CHAPTER V

HOURLY MODEL WEATHER DATA BASE FOR BUILDING ENERGY CALCULATIONS

5.1 The Use of Weather Data

Weather data are indispensable for building energy use calculations. The Energy Calculations Committee of ASHRAE has recommended the use of a full weather data set of 8760 hours which contains real weather sequences that truly represent the long term climatic values of the several critical weather elements. Basically, hourly weather data can be obtained from the weather stations in the United States. It is, however, undesirable to use a set of weather data of one specific year, because the weather conditions of a specific year may not represent those of long term periods for a location in question. Accordingly, the need for a weather data set which represents the long term weather conditions of the location arises.

Through this chapter a set of Hourly Model Weather Data Base was constructed for Oklahoma City area using TD-1440 series of weather tape obtained from National Climatic Data center. The data set consists of 8760 hour critical weather elements including hourly solar radiation data for building energy use calculations. The methodology of TMY presented by Hall, Prairie, Anderson and Boes of Sandia Laboratories in Albuquerque, New Mexico was applied to determine the most typical weather conditions.

Solar radiation intensities were estimated by ASHRAE clear sky solar radiation model and Kimura and Stephensons' regression model for the solar radiation under cloudy sky.

5.2 TMY Methodology

TMY (Typical Meteorological Year) tapes were prepared by Hall, Prairie, Anderson and Boes (1979) of Sandia Laboratories in Albuquerque, New Mexico, using US Weather Service 1440 series data tapes for the years 1954 through 1972. A year of 8760 hours for each of 234 stations was prepared.

Nine weather elements (total horizontal radiation, maximum, minimum and mean of dry-bulb and dew point and the maximum and mean of wind velocity) were identified as critical. They were weighted with the solar radiation as 50% and the rest at 50%.

Typical weather months were identified by their closeness to long- term cumulative distribution functions. In the final selection, lengths of hot and cold periods with sunny or cloudy days were used. The TMY is made up of typical months selected. These tapes are recommended for solar design problems because of the highest weighting factor of solar radiation in selection of typical meteorological months (ASHRAE Handbook, 1985, p. 24.3).

5.3 An Application of TMY Methodology

In this study, the methodology of TMY was applied, with several variations, to construct Hourly Model Weather Data Base for Oklahoma City area. One major difference between the methodologies of TMY and current study was the existence of solar radiation data.

The major steps involved selection of 12 months of typical weather conditions using the daily weather values of recent 10 years, interpolation of missing and/or 3 hourly observed data, and the calculation of solar radiation intensities.

Three hourly or missing weather values were interpolated by linear interpolation and the connection of two consecutive months which may be selected from different years were smoothed by Cubic Spline interpolation.

For the calculation of the clear sky solar radiation and the cloudy sky radiation, ASHRAE method (ASHRAE Handbook, 1985) and the empirical equations introduced by Kimura and Stephenson (1969) were applied, respectively.

Figure 5.1 shows the procedure of constructing the Model Weather Data Base.

5.3.1 Source Weather Data

Every month, National Climatic Data Center issues the "Monthly Summary of Local Climatological Data" consisting of the daily values (Maximum, Minimum, and Average) of weather elements. These values are derived from hourly weather observations of the location. In this study, recent 10 year weather data of January 1976 through December 1985 were used to represent the long term climatic conditions of the Oklahoma City area.

Eight weather elements critical for building energy calculations were selected. Differently from TMY which was for the locations having solar radiation data, this study started with no solar radiation data. The weather elements which were identified as critical include:

(1) daily maximum dry bulb temperature (Tmax)
(2) daily minimum dry bulb temperature (Tmin)
(3) daily average dry bulb temperature (Tave)
(4) daily average dew point temperature (Tdew)
(5) daily maximum wind velocity (Wmax)
(6) daily average wind velocity (Wave)
(7) daily average cloud cover ratio from sunrise to sunset (CCss)
(8) daily average cloud cover ratio from midnight to midnight (CCmm)

The codes in parentheses indicate variable names used in this study.

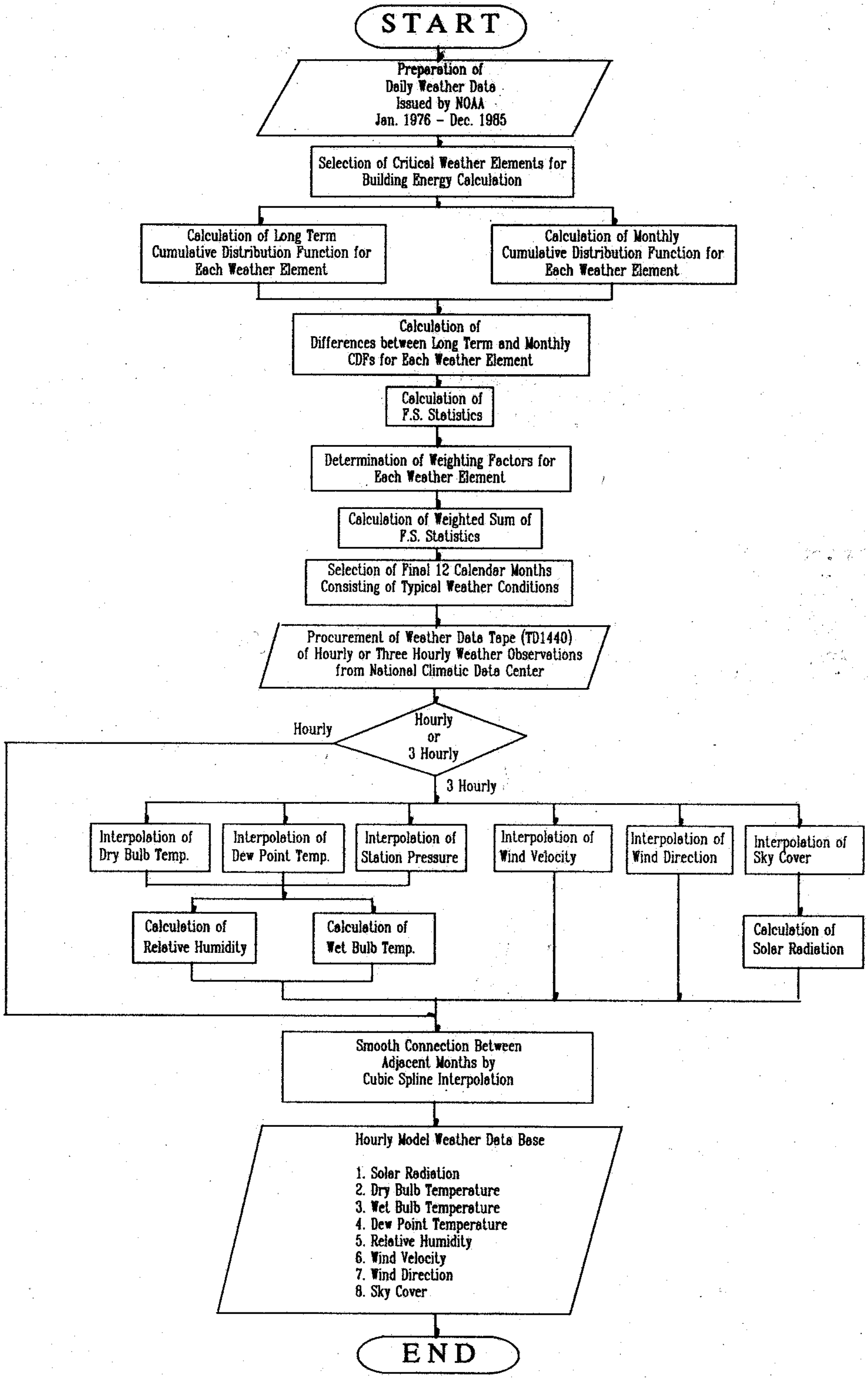

Fig. 5.1 Procedure of constructing Model Weather Data Base

5.3.2 Cumulative Distribution Function

Cumulative distribution functions were obtained by first sorting the data in increasing order, then, using the following equation.

$$CDF_{X(i)} = K / (N+1)^{1} \qquad \text{(Eq. 5.1)}$$

where $CDF_{X(i)}$ = Cumulative distribution function of a value of weather element X(i).

K = the Kth value in order of magnitude of the climatological series

N = the total number of terms in the climatological series.

The division by (N+1) instead of N gives a better estimate of population probabilities, especially at the ends of the distribution (John E. Oliver, 1973, p. 453). CDF is a monotonously increasing step function which is bounded by zero and one. For example, to calculate the long term CDFs of daily average temperatures of March, all the average temperature values over 10 years, i.e., 31 x 10 = 310 data, were sorted to put in increasing order, and then the CDF for every value of average temperature was calculated using above equation. To calculate the monthly CDFs for a March, 31 values were sorted in increasing order. By this way, the two different CDFs, long term and monthly, were given to each of the specific values of average temperature. This procedure was applied to determine the long term and monthly cumulative distributions of the 8 weather elements.

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[1] Oliver, John E., 1973, p. 413

5.3.3 Finkelstein-Schafer Statistics

After determining the cumulative distribution functions, the average of the differences between the monthly CDFs and long term CDFs were calculated for the 8 weather elements to determine the closeness of monthly statistics to the long term statistics. This average differences between the CDFs are called Finkelstein-Schafer (FS) statistics and given by:

$$FS = \frac{\Sigma d_i}{n} \qquad \text{(Eq. 5.2)}$$

where d_i = the absolute difference between the long term CDF and the monthly CDF at a value of a weather element. (i = 1.... n).

n = the total number of different values of a weather element. (If there are several same degrees of average temperatures in a month, only 1 is to be added to count n.)

Tables 5.1.1 through 5.1.12 show the FS statistics for each calendar month.

5.3.4 Weighted Sum of FS Statistics

For the selection of month/year combinations of typical weather conditions, the matching of certain cumulative distribution of some weather elements is more important than matching those of other elements.

The different importance of weather elements may be expressed by weighting factors of the elements. And then, the sum of weighted FS statistics were examined to determine the closeness of the weather condition of a specific month to that of long term. The weighted sum of FS statistics is given by:

$$W_S = \sum_{i=1}^{n} (W_i \times FS_i) \qquad \text{(Eq. 5.3)}$$

where W_S = sum of weighted FS statistics

W_i = Weighting factor of a weather element

FS_i= FS statistics of a weather element

The weighting factors were determined in somewhat subjective manner. To determine the weighting factor of each weather element, the relative importance scales were given to the 8 weather elements. The importance scales were 1 to 9 with the step of 1. The scale 1 means that two weather elements being compared have same importance and 9 indicates that a weather element is extremely more important than the other one.

The 8 weather elements were grouped into 3 categories, temperature group, i.e., wind velocity group and cloud cover group, and then the importance scales were given to them. After determining the weighting factors for these three groups, the importance scales were given to 8 weather elements within each groups. Table 5.2 shows the relative importance scales among the three groups.

Table 5.1.1 F.S. statistic values for January

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.156	0.093	0.220	0.207	0.069	0.104	0.071	0.084	0.033	0.098
Tmin	0.069	0.152	0.178	0.176	0.156	0.079	0.036	0.188	0.045	0.045
Tave	0.142	0.129	0.203	0.208	0.117	0.085	0.048	0.146	0.047	0.082
Tdew	0.048	0.110	0.167	0.097	0.113	0.085	0.069	0.200	0.046	0.031
Wave	0.081	0.154	0.016	0.079	0.071	0.079	0.115	0.087	0.049	0.037
Wmax	0.056	0.025	0.057	0.043	0.056	0.072	0.065	0.144	0.066	0.027
CCss	0.251	0.038	0.110	0.071	0.183	0.068	0.057	0.024	0.119	0.052
CCmm	0.230	0.032	0.101	0.074	0.139	0.057	0.048	0.067	0.129	0.015

Table 5.1.2 F.S. statistic values for February

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.264	0.138	0.303	0.199	0.055	0.083	0.065	0.051	0.142	0.105
Tmin	0.172	0.055	0.196	0.194	0.097	0.048	0.068	0.115	0.107	0.046
Tave	0.243	0.120	0.269	0.196	0.066	0.069	0.071	0.070	0.142	0.084
Tdew	0.048	0.068	0.153	0.093	0.072	0.072	0.036	0.162	0.067	0.042
Wave	0.027	0.067	0.045	0.041	0.126	0.047	0.033	0.110	0.049	0.040
Wmax	0.096	0.058	0.105	0.046	0.043	0.048	0.068	0.185	0.022	0.038
CCss	0.024	0.090	0.163	0.064	0.082	0.088	0.048	0.169	0.206	0.017
CCmm	0.054	0.085	0.121	0.085	0.065	0.059	0.056	0.150	0.240	0.030

Table 5.1.3 F.S. statistic values for March

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.090	0.083	0.081	0.040	0.072	0.075	0.064	0.094	0.151	0.051
Tmin	0.046	0.067	0.089	0.023	0.128	0.059	0.052	0.026	0.118	0.130
Tave	0.044	0.101	0.072	0.037	0.116	0.062	0.065	0.079	0.168	0.061
Tdew	0.050	0.106	0.061	0.048	0.148	0.069	0.026	0.053	0.046	0.154
Wave	0.072	0.095	0.034	0.068	0.099	0.076	0.077	0.085	0.077	0.065
Wmax	0.116	0.089	0.032	0.061	0.153	0.072	0.094	0.159	0.136	0.111
CCss	0.082	0.108	0.095	0.052	0.043	0.037	0.063	0.150	0.036	0.098
CCmm	0.090	0.086	0.083	0.039	0.035	0.038	0.060	0.104	0.029	0.081

Table 5.1.4 F.S. statistic values for April

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.060	0.081	0.148	0.070	0.055	0.171	0.086	0.167	0.140	0.064
Tmin	0.072	0.087	0.132	0.053	0.166	0.178	0.124	0.190	0.144	0.126
Tave	0.083	0.075	0.131	0.063	0.118	0.160	0.084	0.178	0.150	0.090
Tdew	0.057	0.049	0.094	0.061	0.189	0.182	0.101	0.102	0.185	0.114
Wave	0.042	0.058	0.027	0.051	0.033	0.046	0.023	0.027	0.038	0.124
Wmax	0.047	0.040	0.111	0.095	0.044	0.079	0.078	0.054	0.054	0.056
CCss	0.082	0.055	0.051	0.022	0.057	0.062	0.096	0.035	0.060	0.081
CCmm	0.122	0.038	0.100	0.026	0.090	0.050	0.085	0.041	0.062	0.046

Table 5.1.5 F.S. statistic values for May

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.116	0.114	0.058	0.050	0.049	0.064	0.055	0.101	0.062	0.051
Tmin	0.190	0.116	0.057	0.055	0.079	0.071	0.079	0.121	0.038	0.088
Tave	0.163	0.125	0.072	0.057	0.066	0.074	0.082	0.118	0.042	0.074
Tdew	0.133	0.208	0.089	0.033	0.056	0.038	0.089	0.114	0.097	0.046
Wave	0.070	0.154	0.036	0.098	0.105	0.054	0.043	0.079	0.049	0.038
Wmax	0.063	0.076	0.090	0.025	0.031	0.041	0.036	0.126	0.139	0.104
CCss	0.063	0.080	0.048	0.022	0.050	0.095	0.049	0.116	0.033	0.059
CCmm	0.055	0.056	0.085	0.030	0.038	0.107	0.070	0.087	0.028	0.062

Table 5.1.6 F.S. statistic values for June

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.070	0.163	0.038	0.058	0.141	0.074	0.193	0.159	0.053	0.040
Tmin	0.158	0.085	0.068	0.085	0.221	0.088	0.176	0.137	0.094	0.054
Tave	0.121	0.147	0.047	0.091	0.209	0.089	0.203	0.167	0.067	0.048
Tdew	0.105	0.131	0.114	0.029	0.040	0.133	0.057	0.094	0.125	0.136
Wave	0.020	0.124	0.046	0.093	0.061	0.027	0.079	0.169	0.060	0.052
Wmax	0.054	0.043	0.044	0.044	0.086	0.084	0.070	0.176	0.064	0.068
CCss	0.058	0.068	0.104	0.028	0.104	0.052	0.160	0.046	0.073	0.039
CCmm	0.140	0.065	0.115	0.029	0.092	0.061	0.177	0.051	0.069	0.060

Table 5.1.7 F.S. statistic values for July

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.139	0.063	0.257	0.135	0.370	0.055	0.158	0.078	0.076	0.145
Tmin	0.243	0.079	0.183	0.085	0.189	0.158	0.091	0.057	0.110	0.075
Tave	0.198	0.062	0.213	0.111	0.353	0.080	0.148	0.072	0.079	0.122
Tdew	0.097	0.130	0.054	0.211	0.315	0.163	0.193	0.026	0.308	0.056
Wave	0.062	0.124	0.140	0.246	0.091	0.020	0.076	0.060	0.147	0.032
Wmax	0.095	0.074	0.042	0.117	0.072	0.030	0.049	0.089	0.162	0.044
CCss	0.045	0.025	0.101	0.128	0.233	0.060	0.133	0.041	0.072	0.040
CCmm	0.033	0.032	0.080	0.116	0.250	0.063	0.122	0.049	0.066	0.045

Table 5.1.8 F.S. statistic values for August

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.050	0.145	0.059	0.111	0.297	0.194	0.062	0.053	0.061	0.076
Tmin	0.184	0.045	0.032	0.168	0.266	0.148	0.124	0.160	0.067	0.031
Tave	0.081	0.100	0.045	0.146	0.275	0.190	0.079	0.102	0.073	0.065
Tdew	0.202	0.232	0.076	0.110	0.191	0.074	0.033	0.254	0.205	0.064
Wave	0.060	0.080	0.034	0.193	0.110	0.046	0.071	0.195	0.111	0.126
Wmax	0.044	0.062	0.048	0.058	0.164	0.050	0.044	0.135	0.074	0.067
CCss	0.078	0.131	0.030	0.091	0.034	0.079	0.054	0.162	0.029	0.038
CCmm	0.082	0.134	0.025	0.072	0.044	0.090	0.050	0.191	0.032	0.028

