Exhibit No.:	
Issues:	Revenue Requirement
Witness:	Seoung Joun Won
Sponsoring Party:	MO PSC Staff
Type of Exhibit:	Rebuttal Testimony
Case No.:	ER-2014-0351
Date Testimony Prepared:	March 9, 2015

MISSOURI PUBLIC SERVICE COMMISSION

REGULATORY REVIEW DIVISION

REBUTTAL TESTIMONY

OF

SEOUNG JOUN WON, Ph.D.

THE EMPIRE DISTRICT ELECTRIC COMPANY

CASE NO. ER-2014-0351

Jefferson City, Missouri
March 2015

BEFORE THE PUBLIC SERVICE COMMISSION

OF THE STATE OF MISSOURI

In the Matter of The Empire District Electric Company for Authority to File Tariffs Increasing Rates for Electric Service Provided to Customers in the Company's Missouri Service Area.	)))))	Case No. ER-2014-0351

AFFIDAVIT OF SOUNGJOUN WON

STATE OF MISSOURI)
) **ss**
COUNTY OF COLE)

Soungjoun Won, of lawful age, on his oath states: that he has participated in the preparation of the following Rebuttal Testimony in question and answer form, consisting of 8 pages of Rebuttal Testimony to be presented in the above case, that the answers in the following Rebuttal Testimony were given by him; that he has knowledge of the matters set forth in such answers; and that such matters are true to the best of his knowledge and belief.

Soungjoun Won

Soungjoun Won

Subscribed and sworn to before me this 6th day of March, 2015.

SUSAN L. SUNDERMEYER
Notary Public - Notary Seal
State of Missouri
Commissioned for Callaway County
My Commission Expires: October 28, 2018
Commission Number: 14942086

Susan L. Sundermeyer

Notary Public

REBUTTAL TESTIMONY

OF

SEOUNG JOUN WON, Ph.D.

THE EMPIRE DISTRICT ELECTRIC COMPANY

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REBUTTAL TESTIMONY

OF

SEOUNG JOUN WON, Ph.D.

THE EMPIRE DISTRICT ELECTRIC COMPANY

CASE NO. ER-2014-0351

Q. Are you the same Seoung Joun Won who filed in Staff's Cost of Service Report?

A. Yes I am.

EXECUTIVE SUMMARY

Q. What is the purpose of your rebuttal testimony?

A. The purpose of this testimony is to address the weather data that The Empire District Electric Company ("Empire" or "Company") witness Stephen C. Williams used to perform Empire's weather normalization calculations presented in his Direct Testimony.

Q. Which part of the Company's weather data used by Mr. Williams are you going to address?

A. I am addressing the following three issues related to Mr. Williams testimony on normal weather: the time period Mr. Williams used to calculate climate normals (page 6, lines 14-19), the calculation of daily average temperatures for heating degree day ("HDD") and cooling degree day ("CDD"), (page 6, line 19 – page 7, line 13) and the comparison of normal weather and actual weather of the test year for weather normalization (page 7, line 16 – page 8, line 3).

TIME PERIOD FOR CLIMATE NORMALS

Q. What is a "climate normal"?

A. According to the National Oceanic and Atmospheric Administration ("NOAA"), a "climate normal" is defined as the arithmetic mean of a climatological element, such as temperature, computed over three consecutive decades.[1] The most recent U.S. Climate Normals published by NOAA is for the period of January 1, 1981 through December 31, 2010.[2]

Q. What is the purpose of calculating climate normals for the rate case?

A. The purpose of calculating climate normals is to restate the test year actual-customer usage and revenues for weather sensitive rate classes in order to reflect "normal weather" for that period. Because each year's weather is unique, weather-sensitive customer rate classes' usage needs to be adjusted to normal weather conditions to calculate normal revenues.

Q. What weather station and time period did Staff use for purposes of calculating the Staff's normal weather?

A. Staff used the 30-year period of January 1, 1981 through December 31, 2010, which is the most recent climate normal period published by NOAA for the Springfield Regional Airport ("SGF").

Q. What weather station and time period did Mr. Williams use for purposes of calculating the Company's normal weather?

A. Mr. Williams used SGF weather station and the 30-year period of May 1, 1985 through April 31, 2014.

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[1] Retrieved on December 27, 2014, http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals.

[2] Retrieved on December 27, 2014, http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals/1981-2010-normals-data.

Q. Why is it more appropriate to use the latest climate normal period published by NOAA of January 1, 1981 through December 31, 2010?

A. The current published 30-year normal period is the most appropriate normal weather to use because climate normals published by NOAA accounts for anomalies in the temperature data series. The actual historical temperature data series of SGF is inconsistent due to issues such as replacing or relocating equipment. For example, the Automated Surface Observing System ("ASOS") was replaced in November 1995.[3] NOAA accounts for these anomalies in its published 30-year climate normals and calculates a homogenized temperature data series for daily maximum and minimum temperature series. Details of the NOAA homogenization procedure for removing documented and undocumented anomalies in the 30-year time series are explained in a NOAA peer-reviewed publication.[4]

Q. Did NOAA publish a homogenized temperature time series for the time period Mr. Williams used for this rate case?

A. No. NOAA only produces climate normals once every 10 years. The most recent NOAA climate normals used the time period, January 1, 1981 through December 31, 2010 which Staff used for this rate case. The homogenized weather data series in the next NOAA climate normals will not be published until after December 31, 2020.[5]

Q. Is the time period used by Mr. Williams for calculating the Company's normal weather proper?

A. No. There is no NOAA homogenized temperature data series for the 30-year period Mr. Williams used. Consequently, the normal weather used by Mr. Williams did not

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[3] Retrieved on December 27, 2014, http://www.ncdc.noaa.gov/homr/#ncdcstnid=10006338&tab=MSHR.
[4] Menne, M.J., and C.N. Williams, Jr., (2009) Homogenization of temperature series via pairwise comparisons. *J. Climate*, **22**, 1700-1717.
[5] Retrieved on December 27, 2014, http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals.

adjust for known anomalies, and weather normalization adjustments conducted by Mr. Williams are incorrect.

TEMPERATURE DATA SERIES

Q. What kind of weather data series did Mr. Williams use to determine normal weather, HDD and CDD?

A. A Mean Daily Temperature ("MDT") data series was used for weather normalization.

Q. In comparison to Mr. Williams, how did Staff calculate MDT data series?

A. Staff obtained a homogenized data series of maximum daily temperature ("Tmax") and minimum daily temperature ("Tmin") for a given 30-year climate normal period from NOAA and then calculated MDT as the average of Tmax and Tmin of each day.

Q. Why did Staff use data series of Tmax and Tmin for calculating MDT?

A. During the 30-year period, 1981 through 2010, there were documented and undocumented changes of observation equipment and environment. NOAA accounted for these anomalies of the data series and published homogenized data series for Tmax and Tmin associated with the most recent climate normals.

Q. How did Mr. Williams calculate MDT data series?

A. Mr. Williams calculated MDT using hourly temperature data. For example, SGF's MDT on January 1, 2014, is the average of 24 temperature values which have been observed at each hour.

Q. Do you have any concern with using the MDT used by Mr. Williams?

A. Yes. The data series of MDT used by Mr. Williams is inconsistent. During the 30-year period, 1985 through 2014, there were documented and undocumented changes of observation equipment and environment. NOAA did not publish homogenized hourly data series. The data series of MDT used by Mr. Williams did not correct for these anomalies. Therefore, weather normalization adjustments conducted by Mr. Williams are erroneous.

WEATHER NORMALIZAION

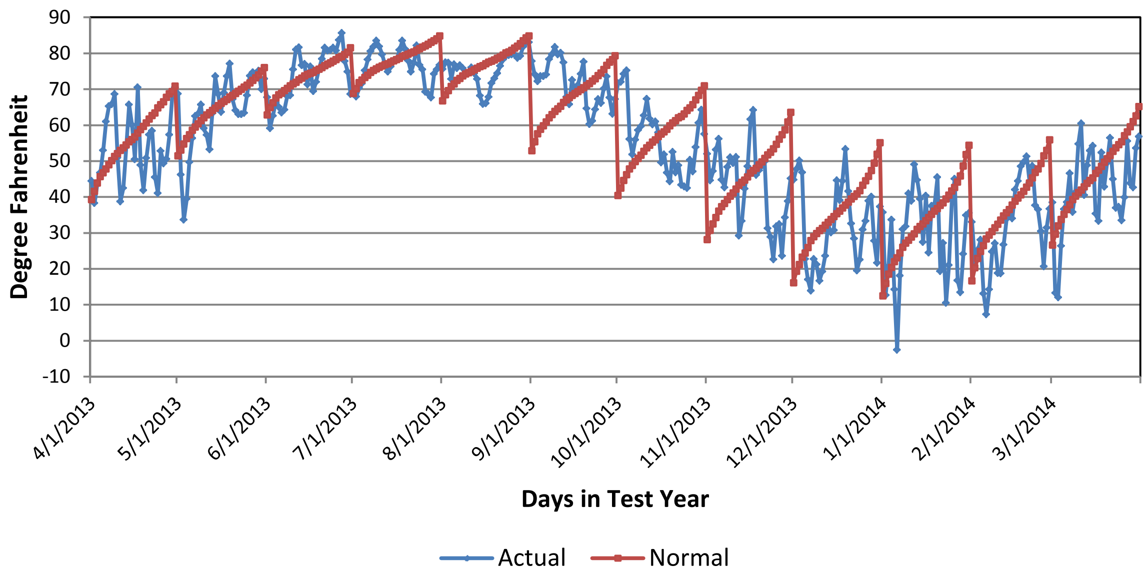
Q. What is your concern on weather with regard to weather normalization?

A. The relationship between normal weather and actual weather used by Mr. Williams is improper. The weather normalization adjustment is based on the difference as measured by HDD and CDD between the actual temperatures and the normal temperatures. If normal weather and actual weather is not properly compared, the weather normalization adjustment is inaccurate.

Q. How are the normal temperature time series and actual temperature time series compared in Mr. Williams' weather normalization?

A. Mr. Williams arranged each month's normal MDTs from lowest to highest and then assigned them to test year calendar date. For example, the normal MDT of January 1, 2014 is the lowest MDT of January MDT data series and the normal MDT of January 31, 2014 is the highest MDT of January MDT data series. Figure 1 shows the relationship between normal and actual MDT data series in the test year.

Figure1.
Empire's Calculated Actual and Normal Mean Daily Temperature

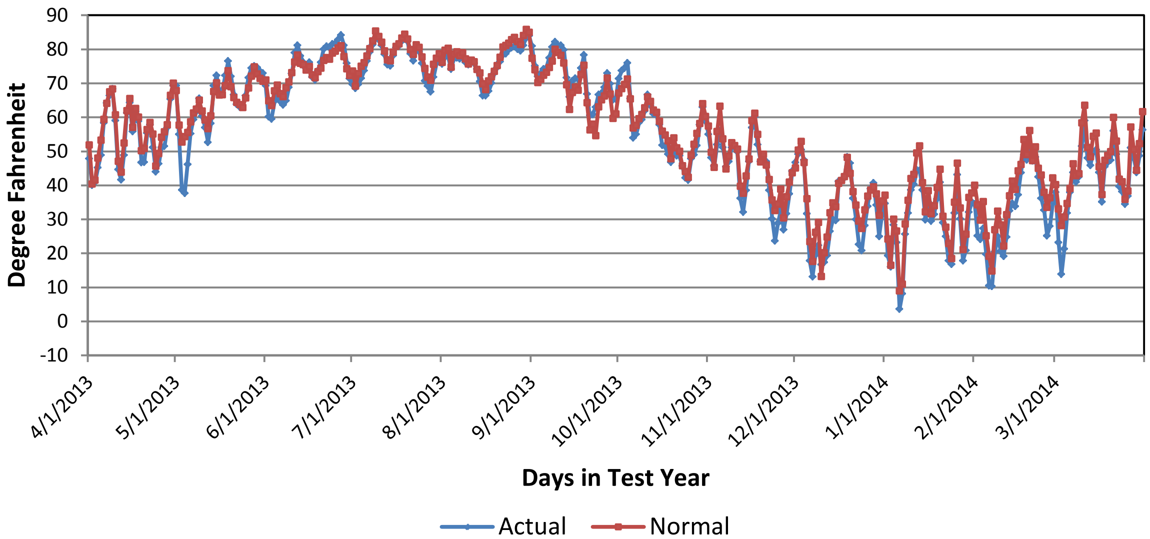


Q. How is normal weather and actual weather compared in Staff's weather normalization?

A. The daily two-day weighted mean temperature ("TWMT") is calculated using the previous day's mean daily temperature with a one-third weight and the current day's mean daily temperature with a two-thirds weight.[6] Each day's normal TWMT is assigned to the date which has the same monthly rank.[7] Figure 2 shows the relationship between normal and actual TWMT data series in the test year.

