A COMPUTER MODEL FOR SIMULATION OF A WATER CONDENSATION SYSTEM

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Abstract

Pure drinking water and a sufficient household water supply are concerns of people everywhere, particularly in areas such as the United States Virgin Islands. Household water supplies of inadequate quality, especially on St. Thomas, can cause health problems, and insufficient water can be inconvenient, disruptive, and expensive.

The system modelled here produces distilled (pure) water by condensation from warm, moist air. Weather conditions such as air temperature and humidity determine the quantity of water actually produced. To simulate the operation of this unit, local FAA weather observations were compiled for a one-year period from July, 1984 through June, 1985.

Computer program listings for summarizing and averaging this data and for simulating the operation of the water condensation process are included. Formats of monthly weather observations and summarized data on computer disk files are also described.

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Introduction

The availability of a sufficient water supply has been an increasing problem in the U.S. Virgin Islands as resident and visitor population and water demand have increased over the past few decades. More recently an additional problem, perhaps more serious, has arisen: although the water supply quantity has been of concern, the quality of the public water supply has occasionally been below legally defined water quality standards, posing potential health dangers/hazards.

The heaviest population growth has been occurring in the rural/suburban areas; and these areas are typically distant or isolated from present urban water distribution systems. Because of the terrain, especially on St. John and St. Thomas, these areas are also the most costly for installation and maintenance of a centralized water distribution system. The domestic water demand in these areas is currently met primarily through rooftop catchment and cisterns (80%) and groundwater (20%). Occasionally the catchment systems are supplemented by water haulers at increased cost and inconvenience.

The water condensation units under study would be at the demand location, so that transportation costs or terrain need not be considered. In addition, the quality/purity of this water is essentially that of "distilled water", consistently higher than that supplied through catchment-cistern systems.

The particular object of this study is to simulate the operation of this unit using actual weather data and determine the expected quantities of pure water that would be produced.

Description of device

The Airwell (TM) water collecting system may be constructed and installed with a variety of materials and physical dimensions and arrangements. A typical system as specified in the patent description is shown in Figure 1.

All pipes and fittings are made from schedule 40 polyvinyl chloride (PVC) pipe, with standard dimension material. In this configuration the vertical 10 foot inlet and 20 foot exhaust pipes are both of 3" diameter pipe, and the four horizontal heat exchanger pipes are of 1-1/2" diameter pipe, each 20 feet long.

These dimensions match the volume of the intake, outlet, and heat exchanger portions of the unit. If the number of heat exchanger pipes were increased to provide additional water production, the size (or number) of the inlet and exhaust pipes should also be increased to maintain this volume matching (U. S. Patent Office, 1982).

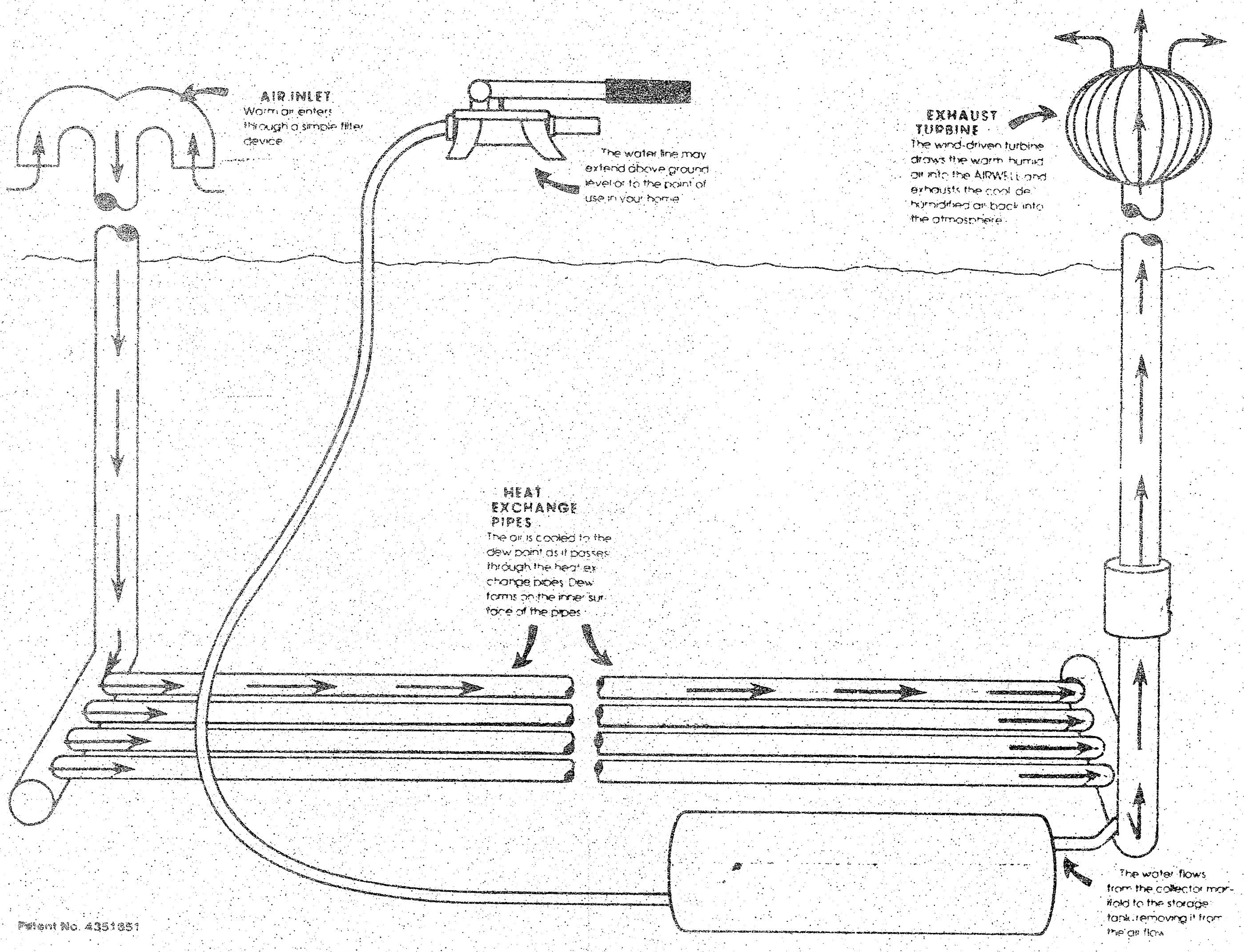

Figure 1. Diagram of water condensing device

Physical operation

As stated in the product description brochure (Airwell, Inc., 1983) the operation of this device begins with the entry of warm air into the inlet pipe. It is possible, but seldom necessary, to incorporate a cyclonic separator at the top of the air inlet pipe. This removes particles from the air through centrifugal force established by the airflow path.

