CHAPTER V

SIMULATION RESULTS

Our simulation was divided into 3 cases. We simulated each case for 4 hottest months: March, April, May, June of 1979. In each case we varied the flat-plate collector area and stratified water storage tank size to find the optimum size, as shown in TABLE 5.1

TABLE 5.1

Sizes of Solar Collector and Storage Tank Investigated

Device	Size		
	Case 1	Case 2	Case 3
Flat-Plate Collector area (m^2) (total width x total length)	91.68 (24x3.82)	76.4 (20x3.82)	106.96 (28x3.82)
Stratified Water Storage Tank (m^3) (width x length x height)	4.824 (0.8x1.8 x3.35)	4.0 (1x2x2)	5.64 (1x2x2.82)

As an example of the dynamic behavior of our solar house, detailed results for the first six days of Case 1, namely, from 1^{st}- 6^{th} March 1979, are shown and discussed here. FIGURE 5.1 shows solar flux incident on the tilted collector plate. As the solar flux heated up the collector plate, the plate temperature rose steadily until 2 p.m. and then fell down until about 6 p.m. (at sun set). This is shown in FIGURE 5.2. When the plate temperature rose 5°C above the water temperature at the bottom of the storage tank, the collector pump was turned on. As the water flowed through the tubes of the collector, it received heat from the plate, and returned to the storage tank. The heat gained by the water is shown in FIGURE 5.3. The first column of each histogram shows the hours of a day. The second one shows the amount of heat gained by the water. The total heat gained during each day is shown at the bottom of each histogram in the unit of kJ. Outside heat loads transferring into the house through the roof, walls and the floor are shown in FIGURE 5.4-5.6. The loads caused the room temperature to rise. When the room temperature shot over 25°C, the absorption chiller was turned on. Only after the room temperature descended below 24°C,[13] was the absorption chiller turned off. The rate of heat removal by the absorption chiller, $\dot{Q}_{cool}$, is shown in FIGURE 5.7. Like FIGURE 5.3, the first column of each histogram shows the hours of a day and the second one shows the rate of heat removal. At the bottom of each histogram is the total daily heat removal in the unit of kJ. Whenever the temperature of the water at the top of the storage tank dropped below 85°C, the flow controller would completely

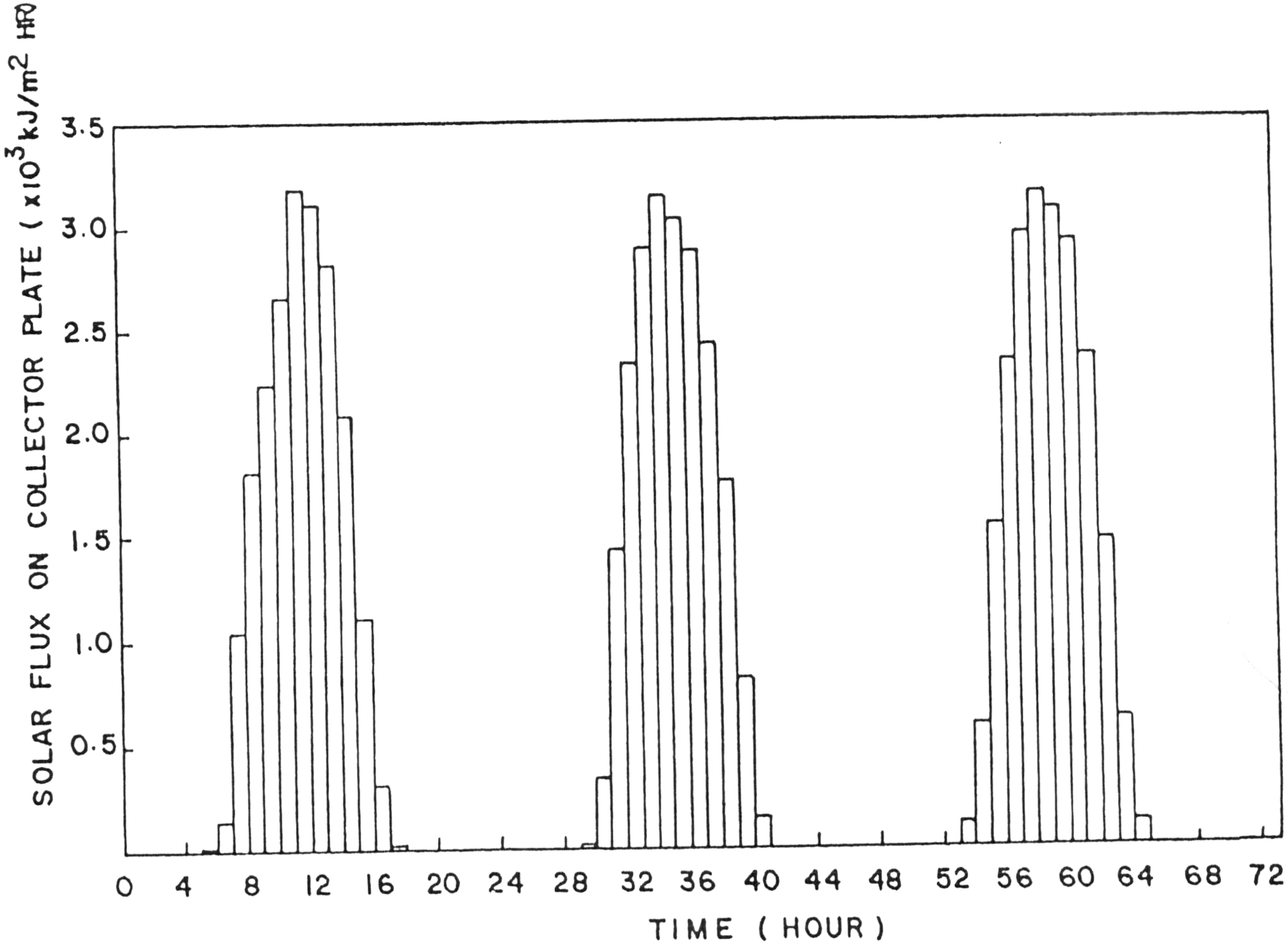

FIGURE 5.1(a) SOLAR FLUX ON COLLECTOR PLATE

(1st - 3rd MARCH 1979)

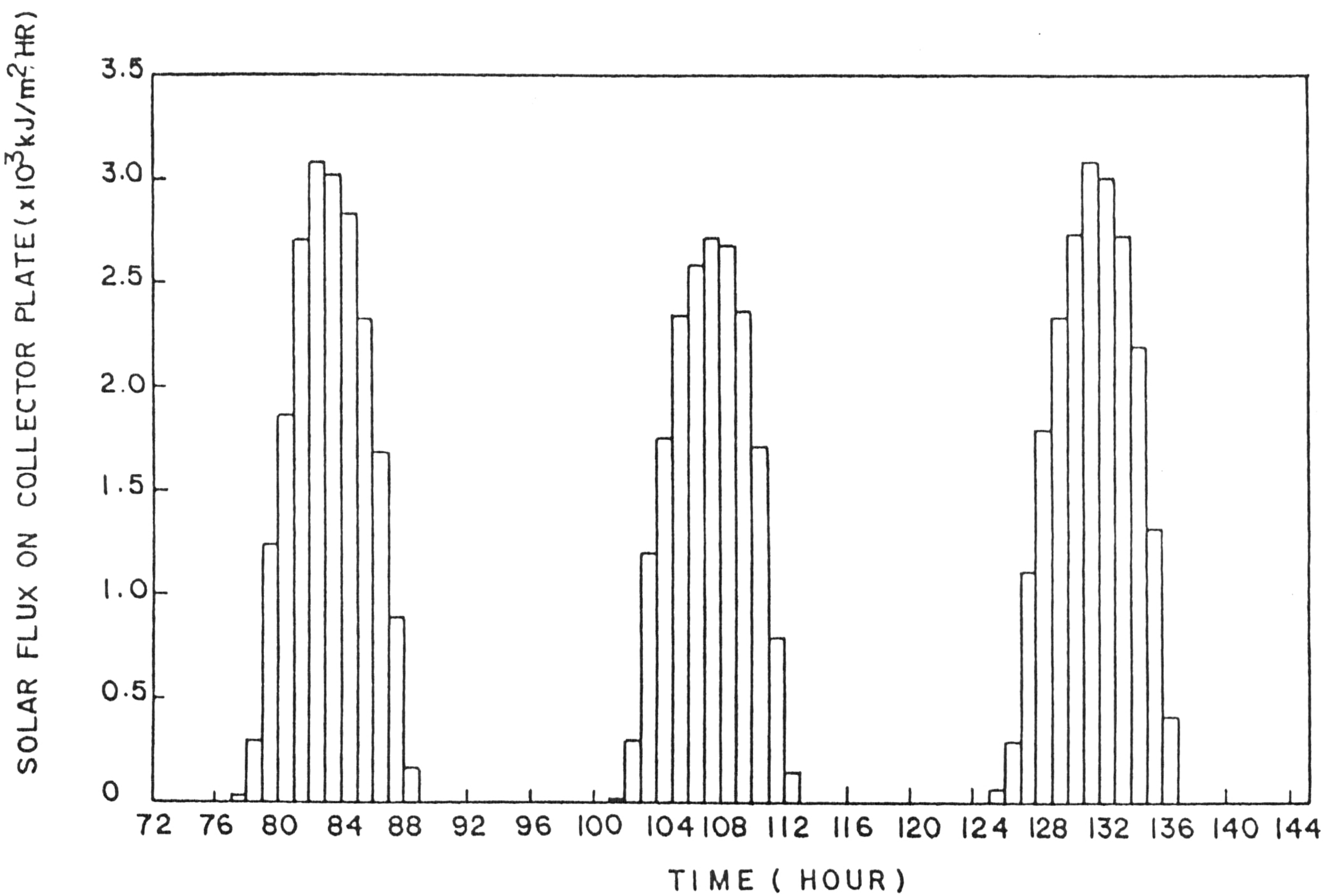

FIGURE 5.1(b) SOLAR FLUX ON COLLECTOR PLATE
(4^{th} - 6^{th} MARCH 1979)

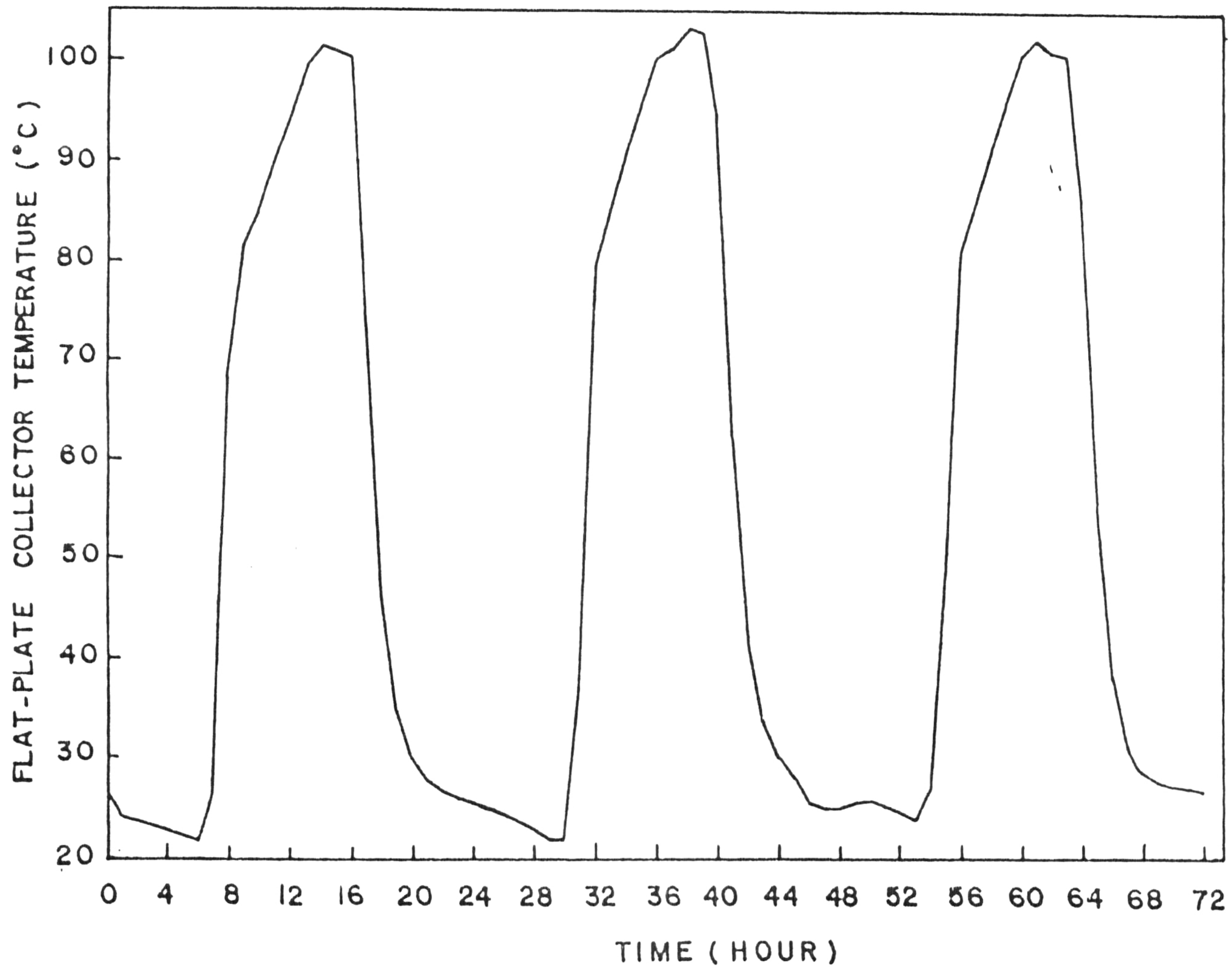

FIGURE 5.2(a) FLAT-PLATE COLLECTOR TEMPERATURE

(1st - 3rd MARCH 1979 , CASE I)

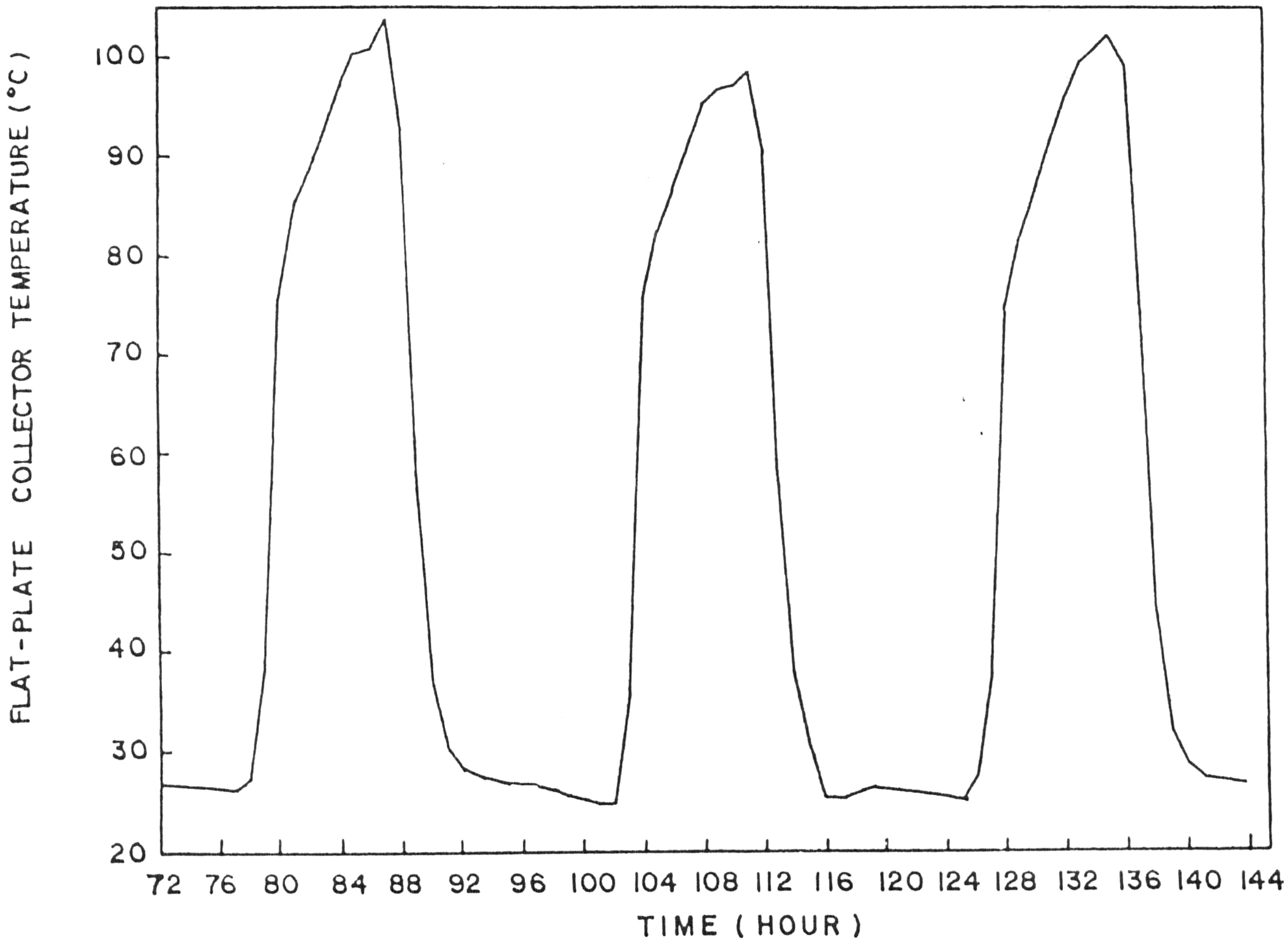

FIGURE 5.2(b) FLAT-PLATE COLLECTOR TEMPERATURE
(4th - 6th MARCH 1979, CASE I)

```
TIME INT ENDING     SUM OF INTEGRALS OVER TIME INTERVAL
 0.1000E 01     0.0
 0.2000E 01     0.0
 0.3000E 01     0.0
 0.4000E 01     0.0
 0.5000E 01     0.0
 0.6000E 01     0.0
 0.7000E 01     0.0
 0.8000E 01     0.0
 0.9000E 01     0.2592E 05
 0.1000E 02     0.7385E 05
 0.1100E 02     0.9830E 05
 0.1200E 02     0.1256E 06
 0.1300E 02     0.1365E 06
 0.1400E 02     0.1214E 06
 0.1500E 02     0.8779E 05
 0.1600E 02     0.2968E 05
 0.1700E 02     0.0
 0.1800E 02     0.0
 0.1900E 02     0.0
 0.2000E 02     0.0
 0.2100E 02     0.0
 0.2200E 02     0.0
 0.2300E 02     0.0
 0.2400E 02     0.0
        TOTAL  =  0.6990E 06
 0.1000E 01     0.0
 0.2000E 01     0.0
 0.3000E 01     0.0
 0.4000E 01     0.0
 0.5000E 01     0.0
 0.6000E 01     0.0
 0.7000E 01     0.0
 0.8000E 01     0.8425E 04
 0.9000E 01     0.5704E 05
 0.1000E 02     0.1101E 06
 0.1100E 02     0.1307E 06
 0.1200E 02     0.1289E 06
 0.1300E 02     0.1201E 06
 0.1400E 02     0.9803E 05
 0.1500E 02     0.6869E 05
 0.1600E 02     0.0
 0.1700E 02     0.0
 0.1800E 02     0.0
 0.1900E 02     0.0
 0.2000E 02     0.0
 0.2100E 02     0.0
 0.2200E 02     0.0
 0.2300E 02     0.0
 0.2400E 02     0.0
        TOTAL  =  0.7220E 06
 0.1000E 01     0.0
 0.2000E 01     0.0
 0.3000E 01     0.0
 0.4000E 01     0.0
 0.5000E 01     0.0
 0.6000E 01     0.0
 0.7000E 01     0.0
 0.8000E 01     0.1466E 05
 0.9000E 01     0.6797E 05
 0.1000E 02     0.1127E 06
 0.1100E 02     0.1381E 06
 0.1200E 02     0.1323E 06
 0.1300E 02     0.1214E 06
 0.1400E 02     0.9539E 05
 0.1500E 02     0.4881E 05
 0.1600E 02     0.2275E 04
 0.1700E 02     0.0
 0.1800E 02     0.0
 0.1900E 02     0.0
 0.2000E 02     0.0
 0.2100E 02     0.0
 0.2200E 02     0.0
 0.2300E 02     0.0
 0.2400E 02     0.0
        TOTAL  =  0.7335E 06
```

FIGURE 5.3(a) HEAT GAINED BY WATER (1st - 3rd MARCH 1979, CASE I)

```
TIME INT ENDING     SUM OF INTEGRALS OVER TIME INTERVAL
 0.1000E 01     0.0           I
 0.2000E 01     0.0           I
 0.3000E 01     0.0           I
 0.4000E 01     0.0           I
 0.5000E 01     0.0           I
 0.6000E 01     0.0           I
 0.7000E 01     0.0           I
 0.8000E 01     0.1451E 05    I***
 0.9000E 01     0.5613E 05    I*************
 0.1000E 02     0.8612E 05    I********************
 0.1100E 02     0.1264E 06    I*****************************
 0.1200E 02     0.1309E 06    I******************************
 0.1300E 02     0.1113E 06    I**************************
 0.1400E 02     0.9889E 05    I***********************
 0.1500E 02     0.5559E 05    I*************
 0.1600E 02     0.1130E 05    I***
 0.1700E 02     0.0           I
 0.1800E 02     0.0           I
 0.1900E 02     0.0           I
 0.2000E 02     0.0           I
 0.2100E 02     0.0           I
 0.2200E 02     0.0           I
 0.2300E 02     0.0           I
 0.2400E 02     0.0           I
          TOTAL = 0.6911E 06
 0.1000E 01     0.0           I
 0.2000E 01     0.0           I
 0.3000E 01     0.0           I
 0.4000E 01     0.0           I
 0.5000E 01     0.0           I
 0.6000E 01     0.0           I
 0.7000E 01     0.0           I
 0.8000E 01     0.8054E 03    I
 0.9000E 01     0.2098E 05    I******
 0.1000E 02     0.7470E 05    I*********************
 0.1100E 02     0.9726E 05    I***************************
 0.1200E 02     0.1059E 06    I******************************
 0.1300E 02     0.1044E 06    I******************************
 0.1400E 02     0.9434E 05    I***************************
 0.1500E 02     0.6273E 05    I******************
 0.1600E 02     0.1037E 05    I***
 0.1700E 02     0.0           I
 0.1800E 02     0.0           I
 0.1900E 02     0.0           I
 0.2000E 02     0.0           I
 0.2100E 02     0.0           I
 0.2200E 02     0.0           I
 0.2300E 02     0.0           I
 0.2400E 02     0.0           I
          TOTAL = 0.5714E 06
 0.1000E 01     0.0           I
 0.2000E 01     0.0           I
 0.3000E 01     0.0           I
 0.4000E 01     0.0           I
 0.5000E 01     0.0           I
 0.6000E 01     0.0           I
 0.7000E 01     0.0           I
 0.8000E 01     0.0           I
 0.9000E 01     0.3526E 05    I*********
 0.1000E 02     0.8014E 05    I*******************
 0.1100E 02     0.1044E 06    I*************************
 0.1200E 02     0.1204E 06    I*****************************
 0.1300E 02     0.1245E 06    I******************************
 0.1400E 02     0.1148E 06    I***************************
 0.1500E 02     0.8547E 05    I*********************
 0.1600E 02     0.2892E 05    I*******
 0.1700E 02     0.0           I
 0.1800E 02     0.0           I
 0.1900E 02     0.0           I
 0.2000E 02     0.0           I
 0.2100E 02     0.0           I
 0.2200E 02     0.0           I
 0.2300E 02     0.0           I
 0.2400E 02     0.0           I
          TOTAL = 0.6938E 06
```

