SOLAR AIRCONDITIONING SYSTEMS

By

ALDWYN C. SANTOS*

Introduction

Cooling systems can generally be classified under two categories: active system (e.g. vapor compression cooling systems and absorption cooling systems) and passive systems, (e.g. evaporative cooling and radiative cooling). Active systems require the consumption of energy to achieve cooling. Passive systems, on the other hand, require little or none of mechanical work associated with active systems. Passive systems depend more on the careful selection of location, configuration and orientation to the sun and breezes.

This paper deals with the first category, specifically the absorption cooling system which is so far the only active system that is compatible with direct solar energy utilization.

The Solar Airconditioner

The essential components of any solar airconditioner includes the following:

a) Heat collection system

b) Back-up system

c) Heat pump (often times an absorption chiller)

d) logic controller

*Coordinator for Conventional Energy Research, PNOC-Energy Research and Development Center.

The design or selection of a particular type of component should consider the fact that most of the technologies capitalizing on solar energy has a high first cost compared to conventional fueled devices/ technology. This is true for solar water heating, for photovoltaics, and holds true for solar airconditioning. The reason behind this is that for a conventional fueled device, one pays initially for the equipment and pays for the fuel at subsequent periodic intervals (e.g. monthly, yearly, etc.) after the acquisition of the equipment. The rate of the fuel bill is directly related to the degree of utilization of the conventional fueled device.

While it is true that solar energy is free, the equipment to collect the energy of the sun is not with the solar based technology, the initial cost includes not only the equipment (for a solar airconditioning system, the absorption chiller) but also, the heat collection system. In effect one pays outright for the fuel supply to be used throughout the life of the solar based system. This cost would then have to be amortized annually, regardless of whether the solar device is being used fully or not. The disparity of the two systems is further aggravated when one considers the possibility of obsolescence. The person that chooses a solar based system would have already paid the fuel supply system which he can no longer use.

Solar Collection Size and Storage Tank Capacity

It is rarely cost-effective to provide all the energy requirements of a solar airconditioning system by means of solar energy. It is possible for instance, to design a collector system and energy storage system that will take care of the heat requirement of the chiller unit during periods when solar radiation is low. If this were to be done, however, the solar system would be oversized most of the time—meaning an extra investment on additional collector area and additional storage tank capacity that would have utility for a limited number of days per year.

A more practical and often time and cost effective approach is to incorporate a back-up system in the design of solar based technologies to take care of those periods when solar energy is insufficient. Fig. 1 and Fig. 2 show the daily and yearly variation in solar energy radiation (insolation). The key objective in determining collector size and storage tank capacity is to minimize:

$$CT = Cy\,(Qs) + Ca\,(Qa)$$

where CT = total annual cost
Cy (Qs) = is the annualized solar cost
Ca (Qa) = annual cost of nonsolar energy

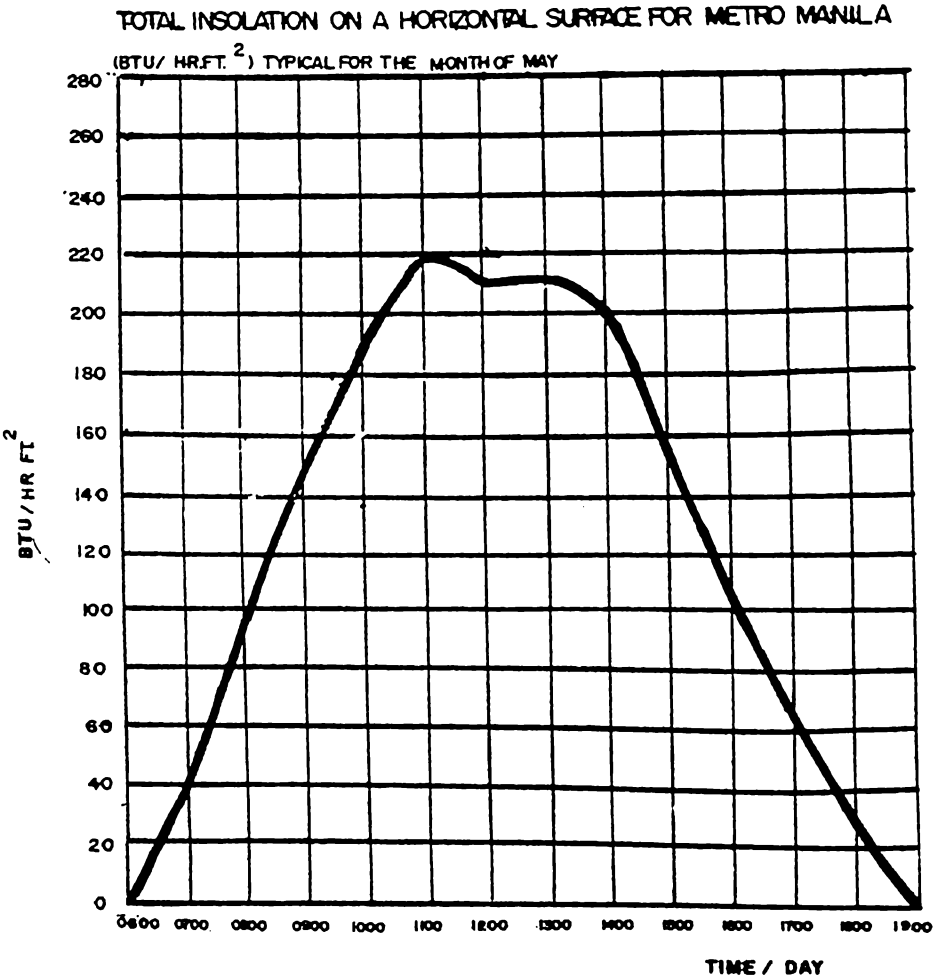

TOTAL INSOLATION ON A HORIZONTAL SURFACE FOR METRO MANILA
(BTU/ HR.FT.^{2}) TYPICAL FOR THE MONTH OF MAY
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
BTU/HR FT^2
0600 0700 0800 0900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900
TIME / DAY

FIG. 1

EXPECTED SOLAR ENERGY INSOLATION ON A TILTED SURFACE FOR METRO MANILA

(Source of Raw Data : PAGASA)