The air begins to cool as it travels underground to the heat exchange pipes. When the dew point is reached, water begins to condense onto the inner pipe surfaces, and flows by gravity to the collector manifold and into the storage tank. This water is then pumped from the storage tank as needed for consumption or further storage.

The cool air, now dehumidified from the condensation process, passes through the outlet pipe and is exhausted back into the atmosphere.

The exhaust turbine which causes the airflow through this system operates with very low wind speeds; engineering data in the patent description were based on minimum speeds of five miles per hour. Although an airflow control unit is included in this design, the inventor reported that field experiments have shown that water production was not significantly reduced by omitting this component.

Since the air circulation is usually provided by a wind-powered fan on the exhaust stack, the system does not require other external power for its condensing operations.

Water condensation theory

The condensation process is based on warm, moisture-laden air being cooled to or beyond the dew point. At this temperature the water vapor in the air changes to a liquid state, begins to condense, and is thus removed from the air. The amount of condensed water produced depends on the initial humidity (vapor pressure) of the warm air and the amount of cooling realized (the temperature difference between the warm incoming air and the cooled exhaust air).

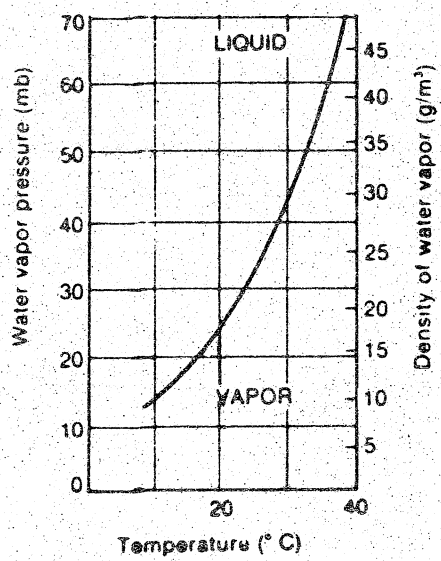

Figure 2. Saturation water vapor pressure and density as a function of temperature

Since the underground temperature is effectively constant, higher surface air temperatures will result in greater temperature differences. The condensation begins as soon as the dew point is reached, so with greater humidity, as cooling takes place, the dew point will be reached sooner, and larger amounts of water will be produced while the air passes through the device.

Data collection

The critical data needed for this simulation include weather conditions of air temperature, relative humidity, and for passive operation, wind speed. When the air temperature and dew point are available, the relative humidity can be calculated.

Initially the simulation was intended to utilize daily or hourly data. First attempts were made to locate all sources of computer-based weather data; failing this, manual or printed data was sought. None was found that directly corresponded to the model parameters. There were several souces of records such as the National Weather Service, which include temperature and wind speed for various locations in the Virgin Islands. However, these are printed (not computer-readable), do not provide consistent daily information, and over the last decade, with changes in federal agency structures, responsibility, and funding, there are inconsistencies and gaps in the data.

It was finally determined that the weather data maintained at the Federal Aviation Administration (FAA) office at the Cyril E. King airport on St. Thomas was potentially most useful, although it was available only from carbon copies of handwritten reports.

Data forms and content

Each day FAA personnel make standard weather observations on an hourly basis from 0645 - 2045 local time (1045-0045 GMT). The data includes air temperature, dew point, wind speed, and other values such as wind direction, cloud cover and ceilings, visibility, etc. (See sample data sheet, appendix d). In addition the maximum and minimum temperatures and cumulative rainfall are recorded at three times during each day: 0745, 1345, and 1945 local times (1145, 1745, and 2345 GMT).

The data observations were made and recorded by various FAA employees during the 15-hour days, seven days per week. Some readings (such as air temperature) could be made directly from an instrument (dry-bulb thermometer), but others (such as dew point) required the observer to perform some data manipulation and table-lookup (using the dry-bulb and wet-bulb temperatures) to determine the dew point. There were also operational inconsistencies in some of the cumulative readings such as rainfall and maximum/minimum temperatures.

From the data sheets it was noted that occasionally observations were not available; missing observations were indicated by the letter 'M' in the affected field. In other cases the recorded data was inconsistent when compared with other fields for that day. For example, the dew point may equal but can never exceed the air temperature; the daily maximum temperature should not be less than any of the three recorded temperature maxima; and the daily minimum should not be greater than any of the recorded temperature minima.

Data editing

The hourly data was entered from the carbon-copy data sheets for July, 1984, through June, 1985. Missing temperatures and dewpoints were indicated by zero values, since zero will not occur for either parameter at this location.

Initial data screening indicated that less than one percent of the temperature and dew point observations were missing; the missing data were replaced by values extrapolated from adjacent observations. In the data for one month (Oct, 84), it was found that several days of data were missing. It is conjectured that this was the result of procedural problems rather than instrument malfunction or failure. As a result, for purposes of this model, data from adjacent days were used to approximate the missing observations.

Summarizing hourly to daily values

The hourly weather data (recorded to an accuracy of one degree F for temperature and dew point) was available for 15 hours each day, but the water condensation production data was based on 24-hour operation. Thus the hourly data had to be summarized to give daily averages; this was done based on 15-hour and 24-hour days.

