Climatic Data for ASHRAE Region X

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INTRODUCTION

This paper explains the technical background of a booklet, Climatic Data for Region X, which has been prepared for the use of air conditioning engineers in Hawaii, California, Nevada and Arizona. In this 400 thousand square-mile area, nearly six times the size of New England, fewer than 100 weather stations record hourly temperatures; yet there are over a thousand localities in which people live and construction may occur. One of the editors prepared a modest design temperature booklet for a portion of this area in 1957. The present publication is the fifth to include Southern California, Nevada and Arizona, and the third for northern California; Hawaii data are presented for the first time.

DESIGN TEMPERATURES

Design temperatures are tabulated on an annual basis first presented by the author in 1972[1]. ASHRAE Handbooks of Fundamentals traditionally have published cooling design temperatures for the June through September period. A comparison of the two methods, with corresponding temperatures for the Los Angeles Airport (LAX) follows:

TABLE 1

June through Sept. - 2928 hr %	Hours	Annual Basis - 8765 hr %	Hours	LAX Temperature
		0.1	9	92° F
1	29	(0.33)		86
		0.5	44	84
2½	73	(0.83)		83
5	146	(1.67)		80
		2.0	175	79

Note that the annual basis presemts a wider range of temperatures, in this case 13° instead of 6° F.

DRY BULB DESIGN TEMPERATURE

To determine the hours at which a design temperature is equalled or exceeded in a normal year, we may plot published data from a "First-Order Station" on probability paper, a remarkable kind of graph paper on which cumulative percentages from a perfect bell curve* will plot as a straight line. Temperature

*Gauss' Normal Error Curve, of the form $y = ^{-x^2}$.

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data rarely approach this standard of perfection. The values for LAX are:

TABLE 2

Dry bulb Temperature	Annual Hours	Cumulative Hours	Cumulative Percent
77-78	148.3	353.7	4.03
79-80	83.9	205.4	2.34
81-82	49.3	121.5	1.39
83-84	28.7	72.2	0.824
85-86	16.0	43.5	0.496
87-88	8.6	27.5	0.314
89-90	4.5	18.9	0.216
91-92	4.5	14.4	0.164
93-94	2.1	9.9	0.113
95-96	2.6	7.8	0.0890
97-98	1.6	5.2	0.0593
99 & over	3.6	3.6	0.0411

Source: Air Temperature Tables, Los Angeles Department of Water & Power, Los Angeles, 1954-63, undated.

When these cumulative percentages are plotted on probability paper, the curve looks like Fig. 1, and the various levels are easily read. This relatively simple process is the basis of the ASHRAE Handbook tables, except that they use data from the four summer months only. The LAX curve in this temperature range is concave upward. Other cities may be similar, concave downward, or, rarely, a straight line.

Our problem is different. Hundreds of stations, many operated by Cooperative Observers, record daily maximum and minimum temperatures. To convert these to pseudo-hourly levels, we use a method proposed by Loren W. Crow CCM, coeditor of the booklet, in ASHRAE Research Project No. 23, 1963[2]. Crow proposed the use of the parameter Median of Extremes (MOE), the middle number of the highest (or lowest) temperature recorded each year for 25 years. Using data from First-Order Stations, he then plots on a map the difference between the MOE and the three levels of design temperatures: 0.1, 0.5 and 1.0%. From these plots, contour lines are drawn. For winter, the MOE is the middle of the array of the coldest temperatures from each year. The median is statistically a better number to use than the average where random data are concerned. Fig. 2 is the summer contour map for Arizona, and Fig. 3 is a work sheet showing how the annual maximum temperatures were tabulated. This work was done by dedicated volunteers, to whom we publicly express our gratitude. We did not have values for 25 years in all cases, and decided to publish any station with seven or more years of data. Tests showed that seven years are almost as good as 25 with respect to temperature spread, and the median rarely varied more than one or two degrees. The resulting values are almost surely within $\pm 2^{\circ}$ of the temperatures that would have resulted from hourly data.