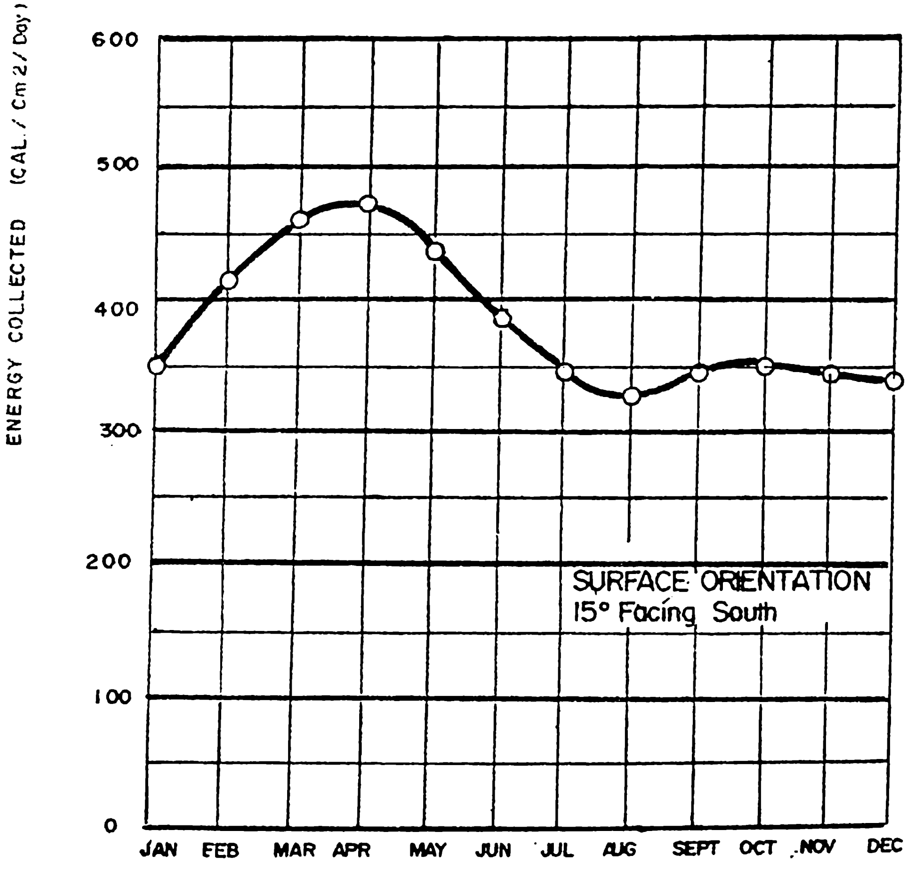


FIG. 2

Generator Operating Temperature

Presently, there are two basic types of solar heat collections systems —the flat plate collectors and the concentrators. The difference in the two systems are:

a) Temperature range attainable—Flat plate collectors can attain temperature ranging from 160°F to near boiling (212°F). Concentrators, on the other hand, can attain temperature greater than 1,500°F.

b) Manner of heat collection—Flat plate collector can collect both diffuse and direct radiation, concentrators can collect direct radiation and practically cannot work with diffuse radiation. Concentrator performance is then affected adversely by such parameter as cloudness level and humidity.

c) Fabrication requirements—Flat plate collectors are relatively easier and less costly to fabricate than concentrators.

The choice of generator operating temperature therefore determines to some extent the kind of solar collection system to be used.

Evaporator Operating Temperature

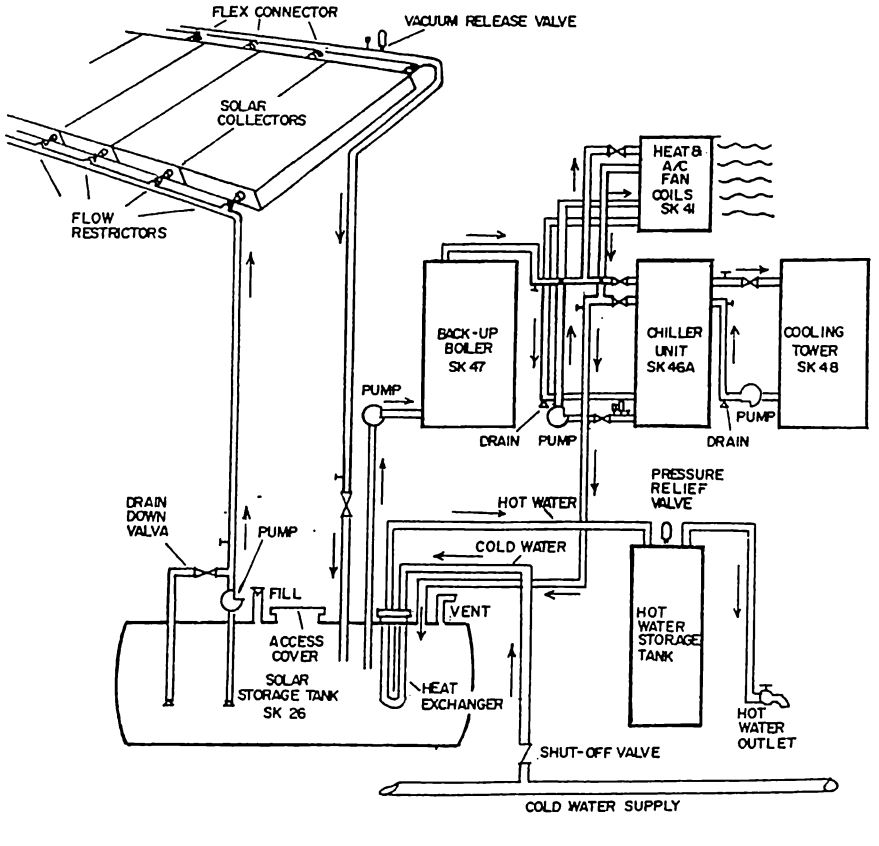
Presently, there are two types of absorption airconditioning system widely used: The Lithium Bromide-Water ($LiBr$-H_2O) system and the Ammonia-Water (NH_3-H_2O) system. Of the two, the lithium bromide-water is more compatible with the flat plate heat collection system. The lithium bromide-water system operates satisfactorily at generator's temperature of 190°-200°F (NH_3-H_2O system operates at generator temperature of 250°-300°F). It has a higher COP (coefficient of performance) than the ammonia-water system and is much simpler, since a rectifying column is not needed. In the ammonia-water system, a rectifying column assures that no water vapor mixed with ammonia enters the evaporator where it is could freeze.

On the other hand, lithium bromide-water systems cannot operate at evaporator temperatures of below 40°F since the refrigerant is water. Since LiBr is corrosive, corrosion offers also a problem with $LiBr$-H_2O system. Another disadvantage of the $LiBr$-H_2O system is the possible occurrence of crystallization during the operation which could disrupt the operation of the chiller. Figs. 3 to 5 show the various types of solar airconditioners commercially available today.