The 15-hour summary files were calculated using recorded (or extrapolated) data values for the 15 observations taken daily while the FAA tower is staffed (0645-2045 local time). Since the 15-hour averages do not take into account the temperatures and dew points during the remaining nine hours each day (from 2045 to 0645 local time), 24-hour averages were also calculated.

Two methods were used to approximate the values for the nine missing observations. One method calculated an average estimate for the nine observations using the last observation (2045 local time) from the previous day, and the first observation (0645 local time) for the current day. This involved carrying forward observations between daily data records, and also between files for the first and last days of each month.

The second method estimated values for the nine missing observations each day using the average of the first and last observations of that day. This method was procedurally much simpler, and eliminated the complexity of carrying data values across record or file boundaries.

Using data from three separate months, both methods were used, giving averages for 10-day sample periods. The overall difference between the two resulting averages was less than 0.5 deg F, with no detectable pattern of higher or lower averages. Therefore the simpler method was chosen giving estimates of the nine missing observations for each day based on first and last observations for that day.

For both 15-hour and 24-hour calculations, the "daily" average, maximum, and minimum values were calculated for air temperature, humidity (based on temperature and dew point observations), and wind speed. During these summary calculations, frequency distributions of the observed values were accumulated and printed out as histograms. This was done to help ensure reasonableness of the data and its manipulation.

Calculations

Since the temperature and dew point observations were recorded in degrees Fahrenheit, Celsius values were calculated from Fahrenheit values with the standard formula:

$$degC = 5/9 * (degF - 32).$$

The relative humidity value was approximated for each hourly set of temperature and dew point observations using this formula [Linsley, Jr, Kohler, Paulhus, 1975].

$$\text{relative humidity (\%)} = \frac{112-0.1*Ta+Td}{(112+0.9*Ta)^8}$$

where Ta=air temperature and Td=dew point temperature, both in degrees Celsius.

Conditions of operation

In the Airwell water condensation system, the main parameters for determining the quantity of water produced are the air temperature and humidity. For a passive system the wind speed must also exceed a threshold level, originally determined to be 5 mph. Optionally, a motor-driven fan could provide the necessary air circulation, requiring a small amount of electrical power (typically about 0.1 VA) for a conventional muffin fan.

From the engineering data in the patent description for this system it can be seen that water production increases with increased temperature and/or increased humidity (and of course decreases as temperature or humidity decreases). However the surface air temperature and humidity vary throughout the day and night, with the general pattern of increasing humidity and decreasing temperature in the evening and night time, and decreasing humidity and increasing temperature in the morning and midday hours. But the heat exchange portion of this device (the horizontal pipes) is in a virtually isothermal environment, so the temperature differential is usually smaller when the humidity is greater, and vice versa. Thus the condensation rate tends to level out despite the daily temperature/humidity changes.

Airflow, volume calculations

As mentioned in the patent, the quantity of water produced by this device was initially calculated from the quantity (in pounds) of air passing through the heat exchanger, and the amount of water per pound of air at the various temperature and humidity levels. Air density and water (vapor) figures were based on standard psychrometric charts; assumed air flow rates and the physical dimensions of the components determined the quantities of air passing through the device.

Approximating production data

The engineering data obtained from the patent and from the product description brochure gives water production figures for temperatures of 70, 80, and 90 degrees F, and for relative humidities of 100, 90, 80, 70, etc. per cent. To facilitate production calculations for the model, a table of water production quantities was calculated for temperatures from 50 to 100 degrees F in one degree increments, and relative humidity from 50 to 100 percent in one percent increments.

It should be noted that the quantity of water produced was assumed to be a linear function over these ranges of temperature and humidity. Thus a least-squares approximation method was used to determine the coefficients for the formula used to generate this table of values (Appendix e). Although alternative tables could be generated using other (non-linear) methods, the increased complexity of that process would not significantly increase the accuracy of the water production calculations.

It is interesting to note that during discussions with the inventor, he stated that the actual water production in field tests was consistently greater than the values shown in patent and product description tables.

Precision of observed and derived data

There are three important areas where the accuracy of numeric values must be considered.

Precise humidity or dewpoint values based on standard psychrometric tables depend on thermometer readings accurate to 0.1 degreee F (Miller and Thompson, 1975). But the weather observations were collected manually, and it is only reasonable to expect that the temperatures were read to the nearest Fahrenheit degree, since they were recorded as integer degrees F.

The formula to approximate relative humidity using calculations based on temperature and dew point data is accurate to within 0.6 percent (Linsley,Jr, Kohler, and Paulhus, 1975).

The engineering computations are based on temperature differentials and the amount of water vapor in the air (humidity). These production figures in liters were calculated for 24-hour time periods and rounded to the nearest liter (or quart in the brochure table). Within the range of production quantities (4 to 36 liters of water), that rounding error could range from 1.5 to 13 percent.

Considering these levels of accuracy, and that of observing and recording the temperatures, the approximated humidity values would be well within the accuracy of the observed weather data and water condensation figures used.

Simulation model

Structure

The model is comprised of several discrete routines. The water production data is read into an array at the beginning of the program. If a larger condensation system were to be used, or if other production figures were determined for a modified configuration, the production data could be changed without affecting the remainder of the model.

The weather summary files are based on daily averages for one month at a time. The user may provide additional data file names for subsequent simulations, and may also indicate the number of days to be included for that month. This is helpful when checking program modifications since it allows small data files to be used.

The temperature and humidity are determined directly from the monthly summary files. If another format were used, this segment could be changed to provide edit checking, conversion, or other calculations as appropriate.

The water production data units are quarts per 24-hour day. The simulation results were converted into gallons to correspond to consumption data which is also in gallons.

Correspondence to device

The computer model used did not attempt to simulate the individual components of this condensing system. The water production data had already integrated the airflow, water vapor pressure and density, temperature, and humidity.

Therefore, the water condensing system was considered as one device in this model.