[6] To calculate the Dth day's two-day weighted mean temperature ($TWMT_D$), the current day's (D) daily mean temperature (DMT_D) is averaged with the prior day's (D-1) daily mean temperature (DMT_{D-1}), applying a 2/3 weight on the current day and 1/3 weight on the prior day: $TWMT_D = (2/3)\ DMT_D + (1/3)\ DMT_{D-1}$. This was done because in the Empire service area, yesterday's weather effects how electricity is used today. Please see Staff's direct report for more detailed information.
[7] Please see Appendix SW-1 of this Rebuttal Testimony for more detailed information.

Figure 2.
Staff's Calculated Two-Day Weighted Mean Daily Temperature



Q. Do you recommend Staff's method?

A. Yes. As shown in Figure 2, Staff's normal temperatures are calculated and assigned to days in the test year reflect the actual test year temperature pattern. This method minimizes the specification bias and error in the weather normalization regression model. Conversely, Empire's improper calculation and assignment of daily normal temperatures leads to increased error and bias in Empire's weather normalization regression model.

CONCLUSION

Q. Please summarize your rebuttal testimony.

A. Mr. Williams used the 30-year normal period, 1985-2014, and hourly data for his calculation of normal weather, not the NOAA homogenized temperature data series. Furthermore, Mr. Williams did not properly assign his normal MDT data series to the days in the test year. These methodical errors are likely to result in a significant bias in the subsequent weather normalization adjustment calculation. For example, Company's estimated October 2013 revenue cycle weather normalized usage is 17 % higher than Staff's.

Q. Does this conclude your rebuttal testimony?

A. Yes, it does.

WEATHER NORMALIZATION OF ELECTRIC LOADS

DEMONSTRATION: CALCULATION OF WEATHER NORMALS

A METHODOLOGY DEVELOPED BY THE
RESEARCH & PLANNING DEPARTMENT
MISSOURI PUBLIC SERVICE COMMISSION

BY

MARTIN TURNER, MANAGER, RESEARCH & PLANNING
AND
EVE A. LISSIK, RESEARCH ENGINEER

RESEARCH AND PLANNING DEPARTMENT
MISSOURI PUBLIC SERVICE COMMISSION

OCTOBER 25, 1991

CALCULATION OF WEATHER NORMALS: A DEMONSTRATION

1. Introduction
   - properties of a weather normal series

2. Variable Definitions

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   - input requirements
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4. Calculation of Normal Weather Variables and the Assignment of Annual Ranks
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INTRODUCTION

Properties of a Weather Normal Series

Some of the difficulties in weather normalizing daily system or class loads are defining exactly what is meant by "normal" weather and identifying the properties that a series of daily normal weather values should have. The method presented here, based on a series of temperature averages, was developed-to provide a daily normal weather series that has the following properties:

1. Both monthly and annual temperature extremes are preserved;
2. Peak normal weather occurs on weekdays;
3. The difference between actual (test period) weather and normal weather is minimized.

Property 1 is necessary because normal weather should approximate, as accurately as possible, the full range of temperatures and temperature patterns occurring both monthly and annually.

Property 2 assigns monthly weather extremes to weekdays rather than weekends because peak loads usually occur on a weekday.

Property 3 is necessary because it will minimize the weather adjustments made to actual loads during the normalization process.

For purposes of demonstration, a one year test period, calendar 1990, will be normalized from an abbreviated historical weather data base with only one heating and one cooling temperature breakpoint. The parameters used for the example are as follows:

1. The historical weather data base consists of only five years: 1986-1990
2. The test period to be normalized runs from January 1, 1990 to December 31, 1990
3. Heating occurs for temperatures less than 55°F
4. Cooling occurs for temperatures greater than 80°F

VARIABLE DEFINITIONS

CDD_i = cooling degree days for day i

DD = temperature rank within each month (DD = 1, 2, 3....29, 30 or 31)

HDD_i = heating degree days for day i

i = day of the year (i = 1, 2, 3, 4...364, 365 or 366)

MM = month number (1 = January, 2 = February.....12 = December)

MRANK = monthly rank

mTave = monthly average temperature

n = number of years of data in the weather data base

$nCDD_i$ = annual normal cooling degree days

$nHDD_i$ = annual normal heating degree days

nTave = annual normal average temperature

$Tave_i$ = mean daily temperature of day i

T_{C*} = cooling temperature breakpoint (* = low, medium, high)

T_{H*} = heating temperature breakpoint (* = low, high)

$Tmax_i$ = maximum daily temperature of day i

$Tmin_i$ = minimum daily temperature of day i

YRANK = annual rank

HISTORICAL WEATHER DATA BASE

Input Requirements

To calculate a series of weather normals from the historical weather data base, the only inputs required are the calendar date, maximum daily temperature and minimum daily temperature. The data base for this example is given in Table 1.1.

Non-Leap Year and Leap Year Weather Adjustments

The addition of one day in the leap year increases the complexity of calculating the weather normal series to the extent that really two series must be calculated, one for leap years containing the date February 29, and another for non-leap years where each February 29 is omitted from the data set.

Even though two weather normal series must be used, they are calculated by exactly the same procedures. The only difference between the two series are the input data sets used.

For the non-leap year series, information for the date, February 29, in leap years are simply eliminated from the historical weather data. For the example presented here, only one line of data is eliminated from the data base because there is only one leap year, 1988. The line removed is:

DATE	$Tmax_i$	$Tmin_i$
22988	54.0	29.0

Removal of all February 29s gives each year of weather data 365 records.

For the leap year series, leap days are created for years that are not leap years by averaging Tmaxs and Tmins respectively for the dates February 28 and March 1 to create a day that is representative of late February. For this input

TABLE 1.1: Historical Weather Variables and Weather Normal Calculations

	1986						1987							1990									
i	DATE	Tmax	Tmin	Tave	HDD	CDD	DATE	Tmax	Tmin	Tave	HDD	CDD	...	DATE	Tmax	Tmin	Tave	HDD	CDD	nTave	nHDD	nCDD	YRANK
1	10186	52.0	23.0				10187	33.0	27.0				...	10190	37.0	28.0							1
2	10286	55.0	39.0				10287	34.0	18.0				...	10290	50.0	28.0							2
3	10386	43.0	33.0				10387	36.0	24.0				...	10390	59.0	36.0							3
4	10486	41.0	20.0				10487	41.0	28.0				...	10490	53.0	28.0							4
5	10586	41.0	14.0				10587	47.0	24.0				...	10590	46.0	24.0							5
6	10686	35.0	17.0				10687	61.0	35.0				...	10690	49.0	28.0							6
7	10786	21.0	7.0				10787	40.0	34.0				...	10790	52.0	30.0							7
8	10886	30.0	6.0				10887	39.0	31.0				...	10890	61.0	31.0							8
9	10986	49.0	17.0				10987	33.0	30.0				...	10990	55.0	38.0							9
10	11086	48.0	28.0				11087	33.0	27.0				...	11090	56.0	30.0							10
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361	122786	33.0	27.0				122787	40.0	36.0				...	122790	28.0	10.0							361
362	122886	45.0	21.0				122887	39.0	30.0				...	122890	43.0	28.0							362
363	122986	42.0	28.0				122987	35.0	28.0				...	122990	57.0	14.0							363
364	123086	35.0	32.0				123087	41.0	28.0				...	123090	14.0	7.0							364
365	123186	37.0	30.0				123187	44.0	24.0				...	123190	22.0	5.0							365

data set, the February 29 data created are given below:

YEAR	DATE	$Tmax_i$	$Tmin_i$
1986	22886	35.0	16.0
1986	30186	47.0	20.0
1986	"22986"	41.0	18.0
1987	22887	54.0	42.0
1987	30187	43.0	36.0
1987	"22987"	48.5	39.0
1989	22889	41.0	25.0
1989	20189	36.0	22.0
1989	"22989"	38.5	23.5
1990	22890	39.0	31.0
1990	30190	49.0	25.0
1990	"22990"	44.0	28.0

CALCULATION OF ANNUAL WEATHER VARIABLES AND THE ASSIGNMENT OF ANNUAL RANKS

Calculation of Historical Weather Variables from Temperature Breakpoints

From the data in Table 1.1, three weather variables are calculated; mean daily temperature ($Tave_i$), daily heating degree days (HDD_i) and daily cooling degree days (CDD_i). these variables are calculated as follows:

Mean Daily Temperature:

$$Tave_i = \frac{Tmax_i + Tmin_i}{2}$$

Daily Heating Degree Days:

$$HDD_i = \begin{cases} T_{H*} - Tave_i & \text{if } Tave_i < T_{H*} \\ 0 & \text{if } Tave_i \geq T_{H*} \end{cases}$$

Daily Cooling Degree Days:

$$CDD_i = \begin{cases} Tave_i - T_{C*} & \text{if } Tave_i > T_{C*} \\ 0 & \text{if } Tave_i \leq T_{C*} \end{cases}$$

The results of these calculations are given in Table 1.2.

