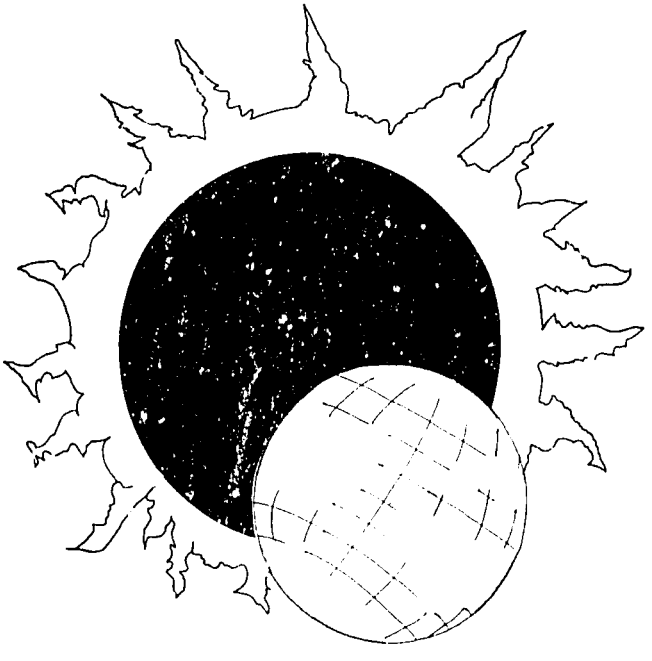

Training in Alternative Energy Technologies

Solar Energy Laboratory

University of Florida

Gainesville

TRAINING PLANT ALTERNATIVE ENERGY
TECHNOLOGIES
SOLAR ENERGY LAB.
UNIVERSITY OF FLORIDA

SOLAR AIR -CONDITIONING
AMMONIA/WATER SYSTEM

PREPARED BY:

Rashad Aburas

Jordan Electricity Authority
Jordan

Juan Francisco Lara

Fibropan, Inc.
Panama

Agustin Leon Pena

National Commission of Energy Policy
Dominican Republic

Ramon A. Pichardo

National Commission of Energy Policy
Dominican Republic

Lynn C. Sheldon

USAID/Panama

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SECTION 1

Solar System Design

Goal: Design on absorption air conditioning system for a tropical climate residence

Purpose: To use the known technology of absorption air conditioning utilizing flat plate collectors for space cooling in a tropical climate. In effect, year round cooling is required.

Activities of System Design

1. Determine Industry's progress to date.

2. Evaluate known and constructed systems.

3. Evaluate and choose types of buiding materials from those available in Third World countries. (Example, brick, concrete block, wood, insulation, double glazed windows, etc.)

4. Design the buildings to minimize cooling losses.

5. Building design should allow for use of natural air flow when practical.

6. Preliminary equipment selection for absorption air conditioning system.

7. Complete preliminary drawings of buildings.

8. Estimate constructed cost of system.

9. Perform economic analysis to determine practicality of actual construction.

When the notion of examining an absorption air conditioning system utilizing flat plate solar collectors was first considered, we analyzed using a system commercially available in the United States. This being the case, the only choice was the Lithium Bromide System.

With further analysis into the operation, we came to the conclusion that a totally solar dependent system would not function effectively in humid tropical climates such as in the Dominican Republic and the Republic of Panama.

Assumptions

Design Conditions:

Outside temperature:	90°F
Inside temperature:	75°F
Average Relative humidity:	78%

Reasons for not selecting Lithium Bromide System

1. Difficult to achieve acceptable cooling effect if water heated from solar collectors is below 190°F.
2. The lithium bromide/water absorptive cooling system is typically de-rated when used in conjunction with solar panels. To illustrate this point, the Florida Solar Energy Center system has a de-rated 25 ton lithium bromide/water system using evacuated tube solar collectors. The system actually produces at peak capacity 17 tons of air conditioning.
3. Without a sophisticated sensor device system the Li Br/H_2O system is subject to "freezing" up and plugging circulation lines with crystallized Li Br. The remedy is to thaw the line.

4. The Li Br/H_2O fluid circulates at pressures less than 1 psia. Higher pressure systems are usually easier to maintain and service.

5. The atmospheric conditions in the humid tropics usually have the solar intensity characteristic of a large amount of diffused radiation and a lesser quantity of direct radiation. Therefore, under these conditions, in general the most sensible application is using flat plate collectors to collect the diffused radiation. Concentrating collectors are ruled out because they require direct radiation to function. The use of concentrating collectors would not supply a constant dependable source of energy since under clouded conditions you collect little or no energy.

6. To achieve sufficiently high temperatures from a solar collecting system, a fairly costly setup is necessary. As an example, the Li Br/H_2O absorption system funded by DOE at the Florida Solar Energy Center at Cape Canaveral built in 1980 cost approximately $250,000.00. It produces 17 tons of air conditioning. Few individual home owners could afford a similar system. An exception to this case would be the DOE demonstration at Dr. John Yellott's residence in Phoenix, Arizona. The Li Br/H_0 system was completed in March 1980 at a cost of $32,000, of which $12,000 was the declared cost of the Japanese Yazaki equipment, $15,000 the installation cost and $5,000 for instrumentation. The system produces three tons of air conditioning. Flat plate collectors are utilized to supply the necessary hot water. This system apparently functions well in the low humidity of less than 10% and beneath the cloudless skies of Arizona. Unfortunately, these climatic conditions do not exist in the humid tropics.

Conclusion:

Through the examination of the Lithium Bromide/water system, it was decided that a more appropriate system would be the ammonia/water system. This system has been in use for many years using a compressor or conventional generator as the heat source instead of energy from the sun. Although, presently there is no commercially produced three ton air conditioning system available, following are the reasons why we decided to use this system.

Reasons for Using the Ammonia/Water Systems:

1. The system will function at optimum design conditions with hot water at 140°F. This is quite easy to achieve with even a well designed home-made panel.
2. There is no chance of problems with crystallization as is true of the Li Br/H_2O system.
3. Ammonia is relatively easy to obtain in any country.