Procedure for model changes

If additional weather data becomes available, or if hourly production rather than daily production is desired, the model can be easily modified to meet those changes. The water production data file would be converted from daily to hourly production quantities, and the input-calculation routines would be modified to cycle through hourly observations rather than daily.

It should also be noted that the temperature and humidity ranges are from 70-90 degrees F, and 40-90% relative humidity. If a wider range of humidity or temperatures is necessary, the program range checks must be modified to correspond to the new desired temperature or humidity ranges.

The water production data units can be changed from quarts and gallons by inserting the appropriate conversion formulas, but the production values must also be changed accordingly.

Table I. Simulated water production

Monthly figures include maximum and minimum daily production, the total quantity produced, and the average daily production during the month being simulated.

All quantities are in U.S. gallons.

Yr/mo	daily max	daily min	monthly tot	daily ave	data 15/24 hr
8407	4.75	3.50	128.00	4.13	15
	4.75	3.75	128.75	4.15	24
8408	5.25	4.00	141.25	4.56	15
	5.25	4.00	142.75	4.60	24
8409	5.25	4.25	144.50	4.82	15
	5.00	4.25	141.25	4.71	24
8410	5.25	3.75	139.25	4.49	15
	5.00	3.75	138.50	4.47	24
8411	5.00	3.00	124.50	4.15	15
	5.00	2.75	122.75	4.09	24
8412	4.25	2.00	93.75	3.02	15
	4.00	2.25	94.75	3.06	24
8501	3.75	2.25	91.00	2.94	15
	3.75	2.25	91.25	2.94	24
8502	3.00	1.50	70.75	2.53	15
	3.00	1.75	72.50	2.59	24
8503	3.50	2.25	86.25	2.78	15
	3.50	2.25	87.00	2.81	24
8504	3.50	2.00	85.75	2.86	15
	3.50	1.50	86.50	2.88	24
8505	4.75	2.75	107.00	3.45	15
	4.75	2.75	110.75	3.57	24
8506	4.25	3.00	108.75	3.63	15
	4.25	2.75	114.00	3.80	24

Results

The simulations showed that one condensing unit (with four heat exchanger pipes, twenty feet long, as specified in the patent description) would supply enough pure water to meet the drinking water needs of a four-person family. (Approximately 4 gallons or 8-9% of the daily estimated water demand is assumed to be used for direct consumption). However, there would not be sufficient capacity to provide additional water needed for household operation.

There are several possibilities for increasing the water production. The number of condensing pipes could be increased (requiring a corresponding increase in air volume), thus providing a larger condensing area. Multiple units could be installed, probably feeding a single storage reservoir. However, before such a choice is made, a careful analysis should be done since it may not be cost-effective with this condensing method to produce the total amount of water needed for general household use in the Virgin Islands.

Conclusion

Within the various household domestic water demands, quality of drinking water is most critical, and the condensed water from these units easily meets those high standards. The water produced by such condensing systems should be used specifically for these household domestic water needs; other sources, including cisterns and groundwater can provide water of lesser quality for less strict demands such as washing and waste disposal.

Based on these simulations using the weather data collected, one condensing system would be able to meet this important pure water demand for one four-person household throughout the year. Of course, proper management and storage procedures would be required to maintain the purity of the water produced, and to ensure its availability.

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Appendix a -- simulation model

```
10  REM SIMULATION OF WATER CONDENSING SYSTEM
20  REM Initial program 28 May 86  JDMunro
40  REM  The table of production values is accessed by
50  REM  two subscripts.  The first is determined by
60  REM  subtracting 40 from the relative humidity.
70  REM  The second is determined by subtracting 70
80  REM  from the temperature.  Example:  production for
90  REM  85% r.h., 80 deg F temp, is in HP(85-40,80-70)
100 REM  or HP(45,10)
110 MAXFILES=2
120 DIM HP(51,21)
130 REM start
140 REM get hum/prod data
150 GOSUB 1000
160 REM get input file name and number of days
170 GOSUB 2000
180 REM main loop
190 FOR D=1 TO ND
200 GOSUB 3000
210 NEXT D
220 PRINT
230 REM end
240 GOSUB 4000
250 REM  repeat for another file?
260 GOTO 170
1000 REM get hum/prod data
1010  INPUT "hum/prod file name";H$
1020  OPEN H$ FOR INPUT AS #2
1030  REM get humidity/production table data
1040 FOR T=70 TO 90
1050 INPUT #2,D$
1060 PRINT T;
1070 FOR H=40 TO 90
1080 HP(H-40,T-70)=VAL(MID$(D$,6+(H-40)*2,2))
1090 NEXT H
1100 NEXT T
1110 PRINT
1120 CLOSE #2
1130 RETURN
2000 REM start routine
2010 INPUT "summary file name('end' to stop)";F$
2020 IF F$="end" THEN STOP
2030 INPUT "how many days";ND
2040 REM initialize
2050 REM max, min, total production
2060 PX=0:PN=99:PT=0:N=0
2070 REM open files
2080 OPEN F$ FOR INPUT AS #1
2090 RETURN
```

```
3000 REM main loop routine
3010 INPUT #1,T$
3020 PRINT N+1;
3030 LT=VAL(MID$(T$,11,2))
3040 LH=VAL(MID$(T$,17,2))
3050 REM check for out of range values
3060 IF LH<40 THEN LH=40:PRINT "hum for day"D
3070 IF LT<70 THEN LT=70:PRINT "tmp for day"D
3080 AM=HP(LH-40,LT-70)
3090 REM add to total production
3100 PT=PT+AM
3110 REM check for max and min prod
3120 IF PX<AM THEN PX=AM
3130 IF PN>AM THEN PN=AM
3140 N=N+1
3150 RETURN
4000 REM end--print out monthly results
4010 PRINT "data for "F$
4020 REM  production is divided by 4 to get gallons from
    quarts
4030 PRINT "max daily prod="PX/4;
4040 PRINT " min daily prod="PN/4
4050 PRINT "tot prod(gals)="PT/4
4060 PRINT "ave daily prod="PT/4/N
4070 CLOSE #1
4080 RETURN
```