$T_{H*} = 55$

$T_{C*} = 80$

TABLE 1.2: Historical Weather Variables and Weather Normal Calculations

	1986						1987							1990									
i	DATE	Tmax	Tmin	Tave	HDD	CDD	DATE	Tmax	Tmin	Tave	HDD	CDD	...	DATE	Tmax	Tmin	Tave	HDD	CDD	nTave	nHDD	nCDD	YRANK
1	10186	52.0	23.0	37.5	17.5	0.0	10187	33.0	27.0	30.0	25.0	0.0	...	10190	37.0	28.0	32.5	22.5	0.0				1
2	10286	55.0	39.0	47.0	8.0	0.0	10287	34.0	18.0	26.0	29.0	0.0	...	10290	50.0	28.0	39.0	16.0	0.0				2
3	10386	43.0	33.0	38.0	17.0	0.0	10387	36.0	24.0	30.0	25.0	0.0	...	10390	59.0	36.0	47.5	7.5	0.0				3
4	10486	41.0	20.0	30.5	24.5	0.0	10487	41.0	28.0	34.5	20.5	0.0	...	10490	53.0	28.0	40.5	14.5	0.0				4
5	10586	41.0	14.0	27.5	27.5	0.0	10587	47.0	24.0	35.5	19.5	0.0	...	10590	46.0	24.0	35.0	20.0	0.0				5
6	10686	35.0	17.0	26.0	29.0	0.0	10687	61.0	35.0	48.0	7.0	0.0	...	10690	49.0	28.0	38.5	16.5	0.0				6
7	10786	21.0	7.0	14.0	41.0	0.0	10787	40.0	34.0	37.0	18.0	0.0	...	10790	52.0	30.0	41.0	14.0	0.0				7
8	10886	30.0	6.0	18.0	37.0	0.0	10887	39.0	31.0	35.0	20.0	0.0	...	10890	61.0	31.0	46.0	9.0	0.0				8
9	10986	49.0	17.0	33.0	22.0	0.0	10987	33.0	30.0	31.5	23.5	0.0	...	10990	55.0	38.0	46.5	8.5	0.0				9
10	11086	48.0	28.0	38.0	17.0	0.0	11087	33.0	27.0	30.0	25.0	0.0	...	11090	56.0	30.0	43.0	12.0	0.0				10
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361	122786	33.0	27.0	30.0	25.0	0.0	122787	40.0	36.0	38.0	17.0	0.0	...	122790	28.0	10.0	19.0	36.0	0.0				361
362	122886	45.0	21.0	33.0	22.0	0.0	122887	39.0	30.0	34.5	20.5	0.0	...	122890	43.0	28.0	35.5	19.5	0.0				362
363	122986	42.0	28.0	35.0	20.0	0.0	122987	35.0	28.0	31.5	23.5	0.0	...	122990	57.0	14.0	35.5	19.5	0.0				363
364	123086	35.0	32.0	33.5	21.5	0.0	123087	41.0	28.0	34.5	20.5	0.0	...	123090	14.0	7.0	10.5	44.5	0.0				364
365	123186	37.0	30.0	33.5	21.5	0.0	123187	44.0	24.0	34.0	21.0	0.0	...	123190	22.0	5.0	13.5	41.5	0.0				365

Calculation of Normal Weather Variables and the Assignment of Annual Ranks

Recall that part of Property 1 of the weather normal series is the preservation of annual temperature extremes. To preserve both hot and cold extremes in the weather normal series, the historical weather variables from the warmest and coldest days of each year need to be averaged together, respectively. In fact, second warmest, third warmest,... coldest days will be handled in the same manner. To accomplish this, weather variables for each year in the data can be sorted by mean daily temperature from highest to lowest and annual ranks can be assigned as follows:

YRANK = 1	warmest day of the year
YRANK = 2	2nd warmest day of the year
YRANK = 3	3rd warmest day of the year
•	•
•	•
•	•
YRANK = 364	2nd coldest day of the year
YRANK = 365	coldest day of the year

Once annual ranks are assigned based on mean daily temperatures normal mean daily temperatures, heating degree days and cooling degree days are calculated as follows:

Normal Mean Daily Temperature:

$$nTave\Big|_{YRANK = constant} = \frac{\sum^{n} Tave}{n}\Big|_{YRANK = constant}$$

Normal Heating Degree Days

$$nHDD\Big|_{YRANK = constant} = \frac{\sum^{n} HDD}{n}\Big|_{YRANK = constant}$$

Normal Cooling Degree Days

$$nCDD\Big|_{YRANK = constant} = \frac{\sum^{n} CDD}{n}\Big|_{YRANK = constant}$$

Ranked weather variables and weather normals are given in Table 1.3.

TABLE 1.3: Historical Weather Variables and Weather Normal Calculations

i	DATE	Tave	HDD	CDD	DATE	Tave	HDD	CDD	...	DATE	Tave	HDD	CDD	nTave	nHDD	nCDD	YRANK
1	71986	91.0	0.0	11.0	80287	91.5	0.0	11.5	...	70490	92.0	0.0	12.0	91.1	0.0	11.1	1
2	72586	90.5	0.0	10.5	80187	89.0	0.0	9.0	...	90690	91.0	0.0	11.0	90.2	0.0	10.2	2
3	71786	87.5	0.0	7.5	72687	88.0	0.0	8.0	...	82890	90.5	0.0	10.0	89.2	0.0	9.2	3
4	72486	87.5	0.0	7.5	73087	88.0	0.0	8.0	...	70990	90.0	0.0	10.0	88.8	0.0	8.8	4
5	71686	87.0	0.0	7.0	81687	88.0	0.0	8.0	...	90590	90.0	0.0	10.0	88.7	0.0	8.7	5
6	70886	87.0	0.0	7.0	80387	87.5	0.0	7.5	...	70890	88.5	0.0	8.5	88.2	0.0	8.2	6
7	71886	87.0	0.0	7.0	73187	87.0	0.0	7.0	...	82790	88.0	0.0	8.0	87.7	0.0	7.7	7
8	70986	86.0	0.0	6.0	72987	86.5	0.0	6.5	...	71090	87.5	0.0	7.5	87.1	0.0	7.1	8
9	70686	85.5	0.0	5.5	82187	86.0	0.0	6.0	...	70390	87.5	0.0	7.5	86.8	0.0	6.8	9
10	62986	85.5	0.0	5.5	72287	85.5	0.0	5.5	...	90490	87.5	0.0	7.5	86.4	0.0	6.4	10
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361	21186	15.0	40.0	0.0	12087	22.0	33.0	0.0	...	123190	13.5	41.5	0.0	12.8	42.2	0.0	361
362	21586	14.5	40.5	0.0	12687	13.5	41.5	0.0	...	123090	10.5	44.5	0.0	10.0	45.0	0.0	362
363	21286	14.0	41.0	0.0	12387	12.0	43.0	0.0	...	122490	9.5	45.5	0.0	9.2	45.8	0.0	363
364	10786	14.0	41.0	0.0	12587	11.0	44.0	0.0	...	122290	9.5	45.5	0.0	7.3	47.7	0.0	364
365	12786	8.0	47.0	0.0	12487	8.5	46.5	0.0	...	122390	4.5	50.5	0.0	3.7	51.3	0.0	365

CALCULATION OF MONTHLY WEATHER VARIABLES AND THE ASSIGNMENT OF MONTHLY RANKS

Property 1 also specifies that in addition to the preservation of yearly temperature extremes, monthly weather patterns must also be preserved. Normal monthly weather is calculated in the same manner that is used calculate normal weather with several notable exceptions:

1. Only monthly normal temperatures (mTaves) are calculated. There are no monthly normal heating or cooling degree days needed.
2. Mean daily temperatures within each year are sorted from highest to lowest within each month.
3. Monthly ranks are assigned to each day in the weather data base where

$$MRANK = 100\ MM + DD$$

To calculate monthly weather variables and assign monthly ranks data for each year are sorted <u>within each month</u> from highest to lowest mean daily temperature. Monthly ranks are assigned as follows:

MRANK = 101	warmest day in January
MRANK = 102	2nd warmest day in January
.	.
.	.
.	.
MRANK = 131	coldest day in January
MRANK = 201	warmest day in February
.	.
.	.
.	.
MRANK = 1231	coldest day in December

For constant rank, monthly normal temperatures are calculated as follows:

$$mTave\Big|_{MRANK = constant} = \frac{\sum^{n} Tave}{n}\Big|_{MRANK = constant}$$

Monthly ranks and monthly normal temperatures are presented in Table 2.1.

TABLE 2.1: Assignment of Monthly Ranks to Historical Weather

i	DATE	Tave	MM	MRANK	DATE	Tave	MM	MRANK	...	DATE	Tave	MM	MRANK	mTave	MRANK
1	11786	58.0	1	101	11487	49.0	1	101	...	11690	61.0	1	101	56.8	101
2	12186	56.0	1	102	10687	48.0	1	102	...	11590	55.5	1	102	53.7	102
3	11686	52.5	1	103	12987	46.5	1	103	...	12390	55.0	1	103	51.5	103
4	10286	47.0	1	104	11387	44.0	1	104	...	11790	52.0	1	104	47.3	104
5	11886	45.5	1	105	11587	40.5	1	105	...	12490	50.5	1	105	45.8	105
6	11186	43.5	1	106	10787	37.0	1	106	...	12790	49.0	1	106	44.1	106
7	11286	42.5	1	107	13087	36.0	1	107	...	12290	48.0	1	107	42.3	107
8	12586	40.5	1	108	13187	36.0	1	108	...	10390	47.5	1	108	41.8	108
9	12086	40.5	1	109	10587	35.5	1	109	...	10990	46.5	1	109	41.2	109
10	12486	40.0	1	110	10887	35.0	1	110	...	10890	46.0	1	110	40.7	110
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361	122786	30.0	12	1227	122987	31.5	12	1227	...	123190	13.5	12	1227	20.8	1227
362	122586	29.0	12	1228	121887	29.0	12	1228	...	123090	10.5	12	1228	18.5	1228
363	121286	28.5	12	1229	121587	28.5	12	1229	...	122490	9.5	12	1229	17.8	1229
364	121086	22.5	12	1230	121687	25.8	12	1230	...	122290	9.5	12	1230	14.8	1230
365	121386	21.0	12	1231	121787	24.0	12	1231	...	122390	4.5	12	1231	12.4	1231

TEST YEAR CALCULATIONS

Input Requirements

For the example presented here, the calendar year 1990 will be normalized. The input requirements for the test year are identical to those of the historical weather data base with one exception. In addition to date, minimum and maximum daily temperatures, the day type (either weekday or weekend) is also required (Table 3.1).

Assignment of Monthly Ranks to the Test Year and the Treatment of Monthly Extremes

Monthly ranks are assigned to the test year in the same manner as the historical weather data base. Within each month, data are sorted from highest to lowest mean daily temperature and monthly ranks are assigned from MRANK = 101 (the warmest day in January) to MRANK = 1231 (the coldest day in December).

There is one very important difference in the assignment of monthly ranks to the test year data. Recall that property 2 states that no temperature extremes can occur on a weekend (because load will not peak on a weekend). For the example here, if monthly ranks are assigned by descending mean daily temperature only, warm weather extremes occur on weekends in March and June; cold weather extremes occur on weekends in January, February, March, July, September and December. Weekend weather extremes are shown in Table 3.2.

Because of property 2, monthly temperature extremes (MRANK = *01 for the warmest days of each month, MRANK = *28, *30, *31 to the coldest days of each month) must be assigned to weekdays (DAYTYPE = 1). All other monthly ranks are then assigned by descending mean daily temperature. The results of assigning monthly ranks in this manner are given in Table 3.3.