Drawbacks of the Ammonia/Water System:

1. Presently there is no commercially available ammonia/water system for solar applications.
2. Ammonia requires the respect that any volatile gas demands. However, freon is more dangerous to work with than ammonia.

SECTION II

Design Aspects considered for the Active and Passively Cooled Residence

Each home builder has to evaluate numerous conditions acceptable or not acceptable to the occupants of the home.

a. Which areas in the home must have a conditioned atmosphere.

b. What effect will the present or future utility rates have on the homeowner.

c. What building practices should be used to result in good insulative qualities of the home.

d. What is the home builder's budget.

e. To what degree can passive air conditioning be used

f. Do any government supported incentives exist to make construction of the system more attractive than a conventional type.

The Selected Design

Total Area of Residence	144 m^2
Area Cooled 100% Passive	45 m^2
Area Cooled 100% Active	75 m^2
Hybrid Area (Active/Passive)	24 m^2
Number of Collectors (4 x 8')	144 m^2

Area Descriptions:

Passive Area - Kitchen

- Maid's quarter's
- Laundry/Service area

Active Area - Bedrooms

- Family Room

Hybrid Area - Living Room

- Dining Room

Principles designed into Active Area:

1. The exterior walls for the actively cooled areas are insulated with earth
2. The roof is well insulated and also are insulated suspended ceiling panal is used.
3. Windows are kept at a minimum size and well blended to reduce heat transfer.
4. In the event the active system malfunctions, the windows can be utilized to create a cross ventilation.
5. The active areas should be constructed to prevent air leakage to the extent practical.

SECTION III

CONSTRUCTION MATERIALS:

Roof: Asbestos - Cement Panels will be used to cover the entire roof.

Roof Insulation: 2" roof insulation will be used throughout the house.

Insulated Suspended Ceiling: Suspended Ceiling with 1" insulation will be used in the actively cooled area and partially in the hybrid area.

Gypsum board ceiling: Gypsum board will be used as ceiling throughout the passively cooled area.

Walls: The wall will be 8" x 16" x 8" concrete blocks with earth berm backfill and water-proof sealer on the exterior bedroom walls.

Floor: The floor will be typical concrete slab construction with terrazo floor tile.

Windows: Windows will be single glazed in the active and hybrid areas. The passive area will use jalousie-type windows.

Additional Air Circulation: Overhead fans could be installed in the passive area to increase air movement.

SECTION IV

LOAD CALCULATIONS

1. Walls

TOTAL AREA: 89.55 m^2

AREA COVERED BY EARTH: 53.75 m^2

AREA SUBJECTED TO HEAT:

$$89.55 - 53.75 = 35.80\ m^2 = 385.4\ ft^2$$

MATERIAL: CONCRETE BLOCK WALL 8"

U: 0.274 (ASHRAE 1977)

DETD: 11.3 DETD = Design Equivalent Temperature Difference

T : 90^oF

Tin: 75^oF

AVERAGE RELATIVE HUMIDITY: 78%

HEAT LOAD: U.A. DETD

: 0.274x385.4x11.3

: 1193.3 BTU/h

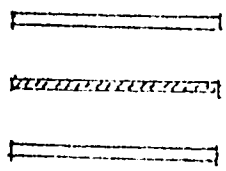
2. ROOFING ABOVE AIR CONDITIONED AREA

AREA: 99 m^2 = 1065.24 ft^2

*69% OF THE ABOVE AREA WILL BE COVERED BY SOLAR COLLECTORS

*31% WILL BE INSULATED WITH FIBERGLASS

a)



- COLLECTORS
- ASBESTOS-CEMENT
- FIBERGLASS INSULATION

R_{fg} = 3.2/inch.

R_t = ------M--------M--------M--------M

$$\frac{1}{h\ (c+r)_1} \qquad R_{fg} \qquad R_{ac} \qquad \frac{1}{h\ (c+r)_4}$$

$R_T = 1/2 + 3.2 + 0.2 + 1/4 = 4.15$

$U_a = 1/R_T$ $\qquad$ $U_a = 0.24$

WE NEED TO OBTAIN A LOWER U, SO OUR SYSTEM WON'T DEAL WITH A BIG HEAT TRANSFER VALVE.

WITH 2 INCHES OF FIBERGLASS:

$R_T = 1/2 + 6.4 + 0.2 + 1/4 = 7.35$

$U_b = 0.136$ $\qquad$ DETD = 34

LOAD: 0.69 x 1065.24 x 0.24 x 34 +

0.31 x 1065.24 x 0.136 x 34

= 7524.7 BTU/h

3. LOAD THROUGH THE FLOOR = 0

4. FENESTRATION

AREA OF WINDOWS = 49.5 m^2 = 532.6 ft^2

LOAD = AREA x GLASS FACTOR

(ASHRAE 1977 P. 25.41)

GLASS = REGULAR SINGLE GLASS

GLASS FACTOR AT To (90^oF) = 24 BTU/hr ft^2

LOAD = 532.6 x 24 = 12,783 BTU/hr.

5. INFILTRATION

1:1 BTU/ft^2 OF GROSS EXPOSED WALL AREA AT To (90^oF)

LOAD: 1.1 x 1193.3 = 1313 BTU/hr

6. OCCUPANCY

225 BTU/hr/Person x 2 Person/Br. x 3 Br.

LOAD = 1350 BTU/Hr.

7. APPLICANCES

LOAD = 1200 BTU/Hr.

TOTAL SENSIBLE HEAT LOAD

1193.3 + 7524.7 + 12783 + 1313 + 1350 + 1200

S.H.L. = 25364 BTU/$_{hr}$

LATENT HEAT LOAD : 30% OF THE SENSIBLE

L.H.L. = 7609.2 BTU/$_{hr}$

TOTAL LOAD: (LATENT + SENSIBLE)

32,973.2 BTU/$_{hr}$

TOTAL LOAD PER DAY: ASSUMING THAT THE SYSTEM WILL BE OPERATED 10 HOURS PER DAY.

