5-12
2035 LET G1=INT(T6)
2040 IF G1<1 THEN LET G1=1
2045 IF G1>6 THEN LET G1=6
2050 LET G2=G1+1
2052 IF G1=2 THEN LET G1=1
2053 IF G2=2 THEN LET G2=3
2055 LET S1=(G1+12)*5
2060 LET S2=(G2+12)*5
2065 REM Calculate D for each
2070 IF T3>G(G1,1) THEN  GO TO 2085
2075 REM Lower end
2080 LET D1=G(G1,2)*T3+G(G1,3) \ GO TO 2095
2085 REM Upper end
2090 LET D1=G(G1,4)*T3+G(G1,5)
2095 IF T3>G(G2,1) THEN  GO TO 2110
2100 REM Lower end
2105 LET D2=G(G2,2)*T3+G(G2,3) \ GO TO 2120
2110 REM Upper end
2115 LET D2=G(G2,4)*T3+G(G2,5)
2120 REM Interpolate
2125 LET D=(T2-S1)*(D2-D1)/(S2-S1)+D1
```

```
2130 GO TO 415
3000 REM Subrot to find energy input rate Y
3005 IF H<.2 THEN PRINT "** Low hot water temperature."
3010 IF H>.7 THEN PRINT "** High hot water temperature."
3015 LET H1=.1*INT(H*10)
3020 IF H1<.2 THEN LET H1=.2
3025 IF H1>.6 THEN LET H1=.6
3030 LET H2=H1+.1
3035 LET B1=H1*10-1
3040 LET B2=H2*10-1
3045 LET Y1=P(B1,1)*(R2-P(B1,2))^2+P(B1,3)
3050 LET Y2=P(B2,1)*(R2-P(B2,2))^2+P(B2,3)
3060 REM Interpolate
3065 LET Y=((H-H1)*(Y2-Y1)/(H2-H1)+Y1)*1000
3066 PRINT "Y= ";Y
3090 GO TO 525
4000 END
```

```
1 REM Absorption chiller program
2 REM Procedure from Trane catalog supplement
3 REM   and SLATS solar collector.
4 REM This program finds the required collector area, given load,
5 REM   chiller entering temperature, and machine size.
20 OPEN "M.DAT" FOR INPUT AS FILE #1
30 DIM #1,M(21,13)
40 OPEN "G.DAT" FOR INPUT AS FILE #2
50 DIM #2,G(7,5)
60 OPEN "P.DAT" FOR INPUT AS FILE #3
70 DIM #3,P(6,3)
75 PRINT "Do you need the list of machine #'s and sizes (1=yes,2=no)";
80 INPUT C0
85 IF C0<>1 THEN  GO TO 100
90 FOR C1=1 TO 21
92 PRINT C1;" : ";M(C1,1);" tons"
95 NEXT C1
100 PRINT  \ PRINT
115 REM input variables
120 PRINT "Hot water temperature into chiller"; \ INPUT T1
121 PRINT "Load"; \ INPUT L
125 IF K=3 THEN 200
130 PRINT "Entering cooling water temperature (65-95 F)"; \ INPUT T2
140 PRINT "Leaving chilled water temperature (40-60 F)"; \ INPUT T3
150 PRINT "Chilled water flow (130-1700 GPM)"; \ INPUT Q1
165 PRINT "Machine # "; \ INPUT I
170 PRINT "Insolation, Btu/hr ft^2 "; \ INPUT I9
175 PRINT "Ambient temperature, F "; \ INPUT T9
180 PRINT "Collector size, ft^2 "; \ INPUT S9
199 PRINT
200 REM Determine heat source correction factor H
201 REM  and leaving hot water temperature T4
210 LET T4=(T1+30.9)/1.21
215 IF T4<158.5 THEN PRINT "** Hot water temperature low."
220 IF T4>239 THEN PRINT "** Hot water temperature high."
230 IF T4<205 THEN LET H=(1.36*T4-205.4)/100 \ GO TO 300
240 LET H=(.99*T4-129.6)/100
300 REM Determine maximum load for this machine
```