Table 5.1.9 F.S. statistic values for September

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.077	0.072	0.114	0.090	0.107	0.066	0.034	0.040	0.095	0.096
Tmin	0.113	0.120	0.178	0.169	0.029	0.052	0.050	0.032	0.079	0.066
Tave	0.117	0.117	0.155	0.127	0.065	0.063	0.037	0.022	0.081	0.071
Tdew	0.060	0.164	0.175	0.080	0.063	0.048	0.103	0.025	0.203	0.058
Wave	0.173	0.137	0.029	0.288	0.079	0.049	0.072	0.100	0.085	0.143
Wmax	0.081	0.025	0.030	0.215	0.047	0.061	0.088	0.082	0.028	0.123
CCss	0.095	0.038	0.110	0.175	0.077	0.043	0.078	0.139	0.051	0.035
CCmm	0.085	0.047	0.099	0.188	0.079	0.047	0.067	0.161	0.051	0.035

Table 5.1.10 F.S. statistic values for October

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.123	0.054	0.121	0.136	0.073	0.126	0.050	0.070	0.075	0.109
Tmin	0.190	0.018	0.051	0.045	0.112	0.042	0.059	0.112	0.059	0.047
Tave	0.176	0.056	0.069	0.105	0.031	0.065	0.060	0.051	0.051	0.045
Tdew	0.147	0.051	0.120	0.112	0.126	0.106	0.036	0.139	0.091	0.128
Wave	0.095	0.063	0.037	0.132	0.062	0.104	0.135	0.060	0.066	0.032
Wmax	0.051	0.089	0.044	0.113	0.041	0.090	0.148	0.071	0.057	0.070
CCss	0.021	0.053	0.235	0.044	0.209	0.187	0.060	0.092	0.149	0.108
CCmm	0.028	0.046	0.198	0.072	0.187	0.180	0.097	0.109	0.169	0.083

Table 5.1.11 F.S. statistic values for November

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.076	0.066	0.030	0.050	0.106	0.062	0.037	0.044	0.036	0.086
Tmin	0.169	0.053	0.061	0.098	0.019	0.097	0.068	0.066	0.045	0.057
Tave	0.120	0.057	0.027	0.069	0.094	0.099	0.062	0.049	0.027	0.075
Tdew	0.190	0.053	0.133	0.156	0.063	0.132	0.062	0.050	0.071	0.043
Wave	0.164	0.059	0.045	0.041	0.047	0.105	0.042	0.048	0.107	0.036
Wmax	0.028	0.026	0.054	0.046	0.022	0.068	0.044	0.061	0.091	0.044
CCss	0.165	0.090	0.079	0.122	0.090	0.029	0.064	0.055	0.035	0.171
CCmm	0.112	0.095	0.131	0.178	0.099	0.044	0.076	0.058	0.055	0.180

Table 5.1.12 F.S. statistic values for December

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.063	0.033	0.049	0.107	0.084	0.069	0.051	0.269	0.048	0.089
Tmin	0.085	0.031	0.126	0.116	0.041	0.043	0.116	0.207	0.155	0.122
Tave	0.042	0.026	0.074	0.114	0.066	0.064	0.089	0.255	0.085	0.105
Tdew	0.097	0.095	0.119	0.031	0.109	0.073	0.118	0.190	0.192	0.093
Wave	0.135	0.074	0.111	0.052	0.062	0.076	0.101	0.037	0.030	0.086
Wmax	0.058	0.089	0.109	0.086	0.055	0.061	0.145	0.058	0.061	0.062
CCss	0.220	0.024	0.047	0.058	0.054	0.023	0.066	0.116	0.177	0.129
CCmm	0.229	0.035	0.045	0.023	0.044	0.019	0.089	0.084	0.166	0.083

Table 5.2 Relative importance scales between 3 major weather groups

	TEMP	WIND	CLOUD
TEMP	1	5	3
WIND		1	1/2
CLOUD			1

This table shows that the temperature group is 5 times and 3 times more important than the wind velocity group and the cloud cover group, respectively, and wind group is less important than cloud cover group by a half times. Above table, then, can be represented by simultaneous linear equation, with the variables of W_T, W_W and W_C for temperature, wind and cloud cover groups, respectively.

$$W_T + W_W + W_C = 1 \quad \text{(Sum of weighting factors equals one)}$$

$$W_T - 5\ W_W = 0$$

$$W_T - 3\ W_C = 0$$

$$W_W - 0.5\ W_C = 0$$

By solving above simultaneous linear equations, the following weighting factors were determined.

$W_T = 0.648$ (weighting factor of temperature group)

$W_W = 0.122$ (weighting factor of wind group)

$W_C = 0.230$ (weighting factor of cloud cover group)

Tables 5.3 through 5.5 show the relative importance scales within each group.

Table 5.3 Relative importance scales within temperature group

Temp.	Tmax	Tmin	Tave	Tdew
Tmax	1	1	1/5	1/2
Tmin		1	1/5	1/2
Tave			1	4
Tdew				1

Table 5.4 Relative importance scales within wind velocity group

Wind Vel.	Wmax	Wave
Wmax	1	1
Wave		1

Table 5.5 Relative importance scales within cloud cover group

Cloud Cover	CCss	CCmm
CCss	1	7
CCmm		1

By solving simultaneous linear equations within each group, the weighting factors were determined as shown in Table 5.6.

The largest weighting factor, 0.389, was given to daily average temperature followed by cloud cover ratio of sunrise to sunset with the weighting factor of 0.2. Relatively large weighting factor was given to the cloud cover ratio of sunrise to sunset, because the cloud cover data were employed to estimate solar radiation data using the equation of Kimura and Stephenson (1969).

Table 5.6 Weighting factors

i) Weather Elements	W_i
1) Average Temperature	0.389
2) Dew Point Temperature	0.123
3) Maximum Temperature	0.069
4) Minimum Temperature	0.069
5) Maximum Wind Velocity	0.060
6) Average Wind Velocity	0.060
7) Cloud Cover, Sunrise to Sunset	0.200
8) Cloud Cover, Midnight to Midnight	0.030
Total	1.000

5.3.5 Selection of Candidates

By examining the weighted sum of FS statistics, 3 candidate years were selected for each of the 12 calendar months. Basically the month/year combinations with smallest weighted sum of FS statistics values were selected as candidates. Table 5.7 gives three candidates month/year combinations for the twelve calendar months. Tables 5.8.1 through 5.8.12 show weighted sums of FS statistics.

Table 5.7 Candidates for 12 calendar months

Months	Cand. #1	Cand. #2	Cand. #3
Jan.	1982	1985	1984
Feb.	1985	1982	1981
Mar.	1979	1981	1982
Apr.	1979	1977	1976
May.	1979	1984	1980
Jun.	1985	1979	1978
Jul.	1983	1977	1981
Aug.	1978	1985	1982
Sep.	1981	1982	1983
Oct.	1977	1982	1985
Nov.	1984	1983	1978
Dec.	1977	1981	1980

Table 5.8.1 Weighted Sum of F.S. statistics for January

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	1.08	0.64	1.52	1.43	0.48	0.72	0.49	0.58	0.23	0.68
Tmin	0.47	1.05	1.23	1.21	1.08	0.55	0.25	1.30	0.31	0.31
Tave	5.52	5.01	7.89	8.08	4.55	3.30	1.86	5.67	1.83	3.20
Tdew	0.60	1.35	2.05	1.20	1.39	1.05	0.84	2.46	0.56	0.38
Wave	0.48	0.93	0.10	0.47	0.43	0.48	0.69	0.52	0.29	0.22
Wmax	0.34	0.15	0.34	0.26	0.33	0.43	0.39	0.87	0.40	0.16
CCss	5.01	0.77	2.21	1.42	3.66	1.36	1.13	0.48	2.38	1.03
CCmm	0.69	0.09	0.30	0.22	0.42	0.17	0.14	0.20	0.39	0.04
WS	14.19	9.98	15.63	14.29	12.33	8.06	5.80	12.07	6.38	6.03

Table 5.8.2 Weighted Sum of F.S. statistics for February

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	1.82	0.95	2.09	1.38	0.38	0.57	0.45	0.35	0.98	0.73
Tmin	1.19	0.38	1.35	1.34	0.67	0.33	0.47	0.79	0.74	0.32
Tave	9.44	4.68	10.46	7.61	2.57	2.70	2.77	2.70	5.53	3.25
Tdew	0.59	0.84	1.88	1.15	0.89	0.88	0.45	1.99	0.83	0.51
Wave	0.16	0.40	0.27	0.25	0.75	0.28	0.20	0.66	0.29	0.24
Wmax	0.58	0.35	0.63	0.28	0.26	0.29	0.41	1.11	0.13	0.23
CCss	0.48	1.80	3.26	1.29	1.64	1.75	0.96	3.37	4.11	0.34
CCmm	0.16	0.26	0.36	0.26	0.19	0.18	0.17	0.45	0.72	0.09
WS	14.42	9.65	20.30	13.55	7.34	6.98	5.87	11.42	13.34	5.71

Table 5.8.3 Weighted Sum of F.S. statistics for March

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.62	0.57	0.56	0.28	0.50	0.52	0.44	0.65	1.04	0.35
Tmin	0.32	0.46	0.61	0.16	0.88	0.41	0.36	0.18	0.81	0.90
Tave	1.72	3.91	2.81	1.44	4.52	2.41	2.54	3.07	6.54	2.36
Tdew	0.62	1.31	0.76	0.59	1.82	0.85	0.32	0.65	0.56	1.90
Wave	0.43	0.57	0.20	0.41	0.59	0.45	0.46	0.51	0.46	0.39
Wmax	0.70	0.54	0.19	0.37	0.92	0.43	0.56	0.96	0.81	0.66
CCss	1.64	2.15	1.89	1.04	0.85	0.74	1.27	2.99	0.72	1.95
CCmm	0.27	0.26	0.25	0.12	0.10	0.11	0.18	0.31	0.09	0.24
WS	6.33	9.77	7.27	4.40	10.18	5.93	6.14	9.32	11.05	8.75

Table 5.8.4 Weighted Sum of F.S. statistics for April

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.41	0.56	1.02	0.49	0.38	1.18	0.59	1.15	0.96	0.44
Tmin	0.49	0.60	0.91	0.37	1.15	1.23	0.86	1.31	0.99	0.87
Tave	3.23	2.91	5.11	2.46	4.58	6.23	3.28	6.93	5.84	3.49
Tdew	0.70	0.60	1.16	0.75	2.32	2.24	1.24	1.26	2.28	1.40
Wave	0.25	0.35	0.16	0.30	0.20	0.27	0.14	0.16	0.23	0.75
Wmax	0.28	0.24	0.66	0.57	0.27	0.48	0.47	0.32	0.32	0.34
CCss	1.64	1.11	1.01	0.44	1.13	1.25	1.93	0.71	1.21	1.63
CCmm	0.36	0.11	0.30	0.08	0.27	0.15	0.25	0.12	0.19	0.14
WS	7.37	6.48	10.34	5.45	10.30	13.02	8.75	11.96	12.01	9.05

Table 5.8.5 Weighted Sum of F.S. statistics for May

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.80	0.78	0.40	0.35	0.34	0.44	0.38	0.69	0.43	0.35
Tmin	1.31	0.80	0.40	0.38	0.54	0.49	0.55	0.84	0.26	0.61
Tave	6.33	4.86	2.79	2.23	2.56	2.88	3.20	4.61	1.64	2.89
Tdew	1.63	2.56	1.09	0.40	0.68	0.47	1.10	1.40	1.19	0.57
Wave	0.42	0.92	0.21	0.59	0.63	0.33	0.26	0.48	0.29	0.23
Wmax	0.38	0.46	0.54	0.15	0.19	0.24	0.22	0.76	0.84	0.62
CCss	1.27	1.60	0.97	0.45	1.00	1.90	0.99	2.31	0.66	1.19
CCmm	0.16	0.17	0.25	0.09	0.12	0.32	0.21	0.26	0.08	0.19
WS	12.31	12.15	6.65	4.63	6.05	7.07	6.90	11.35	5.39	6.64

Table 5.8.6 Weighted Sum of F.S. statistics for June

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.48	1.13	0.26	0.40	0.97	0.51	1.33	1.10	0.37	0.27
Tmin	1.09	0.59	0.47	0.59	1.53	0.61	1.21	0.95	0.65	0.37
Tave	4.72	5.73	1.82	3.56	8.14	3.46	7.88	6.51	2.61	1.86
Tdew	1.30	1.61	1.40	0.36	0.49	1.64	0.70	1.15	1.54	1.68
Wave	0.12	0.75	0.27	0.56	0.36	0.16	0.47	1.01	0.36	0.31
Wmax	0.32	0.26	0.26	0.26	0.52	0.50	0.42	1.06	0.38	0.41
CCss	1.16	1.37	2.07	0.57	2.07	1.04	3.20	0.91	1.45	0.77
CCmm	0.42	0.19	0.35	0.09	0.27	0.18	0.53	0.15	0.21	0.18
WS	9.62	11.61	6.90	6.38	14.35	8.11	15.75	12.84	7.58	5.86

Table 5.8.7 Weighted Sum of F.S. statistics for July

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.96	0.43	1.77	0.93	2.55	0.38	1.09	0.54	0.52	1.00
Tmin	1.68	0.55	1.26	0.59	1.30	1.09	0.63	0.39	0.76	0.52
Tave	7.71	2.39	8.29	4.31	13.72	3.13	5.74	2.79	3.09	4.74
Tdew	1.19	1.59	0.66	2.59	3.88	2.00	2.37	0.32	3.79	0.69
Wave	0.37	0.74	0.84	1.48	0.55	0.12	0.46	0.36	0.88	0.19
Wmax	0.57	0.44	0.25	0.70	0.43	0.18	0.29	0.53	0.97	0.27
CCss	0.91	0.50	2.01	2.55	4.66	1.19	2.67	0.83	1.45	0.79
CCmm	0.10	0.10	0.24	0.35	0.75	0.19	0.36	0.15	0.20	0.13
WS	13.49	**6.74**	15.33	13.50	27.84	**8.28**	13.61	**5.91**	11.67	8.32

Table 5.8.8 Weighted Sum of F.S. statistics for August

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.35	1.00	0.41	0.77	2.05	1.34	0.43	0.36	0.42	0.53
Tmin	1.27	0.31	0.22	1.16	1.84	1.02	0.85	1.10	0.46	0.21
Tave	3.17	3.88	1.74	5.68	10.71	7.39	3.09	3.97	2.84	2.54
Tdew	2.49	2.85	0.94	1.36	2.35	0.91	0.41	3.13	2.52	0.78
Wave	0.36	0.48	0.20	1.16	0.66	0.27	0.43	1.17	0.67	0.75
Wmax	0.26	0.37	0.29	0.35	0.98	0.30	0.27	0.81	0.45	0.40
CCss	1.56	2.62	0.60	1.83	0.68	1.58	1.09	3.24	0.58	0.77
CCmm	0.25	0.40	0.08	0.22	0.13	0.27	0.15	0.57	0.10	0.08
WS	9.71	11.92	**4.47**	12.51	19.40	13.08	**6.70**	14.35	8.03	**6.07**

Table 5.8.9 Weighted Sum of F.S. statistics for September

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.53	0.50	0.79	0.62	0.74	0.45	0.23	0.28	0.66	0.66
Tmin	0.78	0.83	1.23	1.17	0.20	0.36	0.34	0.22	0.55	0.46
Tave	4.55	4.56	6.03	4.96	2.53	2.45	1.43	0.84	3.16	2.77
Tdew	0.74	2.02	2.15	0.99	0.77	0.59	1.27	0.31	2.50	0.71
Wave	1.04	0.82	0.17	1.73	0.47	0.30	0.43	0.60	0.51	0.86
Wmax	0.49	0.15	0.18	1.29	0.28	0.36	0.53	0.49	0.17	0.74
CCss	1.89	0.76	2.19	3.50	1.55	0.85	1.56	2.77	1.03	0.70
CCmm	0.25	0.14	0.30	0.56	0.24	0.14	0.20	0.48	0.15	0.10
WS	10.27	9.78	13.04	14.82	6.77	5.51	**6.00**	**6.00**	8.72	6.99

Table 5.8.10 Weighted Sum of F.S. statistics for October

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.85	0.37	0.84	0.94	0.50	0.87	0.35	0.49	0.51	0.75
Tmin	1.31	0.13	0.35	0.31	0.77	0.29	0.41	0.77	0.41	0.33
Tave	6.84	2.18	2.67	4.09	1.22	2.51	2.34	1.98	1.98	1.76
Tdew	1.81	0.62	1.48	1.38	1.55	1.31	0.44	1.71	1.12	1.58
Wave	0.57	0.38	0.22	0.79	0.37	0.63	0.81	0.36	0.39	0.19
Wmax	0.30	0.54	0.26	0.68	0.25	0.54	0.89	0.43	0.34	0.42
CCss	0.42	1.06	4.69	0.87	4.19	3.73	1.21	1.84	2.97	2.16
CCmm	0.09	0.14	0.60	0.22	0.56	0.54	0.29	0.33	0.51	0.25
WS	12.18	5.41	11.11	9.27	9.41	10.41	6.73	7.91	8.23	7.45

Table 5.8.11 Weighted Sum of F.S. statistics for November

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.53	0.46	0.21	0.34	0.73	0.43	0.26	0.30	0.24	0.59
Tmin	1.16	0.36	0.42	0.68	0.13	0.67	0.47	0.46	0.31	0.39
Tave	4.68	2.21	1.05	2.69	3.65	3.85	2.40	1.92	1.05	2.91
Tdew	2.34	0.66	1.64	1.91	0.78	1.62	0.76	0.61	0.87	0.53
Wave	0.98	0.35	0.27	0.24	0.28	0.63	0.25	0.29	0.64	0.22
Wmax	0.17	0.16	0.32	0.27	0.13	0.41	0.27	0.37	0.54	0.26
CCss	3.31	1.81	1.57	2.45	1.80	0.58	1.28	1.11	0.69	3.42
CCmm	0.34	0.29	0.39	0.53	0.30	0.13	0.23	0.17	0.17	0.54
WS	13.51	6.29	5.88	9.12	7.80	8.33	5.91	5.23	4.53	8.86

Table 5.8.12 Weighted Sum of F.S. statistics for December

ELMNT	76	77	78	79	80	81	82	83	84	85
Tmax	0.43	0.23	0.33	0.74	0.58	0.48	0.35	1.86	0.33	0.61
Tmin	0.59	0.21	0.87	0.80	0.29	0.30	0.80	1.43	1.07	0.84
Tave	1.65	1.01	2.87	4.44	2.56	2.50	3.45	9.94	3.30	4.08
Tdew	1.19	1.17	1.47	0.38	1.34	0.90	1.45	2.34	2.37	1.15
Wave	0.81	0.44	0.67	0.31	0.37	0.45	0.60	0.22	0.18	0.51
Wmax	0.35	0.53	0.66	0.52	0.33	0.37	0.87	0.35	0.37	0.37
CCss	4.40	0.48	0.95	1.15	1.07	0.46	1.32	2.31	3.54	2.59
CCmm	0.69	0.11	0.13	0.07	0.13	0.06	0.27	0.25	0.50	0.25
WS	10.10	4.19	7.95	8.41	6.67	5.51	9.11	18.70	11.65	10.40

5.3.6 Final Selection of Twelve Calendar Months

The final selection of the twelve month/year combinations representing typical long term weather conditions involved examining statistics and persistence structure associated with daily average dry bulb temperature and cloud cover ratio of sunrise to sunset. The statistics examined were the FS statistics and the deviations of the monthly mean and median from the long term mean and median.