Solar king

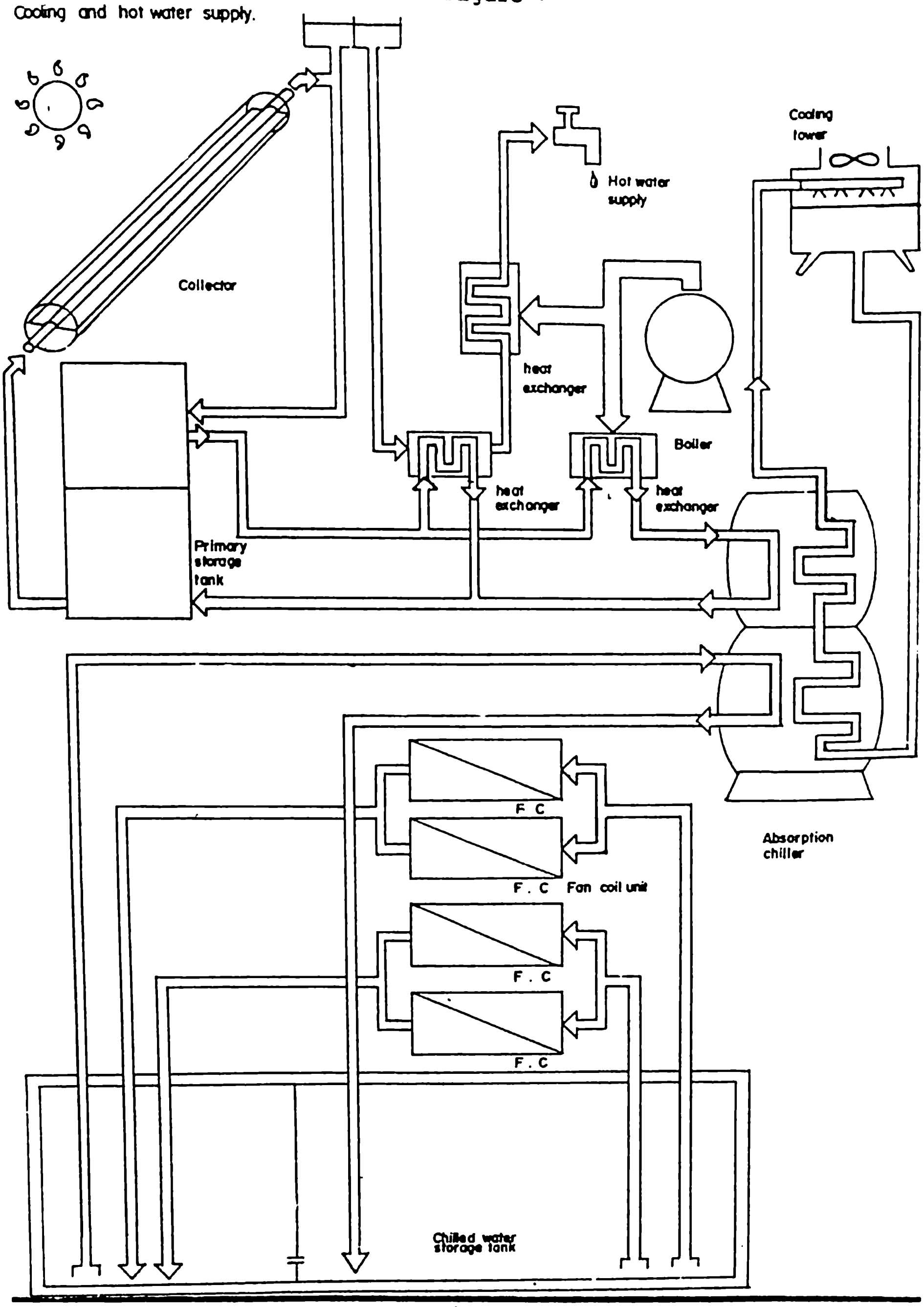
Figure 3

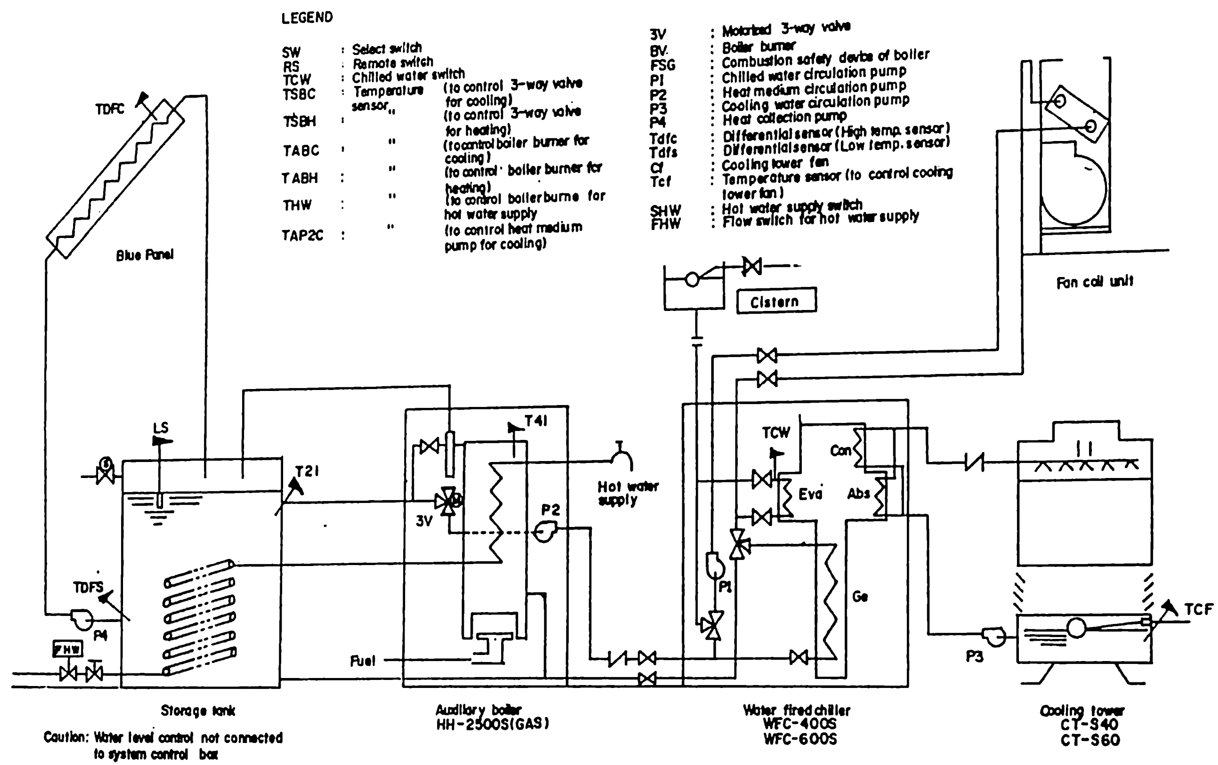
RESIDENTIAL AND COMMERCIAL HEATING
AND AIR CONDITIONING SYSTEM



SANYO SOLAR HEATING & COOLING SYSTEM

Figure 4





Flowchart of Yazaki basic solar air-conditioning system (YBSAS)

Figure 5

The Yazaki 2-ton Solar Airconditioning System

Heat is collected by a series-parallel combination of 30 flat-plate collectors with a total area of 60 m^2 (good for ERDC's 2 ton airconditioning system). The main component of this heat collection system is the flat plate collectors-stainless steel sheets with water pathways running lengthwise at regular intervals insulated at the back and the sides and covered by a glass. A frame holds together these parts.