```
365 LET L1=M(I,1)*H
370 IF L1<L THEN PRINT "Load too high." \ L=L1
380 REM
400 REM Determine available tons A
405 REM Find design condition correction factor D, from subrot
410 GO TO 2000
415 LET A=M(I,1)*H*D
425 REM Find flow correction factor F
430 IF Q1<M(I,2) THEN PRINT "** Low chilled water flow."
435 IF Q1>M(I,3) THEN PRINT "** High chilled water flow."
440 LET F=(M(I,4)*LOG10(Q1)+M(I,5))/100
445 REM Find evaporator tons E
450 LET E=A*F
455 REM Find condenser operating ratio R
460 LET R=L/E
465 REM Find cooling water flow Q2
470 IF R<M(I,6) THEN PRINT "** Low operating ratio."
475 IF R>M(I,7) THEN PRINT "** High operating ratio."
480 IF R>M(I,8) THEN  GO TO 495
485 LET Q2=10^(M(I,9)*10^R+M(I,10)) \ GO TO 500
495 LET Q2=10^(M(I,11)*10^R+M(I,12))
500 REM Find hot water flowrate Q3
501 REM Find load ratio R2
502 LET R2=L/M(I,1)
505 REM Find energy input rate Y, from subrot
510 GO TO 3000
520 REM Find specific heat-density factor C
525 LET C=(-.0642857)*(T1+T4)+510.171
530 LET Q3=Y*L/(T1-T4)/C
600 REM Find cooling water temperature rise T5
605 LET T5=L*(12000+Y)/(500*Q2)
610 REM Find COP Z (Cooling/energyinput)
620 LET Z=12000/Y
650 GO TO 3500
900 REM Outputs
902 PRINT  \ PRINT
905 PRINT "Machine size = ";M(I,1);" tons,"
```

```
908 PRINT "Hot water into chiller at ";T1;" F"
910 PRINT "COP = ";Z \ PRINT
912 PRINT "Load = ";L
913 PRINT "Maximum load= ";L1
915 PRINT "Hot water flow = ";Q3;" GPM"
920 PRINT "Leaving hot water temperature = ";T4;" F"
925 PRINT "Cooling water flow = ";Q2;" GPM"
930 PRINT "Cooling water temperature rise = ";T5;" F"
932 PRINT "Collector area =";S9
933 PRINT "Efficiency of collector =";E9
934 PRINT "overall COP = ";L*12000/I9/S9
935 PRINT  \ PRINT
950 PRINT "Again? (1 = yes, 2 = no)"; \ INPUT K
960 IF K=1 THEN  GO TO 100
965 IF K=3 THEN 100
970 IF K<>2 THEN  GO TO 950
990 CLOSE
995 GO TO 4000
2000 REM Subrot to find design condition correction factor D
2010 REM Check limits
2015 IF T2<=90 THEN  GO TO 2025
2020 IF T3<45 THEN PRINT "*** Cooling water too hot." \ GO TO 950
2025 REM Find the nearest temperatures for which there's data
2030 LET T6=T2/5-12
2035 LET G1=INT(T6)
2040 IF G1<1 THEN LET G1=1
2045 IF G1>6 THEN LET G1=6
2050 LET G2=G1+1
2052 IF G1=2 THEN LET G1=1
2053 IF G2=2 THEN LET G2=3
2055 LET S1=(G1+12)*5
2060 LET S2=(G2+12)*5
2065 REM Calculate D for each
2070 IF T3>G(G1,1) THEN  GO TO 2085
2075 REM Lower end
2080 LET D1=G(G1,2)*T3+G(G1,3) \ GO TO 2095
2085 REM Upper end
```

```
2090 LET D1=G(G1,4)*T3+G(G1,5)
2095 IF T3>G(G2,1) THEN  GO TO 2110
2100 REM Lower end
2105 LET D2=G(G2,2)*T3+G(G2,3) \ GO TO 2120
2110 REM Upper end
2115 LET D2=G(G2,4)*T3+G(G2,5)
2120 REM Interpolate
2125 LET D=(T2-S1)*(D2-D1)/(S2-S1)+D1
2130 GO TO 415
3000 REM Subrot to find energy input rate Y
3005 IF H<.2 THEN PRINT "** Low hot water temperature."
3010 IF H>.7 THEN PRINT "** High hot water temperature."
3015 LET H1=.1*INT(H*10)
3020 IF H1<.2 THEN LET H1=.2
3025 IF H1>.6 THEN LET H1=.6
3030 LET H2=H1+.1
3035 LET B1=H1*10-1
3040 LET B2=H2*10-1
3045 LET Y1=P(B1,1)*(R2-P(B1,2))^2+P(B1,3)
3050 LET Y2=P(B2,1)*(R2-P(B2,2))^2+P(B2,3)
3060 REM Interpolate
3065 LET Y=((H-H1)*(Y2-Y1)/(H2-H1)+Y1)*1000
3090 GO TO 525
3500 REM Solar collector requirements
3501 REM Efficiency=E9, out=T1, in=T4, ambient=T9
3510 LET E9=.407143-.17857*(T4-T9)/I9
3525 LET S9=(T1-T4)*C*Q3/E9/I9
3600 GO TO 900
4000 END
```