Appendix b(1) -- 15-hour averages

```
10  MAXFILES=2
20 REM freq dist, max,min,ave etc t,dp,w,rh
30 DIM TX(31),TN(31),TB(31),DX(31),DN(31),DA(31),
   WX(31),WN(31),WA(31),FT(40),FD(50),FW(50),ZW(31),
   FH(50),HX(31),HN(31),HA(31)
40 REM open files init tots get mo/days
50 PRINT "15-hour summary"
60 INPUT "month(file name)";F1$
70 IF F1$="end" THEN STOP
80 INPUT "how many days?";ND
90 INPUT "output file name:";F2$
100 FD$="n":INPUT "freq dist (y/n)";R$:IF R$="y"
    OR R$="Y" THEN FD$="y"
110 PRINT "f1$="F1$
120 OPEN F1$ FOR INPUT AS #1
130 PRINT "f2$="F2$
140 OPEN F2$ FOR OUTPUT AS #2
150 FOR I=1 TO ND
160 TX(I)=0:TN(I)=99:TB(I)=0:DX(I)=0:DN(I)=99:DA(I)=0:
    WX(I)=0:WN(I)=99:WA(I)=0:ZW(I)=0:
    HX(I)=0:HN(I)=99:HA(I)=0
170 NEXT I
180 PRINT
190 REM min tot/ave max #obs  temp
200 TM(1)=99:TM(2)=0:TM(3)=0:TM(4)=0
210 REM min tot/ave max #obs  dewpt
220 DM(1)=99:DM(2)=0:DM(3)=0:DM(4)=0
230 REM min tot/ave max #obs  wind
240 WM(1)=99:WM(2)=0:WM(3)=0:WM(4)=0
250 REM min tot/ave max #obs rel hum
260 HM(1)=99:HM(2)=0:HM(3)=0:HM(4)=0
270 REM init total rainfall for month
280 TR=0
290 FOR D=1 TO ND:GOSUB 580:NEXT D
300 REM end of processing
310 PRINT #2,"":PRINT #2,"":PRINT #2,
    "15-hour summary from ";F1$
320 REM print monthly max/min/ave
330 LPRINT
340 LPRINT "data from "F1$
350 LPRINT "15-hour summary"
360 TM(2)=INT(TM(2)/TM(4)+.5)
370 LPRINT "temp max min ave="TM(3);TM(1);TM(2)
380 PRINT #2,"temp max min ave="TM(3);TM(1);TM(2)
390 DM(2)=INT(DM(2)/DM(4)+.5)
400 LPRINT "dewpt max min ave="DM(3);DM(1);DM(2)
410 PRINT #2,"dewpt max min ave="DM(3);DM(1);DM(2)
420 WM(2)=INT(WM(2)/WM(4)+.5)
430 LPRINT "wind max min ave="WM(3);WM(1);WM(2)
440 PRINT #2,"wind max min ave="WM(3);WM(1);WM(2)
450 HM(2)=INT(HM(2)/HM(4)+.5)
```

```
460 LPRINT "rel hum max min ave="HM(3);HM(1);HM(2)
470 PRINT #2,"rel hum max min ave="HM(3);HM(1);HM(2)
480 LPRINT "total rainfall ="TR
490 PRINT #2,"total rainfall ="TR
500 REM print freq distrs
510 IF FD$="n" THEN 560
520 GOSUB 1310:REM temps
530 GOSUB 1400:REM dew pts
540 GOSUB 1490:REM wind
550 GOSUB 1580: REM rel humidity
560 CLOSE #1:CLOSE #2
570 GOTO 50:REM that's all, just in case
580 REM for each day
590 TQ=0:DQ=0:WQ=0:HQ=0
600 INPUT #1,T$
610 PRINT MID$(T$,5,2);
620 INPUT #1,R$
630 FOR H=1 TO 15
640 REM get temperature
650 T=VAL(MID$(T$,7+(H-1)*6,2))
660 IF T=0 THEN LPRINT D;H;"00";:GOTO 720
670 TB(D)=TB(D)+T:TM(4)=TM(4)+1:TQ=TQ+1
680 IF T>TX(D) THEN TX(D)=T:XT=H
690 IF T<TN(D) THEN TN(D)=T:NT=H
700 IF T<60 THEN T=61
710 FT(T-60)=FT(T-60)+1
720 REM get dewpoint
730 DP=VAL(MID$(T$,9+(H-1)*6,2))
740 IF DP=0 THEN LPRINT "DP"D;H;:GOTO 810
750 DA(D)=DA(D)+DP:DM(4)=DM(4)+1:DQ=DQ+1
760 IF DP>DX(D)THEN DX(D)=DP:XD=H
770 IF DP<DN(D)THEN DN(D)=DP:ND=H
780 IF DP<50 THEN DP=51
790 FD(DP-50)=FD(DP-50)+1
800 IF T<=DP THEN LPRINT "t<=dp="T;DP;D;H;:T=0:DP=0
810 REM get wind
820 W=VAL(MID$(T$,11+(H-1)*6,2))
830 IF W=0 THEN ZW(D)=ZW(D)+1:LPRINT "w"D;H;:GOTO 890
840 WA(D)=WA(D)+W:WM(4)=WM(4)+1:WQ=WQ+1
850 IF W>WX(D)THEN WX(D)=W:XW=H
860 IF W<WN(D)THEN WN(D)=W:NW=H
870 IF W>50 THEN LPRINT "W>50";D;H;:W=50
880 FW(W)=FW(W)+1
890 REM calc rel hum
900 IF(T=0)OR (DP=0) THEN RH=51:LPRINT "t="T" dp="DP;:
    GOTO 980
910 REM calc rel hum
920 TC=5/9*(T-32):DC=5/9*(DP-32)
930 RH=INT((((112-.1*TC+DC)/(112+.9*TC))^8)*100+.5)
940 HA(D)=HA(D)+RH:HM(4)=HM(4)+1:HQ=HQ+1
950 IF RH>HX(D)THEN HX(D)=RH:XH=H
960 IF RH<HN(D)THEN HN(D)=RH:NH=H
970 IF RH<50 THEN RH=51
```

```
980 FH(RH-50)=FH(RH-50)+1
990 NEXT H
1000 REM get rainfall
1010 REM rf=val(mid$(t$,71))
1020 REM print day info
1030 TM(2)=TM(2)+TB(D):DM(2)=DM(2)+DA(D):
     WM(2)=WM(2)+WA(D):HM(2)=HM(2)+HA(D)
1040 REM calculate averages rounded
1050 TB(D)=INT(TB(D)/TQ+.5):DA(D)=INT(DA(D)/DQ+.5):
     WA(D)=INT(WA(D)/WQ+.5):HA(D)=INT(HA(D)/HQ+.5)
1060 TX$=MID$(STR$(100+TX(D)),3,2)
1070 TN$=MID$(STR$(100+TN(D)),3,2)
1080 TA$=MID$(STR$(100+TB(D)),3,2)
1090 DX$=MID$(STR$(100+DX(D)),3,2)
1100 DN$=MID$(STR$(100+DN(D)),3,2)
1110 DA$=MID$(STR$(100+DA(D)),3,2)
1120 WX$=MID$(STR$(100+WX(D)),3,2)
1130 WN$=MID$(STR$(100+WN(D)),3,2)
1140 WA$=MID$(STR$(100+WA(D)),3,2)
1150 HX$=MID$(STR$(100+HX(D)),3,2)
1160 HN$=MID$(STR$(100+HN(D)),3,2)
1170 HA$=MID$(STR$(100+HA(D)),3,2)
1180 RF$=MID$(STR$(10.0001+RF),3,4)
1190 PRINT #2,MID$(T$,1,6);TX$;TN$;TA$;HX$;HN$;HA$;
     WX$;WN$;WA$;RF$
1200 PRINT MID$(T$,1,6);TX$;TN$;TA$;HX$;HN$;HA$;
     WX$;WN$;WA$;RF$
1210 IF TX(D)>TM(3) THEN TM(3)=TX(D)
1220 IF DX(D)>DM(3) THEN DM(3)=DX(D)
1230 IF WX(D)>WM(3) THEN WM(3)=WX(D)
1240 IF HX(D)>HM(3) THEN HM(3)=HX(D)
1250 IF TN(D)<TM(1) THEN TM(1)=TN(D)
1260 IF DN(D)<DM(1) THEN DM(1)=DN(D)
1270 IF WN(D)<WM(1) THEN WM(1)=WN(D)
1280 IF HN(D)<HM(1) THEN HM(1)=HN(D)
1290 TR=TR+RF
1300 RETURN
1310 REM temp freq dists
1320 LPRINT "temperature freq dists"
1330 FOR T=60 TO 100
1340 IF FT(T-60)=0 THEN 1370
1350 LPRINT " "T"="FT(T-60)";";
1360 LPRINT TAB(12);STRING$(INT(FT(T-60)/2),"*")
1370 NEXT T
1380 LPRINT
1390 RETURN
1400 REM dew pt freq dists
1410 LPRINT "dew point freq dists"
1420 FOR D=50 TO 100
1430 IF FD(D-50)=0 THEN 1460
1440 LPRINT " "D"="FD(D-50)";";
1450 LPRINT TAB(12);STRING$(INT(FD(D-50)/2),"*")
1460 NEXT D
```

```
1470 LPRINT
1480 RETURN
1490 REM wind freq dists
1500 LPRINT "wind freq dists"
1510 FOR W=1  TO 50
1520 IF FW(W)=0 THEN 1550
1530 LPRINT " "W"="FW(W)";";
1540 LPRINT TAB(12);STRING$(INT(FW(W)/2),"*")
1550 NEXT W
1560 LPRINT
1570 RETURN
1580 REM rel humidity freq dists
1590 LPRINT "rel humidity freq dists"
1600 FOR R=50 TO 100
1610 IF FH(R-50)=0 THEN 1640
1620 LPRINT " "R"="FH(R-50)";";
1630 LPRINT TAB(12);STRING$(INT(FH(R-50)/2),"*")
1640 NEXT R
1650 LPRINT
1660 RETURN
```