LOAD/DAY : 32973.2 x 10 = 329,732 BTU/$_{DAY}$

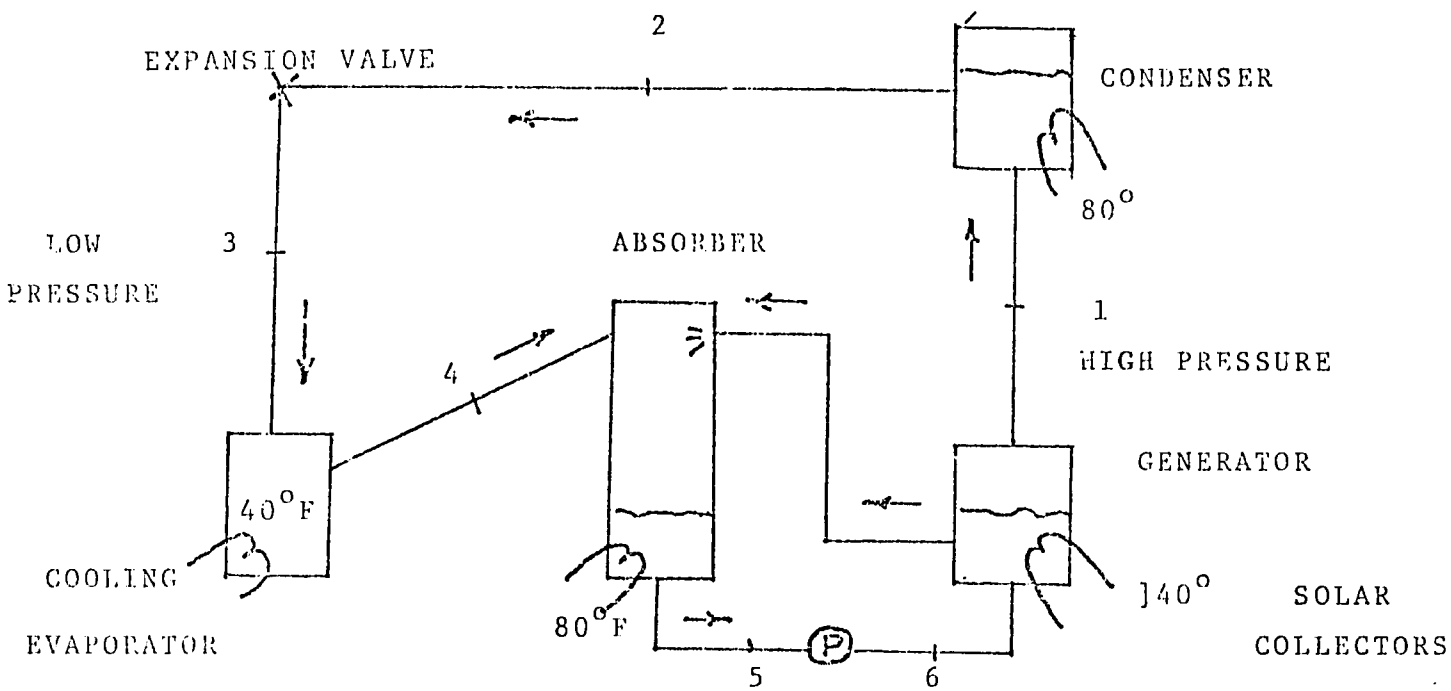
COLLECTOR OUTPUT = 1000 BTU/$_{ft^2}$ DAY.

COLLECTOR AREA: 329,732/$_{1000}$

:329.7 ft^2

SECTION V

ABSORPTION AIR CONDITIONING SYSTEM
NH_3/H_2O



Symbols

T = Temperature, °F

P = Pressure, PSIG

X = Concentration, in terms of NH_3

W = Flow Rate

h = enthalphy; BTU/lb

	T °F	P PSIG	CONC.	$\dot{W}$ lb./TIME	h BTU/lb.	3 TON Unit
Design Criteria						
1	140	140	PURE NH_3 1	1	677	73.3 PURE NH_3
2	80	140	1	1	132	73.3
3	40	60	1	1	132	73.3
4	40	60	1	1	623	73.3
5	80	60	.60	6.76	-4	495.51
6	80	60	.60	6.76	-3.7	495.51
7	140	140	.53	5.76	52	422.21

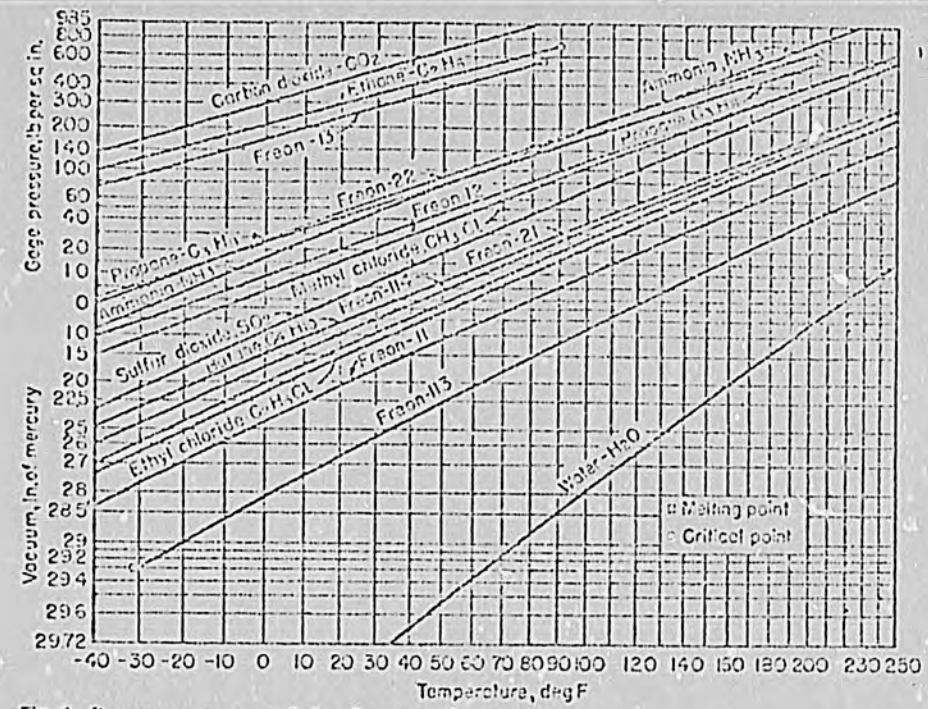


Fig. 1 Pressure-temperature relations for saturated vapors of refrigerants.