Finally the 12 month/year combinations as shown in Table 5.9 were selected for twelve calendar months of the most typical climatic conditions in Oklahoma City area. Tables 5.10.1 and 5.10.2 give the means, standard deviations, and medians of daily average temperature and cloud cover for the 3 candidate years. Figures 5.2.1 through 5.2.24 show the cumulative distributions of daily average dry bulb temperature and cloud cover of the candidates for 12 calendar months.

Table 5.9 Model Weather Month/Year combinations for 12 calendar months

Month	Year	Month	Year
January	1982	July	1983
February	1985	August	1978
March	1979	September	1981
April	1979	October	1977
May	1979	November	1984
June	1985	December	1981

Table 5.10.1 Statistics of Tave and CCss for candidate years

MONTH	ELE-MENT	YEAR	MEAN VALUE	MEAN Diff.	S.D. VALUE	S.D. Diff.	MEDIAN VALUE	MEDIAN Diff.
JAN	Tave	LONG	33.6581	-	11.0048	-	34.0	-
		82	35.5484	1.8903	12.5242	1.5194	36.0	2.0
		85	30.8387	-2.8194	9.1619	-1.8429	32.0	-2.0
		84	34.2258	0.5677	12.8341	1.8293	38.0	4.0
	CCss	LONG	5.7903	-	3.9030	-	7.0	-
		82	5.9032	0.1129	3.4771	-0.4259	6.0	-1.0
		85	6.1290	0.3387	3.7125	-0.1905	8.0	1.0
		84	4.4839	-1.3064	3.9989	0.0959	4.0	-3.0
FEB	Tave	LONG	40.7224	-	12.9673	-	42.0	-
		85	37.3929	-3.3295	12.9310	-0.0363	41.0	-1.0
		82	37.8929	-2.8295	14.3794	1.4121	39.0	-3.0
		81	44.1786	3.4562	14.1752	1.2079	46.0	-4.0
	CCss	LONG	5.9929	-	3.7531	-	7.0	-
		85	6.2500	0.2571	3.8067	0.0536	7.0	0.0
		82	6.5357	0.5428	3.5011	-0.2520	7.5	0.5
		81	5.0357	-0.9572	4.5032	0.7501	4.0	-3.0
MAR	Tave	LONG	50.8355	-	9.2297	-	51.0	-
		79	51.6774	0.8419	8.2032	-1.0265	50.0	-1.0
		81	52.0968	1.2613	6.6199	-2.6098	52.0	1.0
		82	52.9677	2.1322	10.0945	0.8648	54.0	3.0
	CCss	LONG	6.1097	-	3.7027	-	7.0	-
		79	5.7742	-0.3355	3.4901	-0.2126	5.0	-2.0
		81	6.1290	0.0193	3.3935	-0.3092	7.0	0.0
		82	6.8065	0.6968	3.3707	-0.3320	8.0	1.0
APR	Tave	LONG	59.8367	-	8.5338	-	61.0	-
		79	58.3667	-1.4700	7.8630	-0.6708	59.5	-1.5
		77	60.6667	0.8300	12.1011	3.5673	64.5	3.5
		76	61.8333	1.9966	5.1361	-3.3978	61.5	0.5
	CCss	LONG	5.6633	-	3.5832	-	6.0	-
		79	5.8333	0.1700	3.5534	-0.0298	6.0	0.0
		77	5.1333	-0.5300	3.9543	0.3711	5.5	-0.5
		76	6.6000	0.9367	3.3896	-0.1936	8.0	2.0
MAY	Tave	LONG	65.5323	-	6.7429	-	68.0	-
		79	66.0000	0.4677	7.3621	0.6192	67.0	-1.0
		84	68.6774	3.1451	6.7941	0.0512	71.0	3.0
		80	68.9032	3.3709	6.5542	-0.1887	67.0	-1.0
	CCss	LONG	5.9807	-	3.3462	-	7.0	-
		79	6.0323	0.0516	3.4591	0.1129	7.0	0.0
		84	5.8065	-0.1743	3.6531	0.3069	6.0	-1.0
		80	6.3226	0.3419	2.8094	-0.5369	7.0	0.0
JUN	Tave	LONG	76.7067	-	5.7809	-	77.5	-
		85	76.2000	-0.5067	4.9018	-0.8791	77.0	-0.5
		79	74.8000	-1.9067	5.8037	0.0228	75.0	-2.5
		78	77.6000	0.8933	5.7870	0.0061	78.0	0.5
	CCss	LONG	5.2733	-	3.3320	-	6.0	-
		85	5.6333	0.3600	3.3060	-0.0260	5.5	-0.5
		79	5.2667	-0.0066	3.1397	-0.1923	5.5	-0.5
		78	4.1333	-1.1400	3.4314	0.0994	4.0	-2.0

Table 5.10.2 Statistics of Tave and CCss for candidate years

MONTH	ELE-MENT	YEAR	MEAN		S.D.		MEDIAN	
			VALUE	Diff.	VALUE	Diff.	VALUE	Diff.
JUL	Tave	LONG	83.0613	-	4.4292	-	83.0	-
		83	81.8710	-1.1903	4.6314	0.2022	83.0	0.0
		77	83.2258	0.1645	3.4030	-1.0262	83.0	0.0
		81	84.4516	1.3903	5.2398	0.8106	85.0	2.0
	CCss	LONG	3.6613	-	3.1743	-	3.0	-
		83	3.2581	-0.4032	3.3363	0.1620	2.0	-1.0
		77	3.5484	-0.1129	3.3450	0.1707	2.0	-1.0
		81	4.2903	0.6290	3.1853	0.0110	4.0	1.0
AUG	Tave	LONG	82.5032	-	4.6799	-	83.0	-
		78	82.8387	0.3355	5.2795	0.5996	84.0	1.0
		85	81.5161	-0.9871	4.4786	-0.2013	82.0	-1.0
		82	83.6452	1.1420	3.7554	-0.9245	84.0	1.0
	CCss	LONG	4.3387	-	3.2538	-	4.0	-
		78	4.6452	0.3065	3.3020	0.0482	5.0	1.0
		85	3.9677	-0.3710	3.2196	-0.0342	3.0	-1.0
		82	4.9033	0.5646	3.3502	0.0964	5.0	1.0
SEP	Tave	LONG	75.0033	-	8.3792	-	77.0	-
		81	74.4000	-0.6033	6.7701	-1.6091	76.5	-0.5
		82	74.7000	-0.3033	7.8484	-0.5309	76.5	-0.5
		83	85.1333	10.1300	8.3076	-0.0716	77.0	0.0
	CCss	LONG	4.6433	-	3.5096	-	4.0	-
		81	4.2667	-0.3766	3.2793	-0.2303	4.0	0.0
		82	5.5000	0.8567	3.2563	-0.2533	5.5	1.5
		83	3.1333	-1.5100	3.2027	-0.3069	2.0	-2.0
OCT	Tave	LONG	62.1323	-	8.4665	-	63.0	-
		77	62.8387	0.7064	6.4761	-1.9904	63.0	0.0
		82	62.8710	0.7387	8.5742	0.1077	61.0	-2.0
		85	6.5161	-55.6162	6.7817	-1.6848	62.0	-1.0
	CCss	LONG	5.0129	-	3.8339	-	5.0	-
		77	4.6774	-0.3355	3.6367	-0.1972	5.0	0.0
		82	4.6774	-0.3355	3.2289	-0.6050	5.0	0.0
		85	6.2903	1.2774	3.8660	0.0321	8.0	3.0
NOV	Tave	LONG	48.8633	-	10.0750	-	49.0	-
		84	49.7667	0.9034	9.0884	-0.9866	48.5	-0.5
		83	50.6333	1.7700	10.3906	0.3156	51.0	2.0
		78	50.3000	1.4367	9.6674	-0.4076	50.0	1.0
	CCss	LONG	5.6667	-	3.9447	-	7.0	-
		84	5.3333	-0.3334	3.9334	-0.0114	5.5	-1.5
		83	5.7667	0.1000	4.3604	0.4157	8.0	1.0
		78	6.6333	0.9666	3.8190	-0.1257	9.0	2.0
DEC	Tave	LONG	38.8613	-	11.4879	-	40.0	-
		77	40.2903	1.4290	10.0704	-1.4175	41.0	1.0
		81	39.2903	0.4290	7.8791	-3.6088	39.0	-1.0
		80	42.1613	3.3000	11.9362	0.4483	44.0	4.0
	CCss	LONG	5.4548	-	3.9384	-	6.0	-
		77	5.5161	0.0613	3.8286	-0.1098	6.0	0.0
		81	5.6452	0.1904	3.9879	0.0495	6.0	0.0
		80	6.0000	0.5452	3.6878	-0.2506	9.0	3.0