FIGURE 5.3(b) HEAT GAINED BY WATER (4^{th} - 6^{th} MARCH 1979, CASE I)

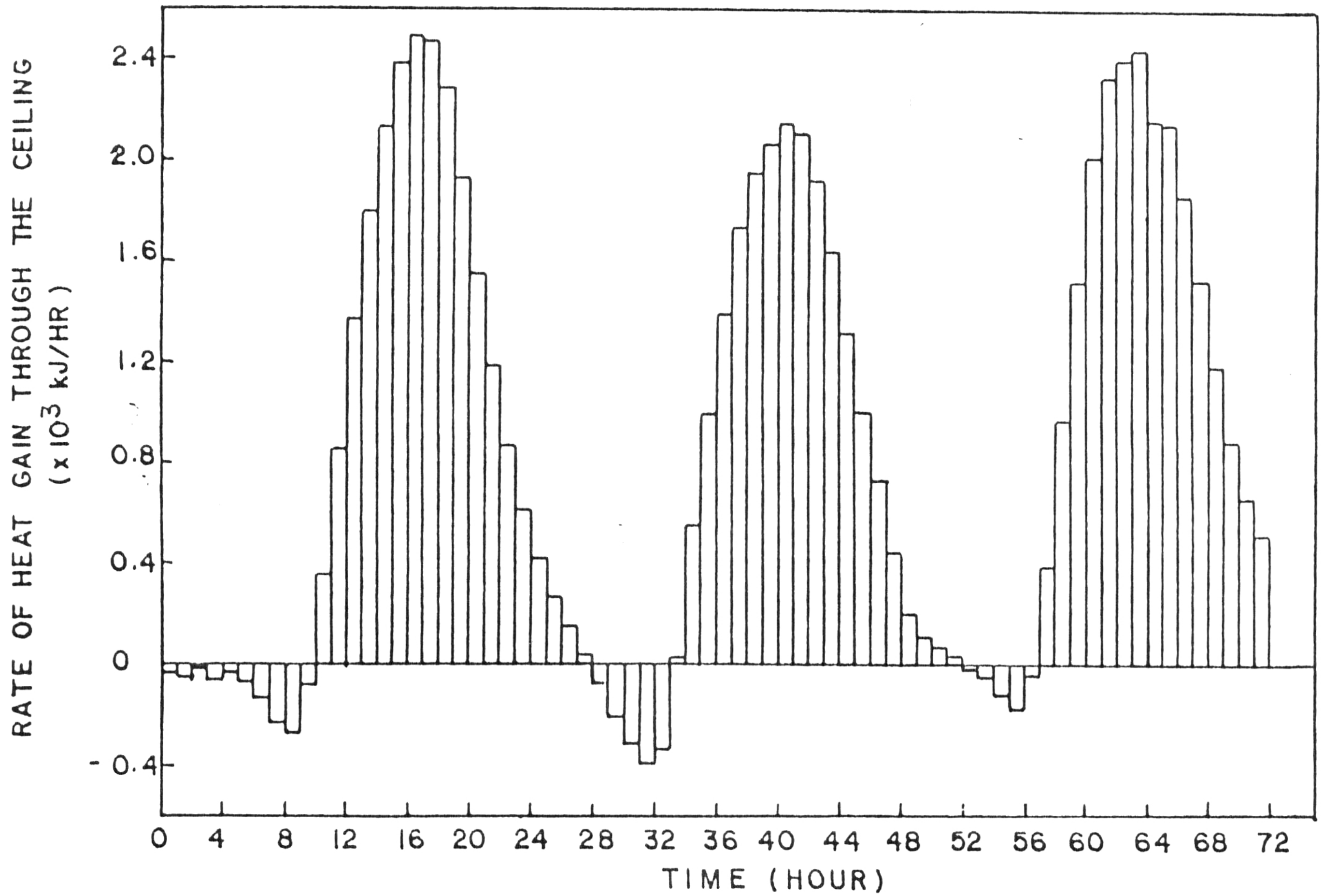

FIGURE 5.4(a) HEAT GAIN THROUGH THE CEILING
(1st - 3rd MARCH 1979, CASE I)

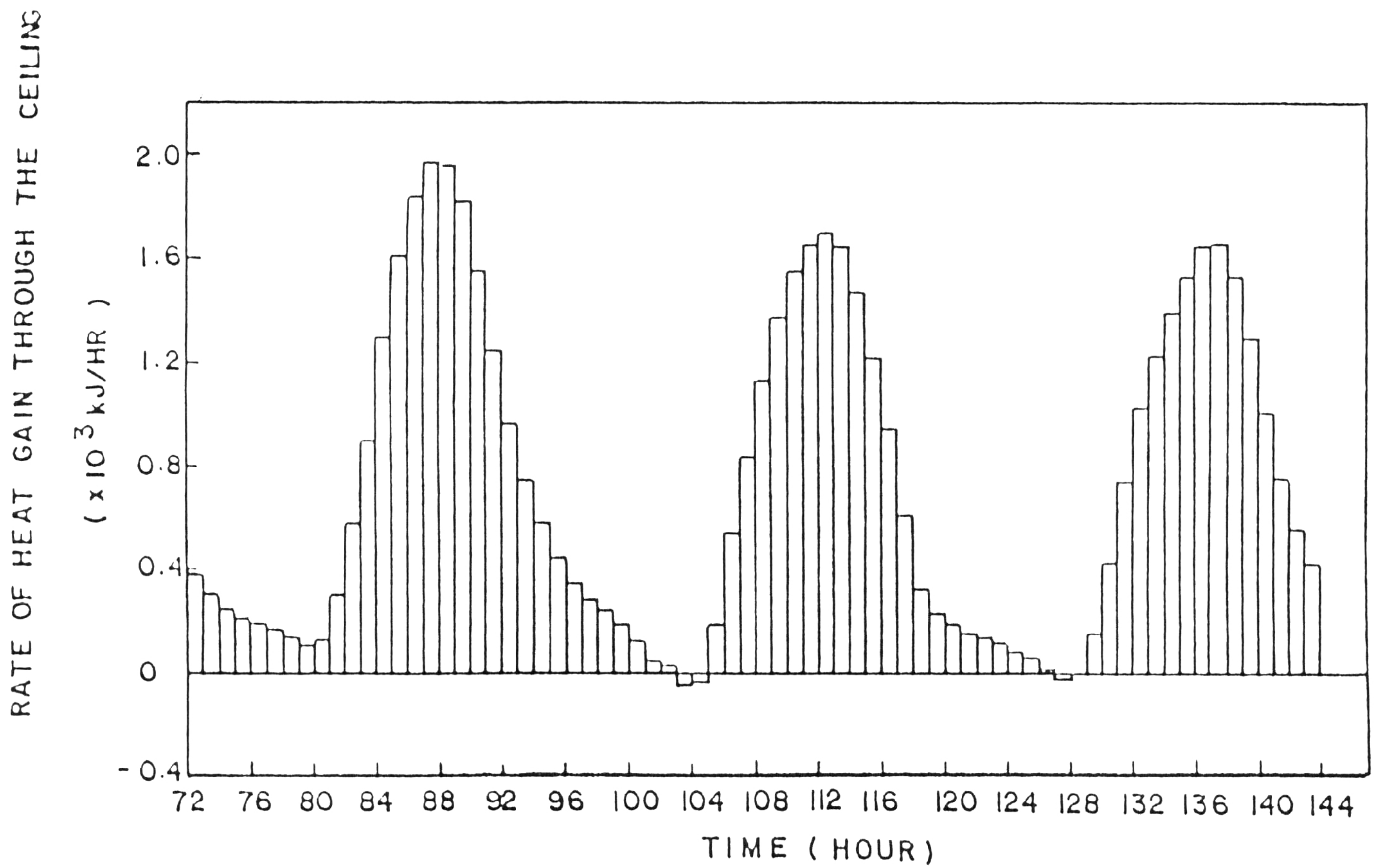

FIGURE 5.4(b) HEAT GAIN THROUGH THE CEILING

(4th - 6th MARCH 1979, CASE I)

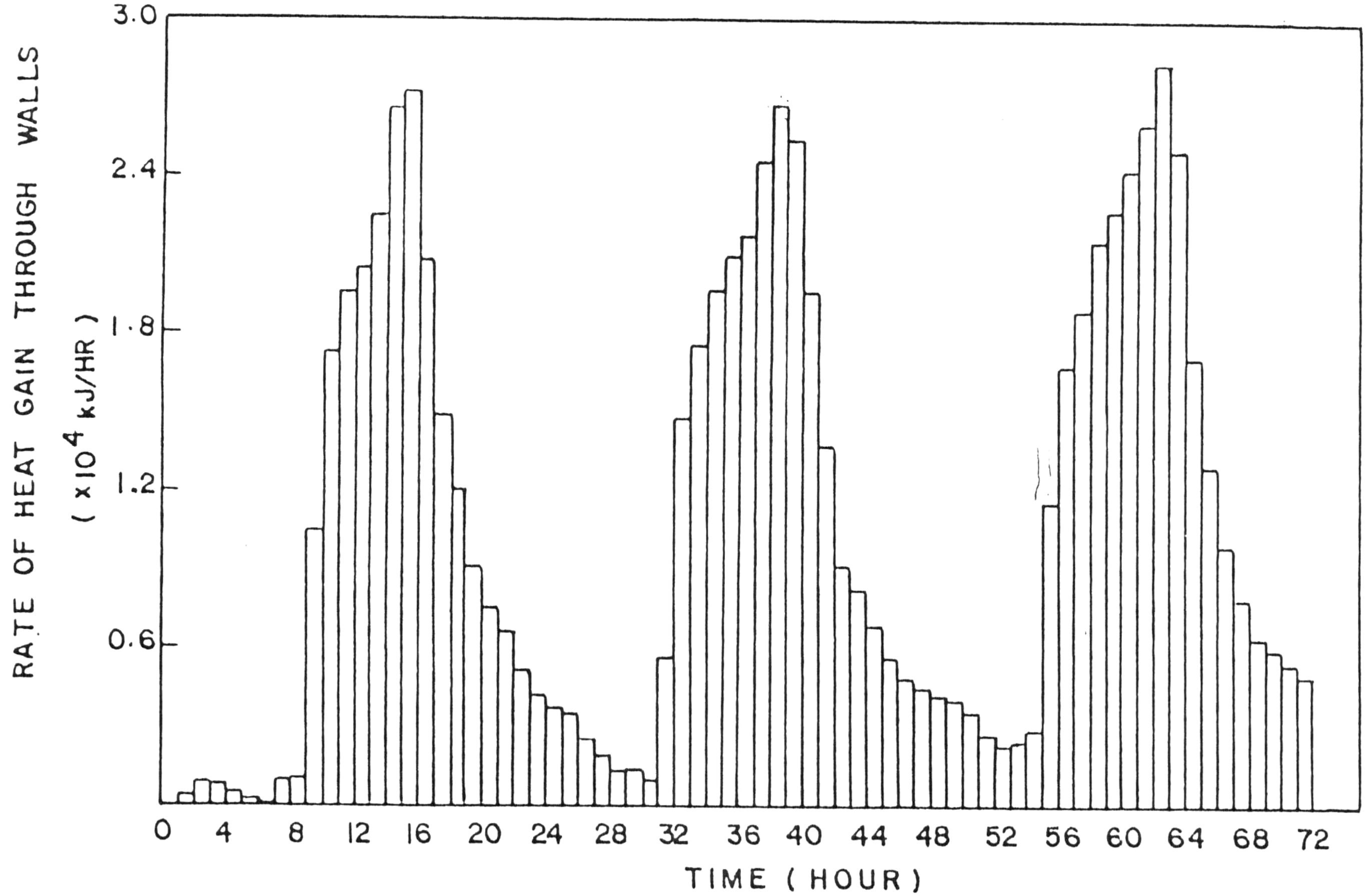

FIGURE 5.5(a) HEAT GAIN THROUGH WALLS
(1st - 3rd MARCH 1979)

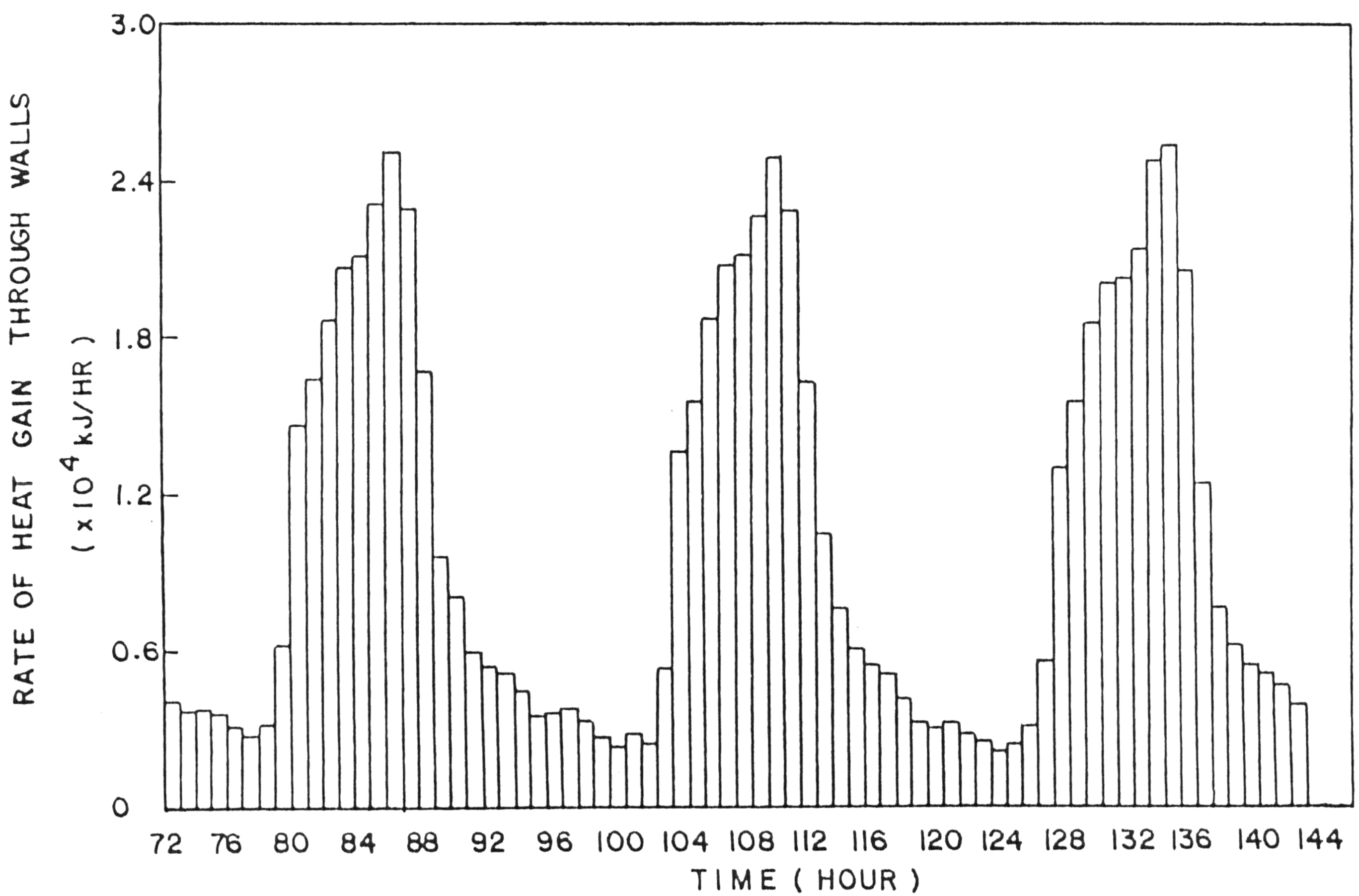

FIGURE 5.5(b) HEAT GAIN THROUGH WALLS
(4th - 6th MARCH 1979)

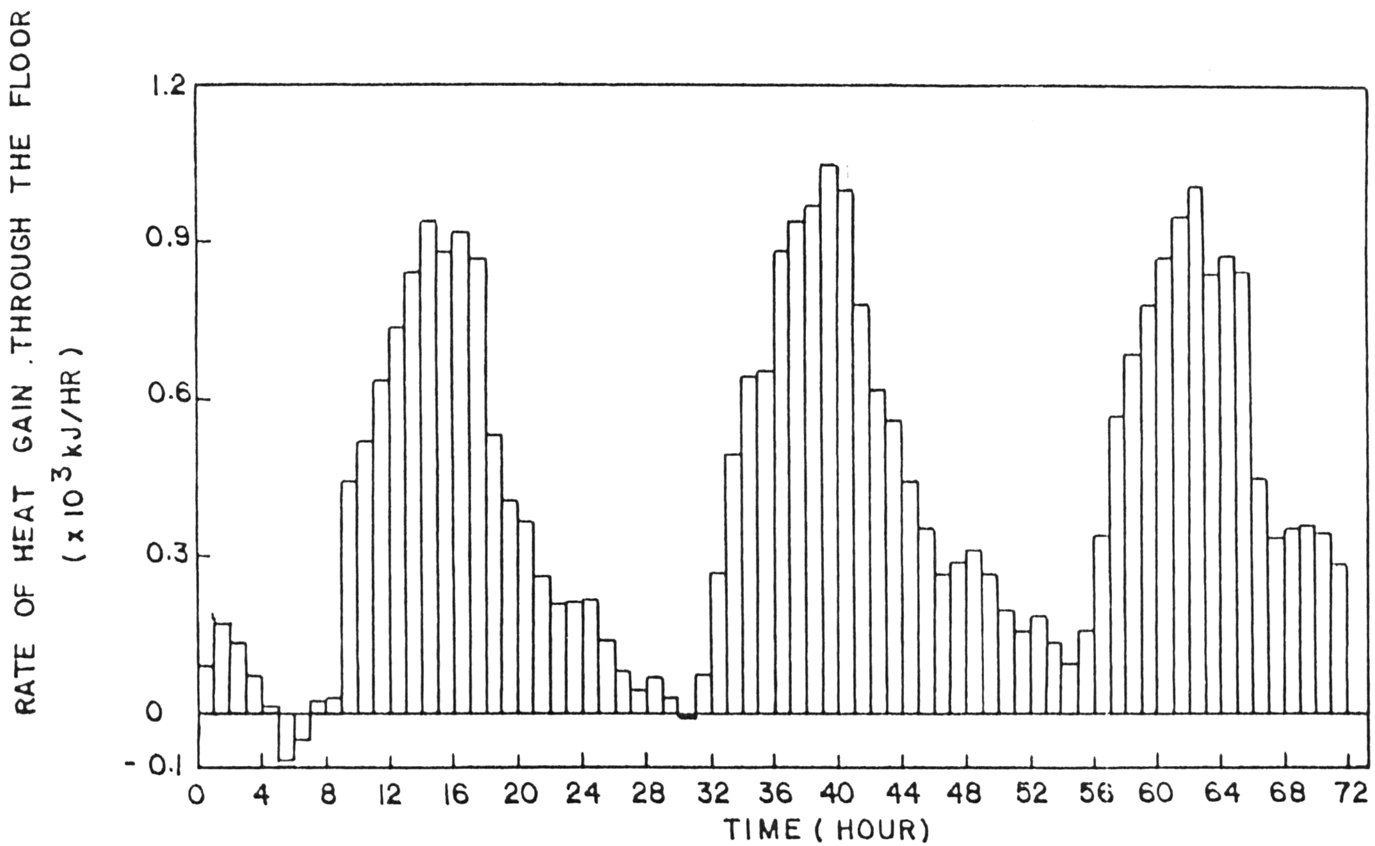

FIGURE 5.6(d) HEAT GAIN THROUGH THE FLOOR

(1st - 3rd MARCH 1979)