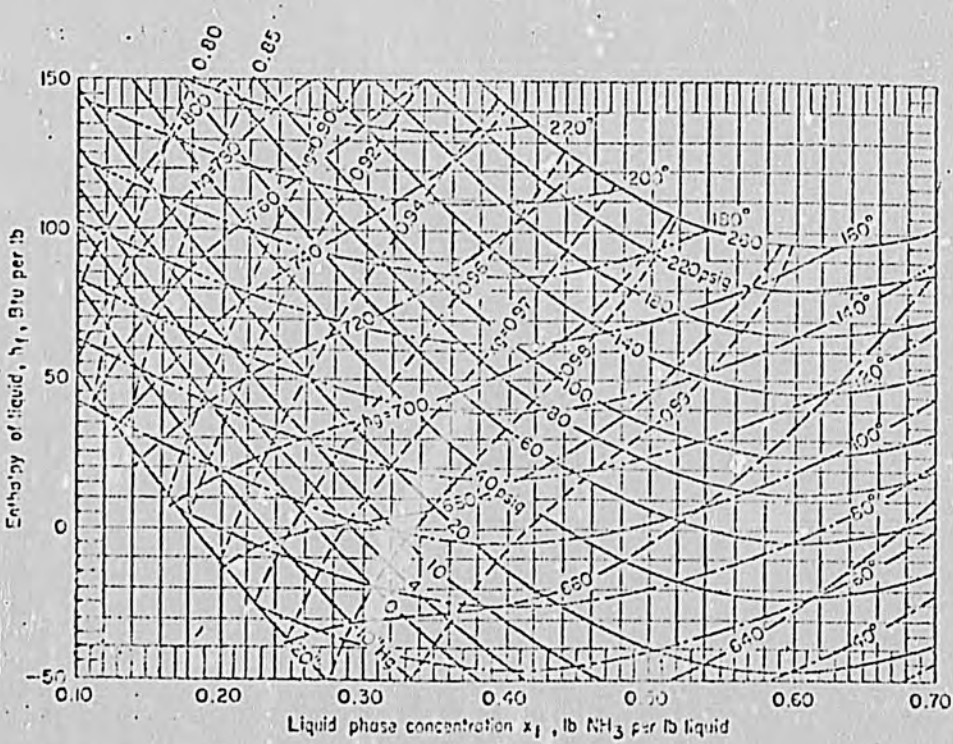


Fig. 14 Physical properties of ammonia-water solutions.

Table 33. Properties of Saturated Ammonia—(Continued)

Temp, deg F. t	Pressure, psia. p	Specific volume, cu ft per lb: Sat liquid, v_f	Sat vapor, v_g	Enthalpy, Btu: Sat liquid, h_f	Vaporization, h_{fg}	Sat vapor, h_g	Entropy: Sat liquid, s_f	Vaporization, s_{fg}	Sat vapor, s_g
0	30.42	0.02419	9.116	42.9	568.9	611.8	0.0975	1.2377	1.3352
2	31.92	0.02424	8.714	45.1	567.3	612.4	0.1022	1.2290	1.3312
4	33.47	0.02430	8.333	47.2	565.6	613.9	0.1069	1.2204	1.3273
6	35.09	0.02435	7.971	49.4	563.2	613.6	0.1115	1.2119	1.3234
8	36.77	0.02440	7.629	51.6	562.7	614.3	0.1162	1.2033	1.3195
10	38.51	0.02446	7.304	53.8	561.1	614.9	0.1208	1.1949	1.3157
12	40.31	0.02451	6.996	56.0	559.5	615.5	0.1253	1.1864	1.3118
14	42.16	0.02457	6.705	58.2	557.9	616.1	0.1300	1.1781	1.3081
16	44.12	0.02462	6.425	60.3	556.3	616.6	0.1346	1.1697	1.3043
18	46.13	0.02469	6.161	62.5	554.7	617.2	0.1392	1.1614	1.3006
20	48.21	0.02474	5.910	64.7	553.1	617.8	0.1437	1.1532	1.2969
22	50.35	0.02479	5.671	66.9	551.4	618.3	0.1483	1.1450	1.2933
24	52.59	0.02486	5.443	69.1	549.8	618.9	0.1528	1.1369	1.2897
26	54.90	0.02491	5.227	71.3	548.1	619.4	0.1573	1.1288	1.2861
28	57.28	0.02497	5.021	73.5	546.4	619.9	0.1618	1.1207	1.2825
30	59.74	0.02503	4.825	75.7	544.8	620.5	0.1663	1.1127	1.2790
32	62.29	0.02508	4.637	77.9	543.1	621.0	0.1708	1.1047	1.2755
34	64.91	0.02514	4.459	80.1	541.4	621.5	0.1753	1.0968	1.2721
36	67.63	0.02521	4.289	82.3	539.7	622.0	0.1797	1.0889	1.2686
38	70.43	0.02527	4.126	84.6	537.9	622.5	0.1841	1.0811	1.2652
40	73.32	0.02533	3.971	86.8	536.2	623.0	0.1886	1.0733	1.2618
42	76.31	0.02539	3.823	89.0	534.4	623.4	0.1930	1.0655	1.2585
44	79.35	0.02545	3.682	91.2	532.7	623.9	0.1974	1.0578	1.2552
46	82.55	0.02551	3.547	93.5	530.9	624.4	0.2018	1.0501	1.2519
48	85.82	0.02558	3.418	95.7	529.1	624.5	0.2062	1.0424	1.2486
50	89.19	0.02564	3.294	97.9	527.3	625.2	0.2105	1.0348	1.2453
52	92.66	0.02571	3.176	100.2	525.5	625.7	0.2149	1.0272	1.2421
54	96.23	0.02577	3.063	102.4	523.7	626.1	0.2192	1.0197	1.2389
56	99.91	0.02584	2.954	104.7	521.8	626.5	0.2236	1.0121	1.2357
58	103.7	0.02590	2.851	106.9	520.0	626.9	0.2279	1.0046	1.2325
60	107.6	0.02597	2.751	109.2	518.1	627.3	0.2322	0.9972	1.2294
62	111.6	0.02603	2.656	111.5	516.2	627.7	0.2365	0.9897	1.2262
64	115.7	0.02611	2.565	113.7	514.3	628.0	0.2408	0.9823	1.2231
66	120.0	0.02618	2.477	116.0	512.4	628.4	0.2451	0.9750	1.2201
68	124.3	0.02625	2.393	118.3	510.5	628.8	0.2494	0.9676	1.2170
70	128.8	0.02632	2.312	120.5	508.6	629.1	0.2537	0.9603	1.2140
72	133.4	0.02639	2.235	122.8	506.6	629.4	0.2579	0.9531	1.2110
74	138.1	0.02646	2.161	125.1	504.7	629.8	0.2622	0.9458	1.2080
76	143.0	0.02653	2.089	127.4	502.7	630.1	0.2664	0.9386	1.2050
78	147.9	0.02661	2.021	129.7	500.7	630.4	0.2706	0.9314	1.2020
80	153.0	0.02668	1.955	132.0	498.7	630.7	0.2749	0.9242	1.1991
82	158.3	0.02675	1.892	134.3	496.7	631.0	0.2791	0.9171	1.1962
84	163.7	0.02684	1.831	136.6	494.7	631.3	0.2833	0.9100	1.1933
86	169.2	0.02691	1.772	138.9	492.6	631.5	0.2875	0.9029	1.1904
88	174.8	0.02699	1.716	141.2	490.6	631.8	0.2917	0.8958	1.1875
90	180.6	0.02707	1.661	143.5	488.5	632.0	0.2958	0.8888	1.1846
92	186.6	0.02715	1.609	145.8	486.4	632.2	0.3000	0.8818	1.1818
94	192.7	0.02723	1.557	148.2	484.3	632.5	0.3041	0.8748	1.1789
96	198.9	0.02731	1.509	150.5	482.1	632.6	0.3083	0.8678	1.1761
98	205.3	0.02739	1.461	152.9	480.0	632.9	0.3125	0.8608	1.1733
100	211.9	0.02747	1.419	155.2	477.8	633.0	0.3166	0.8539	1.1705
105	228.9	0.02769	1.313	161.1	472.3	633.4	0.3269	0.8366	1.1635
110	247.0	0.02790	1.217	167.0	466.7	633.7	0.3372	0.8194	1.1566
115	266.2	0.02813	1.128	173.0	460.9	633.9	0.3474	0.8023	1.1497
120	286.4	0.02836	1.047	179.0	455.0	634.0	0.3576	0.7851	1.1427