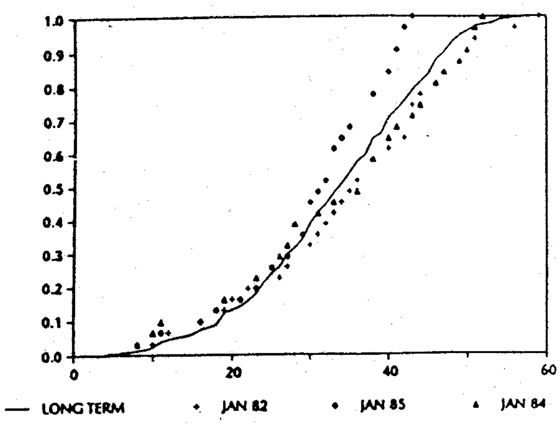

Fig. 5.2.1 CDFs of January Tave

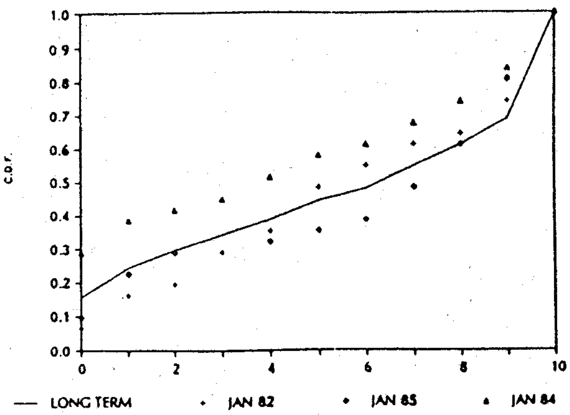

Fig. 5.2.2 CDFs of January CCss

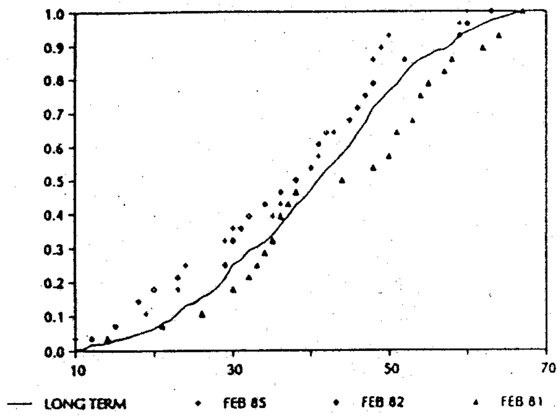

Fig. 5.2.3 CDFs of February Tave

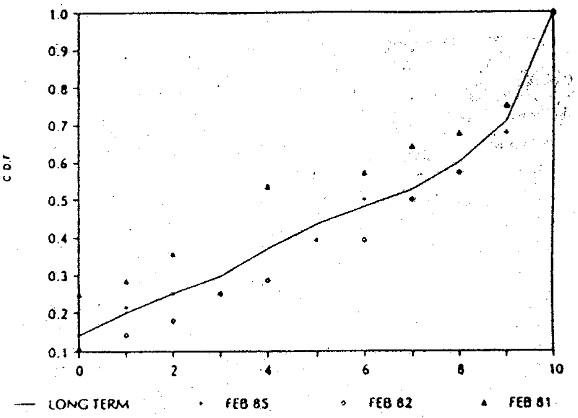

Fig. 5.2.4 CDFs of February CCss

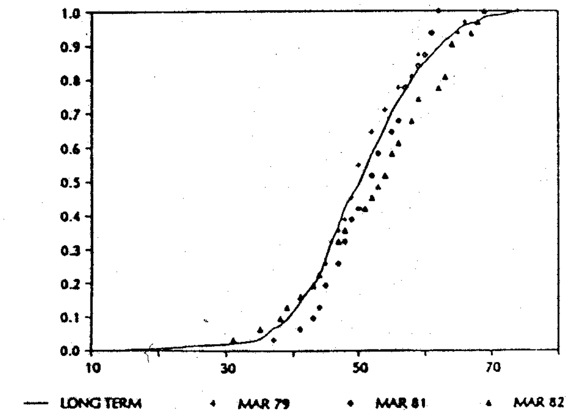

Fig. 5.2.5 CDFs of March Tave

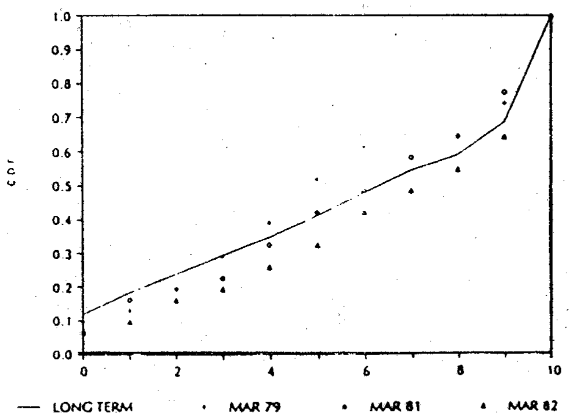

Fig. 5.2.6 CDFs of March CCss

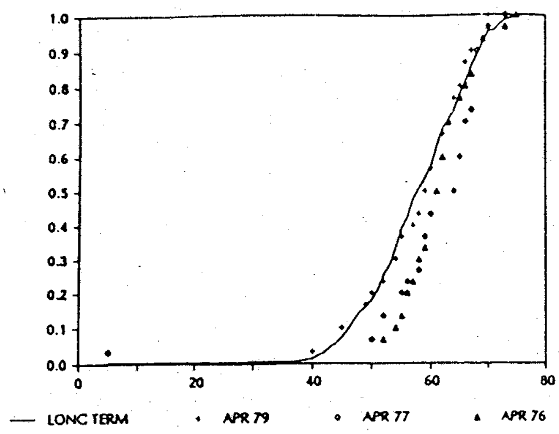

Fig. 5.2.7 CDFs of April Tave

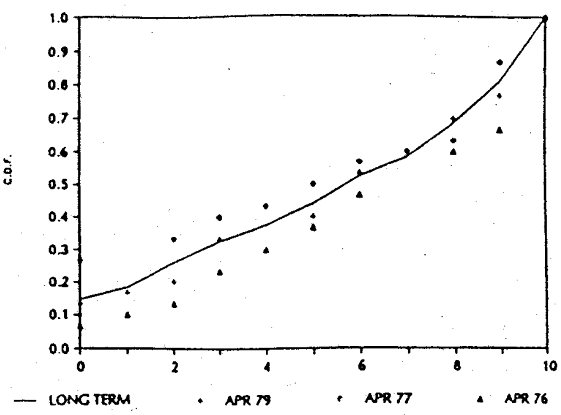

Fig. 5.2.8 CDFs of April CCss

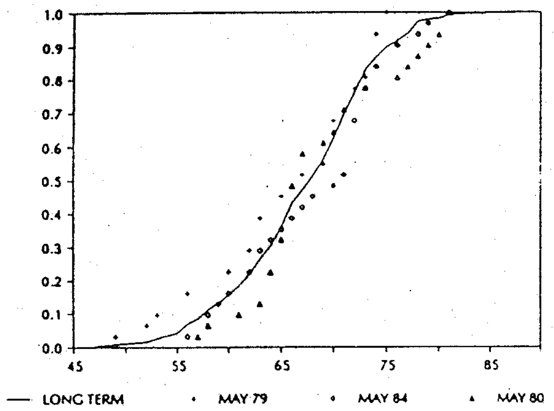

Fig. 5.2.9 CDFs of May Tave

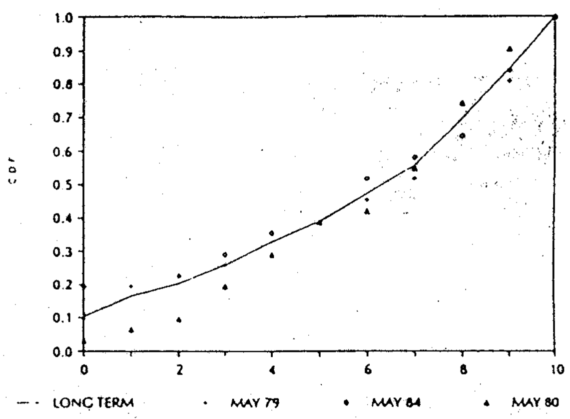

Fig. 5.2.10 CDFs of May CCss

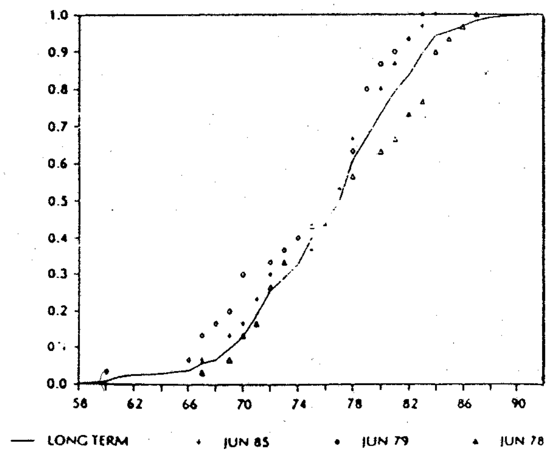

Fig. 5.2.11 CDFs of June Tave

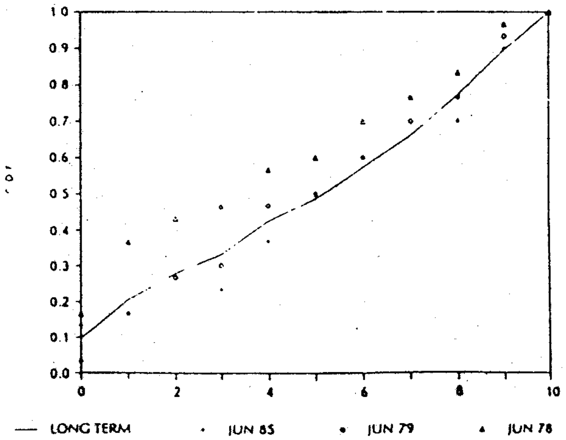

Fig. 5.2.12 CDFs of June CCss

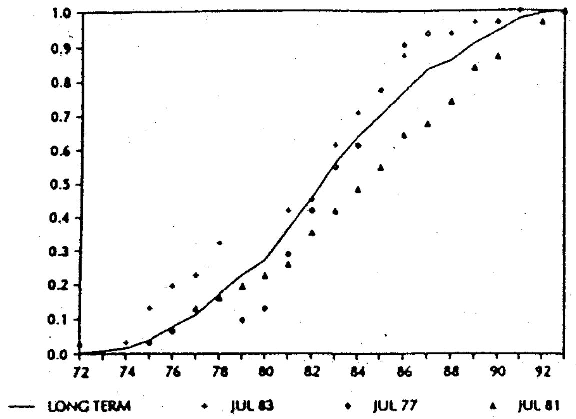

Fig. 5.2.13 CDFs of July Tave

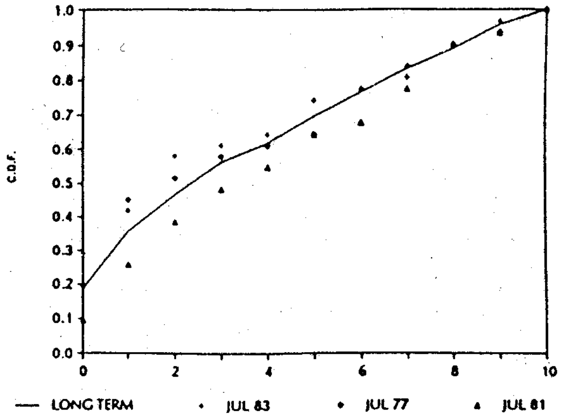

Fig. 5.2.14 CDFs of July CCss

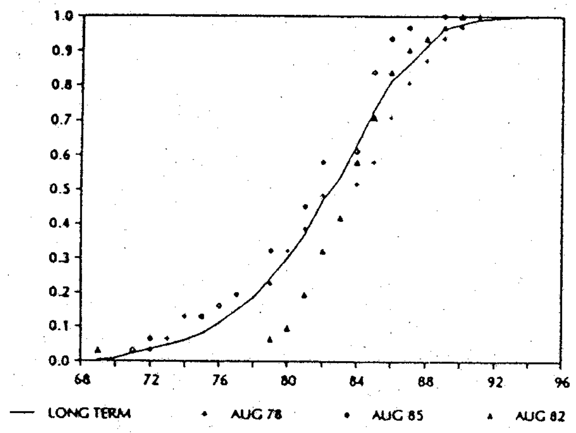

Fig. 5.2.15 CDFs of August Tave

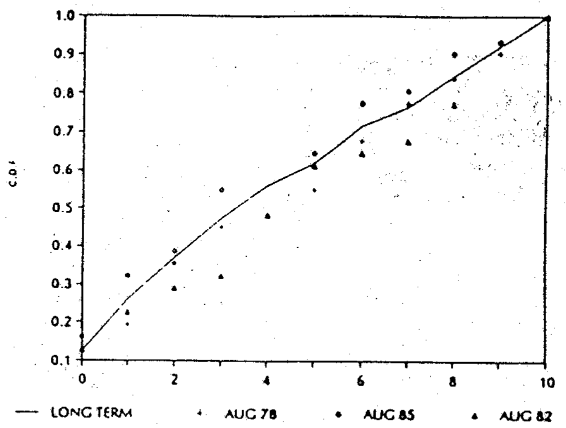

Fig. 5.2.16 CDFs of August CCss

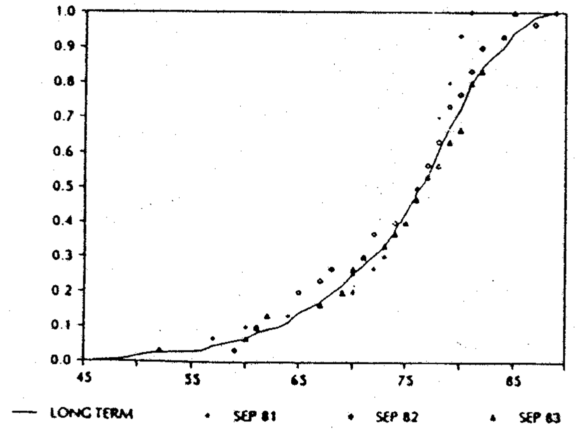

Fig. 5.2.17 CDFs of September Tave

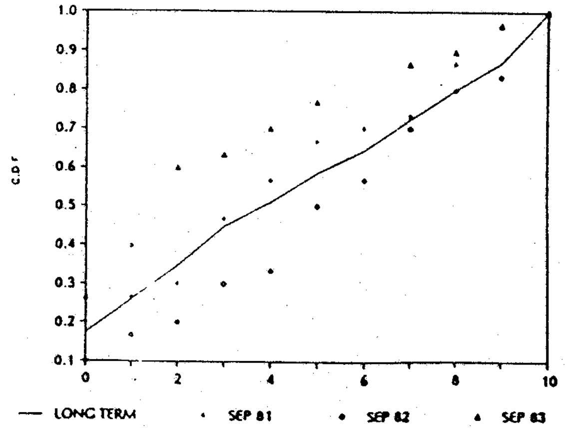

Fig.5.2.18 CDFs of September CCss

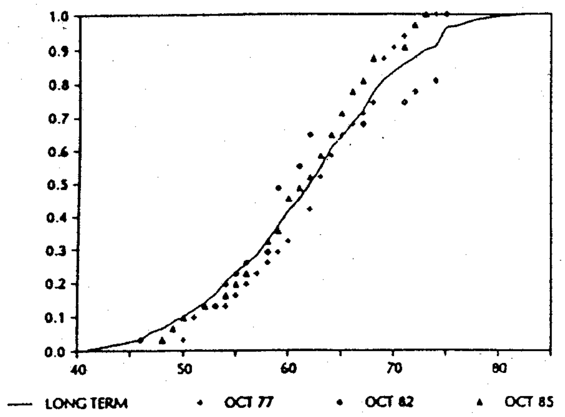

Fig. 5.2.19 CDFs of October Tave

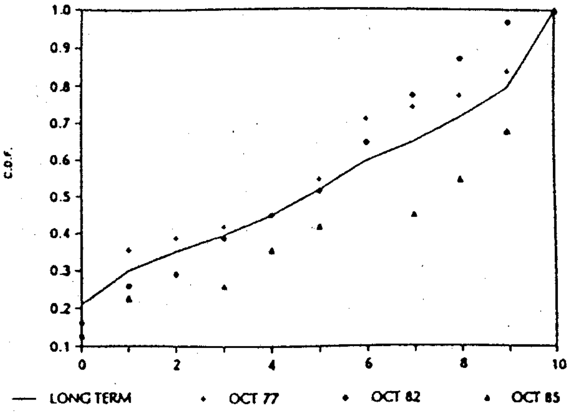

Fig. 5.2.20 CDFs of October CCss

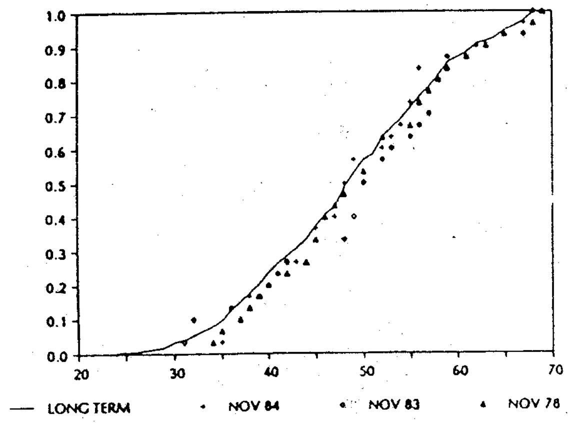

Fig. 5.2.21 CDFs of November Tave

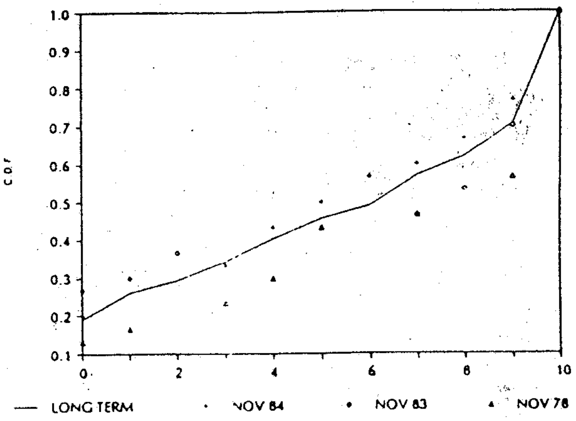

Fig. 5.2.22 CDFs of November CCss

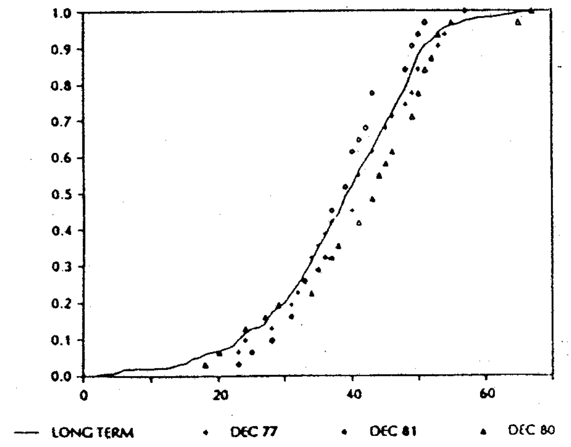

Fig. 5.2.23 CDFs of December Tave

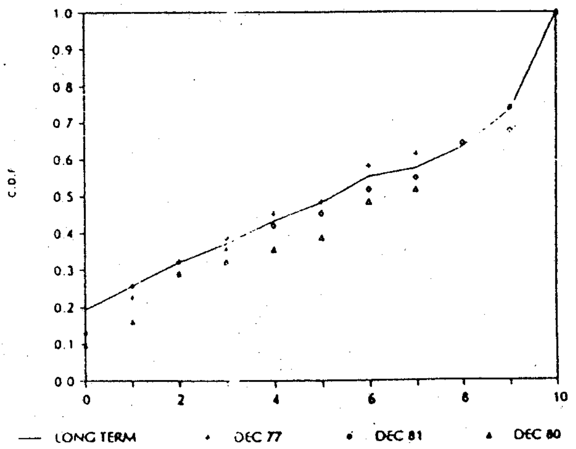

Fig. 5.2.24 CDFs of December CCss

5.3.7 Linear Interpolation of Three Hourly Data

After selecting the twelve calendar months of typical weather conditions in Oklahoma City area, TD-1440 weather data tape (WBAN Hourly Surface Observation) was purchased from the National Climatic Data Center to construct real hourly weather data. This tape contains 41 kinds of weather elements of hourly or 3 hourly surface observations. As critical weather elements for building energy calculations, the following eight weather elements were selected.

1) Dry Bulb Temperature (Tdb)
2) Dew Point Temperature (Tdp)
3) Wet Bulb Temperature (Twb)
4) Relative Humidity (Rhu)
5) Wind Velocity (Wvl)
6) Wind Direction (Wdr)
7) Station Pressure (Spr)
8) Cloud Cover (CC)

Beginning January 1, 1965, for most National Weather Service stations and March 1, 1972, for most Naval Weather Service stations the digitizing of the Airways Observations was reduced from 24 observations per day to 8 observations per day. This three hourly observations correspond to record observations at 00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00, and 21:00 o'clock in Local Standard Time (Local Clock Time). Beginning with August 1981 data, 24 observations per day were again digitized for most active stations (NOAA, Reference Manuals for TD-1440 and TD-3280 Weather Tapes). Table 5.11 shows the model weather month/year combinations consisting of three hourly observations.

Table 5.11 Month/Year combinations of 3 hourly observations

Month	Year
March	1979
April	1979
May	1979
August	1978
October	1977

Among the eight weather elements, 6 weather elements of 3 hourly observations except wet bulb temperature and relative humidity were interpolated by linear interpolation method. For calculating wet bulb temperature and relative humidity, the following equations which were used by National Climatic Data Center (NCDC : Reference Manual for TD-1440, p. 13) were applied.

1) Computation of wet bulb temperature

When dry bulb temperature is 0 or above:

$$Twb=Tdb-(.034Q-.00072Q(Q-1))(Tdb+Tdp-2Spr+108) \quad \text{(Eq. 5.4)}$$

When dry bulb temperature is below zero:

$$Twb=Tdb-(.34Q-.006Q^2)(.6(Tdb+Tdp)-2Spr+108) \quad \text{(Eq. 5.5)}$$

where Twb = Wet Bulb Temperature [°F]

Tdb = Dry Bulb Temperature [°F]

Tdp = Dew Point Temperature [°F]

Spr = Station Pressure [Inch.Hg]

Q = (Tdb-Tdp)/10 [°F]

2) Computation of relative humidity

$$Rhu = \left[\frac{173 - .1Tdb + Tdp}{173 + .9Tdb} \right]^{8} \quad [\%] \qquad \text{(Eq. 5.6)}$$

Figures 5.3.1 and 5.3.2 show examples of interpolated dry bulb and dew point temperature values of March 21 through 24, 1979.

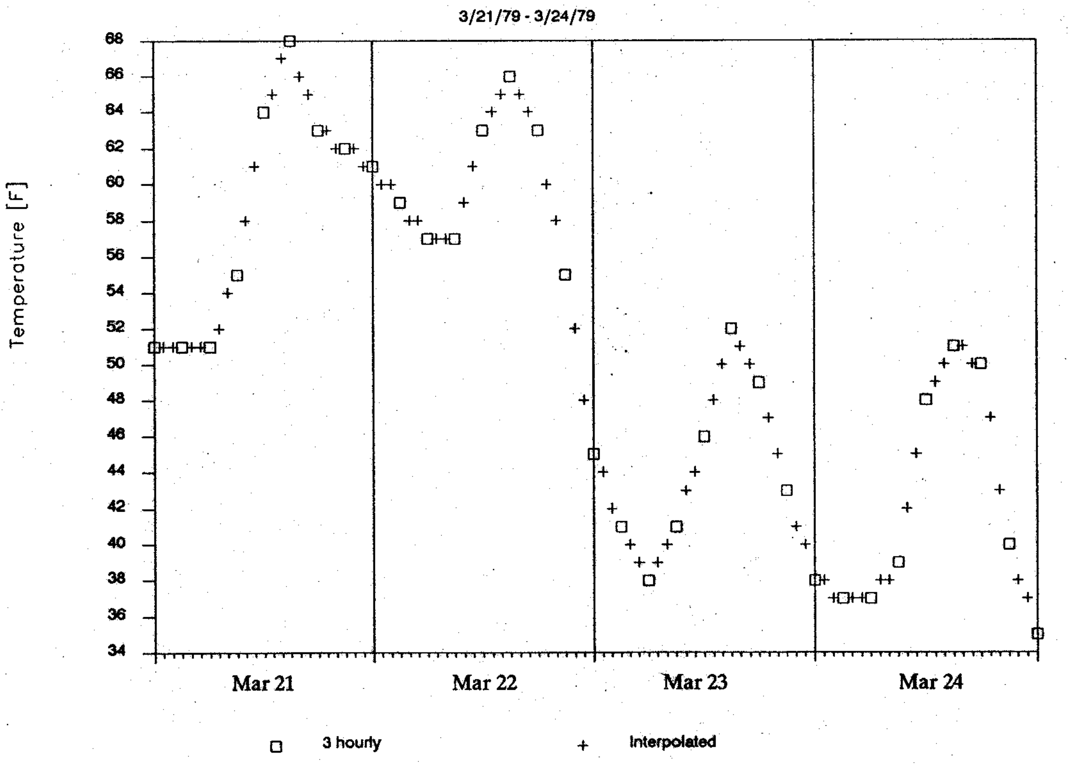

Fig. 5.3.1 Linear interpolation of dry bulb temperature (Tdb).