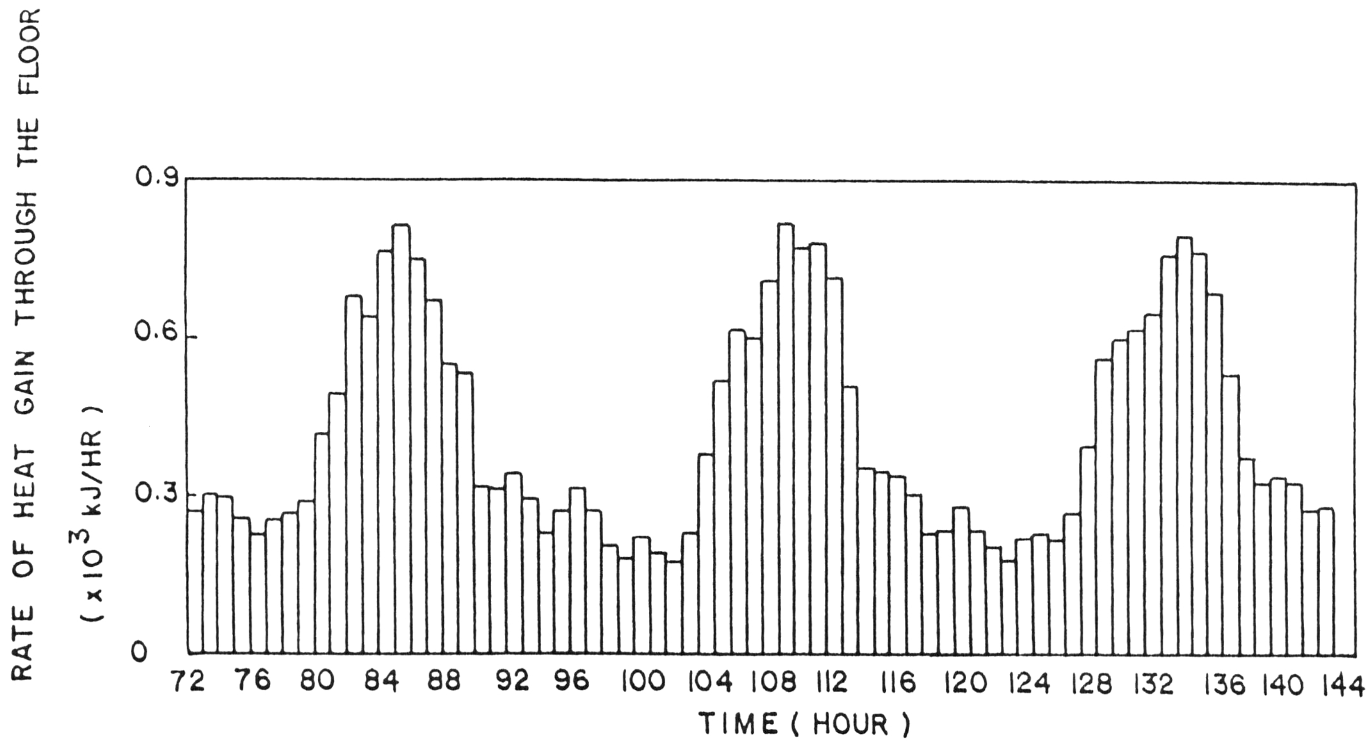

FIGURE 5.6(b) HEAT GAIN THROUGH THE FLOOR

(4^{th} - 6^{th} MARCH 1979)

divert the flow through the main heater loop. The main heater was set to control its outlet water temperature at $85^{o}C$. The amount of supplemental energy supplied by the main heater during the six days is shown in FIGURE 5.8. The first column of each histogram shows the hours of a day and the second one shows the supplemental energy supplied by the main heater. The daily supplemental energy is shown at the bottom of each histogram in the unit of kJ. Only when the temperature of the water at the top of the storage tank was over $88^{o}C$, would the diverter return all flow to the main loop between the storage tank and the absorption chiller. The ambient and room temperatures are shown in FIGURE 5.9. The temperatures of the water at the top and bottom of the storage tank are shown in FIGURE 5.10. FIGURE 5.11 shows the thermal efficiency of the absorption chiller. The absorption chiller's efficiency was simply $\dot{Q}_{cool}$ divided by $\dot{Q}_{input}$. The collector plate efficiency is obtained by dividing $\dot{Q}_{f_{gain}}$ by the total solar energy incident on the tilted collector plate. The collector plate efficiency is shown in FIGURE 5.12.

```
TIME INT ENDING      SUM OF  INTEGRALS OVER TIME INTERVAL
 0.1000E 01     0.2434E 05     I********************
 0.2000E 01     0.2434E 05     I********************
 0.3000E 01     0.3652E 04     I***
 0.4000E 01     0.0            I
 0.5000E 01     0.0            I
 0.6000E 01     0.0            I
 0.7000E 01     0.0            I
 0.8000E 01     0.0            I
 0.9000E 01     0.0            I
 0.1000E 02     0.0            I
 0.1100E 02     0.5596E 04     I****
 0.1200E 02     0.2922E 05     I************************
 0.1300E 02     0.5038E 04     I****
 0.1400E 02     0.1705E 05     I**************
 0.1500E 02     0.3240E 05     I***************************
 0.1600E 02     0.5649E 04     I*****
 0.1700E 02     0.3743E 05     I*******************************
 0.1800E 02     0.3531E 05     I*****************************
 0.1900E 02     0.5670E 04     I*****
 0.2000E 02     0.3436E 05     I****************************
 0.2100E 02     0.2726E 05     I**********************
 0.2200E 02     0.1197E 04     I*
 0.2300E 02     0.1034E 05     I********
 0.2400E 02     0.2290E 05     I*******************
          TOTAL = 0.3217E 06
 0.1000E 01     0.1725E 05     I**************
 0.2000E 01     0.0            I
 0.3000E 01     0.0            I
 0.4000E 01     0.1571E 05     I*************
 0.5000E 01     0.1595E 05     I*************
 0.6000E 01     0.0            I
 0.7000E 01     0.0            I
 0.8000E 01     0.0            I
 0.9000E 01     0.0            I
 0.1000E 02     0.2285E 05     I*******************
 0.1100E 02     0.1709E 05     I**************
 0.1200E 02     0.2045E 04     I**
 0.1300E 02     0.3995E 05     I*********************************
 0.1400E 02     0.5717E 04     I****
 0.1500E 02     0.3070E 05     I*************************
 0.1600E 02     0.3652E 05     I******************************
 0.1700E 02     0.1634E 05     I*************
 0.1800E 02     0.2178E 05     I******************
 0.1900E 02     0.3147E 05     I**************************
 0.2000E 02     0.2852E 05     I***********************
 0.2100E 02     0.2306E 05     I*******************
 0.2200E 02     0.9934E 04     I********
 0.2300E 02     0.1119E 04     I*
 0.2400E 02     0.2219E 05     I******************
          TOTAL = 0.3582E 06
 0.1000E 01     0.2193E 05     I******************
 0.2000E 01     0.3279E 04     I***
 0.3000E 01     0.0            I
 0.4000E 01     0.1006E 05     I********
 0.5000E 01     0.2258E 05     I*******************
 0.6000E 01     0.3402E 04     I***
 0.7000E 01     0.0            I
 0.8000E 01     0.0            I
 0.9000E 01     0.9647E 04     I********
 0.1000E 02     0.2055E 05     I*****************
 0.1100E 02     0.1767E 05     I**************
 0.1200E 02     0.1573E 04     I*
 0.1300E 02     0.3147E 05     I**************************
 0.1400E 02     0.3183E 05     I**************************
 0.1500E 02     0.3273E 05     I***************************
 0.1600E 02     0.8425E 04     I*******
 0.1700E 02     0.3504E 05     I*****************************
 0.1800E 02     0.3657E 05     I******************************
 0.1900E 02     0.1874E 05     I***************
 0.2000E 02     0.1383E 05     I***********
 0.2100E 02     0.2492E 05     I********************
 0.2200E 02     0.2173E 05     I******************
 0.2300E 02     0.1404E 05     I***********
 0.2400E 02     0.0            I
          TOTAL = 0.3810E 06
```

FIGURE 5.7 (a) RATE OF HEAT REMOVAL (1st - 3rd MARCH 1979, CASE I)

TIME INT ENDING	SUM OF INTEGRALS OVER TIME INTERVAL
0.1000E 01	0.1185E 05
0.2000E 01	0.2173E 05
0.3000E 01	0.1201E 05
0.4000E 01	0.0
0.5000E 01	0.0
0.6000E 01	0.1912E 05
0.7000E 01	0.1719E 05
0.8000E 01	0.0
0.9000E 01	0.0
0.1000E 02	0.9864E 04
0.1100E 02	0.2576E 05
0.1200E 02	0.1104E 05
0.1300E 02	0.1230E 05
0.1400E 02	0.3410E 05
0.1500E 02	0.1497E 05
0.1600E 02	0.1830E 05
0.1700E 02	0.3381E 05
0.1800E 02	0.3181E 05
0.1900E 02	0.0
0.2000E 02	0.2609E 05
0.2100E 02	0.2578E 05
0.2200E 02	0.5565E 04
0.2300E 02	0.0
0.2400E 02	0.2126E 05
TOTAL =	0.3529E 06

0.1000E 01	0.2238E 05
0.2000E 01	0.1119E 04
0.3000E 01	0.0
0.4000E 01	0.1013E 05
0.5000E 01	0.2277E 05
0.6000E 01	0.3420E 04
0.7000E 01	0.0
0.8000E 01	0.0
0.9000E 01	0.7721E 04
0.1000E 02	0.2162E 05
0.1100E 02	0.1558E 05
0.1200E 02	0.0
0.1300E 02	0.2763E 05
0.1400E 02	0.3067E 05
0.1500E 02	0.0
0.1600E 02	0.3159E 05
0.1700E 02	0.3333E 05
0.1800E 02	0.2128E 05
0.1900E 02	0.1086E 05
0.2000E 02	0.2732E 05
0.2100E 02	0.2214E 05
0.2200E 02	0.5363E 04
0.2300E 02	0.0
0.2400E 02	0.1639E 05
TOTAL =	0.3313E 06

0.1000E 01	0.2186E 05
0.2000E 01	0.5484E 04
0.3000E 01	0.0
0.4000E 01	0.1126E 04
0.5000E 01	0.2251E 05
0.6000E 01	0.1012E 05
0.7000E 01	0.0
0.8000E 01	0.0
0.9000E 01	0.3243E 04
0.1000E 02	0.2117E 05
0.1100E 02	0.2054E 05
0.1200E 02	0.3801E 04
0.1300E 02	0.1490E 05
0.1400E 02	0.3273E 05
0.1500E 02	0.8004E 04
0.1600E 02	0.2033E 05
0.1700E 02	0.3218E 05
0.1800E 02	0.3351E 05
0.1900E 02	0.5012E 04
0.2000E 02	0.2397E 05
0.2100E 02	0.2636E 05
0.2200E 02	0.1437E 05
0.2300E 02	0.0
0.2400E 02	0.1413E 05
TOTAL =	0.3346E 06

FIGURE 5.7 (b) RATE OF HEAT REMOVAL (4th - 6th MARCH 1979, CASE I)

```
TIME INT ENDING      SUM OF INTEGRALS OVER TIME INTERVAL
 0.1000E 01     0.3756E 05    I*********************************
 0.2000E 01     0.3756E 05    I*********************************
 0.3000E 01     0.5636E 04    I*****
 0.4000E 01     0.0           I
 0.5000E 01     0.0           I
 0.6000E 01     0.0           I
 0.7000E 01     0.0           I
 0.8000E 01     0.0           I
 0.9000E 01     0.0           I
 0.1000E 02     0.0           I
 0.1100E 02     0.8635E 04    I*******
 0.1200E 02     0.5179E 04    I****
 0.1300E 02     0.0           I
 0.1400E 02     0.0           I
 0.1500E 02     0.0           I
 0.1600E 02     0.0           I
 0.1700E 02     0.0           I
 0.1800E 02     0.0           I
 0.1900E 02     0.0           I
 0.2000E 02     0.0           I
 0.2100E 02     0.0           I
 0.2200E 02     0.0           I
 0.2300E 02     0.1238E 05    I**********
 0.2400E 02     0.3535E 05    I******************************
          TOTAL = 0.1423E 06
 0.1000E 01     0.2662E 05    I************************
 0.2000E 01     0.0           I
 0.3000E 01     0.0           I
 0.4000E 01     0.2424E 05    I**********************
 0.5000E 01     0.2841E 05    I**************************
 0.6000E 01     0.0           I
 0.7000E 01     0.0           I
 0.8000E 01     0.0           I
 0.9000E 01     0.0           I
 0.1000E 02     0.3299E 05    I*******************************
 0.1100E 02     0.0           I
 0.1200E 02     0.0           I
 0.1300E 02     0.0           I
 0.1400E 02     0.0           I
 0.1500E 02     0.0           I
 0.1600E 02     0.0           I
 0.1700E 02     0.0           I
 0.1800E 02     0.0           I
 0.1900E 02     0.0           I
 0.2000E 02     0.0           I
 0.2100E 02     0.1185E 05    I**********
 0.2200E 02     0.1533E 05    I*************
 0.2300E 02     0.1843E 04    I**
 0.2400E 02     0.3436E 05    I********************************
          TOTAL = 0.1756E 06
 0.1000E 01     0.3384E 05    I*******************************
 0.2000E 01     0.5061E 04    I****
 0.3000E 01     0.0           I
 0.4000E 01     0.1553E 05    I*************
 0.5000E 01     0.3484E 05    I********************************
 0.6000E 01     0.5250E 04    I*****
 0.7000E 01     0.0           I
 0.8000E 01     0.0           I
 0.9000E 01     0.1494E 05    I*************
 0.1000E 02     0.3065E 05    I****************************
 0.1100E 02     0.0           I
 0.1200E 02     0.0           I
 0.1300E 02     0.0           I
 0.1400E 02     0.0           I
 0.1500E 02     0.0           I
 0.1600E 02     0.0           I
 0.1700E 02     0.0           I
 0.1800E 02     0.0           I
 0.1900E 02     0.0           I
 0.2000E 02     0.0           I
 0.2100E 02     0.1687E 04    I*
 0.2200E 02     0.3354E 05    I*******************************
 0.2300E 02     0.2167E 05    I********************
 0.2400E 02     0.0           I
          TOTAL = 0.1970E 06
```

FIGURE 5.8(a) SUPPLEMENTAL ENERGY SUPPLIED BY MAIN HEATER

(1st - 3rd MARCH 1979, CASE I)

TIME INT ENDING	SUM OF INTEGRALS OVER TIME INTERVAL
0.1000E 01	0.1509E 05
0.2000E 01	0.3354E 05
0.3000E 01	0.2192E 05
0.4000E 01	0.0
0.5000E 01	0.0
0.6000E 01	0.2950E 05
0.7000E 01	0.2652E 05
0.8000E 01	0.0
0.9000E 01	0.0
0.1000E 02	0.1522E 05
0.1100E 02	0.1518E 05
0.1200E 02	0.0
0.1300E 02	0.0
0.1400E 02	0.0
0.1500E 02	0.0
0.1600E 02	0.0
0.1700E 02	0.0
0.1800E 02	0.0
0.1900E 02	0.0
0.2000E 02	0.0
0.2100E 02	0.0
0.2200E 02	0.6863E 04
0.2300E 02	0.0
0.2400E 02	0.3201E 05
TOTAL =	0.1967E 06
0.1000E 01	0.3454E 05
0.2000E 01	0.1727E 04
0.3000E 01	0.0
0.4000E 01	0.1620E 05
0.5000E 01	0.3515E 05
0.6000E 01	0.5277E 04
0.7000E 01	0.0
0.8000E 01	0.0
0.9000E 01	0.1192E 05
0.1000E 02	0.3344E 05
0.1100E 02	0.2447E 05
0.1200E 02	0.0
0.1300E 02	0.0
0.1400E 02	0.0
0.1500E 02	0.0
0.1600E 02	0.0
0.1700E 02	0.0
0.1800E 02	0.0
0.1900E 02	0.0
0.2000E 02	0.0
0.2100E 02	0.1832E 05
0.2200E 02	0.8330E 04
0.2300E 02	0.0
0.2400E 02	0.2578E 05
TOTAL =	0.2152E 06
0.1000E 01	0.3374E 05
0.2000E 01	0.8467E 04
0.3000E 01	0.0
0.4000E 01	0.1737E 04
0.5000E 01	0.3474E 05
0.6000E 01	0.1551E 05
0.7000E 01	0.0
0.8000E 01	0.0
0.9000E 01	0.5224E 04
0.1000E 02	0.3297E 05
0.1100E 02	0.2063E 05
0.1200E 02	0.0
0.1300E 02	0.0
0.1400E 02	0.0
0.1500E 02	0.0
0.1600E 02	0.0
0.1700E 02	0.0
0.1800E 02	0.0
0.1900E 02	0.0
0.2000E 02	0.0
0.2100E 02	0.0
0.2200E 02	0.1325E 05
0.2300E 02	0.0
0.2400E 02	0.2102E 05
TOTAL =	0.1979E 06

FIGURE 5.8(b) SUPPLEMENTAL ENERGY SUPPLIED BY MAIN HEATER

(4th - 6th MARCH 1979, CASE I)

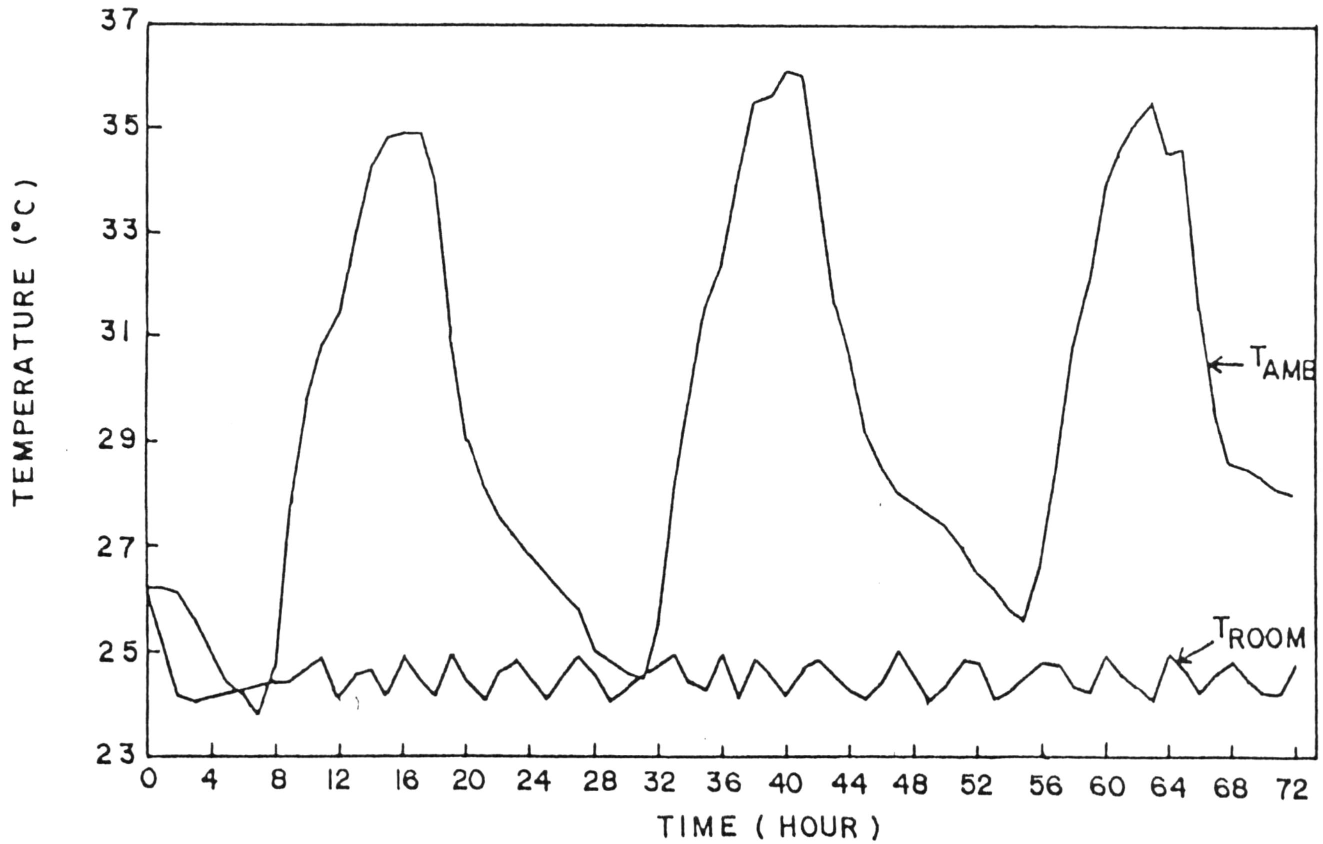

FIGURE 5.9(a) AMBIENT AND ROOM TEMPERATURES
(1st - 3rd MARCH 1979, CASE I)

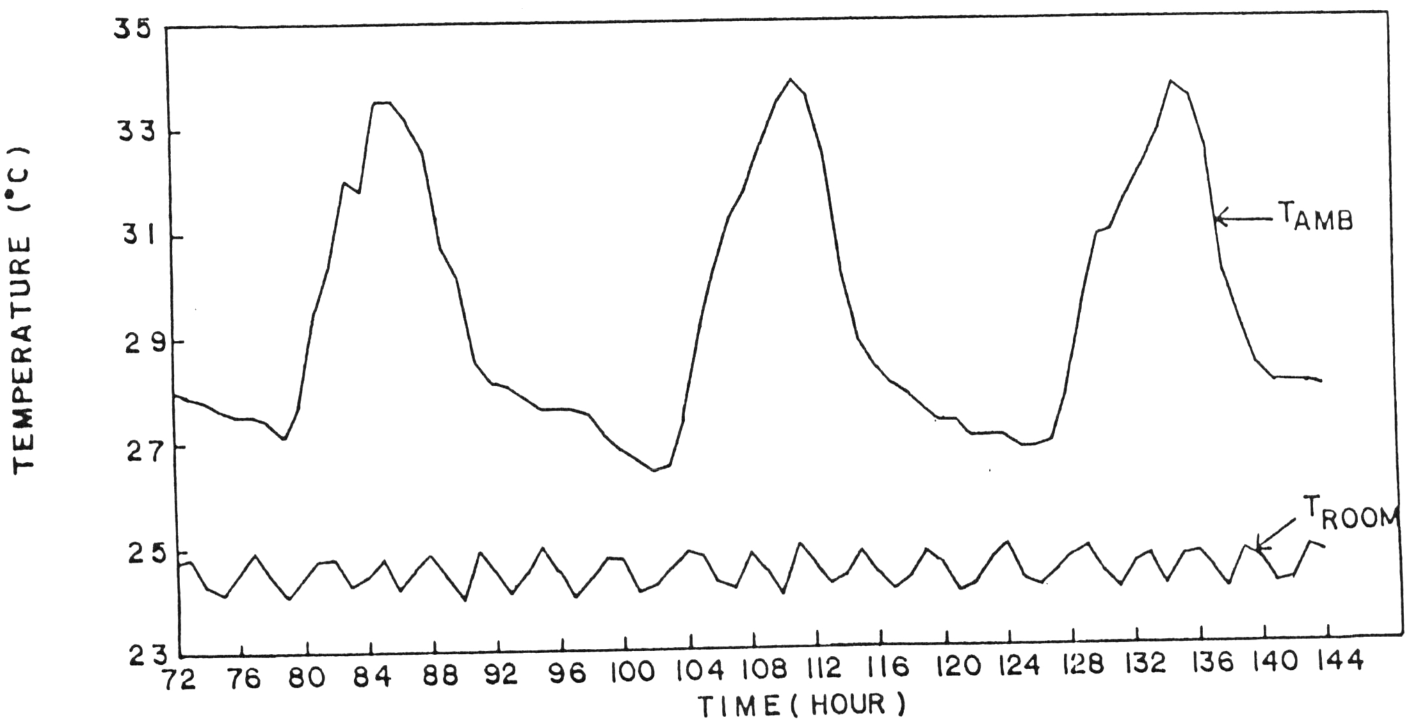

FIGURE 5.9 (b) AMBIENT AND ROOM TEMPERATURES
(4th - 6th MARCH 1979, CASE I)

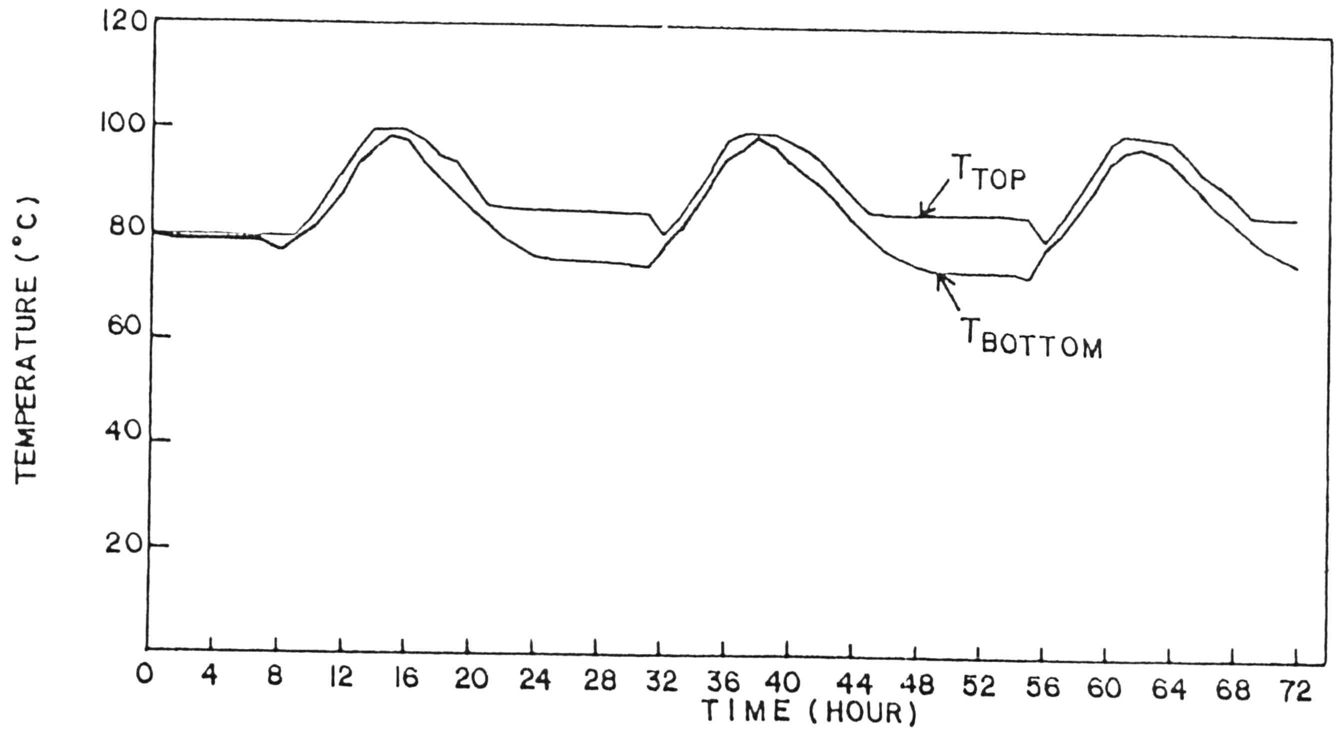

FIGURE 5.10(a) WATER TEMPERATURE IN THE STORAGE TANK
(1st - 3rd MARCH 1979, CASE I)