The glass cover allows solar radiation (short wave-length) to penetrate to the plate at the same time, it prevents reradiated energy (Long wavelength) by the plate from escaping.

The plate absorbs the heat which is then imparted to the water inside the water tube. To increase efficiency of heat collection, the plates are coated with a selective coating (special coating a high absorptivity). For most applications, however, an ordinary flat black paint will do.

Water is stored in an insulated water tank, which has several temperature-sensing thermistors located at various heights.

A heat collection pump circulates water from the bottom of the storage tank to the flat plate collectors. This pump is automatically turned on by the collector temperature at the bottom of the storage tank. Once the temperature of the collector goes as low as 0.5°C above the temperature at the bottom of the storage tank, the heat circulating pump is automatically turned off. Figs. 6 and 7 shows typical COP's of the chiller when the sun is intense and when there is not much solar radiation. Figs. 8 to 11 shows typical temperature variations at various times of day.

The above arrangement assures that water is circulated only when there is sufficient solar energy.

Back-up System

A back-up system in most cases is incorporated with the design of solar airconditioning system to provide heat energy during days when solar energy is insufficient or during times when the storage tank temperature is not high enough to operate the chiller. Again, activation of the back-up system is done automatically. It is automatically triggered when the chiller is operated and the water at the storage tank is below 80°C and is cut-off when the storage tank temperature reaches 80°C.

To prevent the back-up system (back-up boiler) from heating the water inside the storage tank, it is usually isolated by a valve.