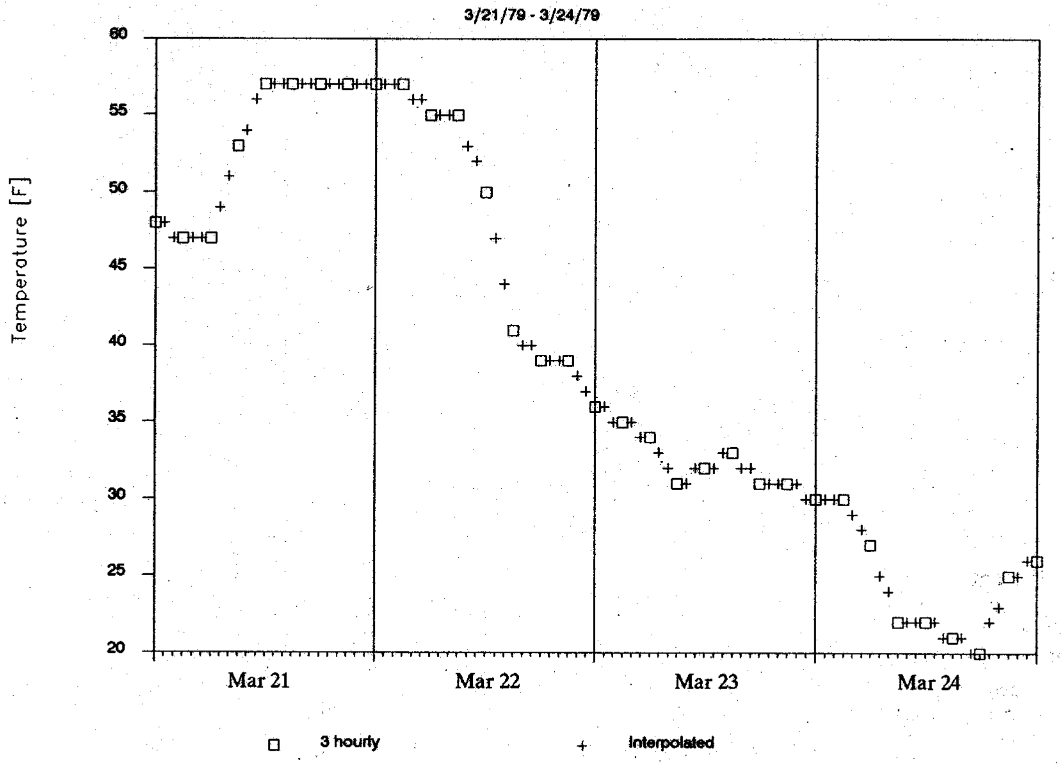

Fig. 5.3.2 Linear interpolation of dew point temperature (Tdp)

5.3.8 Cubic Spline Interpolation for Connections

Up to this point, all the procedures were carried out upon month by month basis. A month/year combinations of typical weather conditions were singled out from 10 month/year combinations, and linear interpolation was also performed for each month.

When the months were connected to construct 12 calendar months, the problem of smoothness occurred otherwise the months were selected from a same year. Even though each model month/year may be typical in weather conditions for the location, the weather conditions at 23:00 o'clock of the last day of a month may not be connected smoothly with those at 00:00 o'clock of the first day of the next month when the 2 months were selected from different years. In this study the months of March, April, and May were selected from the same year of 1979. Except the connections of these months, the following cases of connections were examined for their smoothness.

Case 1, Jan. 1982 ..... Feb. 1985
Case 2, Feb. 1985 ..... Mar. 1979
Case 3, May 1979 ..... Jun. 1985
Case 4, Jun. 1985 ..... Jul. 1983
Case 5, Jul. 1983 ..... Aug. 1978
Case 6, Aug. 1978 ..... Sep. 1981
Case 7, Sep. 1981 ..... Oct. 1977
Case 8, Oct. 1977 ..... Nov. 1984
Case 9, Nov. 1984 ..... Dec. 1981

At first, the examinations were made for dry bulb temperature, dew point temperature, wind direction, wind velocity, and station pressure by plotting the hourly values of the last two days of first months and those of the first two days of the next months.

Because wind direction and wind velocity showed dramatic changes even during a day, and station pressure showed minimal changes between 28 and 29 inHg without certain pattern, these weather elements were not smoothed. But, as dry bulb temperatures showed fluctuations with specific patterns according to the time of the day through the year and dew point temperatures showed almost same patterns as those of the dry bulb temperatures, these two weather elements were smoothed by Cubic Spline interpolation when the values changed abruptly at the connections between the two consecutive months.

Among the 9 cases above, only 2 cases (5 and 9) had smooth connections. Figures 5.4.1 and 5.4.2 show these cases. For the other 7 cases, the original values between 7:00 p.m. of the last day of the first month and 5:00 a.m. of the first day of the next month, 11 data, were replaced with the interpolated values. Figures 5.5.1 through 5.11.2 show these cases. Of course, wet bulb temperature and relative humidity were re-calculated using the interpolated values of dry bulb and dew point temperatures.

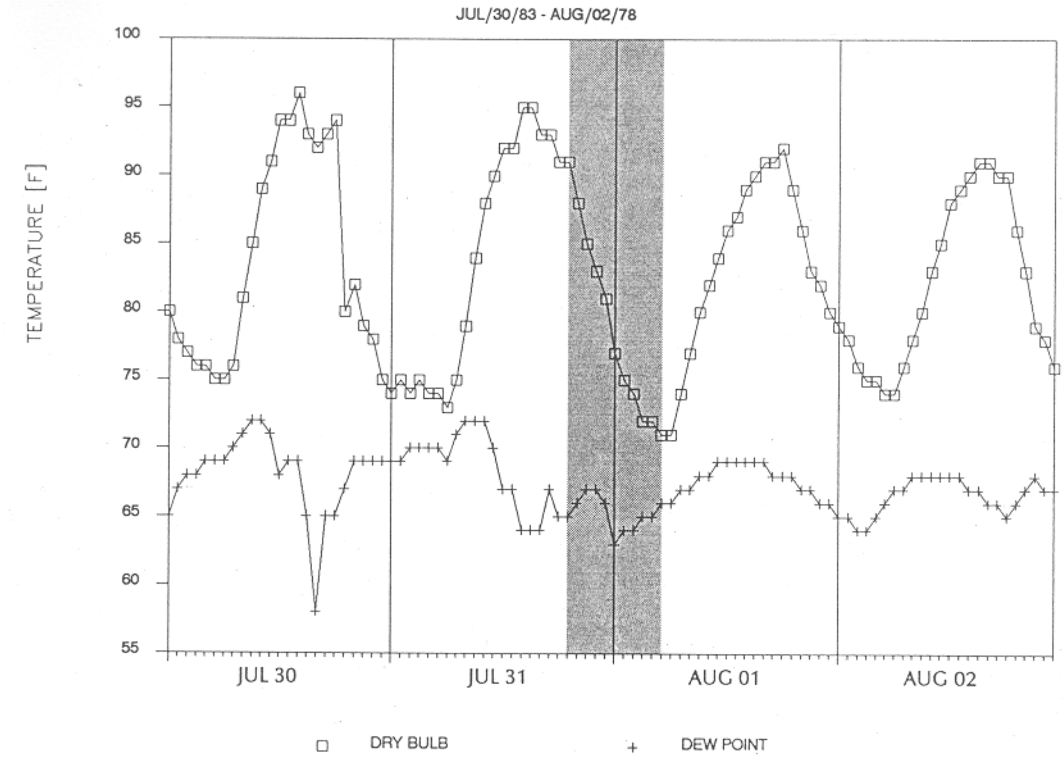

Fig. 5.4.1 Connection case 5 (Original data)

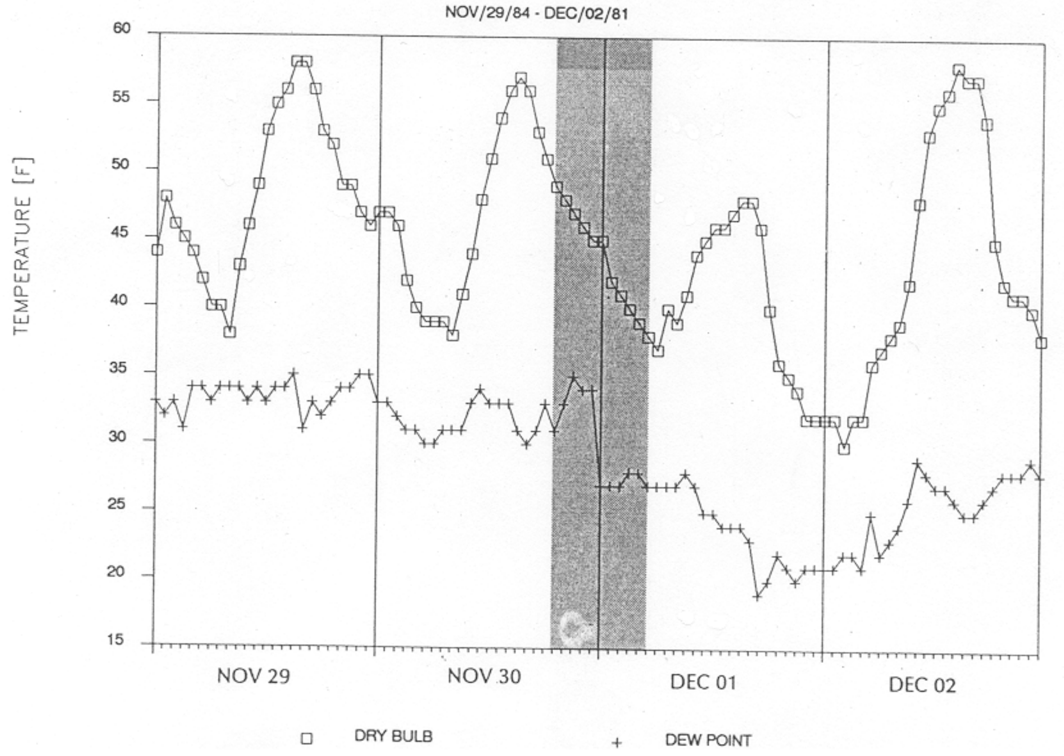

Fig. 5.4.2 Connection case 9 (Original data)

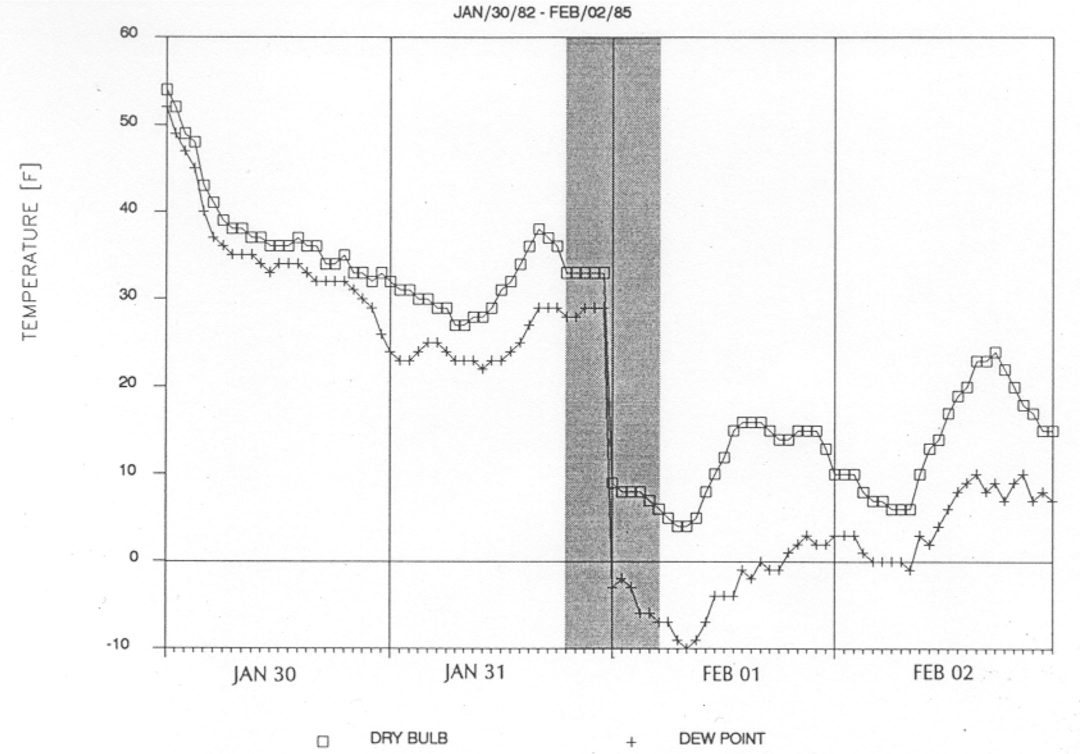

Fig. 5.5.1 Connection case 1 (Original data)

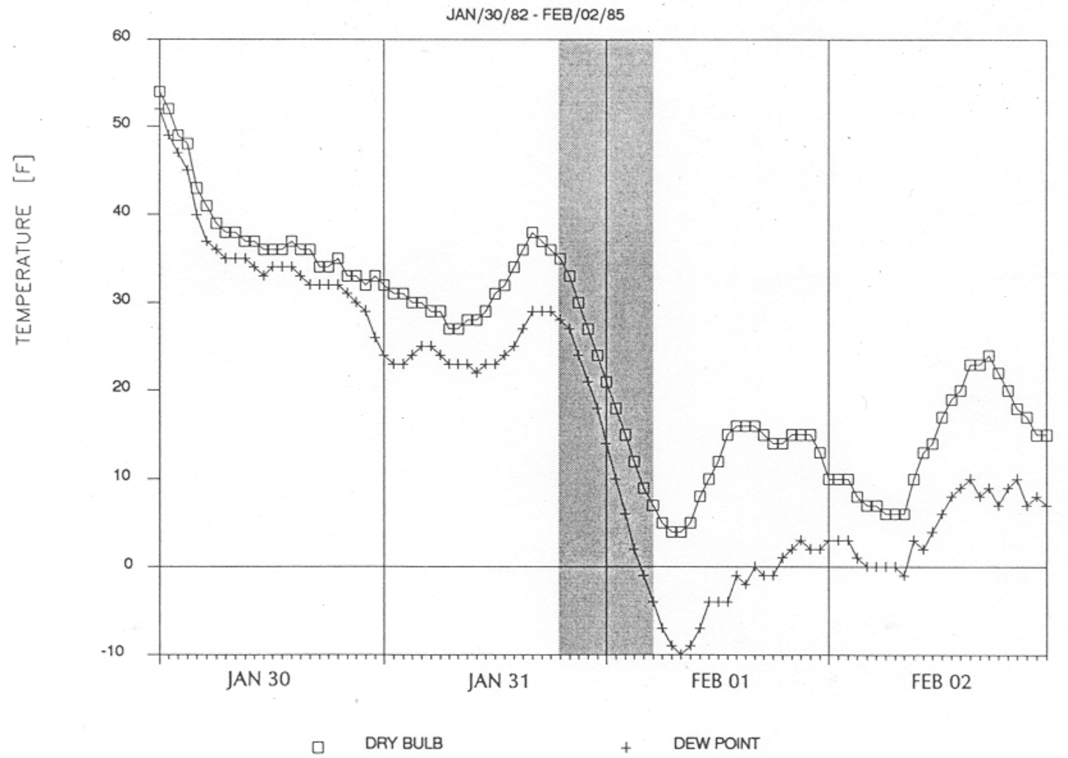

Fig. 5.5.2 Connection case 1 (Cubic Splined)

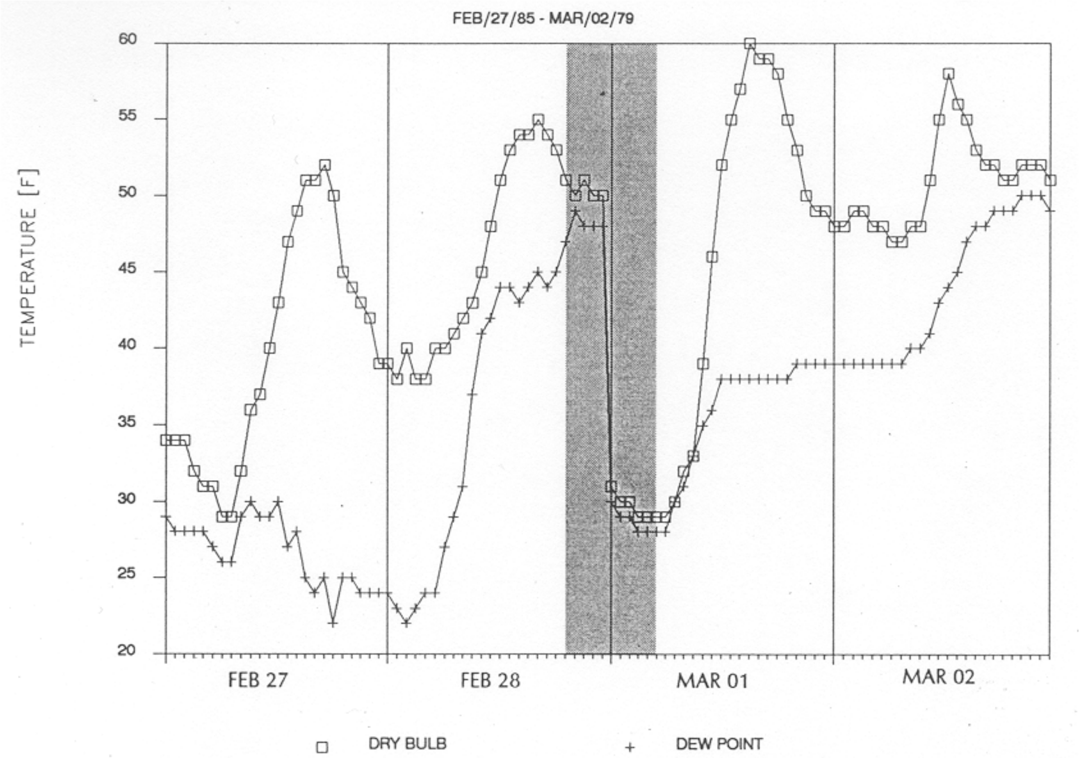

Fig. 5.6.1 Connection case 2 (Original data)