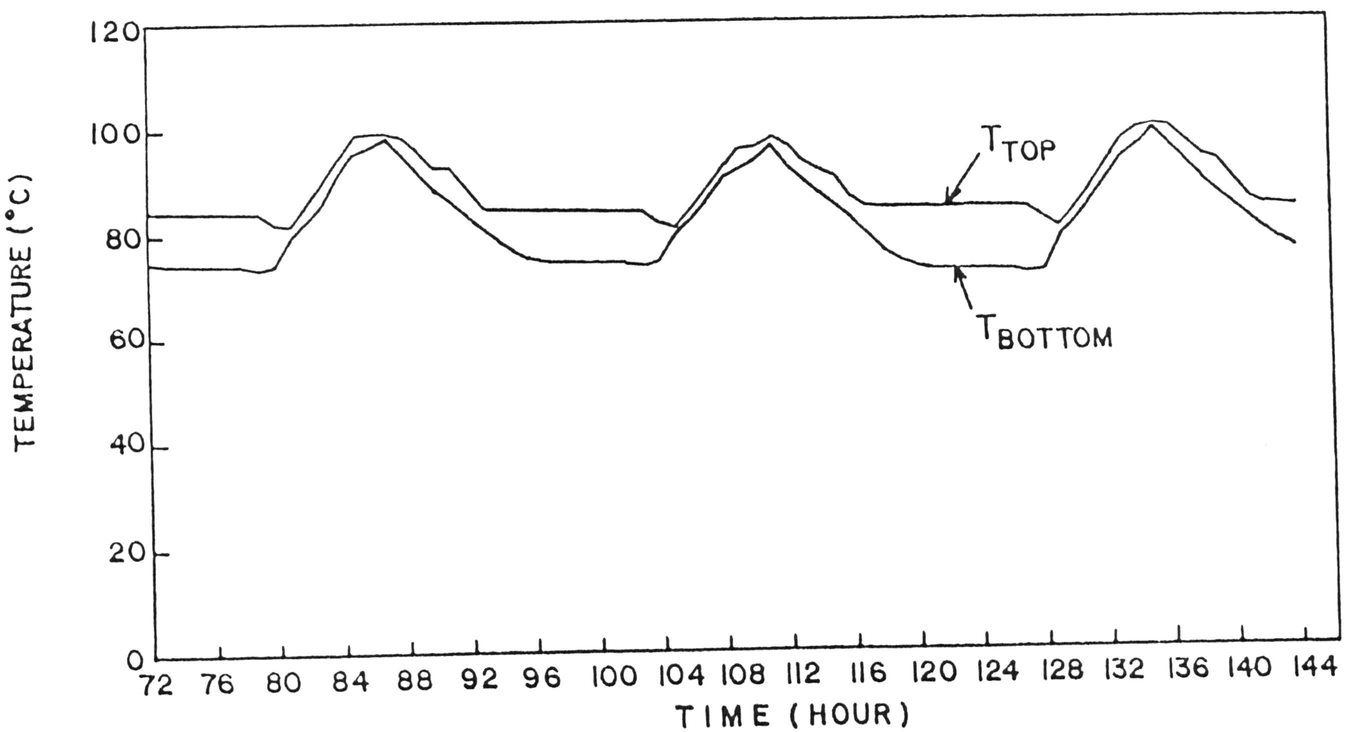

FIGURE 5.10(b) WATER TEMPERATURE IN THE STORAGE TANK
(4th - 6th MARCH 1979, CASE I)

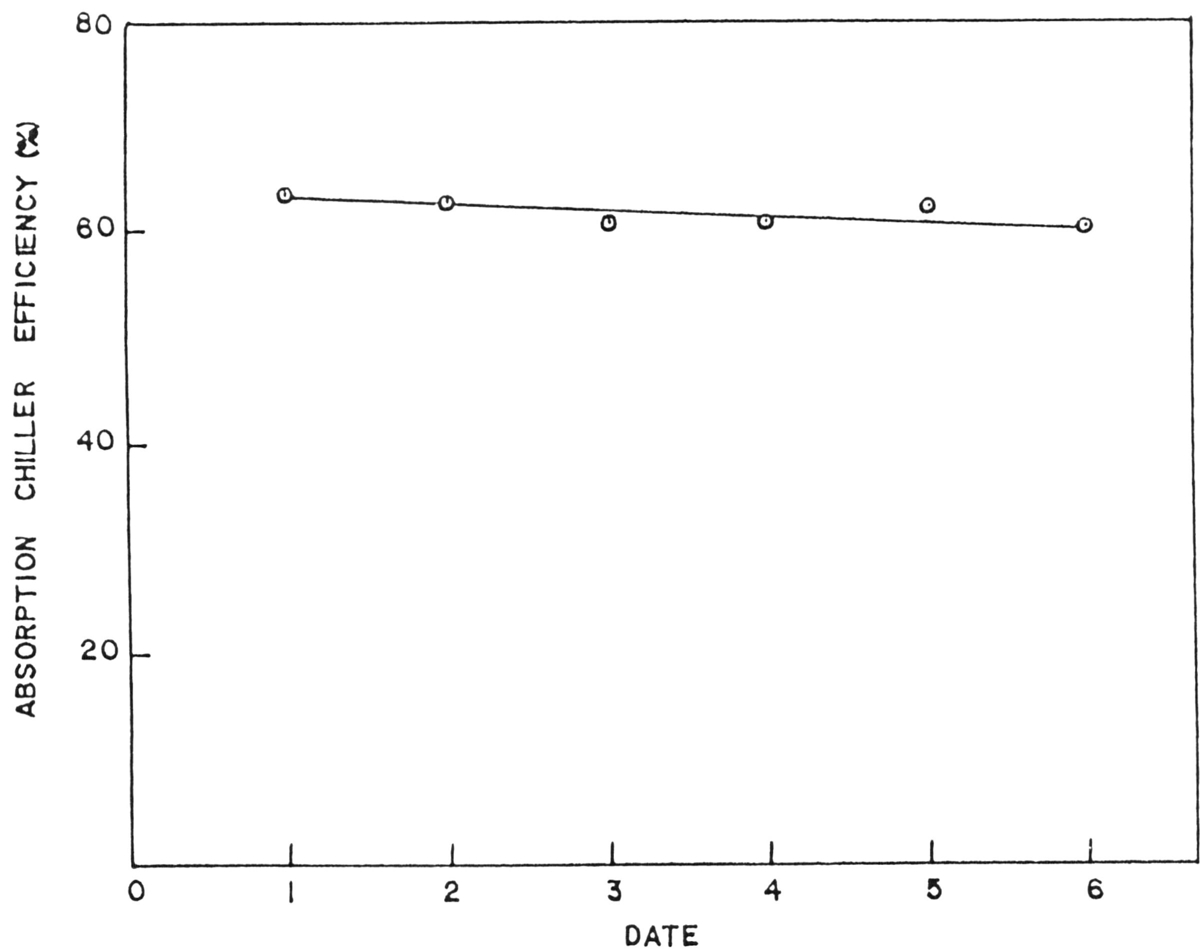

FIGURE 5.11 ABSORPTION CHILLER EFFICIENCY (1st - 6th MARCH 1979, CASE I)

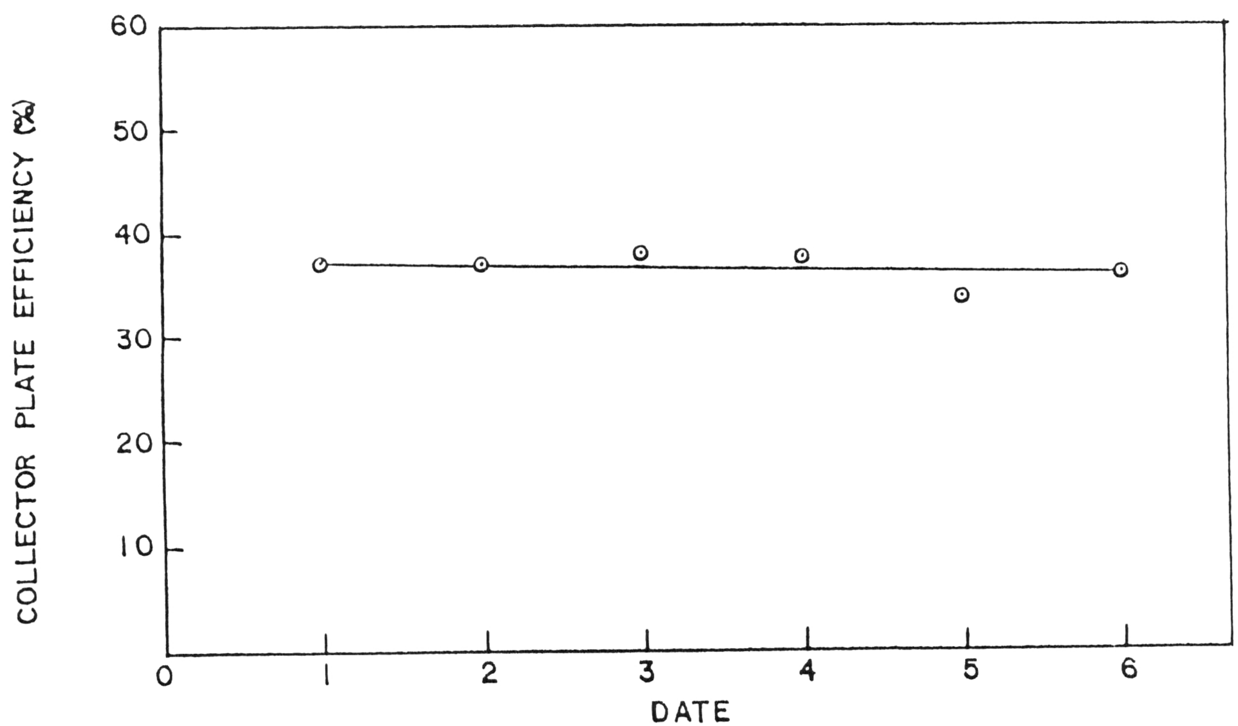

FIGURE 5.12 COLLECTOR PLATE EFFICIENCY (1st - 6th MARCH 1979, CASE I)

FIGURE 5.13 shows daily solar flux incident on the tilted collector plate in March, April, May and June, 1979, respectively, and FIGURE 5.14 shows the same daily solar flux incident on a horizontal plane. As preliminary study, simulation was carried out for April of Case 1. At first, the water temperature above which the absorption chiller was fired by the hot water from the storage tank was set at 83°C, and the temperature at which the main heater loop was switched on was set at 80°C. However, the preliminary simulation results revealed that the absorption chiller could not readily meet the heat loads and the room temperature was over 25°C for a relatively long period. Consequently, the control temperatures were set at 88° and 85°C, respectively, since this is the optimum temperature range for the ARKLA WF 36 three-ton absorption chiller.

As evident from FIGURE 5.15, Case 3 gave the largest total solar heat collection, and Case 2 the smallest. This was simply because the total collector areas were different and solar heat collection varied according to the total amount of solar energy incident on the whole collector plate. The collector plate efficiency for the 4-month period is shown in FIGURE 5.16.

On the other hand, the collector plate efficiency was highest for the smallest collector area. Thus Case 3 gave the lowest while Case 2 gave the highest efficiency.

The reason that Case 2 (the smallest collector area) gave the highest collector plate efficiency is that it had on the average the lowest water températeure in the storage tank. The cooling loads of the house were essentially the same in all cases while the amount of solar energy collected was smallest for Case 2. So the amount of accumulated heat remaining within the storage tank will be least for Case 2 causing the water temperature to be also lowest. For example, suppose the daily house cooling load was 3.22×10^5 kJ/day, and the daily amounts of solar energy collected by Cases 2 and 3 were 6.02×10^5 kJ/day and 8.32×10^5 kJ/day, respectively. For simplicity, assume that the storage tank water was hot enough to operate the absorption chiller all day without supplemental energy. Since the heat losses from the storage tank were small for both cases, and the amounts of water in the tanks were 4.0 m^3 and 5.64 m^3, respectively, the water temperatures in the storage tank would have dropped 36°C and 35.3°C for Cases 2 and 3, respectively. Thus the average temperature of the water temperature in the tank would generally be lowest for Case 2, and increase with increasing collector area. The same conclusion was reached when we looked at the detailed simulation results for the three cases.

As we can see from FIGURE 5.16, the efficiency of the collector plate was affected by the inlet water temperature, because a lower overall plate temperature should cause less