```
1 REM Absorption chiller program
2 REM Procedure from Trane catalog supplement
3 REM   and SLATS solar collector.
4 REM This program finds the amount of auxiliary heat needed to
5 REM   support a given load.
20 OPEN "M.DAT" FOR INPUT AS FILE #1
30 DIM #1,M(21,13)
40 OPEN "G.DAT" FOR INPUT AS FILE #2
50 DIM #2,G(7,5)
60 OPEN "P.DAT" FOR INPUT AS FILE #3
70 DIM #3,P(6,3)
75 PRINT "Do you need the list of machine #'s and sizes (1=yes,2=no)";
80 INPUT C0
85 IF C0<>1 THEN  GO TO 100
90 FOR C1=1 TO 21
92 PRINT C1;" : ";M(C1,1);" tons"
95 NEXT C1
100 PRINT  \ PRINT
115 REM input variables
120 PRINT "Hot water temperature into chiller"; \ INPUT T1
122 PRINT "Insolation, Btu/hr ft^2 "; \ INPUT I9
123 PRINT "Load"; \ INPUT L
125 IF K=3 THEN 200
130 PRINT "Entering cooling water temperature (65-95 F)"; \ INPUT T2
140 PRINT "Leaving chilled water temperature (40-60 F)"; \ INPUT T3
150 PRINT "Chilled water flow (130-1700 GPM)"; \ INPUT Q1
165 PRINT "Machine # "; \ INPUT I
175 PRINT "Ambient temperature, F "; \ INPUT T9
180 PRINT "Collector size, ft^2 "; \ INPUT S9
199 PRINT
200 REM Determine heat source correction factor H
201 REM  and leaving hot water temperature T4
210 LET T4=(T1+30.9)/1.21
215 IF T4<158.5 THEN PRINT "** Hot water temperature low."
220 IF T4>239 THEN PRINT "** Hot water temperature high."
230 IF T4<205 THEN LET H=(1.36*T4-205.4)/100 \ GO TO 300
```

```
240 LET H=(.99*T4-129.6)/100
300 REM Determine maximum load for this machine
365 LET L1=M(I,1)*H
370 IF L1<L THEN PRINT "Load too high." \ L=L1
380 REM
400 REM Determine available tons A
405 REM Find design condition correction factor D, from subrot
410 GO TO 2000
415 LET A=M(I,1)*H*D
425 REM Find flow correction factor F
430 IF Q1<M(I,2) THEN PRINT "** Low chilled water flow."
435 IF Q1>M(I,3) THEN PRINT "** High chilled water flow."
440 LET F=(M(I,4)*LOG10(Q1)+M(I,5))/100
445 REM Find evaporator tons E
450 LET E=A*F
455 REM Find condenser operating ratio R
460 LET R=L/E
465 REM Find cooling water flow Q2
470 IF R<M(I,6) THEN PRINT "** Low operating ratio."
475 IF R>M(I,7) THEN PRINT "** High operating ratio."
480 IF R>M(I,8) THEN  GO TO 495
485 LET Q2=10^(M(I,9)*10^R+M(I,10)) \ GO TO 500
495 LET Q2=10^(M(I,11)*10^R+M(I,12))
500 REM Find hot water flowrate Q3
501 REM Find load ratio R2
502 LET R2=L/M(I,1)
505 REM Find energy input rate Y, from subrot
510 GO TO 3000
520 REM Find specific heat-density factor C
525 LET C=(-.0642857)*(T1+T4)+510.171
530 LET Q3=Y*L/(T1-T4)/C
600 REM Find cooling water temperature rise T5
605 LET T5=L*(12000+Y)/(500*Q2)
610 REM Find COP Z (Cooling/energyinput)
620 LET Z=12000/Y
650 GO TO 3500
```