TABLE 3.1: Assignment of Monthly Ranks to the Test Year

i	DATE	Tmax	Tmin	Tave	MM	DAY TYPE	MRANK
			1990				
1	10190	37.0	28.0	32.5		1	
2	10290	50.0	28.0	39.0		1	
3	10390	59.0	36.0	47.5		1	
4	10490	53.0	28.0	40.5		1	
5	10590	46.0	24.0	35.0		1	
6	10690	49.0	28.0	38.5		2	
7	10790	52.0	30.0	41.0		3	
8	10890	61.0	31.0	46.0		1	
9	10990	55.0	38.0	46.5		1	
10	11090	56.0	30.0	43.0		1	
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.	.	.	.	.		.	
361	122790	28.0	10.0	19.0		1	
362	122890	43.0	28.0	35.5		1	
363	122990	57.0	14.0	35.5		2	
364	123090	14.0	7.0	10.5		3	
365	123190	22.0	5.0	13.5		1	

TABLE 3.2: Assignment of Monthly Ranks to the Test Year

i	DATE	Tave	MM	DAY TYPE	MRANK	MRANK
1	11690	61.0	1	1	101	101
2	11590	55.5	1	1	102	102
3	12390	55.0	1	1	103	103
4	11790	52.0	1	1	104	104
5	12490	50.5	1	1	105	105
6	12790	49.0	1	2	106	106
7	12290	48.0	1	1	107	107
8	10390	47.5	1	1	108	108
9	10990	46.5	1	1	109	109
10	10890	46.0	1	1	110	110
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.	.	.	.	.	.	.
361	123190	13.5	12	1	1227	1227
362	123090	10.5	12	3	1228	1228
363	122490	9.5	12	1	1231	1229
364	122290	9.5	12	2	1229	1230
365	122390	4.5	12	3	1230	1231

Assignment of Monthly Ranks to the Test Year

i	DATE	Tave	MM	DAY TYPE	MRANK
1	11690	61.0	1	1	101
2	11590	55.5	1	1	102
3	12390	55.0	1	1	103
4	11790	52.0	1	1	104
5	12490	50.5	1	1	105
6	12790	49.0	1	2	106
7	12290	48.0	1	1	107
8	10390	47.5	1	1	108
9	10990	46.5	1	1	109
10	10890	46.0	1	1	110
11	11490	45.5	1	3	111
12	13090	44.0	1	1	112
13	12090	44.0	1	2	113
14	11190	43.5	1	1	114
15	13190	43.5	1	1	115
16	11090	43.0	1	1	116
17	12690	42.5	1	1	117
18	12590	41.5	1	1	118
19	10790	41.0	1	3	119
20	10490	40.5	1	1	120
21	12190	40.0	1	3	121
22	10290	39.0	1	1	122
23	10690	38.5	1	2	123
24	12990	38.0	1	1	124
25	11890	37.0	1	1	125
26	12890	36.5	1	3	126
27	10590	35.0	1	1	127
28	11990	33.5	1	1	128
29	10190	32.5	1	1	129
30	11290	29.5	1	1	130
31	11390	29.0	1	2	131
32	20890	56.0	2	1	201
33	21390	54.0	2	1	202
34	21290	53.0	2	1	203
35	20990	50.5	2	1	204
36	22290	50.0	2	1	205
37	20190	48.0	2	1	206
38	22190	47.0	2	1	207
39	20790	47.0	2	1	208
40	22790	45.5	2	1	209
41	21190	45.5	2	3	210
42	21090	44.5	2	2	211
43	20590	43.0	2	1	212
44	20690	42.5	2	1	213
45	21890	42.0	2	3	214
46	22390	40.5	2	1	215
47	20290	40.5	2	1	216
48	21990	38.0	2	1	217
49	20390	37.5	2	2	218
50	20490	37.0	2	3	219
51	21590	36.0	2	1	220
52	21490	36.0	2	1	221
53	22690	35.5	2	1	222
54	22890	35.0	2	1	223
55	22090	34.5	2	1	224
56	21690	33.5	2	1	225
57	22490	32.5	2	2	226
58	21790	30.0	2	2	227
59	22590	22.0	2	3	228
60	31090	73.5	3	2	301
61	31290	73.0	3	1	302
62	31390	71.5	3	1	303
63	31190	70.0	3	3	304
64	31490	66.0	3	1	305
65	30990	63.0	3	1	306
66	31590	57.0	3	1	307
67	30890	56.5	3	1	308
68	31690	56.0	3	1	309
69	32290	55.0	3	1	310
70	30590	54.0	3	1	311
71	32190	54.0	3	1	312
72	31790	52.0	3	2	313
73	33190	52.0	3	2	314
74	32990	49.0	3	1	315
75	33090	48.5	3	1	316
76	30690	47.0	3	1	317
77	32890	46.5	3	1	318
78	30290	44.0	3	1	319
79	30490	43.5	3	3	320
80	32790	43.5	3	1	321
81	30790	42.5	3	1	322
82	31890	42.0	3	3	323
83	30390	40.5	3	2	324

84	32690	39.5	3	1	325
85	32090	39.0	3	1	326
86	30190	37.0	3	1	327
87	32590	33.0	3	3	328
88	32390	32.5	3	1	329
89	31990	31.5	3	1	330
90	32490	29.5	3	2	331
91	42490	78.5	4	1	401
92	42590	77.0	4	1	402
93	42690	76.0	4	1	403
94	42390	74.5	4	1	404
95	42790	71.5	4	1	405
96	42290	66.0	4	3	406
97	42090	64.5	4	1	407
98	42190	64.0	4	2	408
99	42990	62.5	4	3	409
100	40190	59.5	4	3	410
101	40990	59.0	4	1	411
102	43090	57.0	4	1	412
103	42890	56.0	4	2	413
104	40890	55.5	4	3	414
105	41990	54.5	4	1	415
106	41690	54.5	4	1	416
107	40490	53.0	4	1	417
108	41090	49.0	4	1	418
109	41490	48.0	4	2	419
110	41890	48.0	4	1	420
111	41590	47.5	4	3	421
112	41790	46.5	4	1	422
113	40590	46.0	4	1	423
114	41390	45.0	4	1	424
115	41290	43.5	4	1	425
116	40790	42.5	4	2	426
117	40690	42.5	4	1	427
118	40390	42.5	4	1	428
119	40290	42.0	4	1	429
120	41190	41.5	4	1	430
121	52590	74.5	5	1	501
122	50890	71.0	5	1	502
123	52690	70.0	5	2	503
124	52990	68.0	5	1	504
125	50790	68.0	5	1	505
126	52890	68.0	5	1	506
127	53190	67.5	5	1	507
128	51990	67.5	5	2	508
129	51890	67.5	5	1	509
130	51590	67.5	5	1	510
131	52490	66.5	5	1	511
132	52790	66.5	5	3	512
133	51690	65.5	5	1	513
134	51490	65.0	5	1	514
135	52090	65.0	5	3	515
136	52390	63.0	5	1	516
137	51790	63.0	5	1	517
138	50990	63.0	5	1	518
139	50690	62.0	5	3	519
140	53090	61.5	5	1	520
141	52290	61.5	5	1	521
142	50490	61.0	5	1	522
143	50190	60.0	5	1	523
144	51290	59.0	5	2	524
145	50590	58.0	5	2	525
146	51190	58.0	5	1	526
147	51390	57.5	5	3	527
148	50290	57.5	5	1	528
149	52190	57.0	5	1	529
150	51090	55.5	5	1	530
151	50390	54.5	5	1	531
152	61790	86.0	6	3	601
153	62890	85.0	6	1	602
154	61690	84.5	6	2	603
155	62990	84.0	6	1	604
156	63090	84.0	6	2	605
157	61990	83.0	6	1	606
158	62790	83.0	6	1	607
159	61890	82.5	6	1	608
160	61390	82.5	6	1	609
161	60890	81.5	6	1	610
162	62690	81.0	6	1	611
163	62190	79.5	6	1	612
164	61590	79.5	6	1	613
165	61290	78.5	6	1	614
166	62590	78.0	6	1	615
167	60290	77.5	6	2	616
168	60990	77.5	6	2	617
169	61490	76.5	6	1	618
170	60190	76.5	6	1	619
171	62090	75.5	6	1	620
172	61190	75.0	6	1	621

173	61090	74.0	6	3	622
174	60790	74.0	6	1	623
175	62490	74.0	6	3	624
176	62290	72.0	6	1	625
177	62390	71.0	6	2	626
178	60690	71.0	6	1	627
179	60390	69.0	6	3	628
180	60590	63.0	6	1	629
181	60490	57.5	6	1	630
182	70490	92.0	7	1	701
183	70990	90.0	7	1	702
184	70890	88.5	7	3	703
185	71090	87.5	7	1	704
186	70390	87.5	7	1	705
187	70590	87.0	7	1	706
188	70190	86.5	7	3	707
189	72790	85.0	7	1	708
190	72890	85.0	7	2	709
191	71990	84.5	7	1	710
192	72990	84.0	7	3	711
193	70790	83.0	7	2	712
194	71890	83.0	7	1	713
195	70290	82.0	7	1	714
196	70690	81.5	7	1	715
197	72090	80.5	7	1	716
198	73090	79.5	7	1	717
199	72190	79.0	7	2	718
200	71690	79.0	7	1	719
201	71790	79.0	7	1	720
202	72690	78.5	7	1	721
203	72590	78.0	7	1	722
204	71190	77.5	7	1	723
205	72490	75.5	7	1	724
206	73190	74.0	7	1	725
207	72390	73.5	7	1	726
208	72290	73.0	7	3	727
209	71590	72.0	7	3	728
210	71290	71.5	7	1	729
211	71390	65.5	7	1	730
212	71490	62.0	7	2	731
213	82890	90.5	8	1	801
214	82790	88.0	8	1	802
215	81990	86.5	8	3	803
216	81890	85.5	8	2	804
217	82690	84.0	8	3	805
218	81790	82.5	8	1	806
219	82090	82.0	8	1	807
220	82990	81.5	8	1	808
221	82590	80.5	8	2	809
222	80390	79.5	8	1	810
223	82490	79.0	8	1	811
224	83090	79.0	8	1	812
225	83190	78.5	8	1	813
226	82390	78.5	8	1	814
227	81190	77.5	8	2	815
228	80490	77.5	8	2	816
229	80290	77.0	8	1	817
230	81290	76.5	8	3	818
231	81090	76.0	8	1	819
232	80590	75.5	8	3	820
233	82190	75.5	8	1	821
234	81390	75.0	8	1	822
235	81490	74.0	8	1	823
236	81690	73.5	8	1	824
237	80190	73.0	8	1	825
238	81590	73.0	8	1	826
239	82290	73.0	8	1	827
240	80990	72.5	8	1	828
241	80890	71.5	8	1	829
242	80690	69.5	8	1	830
243	80790	67.5	8	1	831
244	90690	91.0	9	1	901
245	90590	90.0	9	1	902
246	90490	87.5	9	1	903
247	90290	85.0	9	3	904
248	90790	84.5	9	1	905
249	90190	83.5	9	2	906
250	90390	83.5	9	1	907
251	91090	80.0	9	1	908
252	90990	79.5	9	3	909
253	91290	79.5	9	1	910
254	91390	78.0	9	1	911
255	91190	78.0	9	1	912
256	90890	77.0	9	2	913
257	92890	76.0	9	1	914
258	92790	75.5	9	1	915
259	91490	75.5	9	1	916
260	92690	74.5	9	1	917
261	92590	71.5	9	1	918