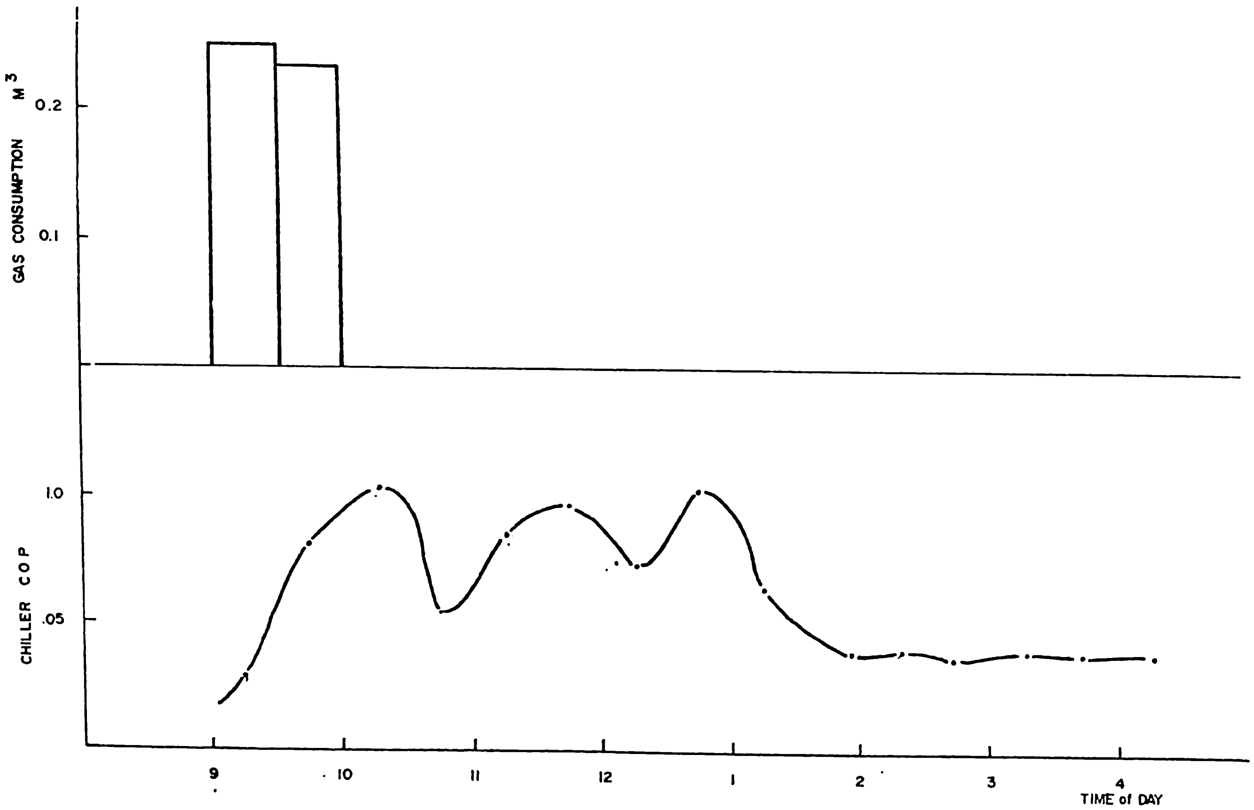

GAS CONSUMPTION M 3
0.2
0.1
CHILLER C O P
1.0
.05
9
10
11
12
1
2
3
4
TIME of DAY

Figure 6

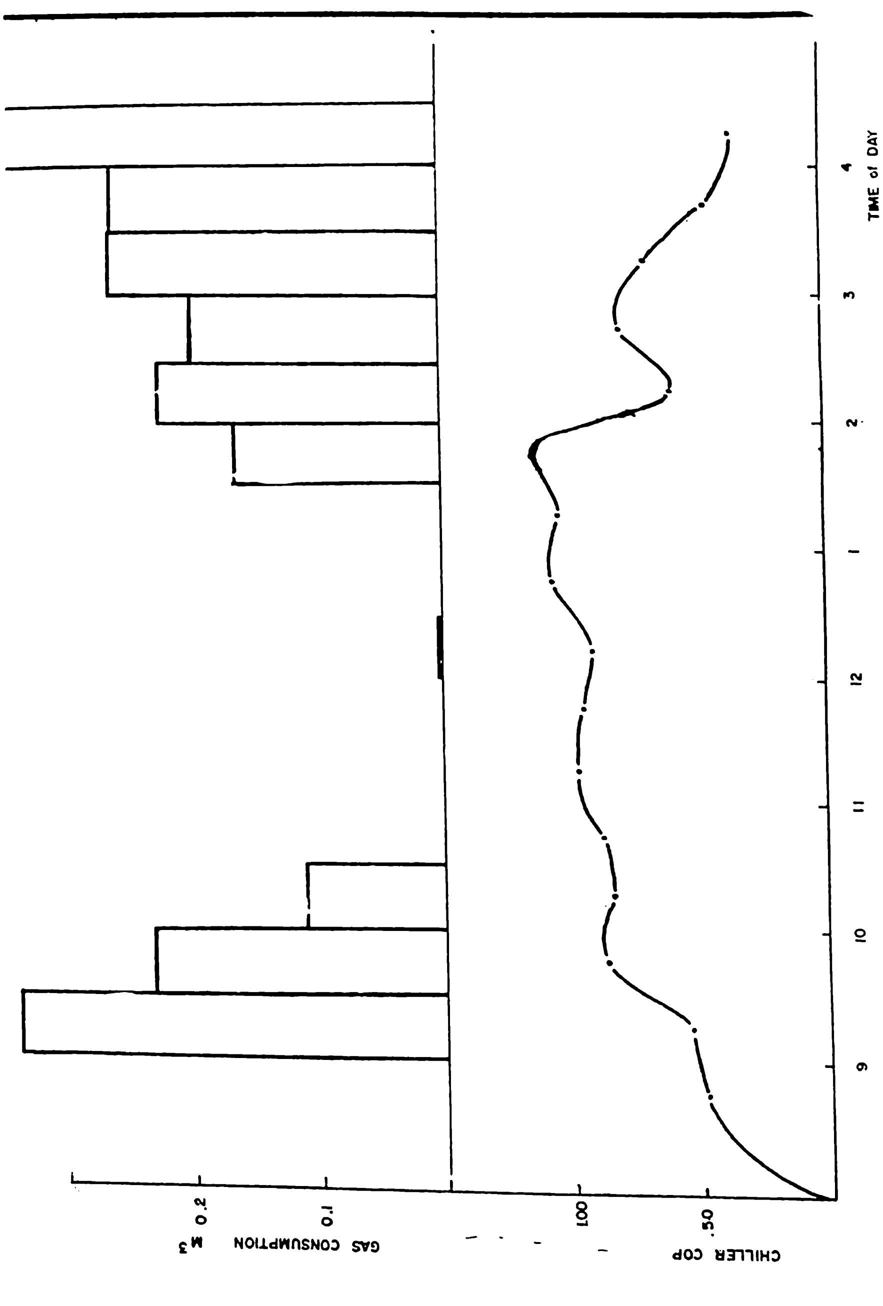

GAS CONSUMPTION M 3
0.2
0.1
CHILLER COP
1.00
.50
9
10
11
12
1
2
3
4
TIME of DAY

Figure 7

Absorption Chiller System

The absorption chiller system is activated by a remote switch. Upon activation of the chiller unit, a second temperature sensing unit located at the top of hot water tank senses the temperature of the water. When the water temperature is 80°C or higher, the heat medium pump is automatically turned on, supplying hot water to the generator of the chiller. If however, the water temperature at the top of the storage tank is below 80°C, the back-up boiler is automatically turned on. In this situation, the heat medium pump is turned on only when the water inside the boiler reaches 90°C.

Once the chiller is in operation it can operate even if the water inside the storage tank goes as low as 77°C.

Economics of Solar Airconditioning

The following comparative economic analysis is based on a three-year performance of the two ton solar airconditioner as against an equivalent electric-operated vapor compression air conditioning system.

Table 2 shows the electric operated parts of the solar air conditioner and their corresponding wattage and number of hours of operation per year.

Based on the figures in Table 1, the electric consumption of a solar airconditioner is 2,408.88 kw-hr/yr (240 days/year) and an LPG consumption of 900 kg/year. A similar electric-operated vapor compression airconditioning system would cost on the other hand, 13,370.88 kw-hr/year (240 days/year). Below is a summary of initial investment and operation costs/year:

	Solar Airconditioner	Electric Vapor Compression
Operating Cost:		
Electricity	843.11	4,679.81
LPG (at 3.6/kg)	3,240.00	–
Total Operating Cost Per Year	4,083.11	4,679.81
Initial Cost:	100,000.00	40,000.00
Simple Payback period (PB)		

$$PB = \frac{\text{difference in initial investment}}{\text{saving/year}}$$

$$= \frac{60,000}{579,79/\text{year}}$$

$$= 100.55 \text{ years (this assumes a uniform savings every year)}$$

If however, we are to consider the fact that the cost of fuel is not consistent and increases from year to year, the payback will be the number of years it would take for the summation of yearly savings to equal the differential in initial investments.

Table 1. EQUIPMENT SPECIFICATION

Equipment	Specification	
Solar Collectors	Material --------	Special Stainless Steel
	Selective --------	Absorptance: 0.93
		Emittance : 0.11
	No. of Units ----	30
	Effective heat Collection Area ---------	56.7 m^2
	Titled Angle --	15°
Refrigeration Chiller	Capacity -------	6000 Kcal/hr
	Solution -------	Lithium Bromide-Water
	Generator Water Temperature	Maximum : 100°C
		Minimum : 75°C
Auxilliary Heat Source	Input -------------	15000 Kcal/hr
	Efficiency ------	0.80
	Fuel -------------	LPG
Cooling Tower	Heat Radiation Capacity ------	16000 Kcal/hr
	Cooling Water Circulation Volume -------	3200 li/hr
	Cooling fan output rate — 100 W	

Table 2. ENERGY CONSUMPTION OF 1.98-TON SOLAR AIRCON FOR 8-HR. OPERATION

	Electrical heat, W	No. of Hours in Operation	Energy Consumption, kw/hr
1. Chiller includes chilled hot water circulating pump, palladium cell heater, relay, etc.	165	8	1.32
2. Boiler includes heat medium circulating pump, motorized 3-way valves, relays, etc.	202	*(.80) 8	1.293
3. Cooling Tower includes fan motor, cooling water circulating pump, relays, etc.	410	*(.80) 8	2.624
4. Heat Collection Pump	300	*(.70) 8	1.68
5. Air Handling Unit includes fan motor	390	8	3.12
TOTAL	1.467		10.037 kw.hı

*Service Factor

n

Sj (1 + f) = differential in initial injvestment

j∴

==

j=0

where: Sj = savings at year j
f = fuel escalation rate

The left hand side of the equation is a geometric progression whose sum is equal to

$S_o($[1]

$$S_o(1 + f)^{n+1} - 1)/f$$

where: S_o = savings on the first year
n = number of years
f = fuel escalation rate