Finally, some localities may have private weather stations (newspapers, utilities), but temperatures never get into official publications. Some localities have no weather stations at all. This occurs most frequently in California; cities like Glendale (population 130 thousand) and Alhambra (62 thousand) have no published temperature history. Fortunately, Glendale lies between Pasadena and Burbank; good data are available for both these cities, and we use simple interpolation. Judgment is necessary; for example, the dry-bulb correction for elevation is 4° per 1000 feet.

MEAN COINCIDENT WET BULBS (MCWB)

Wet-bulb temperatures at any given dry bulb may vary from equality with the dry bulb to 30° or more below it. The mean wet bulb at a design dry bulb (DDB) is useful in calculating the enthalpy of outside air used for ventilation or process. However, the MCWB proved to be an elusive parameter. The principal sources were the DoD publication, AFM 88-29[3], and unpublished data from DoD files. After efforts to develop a relation between DDB and MCWB failed, a geographical pattern between design wet bulbs (DWBs) and MCWBs emerged and was used. Coastal localities have small differences between DWBs and MCWBs, 0 to 2° F. Inland areas show differences from 4 to 8° F. Fig. 4 shows the relations for southern California. The MCWB values we published were interpolated from the closest data; due to local variations and inconsistencies, contour lines didn't work out.

DESIGN WET BULB TEMPERATURES

The definitive source of wet-bulb data is still Evaluated Weather Data for Cooling Equipment Design[4], "The Fluor Book," prepared by Crow and published by Fluor Products Company in 1958, with an assist from Southern and Central California Weather Data[5], prepared by Henrichs and published by Southern California Edison Company in 1970. Our DWB values were prepared from these publications, using probability paper and the method described above.

In 1959 K. H. Watts proposed a method, refined by the author, for obtaining DWB for the maximum-minimum stations. Briefly, we found that in a given meteorological area, the level of moisture was substantially constant at design levels and at equal elevations. As an example, much of southern California is influenced by onshore winds from the generally cool Pacific Ocean. When DDB and DWB are corrected to 0 elevation and plotted on a psychrometric chart, one gets a fairly good linear relationship with a small negative slope. The correction that worked out best was 4° F per 1000 ft for dry bulb and 2° F per 1000 ft for wet bulb. The procedure for San Bernardino is:

DDB at 0.5% level	102 ° F
Elevation 1125 ft, add	4.5
DDB at 0 elevation	106.5°
DWB at 0.5% level	72°
Elevation 1125 ft, add	2.2
DWB at 0 elevation	74.2°

This point (106.5/74.2) and similar ones from other stations were programmed on an HP-97 and resulted in the regression line of Fig. 5. The effect of the Pacific winds begins to disappear about 50 miles from the coast and at about 105° DDB, and there is a scatter of points for the high and low deserts. Vandenberg Air Force Base and its surrounding territory form an interesting exception to the general rule. Wet bulbs are quite low in that area.

OUTDOOR DAILY RANGE (ODR)

Outdoor Daily Range is the difference between the average maximum and the average minimum temperatures for the warmest month. Except for the obvious effect of the Pacific and large lakes in reducing this number to 10 or 12° F, the ODR seems to be unique to a locality and to bear no relation to latitude, elevation, or any other familiar variable. (Actually, ODR varies with nightly radiation, a function of the character of the surface, for which no published data were found.)

Data from NOAA[6], AFM 88-29[3], and from the venerable Climatic Summary of the United States (1932)[7], known to elder meteorologists as the W-2 Series, were the sources. Other localities were interpolated.

The highest ODR, 48° F, occurs at Hat Creek Power House 1 and at Portola, both in northern California. How does one prepare for a climate that changes in July from 39° just before sunrise to 87° in the afternoon?

WINTER DESIGN TEMPERATURES

Three levels of winter design temperatures also were prepared, with one important difference: the actual listing of the winter MOE and the recommendation that it be used as the residential design level. The other two columns are headed 0.2% and 0.6%, corresponding to 18 and 53 hours in a normal year. Present ASHRAE Handbook tables are headed 99% and 97½% of three winter months, corresponding to 22 and 55 hours. Since these levels have been generally accepted in the past, we see no reason to change them.

The 18-hour design temperature is recommended for use with commercial applications, which have substantial internal loads and mostly daytime occupancy. The 53-hour design temperature may be applied to buildings of massive construction.