```
900 REM Outputs
902 PRINT  \ PRINT
905 PRINT "Machine size = ";M(I,1);" tons,"
908 PRINT "Hot water into chiller at ";T1;" F"
910 PRINT "COP = ";Z \ PRINT
912 PRINT "Load = ";L
913 PRINT "Maximum load= ";L1
915 PRINT "Hot water flow = ";Q3;" GPM"
920 PRINT "Leaving hot water temperature = ";T4;" F"
925 PRINT "Cooling water flow = ";Q2;" GPM"
930 PRINT "Cooling water temperature rise = ";T5;" F"
932 PRINT "Collector area =";S9
933 PRINT "Efficiency of collector =";E9
934 LET E8=U2/(U+U2)*L*12000/I9/S9
935 PRINT "Overall COP = ";E8
940 PRINT  \ PRINT
950 PRINT "Again? (1 = yes, 2 = no)"; \ INPUT K
960 IF K=1 THEN  GO TO 100
965 IF K=3 THEN 100
970 IF K<>2 THEN  GO TO 950
990 CLOSE
995 GO TO 4000
2000 REM Subrot to find design condition correction factor D
2010 REM Check limits
2015 IF T2<=90 THEN  GO TO 2025
2020 IF T3<45 THEN PRINT "*** Cooling water too hot." \ GO TO 950
2025 REM Find the nearest temperatures for which there's data
2030 LET T6=T2/5-12
2035 LET G1=INT(T6)
2040 IF G1<1 THEN LET G1=1
2045 IF G1>6 THEN LET G1=6
2050 LET G2=G1+1
2052 IF G1=2 THEN LET G1=1
2053 IF G2=2 THEN LET G2=3
2055 LET S1=(G1+12)*5
2060 LET S2=(G2+12)*5
```

```
2065 REM Calculate D for each
2070 IF T3>G(G1,1) THEN  GO TO 2085
2075 REM Lower end
2080 LET D1=G(G1,2)*T3+G(G1,3) \ GO TO 2095
2085 REM Upper end
2090 LET D1=G(G1,4)*T3+G(G1,5)
2095 IF T3>G(G2,1) THEN  GO TO 2110
2100 REM Lower end
2105 LET D2=G(G2,2)*T3+G(G2,3) \ GO TO 2120
2110 REM Upper end
2115 LET D2=G(G2,4)*T3+G(G2,5)
2120 REM Interpolate
2125 LET D=(T2-S1)*(D2-D1)/(S2-S1)+D1
2130 GO TO 415
3000 REM Subrot to find energy input rate Y
3005 IF H<.2 THEN PRINT "** Low hot water temperature."
3010 IF H>.7 THEN PRINT "** High hot water temperature."
3015 LET H1=.1*INT(H*10)
3020 IF H1<.2 THEN LET H1=.2
3025 IF H1>.6 THEN LET H1=.6
3030 LET H2=H1+.1
3035 LET B1=H1*10-1
3040 LET B2=H2*10-1
3045 LET Y1=P(B1,1)*(R2-P(B1,2))^2+P(B1,3)
3050 LET Y2=P(B2,1)*(R2-P(B2,2))^2+P(B2,3)
3060 REM Interpolate
3065 LET Y=((H-H1)*(Y2-Y1)/(H2-H1)+Y1)*1000
3090 GO TO 525
3500 REM Solar collector requirements
3501 REM Efficiency=E9, out=T1, in=T4, ambient=T9
3510 LET E9=.407143-.17857*(T4-T9)/I9
3522 FOR J0=1 TO 5
3525 LET T0=E9*I9*S9/C/Q3+T4
3530 LET C=(-.0642857)*(T0+T4)+510.171
3535 NEXT J0
3540 PRINT "T out of collector = ";T0;" F"
3545 LET C=(-.0642857)*(T0+T1)+510.171
```

```
3550 LET U=Q3*C*(T1-T0)
3555 PRINT "Heat added by auxiliary = ";U;" Btu/hr"
3556 LET C=(-.0642857)*(T0+T4)+510.171
3557 LET U2=Q3*C*(T0-T4)
3560 PRINT "Heat added by solar panel = ";U2
3565 PRINT "Solar used / total used =";
3566 PRINT U2/(U2+U);
3600 GO TO 900
4000 END
```