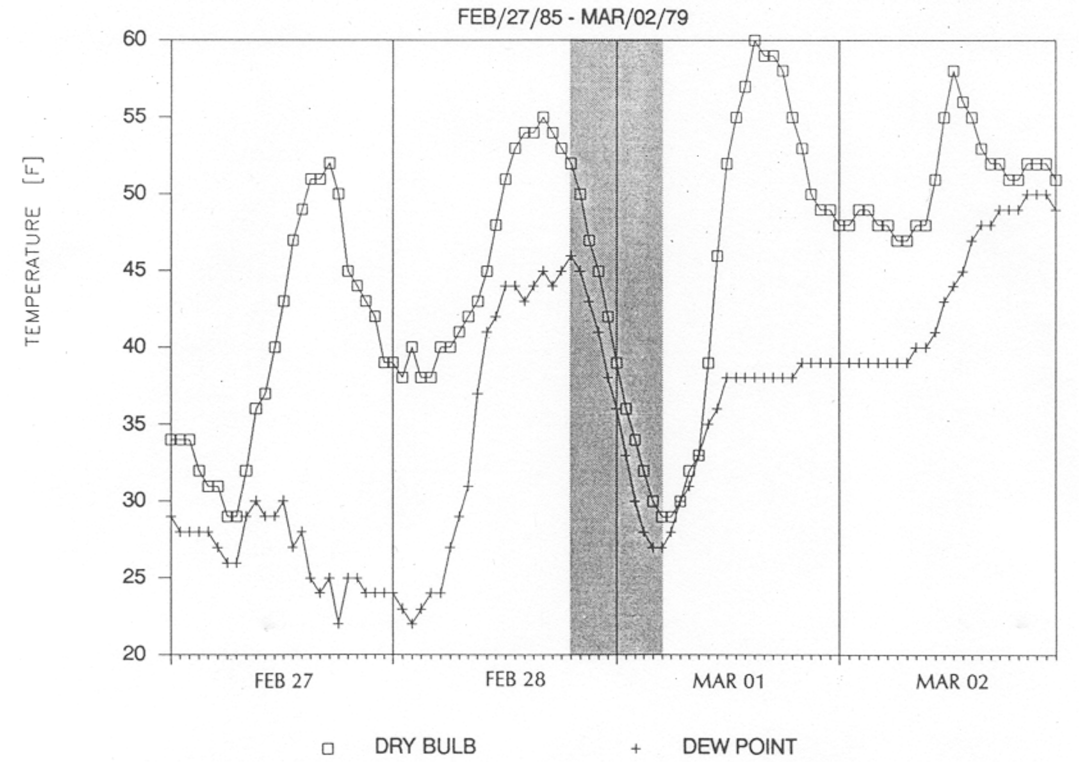

Fig. 5.6.2 Connection case 2 (Cubic Splined)

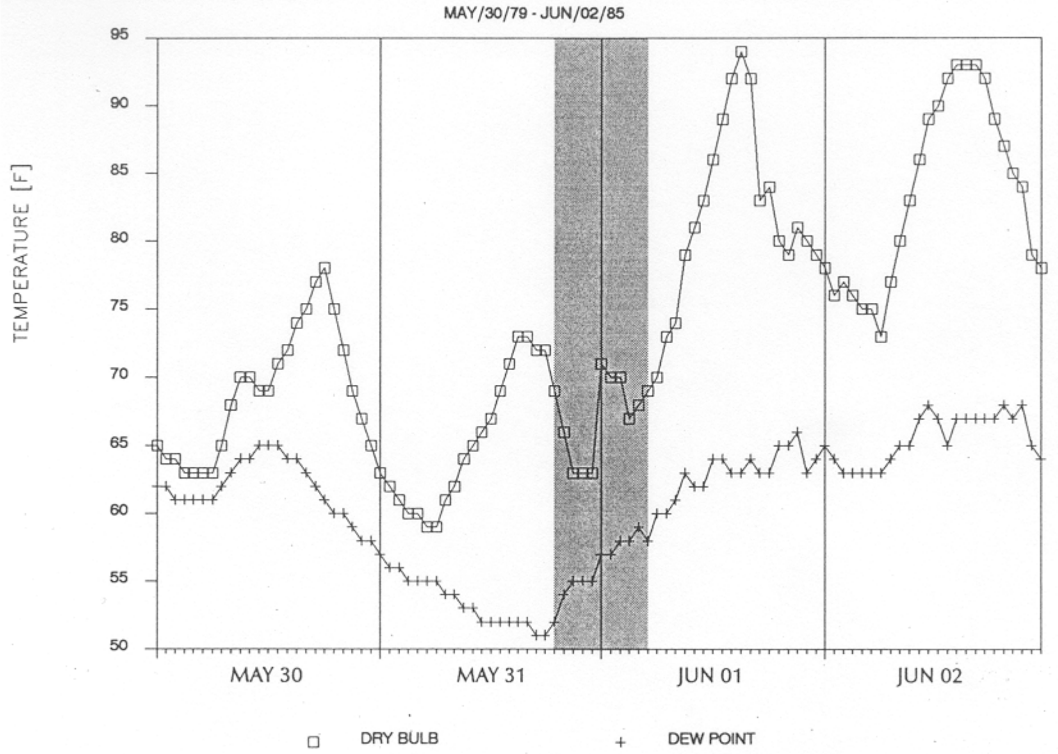

Fig. 5.7.1 Connection case 3 (Original data)

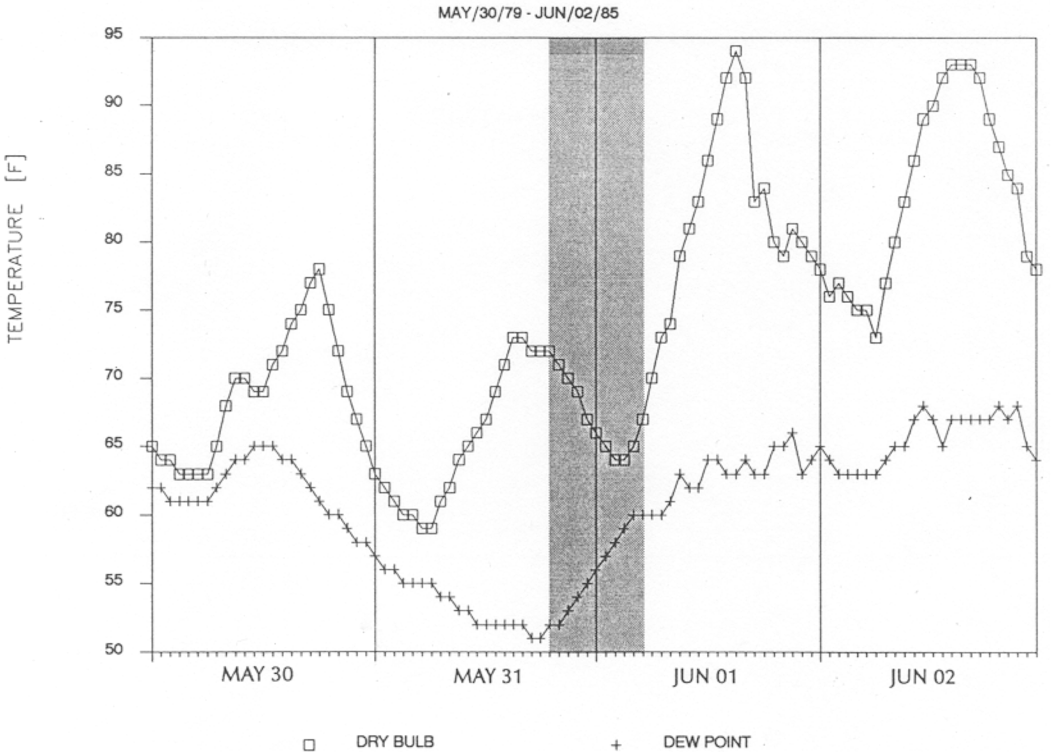

Fig. 5.7.2 Connection case 3 (Cubic Splined)

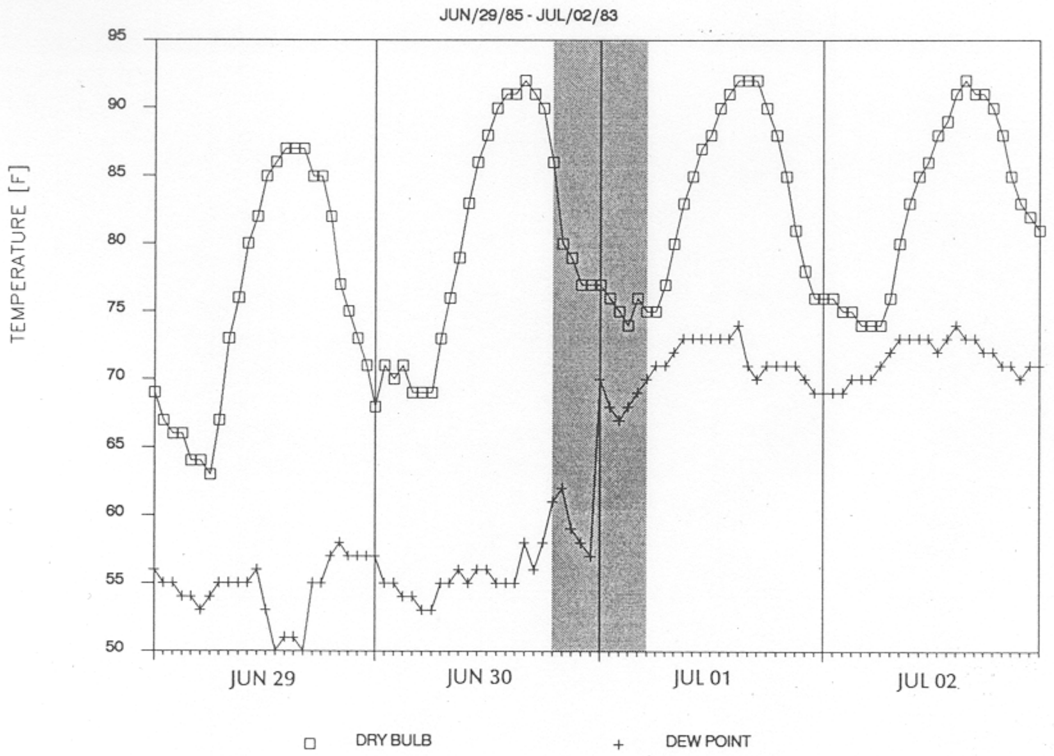

Fig. 5.8.1 Connection case 4 (Original data)

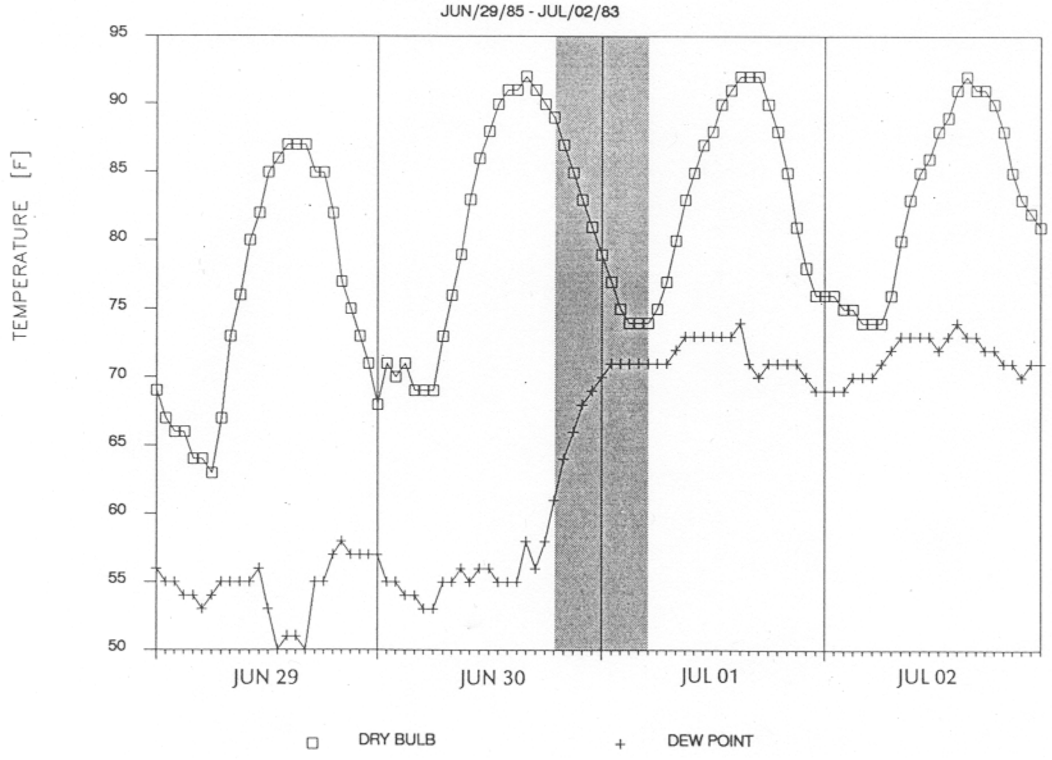

Fig. 5.8.2 Connection case 4 (Cubic Splined)

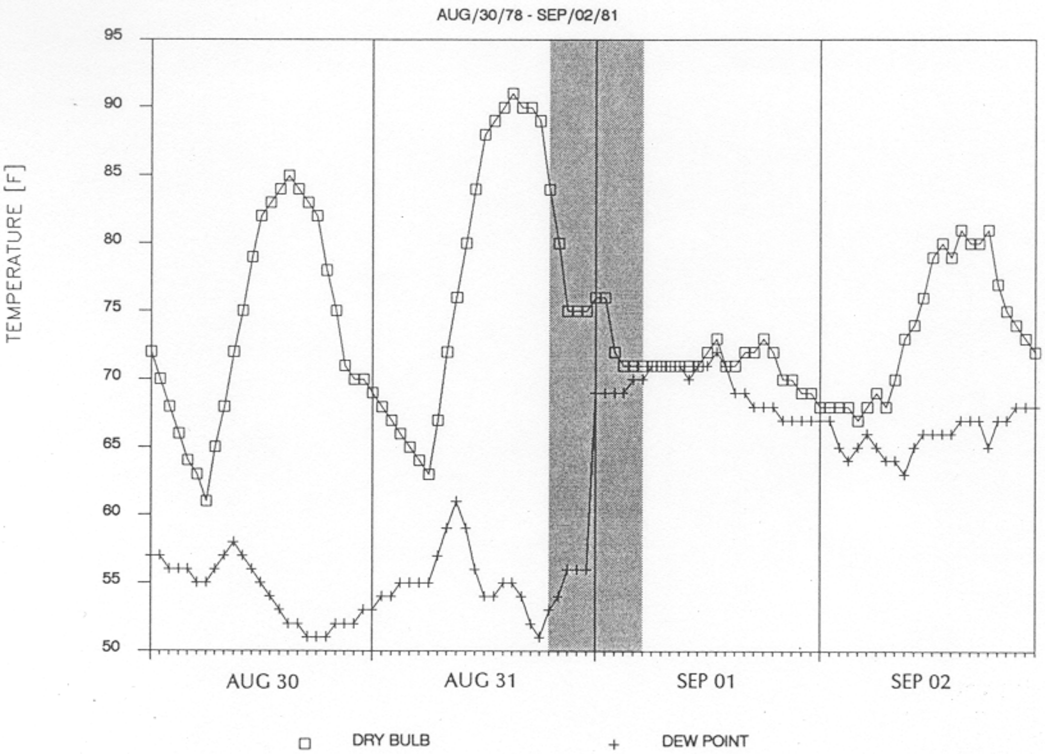

Fig. 5.9.1 Connection case 6 (Original data)

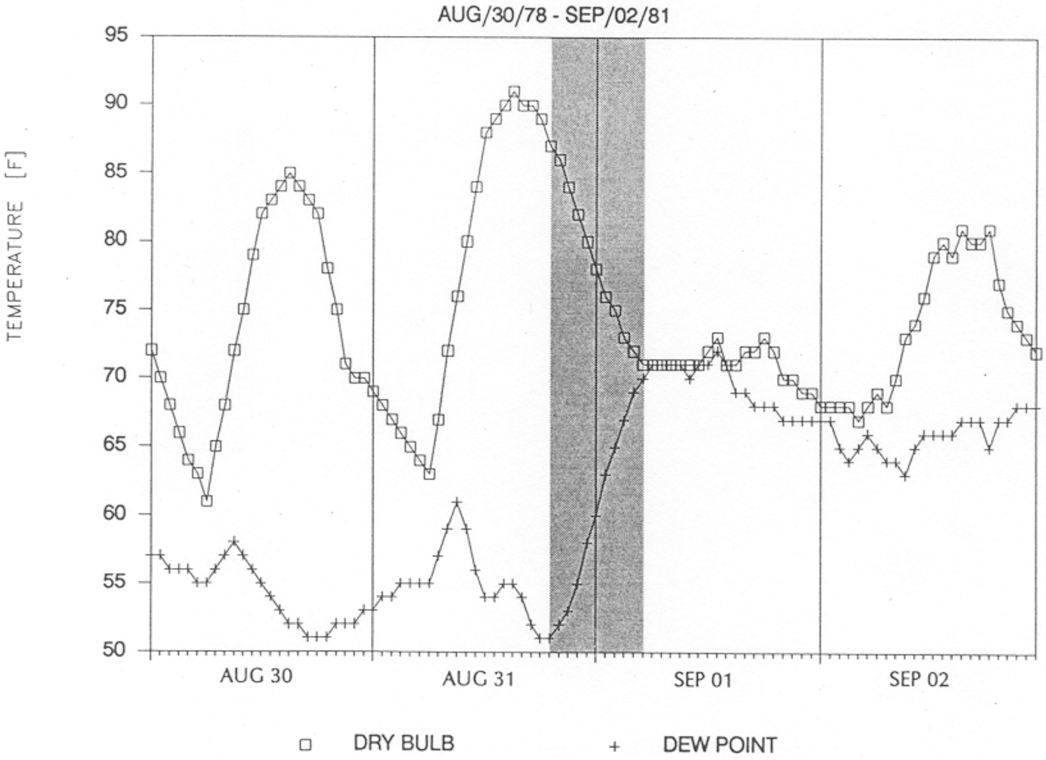

Fig. 5.9.2 Connection case 6 (Cubic Splined)