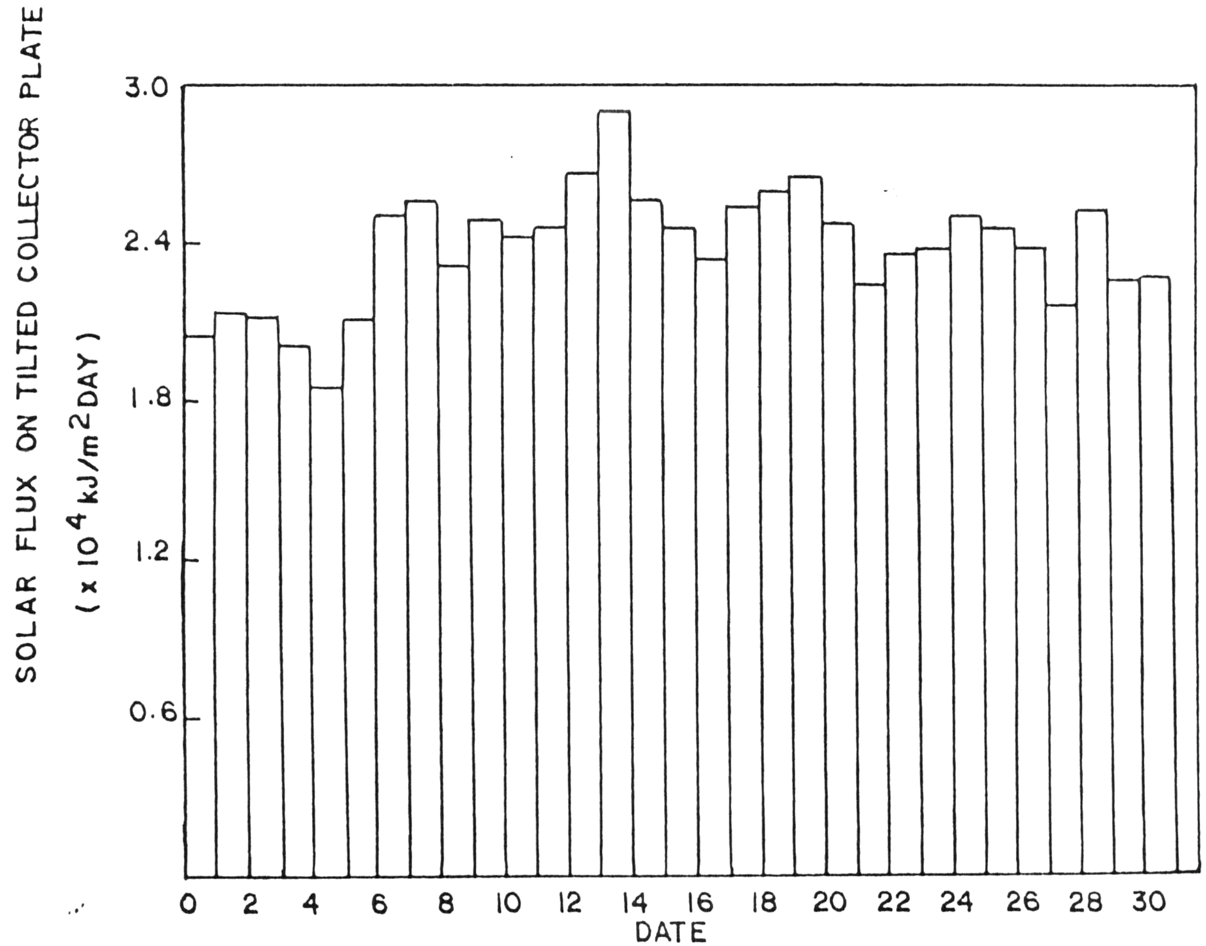

FIGURE 5.13(a) SOLAR FLUX ON TILTED COLLECTOR PLATE IN MARCH 1979

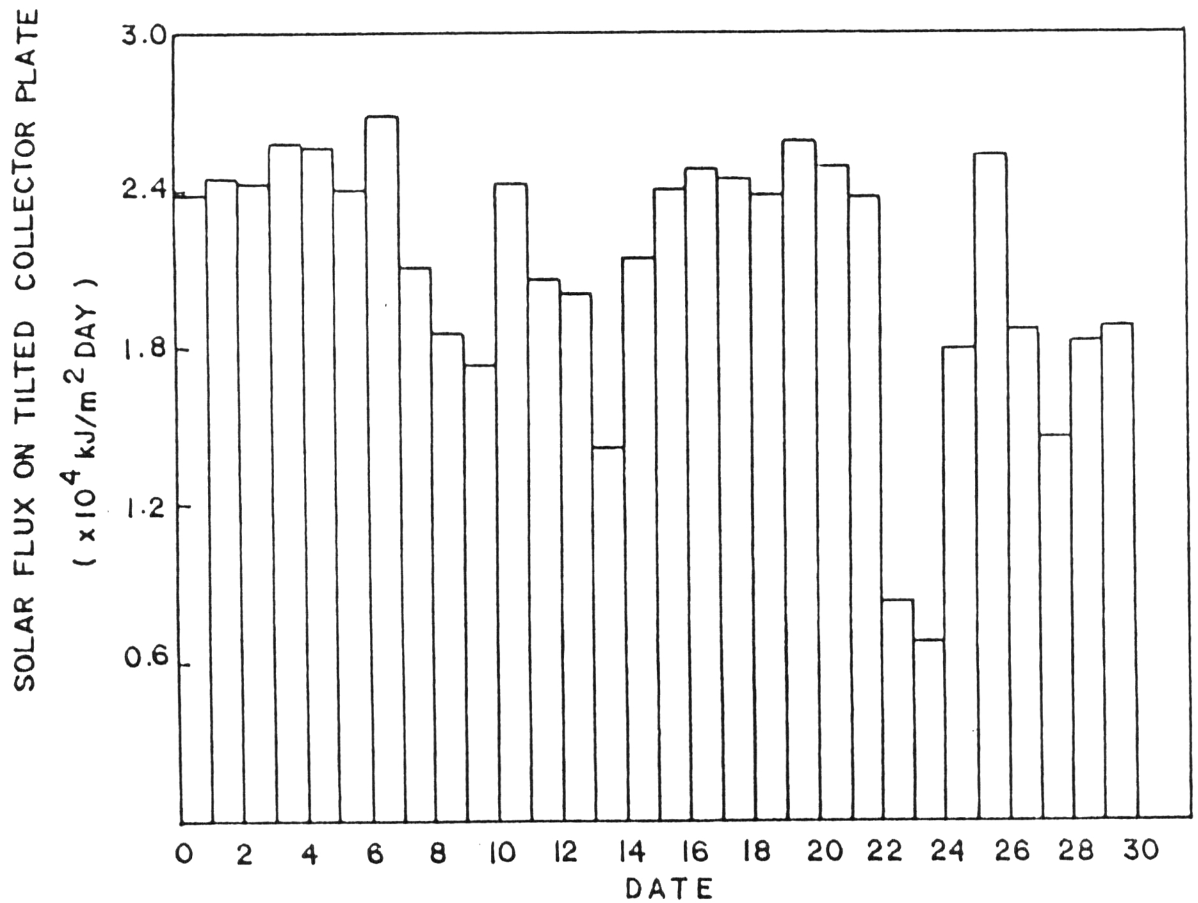

FIGURE 5.13(b) SOLAR FLUX ON TILTED COLLECTOR PLATE IN APRIL 1979

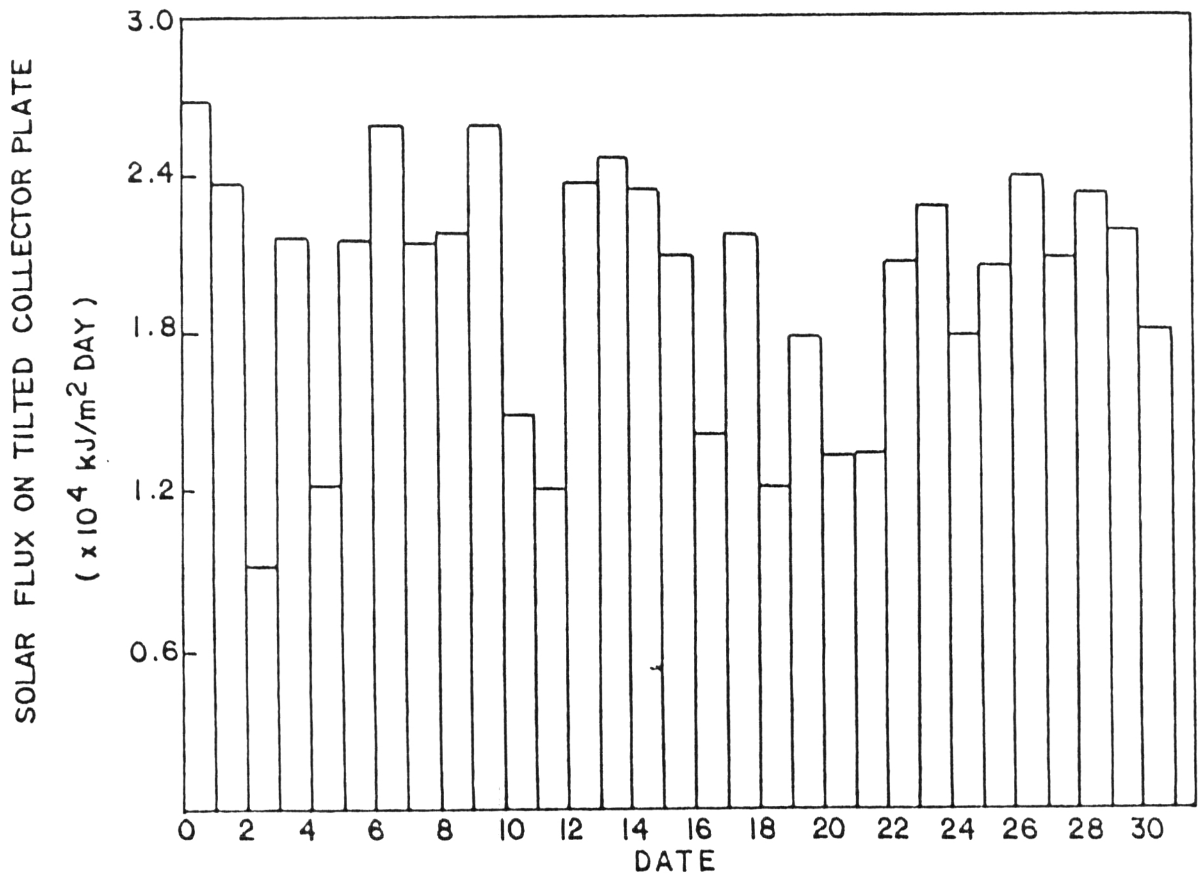

FIGURE 5.13(c) SOLAR FLUX ON TILTED COLLECTOR PLATE IN MAY 1979

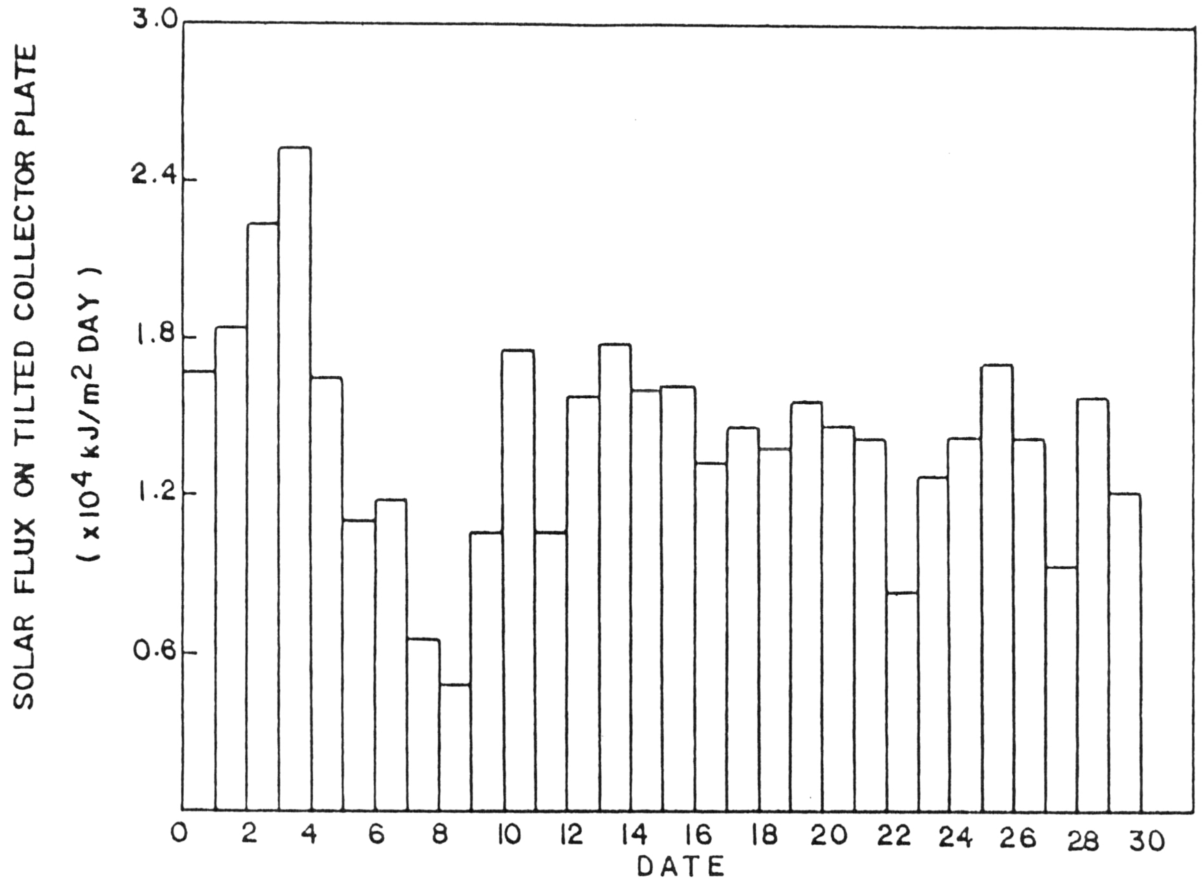

FIGURE 5.13(d) SOLAR FLUX ON TILTED COLLECTOR PLATE IN JUNE 1979

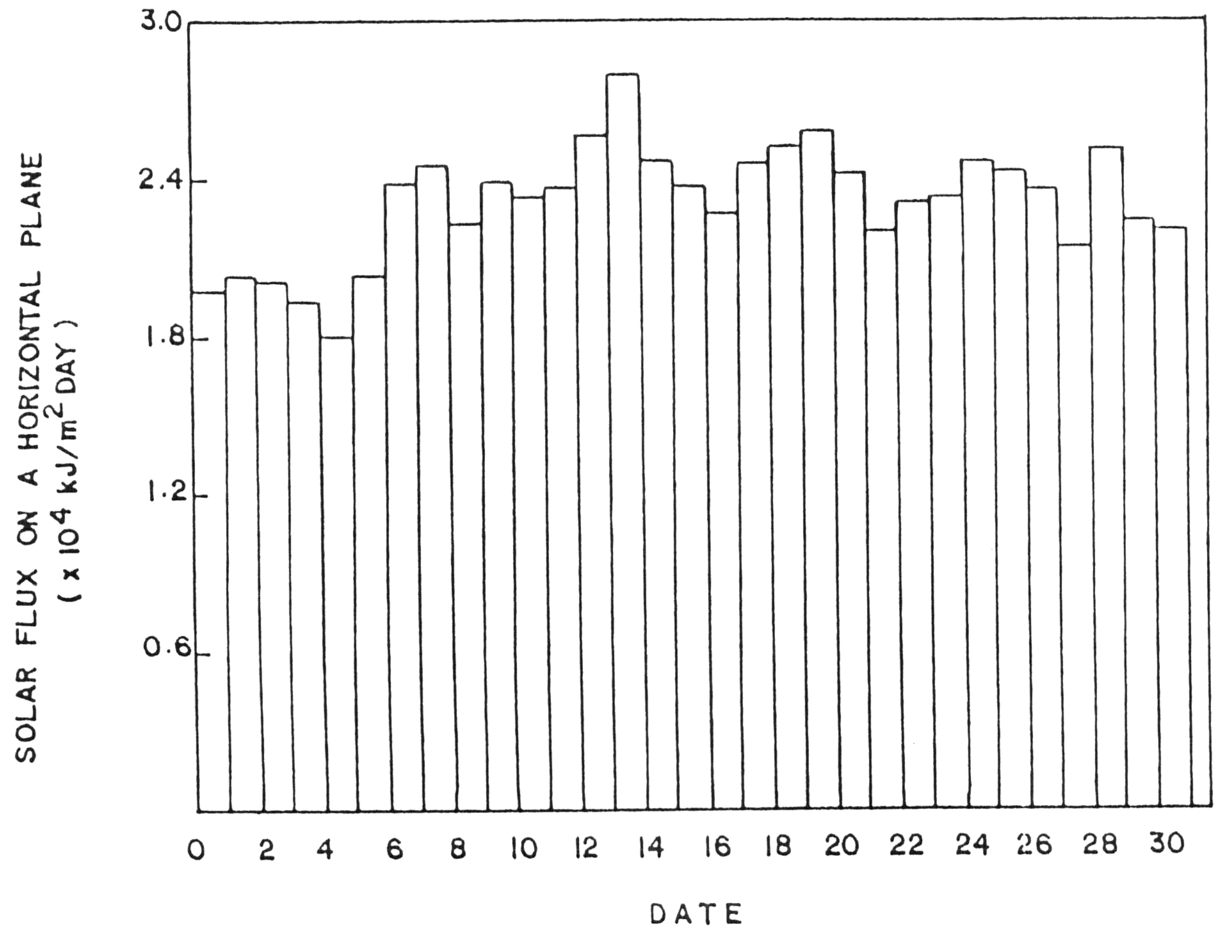

FIGURE 5.14 (a) SOLAR FLUX ON A HORIZONTAL PLANE IN MARCH 1979

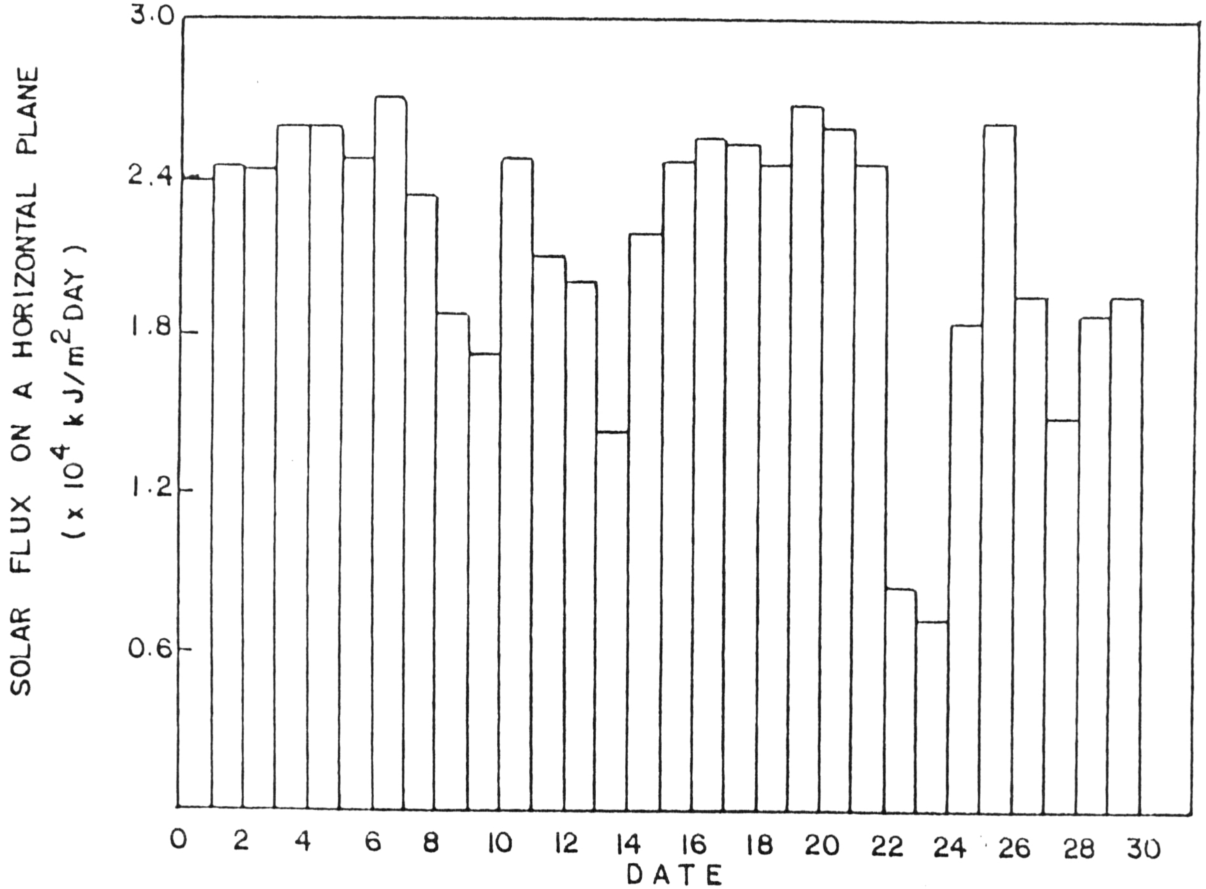

FIGURE 5.14(b) SOLAR FLUX ON A HORIZONTAL PLANE
IN APRIL 1979

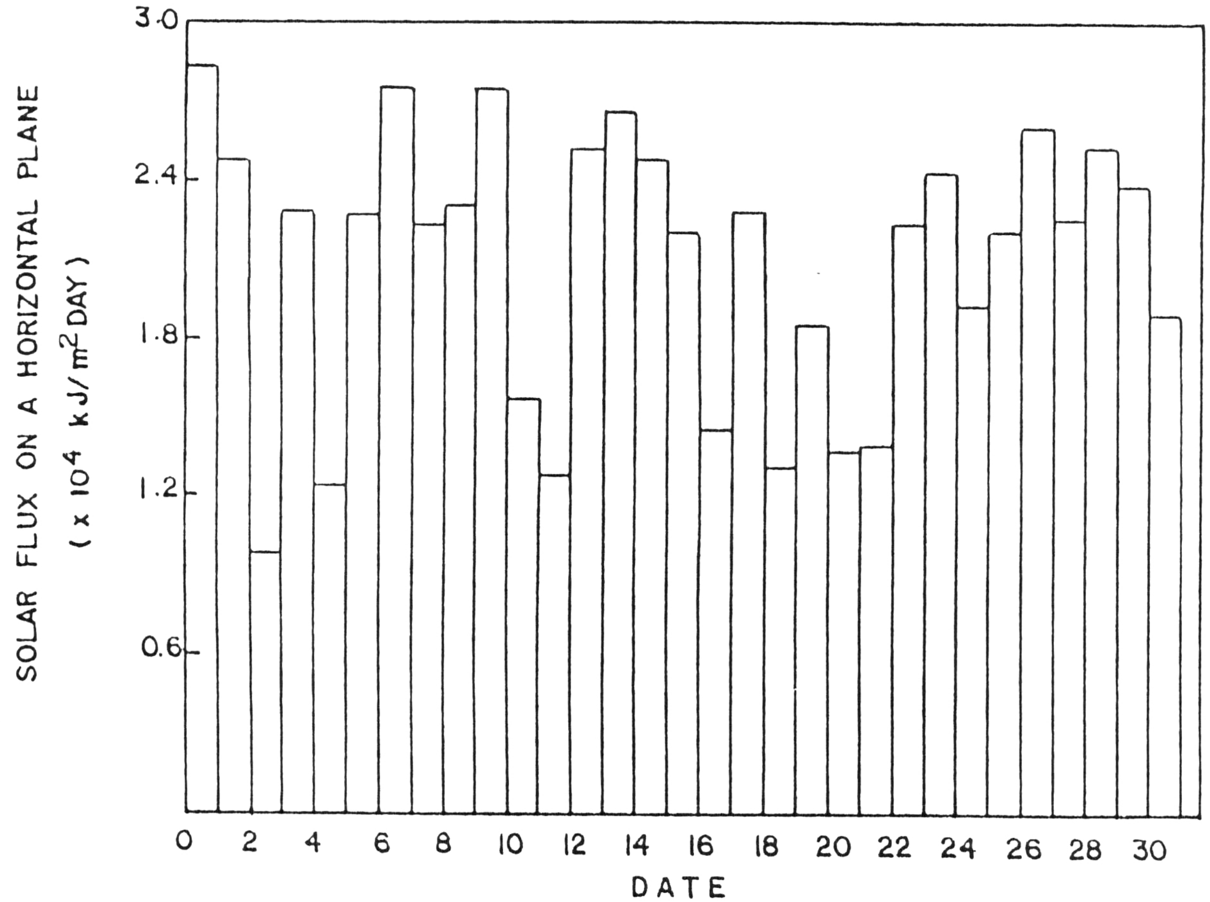

FIGURE 5.14 (c) SOLAR FLUX ON A HORIZONTAL PLANE IN MAY 1979

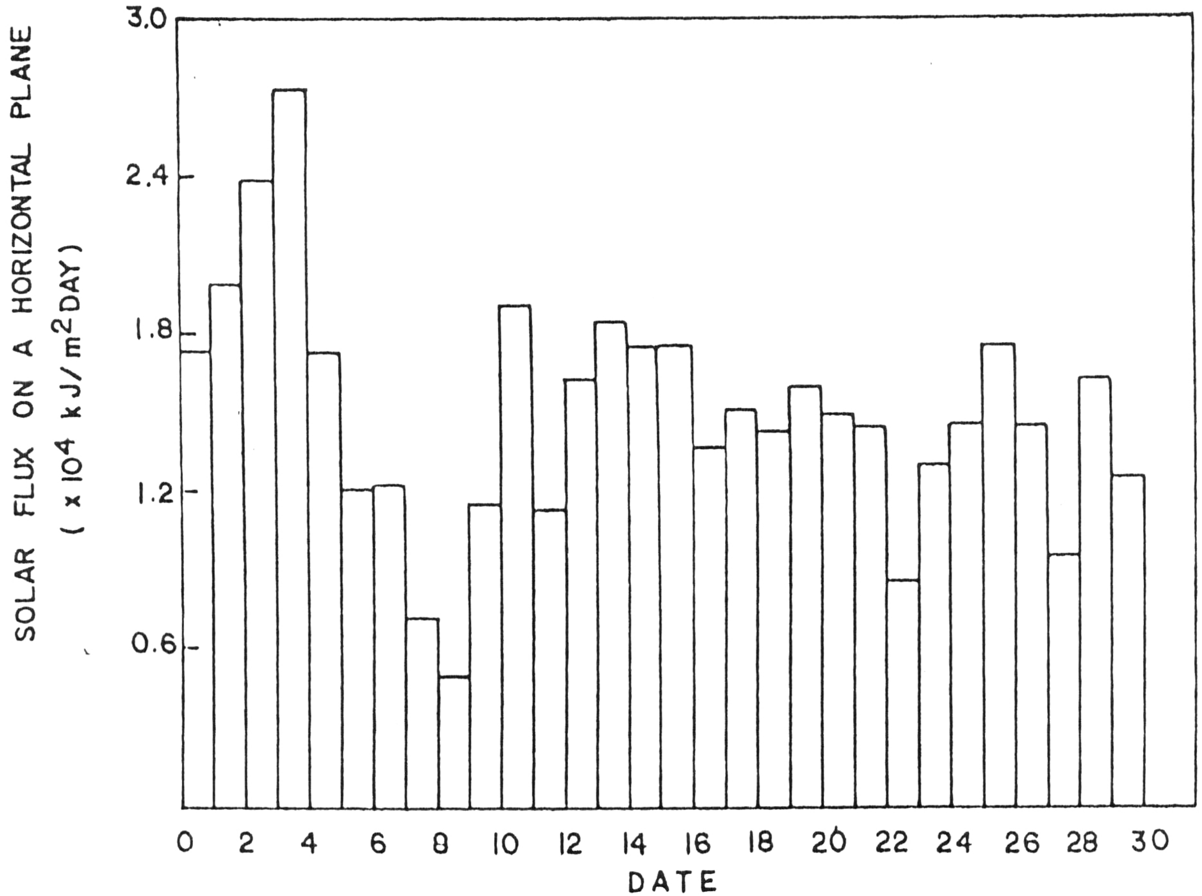

FIGURE 5.14(d) SOLAR FLUX ON A HORIZONTAL PLANE IN JUNE 1979

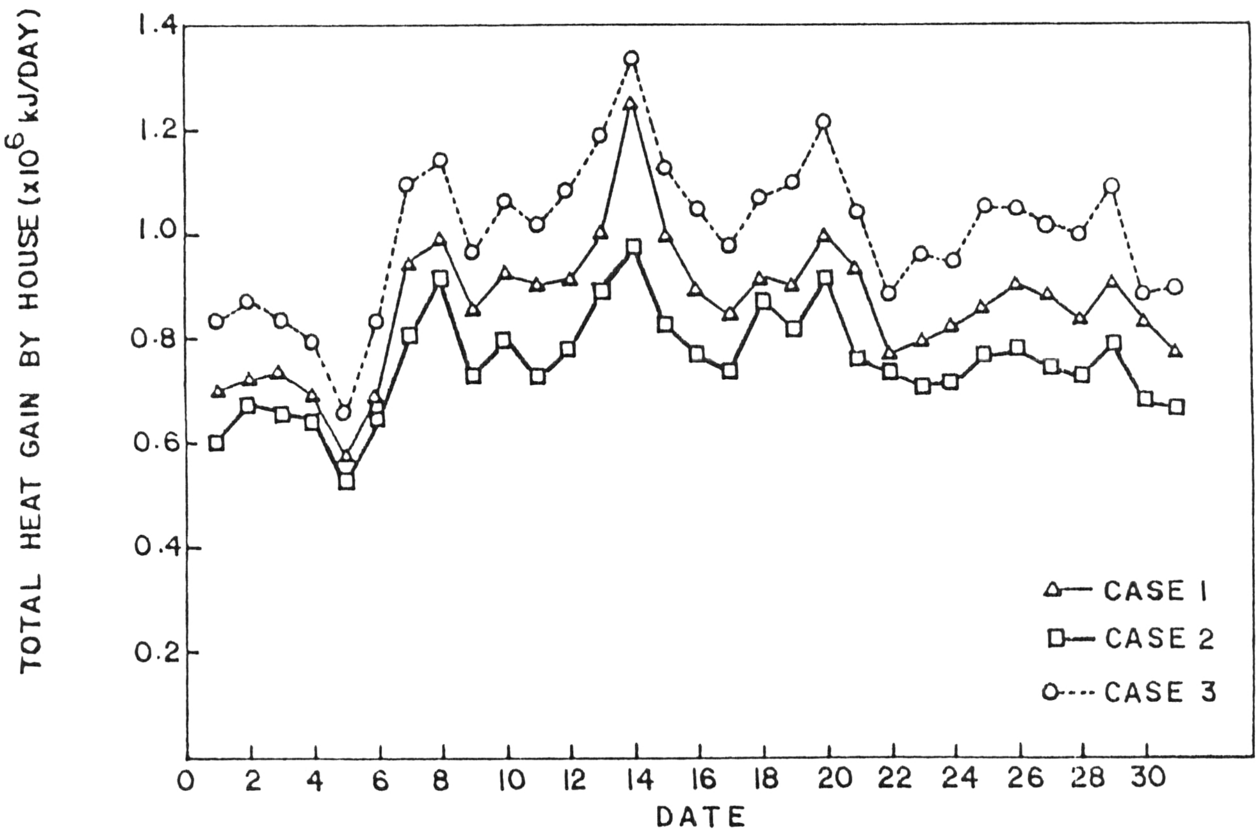

FIGURE 5.15 (a) TOTAL HEAT GAIN BY HOUSE IN MARCH 1979

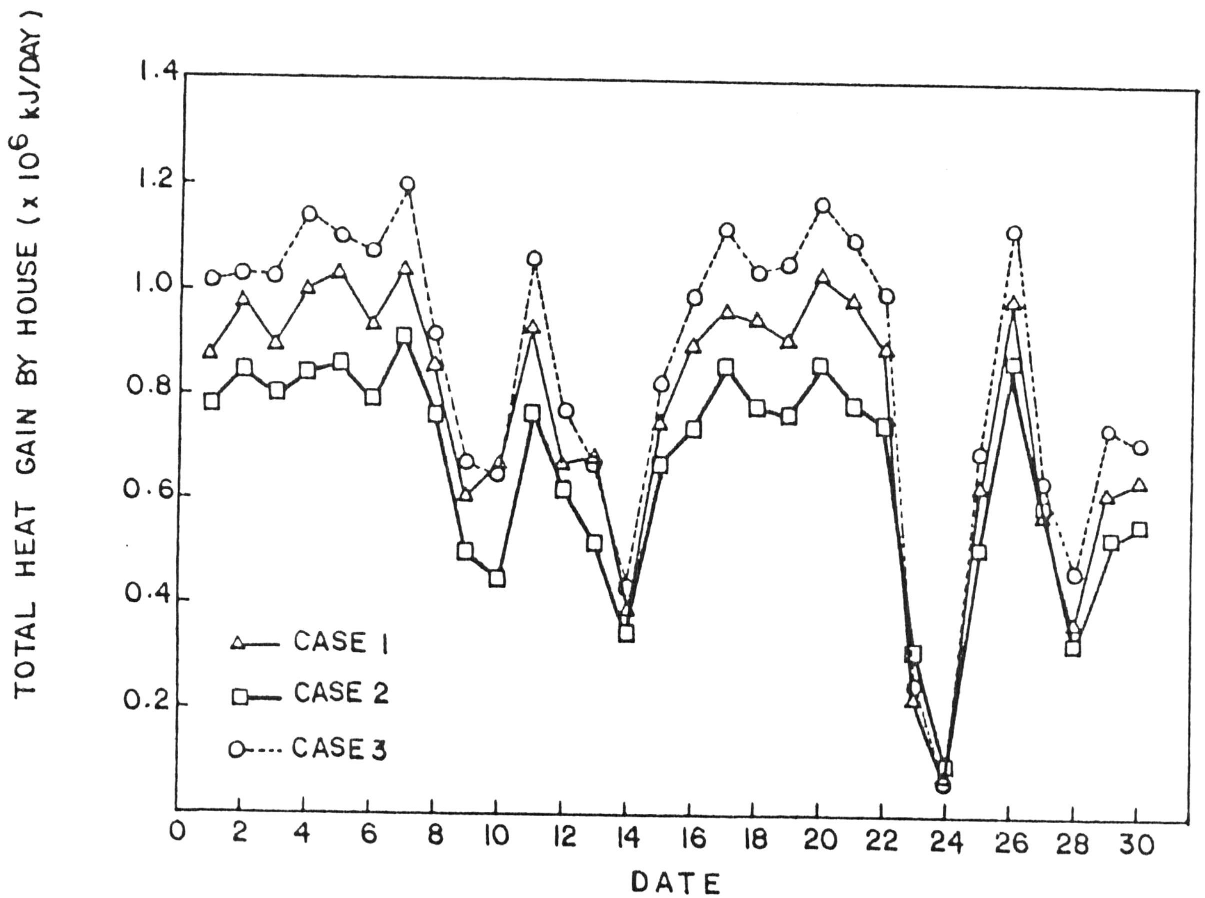

FIGURE 5.15 (b) TOTAL HEAT GAIN BY HOUSE IN APRIL 1979

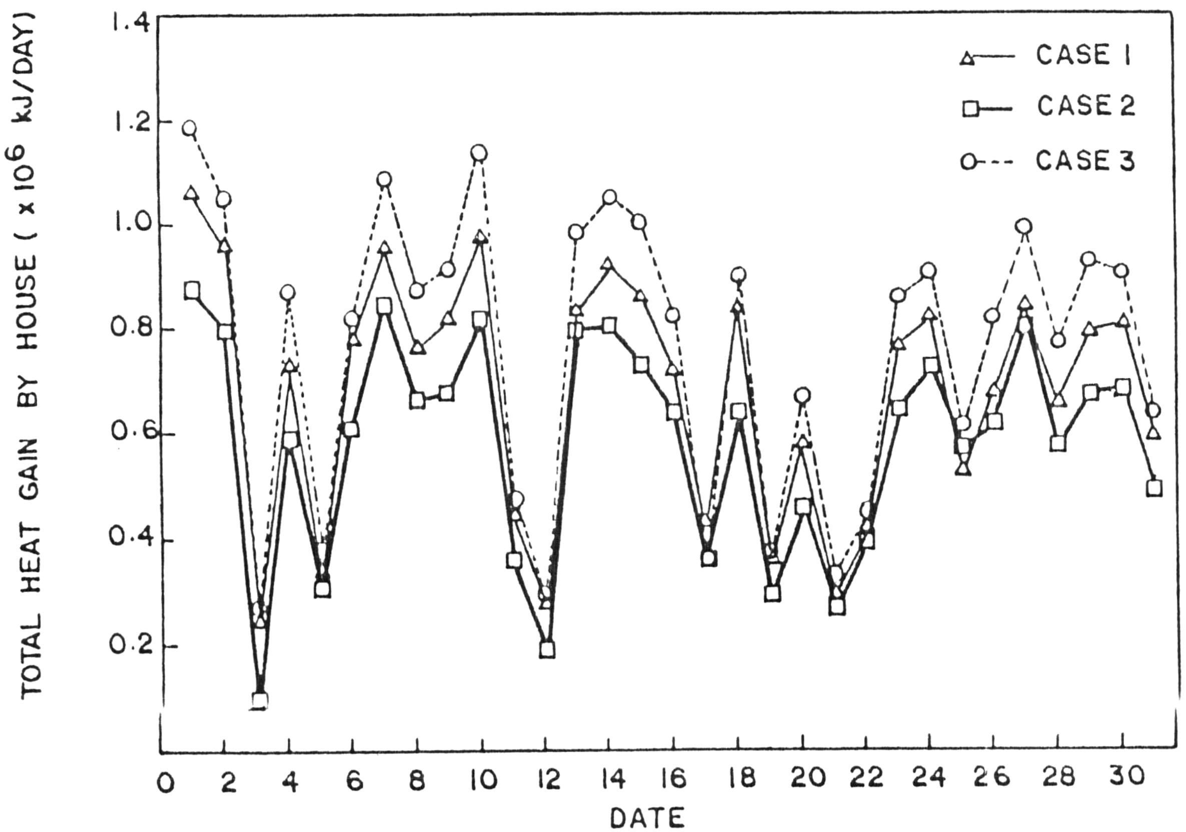

FIGURE 5.15(c) TOTAL HEAT GAIN BY HOUSE IN MAY 1979

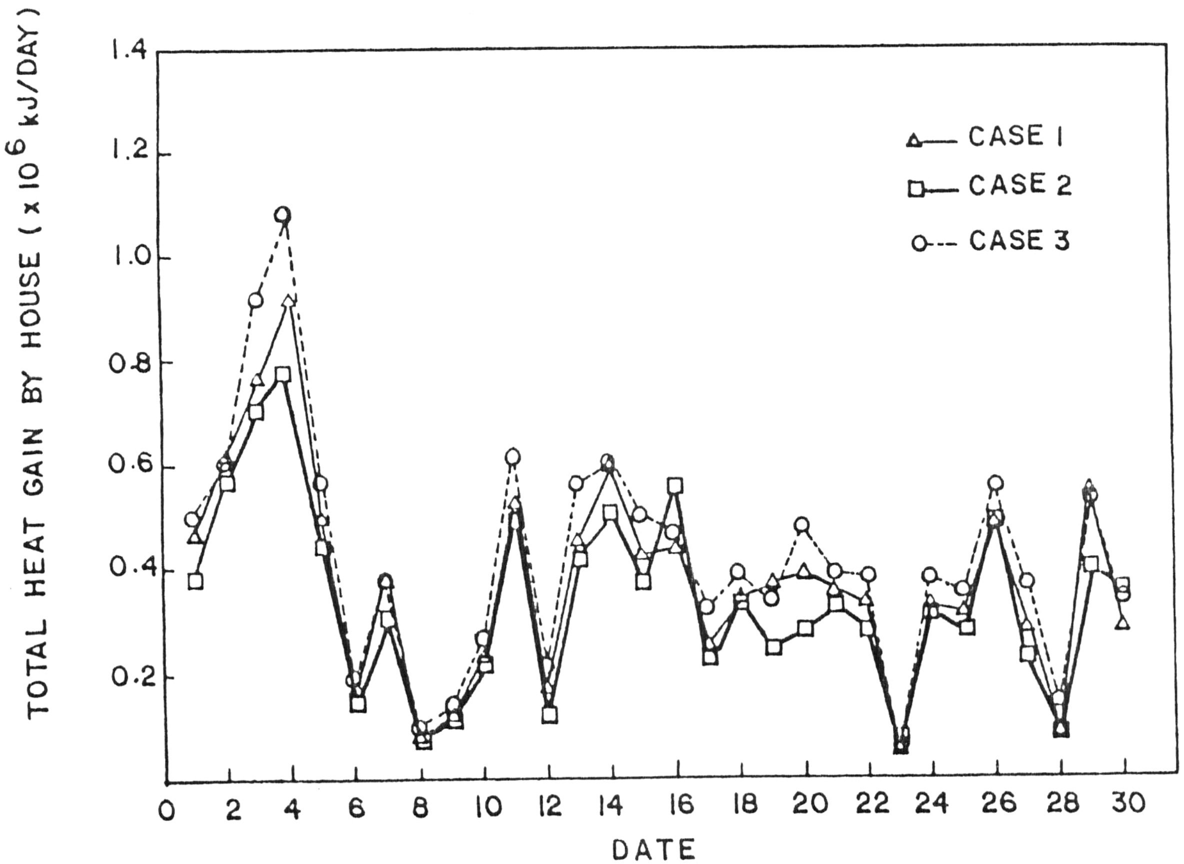

FIGURE 5.15 (d) TOTAL HEAT GAIN BY HOUSE IN JUNE 1979

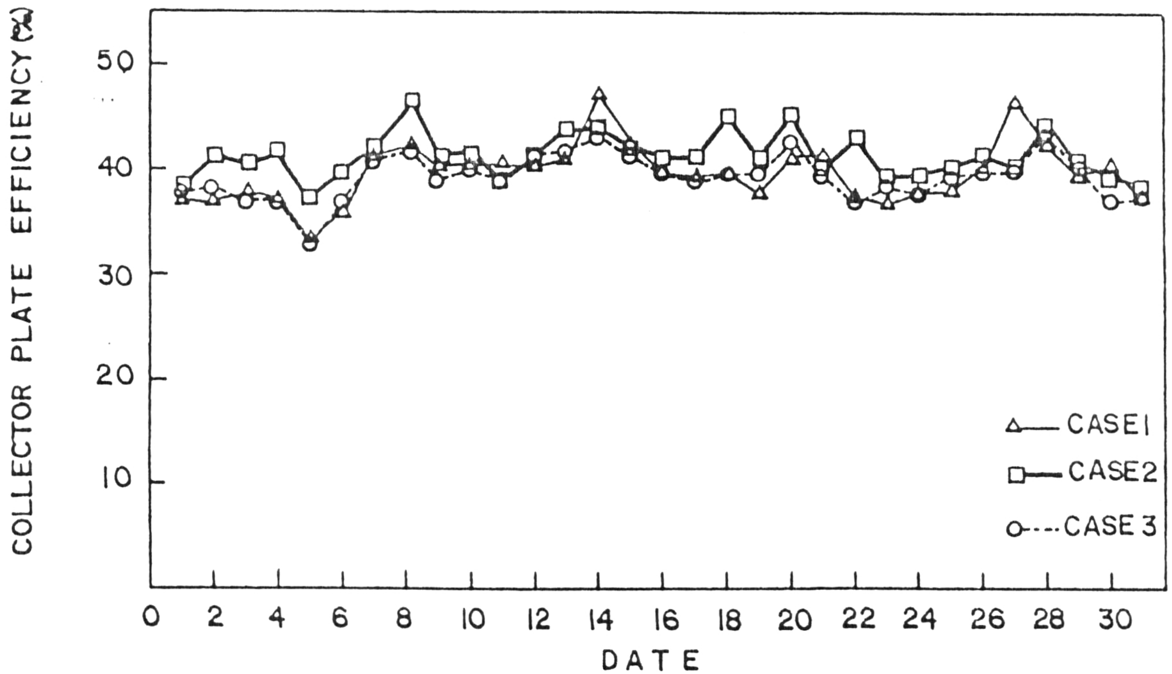

FIGURE 5.16(a) COLLECTOR PLATE EFFICIENCY IN MARCH 1979

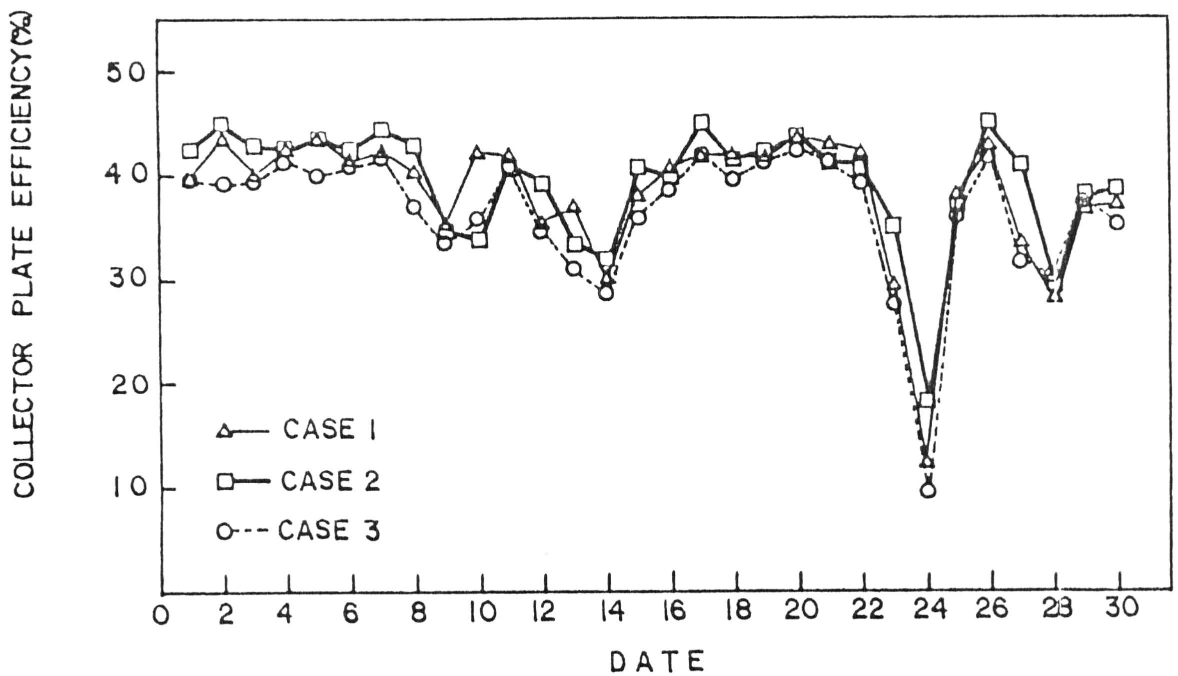

FIGURE 5.16 (b) COLLECTOR PLATE EFFICIENCY IN APRIL 1979

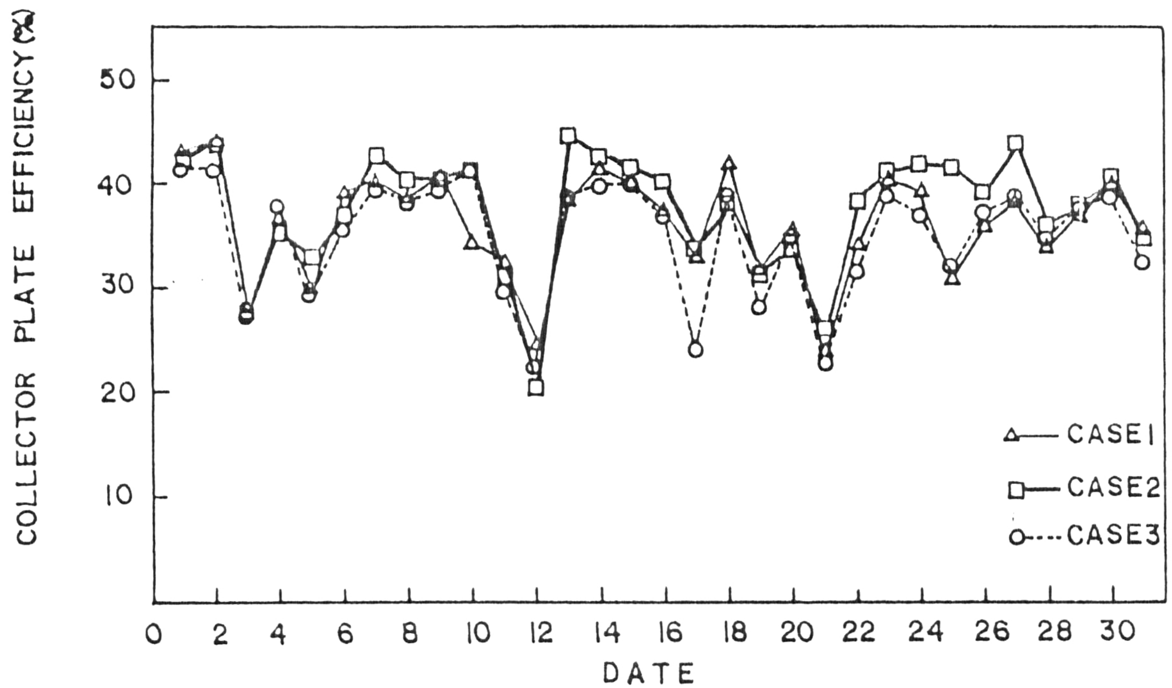

FIGURE 5.16 (c) COLLECTOR PLATE EFFICIENCY IN MAY 1979