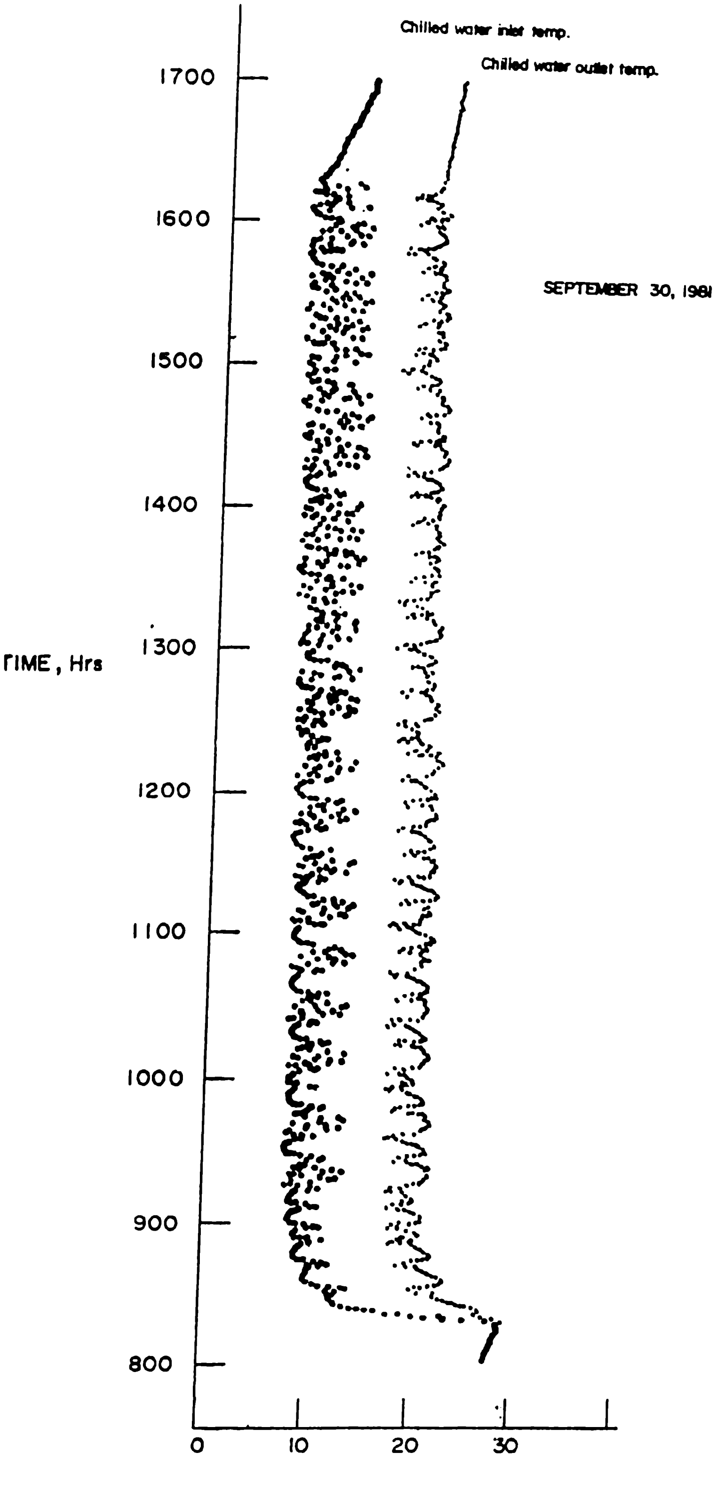
$$\log = \frac{(\text{investment})\ (f) + 1}{S_o}$$

$$\text{n therefore would equal} = \frac{}{\log\ (1 + f)}$$

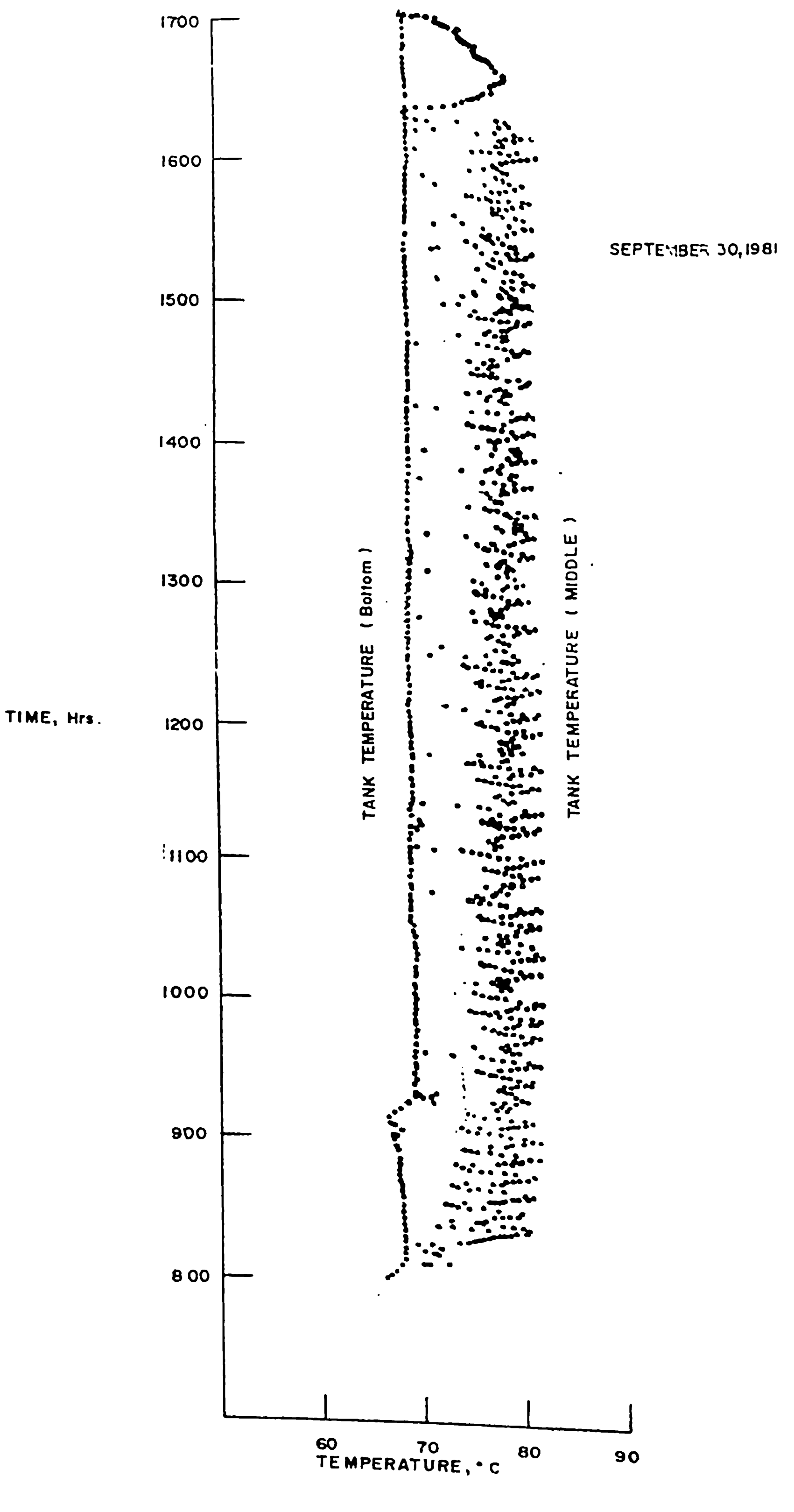
at a fuel escalation rate of 5%
n = 35.82 years
and at a fuel escalation rate of 10%
n = 24.21 years

The above figures do not give a very encouraging picture for solar airconditioning. Also, it is stressed here that the economic analysis was based on a small unit.