DEGREE DAYS

We have not included Cooling Degree Days. The author sees little use for this statistic and the Technical Committee agreed. Heating Degree Days (HDDs) are a measure of the severity and length of the heating season, and we have published them to the conventional 65° base.* Nearly all of the numbers are official for the period 1951-80, and were made available through the courtesy of Frank Quinlan of NOAA Asheville[6,8], who arranged to run the four states of Region X out of order to meet our publication schedule.

Some of the HDDs for Hawaii and Nevada were calculated from earlier data using the same method proposed by H. C. S. Thom in his classical 1954 paper, The Rational Relationship between Heating Degree Days and Temperature[9]. This paper was written because of the practical impossibility of tabulating and analyzing the difference between 65° and the daily mean temperature for 30 years -- a possible maximum of over 10 thousand numbers per locality.

The basic formula for monthly HDDs to the 65° base is:

$$HDD_m = 30\ (31,\ 28)\ (65 - t_m) \qquad (1)$$

where

t_m is the monthly mean temperature and all negatives are cast out.

If t_m is 65.0, then HDD_m becomes 0. But it is possible to have t_m 65° when half the days average 60° and the other half average 70°, in which case HDD_m becomes 15 (65 - 60) or 75. Thom's paper developed a graphical method of adding this correction through the use of standard deviation of the probability curve. Standard deviations of monthly average temperatures have been published as contour maps. In general, HDDs ending in 0 were calculated by the author, after programming Thom's curve for the HP-97 calculator. The process is laborious and was not done for Arizona and California, but HDDs for any one locality can be calculated to fair accuracy in about half an hour. Fig. 6 shows the number to be added to the basic monthly HDD for each value of the monthly mean temperature and standard deviation.

One other exception is that First-Order Stations had not been run for 1951-80, and the published HDDs are the familiar ones for the period 1941-70.

Fig. 7 is a typical page of tabulated design temperatures. The booklet also contains narrative descriptions of climatic regions for each state as well as a section of general weather information. "Local Temperature Modifiers" describes the "heat island" phenomenon, the increase of temperature in metropolitan areas due to the heat output from industrial processes and transportation. Maps showing this effect in the Bay Area and South Coast Air Basin are included.

The booklet closes with an exposition of solar radiation data, both in tabular and graphical form. Values are expressed in Langleys; a Langley is one gram-calorie per square centimeter, or about 3.7 Btu/ft^2.

Why was this publication necessary? Because there are large variations in Region X in both dry-bulb and wet-bulb temperatures. The lowest temperature ever recorded in the region seems to have been -50° F at San Jacinto in the far northeast corner of Nevada, probably some time in the 1930s. San Jacinto

*Heavily insulated residences will usually have a "balance temperature" between 55 and 60° F, and HDD to the 65° base are not accurate criteria for energy consumption estimates.

no longer has a weather station, but Elko has a record low of -43° F, or 75 "degrees of frost." There is no question about the all-time high: 134° F has been officially recorded several times at Furnace Creek Ranch in Death Valley. This is not only the maximum for Region X, but for the Western Hemisphere[10].

In southern California, the summer DDB at the 0.5% (44-hr) level varies from 78° at Santa Monica to 92° at Los Angeles City Office 16 miles inland, to 101° at Ontario, 32 miles farther east. In 48 miles airline, the design temperature changes by 23°, about half a degree per mile. That is why so many localities need to be published.

ACKNOWLEDGMENTS

How was the booklet financed? By cooperation between the Golden Gate and Southern California Chapters of ASHRAE with help from six other chapters. The original source of funds was the Western Air-Conditioning Industries Association (WACIA), which turned over its surplus from equipment shows to the two sponsoring chapters. The chapters will sell the book for $17.50, and use all surplus thus generated for scholarship and research. Copies may be obtained from:

ASHRAE-Climatic Data
P.O. Box 606
Alhambra, CA 91802
(Check must accompany order.)

The booklet has been eagerly awaited. Previous editions (or Xerox copies of them) are in use in just about every design office in the area, and have always sold out their print runs. We have every assurance that this one will be equally successful. The editors are grateful for their opportunity to share in this project.

REFERENCES

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2. Loren W. Crow, Study of Weather Design Conditions, RP-23, ASHRAE, 1963.