Appendix b(2) -- 24 hour averages

```
10 REM Summarize hourly observations, with 24-hour
     calculation routine
20 REM added to the summary process
30 REM freq dist, max,min,ave etc t,dp,w,rh
40 REM 15 June 86  jdm  mod for 24-hour summary
50 MAXFILES=2
60 DIM TX(31),TN(31),TB(31),DX(31),DN(31),DA(31),WX(31),
   WN(31),WA(31),FT(40),FD(50),FW(50),ZW(31),FH(50),HX(31),
   HN(31),HA(31)
70 REM open files init tots get mo/days
80 PRINT "24-hour summary"
90 INPUT "month(file name)";F1$
100 IF F1$="end" THEN STOP
110 INPUT "how many days?";ND
120 INPUT "output file name:";F2$
130 FD$="n":INPUT "freq dist (y/n)";R$:IF R$="y" OR R$="Y"
    THEN FD$="y"
140 PRINT "f1$="F1$
150 OPEN F1$ FOR INPUT AS #1
160 PRINT "f2$="F2$
170 OPEN F2$ FOR OUTPUT AS #2
180 FOR I=1 TO ND
190 TX(I)=0:TN(I)=99:TB(I)=0:DX(I)=0:DN(I)=99:DA(I)=0:
    WX(I)=0:WN(I)=99:WA(I)=0:ZW(I)=0:HX(I)=0:HN(I)=99:
    HA(I)=0
200 NEXT I
210 PRINT
220 REM min tot/ave max #obs  temp
230 TM(1)=99:TM(2)=0:TM(3)=0:TM(4)=0
240 REM min tot/ave max #obs  dewpt
250 DM(1)=99:DM(2)=0:DM(3)=0:DM(4)=0
260 REM min tot/ave max #obs  wind
270 WM(1)=99:WM(2)=0:WM(3)=0:WM(4)=0
280 REM min tot/ave max #obs rel hum
290 HM(1)=99:HM(2)=0:HM(3)=0:HM(4)=0
300 REM init total rainfall for month
310 TR=0
320 FOR D=1 TO ND:GOSUB 610:NEXT D
330 REM end of processing
340 PRINT #2,"":PRINT #2,"":PRINT #2,
    "24-hour summary from ";F1$
350 REM print monthly max/min/ave
360 LPRINT
370 LPRINT "data from "F1$
380 LPRINT "24-hour summary"
390 TM(2)=INT(TM(2)/TM(4)+.5)
400 LPRINT "temp max min ave="TM(3);TM(1);TM(2)
410 PRINT #2,"temp max min ave="TM(3);TM(1);TM(2)
420 DM(2)=INT(DM(2)/DM(4)+.5)
430 LPRINT "dewpt max min ave="DM(3);DM(1);DM(2)
440 PRINT #2,"dewpt max min ave="DM(3);DM(1);DM(2)
```

```
450 WM(2)=INT(WM(2)/WM(4)+.5)
460 LPRINT "wind max min ave="WM(3);WM(1);WM(2)
470 PRINT #2,"wind max min ave="WM(3);WM(1);WM(2)
480 HM(2)=INT(HM(2)/HM(4)+.5)
490 LPRINT "rel hum max min ave="HM(3);HM(1);HM(2)
500 PRINT #2,"rel hum max min ave="HM(3);HM(1);HM(2)
510 LPRINT "total rainfall ="TR
520 PRINT #2,"total rainfall ="TR
530 REM print freq distrs
540 IF FD$="n" THEN 590
550 GOSUB 1440:REM temps
560 GOSUB 1530:REM dew pts
570 GOSUB 1620:REM wind
580 GOSUB 1710: REM rel humidity
590 CLOSE #1:CLOSE #2
600 GOTO 80: REM check for more
610 REM for each day
620 TQ=0:DQ=0:WQ=0:HQ=0
630 INPUT #1,T$
640 PRINT MID$(T$,5,2);
650 INPUT #1,R$
660 FOR H=1 TO 15
670 REM get temperature
680 T=VAL(MID$(T$,7+(H-1)*6,2))
690 IF T=0 THEN LPRINT D;H;"00";:GOTO 750
700 TB(D)=TB(D)+T:TM(4)=TM(4)+1:TQ=TQ+1
710 IF T>TX(D) THEN TX(D)=T:XT=H
720 IF T<TN(D) THEN TN(D)=T:NT=H
730 IF T<60 THEN T=61
740 FT(T-60)=FT(T-60)+1
750 REM get dewpoint
760 DP=VAL(MID$(T$,9+(H-1)*6,2))
770 IF DP=0 THEN LPRINT "DP"D;H;:GOTO 840
780 DA(D)=DA(D)+DP:DM(4)=DM(4)+1:DQ=DQ+1
790 IF DP>DX(D)THEN DX(D)=DP:XD=H
800 IF DP<DN(D)THEN DN(D)=DP:ND=H
810 IF DP<50 THEN DP=51
820 FD(DP-50)=FD(DP-50)+1
830 IF T<=DP THEN LPRINT "t<=dp="T;DP;D;H;:T=0:DP=0
840 REM get wind
850 W=VAL(MID$(T$,11+(H-1)*6,2))
860 IF W=0 THEN ZW(D)=ZW(D)+1:LPRINT "w"D;H;:GOTO 920
870 WA(D)=WA(D)+W:WM(4)=WM(4)+1:WQ=WQ+1