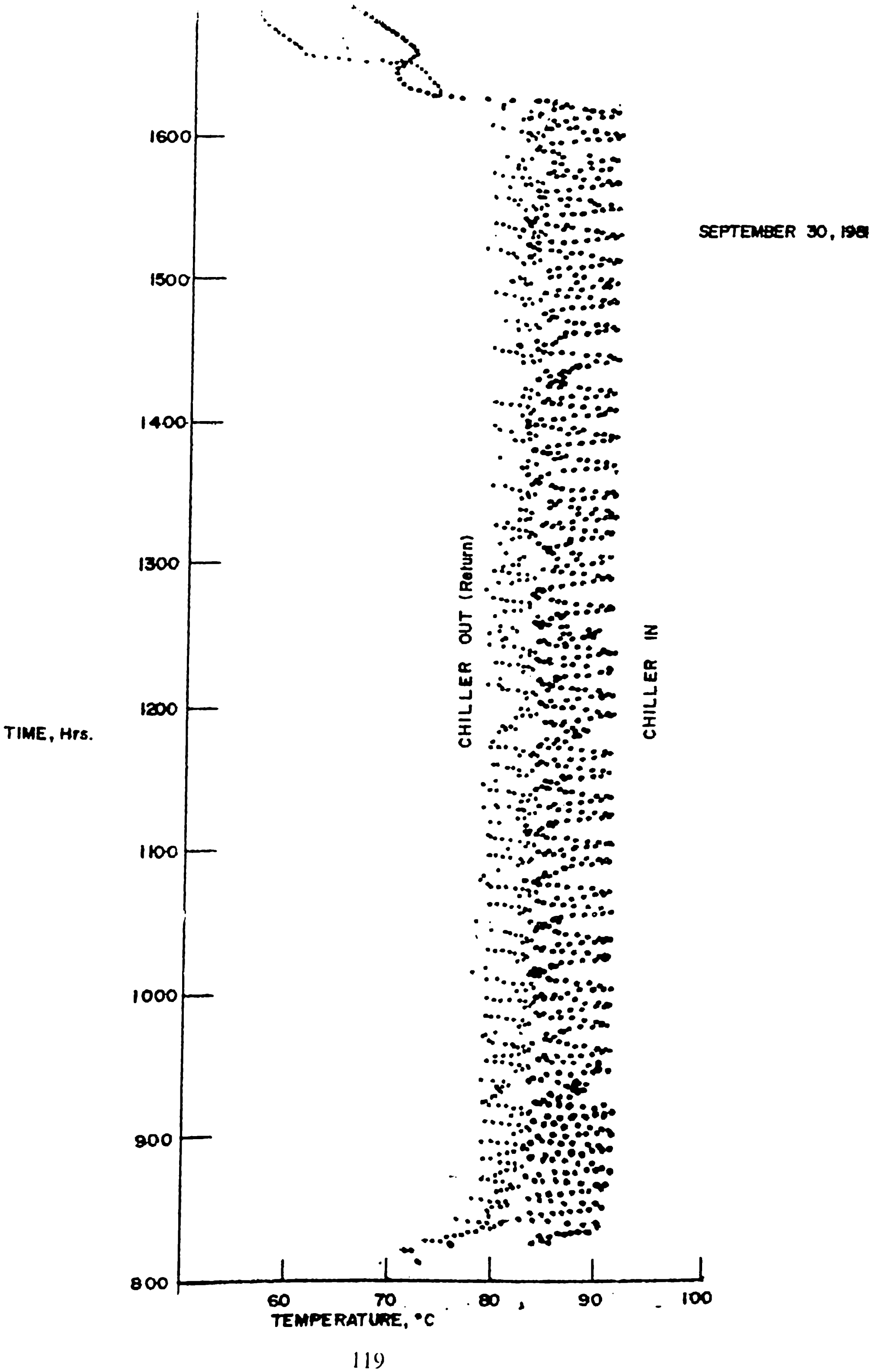
Solar cooling is of course in its development stage and still need refinements in terms of lowering down the cost, minimization of electric operated parts, improvements of heat collection and storage efficiency, and selection of suitable medium fluid (other than water).