1. To Calculate the P at 1;2 140 PSIG

Using Refrigerant Pressure Gage vs. Temperature, ^{o}F chart (Mark's Mechanical Eng. Handbook (9-6; Figure 1). Knowing the pressure at 1 and 2 must be equivalent or the vapor and condensate will not flow we can deduce the pressure at 2 is the same as the pressure at 1. In addition, the pressure at 2 is controlled by the temperature of the condenser. For $80^{o}F$ the pressure at 2 is 140 PSIG.

2. Calculate the p at 3; 4; 5 60 PSIG

Using the same chart as in 1, we can calculate the pressure at 3 and 4. These pressures will be equivalent. We know that after passing through the expansion valve the temperature drops and the pressure also decreases. Using $40^{o}F$ from the Refrigerant Pressure Gage vs. Temperature Chart we find P_3 = 60 PSIG; P_4 = 60 PSIG. The same holds true for the P_5 . P_5 = 60 PSIG.

3. Determine T at 6. The $T_6 = T_5$ since a pump is the only element between 5 and 6. The heat is negligible for this calculation.

4. The pressure 6 and 7 are the same as 1 and 2. 1, 2, 6, 7 represent the high pressure side of the system. While 3,4,5 represent the low pressure side.

5. Calculating the Concentrations for the System.

Since NH_3 has a boiling point much lower than water at 140^oF in the generator, the NH_3 will boil off. In effect, 1, 2, 3, 4 will be pure NH_3. We can also deduce that in the absorber we will have a strong solution of NH_3 and in the generator since the NH_3 is being boiled off, a weak solution of NH_3 will exist.

6. Concentrations.

The formula to determine a concentration of each substance of a compound is $x = \frac{NH_3}{NH_3 + H_2O}$

7. Calculate the Concentration of NH_3

Use the Enthalphy vs. Liquid Phase Concentration of NH_3 (Mark's Handbook)

for NH_3 at point 7 for $T_1 = 140^oF$; $P_7 = 140$ PSIG

$X_7 = .53$

8. Calculate the Concentration of NH_3 in the absorber

Use the same chart as in 7.

$T_5 = 80^oF$ $P_5 = 60$ PSIG

$X_5 = .6$ the X at 6 is the same as X_5

$X_6 = .6$

9. To have simple algebraic equations to use, we can reduce the unknowns by assuming we will calculate the no. of lbs. of NH_3 in terms of 1 lb. of H_2O.