262	91590	69.5	9	2	919
263	92090	69.0	9	1	920
264	92990	67.5	9	2	921
265	91990	67.5	9	1	922
266	91690	67.5	9	3	923
267	92190	65.5	9	1	924
268	92290	65.0	9	2	925
269	93090	63.0	9	3	926
270	91790	62.5	9	1	927
271	91890	62.0	9	1	928
272	92490	58.0	9	1	929
273	92390	55.0	9	3	930
274	100590	75.0	10	1	1001
275	100690	75.0	10	2	1002
276	100290	71.5	10	1	1003
277	100390	68.0	10	1	1004
278	103190	68.0	10	1	1005
279	100190	67.5	10	1	1006
280	101690	67.5	10	1	1007
281	100490	66.0	10	1	1008
282	103090	66.0	10	1	1009
283	101490	64.5	10	3	1010
284	101790	63.0	10	1	1011
285	100790	62.5	10	3	1012
286	102790	59.5	10	2	1013
287	102090	59.0	10	2	1014
288	101390	58.0	10	2	1015
289	101590	57.5	10	1	1016
290	100890	56.5	10	1	1017
291	102990	56.5	10	1	1018
292	102190	53.0	10	3	1019
293	101290	51.5	10	1	1020
294	102390	51.5	10	1	1021
295	102490	49.5	10	1	1022
296	101890	49.5	10	1	1023
297	101190	49.0	10	1	1024
298	102890	49.0	10	3	1025
299	101990	49.0	10	1	1026
300	102290	49.0	10	1	1027
301	100990	48.0	10	1	1028
302	102690	48.0	10	1	1029
303	102590	46.0	10	1	1030
304	101090	44.5	10	1	1031
305	110290	70.0	11	1	1101
306	110390	67.0	11	2	1102
307	111590	66.5	11	1	1103
308	110190	66.5	11	1	1104
309	112690	65.5	11	1	1105
310	112190	64.5	11	1	1106
311	112590	63.0	11	3	1107
312	111490	62.5	11	1	1108
313	112790	58.5	11	1	1109
314	112490	57.5	11	2	1110
315	112090	57.0	11	1	1111
316	110490	54.0	11	3	1112
317	111690	54.0	11	1	1113
318	111990	53.5	11	1	1114
319	111390	53.0	11	1	1115
320	111190	52.0	11	3	1116
321	111290	51.0	11	1	1117
322	112390	50.0	11	1	1118
323	111090	48.5	11	2	1119
324	112290	48.0	11	1	1120
325	113090	46.0	11	1	1121
326	111790	46.0	11	2	1122
327	111890	45.5	11	3	1123
328	110690	42.5	11	1	1124
329	110990	41.5	11	1	1125
330	110590	40.5	11	1	1126
331	110790	40.0	11	1	1127
332	112990	39.0	11	1	1128
333	110890	38.5	11	1	1129
334	112890	38.0	11	1	1130
335	121190	56.0	12	1	1201
336	121090	53.5	12	1	1202
337	121290	51.0	12	1	1203
338	120990	49.5	12	3	1204
339	122090	48.5	12	1	1205
340	120190	48.0	12	2	1206
341	121590	45.5	12	2	1207
342	120290	45.0	12	3	1208
343	120890	43.0	12	2	1209
344	120590	43.0	12	1	1210
345	121790	42.5	12	1	1211
346	120390	41.0	12	1	1212
347	121990	40.0	12	1	1213
348	121890	38.5	12	1	1214
349	121490	38.5	12	1	1215
350	120690	38.0	12	1	1216

351	121390	38.0	12	1	1217
352	121690	37.0	12	3	1218
353	120790	36.0	12	1	1219
354	122990	35.5	12	2	1220
355	122890	35.5	12	1	1221
356	122190	33.0	12	1	1222
357	120490	32.5	12	1	1223
358	122590	24.0	12	1	1224
359	122790	19.0	12	1	1225
360	122690	14.0	12	1	1226
361	123190	13.5	12	1	1227
362	123090	10.5	12	3	1228
363	122490	9.5	12	1	1229
364	122290	9.5	12	2	1230
365	122390	4.5	12	3	1231

TABLE 3: Assignment of Monthly Ranks to the Test Year

I	DATE	Tave	MM	DAY TYPE	MRANK
1	11690	61.0	1	1	101
2	11590	55.5	1	1	102
3	12390	55.0	1	1	103
4	11790	52.0	1	1	104
5	12490	50.5	1	1	105
6	12790	49.0	1	2	106
7	12290	48.0	1	1	107
8	10390	47.5	1	1	108
9	10990	46.5	1	1	109
10	10890	46.0	1	1	110
11	11490	45.5	1	3	111
12	13090	44.0	1	1	112
13	12090	44.0	1	2	113
14	11190	43.5	1	1	114
15	13190	43.5	1	1	115
16	11090	43.0	1	1	116
17	12690	42.5	1	1	117
18	12590	41.5	1	1	118
19	10790	41.0	1	3	119
20	10490	40.5	1	1	120
21	12190	40.0	1	3	121
22	10290	39.0	1	1	122
23	10690	38.5	1	2	123
24	12990	38.0	1	1	124
25	11890	37.0	1	1	125
26	12890	36.5	1	3	126
27	10590	35.0	1	1	127
28	11990	33.5	1	1	128
29	10190	32.5	1	1	129
30	11290	29.5	1	1	131
31	11390	29.0	1	2	130
32	20890	56.0	2	1	201
33	21390	54.0	2	1	202
34	21290	53.0	2	1	203
35	20990	50.5	2	1	204
36	22290	50.0	2	1	205
37	20190	48.0	2	1	206
38	22190	47.0	2	1	207
39	20790	47.0	2	1	208
40	22790	45.5	2	1	209
41	21190	45.5	2	3	210
42	21090	44.5	2	2	211
43	20590	43.0	2	1	212
44	20690	42.5	2	1	213
45	21890	42.0	2	3	214
46	22390	40.5	2	1	215
47	20290	40.5	2	1	216
48	21990	38.0	2	1	217
49	20390	37.5	2	2	218
50	20490	37.0	2	3	219
51	21590	36.0	2	1	220
52	21490	36.0	2	1	221
53	22690	35.5	2	1	222
54	22890	35.0	2	1	223
55	22090	34.5	2	1	224
56	21690	33.5	2	1	228
57	22490	32.5	2	2	225
58	21790	30.0	2	2	226
59	22590	22.0	2	3	227
60	31090	73.5	3	2	302
61	31290	73.0	3	1	301
62	31390	71.5	3	1	303
63	31190	70.0	3	3	304
64	31490	66.0	3	1	305
65	30990	63.0	3	1	306
66	31590	57.0	3	1	307
67	30890	56.5	3	1	308
68	31690	56.0	3	1	309
69	32290	55.0	3	1	310
70	30590	54.0	3	1	311
71	32190	54.0	3	1	312
72	31790	52.0	3	2	313
73	33190	52.0	3	2	314
74	32990	49.0	3	1	315
75	33090	48.5	3	1	316
76	30690	47.0	3	1	317
77	32890	46.5	3	1	318
78	30290	44.0	3	1	319
79	30490	43.5	3	3	320
80	32790	43.5	3	1	321
81	30790	42.5	3	1	322
82	31890	42.0	3	3	323
83	30390	40.5	3	2	324

84	32690	39.5	3	1	325
85	32090	39.0	3	1	326
86	30190	37.0	3	1	327
87	32590	33.0	3	3	328
88	32390	32.5	3	1	329
89	31990	31.5	3	1	331
90	32490	29.5	3	2	330
91	42490	78.5	4	1	401
92	42590	77.0	4	1	402
93	42690	76.0	4	1	403
94	42390	74.5	4	1	404
95	42790	71.5	4	1	405
96	42290	66.0	4	3	406
97	42090	64.5	4	1	407
98	42190	64.0	4	2	408
99	42990	62.5	4	3	409
100	40190	59.5	4	3	410
101	40990	59.0	4	1	411
102	43090	57.0	4	1	412
103	42890	56.0	4	2	413
104	40890	55.5	4	3	414
105	41990	54.5	4	1	415
106	41690	54.5	4	1	416
107	40490	53.0	4	1	417
108	41090	49.0	4	1	418
109	41490	48.0	4	2	419
110	41890	48.0	4	1	420
111	41590	47.5	4	3	421
112	41790	46.5	4	1	422
113	40590	46.0	4	1	423
114	41390	45.0	4	1	424
115	41290	43.5	4	1	425
116	40790	42.5	4	2	426
117	40690	42.5	4	1	427
118	40390	42.5	4	1	428
119	40290	42.0	4	1	429
120	41190	41.5	4	1	430
121	52590	74.5	5	1	501
122	50890	71.0	5	1	502
123	52690	70.0	5	2	503
124	52990	68.0	5	1	504
125	50790	68.0	5	1	505
126	52890	68.0	5	1	506
127	53190	67.5	5	1	507
128	51990	67.5	5	2	508
129	51890	67.5	5	1	509
130	51590	67.5	5	1	510
131	52490	66.5	5	1	511
132	52790	66.5	5	3	512
133	51690	65.5	5	1	513
134	51490	65.0	5	1	514
135	52090	65.0	5	3	515
136	52390	63.0	5	1	516
137	51790	63.0	5	1	517
138	50990	63.0	5	1	518
139	50690	62.0	5	3	519
140	53090	61.5	5	1	520
141	52290	61.5	5	1	521
142	50490	61.0	5	1	522
143	50190	60.0	5	1	523
144	51290	59.0	5	2	524
145	50590	58.0	5	2	525
146	51190	58.0	5	1	526
147	51390	57.5	5	3	527
148	50290	57.5	5	1	528
149	52190	57.0	5	1	529
150	51090	55.5	5	1	530
151	50390	54.5	5	1	531
152	61790	86.0	6	3	602
153	62890	85.0	6	1	601
154	61690	84.5	6	2	603
155	62990	84.0	6	1	604
156	63090	84.0	6	2	605
157	61990	83.0	6	1	606
158	62790	83.0	6	1	607
159	61890	82.5	6	1	608
160	61390	82.5	6	1	609
161	60890	81.5	6	1	610
162	62690	81.0	6	1	611
163	62190	79.5	6	1	612
164	61590	79.5	6	1	613
165	61290	78.5	6	1	614
166	62590	78.0	6	1	615
167	60290	77.5	6	2	616
168	60990	77.5	6	2	617
169	61490	76.5	6	1	618
170	60190	76.5	6	1	619
171	62090	75.5	6	1	620
172	61190	75.0	6	1	621

173	61090	74.0	6	3	622
174	60790	74.0	6	1	623
175	62490	74.0	6	3	624
176	62290	72.0	6	1	625
177	62390	71.0	6	2	626
178	60690	71.0	6	1	627
179	60390	69.0	6	3	628
180	60590	63.0	6	1	629
181	60490	57.5	6	1	630
182	70490	92.0	7	1	701
183	70990	90.0	7	1	702
184	70890	88.5	7	3	703
185	71090	87.5	7	1	704
186	70390	87.5	7	1	705
187	70590	87.0	7	1	706
188	70190	86.5	7	3	707
189	72790	85.0	7	1	708
190	72890	85.0	7	2	709
191	71990	84.5	7	1	710
192	72990	84.0	7	3	711
193	70790	83.0	7	2	712
194	71890	83.0	7	1	713
195	70290	82.0	7	1	714
196	70690	81.5	7	1	715
197	72090	80.5	7	1	716
198	73090	79.5	7	1	717
199	72190	79.0	7	2	718
200	71690	79.0	7	1	719
201	71790	79.0	7	1	720
202	72690	78.5	7	1	721
203	72590	78.0	7	1	722
204	71190	77.5	7	1	723
205	72490	75.5	7	1	724
206	73190	74.0	7	1	725
207	72390	73.5	7	1	726
208	72290	73.0	7	3	727
209	71590	72.0	7	3	728
210	71290	71.5	7	1	729
211	71390	65.5	7	1	731
212	71490	62.0	7	2	730
213	82890	90.5	8	1	801
214	82790	88.0	8	1	802
215	81990	86.5	8	3	803
216	81890	85.5	8	2	804
217	82690	84.0	8	3	805
218	81790	82.5	8	1	806
219	82090	82.0	8	1	807
220	82990	81.5	8	1	808
221	82590	80.5	8	2	809
222	80390	79.5	8	1	810
223	82490	79.0	8	1	811
224	83090	79.0	8	1	812
225	83190	78.5	8	1	813
226	82390	78.5	8	1	814
227	81190	77.5	8	2	815
228	80490	77.5	8	2	816
229	80290	77.0	8	1	817
230	81290	76.5	8	3	818
231	81090	76.0	8	1	819
232	80590	75.5	8	3	820
233	82190	75.5	8	1	821
234	81390	75.0	8	1	822
235	81490	74.0	8	1	823
236	81690	73.5	8	1	824
237	80190	73.0	8	1	825
238	81590	73.0	8	1	826
239	82290	73.0	8	1	827
240	80990	72.5	8	1	828
241	80890	71.5	8	1	829
242	80690	69.5	8	1	830
243	80790	67.5	8	1	831
244	90690	91.0	9	1	901
245	90590	90.0	9	1	902
246	90490	87.5	9	1	903
247	90290	85.0	9	3	904
248	90790	84.5	9	1	905
249	90190	83.5	9	2	906
250	90390	83.5	9	1	907
251	91090	80.0	9	1	908
252	90990	79.5	9	3	909
253	91290	79.5	9	1	910
254	91390	78.0	9	1	911
255	91190	78.0	9	1	912
256	90890	77.0	9	2	913
257	92890	76.0	9	1	914
258	92790	75.5	9	1	915
259	91490	75.5	9	1	916
260	92690	74.5	9	1	917
261	92590	71.5	9	1	918