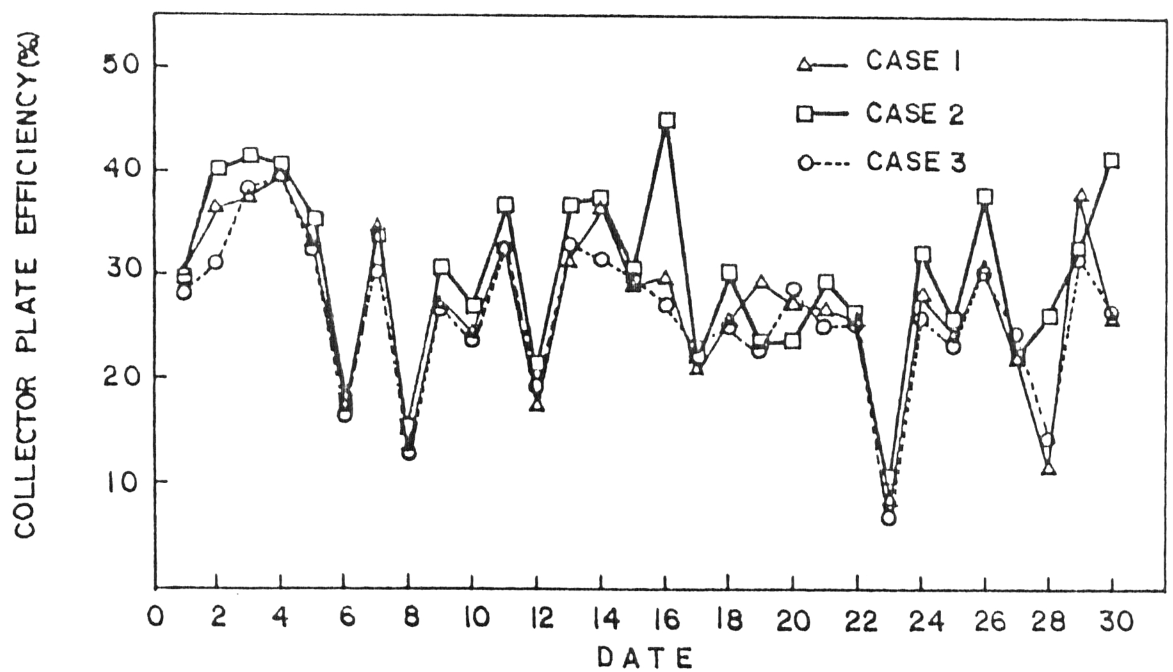

FIGURE 5.16 (d) COLLECTOR PLATE EFFICIENCY IN JUNE 1979

conduction and radiation heat losses. In other words, the lower the inlet water temperature, the higher the plate efficiency. There were, however, some reverse instances on a day-to-day basis. This was because the performance of the collector plate not only depended on the history of the storage tank water temperature but also was affected by occasional intervention by the main heater. Furthermore, the different collector areas also affected the working hours of the main heater, the absorption chiller (also the circulation pump) and the collector pump.

Monthly space cooling load, $\dot{Q}_{cool}$, for the 3 cases was essentially the same because the same room temperature control band was adopted for the same house. The daily cooling load is shown in FIGURE 5.17. The amount of supplemental energy supplied by the main heater for each case varied conversely with the collector plate area. This is shown in FIGURE 5.18. Naturally, more supplemental energy was needed in the case of a smaller collector area, so the time that water was circulated in the main heater loop was also longer. To meet the same cooling load, the absorption chiller in Case 2 had to be turned on for the longest time since the cooling capacity was lower when the inlet water temperature was low (see FIGURE B.7.2) and the inlet water temperature in the main heater loop was always lower than the temperature of the storage tank water used to fire the absorption chiller.