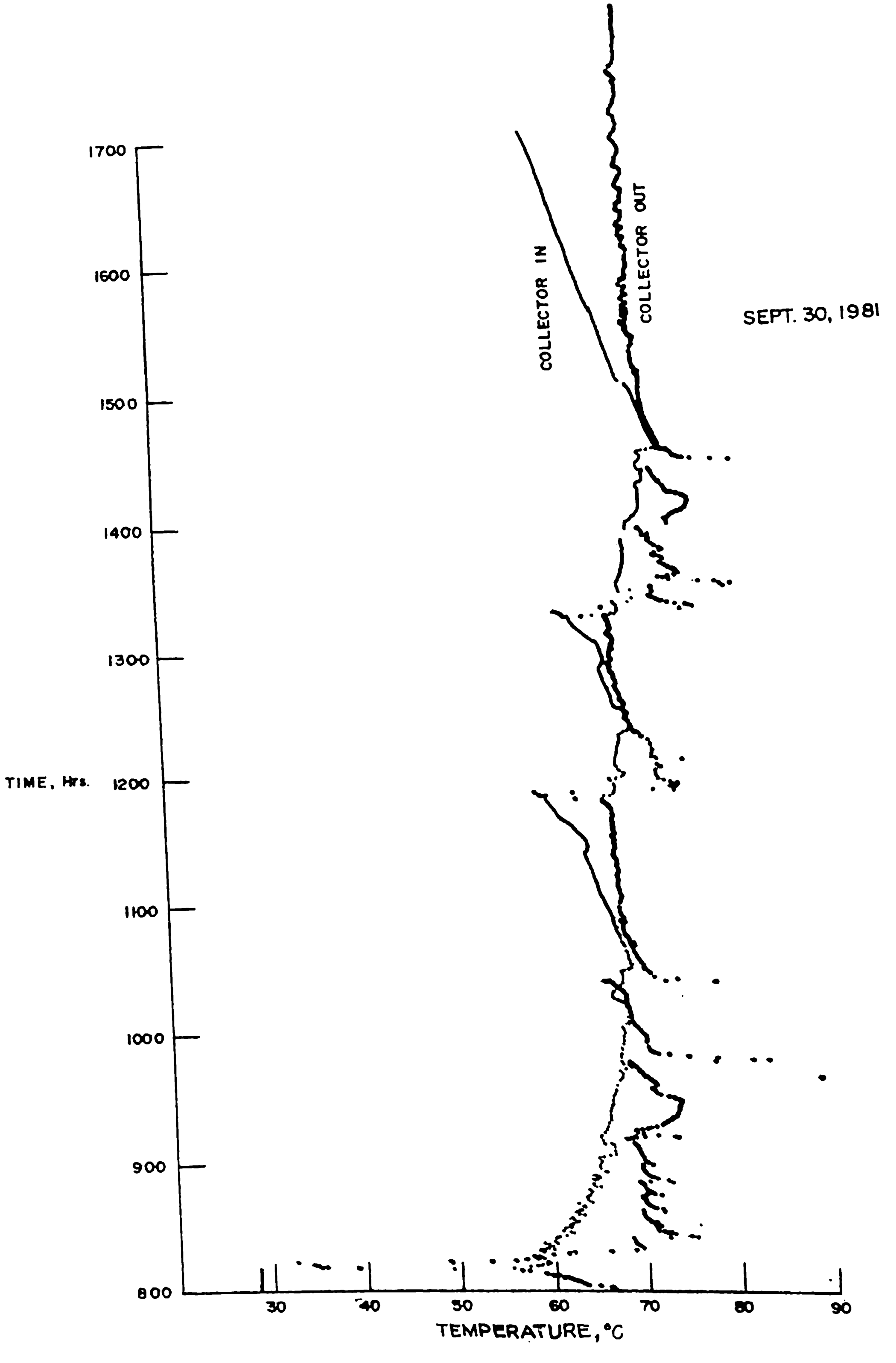


Chilled water inlet temp.
Chilled water outlet temp.
SEPTEMBER 30, 1981
1700
1600
1500
1400
1300
TIME, Hrs
1200
1100
1000
900
800
0
10
20
30

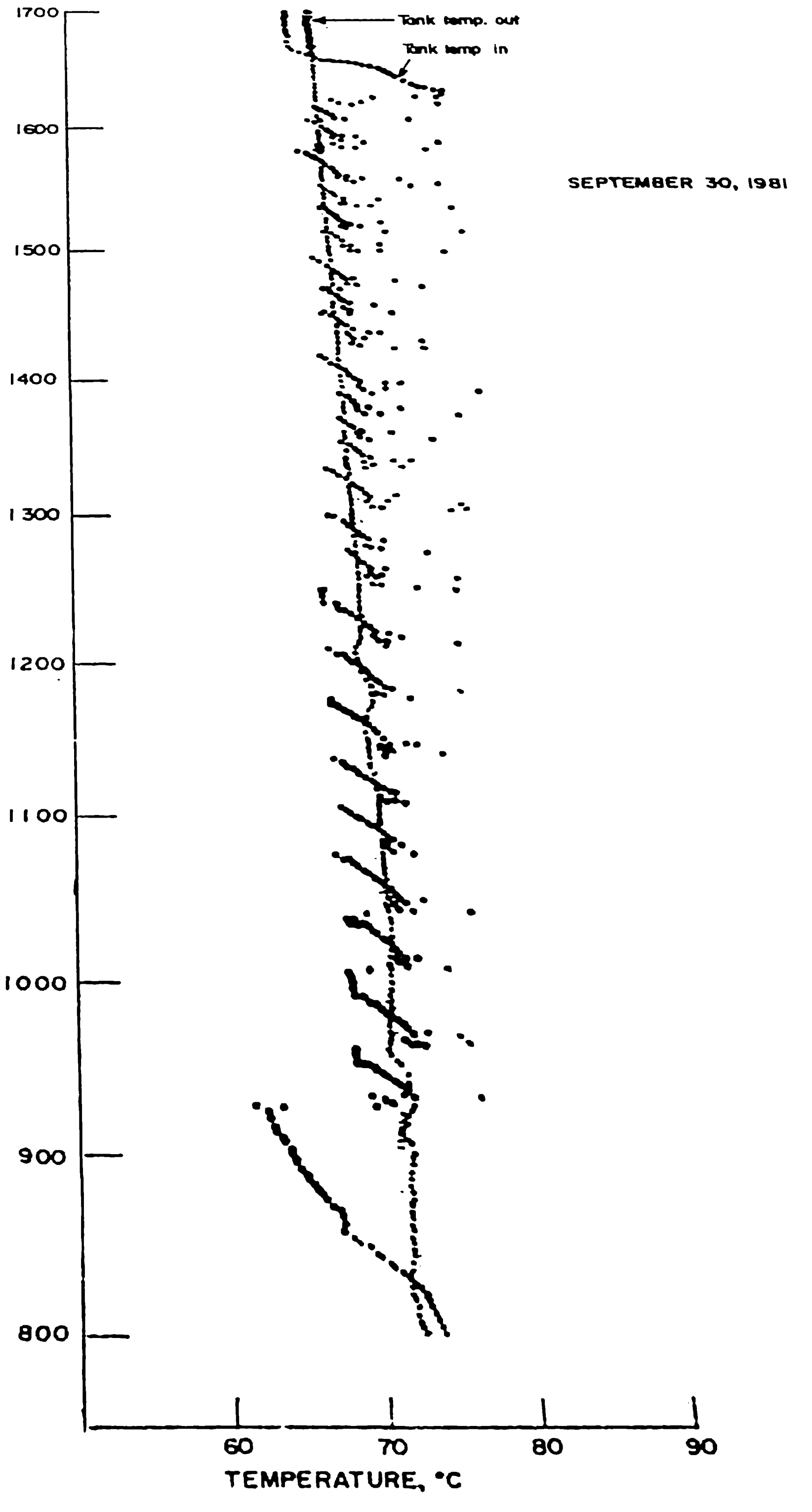


SEPTEMBER 30,1981
TIME, Hrs.
1700
1600
1500
1400
1300
1200
1100
1000
900
800
TANK TEMPERATURE (Bottom)
TANK TEMPERATURE (MIDDLE)
60
70
80
90
TEMPERATURE, °C


SEPTEMBER 30, 1981
TIME, Hrs.
1600
1500
1400
1300
1200
1100
1000
900
800
CHILLER OUT (Return)
CHILLER IN
60
70
80
90
100
TEMPERATURE, °C



1700
1600
1500
1400
1300
TIME, Hrs.
1200
1100
1000
900
800
30
40
50
60
70
80
90
TEMPERATURE, °C
COLLECTOR IN
COLLECTOR OUT
SEPT. 30, 1981


Tank temp. out
Tank temp in
SEPTEMBER 30, 1981
1700
1600
1500
1400
1300
1200
1100
1000
900
800
60
70
80
90
TEMPERATURE, °C

AIRCONDITIONING CYCLE SCHEMATIC DIAGRAM