880 IF W>WX(D)THEN WX(D)=W:XW=H
890 IF W<WN(D)THEN WN(D)=W:NW=H
900 IF W>50 THEN LPRINT "W>50";D;H;:W=50
910 FW(W)=FW(W)+1
920 REM check for reasonable temp and dew pts
930 IF(T=0)OR (DP=0) THEN RH=51:LPRINT "t="T" dp="DP;:
    GOTO 1010
940 REM calc rel hum
950 TC=5/9*(T-32):DC=5/9*(DP-32)
960 RH=INT((((112-.1*TC+DC)/(112+.9*TC))^8)*100+.5)
```

```
970 HA(D)=HA(D)+RH:HM(4)=HM(4)+1:HQ=HQ+1
980 IF RH>HX(D)THEN HX(D)=RH:XH=H
990 IF RH<HN(D)THEN HN(D)=RH:NH=H
1000 IF RH<50 THEN RH=51
1010 FH(RH-50)=FH(RH-50)+1
1020 NEXT H
1030 REM get 9 nighttime values for 24-hr summary
1040 T1=VAL(MID$(T$,7+(1-1)*6,2))
1050 TF=VAL(MID$(T$,7+(15-1)*6,2))
1060 D1=VAL(MID$(T$,9+(1-1)*6,2))
1070 DF=VAL(MID$(T$,9+(15-1)*6,2))
1080 W1=VAL(MID$(T$,11+(1-1)*6,2))
1090 WF=VAL(MID$(T$,11+(15-1)*6,2))
1100 NT=(T1+TF)/2: ND=(D1+DF)/2: NW=(W1+WF)/2
1110 TC=5/9*(NT-32):DC=5/9*(ND-32)
1120 NH=INT((((112-.1*TC+DC)/(112+.9*TC))^8)*100+.5)
1130 TB(D)=TB(D)+9*NT:TM(4)=TM(4)+9:TQ=TQ+9
1140 HA(D)=HA(D)+9*NH:HM(4)=HM(4)+9:HQ=HQ+9
1150 WA(D)=WA(D)+9*NW:WM(4)=WM(4)+9:WQ=WQ+9
1160 REM print day info
1170 TM(2)=TM(2)+TB(D):DM(2)=DM(2)+DA(D):WM(2)=WM(2)+WA(D):
     HM(2)=HM(2)+HA(D)
1180 TB(D)=INT(TB(D)/TQ+.5):DA(D)=INT(DA(D)/DQ+.5):
     WA(D)=INT(WA(D)/WQ+.5):HA(D)=INT(HA(D)/HQ+.5)
1190 TX$=MID$(STR$(100+TX(D)),3,2)
1200 TN$=MID$(STR$(100+TN(D)),3,2)
1210 TA$=MID$(STR$(100+TB(D)),3,2)
1220 DX$=MID$(STR$(100+DX(D)),3,2)
1230 DN$=MID$(STR$(100+DN(D)),3,2)
1240 DA$=MID$(STR$(100+DA(D)),3,2)
1250 WX$=MID$(STR$(100+WX(D)),3,2)
1260 WN$=MID$(STR$(100+WN(D)),3,2)
1270 WA$=MID$(STR$(100+WA(D)),3,2)
1280 HX$=MID$(STR$(100+HX(D)),3,2)
1290 HN$=MID$(STR$(100+HN(D)),3,2)
1300 HA$=MID$(STR$(100+HA(D)),3,2)
1310 RF$=MID$(STR$(10.0001+RF),3,4)
1320 PRINT #2,MID$(T$,1,6);TX$;TN$;TA$;HX$;HN$;HA$;
     WX$;WN$;WA$;RF$
1330 PRINT MID$(T$,1,6);TX$;TN$;TA$;HX$;HN$;HA$;
     WX$;WN$;WA$;RF$
1340 IF TX(D)>TM(3) THEN TM(3)=TX(D)
1350 IF DX(D)>DM(3) THEN DM(3)=DX(D)
1360 IF WX(D)>WM(3) THEN WM(3)=WX(D)
1370 IF HX(D)>HM(3) THEN HM(3)=HX(D)
1380 IF TN(D)<TM(1) THEN TM(1)=TN(D)
1390 IF DN(D)<DM(1) THEN DM(1)=DN(D)
1400 IF WN(D)<WM(1) THEN WM(1)=WN(D)
1410 IF HN(D)<HM(1) THEN HM(1)=HN(D)
1420 TR=TR+RF
1430 RETURN
1440 REM temp freq dists
1450 LPRINT "temperature freq dists"
```

```
1460 FOR T=60 TO 100
1470 IF FT(T-60)=0 THEN 1500
1480 LPRINT " "T"="FT(T-60)";";
1490 LPRINT TAB(12);STRING$(INT(FT(T-60)/2),"*")
1500 NEXT T
1510 LPRINT
1520 RETURN
1530 REM dew pt freq dists
1540 LPRINT "dew point freq dists"
1550 FOR D=50 TO 100
1560 IF FD(D-50)=0 THEN 1590
1570 LPRINT " "D"="FD(D-50)";";
1580 LPRINT TAB(12);STRING$(INT(FD(D-50)/2),"*")
1590 NEXT D
1600 LPRINT
1610 RETURN
1620 REM wind freq dists
1630 LPRINT "wind freq dists"
1640 FOR W=1  TO 50
1650 IF FW(W)=0 THEN 1680
1660 LPRINT " "W"="FW(W)";";
1670 LPRINT TAB(12);STRING$(INT(FW(W)/2),"*")
1680 NEXT W
1690 LPRINT
1700 RETURN
1710 REM rel humidity freq dists
1720 LPRINT "rel humidity freq dists"
1730 FOR R=50 TO 100
1740 IF FH(R-50)=0 THEN 1770
1750 LPRINT " "R"="FH(R-50)";";
1760 LPRINT TAB(12);STRING$(INT(FH(R-50)/2),"*")
1770 NEXT R
1780 LPRINT
1790 RETURN
```