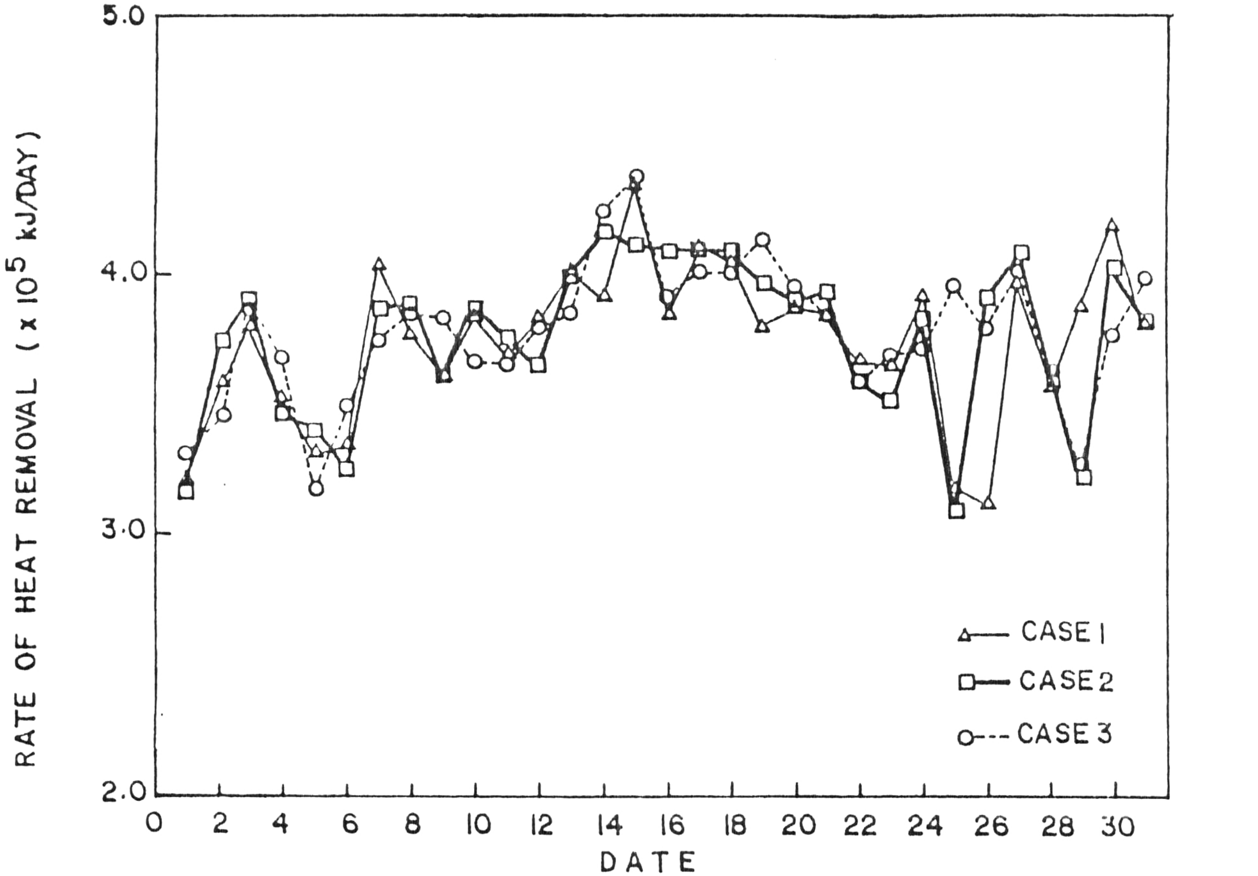

FIGURE 5.17 (a) DAILY RATE OF HEAT REMOVAL IN MARCH 1979

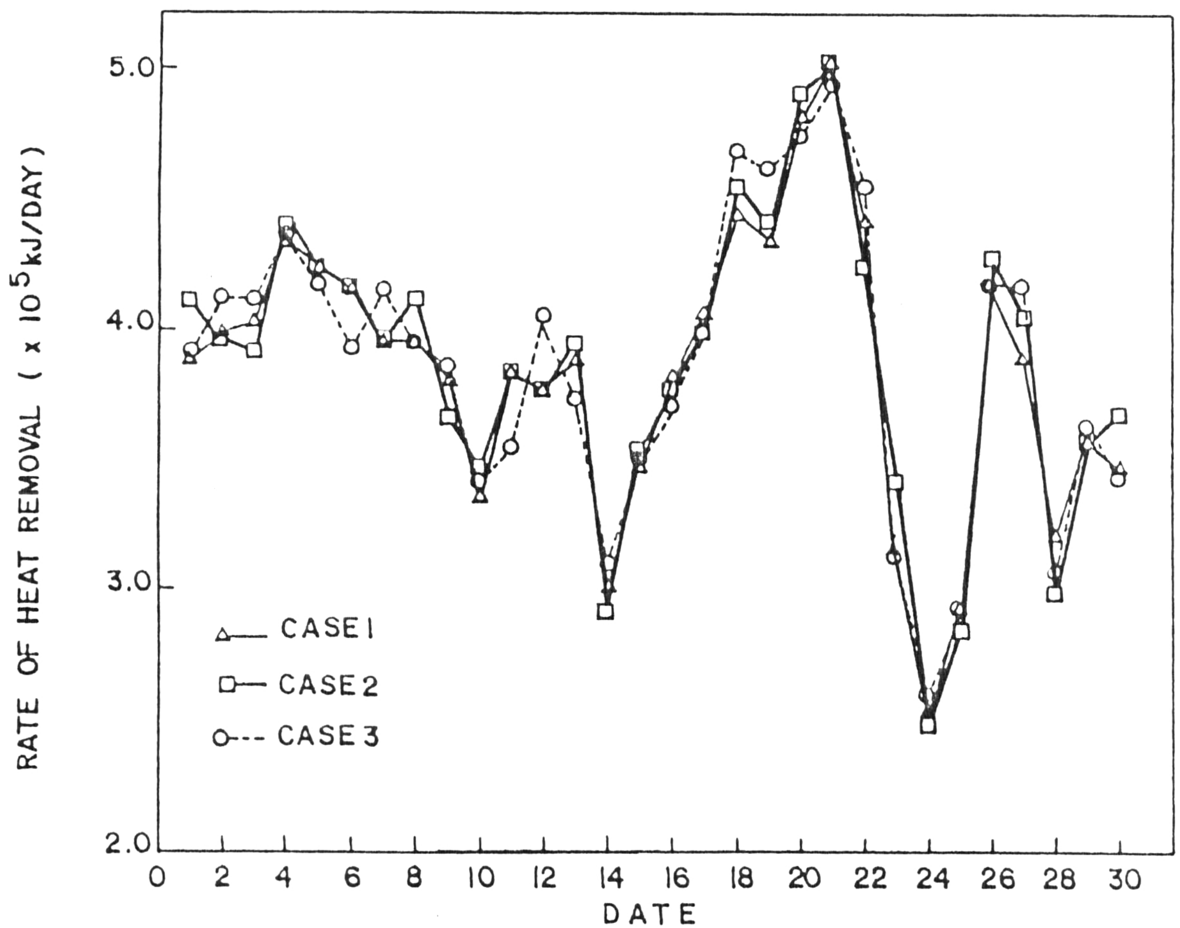

FIGURE 5.17 (b) DAILY RATE OF HEAT REMOVAL IN APRIL 1979

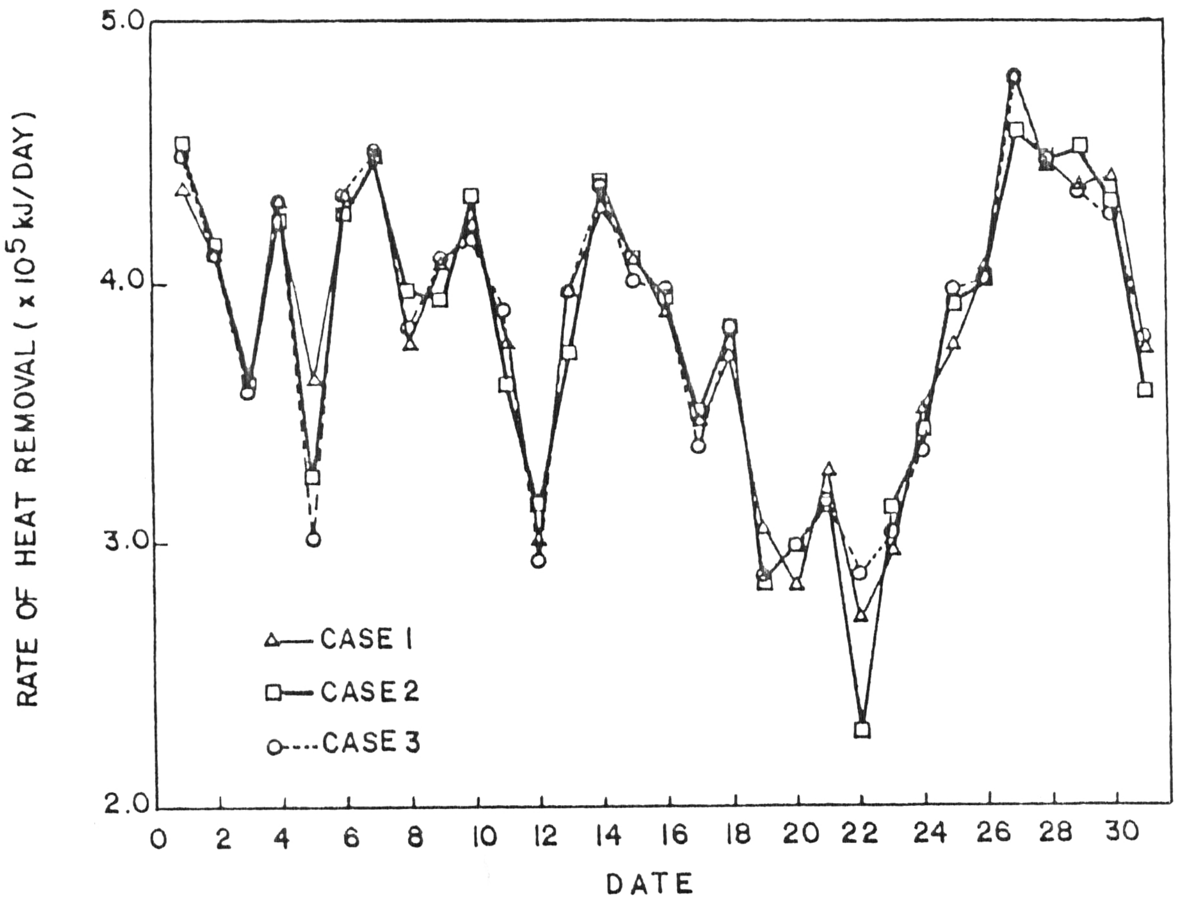

FIGURE 5.17(c) DAILY P RATE OF HEAT REMOVAL IN MAY 1979

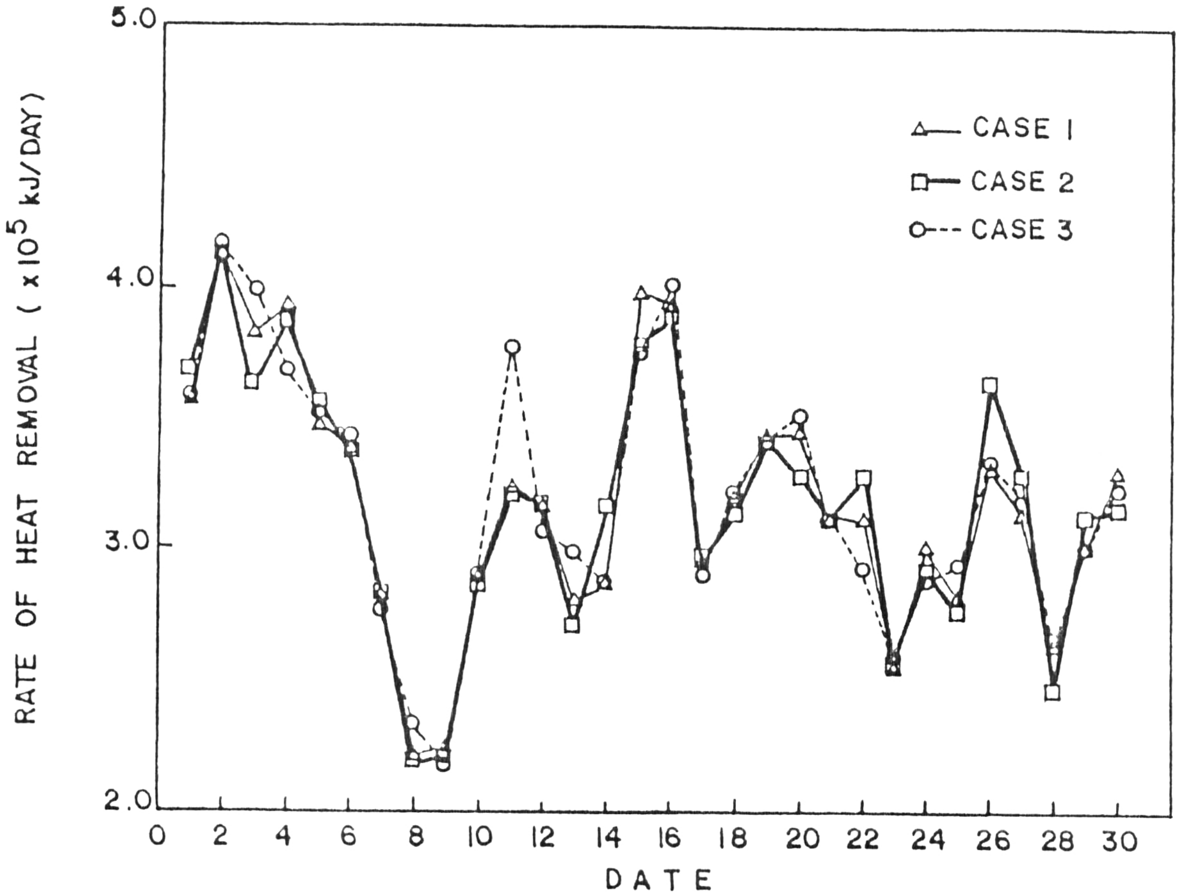

FIGURE 5.17(d) DAILY RATE OF HEAT REMOVAL IN JUNE 1979

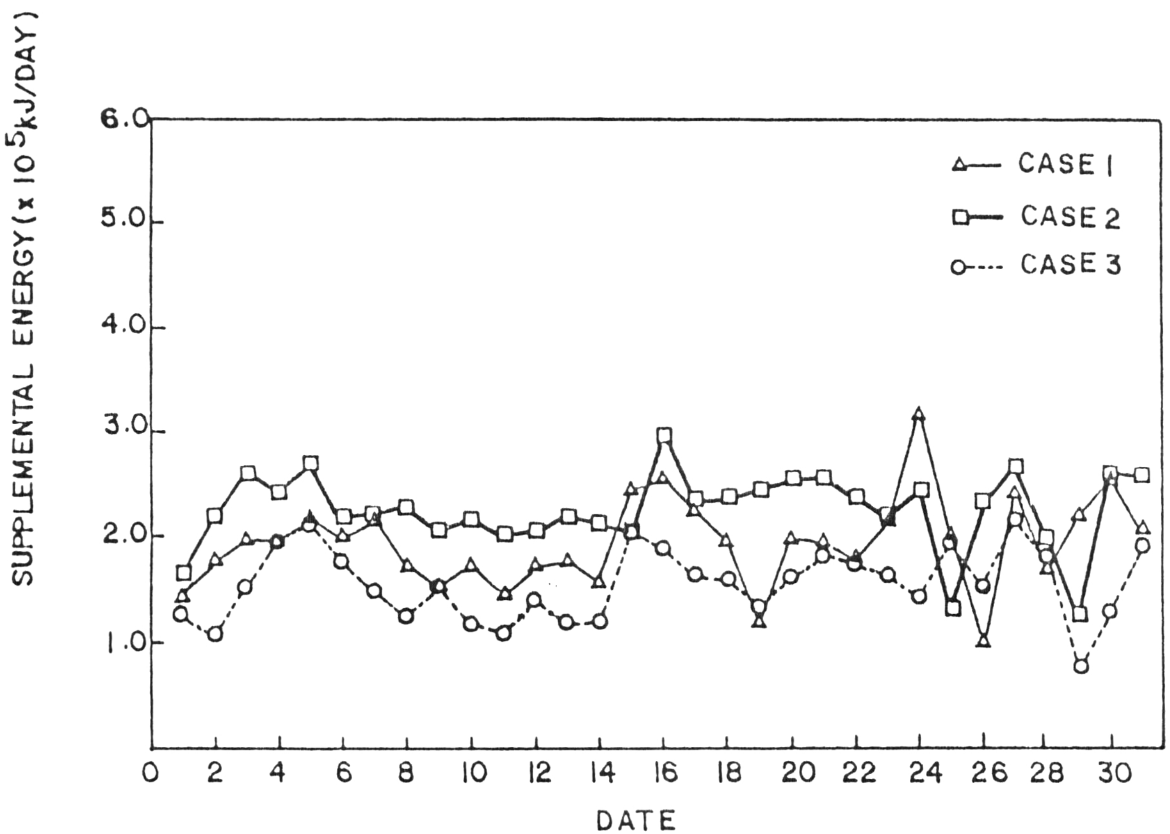

FIGURE 5.18 (a) SUPPLEMENTAL ENERGY SUPPLIED BY MAIN HEATER IN MARCH 1979

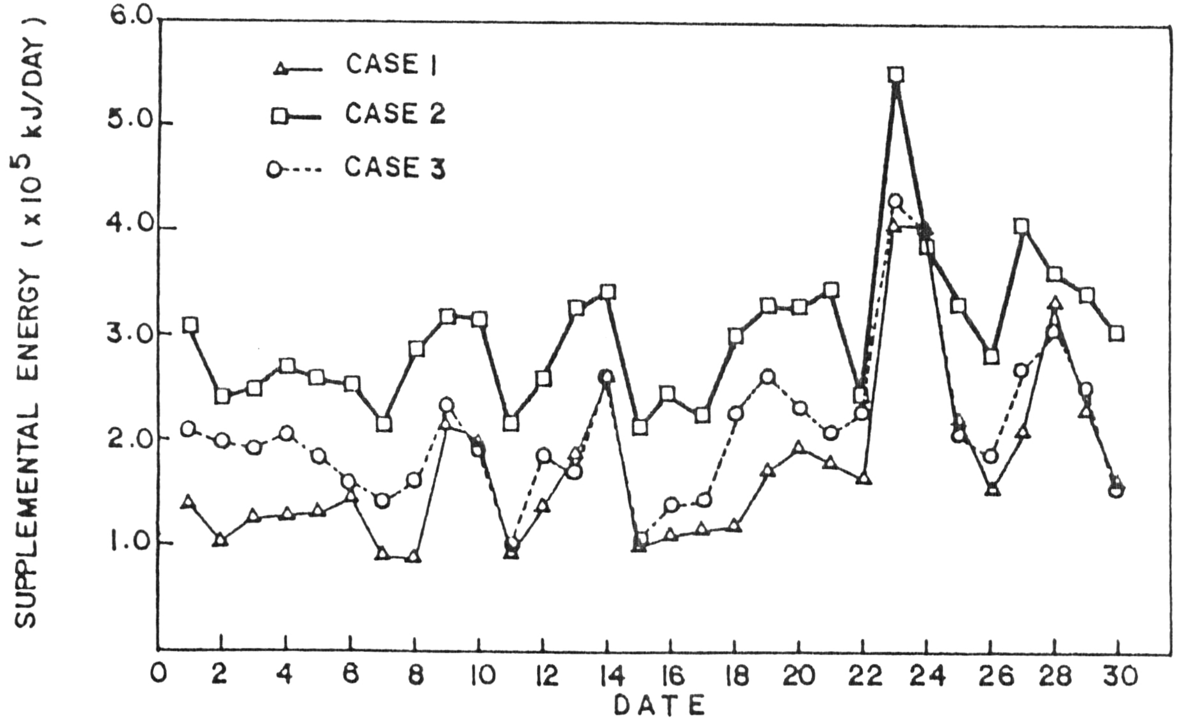

FIGURE 5.18 (b) SUPPLEMENTAL ENERGY SUPPLIED BY MAIN HEATER IN APRIL 1979

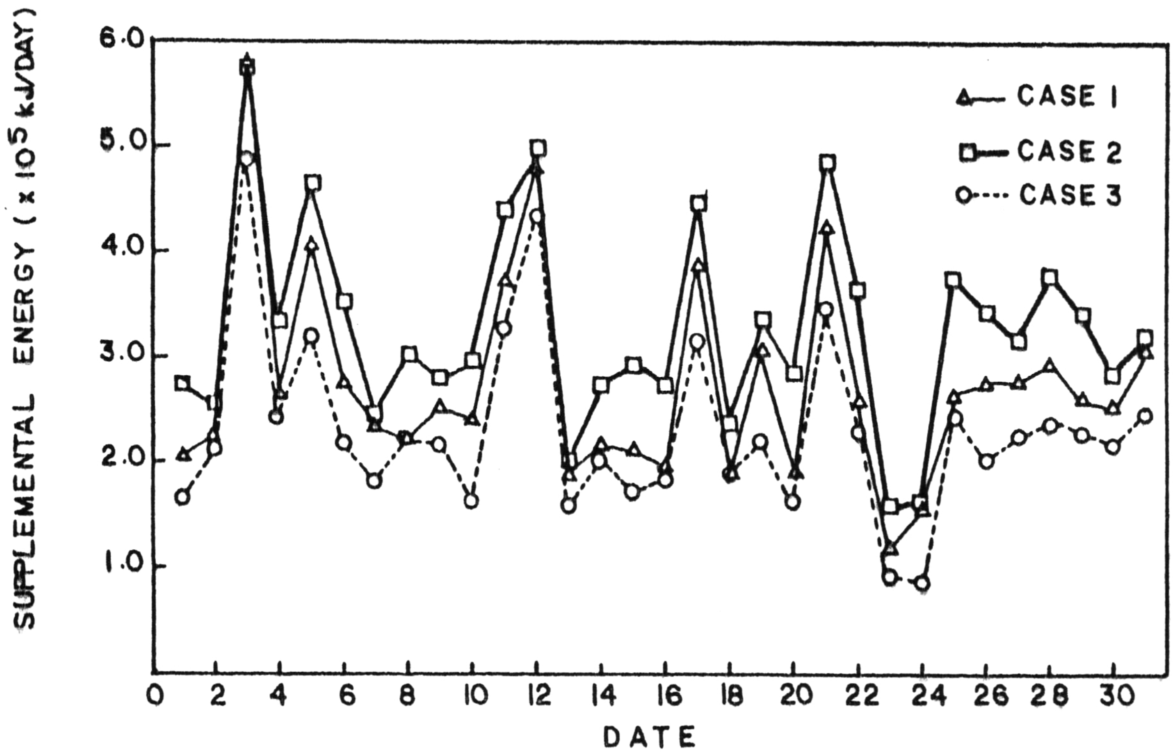

FIGURE 5.18 (c) SUPPLEMENTAL ENERGY SUPPLIED BY MAIN HEATER IN MAY 1979

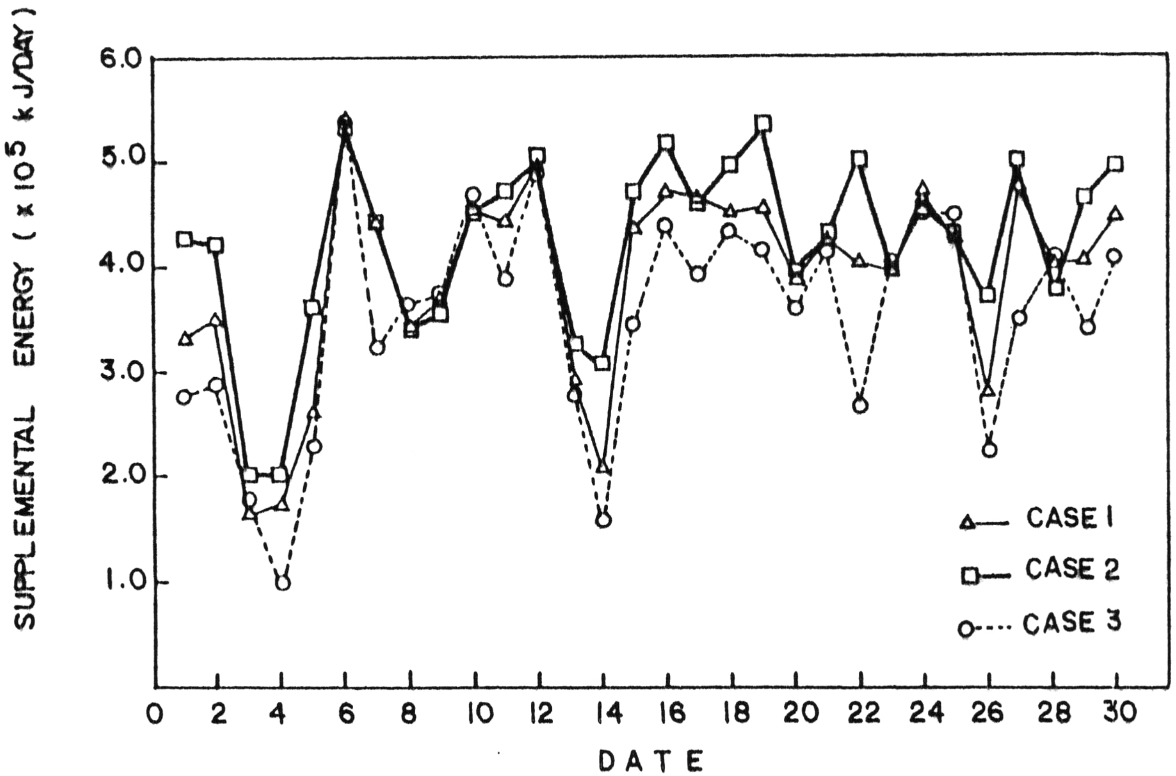

FIGURE 5.18 (d) SUPPLEMENTAL ENERGY SUPPLIED BY MAIN HEATER IN JUNE 1979

On the other hand, the absorption chiller efficiencies were essentially the same for the 3 cases (see TABLE 5.3), even though the instantaneous values depended on the did fluctuate as shown in FIGURE 5.19.