```
1 REM Absorption chiller program
2 REM Procedure from Trane catalog supplement
3 REM   and SLATS solar collector.
4 REM This program iterates to find the max.load for 100%
5 REM     solar operation.
20 OPEN "M.DAT" FOR INPUT AS FILE #1
30 DIM #1,M(21,13)
40 OPEN "G.DAT" FOR INPUT AS FILE #2
50 DIM #2,G(7,5)
60 OPEN "P.DAT" FOR INPUT AS FILE #3
70 DIM #3,P(6,3)
75 PRINT "Do you need the list of machine #'s and sizes (1=yes,2=no)";
80 INPUT CO
85 IF CO<>1 THEN  GO TO 100
90 FOR C1=1 TO 21
92 PRINT C1;" : ";M(C1,1);" tons"
95 NEXT C1
100 PRINT  \ PRINT
115 REM input variables
121 T1=204
122 PRINT "Insolation, Btu/hr ft^2 "; \ INPUT I9
123 PRINT "Load"; \ INPUT L
124 PRINT "Collector size, ft^2 "; \ INPUT S9
125 IF K=3 THEN 200
130 PRINT "Entering cooling water temperature (65-95 F)"; \ INPUT T2
140 PRINT "Leaving chilled water temperature (40-60 F)"; \ INPUT T3
150 PRINT "Chilled water flow (130-1700 GPM)"; \ INPUT Q1
165 PRINT "Machine # "; \ INPUT I
175 PRINT "Ambient temperature, F "; \ INPUT T9
199 PRINT
200 REM Determine heat source correction factor H
201 REM  and leaving hot water temperature T4
210 LET T4=(T1+30.9)/1.21
215 IF T4<158.5 THEN PRINT "** Hot water temperature low."
220 IF T4>239 THEN PRINT "** Hot water temperature high."
230 IF T4<205 THEN LET H=(1.36*T4-205.4)/100 \ GO TO 300
```

```
240 LET H=(.99*T4-129.6)/100
300 REM Determine maximum load for this machine
365 LET L1=M(I,1)*H
370 IF L1<L THEN PRINT "Load too high." \ K=3 \ GO TO 115
380 REM
400 REM Determine available tons A
405 REM Find design condition correction factor D, from subrot
410 GO TO 2000
415 LET A=M(I,1)*H*D
425 REM Find flow correction factor F
430 IF Q1<M(I,2) THEN PRINT "** Low chilled water flow."
435 IF Q1>M(I,3) THEN PRINT "** High chilled water flow."
440 LET F=(M(I,4)*LOG10(Q1)+M(I,5))/100
445 REM Find evaporator tons E
450 LET E=A*F
455 REM Find condenser operating ratio R
460 LET R=L/E
465 REM Find cooling water flow Q2
470 IF R<M(I,6) THEN PRINT "** Low operating ratio."
475 IF R>M(I,7) THEN PRINT "** High operating ratio."
480 IF R>M(I,8) THEN  GO TO 495
485 LET Q2=10^(M(I,9)*10^R+M(I,10)) \ GO TO 500
495 LET Q2=10^(M(I,11)*10^R+M(I,12))
500 REM Find hot water flowrate Q3
501 REM Find load ratio R2
502 LET R2=L/M(I,1)
505 REM Find energy input rate Y, from subrot
510 GO TO 3000
520 REM Find specific heat-density factor C
525 LET C=(-.0642857)*(T1+T4)+510.171
530 LET Q3=Y*L/(T1-T4)/C
600 REM Find cooling water temperature rise T5
605 LET T5=L*(12000+Y)/(500*Q2)
610 REM Find COP Z (Cooling/energyinput)
620 LET Z=12000/Y
650 GO TO 3500
```