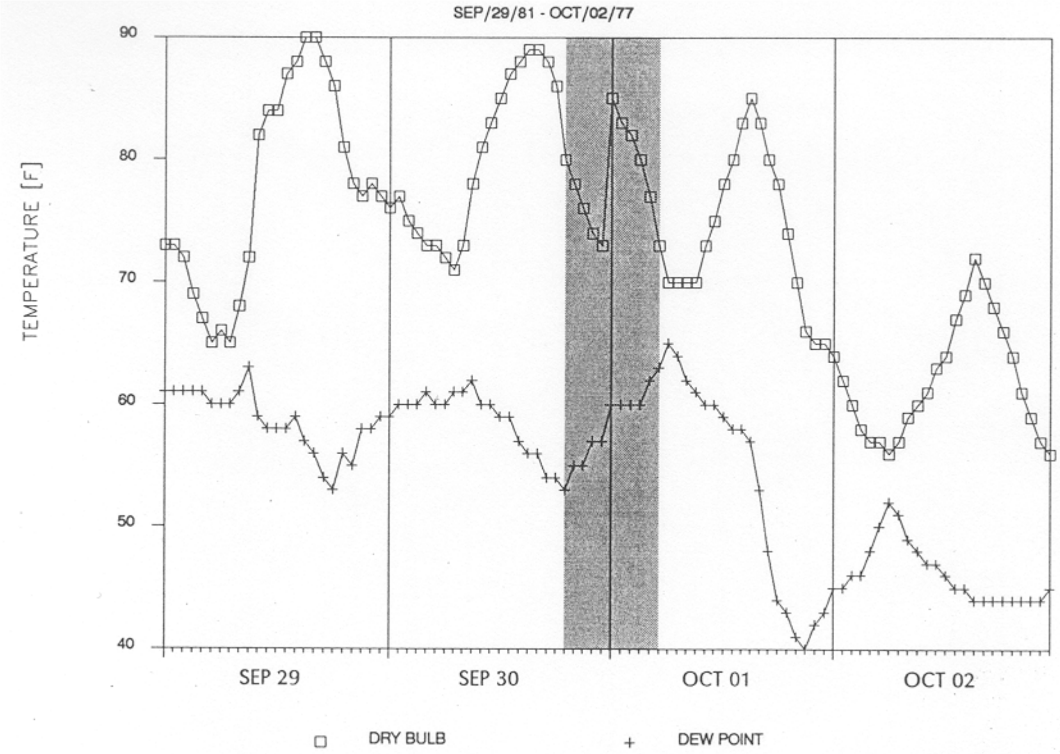

Fig. 5.10.1 Connection case 7 (Original data)

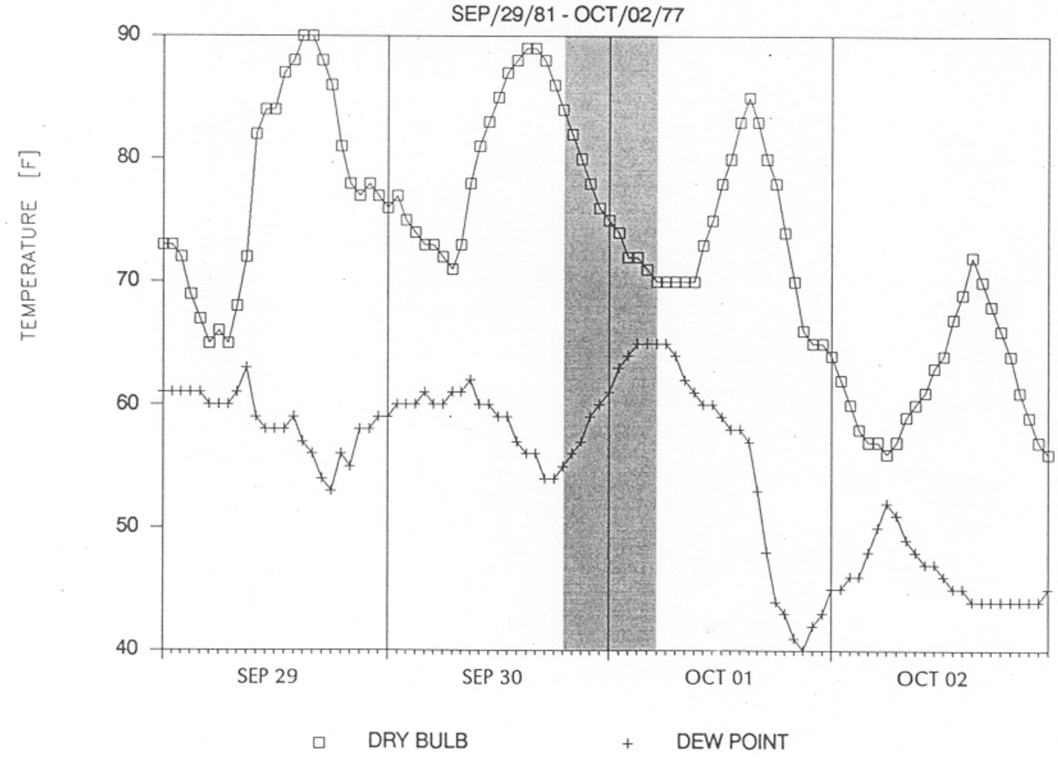

Fig. 5.10.2 Connection case 7 (Cubic Splined)

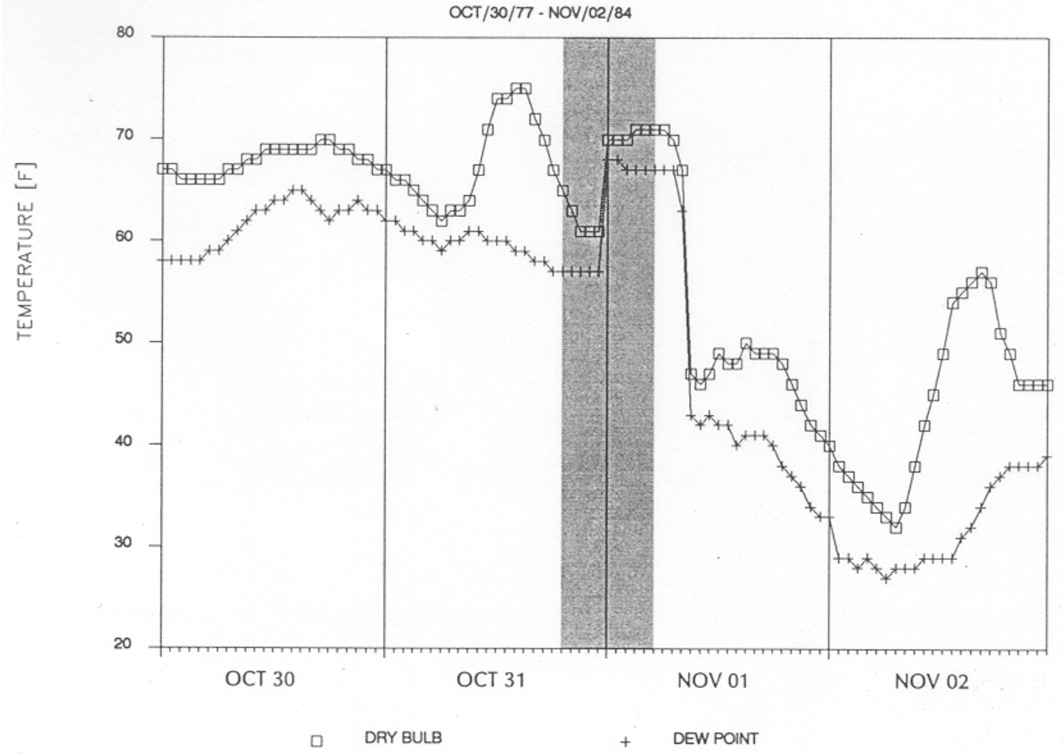

Fig. 5.11.1 Connection case 8 (Original data)

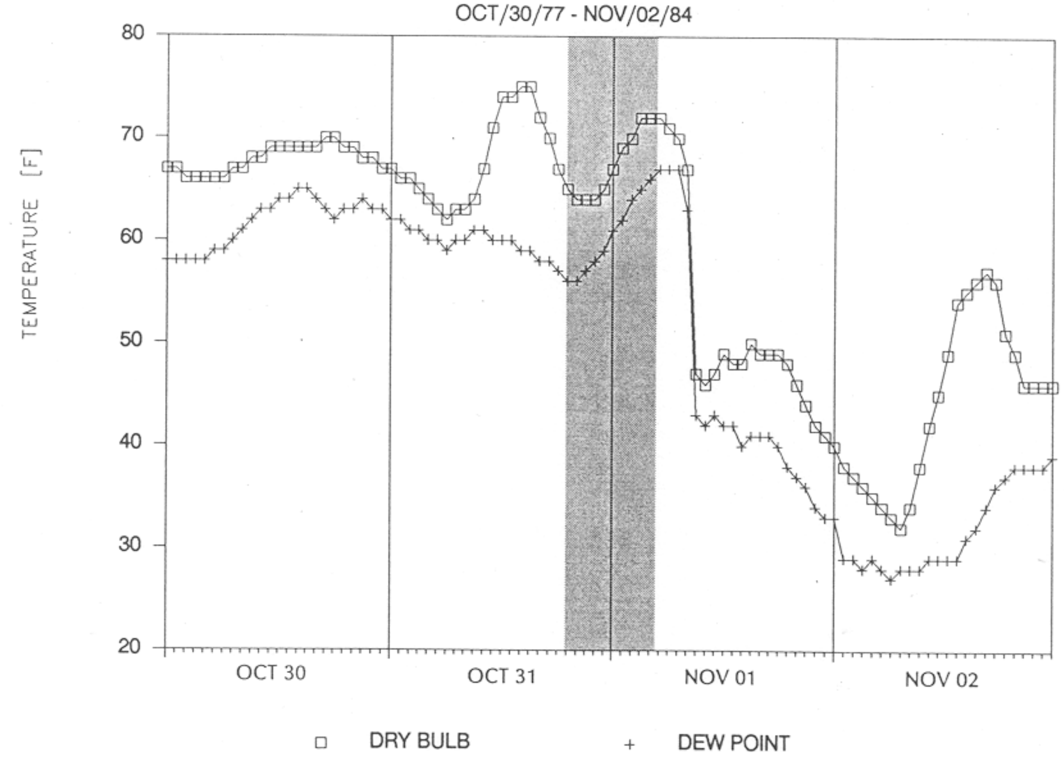

Fig. 5.11.2 Connection case 8 (Cubic Splined)

5.4 Estimation of Hourly Solar Radiation

Currently there are about 1078 weather stations throughout the United States (Ecodyne Corporation, 1980, Appendices 1-5 to 1-10), but less than 50 weather stations are recording the hourly values of the solar radiation. Considering that the solar radiation and ambient temperature are most important data for building energy calculations, it may be useful to find a way of constructing weather data base which contains solar radiation data for the locations having no solar radiation data.

In this study, existing algorithms were applied to estimate the hourly solar radiation data for Oklahoma City area. The main step involves estimating solar radiation under clear sky condition using ASHRAE (Fundamentals Handbook, 1977) method and converting them to solar radiation under cloudy sky condition using the algorithm of Kimura and Stephenson (1969). Figure 5.12 shows the procedure for calculating solar radiation intensities. The variable names of the flow chart are those of computer program for estimating hourly solar radiation.

Before estimating hourly solar radiation, the local standard time at which the other meteorological data were recorded was converted to Local Apparent Time, i.e., Solar Time. The daylight-savings-time which begins at 2 a.m. on the last Sunday of April and ends at 2 a.m. on the last Sunday of October was assumed to exist from April 30 to October 30. Figure 5.12 shows the procedure for estimating solar radiation intensities. The variable names of the chart are those used in a computer program for solar radiation estimation.

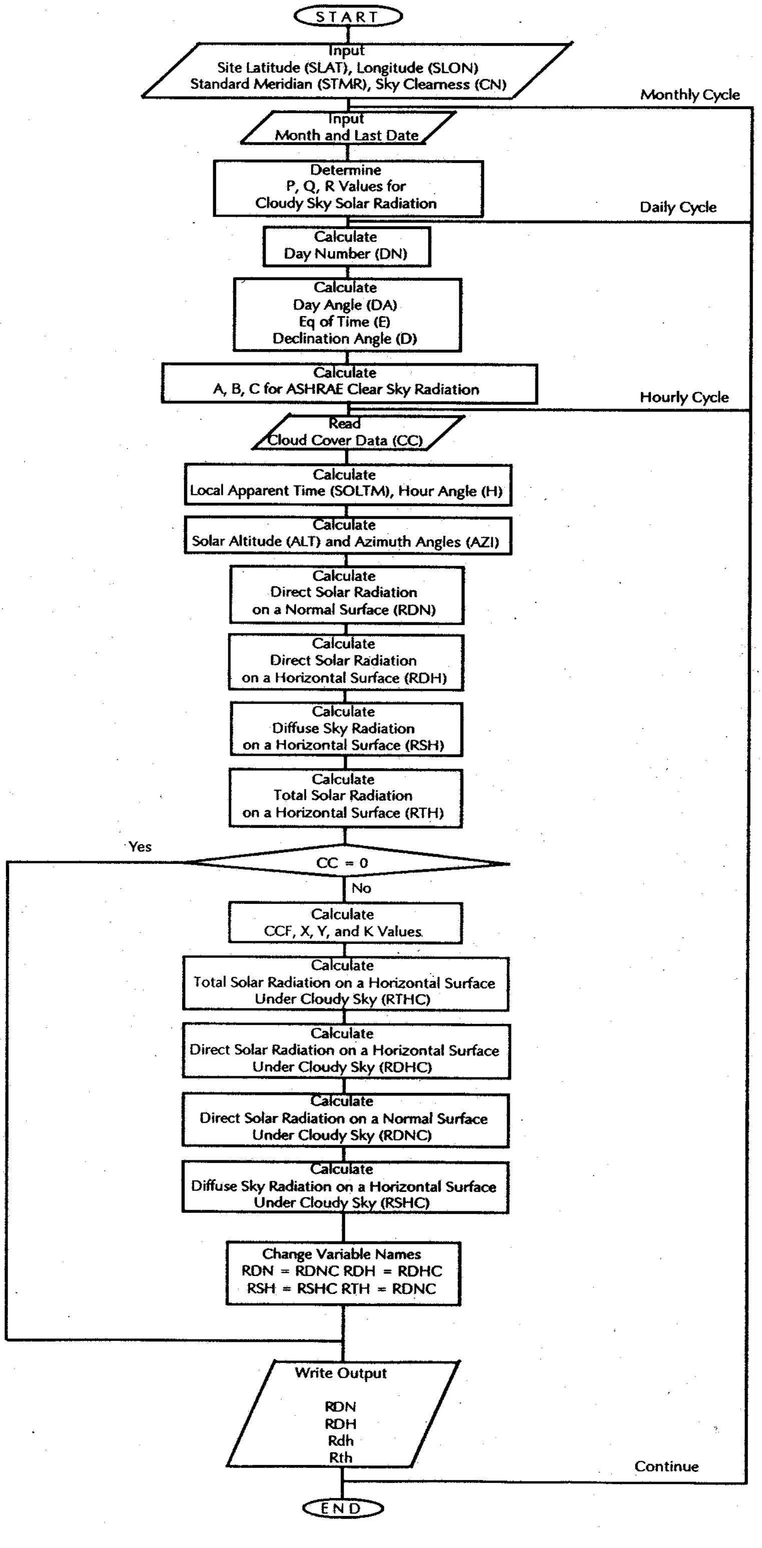

Fig. 5.12 Procedure for Estimating Solar Radiation

5.4.1 Solar Geometry

5.4.1.1 Sun-Earth distance (R)

The mean Sun-Earth distance (Ro) is called 1 Astronomical Unit (A.U.) and equivalent to 1.496×10^8 km. The minimum and maximum sun-earth distances are 0.983 A.U. and 1.017 A.U., respectively. At any given day of the year, the reciprocal of the square of the Sun-Earth distance (R) is given by the following expressions.

1) An expression suitable for most engineering applications:

$$(Ro/R)^2 = e = 1 + 0.033 \cos(2\pi \, Nd / 365) \qquad \text{(Eq. 5.7)}$$

where Nd = day number from January 1st.

2) More accurate expression by Spencer (1971):

$$(Ro/R)^2 = e = 1.00011 + 0.34221 \cos d + 0.00128 \sin d + 0.000719 \cos^2 d + 0.000077 \sin^2 d \qquad \text{(Eq. 5.8)}$$

where $d = 2\pi(Nd-1)/365$ (= day angle in radians) (Eq. 5.9)

5.4.1.2 Solar Declination Angle (δ)

This angle indicates the angle between the line joining the centers of the sun and the earth to the equatorial plane. This angle changes every day and called solar declination. It becomes zero at the vernal and the autumnal equinoxes, + 23.5° at the summer solstice, and -23.5° at the winter solstice. The values can be calculated by below formulae.