Absorber

$X_6 = X_6 = .6$ for $1^{\#}$ H_2O

$$X = \frac{NH_3}{NH_3 + H_2O}$$

$$.6 = \frac{NH_3}{NH_3 + 1^{\#}}$$

$$.6\ NH_3 + .6 = NH_3$$

$$NH_3 = \frac{.6}{.4} = 1.5^{\#}$$

Total Solution $_{5,\ 6}$ = $1^{\#}$ + ; $1.5^{\#}$ = $2.5^{\#}$

Generator

$$X_7 = .53 = \frac{NH_3}{NH_3 + H_2O} \quad ; \qquad .53 = \frac{NH_3}{NH_3 + 1}$$

$$.5\ NH_3 + .53 = NH_3$$

$$NH_3 = \frac{.53}{.47} = 1.13^{\#}$$

Total Solution$_7$ = $1\# + 1.13^{\#} = 2.13^{\#}$

10. To determine the amount of solution that is circulating; subtract the quantity of solution for the generator from the quantity of solution for the absorber.

$$2.5^{\#} - 2.13^{\#} = .37^{\#}$$

11. To deliver $1^{\#}$ NH_3 the required circulation is:

$$\frac{1}{.37} = \frac{\text{Total Solution}_5}{\text{Solution of Absorber}_5} \; ; \quad \frac{1}{.37} = \frac{\text{Solution}_5}{2.5\#}$$

$$\text{Solution}_{5,\,6} = 6.76^{\#}$$

$$\frac{1}{.37} = \frac{\text{Total Solution}_7}{\text{Solution of Generator}_5} \; ; \quad \frac{1}{.37} = \frac{\text{Solution}_7}{.13\#}$$

$$\text{Solution}_7 = 5.76^{\#}$$

12. h = enthalphy

Use chart from Mark's Handbook; 19 - 12; Figure 14

h_1 for P_1 = 140 PSIG $T_1 = 140^{\circ}F$ h_1 = 677 BTU/lb.

This is in the liquid phase of ammonia

$h_2 = h_3$ because the volume does not change from 2 to 3.

Use Chart in Mark's Handbook 4-34, Figure 33 for

$T = 80^{\circ}F$

This is in the saturated liquid state $h_2 = h_3$ = 132 BTU/lb.

h_4 is determined by the saturated vapor temperature of ammonia. $T_4 = 40^{\circ}F$ h_4 = 623 BTU/lb.

From Mark's Handbook 4-34; Figure 33

h_5 is determined from the liquid phase of ammonia

Use chart from Mark's Handbook; 19 - 12; Figure 14

$$h_5 = -4 \text{ BTU/lb.}$$

h_6

$$h_6 = h_5 + \frac{V_5}{J}(P_6 - P_5) = -4 + \frac{0.02}{778}(144)(140-60) = -3.7 \text{ BTU/lb.}$$

V_5 = Volume at point 5

J = Conversion factor

h_7 is determined from Mark's Handbook;

19 - 12; Figure 14

h_7 = 52 BTU/lb.

13. Calculate Q values for $1^{\#}$ NH_3 circulating

Condenser

$$PE_1 + KE_1 + U_1 + P_1 V_1 + {}_1Q_2 = PE_2 + KE_2 + U_2 + P_2 V_2 + W$$

$$PE_1 + KE_1 + U_1 + P_1 V_1 + {}_1Q_2 = PE_2 + KE_2 + U_2 + P_2 V_2 + W^o$$

$$U_1 = h_1$$

$$U_2 = h_2$$

$${}_1Q_2 = h_2 - h_1 = 137 - 677 = -545 \text{ BTU/hr } \#NH_3$$

Evaporator

$${}_3Q_4 = h_4 - h_3 = 623 - 132 = 491 \text{ BTU/hr. } \#NH_3$$

We know 1 ton of Air Conditioning $= \dfrac{\dfrac{144\ \text{BTU}}{1\ \text{lb.}} \times \dfrac{2000^{\#}}{1\ \text{ton}}}{24\ \text{Hours}}$

1 Ton A.C. = 12000 BTU/hr.

However, we have determined from our building design that three (3) tons of Air Conditioning is necessary:

$$3\ \text{Tons AC} \times \frac{12000\ \text{BTU/hr.}}{\text{Ton AC}} = 36000\ \frac{\text{BTU}}{\text{hr.}}$$

The flow for 3 tons needed is:

$$\dot{w}_3 = \frac{36000\ \frac{\text{BTU}}{\text{hr.}}}{491\ \text{BTU/lb}\ NH_3} = 73.3^{\#}\ NH_3/\text{hr.}$$

For 3 Ton system

The lbs. of NH_3 in 1, 2, 3, 4 are $73.3^{\#}$ NH_3/hr.

for 5 and 6

$$73.3^{\#}\ (\dot{w}_5) = 73.3^{\#}\ (6.76) = 495.5^{\#}$$

for 7 $\quad 73.3^{\#}\ (\dot{w}_7) = 73.3^{\#}\ (5.76) = 422.21^{\#}$

14. To determine COP for system

COP = Coefficient of Performance

$$\dot{w}_6\ h_6 + {}_6Q_{7,1} = \dot{w}_1\ h_1 + \dot{w}_7\ h_7$$

$$6.76\ (-3.7) + {}_6Q_{7,1} = 1\ (677) + 5.76\ (52)$$

$${}_6Q_{7,1} = 677 + 299.52 + 25.10 = 1001.53\ \text{BTU}$$

$$COP = \frac{\text{Refrigerant Effect}}{\text{Heat Input to Generator}} = \frac{491 \text{ BTU/hr.}}{1001.53 \text{ BTU/hr.}} \quad .49$$

For 3 Ton System

Generator

$$6^{Q}7,^{1} = 1001.53 \frac{\text{BTU}}{\text{hr.}} \times 73.3 \ \#NH_3 = 73,412.15 \text{ BTU/hr.}$$

15. To calculate collector Area

$$\text{Collector Area} = \frac{\text{Q generator} \times \text{hours working per day}}{\text{Average BTU/ft}^2 \text{ day collectable}}$$

Assume the average collectable BTU/ft^2 day= 1000 BTU/ft^2 day

Assume panels to be used will be standard 4' x 8' panels, Single glazed, commercially produced panel. Assume average cost per panel with mounting hardware would cost $340/32SF.

Assume system will work 10 hours per day.

$$\text{Collector Area} = \frac{73412.15 \text{ BTU/hr.} \times 10 \text{ hours/day}}{1000 \text{ BTU/ft}^2 \text{ day}} = 734.12 \text{ SF}$$

$$\text{Number of 4' x 8' Panels} = \frac{734.12 \text{ SF}}{32 \text{ SF/Panel}} = 22.9 \qquad 23 \text{ Panels}$$

SECTION IV

ECONOMIC ANALYSIS

The Present Worth and the Annual Cost Methods were used to analyze the feasibility of the system.