262	91590	69.5	9	2	919
263	92090	69.0	9	1	920
264	92990	67.5	9	2	921
265	91990	67.5	9	1	922
266	91690	67.5	9	3	923
267	92190	65.5	9	1	924
268	92290	65.0	9	2	925
269	93090	63.0	9	3	926
270	91790	62.5	9	1	927
271	91890	62.0	9	1	928
272	92490	58.0	9	1	930
273	92390	55.0	9	3	929
274	100590	75.0	10	1	1001
275	100690	75.0	10	2	1002
276	100290	71.5	10	1	1003
277	100390	68.0	10	1	1004
278	103190	68.0	10	1	1005
279	100190	67.5	10	1	1006
280	101690	67.5	10	1	1007
281	100490	66.0	10	1	1008
282	103090	66.0	10	1	1009
283	101490	64.5	10	3	1010
284	101790	63.0	10	1	1011
285	100790	62.5	10	3	1012
286	102790	59.5	10	2	1013
287	102090	59.0	10	2	1014
288	101390	58.0	10	2	1015
289	101590	57.5	10	1	1016
290	100890	56.5	10	1	1017
291	102990	56.5	10	1	1018
292	102190	53.0	10	3	1019
293	101290	51.5	10	1	1020
294	102390	51.5	10	1	1021
295	102490	49.5	10	1	1022
296	101890	49.5	10	1	1023
297	101190	49.0	10	1	1024
298	102890	49.0	10	3	1025
299	101990	49.0	10	1	1026
300	102290	49.0	10	1	1027
301	100990	48.0	10	1	1028
302	102690	48.0	10	1	1029
303	102590	46.0	10	1	1030
304	101090	44.5	10	1	1031
305	110290	70.0	11	1	1101
306	110390	67.0	11	2	1102
307	111590	66.5	11	1	1103
308	110190	66.5	11	1	1104
309	112690	65.5	11	1	1105
310	112190	64.5	11	1	1106
311	112590	63.0	11	3	1107
312	111490	62.5	11	1	1108
313	112790	58.5	11	1	1109
314	112490	57.5	11	2	1110
315	112090	57.0	11	1	1111
316	110490	54.0	11	3	1112
317	111690	54.0	11	1	1113
318	111990	53.5	11	1	1114
319	111390	53.0	11	1	1115
320	111190	52.0	11	3	1116
321	111290	51.0	11	1	1117
322	112390	50.0	11	1	1118
323	111090	48.5	11	2	1119
324	112290	48.0	11	1	1120
325	113090	46.0	11	1	1121
326	111790	46.0	11	2	1122
327	111890	45.5	11	3	1123
328	110690	42.5	11	1	1124
329	110990	41.5	11	1	1125
330	110590	40.5	11	1	1126
331	110790	40.0	11	1	1127
332	112990	39.0	11	1	1128
333	110890	38.5	11	1	1129
334	112890	38.0	11	1	1130
335	121190	56.0	12	1	1201
336	121090	53.5	12	1	1202
337	121290	51.0	12	1	1203
338	120990	49.5	12	3	1204
339	122090	48.5	12	1	1205
340	120190	48.0	12	2	1206
341	121590	45.5	12	2	1207
342	120290	45.0	12	3	1208
343	120890	43.0	12	2	1209
344	120590	43.0	12	1	1210
345	121790	42.5	12	1	1211
346	120390	41.0	12	1	1212
347	121990	40.0	12	1	1213
348	121890	38.5	12	1	1214
349	121490	38.5	12	1	1215
350	120690	38.0	12	1	1216

351	121390	38.0	12	1	1217
352	121690	37.0	12	3	1218
353	120790	36.0	12	1	1219
354	122990	35.5	12	2	1220
355	122890	35.5	12	1	1221
356	122190	33.0	12	1	1222
357	120490	32.5	12	1	1223
358	122590	24.0	12	1	1224
359	122790	19.0	12	1	1225
360	122690	14.0	12	1	1226
361	123190	13.5	12	1	1227
362	123090	10.5	12	3	1228
363	122490	9.5	12	1	1231
364	122290	9.5	12	2	1229
365	122390	4.5	12	3	1230

ASSIGNMENT OF WEATHER NORMALS TO THE TEST YEAR

It is now possible to assign the normal weather variables: normal daily temperature (nTave) normal heating degree days (nHDD) and normal cooling degree days (nCDD) to the test year. This is accomplished by matching test year, monthly normal, and normal weather variables by the ranking schemes previously established.

Assignment of Monthly Ranks to Annual Normal Weather

Monthly weather variables (mTave and MRANK) are matched to the normal weather variables by annual rank (YRANK). Recall that annual rank is assigned to normal daily temperatures by descending temperature with YRANK = 1 assigned to the warmest day of the normal year and YRANK = 365 assigned to the coldest day of the normal year. To match normal weather variables to monthly weather variables, both sets of variables are sorted by descending daily temperatures (nTave and mTave) and matched one to one. Therefore the warmest normal temperature and corresponding weather variables are matched to the warmest monthly temperature and MRANK (usually annual weather variables with YRANK = 1 are matched to monthly weather variables with MRANK = 701 or 801). When normal variables are matched in this way, a monthly rank is then associated with each day of annual normal weather. Table 4.1 shows test year, monthly normal and annual normal weather variables with assigned ranks and Table 4.2 shows monthly normal weather variables matched to annual normal weather variables through descending temperature (or ascending annual rank).

Assignment of Normal Weather to the Test Year

With monthly ranks assigned to normal weather variables, these variables can then be directly assigned to the test year by corresponding monthly rank. This result is shown in Table 4.3. If all the data are arranged by chronological test year date, the results given in Table 4.4 are obtained.

TABLE 4.1: Assignment of Normal Weather to the Test Year

i	DATE	Tave	MRANK	mTave	MRANK	nTave	nHDD	nCDD	YRANK
1	11690	61.0	101	56.8	101	91.1	0.0	11.1	1
2	11590	55.5	102	53.7	102	90.2	0.0	10.2	2
3	12390	55.0	103	51.5	103	89.2	0.0	9.2	3
4	11790	52.0	104	47.3	104	88.8	0.0	8.8	4
5	12490	50.5	105	45.8	105	88.7	0.0	8.7	5
6	12790	49.0	106	44.1	106	88.2	0.0	8.2	6
7	12290	48.0	107	42.3	107	87.7	0.0	7.7	7
8	10390	47.5	108	41.8	108	87.1	0.0	7.1	8
9	10990	46.5	109	41.2	109	86.8	0.0	6.8	9
10	10890	46.0	110	40.7	110	86.4	0.0	6.4	10
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361	123190	13.5	1227	20.8	1227	12.8	42.2	0.0	361
362	123090	10.5	1228	18.5	1228	10.0	45.0	0.0	362
363	122490	9.5	1231	17.8	1229	9.2	45.8	0.0	363
364	122290	9.5	1229	14.8	1230	7.3	47.7	0.0	364
365	122390	4.5	1230	12.4	1231	3.7	51.3	0.0	365

TABLE 4.2: Assignment of Normal Weather to the Test Year

i	DATE	Tave	MRANK	mTave	MRANK	nTave	nHDD	nCDD	YRANK
1	11690	61.0	101	90.4	701	91.1	0.0	11.1	1
2	11590	55.5	102	89.7	702	90.2	0.0	10.2	2
3	12390	55.0	103	89.1	801	89.2	0.0	9.2	3
4	11790	52.0	104	88.1	703	88.8	0.0	8.8	4
5	12490	50.5	105	87.4	704	88.7	0.0	8.7	5
6	12790	49.0	106	87.2	802	88.2	0.0	8.2	6
7	12290	48.0	107	86.8	705	87.7	0.0	7.7	7
8	10390	47.5	108	86.2	601	87.1	0.0	7.1	8
9	10990	46.5	109	85.9	706	86.8	0.0	6.8	9
10	10890	46.0	110	85.8	803	86.4	0.0	6.4	10
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361	123190	13.5	1227	17.8	1229	12.8	42.2	0.0	361
362	123090	10.5	1228	15.6	131	10.0	45.0	0.0	362
363	122490	9.5	1231	15.0	228	9.2	45.8	0.0	363
364	122290	9.5	1229	12.4	1231	7.3	47.7	0.0	364
365	122390	4.5	1230	12.4	1231	3.7	51.3	0.0	365

TABLE 4.3: Assignment of Normal Weather to the Test Year

i	DATE	Tave	MRANK	mTave	MRANK	nTave	nHDD	nCDD	YRANK
1	11690	61.0	101	56.8	101	56.2	0.0	0.0	195
2	11590	55.5	102	53.7	102	54.0	1.1	0.0	210
3	12390	55.0	103	51.5	103	51.9	3.1	0.0	221
4	11790	52.0	104	47.3	104	46.5	8.5	0.0	250
5	12490	50.5	105	45.8	105	45.6	9.4	0.0	257
6	12790	49.0	106	44.1	106	44.2	10.8	0.0	263
7	12290	48.0	107	42.3	107	42.6	12.4	0.0	275
8	10390	47.5	108	41.8	108	41.8	13.2	0.0	278
9	10990	46.5	109	41.2	109	40.9	14.1	0.0	282
10	10890	46.0	110	40.7	110	40.6	14.4	0.0	284
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361	123190	13.5	1227	20.8	1227	19.7	35.3	0.0	356
362	123090	10.5	1228	18.5	1228	15.9	39.1	0.0	359
363	122290	9.5	1229	17.8	1229	12.8	42.2	0.0	361
364	122390	4.5	1230	14.8	1230	7.3	47.7	0.0	364
365	122490	9.5	1231	12.4	1231	3.7	51.3	0.0	365

TABLE 4.4: Assignment of Normal Weather to the Test Year

i	DATE	Tave	MRANK	mTave	MRANK	nTave	nHDD	nCDD	YRANK
1	10190	32.5	129	20.9	129	20.5	34.5	0.0	355
2	10290	39.0	122	31.3	122	32.1	22.9	0.0	330
3	10390	47.5	108	41.8	108	41.8	13.2	0.0	278
4	10490	40.5	120	32.4	120	32.9	22.1	0.0	326
5	10590	35.0	127	25.3	127	24.7	30.3	0.0	349
6	10690	38.5	123	30.4	123	31.4	23.6	0.0	333
7	10790	41.0	119	33.4	119	33.7	21.3	0.0	321
8	10890	46.0	110	40.7	110	40.6	14.4	0.0	284
9	10990	46.5	109	41.2	109	40.9	14.1	0.0	282
10	11090	43.0	116	36.5	116	36.3	18.7	0.0	308
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361	122790	19.0	1225	24.2	1225	24.0	31.0	0.0	351
362	122890	35.5	1221	29.7	1221	30.5	24.5	0.0	335
363	122990	35.5	1220	30.4	1220	31.6	23.4	0.0	332
364	123090	10.5	1228	18.5	1228	15.9	39.1	0.0	359
365	123190	13.5	1227	20.8	1227	19.7	35.3	0.0	356

INTERPRETATION OF THE RESULTS

What the Weather Variables Really Mean

Having gone through this rather laborious scheme of sorting, ranking, averaging and matching, what do all these numbers really mean? Consider the first line of Table 4.4. It can be interpreted as follows:

The first day of the test year (DATE = 10190), the actual mean daily temperature (Tave) WAS 32.5^{O}F. It was the 29th warmest or 3rd coldest day of January 1990 (MRANK = 129). Normally the 29th warmest day in January is 20.9^{O}F (mTave). Based on historical weather the 29th warmest day in January, is the 355th warmest or 11th coldest day of the year (YRANK = 355). Normally, the 355th warmest day of the year has a mean daily temperature (nTave) of 20.5^{O}F. In a normal year, 34.5 heating degree days (nHDD) are required for the 11th coldest day of the year if the heating occurs when it is less than 55^{O}F (T_{H*} = 55^{O}F). There is no cooling (nCDD = 0.0). It is important to note that in this particular instance the first day of the test year is warmer than normal.