```
900 REM Outputs
902 PRINT  \ PRINT
905 PRINT "Machine size = ";M(I,1);" tons,"
908 PRINT "Hot water into chiller at ";T1;" F"
910 PRINT "COP = ";Z \ PRINT
912 PRINT "Load = ";L
913 PRINT "Maximum load= ";L1
915 PRINT "Hot water flow = ";Q3;" GPM"
920 PRINT "Leaving hot water temperature = ";T4;" F"
925 PRINT "Cooling water flow = ";Q2;" GPM"
930 PRINT "Cooling water temperature rise = ";T5;" F"
932 PRINT "Collector area =";S9
933 PRINT "Efficiency of collector =";E9
934 LET E8=U2/(U+U2)*L*12000/I9/S9
935 PRINT "Overall COP = ";E8
936 IF U<0 THEN LET L=L-25*U/U2 \ K=3 \ GO TO 200
939 IF U>2 THEN LET L=L-50*U/U2 \ K=3 \ GO TO 200
940 PRINT  \ PRINT
950 PRINT "Again? (1 = yes, 2 = no)"; \ INPUT K
960 IF K=1 THEN  GO TO 100
965 IF K=3 THEN 100
970 IF K<>2 THEN  GO TO 950
990 CLOSE
995 GO TO 4000
2000 REM Subrot to find design condition correction factor D
2010 REM Check limits
2015 IF T2<=90 THEN  GO TO 2025
2020 IF T3<45 THEN PRINT "*** Cooling water too hot." \ GO TO 950
2025 REM Find the nearest temperatures for which there's data
2030 LET T6=T2/5-12
2035 LET G1=INT(T6)
2040 IF G1<1 THEN LET G1=1
2045 IF G1>6 THEN LET G1=6
2050 LET G2=G1+1
2052 IF G1=2 THEN LET G1=1
2053 IF G2=2 THEN LET G2=3
```

```
2055 LET S1=(G1+12)*5
2060 LET S2=(G2+12)*5
2065 REM Calculate D for each
2070 IF T3>G(G1,1) THEN  GO TO 2085
2075 REM Lower end
2080 LET D1=G(G1,2)*T3+G(G1,3) \ GO TO 2095
2085 REM Upper end
2090 LET D1=G(G1,4)*T3+G(G1,5)
2095 IF T3>G(G2,1) THEN  GO TO 2110
2100 REM Lower end
2105 LET D2=G(G2,2)*T3+G(G2,3) \ GO TO 2120
2110 REM Upper end
2115 LET D2=G(G2,4)*T3+G(G2,5)
2120 REM Interpolate
2125 LET D=(T2-S1)*(D2-D1)/(S2-S1)+D1
2130 GO TO 415
3000 REM Subrot to find energy input rate Y
3005 IF H<.2 THEN PRINT "** Low hot water temperature."
3010 IF H>.7 THEN PRINT "** High hot water temperature."
3015 LET H1=.1*INT(H*10)
3020 IF H1<.2 THEN LET H1=.2
3025 IF H1>.6 THEN LET H1=.6
3030 LET H2=H1+.1
3035 LET B1=H1*10-1
3040 LET B2=H2*10-1
3045 LET Y1=P(B1,1)*(R2-P(B1,2))^2+P(B1,3)
3050 LET Y2=P(B2,1)*(R2-P(B2,2))^2+P(B2,3)
3060 REM Interpolate
3065 LET Y=((H-H1)*(Y2-Y1)/(H2-H1)+Y1)*1000
3090 GO TO 525
3500 REM Solar collector requirements
3501 REM Efficiency=E9, out=T1, in=T4, ambient=T9
3510 LET E9=.407143-.17857*(T4-T9)/I9
3522 FOR J0=1 TO 5
3525 LET T0=E9*I9*S9/C/Q3+T4
3530 LET C=(-.0642857)*(T0+T4)+510.171
```

```
3535 NEXT JO
3540 PRINT "T out of collector = ";TO;" F"
3545 LET C=(-.0642857)*(TO+T1)+510.171
3550 LET U=Q3*C*(T1-TO)
3555 PRINT "Heat added by auxiliary = ";U;" Btu/hr"
3556 LET C=(-.0642857)*(TO+T4)+510.171
3557 LET U2=Q3*C*(TO-T4)
3560 PRINT "Heat added by solar panel = ";U2
3600 GO TO 900
4000 END
```