1. Present Worth Method:

Under the present worth method the investment is valued at 10%, escalation assumed to be 8% per year, and the systems to have a life of 20 years. The total present worth of the solar system is $25,018 while the conventional system is valued at $25,235. It is evident with a 20-year life and the assumed first costs they are nearly equivalent.

2. Annual Cost Method:

The assumptions for calculating the annual cost differ from those used with the present worth method since the team was not in total agreement as to the cost of money and the useful life of the system. The assumed rate of interest is 12% and the life of the project is 15 years. The cost of electricity was varied from $0.11/kwh to $0.27/kwh. The point of break even is approximately $0.26/kwh.

COST OF AMMONIA/WATER ABSORPTION AIR CONDITIONING SYSTEM.

- 23 SOLAR COLLECTORS INC. MOUNTING HARDWARE @ $340.00 Each $ 7,820

- COST OF AMMONIA/WATER ABSORPTION SYSTEM FOR MATERIALS AND ASSEMBLY (NO SHIPPING CHARGES INCL. NO SYSTEM DESIGN FEES INCL.)..... $10,180

TOTAL CAPITAL COST $18,000

YEARLY MAINTENANCE

1% CAPITAL COST $ 180.

OPERATIONAL COST BASED ON AN ASSUMED ELECTRICAL LOAD OF .745 kwh

ELECTRICAL LOAD/YEAR =

.745 KWH x 10 HOURS/DAY X .8 x 365 DAYS/YEAR =

2,175 KWH/YEAR

COST OF CONVENTIONAL SYSTEM: AIR COOLED.

- 3 TON ARKLA ACD - 36 - AIR COOLED PACKAGE: CHILLER + FAN COIL	$ 3,966
- DUCTS. 150 ft @ $1.50/ft	$ 225.
- ESTIMATED LABOR COST	$ 2,000.
- CONTINGENCIES 10%	$ 619.
TOTAL CAPITAL COST	$ 6,810.

YEARLY MAINTENANCE

2% CAPITAL COST	$ 136.

OPERATIONAL COST BASED ON AN ASSUMED ELECTRICAL LOAD OF 3 KWH

ELECTRICAL LOAD/YEAR

3 KWH x 10 Hours/Day x .8 x 365 DAYS/YEAR =

8,760 KWH/YEAR

PRESENT WORTH METHOD

Assume Rate of Interest = 10% Escalation = 8%

	SOLAR ($)	CONVENTIONAL ($)
Total First Cost Present Worth	18,000	6,810
Life = 20 Years		
Annual Operating and Maintenance Costs	419	1,100
Present Worth of Annual O & M	7,018	18,425
Present Worth	25,018	25,235

$$\text{P.W. Factor} = \frac{a\,(a^n - 1)}{a - 1} \qquad \text{where } a = \frac{[1 + \text{escalation rate}]}{1 + \text{interest rate}}$$

n = Project Life

$$\text{P.W. Factor} = \frac{\frac{(1.08)}{1.10}\,(.982^{20} - 1)}{.982 - 1} = \frac{.982\,(.693 - 1)}{.982 - 1}$$

$$\text{P.W. Factor} = \frac{.982\,(-.307)}{-.018} = 16.75$$

P.W. = P.W. Factor (Annual Operating and Maintenance Costs)

P.W. - 16.75 (419) = 7018.25 = $7,018

CONVENTIONAL SYSTEM

P.W. = P.W. Factor (Annual O & M Costs)

P.W. = 16.75 (1100) = $18,425

ANNUAL COST METHOD

Case 1:

Assumptions:

General

Electric Rate = \$0.11/kwh

Rate of Interest = 12%

Life of Project = 15 years

Solar

Capital Cost = \$18,000

Annual Maintenance = \$180

(1% Capital Cost)

Annual Operating = 2175 kwh/year x\$0.11/$_{kwh}$ = \$239

Conventional = Air Cooled

Capital Cost = \$6,810

Annual Maintenance = \$136

(2% Capital Cost)

Annual Operating = 8760 kwh/$_{year}$ x \$0.11/ $_{kwh}$ = \$964

Comparison

1. Solar

a. Capital Recovery = A = P (A/P, 12%, 15)

= 18000 x 0.147

= \$2646

Comparison (Continued)

1. Solar

b. Operation = $239

c. Maintenance= $180

Total Annual Cost = $3065

2. Conventional

a. Capital Recovery = A = P (A/P, 12%, 15)

= 6810 x 0.147

= $1001

b. Operation = $ 964

c. Maintenance = $ 136

TOTAL ANNUAL COST = $2,101

CASE 2:

Assumptions:

General

Electric Rate = $0.15/kwh

Rate of Interest = 12%

Life of Project = 15 years

Solar

Annual Operating = 2175 $kwh/_{yr}$ x $0.15/$_{kwh}$ = $326

Conventional

Annual Operating = 8760 $kwh/_{yr}$ x $0.15/$_{kwh}$ = $1314

Comparison

1. Solar

a. Capital Recovery = A = P (A/P, 12%, 15)

= 18000 x 0.147 = $2,646

b. Operation = $ 326

c. Maintenance = $ 180

TOTAL ANNUAL COST = $3,152

2. Conventional

a. Capital Recovery = A = P (A/P, 12% , 15)

= 6810 x 0.147 = $1001

b. Operation = $1314

c. Maintenance = $ 136

TOTAL ANNUAL COST = $2451

CASE 3:

Assumptions:

General

Electric Rate = $ 0.25/kwh

Rate of Interest = 12%

Life of Project = 15 years

Solar

Annual Operating = 2175 kwh/year x $0.25/$_{kwh}$ = $544

Conventional

Annual Operating = 8760 kwh/year x $0.25/$_{kwh}$ = $2190

Comparison

1. Solar

a. Capital Recovery = A = P (A/P, 12% , 15)

=18000 x 0.147 = $2646

b. Operation =$544

c. Maintenance =$180

TOTAL ANNUAL COST =$3370

2. Conventional

a. Capital Recovery = A = P (A/P, 12% , 15)