Because the collector plate temperature at the water outlet was higher for a larger collector if other conditions were the same,[(19)] the outlet plate temperature for Case 3 was expected to be highest. This fact was confirmed by our detailed simulation results. Therefore, even though the average temperature of the storage tank water was highest for Case 3, the corresponding outlet plate temperature turned out to remain high for a much longer time. This caused the collector pump for Case 3 to be on for the longest time.

The monthly results for the 3 cases are listed in TABLE 5.2, whereas the overall 4-month results are shown in TABLE 5.3. From TABLE 5.2, the solar fluxes incident on the tilted collector plate in March, April, May and June, 1979, were 7.34×10^5, 6.37×10^5, 6.12×10^5 and 4.26×10^5 $kJ/m^2 month$, respectively. The monthly solar flux decreased from March to June. As expected, the amount of heat collected by the water flowing through the collector plate also varied according to the solar flux. The same can be said of the total working hours of the collector pump. As mentioned earlier, the average collector plate efficiency of Case 2 was the highest due to less conduction and radiation heat losses. Monthly cooling loads in March, April,

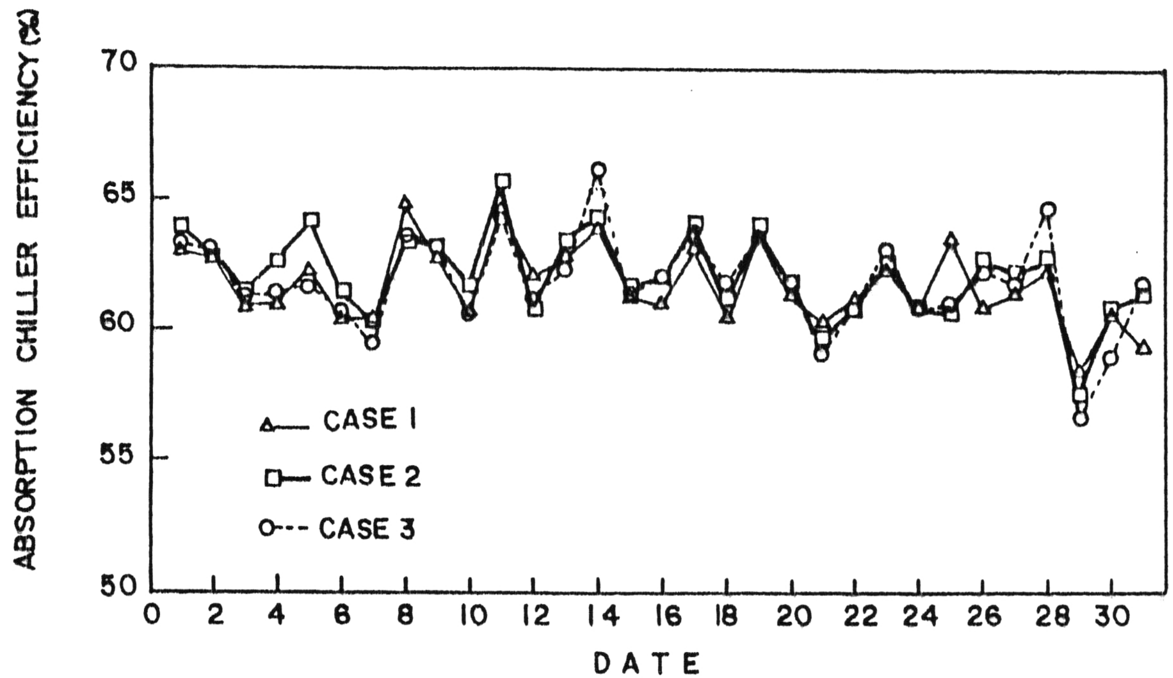

FIGURE 5.19 (a) ABSORPTION CHILLER EFFICIENCY IN MARCH 1979

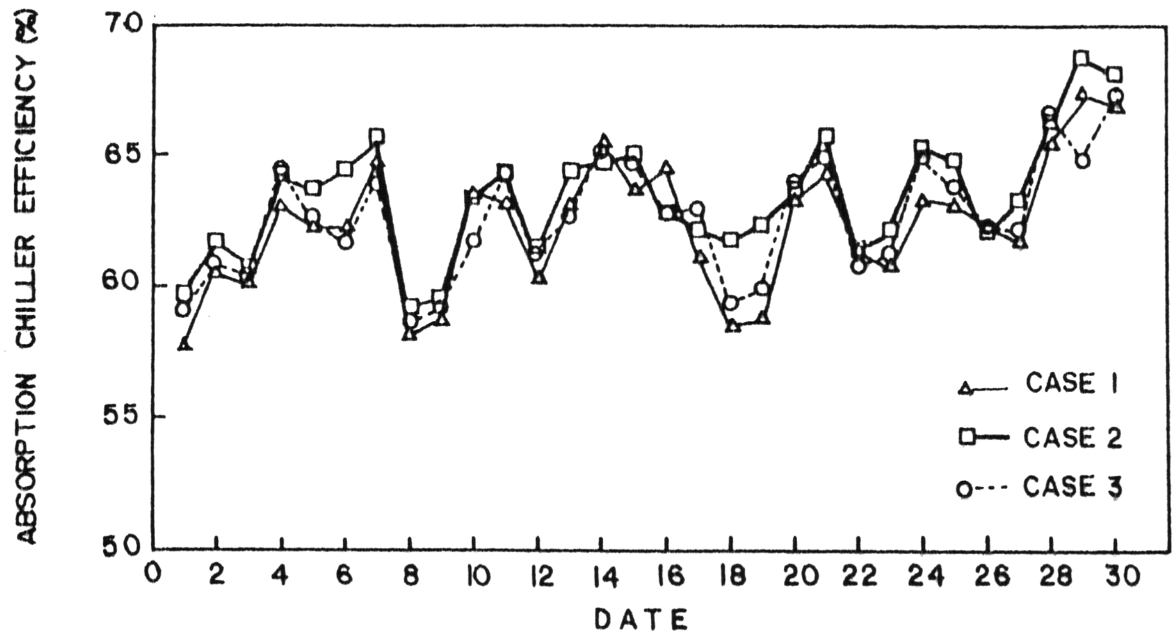

FIGURE 5.19 (b) ABSORPTION CHILLER EFFICIENCY IN APRIL 1979

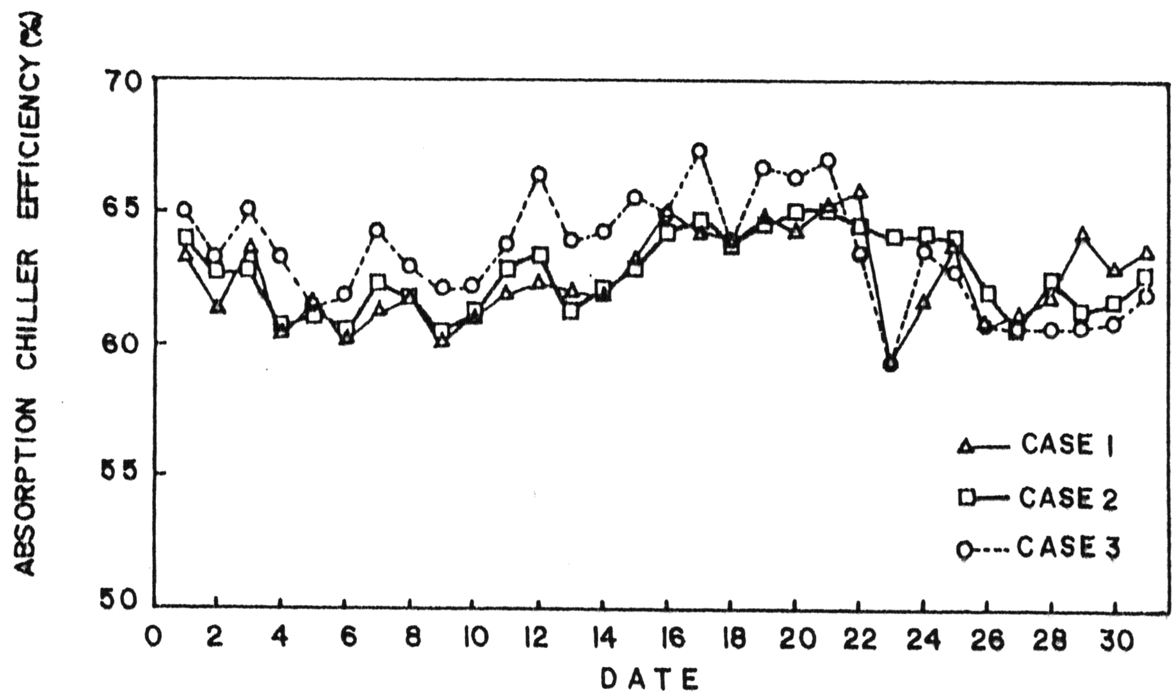

FIGURE 5.19 (c) ABSORPTION CHILLER EFFICIENCY IN MAY 1979

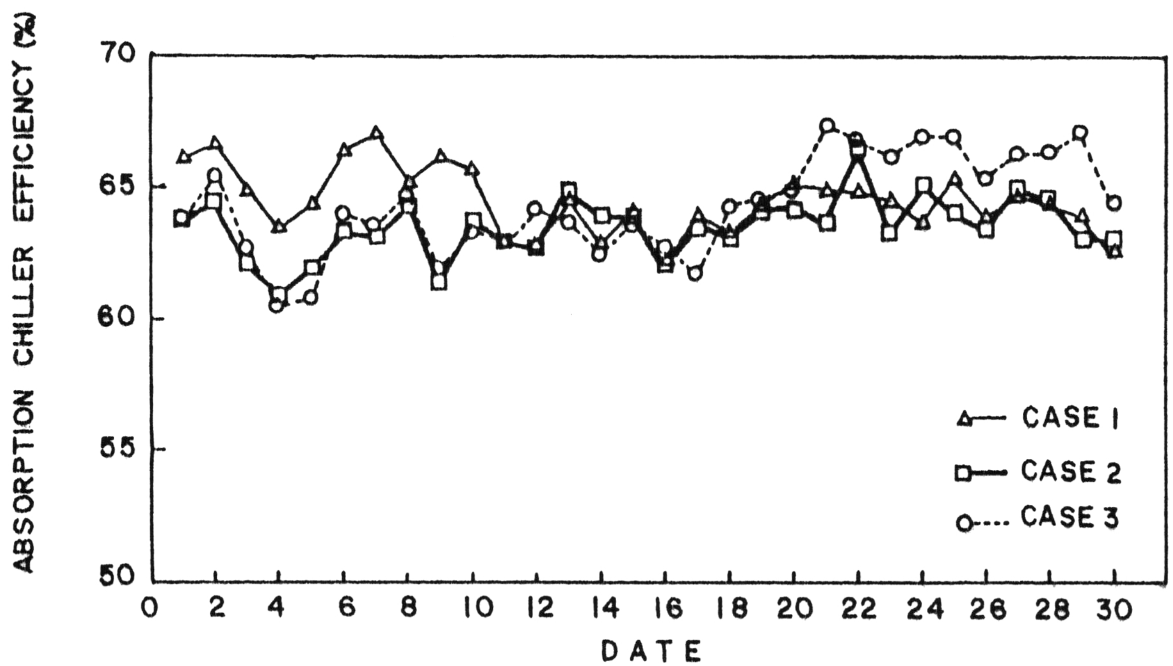

FIGURE 5.19(d) ABSORPTION CHILLER EFFICIENCY IN JUNE 1979

May and June, 1979, were 1.17×10^7, 1.16×10^7, 1.19×10^7 and 9.6×10^6 kJ/month, respectively. This implied that even though the monthly solar flux was smaller in May than in March, the weather was hotter in May. So we could expect a significantly larger amount of supplemental energy supplied by main heater in May than in March, as obvious from TABLE 5.2. It is interesting to note that the cooling capacity of the absorption chiller in Cases 1 and 2 could not always meet the cooling loads since the inlet water temperature of 85°C from the main heater loop was not always sufficiently high (see TABLE 5.2 and FIGURE B.7.2)

As shown in TABLE 5.3 the total solar flux incident on the tilted collector plates during the 4-month period was 2.41×10^6 kJ/m^2. The total amounts of heat collection for Cases 1, 2 and 3 were 8.35×10^7, 7.12×10^7 and 9.32×10^7 kJ, respectively. As explained earlier, Case 3 gave a collector plate efficiency of 36.12 % which was the lowest while Case 2 gave a highest collector plate efficiency of 38.67 %. The total amounts of 4-month supplemental energy supplied by the main heater were 3.17×10^7, 3.89×10^7 and 3.09×10^7 kJ for Cases 1, 2 and 3, respectively. In short, least supplemental energy was required when the collector area was largest.

From the point of view of performance only, Case 3 was the most attractive one for room temperature control and energy saving because the room temperature rose above 25°C only for 7.4 hours and the required supplemental energy was only 43.36%.

TABLE 5.2(a)

Simulation Results for March 1979

Variable	Simulation Case		
	Case 1	Case 2	Case 3
1. Solar flux incident on tilted collector plate (kJ/m^{2}month)	7.34×10^5	7.34×10^5	7.34×10^5
2. Heat collected by water flowing through the collector plate (kJ/month)	2.69×10^7	2.33×10^7	3.11×10^7
3. Overall collector plate efficiency $\left(\frac{\text{Item 2} \times 100}{\text{Item 1} \times \text{collector area}}\right)$(%)	39.92	41.47	39.47
4. Total working hours of collector pump (hours/month)	237.5	238.2	242.4
5. Daily average collector pump working hours (hours/day)	7.66	7.68	7.82
6. Monthly cooling load (kJ/month)	1.18×10^7	1.17×10^7	1.17×10^7
7. Overall absorption chiller efficiency $\left(\frac{\text{Item 6}}{Q_{input}} \times 100\right)$ (%)	61.66	62.06	61.82
8. Total absorption chiller working hours (hours/month)	418.1	425.5	400.1

TABLE 5.2(a) (Contd.)

Simulation Results for March 1979

Variable	Simulation Case		
	Case 1	Case 2	Case 3
9. Daily average absorption chiller working hours (hours/day)	13.49	13.73	12.91
10. Supplemental energy supplied by main heater (kJ/month)	6.10×10^6	6.97×10^6	4.76×10^6
11. Percent of energy supplied to absorption chiller by main heater $\left(\frac{\text{Item 7} \times \text{Item 10} \times 100}{\text{Item 6}}\right)$ (%)	31.95	37.12	25.11
12. Total working hours of the main heater (hours/month)	386.9	438.8	337.8
13. Daily average working hours of the main heater (hours/day)	12.48	14.15	10.90
14. Energy vented due to boiling (kJ/month)	4.73×10^6	2.64×10^6	7.81×10^6
15. Total hours that room temperature rose above 25°C (hours/month)	0	0	0

TABLE 5.2(b)

Simulation Results for April 1979

Variable	Simulation Case		
	Case 1*	Case 2	Case 3
1. Solar flux incident on tilted collector plate (kJ/m^2month)	6.37×10^5	6.37×10^5	6.37×10^5
2. Heat collected by water flowing through the collector plate (kJ/month)	2.37×10^7	1.97×10^7	2.57×10^7
3. Overall collector plate efficiency $\left(\frac{\text{Item 2} \times 100}{\text{Item 1} \times \text{collector area}}\right)$(%)	40.59	40.48	37.74
4. Total working hours of collector pump (hours/month)	220.6	215.8	220.3
5. Daily average collector pump working hours (hours/day)	7.35	7.19	7.34
6. Monthly cooling load (kJ/month)	1.16×10^7	1.16×10^7	1.16×10^7
7. Overall absorption chiller efficiency $\left(\frac{\text{Item 6}}{\dot{Q}_{input}} \times 100\right)$(%)	62.12	63.00	62.45
8. Total absorption chiller working hours (hours/month)	500.5	450.6	420.5

TABLE 5.2(b) (Contd.)

Simulation Results for April 1979

Variable	Simulation Case		
	Case 1*	Case 2	Case 3
9. Daily average absorption chiller working hours (hours/day)	16.68	15.02	14.02
10. Supplemental energy supplied by main heater (kJ/month)	5.37×10^6	9.09×10^6	6.40×10^6
11. Percent of energy supplied to absorption chiller by main heater $\left(\frac{\text{Item 7 x Item 10 x 100}}{\text{Item 6}}\right)$ (%)	28.76	49.37	34.45
12. Total working hours of the main heater (hours/month)	301.0	482.8	383.1
13. Daily average working hours of the main heater (hours/day)	10.03	16.09	12.77
14. Energy vented due to boiling (kJ/month)	1.95×10^6	1.70×10^6	4.82×10^6
15. Total hours that room temperature rose above 25°C (hours/month)	27.5	6.2	0

* During April, 1979, of Case 1 only, hot water from the storage tank was drawn to run the absorption chiller as long as its temperature was above 80°C (compared to 85°C for the rest of this study)

TABLE 5.2(c)

Simulation Results for May 1979

Variable	Simulation Case		
	Case 1	Case 2	Case 3
1. Solar flux incident on tilted collector plate (kJ/m^2 month)	$6.12x10^5$	$6.12x10^5$	$6.12x10^5$
2. Heat collected by water flowing through the collector plate (kJ/month)	$2.10x10^7$	$1.80x10^7$	$2.37x10^7$
3. Overall collector plate efficiency $\left(\frac{\text{Item 2 x 100}}{\text{Item 1 x collector area}}\right)$ (%)	37.35	38.47	36.17
4. Total working hours of collector pump (hours/month)	213.7	209.7	216.7
5. Daily average collector pump woeking hours (hours/day)	6.89	6.76	6.99
6. Monthly cooling load (kJ/month)	$1.19x10^7$	$1.18x10^7$	$1.19x10^7$
7. Overall absorption chiller efficiency $\left(\frac{\text{Item 6}}{\dot{Q}_{input}} \text{ x } 100\right)$ (%)	62.39	62.58	63.28
8. Total absorption chiller working hours (hours/month)	452.6	469.0	438.2

TABLE 5.2(c) (Contd.)

Simulation Results for May 1979

Variable	Simulation Case		
	Case 1	Case 2	Case 3
9. Daily average absorption chiller working hours (hours/day)	14.60	15.13	14.14
10. Supplemental energy supplied by main heater (kJ/month)	8.53×10^6	1.02×10^7	8.77×10^6
11. Percent of energy supplied to absorption chiller by main heater $\left(\frac{\text{Item 7} \times \text{Item 10} \times 100}{\text{Item 6}}\right)$ (%)	44.74	54.04	46.64
12. Total working hours of the main heater (hours/month)	475.4	527.1	421.9
13. Daily average working hours of the main heater (hours/day)	15.34	17.00	13.61
14. Energy vented due to boiling (kJ/month)	1.62×10^6	0.70×10^6	2.98×10^6
15. Total hours that room temperature rose above 25°C (hours/month)	4.4	17.0	0

TABLE 5.2(d)

Simulation Results for June 1979

Variable	Simulation Case		
	Case 1	Case 2	Case 3
1. Solar flux incident on tilted collector plate (kJ/m^2 month)	4.26×10^5	4.26×10^5	4.26×10^5
2. Heat collected by water flowing through the collector plate (kJ/month)	1.19×10^7	1.02×10^7	1.27×10^7
3. Overall collector plate efficiency $\left(\frac{\text{Item 2} \times 100}{\text{Item 1} \times \text{collector area}}\right)$ (%)	30.35	31.46	27.79
4. Total working hours of collector pump (hours/month)	167.3	164.6	180.0
5. Daily average collector pump working hours (hours/day)	5.58	5.49	6.00
6. Monthly cooling load (kJ/month)	9.55×10^6	9.53×10^6	9.61×10^6
7. Overall absorption chiller efficiency $\left(\frac{\text{Item 6}}{\dot{Q}_{input}} \times 100\right)$ (%)	64.43	63.49	64.18
8. Total absorption chiller working hours (hours/month)	421.5	428.7	415.3

TABLE 5.2(d) (Contd.)

Simulation Results for June 1979

Variable	Simulation Case		
	Case 1	Case 2	Case 3
9. Daily average absorption chiller working hours (hours/day)	14.05	14.29	13.84
10. Supplemental energy supplied by main heater (kJ/month)	1.17×10^7	1.27×10^7	1.10×10^7
11. Percent of energy supplied to absorption chiller by main heater $\left(\frac{\text{Item 7 x Item 10 x 100}}{\text{Item 6}}\right)$ (%)	78.94	84.48	73.53
12. Total working hours of the main heater (hours/month)	628.1	656.5	588.5
13. Daily average working hours of the main heater (hours/day)	20.94	21.88	19.62
14. Energy vented due to boiling (kJ/month)	0.18×10^6	0.07×10^6	0.37×10^6
15. Total hours that room temperature rose above 25°C (hours/month)	20.4	28.7	7.4

TABLE 5.3

Overall Simulation Results for 4 Months

Variable	Simulation Case		
	Case 1	Case 2	Case 3
1. Total solar flux incident on tilted collector plate (kJ/m^2)	$2.41 x 10^6$	$2.41 x 10^6$	$2.41 x 10^6$
2. Total heat collected by water flowing through the collector plate (kJ)	$8.35 x 10^7$	$7.12 x 10^7$	$9.32 x 10^7$
3. Overall collector plate efficiency $\left(\frac{\text{Item 2 x 100}}{\text{Item 1 x collector area}}\right)$(%)	37.79	38.67	36.12
4. Total working hours of collector pump (hours)	839.1	828.3	859.4
5. Daily average collector pump working hours (hours/day)	6.88	6.79	7.04
6. Total cooling load (kJ)	$4.49 x 10^7$	$4.46 x 10^7$	$4.48 x 10^7$
7. Overall absorption chiller efficiency $\left(\frac{\text{Item 6}}{\dot{Q}_{input}} \text{ x } 100\right)$ (%)	62.55	62.74	62.87
8. Total absorption chiller working hours (hours)	1792.7	1773.8	1674.1

TABLE 5.3 (Contd.)

Overall Simulation Results for 4 Months

Variable	Simulation Case		
	Case 1	Case 2	Case 3
9. Daily average absorption chiller working hours (hours/day)	14.69	14.54	13.72
10. Total supplemental energy supplied by main heater (kJ)	$3.17x10^7$	$3.89x10^7$	$3.09x10^7$
11. Percent of energy supplied to absorption chiller by main heater $\left(\frac{\text{Item 7 x Item 10 x 100}}{\text{Item 6}}\right)$ (%)	44.31	54.78	43.36
12. Total working hours of the main heater (hours)	1791.4	2105.2	1731.3
13. Daily average working hours of the main heater (hours/day)	14.68	17.26	14.19
14. Total energy vented due to boiling (kJ)	$8.48x10^6$	$5.11x10^6$	$1.60x10^7$
15. Total hours that room temperature rose above 25°C (hours)	52.3	51.9	7.4