Graphical Results

1. Annual ranking of the historical weather
2. Monthly ranking of the historical weather
3. The difference between annual normal temperature and monthly normal temperatures
4. The difference between actual and normal weather

Figure 1. Annual Ranks

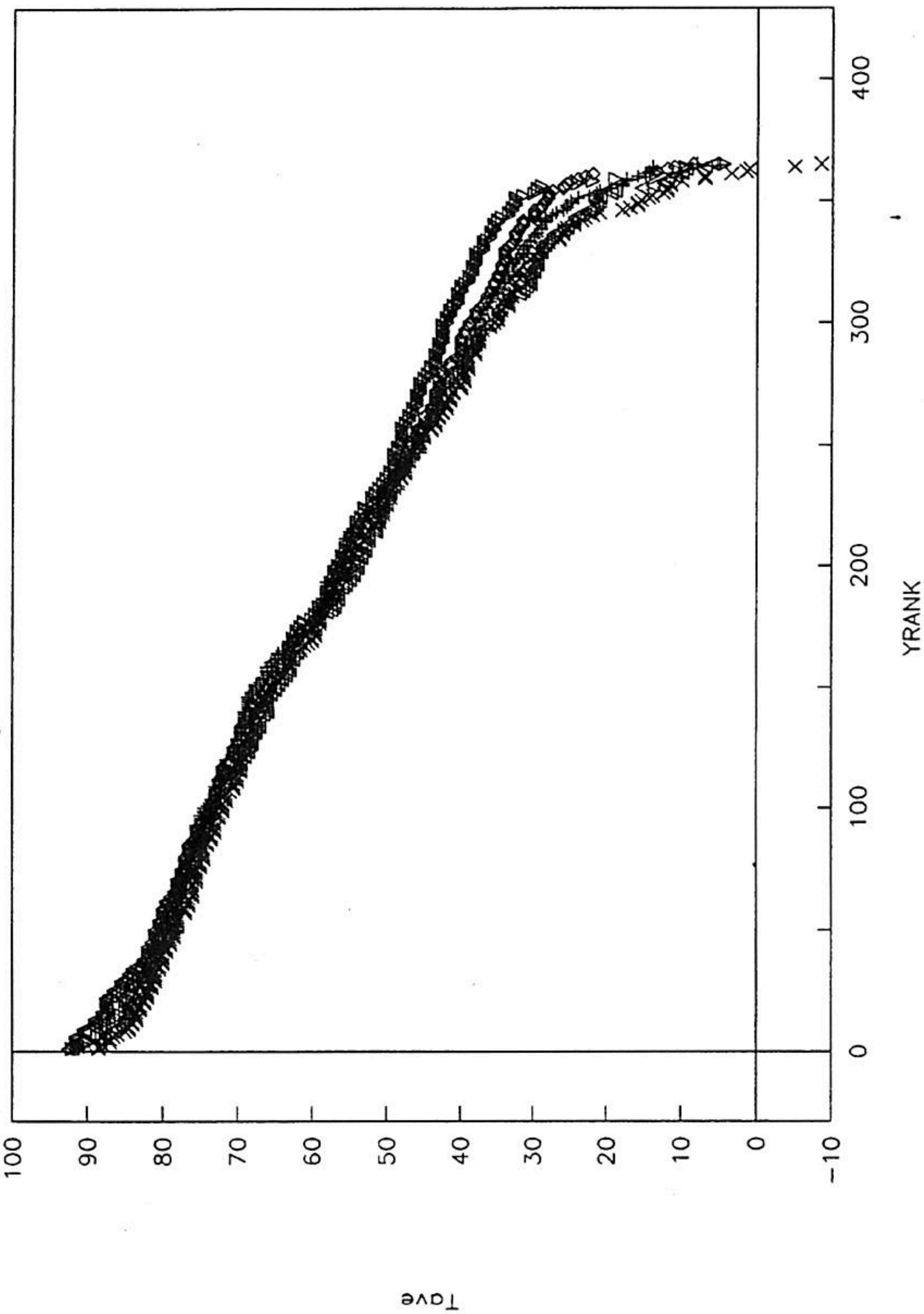


Figure 2. Monthly Ranks

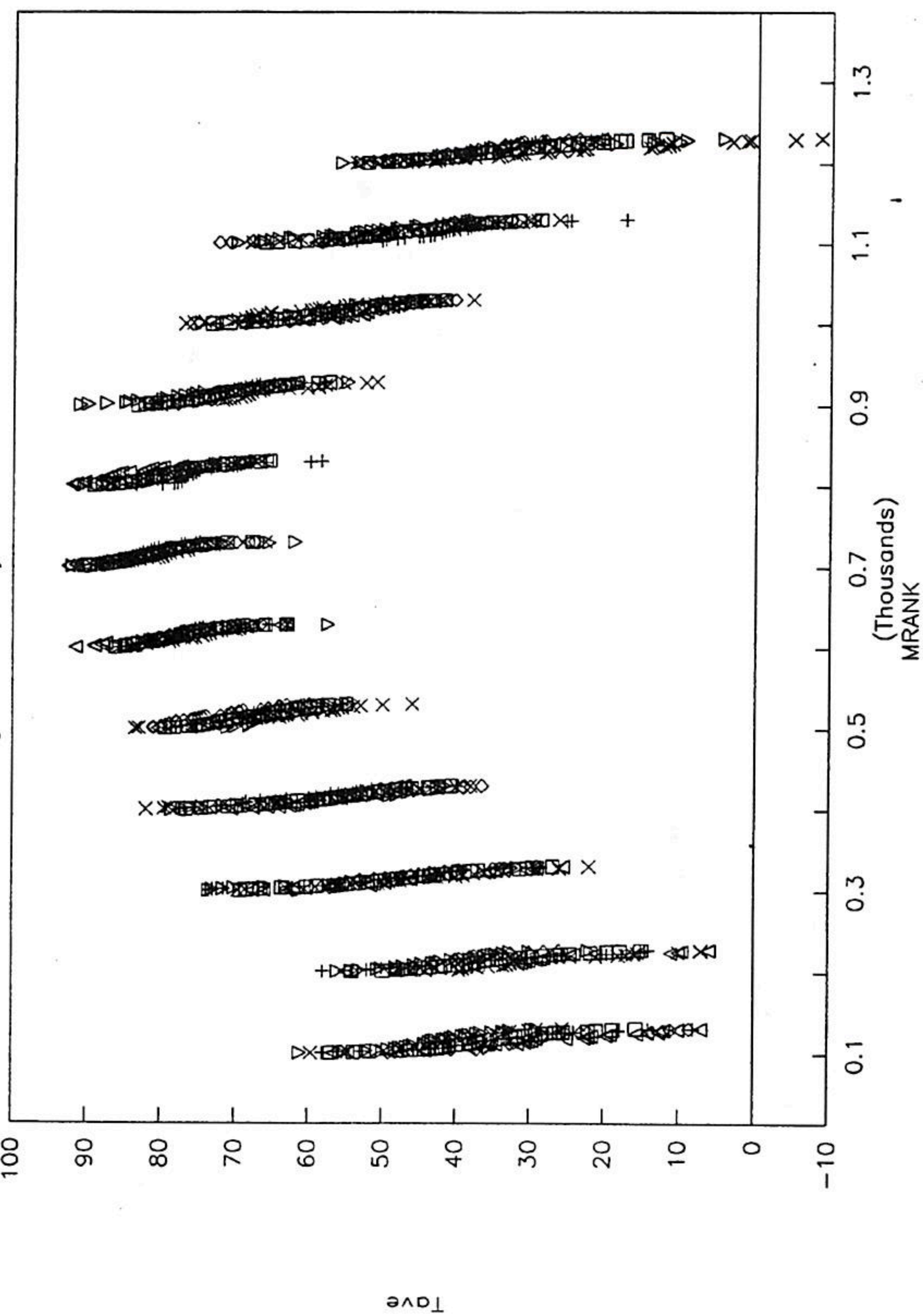
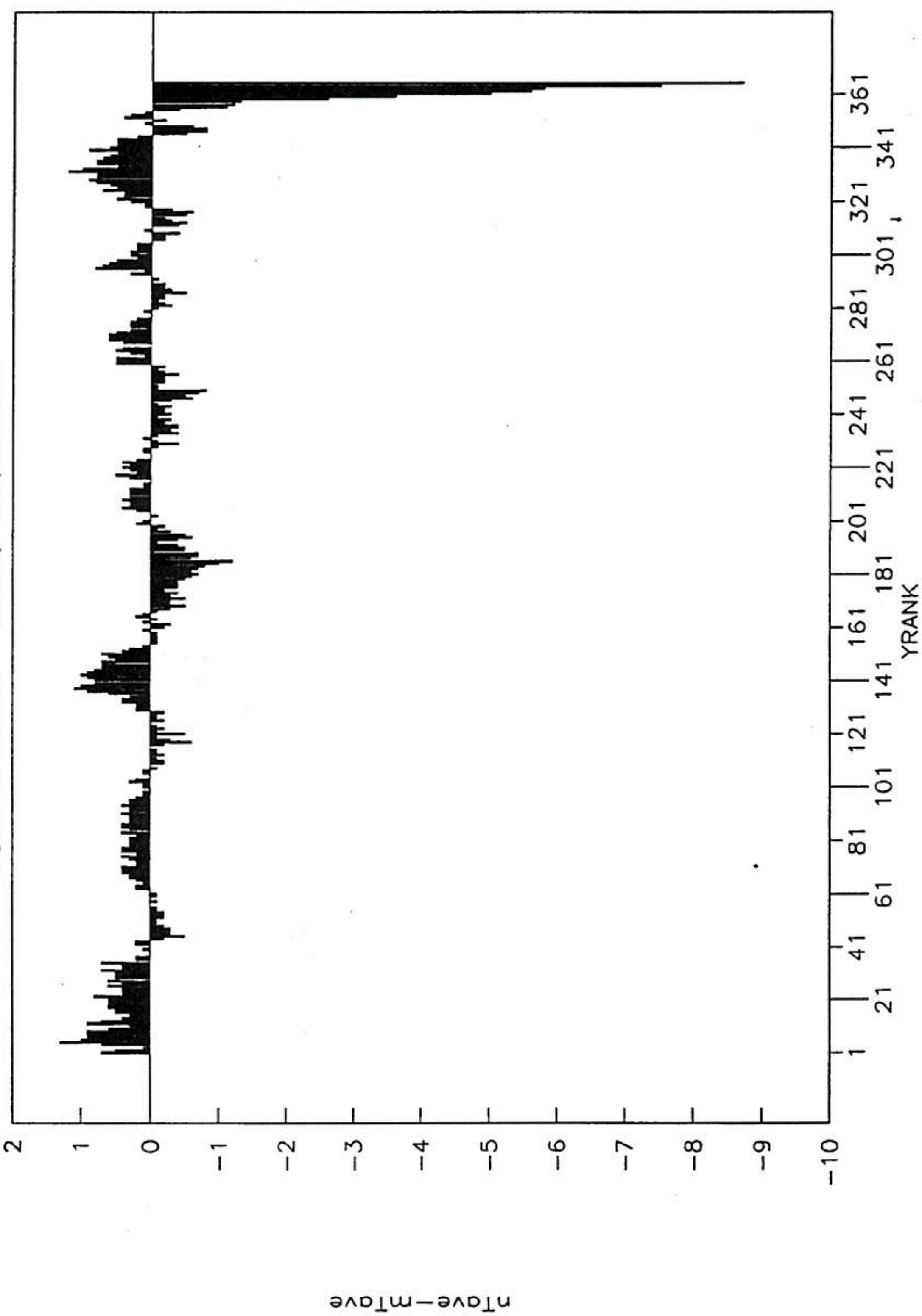