= 6810 x 0.147 = $1001

b. Operation = $2190

c. Maintenance = $ 136

CASE 4:

Assumptions:

General

Electric Rate = $0.27/kwh

Rate of Interest = 12%

Life of Project = 15 years

Solar

Annual Operating = 2175 $kwh/_{yr}$ x $0.27/kwh = $587

Conventional

Annual Operating = 8760 $kwh/_{yr}$ x $0.27/kwh = $2365

Comparison

1. Solar

a. Capital Recovery = A = P(A/P, 12%, 15)

18,000 x 0.147 = $2646

b. Operation = $ 587

c. Maintenance = $ 180

TOTAL ANNUAL COST = $3413

2. Conventional

a. Capital Recovery = A = P (A/P, 12%, 15)

=6810 x 0.147 = $1001

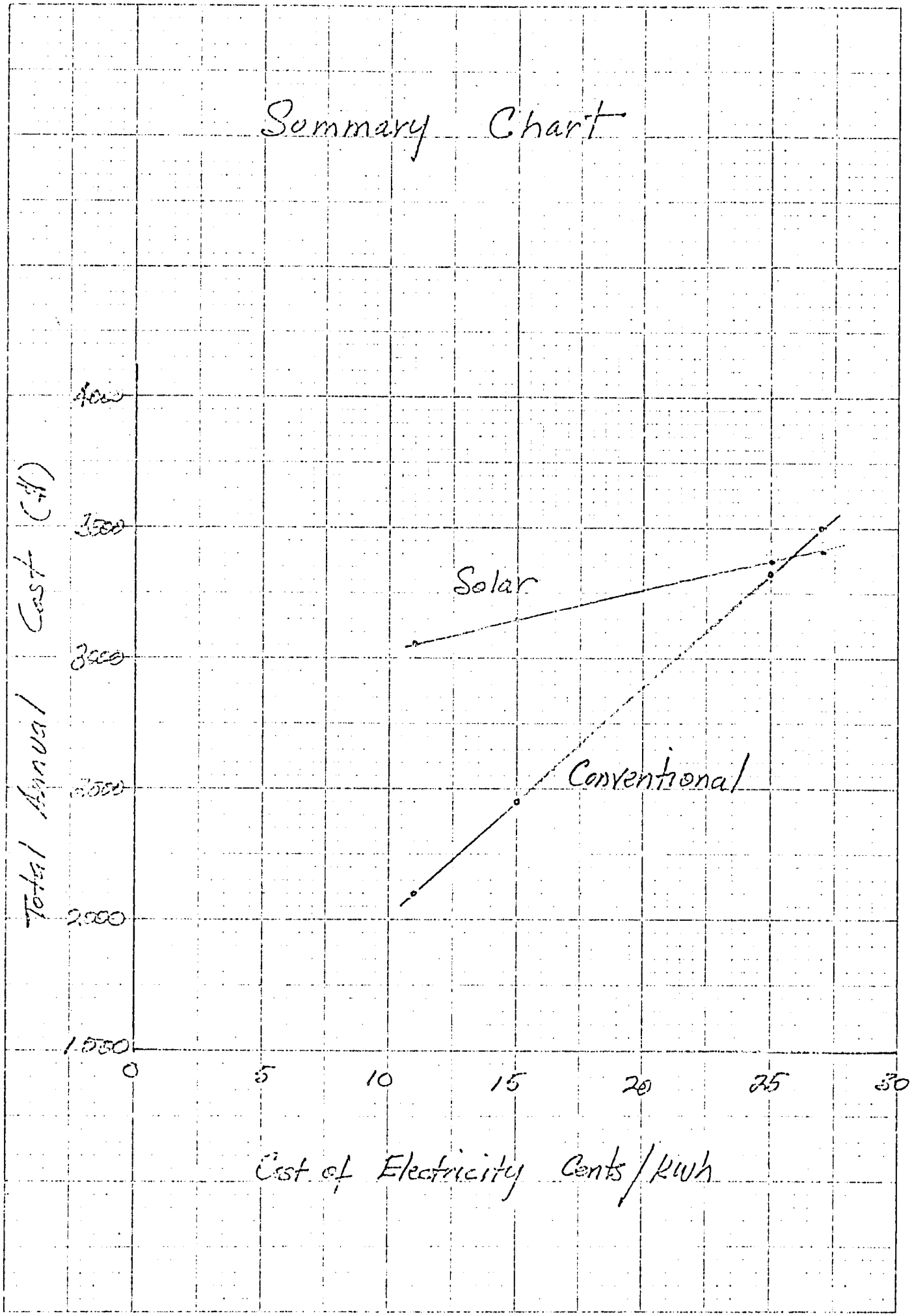
b. Operating =$2365

c. Maintenance =$ 136

TOTAL ANNUAL COST =$3502

SUMMARY CHART

		COST OF ELECTRICITY $ /kwh			
		0.11	0.15	0.25	0.27
TOTAL ANNUAL COST ($)	CONVENTIONAL	2101	2451	3327	3502
	SOLAR	3065	3152	3370	3413


Summary Chart
Total Annual Cost ($)
4000
3500
3000
2500
2000
1500
0
5
10
15
20
25
30
Solar
Conventional
Cost of Electricity Cents/kWh

SECTION VII

CONCLUSIONS

Considering the analysis in general terms a number of events need to occur before the Ammonia/Water absorptive system will be more attractive than the present conventional air cooled systems available.

1. The price of commercial solar panels needs to drop.
2. The cost of electricity must exceed 11 cents per kwh.
3. Mass production of the ammonia/water system must approach the present cost of the air - cooled conventional system.
4. If a government considers general acceptance important, the capital costs should be subsidized.

PRESENT WORTH METHOD

Assume Rate of Interest = 10% Escalation = 8%

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$$\text{P.W. Factor} = \frac{.982\,(-.307)}{-.018} = 16.75$$

P.W. = P.W. Factor (Annual Operating and Maintenance Costs)

P.W. - 16.75 (419) = 7018.25 = $7,018