1) Formula by Perrin de Brichambant (1975):

$$\delta = \sin^{-1}(0.4 \sin(360/365 \times (Nd - 82))) \; [°] \qquad \text{(Eq. 5.10)}$$

2) Formula by Cooper (1969):

$$\delta = 23.45 \sin(360/365 \times (Nd + 284)) \; [°] \qquad \text{(Eq. 5.11)}$$

3) Formula by Spencer (1971):

$$\delta = (180/\pi)(0.006918-0.399912\cos d + 0.070257\sin d - 0.006758\cos 2d + 0.000907\sin 2d - 0.002697\cos 3d + 0.00148\sin 3d) \; [°] \qquad \text{(Eq. 5.12)}$$

4) Formula by Woolf (1972):

$$\delta = 279.9348+1.914827 \sin d- 0.079525 \cos d + 0.019938 \sin 2d = 0.001620 \cos 2d + d \; [°] \qquad \text{(Eq. 5.13)}$$

5.4.1.3 Equation of Time

This is an important quantity, which has to be taken into account for the calculation of solar radiation data. As the earth orbits the sun, its speed varies depending upon its distance from the sun. As the earth move closer to the sun, the earth slows down, and as the earth swing away from the sun, it speed up (E. Mazria, 1979, p. 288). This represents the deviation in clock time with respect to the same position of the sun and to a stationary observer on the earth. It is a common practice to record radiation data in terms of local apparent time (L.A.T); which is also called the true solar time (T.S.T). On the other hand, meteorological data such as temperature and wind speed are often recorded in terms of local clock time. While computing radiation data, it is desirable to convert local standard time (L.S.T) (i.e. the clock time) to local apparent time (M.S. Sodha et al. 1986, p. 42). An expression fitted by sine and cosine functions were presented by Spencer (1971):

$$E = 229.18(0.000075 + 0.001868 \cos d - 0.032077 \sin d - 0.014615 \cos 2d - 0.04089 \sin 2d) \quad \text{(Eq. 5.14)}$$

Figure 5.13 shows values for the "equation of time," or the difference between sun time and earth time calculated by the Spencer's expression. The upper part of the chart (+) gives values when the sun is ahead of clock time, and the lower part (-) when the sun is behind.

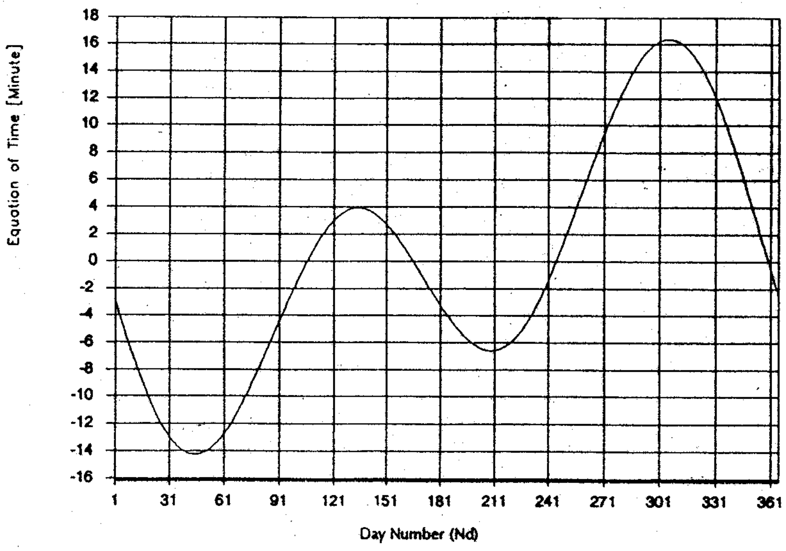

Fig. 5.13 Equation of Time by Spencer's Equation

5.4.1.4 Apparent Motion of the Sun

The relation between a particular site on the earth and the sun must be expressed with terms which include accommodation for the geographical location of the earth, the status of the earth's rotation (usually expressed as the time of the day), and the relationship between the positions of the earth and the sun in space. Any position on the earth can be designated by its latitude, longitude, and elevation above sea level. The position of the sun as observed from this site is designated by the angle of elevation above the horizon and its azimuth angle formed by the sun's projection to the horizon and due south. Figure 5.14 shows the position of the sun related to a location on the earth.

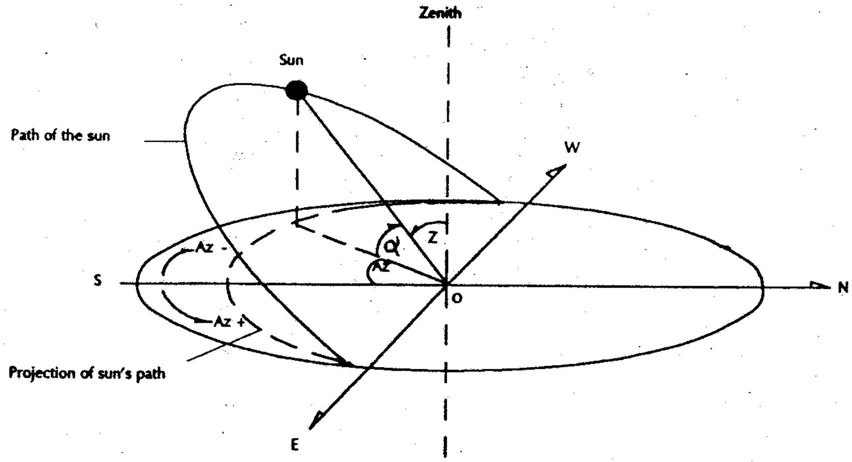

Fig. 5.14 Position of the Sun

where Z = Zenith angle in degrees

α = Solar Altitude ; α= 90 - Z in degrees
Az = Solar Azimuth in degrees, South Zero, East positive

(1) Solar Altitude Angle (α)

$$\cos Z = \sin \delta \sin L + \cos L \cos \delta \cos w \quad \text{(Eq. 5.15)}$$

$$= \sin \alpha$$

hence $\alpha = \sin^{-1}(\sin \delta \sin L + \cos L \cos \delta \cos w)$ (Eq. 5.16)

where L = Local Latitude in degrees, positive in North

δ = Solar Declination Angle in degrees

w = Solar Hour Angle

= (12 - Solartime) * 15 (Eq. 5.17)

Solartime = t + [E+4*(Lst-Lloc)]/60 - DST (Eq. 5.18)

where t = Clock Time of the Day (Local Standard Time)

E = Equation of Time in Minutes

Lst = Standard meridian for local time (Table 5.11)

Lloc= Longitude of site in degrees West

DST = 1 when Daylight Savings Time is in effect, 0 otherwise

Table 5.12 shows the time zones and its standard meridian of the continental U.S.A.

Table 5.12 Standard meridians in continental United States

Time Zone	Standard Meridian	Representative Cities
Eastern	75°W	Camden, NJ
Central	90°W	Memphis, TN
Mountain	105°W	Denver, CO
Pacific	120°W	South Lake Tahoe, CA

(2) Solar Azimuth Angle (Az)

$$\cos Az = (\sin \alpha \sin L - \sin \delta)/(\cos \alpha \cos L) \qquad \text{(Eq. 5.19)}$$

where $0 < Az < 90, \cos Az > 0$

$90 < Az < 180, \cos Az > 0$

then $Az = \sin\{(\cos \delta \sin w) / \cos \alpha\}$ (Eq. 5.20)

(3) Sunrise Hour Angle (ws)

Assuming that the solar altitude is zero at the moment of sunrise, sunrise hour angle can be derived from the following equations.

$$\alpha = \sin^{-1}(\sin \delta \sin L + \cos L \cos \delta \cos w) = 0 \qquad \text{(Eq. 5.21)}$$

i.e., $\sin \delta \sin L + \cos L \cos \delta \cos w = 0$ (Eq. 5.22)

then $\cos w = -(\sin \delta \sin L)/(\cos \delta \cos L)$

$= -(\tan \delta \tan L)$ (Eq. 5.23)

and sunrise hour angle (ws) is given by:

$$ws = \cos^{-1}(-\tan \delta \tan L) \qquad \text{(Eq. 5.24)}$$

(4) Sunrise time (St) in Local Apparent Time

Sunrise time can be expressed by:

$$St = 12 - ws/15 \qquad \text{(Eq. 5.25)}$$

(5) Day length (DL)

Day length can be calculated by the following equation.

$$DL = (2/15) \cos^{-1}(-\tan \delta \tan L) \qquad \text{(Eq. 5.26)}$$

$$= (2/15)\ ws \qquad \text{(Eq. 5.27)}$$

5.4.2 Solar Radiation under Clear Sky Condition

5.4.2.1 Solar Constant (I_{SC})

Solar constant is defined as the total energy emitted by the sun per unit of area perpendicular to the sun's ray in near-earth space at the average earth distance from the sun per unit of time (AMETEK Inc., 1979, p. 15). Various measured values of solar constant vary from 1338 [W/m²] to 1368 [W/m²]. This is a consequence of the measurement techniques used, spacecraft instrumentation or terrestrial astronomical data, both of which contain sources of inaccuracy. Table 5.13 shows the average value of the solar constant in different unit systems.

Table 5.13 Solar constant (AMETEK Inc., 1979, p.16)

I_{SC} = 1354 Watts per square meter
= 1.354 Kilowatts per square meter
= 429 BTU per hour per square foot
= 1.94 Langleys per minute

5.4.2.2 Clear Sky Irradiation Model by ASHRAE

ASHRAE has presented the simple methods to approximate solar radiation, which are based upon the works of Moon(1940), Threlkeld and Jordan (1958), and Stephenson (1967).

(1) Direct Beam Solar Radiation from the sun (I_{DN}, I_{DH})

At the earth's surface on a clear day, direct solar radiation on a normal surface, I_{DN}, is represented by:

$$I_{DN} = A\ CN\ e^{-B/\sin\alpha}\ \text{[BTU/hr-ft}^2\text{]} \qquad \text{(Eq. 5.28)}$$

where A = Apparent Solar Irradiation at air mass of 0

B = Atmospheric Extinction Coefficient

α = Solar Altitude

CN = Clearness of Sky (see Figure 5.15)

The two coefficients, A and B, are generally harmonic in nature and can be curve fit by the following first order cosine function with the variable of day angle (d) (W. Murphy, 1986).

$$A = 361.5 + 22.5 \cos d \qquad \text{(Eq. 5.29)}$$

$$B = 0.1745 - 0.0325 \cos d \qquad \text{(Eq. 5.30)}$$

Then, direct solar radiation on a horizontal surface (I_{DH}) can be calculated by the following equation.

$$I_{DH} = I_{DN} \sin\alpha \quad \text{[BTU/hr-ft}^2\text{]} \qquad \text{(Eq. 5.31)}$$

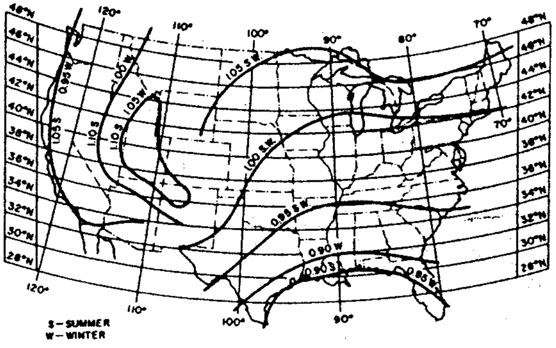

Fig. 5.15 Sky clearness (CN) values (ASHRAE, 1985, p. 27.3)

(2) Diffuse Sky Radiation on a Horizontal Surface (I_{dh})

The diffuse radiation falling on a horizontal surface from the sky can be approximated by:

$$I_{dh} = C\ I_{DN} / CN^2 \quad [\mathrm{BTU/hr\text{-}ft^2}] \qquad \text{(Eq. 5.32)}$$

The coefficient, C, diffuse fraction factor, can be curve fit by the following first order cosine function (W. Murphy, 1986).

$$C = 0.0965 - 0.0395 \cos d \qquad \text{(Eq. 5.33)}$$

(4) Total Solar Radiation on a Horizontal Surface (I_{TH}) under Clear Sky

The total solar radiation on a horizontal surface consists of two components, direct-beam radiation from the sun and diffuse radiation from the blue sky.

$$I_{TH} = I_{DH} + I_{dh} \quad [\mathrm{BTU/hr\text{-}ft^2}] \qquad \text{(Eq. 5.34)}$$

5.4.3 Solar Radiation under Cloudy Sky Condition

The nature and intensity of diffuse radiation on cloudy and partially cloudy days is quite different from that of clear days.

Kimura and Stephenson (1969) analyzed 1967 Canadian data for observed solar radiation with respect to the cloud cover data, type of cloud, and the calculated solar radiation under a cloudless conditions at the same solar time. The cloud cover observations are made every hour (Local Standard Time) by experienced cloud observers estimating the amount of cloud on a scale of 0 to 10. A clear sky with no cloud is designated as CC=0 and a completely overcast sky is denoted as CC=10.

Based upon their analysis, a comprehensive methodology was developed for the calculation of cloudy day solar radiation.

5.4.3.1 Total Solar Radiation on a Horizontal Surface under Cloudy Sky

The total solar radiation from the cloudy sky can be expressed in terms of total solar radiation from the cloudless sky (I_{TH}) and cloud cover factor (CCF) as a parameter.

$$I_{THC} = I_{TH}\ CCF \quad [BTU/hr\text{-}ft^2] \qquad \text{(Eq. 5.35)}$$

Kimura and Stephenson set the following regression model for the CCF as a function of the cloud cover (CC) recorded by the experienced observer.

$$CCF = P + Q\ CC + R\ CC^2 \qquad \text{(Eq. 5.36)}$$

Then, the parameters, P, Q and R, were examined with solar altitude angle (α) for March, June, September, and December, which represented spring, summer, fall and winter, respectively. Table 5.14 shows the values of the 3 parameters.

Table 5.14 P, Q and R values

Month	sin α	P	Q	R
March	0.5 - 0.9	1.06	0.012	-0.0084
June	0.5 - 1.0	0.96	0.033	-0.0106
September	0.5 - 0.9	0.95	0.030	-0.0108
December	0.3 - 0.5	1.14	0.003	-0.0082

5.4.3.2 Direct and Diffuse Solar Radiation on a Horizontal Surface under Cloudy Sky

Kimura and Stephenson, then, determined equations to calculate direct and diffuse components based upon the equation by Parmelee (1954), who showed that the diffuse and direct components for cloudless conditions are related by an expression:

$$I_{dh} = X - Y\ I_{DH}\quad [\text{BTU/hr-ft}^2] \qquad \text{(Eq. 5.37)}$$

where I_{dh} = Diffuse radiation under cloudless sky

I_{DH} = Direct radiation under cloudless sky

X and Y are functions of the solar altitude angle.

The Direct (I_{DHC}) and diffuse (I_{dhc}) components of solar radiation under cloudy sky can be expressed by:

$$I_{DHC} = I_{th}\ K\ (1-CC/10)\quad [\text{BTU/hr-ft}^2] \qquad \text{(Eq. 5.38)}$$

$$I_{dhc} = I_{th}\ \{CCF - K(1-CC/10)\}\quad [\text{BTU/hr-ft}^2] \qquad \text{(Eq. 5.39)}$$

where I_{DHC} = Direct solar radiation on a horizontal surface under cloudy sky

I_{dhc} = diffuse sky radiation on a horizontal surface under cloudy sky

$$K = \sin\alpha\ /(C+\sin\alpha) + (P-1)/(1-Y) \qquad \text{(Eq. 5.40)}$$

$$Y = 0.309-0.137\ \sin\alpha + 0.394\ \sin^2\alpha \qquad \text{(Eq. 5.41)}$$

The detailed derivation procedures of above equations can be found in the paper of Kimura and Stephenson (1969).

5.5 Record Formats of Hourly Model Weather data Base

The final Model Weather Data Base for Oklahoma City area were constructed and it was recorded on two floppy diskettes in ASCII format. Table 5.15 shows the record formats of the data set.

Table 5.15 Record formats of Model Weather Data

Item	Unit	Format	Column #
Date & Time		MMDDTT	1 - 6
Dry bulb temp.	°F	###	8 - 10
Dew point temp.	°F	###	12 - 14
Wet bulb temp.	°F	##	16 - 17
Relative humidity	%	###	19 - 21
Wind velocity	Knot	##	23 - 24
Wind direction	36th	##	26 - 27
Station pressure	Inch-Hg	##.##	29 - 33
Cloud cover	10th	##	35 - 36
I_{DN}	BTU/hr-ft^2	###.#	38 - 42
I_{DH}	BTU/hr-ft^2	###.#	44 - 48
I_{dh}	BTU/hr-ft^2	###.#	50 - 54
I_{TH}	BTU/hr-ft^2	###.#	56 - 60

where I_{DN} = Direct solar radiation on a normal surface
I_{DH} = Direct solar radiation on a horizontal surface
I_{dh} = Diffuse sky radiation on a horizontal surface
I_{TH} = Total radiation on a horizontal surface

The numeric codes from 0 to 36 for wind direction indicate true degree, 10th of degree rotating clockwise, from which wind is blowing (NCDC : Reference Manual for TD-1440, p. 12). Table 5.16 shows the true wind direction for each numeric code.

Table 5.16 True wind directions

Code Figure	Wind Direction	Code Figure	Wind Direction
0	Calm	19	185° - 194°
1	5° - 14°	20	195° - 204°
2	15° - 24°	21	205° - 214°
3	25° - 34°	22	215° - 224°
4	35° - 44°	23	225° - 234°
5	45° - 54°	24	235° - 244°
6	55° - 64°	25	245° - 254°
7	64° - 74°	26	255° - 264°
8	75° - 84°	27	265° - 274°
9	85° - 94°	28	275° - 284°
10	95° - 104°	29	285° - 294°
11	105° - 114°	30	295° - 304°
12	115° - 124°	31	305° - 314°
13	125° - 134°	32	315° - 324°
14	135° - 144°	33	325° - 334°
15	145° - 154°	34	335° - 344°
16	155° - 164°	35	345° - 354°
17	165° - 174°	36	355° - 4°
18	175° - 184°		