Figure 3. Normal – Monthly Temperatures



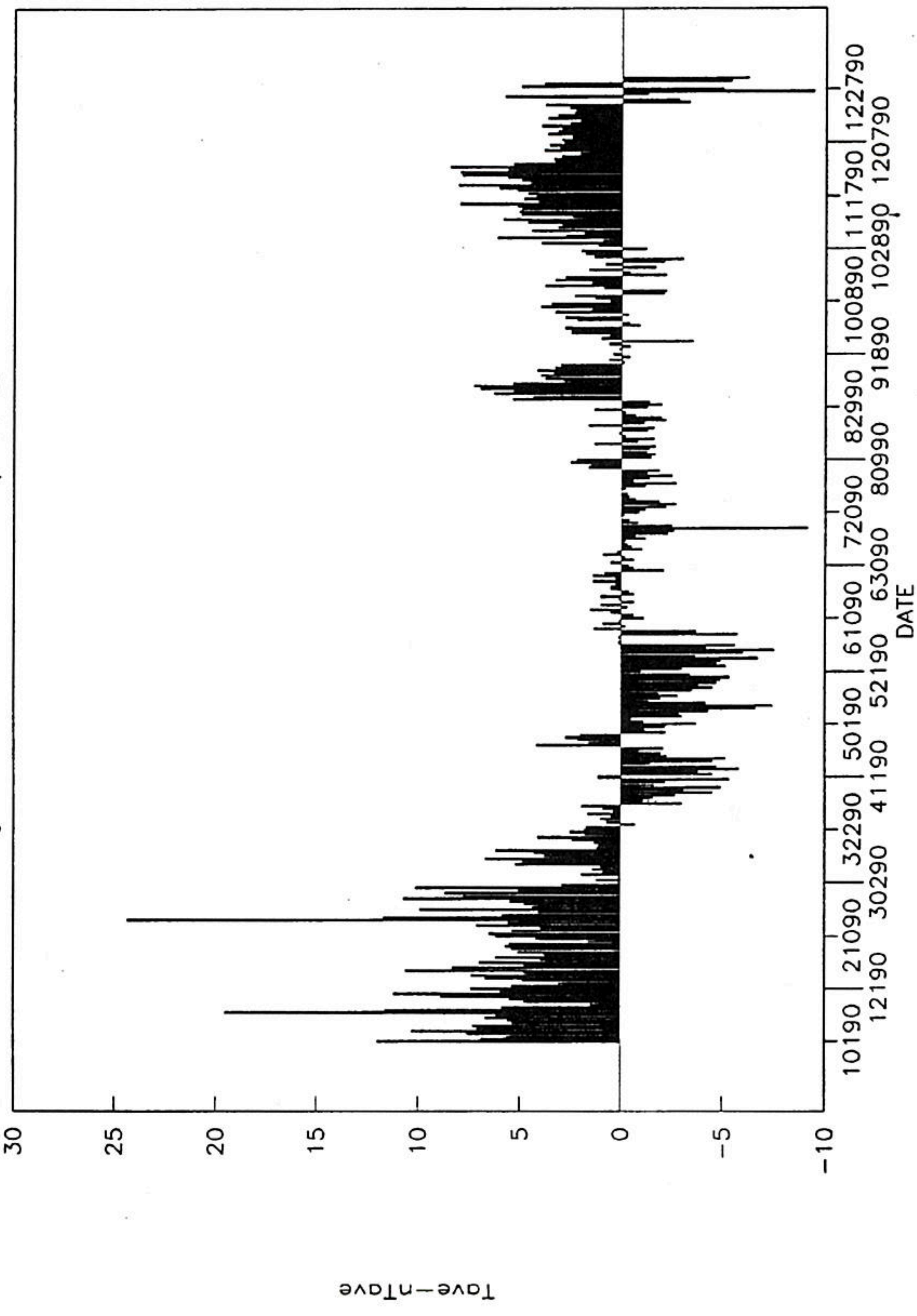


Figure 4. Actual – Normal Temperatures

MODIFICATIONS OF THE NORMALIZATION PROCESS

Only basic concepts of weather normalization are presented here. There are several modifications of this procedure that are commonly used.

1. Temperature variables other than mean daily temperature can be used in the computations (e.g. two day weighted mean daily temperature).
2. Multiple heating and cooling breakpoints are usually used (two heating, three cooling).
3. Holidays can be used as a separate day type.
4. Weather extremes can be allowed on weekends.
5. Heating and cooling indices can be calculated in place of heating and cooling degree days.

TABLE 1: Historical Weather Variables and Weather Normal Calculations

	1986						1987						1988						1989						1990									
i	DATE	Tmax	Tmin	Tave	HDD	CDD	DATE	Tmax	Tmin	Tave	HDD	CDD	DATE	Tmax	Tmin	Tave	HDD	CDD	DATE	Tmax	Tmin	Tave	HDD	CDD	DATE	Tmax	Tmin	Tave	HDD	CDD	nTave	nHDD	nCDD	YRANK
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364																																		364
365																																		365

TABLE 2: Assignment of Monthly Ranks to Historical Weather

	1986						1987						1988						1989						1990							
i	DATE	Tmax	Tmin	Tave	MM	MRANK	DATE	Tmax	Tmin	Tave	MM	MRANK	DATE	Tmax	Tmin	Tave	MM	MRANK	DATE	Tmax	Tmin	Tave	MM	MRANK	DATE	Tmax	Tmin	Tave	MM	MRANK	mTave	MRANK
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TABLE 3: Assignment of Monthly Ranks to the Test Year

i	DATE	Tmax	Tmin	Tave	MM	DAY TYPE	MRANK
1							
2							
3							
4							
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6							
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TABLE 4: Assignment of Normal Weather to the Test Year

i	DATE	Tave	MRANK	mTave	MRANK	nTave	nHDD	nCDD	YRANK
1									
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3									
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365									

STEP #1 Input Requirements

1. Retrieve the file TABLE1.WK1

2. Import the weather data files, as numbers, into the spreadsheet as follows:
   a. TEMP86.PRN to cell A7
   b. TEMP87.PRN to cell K7
   c. TEMP88.PRN to cell R7
   d. TEMP89.PRN to cell Y7
   e. TEMP90.PRN to cell AF7

STEP #2 Non-Leap Year and Leap Year Weather Adjustments

1. For practice, create Tmaxs and Tmins for the dates February 29, 1986, February 29, 1987, February 29, 1989, and February 29, 1990

2. Since the test year has only 365 days, delete all leap days. (Delete row 66 on the spreadsheet).

STEP #3 Calculation of Historical Weather Variables from Temperature Breakpoints

1. Calculate Taves, HDDs from a temperature breakpoint of 55^{o}F and CDDs from a temperature breakpoint of 80^{o}F for all days in the database.

2. To save memory, convert all formulas to values

3. Because the weather normalization series is calculated only from $Tave_i$, delete all columns containing $Tmax_i$ and $Tmin_i$. Make sure all formulas have been converted to values first!

STEP #4 Calculation of Annual Normal Weather Variables and the Assignment of Annual Ranks

1. For each year in the weather data base, sort each year's data from highest to lowest mean daily temperature. Be sure that <u>all</u> the data are sorted. (DATE, Tave, HDD, CDD should all be included in the sort range.)

2. For each YRANK = constant, calculate
   a. nT_{ave} by averaging Taves from 1986 to 1990;
   b. nHDD by averaging HDDs from 1986 to 1990;
   c. nCDD by averaging CDDs from 1986 to 1990;

3. Make a print file of the results (nTave, nHDD, nCDD, YRANK)

STEP #5 Calculation of Monthly Weather Variables and the Assignment of Monthly Rates

1. Retrieve the file TABLE2.WK1

2. Import the weather data files, as numbers, into the spreadsheet as follows:
   a. TEMP86.PRN to cell A7;
   b. TEMP87.PRN to cell K7;
   c. TEMP88.PRN to cell R7;
   d. TEMP89.PRN to cell Y7;
   e. TEMP90.PRN to cell AF7;

3. Delete all leap days (Delete row 66)

4. Calculate $Tave_i$ for all the data from Tmaxs and Tmins. Convert the formulas to values and delete columns containing Tmax and Tmin.

5. Assign a monthly number, MM, from 1 = January to 12 = December for each day in the data base. This is a dummy variable that will be sorted on and used to calculate MRANK.

6. For each year in the data base, sort all the data by month and descending mean daily temperature (Sort DATE, Tave, MM by ascending MM (primary) and descending Tave (secondary)).

7. Assign MRANK from 101 to 1231 to each day in the data base.

8. For MRANK = constant, calculate mTave by averaging the Taves from 1986 to 1990.

9. Make a print file of the results, mTave and MRANK.

STEP #6 Test Year Input Requirements

1. Retrieve the file TABLE3.WK1

2. Import the weather data file TEMP90.PRN as numbers into cell A7.

3. Delete row 66 (space for leap day)

4. Calculate Taves from Tmaxs and Tmins. Convert formulas to values and delete the columns containing Tmax and Tmin.

5. Assign day types as follows:
   1 = weekday (Monday through Friday)
   2 = Saturday
   3 = Sunday
   NOTE: January 1, 1990 is a Monday

STEP #7 Assignment of Monthly Ranks to the Test Year and the Treatment of Monthly Extremes

1. Assign a monthly number, MM, from 1 = January to 12 = December to each day in the test year.

2. Sort all the data by month and descending mean daily temperature (Sort DATE, Tave, MM, DAYTYPE by ascending MM (primary) and descending Tave (secondary)).

3. Assign MRANKS from 101 to 1231 to each day in the test ygar by descending Tave.

4. Inspect hot and cold temperature extremes in the test year and manually adjust MRANKS so that MRANK extremes occur with weekday temperature extremes.

5. Delete the columns containing MM, and DAYTYPE. Make a print file of the remaining results DATE, Tave, MRANK.

STEP #8 Assignment of Monthly Ranks to Annual Normal Weather

1. Retrieve the file TABLE 4.WK1

2. Import the print file created from the test year data (STEP #7) into cell A7.

3. Import the print file created from the monthly normals (STEP #5) into cell H7.

4. Import the print file created from the annual normals (STEP #4) into cell K7.

5. Sort the monthly weather variables mTave and MRANK by descending mTave.

6. Sort the annual normal weather variables (nTave, nHDD, nCDD and YRANK) by descending nTave. (*These variables probably already exist in this form from STEP #4)

STEP #9 Assignment of Normal Weather to the Test Year

1. Sort annual normal and monthly normal weather variables by ascending MRANK (Sort mTave, MRANK, nTave, nHDD, nCDD, and YRANK by ascending MRANK)

2. Sort the test year data (DATE, Tave, MRANK) by ascending MRANK.

3. Sort everything (DATE, Tave, MRANK, mTave, MRANK, nTave, nHDD, nCDD and YRANK) chronologically.