```
1 REM SOLAR COOLING
2 REM Procedure from Trane catalog supplement
3 REM   and SLATS solar collector.
4 REM This program computes overall COP and total daily COP
15 DIM V(3,3)
20 OPEN "M.DAT" FOR INPUT AS FILE #1
30 DIM #1,M(21,13)
40 OPEN "G.DAT" FOR INPUT AS FILE #2
50 DIM #2,G(7,5)
60 OPEN "P.DAT" FOR INPUT AS FILE #3
70 DIM #3,P(6,3)
75 PRINT "increment for insolation "; \ INPUT F9
78 I9=257+F9
80 S8=14000
85 LET F2=0
90 LET T1=204 \ T2=85 \ T3=45 \ T9=78
100 I9=I9-F9
101 PRINT "*************************************************************"
102 PRINT "System #1: one large machine."
103 F1=1
105 LET Q1=300 \ L=150 \ I=8 \ S9=28000
106 IF I9<0 THEN  GO TO 3595
112 GO TO 200
115 F1=2
116 I=3 \ Q1=150 \ S8=14000 \ L=75
117 PRINT  \ PRINT " System #2: two machines."
118 PRINT "First machine: all-solar as long as possible."
119 IF I9<=231 THEN LET S8=16000
120 IF I9<=211 THEN LET S8=18000
121 IF I9<=195 THEN LET S8=20000
122 IF I9<=183 THEN LET S8=22000
123 IF I9<=172 THEN LET S8=24000
124 IF I9<=162 THEN LET S8=26000
126 IF I9<=155 THEN  GO TO 3588
127 LET S9=S8
129 GO TO 200
130 F1=3
```

```
131 I=4
132 S9=28000-S8
134 L=L9
136 PRINT  \ PRINT "System #2, second machine ."
200 REM Determine heat source correction factor H
201 REM  and leaving hot water temperature T4
210 LET T4=(T1+30.9)/1.21
215 IF T4<158.5 THEN PRINT "** Hot water temperature low."
220 IF T4>239 THEN PRINT "** Hot water temperature high."
230 IF T4<205 THEN LET H=(1.36*T4-205.4)/100 \ GO TO 300
240 LET H=(.99*T4-129.6)/100
300 REM Determine maximum load for this machine
365 LET L1=M(I,1)*H
370 IF L1<L THEN PRINT "Load too high."
380 REM
400 REM Determine available tons A
405 REM Find design condition correction factor D, from subrot
410 GO TO 2000
415 LET A=M(I,1)*H*D
425 REM Find flow correction factor F
430 IF Q1<M(I,2) THEN PRINT "** Low chilled water flow."
435 IF Q1>M(I,3) THEN PRINT "** High chilled water flow."
440 LET F=(M(I,4)*LOG10(Q1)+M(I,5))/100
445 REM Find evaporator tons E
450 LET E=A*F
455 REM Find condenser operating ratio R
460 LET R=L/E
465 REM Find cooling water flow Q2
470 IF R<M(I,6) THEN PRINT "** Low operating ratio."
475 IF R>M(I,7) THEN PRINT "** High operating ratio."
480 IF R>M(I,8) THEN  GO TO 495
485 LET Q2=10^(M(I,9)*10^R+M(I,10)) \ GO TO 500
495 LET Q2=10^(M(I,11)*10^R+M(I,12))
500 REM Find hot water flowrate Q3
501 REM Find load ratio R2
502 LET R2=L/M(I,1)
505 REM Find energy input rate Y, from subrot
```

```
510 GO TO 3000
520 REM Find specific heat-density factor C
525 LET C=(-.0642857)*(T1+T4)+510.171
530 LET Q3=Y*L/(T1-T4)/C
600 REM Find cooling water temperature rise T5
605 LET T5=L*(12000+Y)/(500*Q2)
610 REM Find COP Z (Cooling/energyinput)
620 LET Z=12000/Y
650 GO TO 3500
900 REM Outputs
902 PRINT "Load = ";L;" tons."
911 PRINT "Instantaneous overall COP = ";E8
914 PRINT "at insolation of";I9;" Btu/hr ft^2"
915 IF F1=2 THEN V2=U2/(U+U2)*L \ GO TO 130
916 IF F1=3 THEN V1=U2/(U+U2)*L+V2
917 IF F1=1 THEN V1=U2/(U+U2)*L
921 V=41 \ IF I9<18 THEN PRINT "** Low insolation."
924 IF I9>59 THEN LET V=54
927 IF I9>113 THEN LET V=52
930 IF I9>165 THEN LET V=40
933 IF I9>205 THEN LET V=30
936 IF I9>235 THEN LET V=22
937 IF F1=3 THEN PRINT "System 2 COP = ";V1*3/I9/7
938 LET V(1,F1)=V(1,F1)+V1*12000/V*F9
940 LET V(2,F1)=V(2,F1)+I9*28000/V*F9
941 PRINT "Running totals....",V(1,F1);V(2,F1);V(1,F1)/V(2,F1)
945 IF F1=1 THEN  GO TO 115
947 IF F1=3 THEN  GO TO 100
990 CLOSE
995 GO TO 4000
2000 REM Subrot to find design condition correction factor D
2010 REM Check limits
2015 IF T2<=90 THEN  GO TO 2025
2020 IF T3<45 THEN PRINT "*** Cooling water too hot." \ GO TO 950
2025 REM Find the nearest temperatures for which there's data
2030 LET T6=T2/5-12
2035 LET G1=INT(T6)
```