Appendix c -- least squares

```
10 REM least squares approximation  May,86 JDMunro
20 REM initialize sums
30 GOSUB 100
40 REM input and add to sums
50 GOSUB 300
60 REM calculate and print answers
70 GOSUB 500
80 REM that's all
85 INPUT "hard copy title (rtn to ignore)";R$
88 IF R$<>"" THEN GOSUB 700
90 END
100 REM initialize sums
110 SB=0:SX=0:SY=0:XQ=0:YQ=0:N=0
170 RETURN
300 REM input and add to sums
310 INPUT "temp,quan";X,Y
320 IF X=0 THEN RETURN
320 SB=SB+(X*Y)
330 SX=SX+X
340 SY=SY+Y
350 XQ=XQ+(X*X)
360 YQ=YQ+(Y*Y)
370 N=N+1
380 GOTO 310
500 REM calculate and print answers
510 PRINT "sumxy="SB;" sumx="SX;" sumy="SY;
    "sum(xsq)="XQ;"sumx="SX;" n="N
520 B=(N*SB - (SX*SY))/(N*XQ - SX*SY)
530 A=(SY/N)-(B*(SX/N))
540 PRINT "a="A;" b="B
550 REM std error
555 S=(YQ - A*SY - B*SB) / (N - 2)
558 SE=SQR(S)
560 PRINT "std error of estimate="SE
570 CN=(N*SB - SX*SY)
575 CD=SQR((N*XQ-SX*SX)*(N*YQ-SY*SY))
578 CC=CN/CD
580 PRINT "corr.coeff="CC
585 VA=CC*CC
590 PRINT "coeff of determination(var)="VA
699 RETURN
700 REM lprint answers
710 LPRINT R$
720 LPRINT "sumxy="SB;" sumx="SX;" sumy="SY;
    "sum(xsq)="XQ;"sum(ysq)="YQ;" n="N
730 LPRINT "a="A;" b="B
740 LPRINT "std error of estimate="SE
750 LPRINT "corr.coeff="CC
760 LPRINT "coeff of determination (var)="VA
770 RETURN
```