```
2040 IF G1<1 THEN LET G1=1
2045 IF G1>6 THEN LET G1=6
2050 LET G2=G1+1
2052 IF G1=2 THEN LET G1=1
2053 IF G2=2 THEN LET G2=3
2055 LET S1=(G1+12)*5
2060 LET S2=(G2+12)*5
2065 REM Calculate D for each
2070 IF T3>G(G1,1) THEN  GO TO 2085
2075 REM Lower end
2080 LET D1=G(G1,2)*T3+G(G1,3) \ GO TO 2095
2085 REM Upper end
2090 LET D1=G(G1,4)*T3+G(G1,5)
2095 IF T3>G(G2,1) THEN  GO TO 2110
2100 REM Lower end
2105 LET D2=G(G2,2)*T3+G(G2,3) \ GO TO 2120
2110 REM Upper end
2115 LET D2=G(G2,4)*T3+G(G2,5)
2120 REM Interpolate
2125 LET D=(T2-S1)*(D2-D1)/(S2-S1)+D1
2130 GO TO 415
3000 REM Subrot to find energy input rate Y
3005 IF H<.2 THEN PRINT "** Low hot water temperature."
3010 IF H>.7 THEN PRINT "** High hot water temperature."
3015 LET H1=.1*INT(H*10)
3020 IF H1<.2 THEN LET H1=.2
3025 IF H1>.6 THEN LET H1=.6
3030 LET H2=H1+.1
3035 LET B1=H1*10-1
3040 LET B2=H2*10-1
3045 LET Y1=P(B1,1)*(R2-P(B1,2))^2+P(B1,3)
3050 LET Y2=P(B2,1)*(R2-P(B2,2))^2+P(B2,3)
3060 REM Interpolate
3065 LET Y=((H-H1)*(Y2-Y1)/(H2-H1)+Y1)*1000
3090 GO TO 525
3500 REM Solar collector requirements
3501 REM Efficiency=E9, out=T1, in=T4, ambient=T9
```

```
3510 LET E9=.407143-.17857*(T4-T9)/I9
3522 FOR J0=1 TO 5
3525 LET T0=E9*I9*S9/C/Q3+T4
3530 LET C=(-.0642857)*(T0+T4)+510.171
3535 NEXT J0
3545 LET C=(-.0642857)*(T0+T1)+510.171
3550 LET U=Q3*C*(T1-T0)
3555 REM "Heat added by auxiliary = ";U;" Btu/hr"
3556 LET C=(-.0642857)*(T0+T4)+510.171
3557 LET U2=Q3*C*(T0-T4)
3558 IF U2<0 THEN  GO TO 3595
3560 REM "Heat added by solar panel = ";U2
3565 REM "Solar used / total used =";
3566 REM U2/(U2+U);
3567 IF S9=0 THEN LET E8=0 \ GO TO 3577
3570 LET E8=U2/(U+U2)*L*12000/I9/S9
3575 REM "Instantaneous overall COP = ";E8
3577 IF F1<>2 THEN  GO TO 900
3578 IF F2=1 THEN L9=75 \ GO TO 900
3580 IF U<-1 THEN LET L=L-25*U/U2 \ GO TO 200
3582 IF U>0 THEN LET L=L-50*U/U2 \ GO TO 200
3584 LET L9=150-L
3586 GO TO 900
3588 PRINT "machine #1 also needs aux.firing."
3590 LET F2=1
3591 LET S8=28000 \ GO TO 127
3595 PRINT "Solar panel would lose heat after this point.";
3999 CLOSE
4000 END
```