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9. H. C. S. Thom, "The Rational Relationship between Heating Degree Days and Temperature," Monthly Weather Review, U. S. Department of Commerce, Jan. 1954.

10. U. S. Department of Agriculture, Climate & Man, 1941 Yearbook of Agriculture, Washington, D. C.

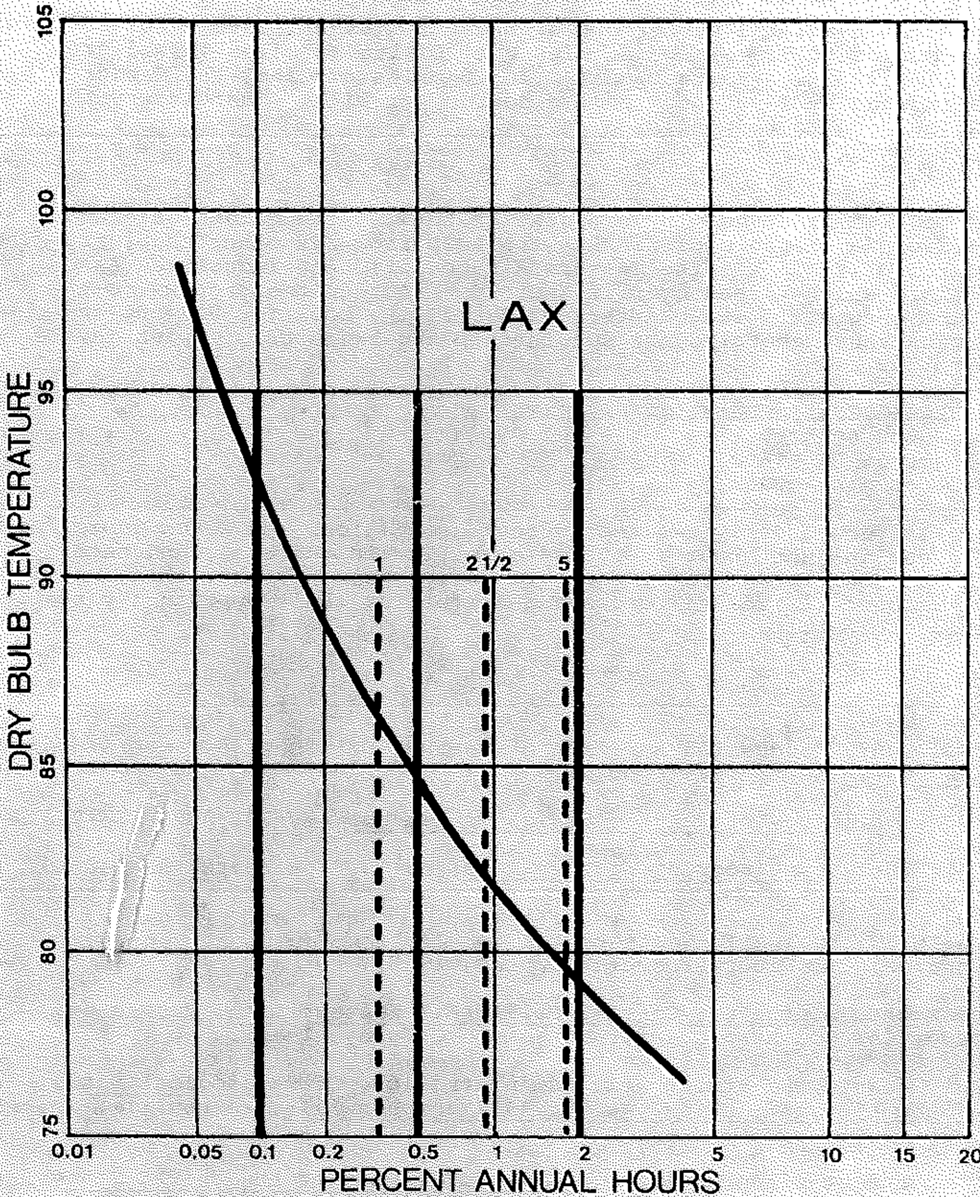

Figure 1. Design temperatures for Los Angeles airport

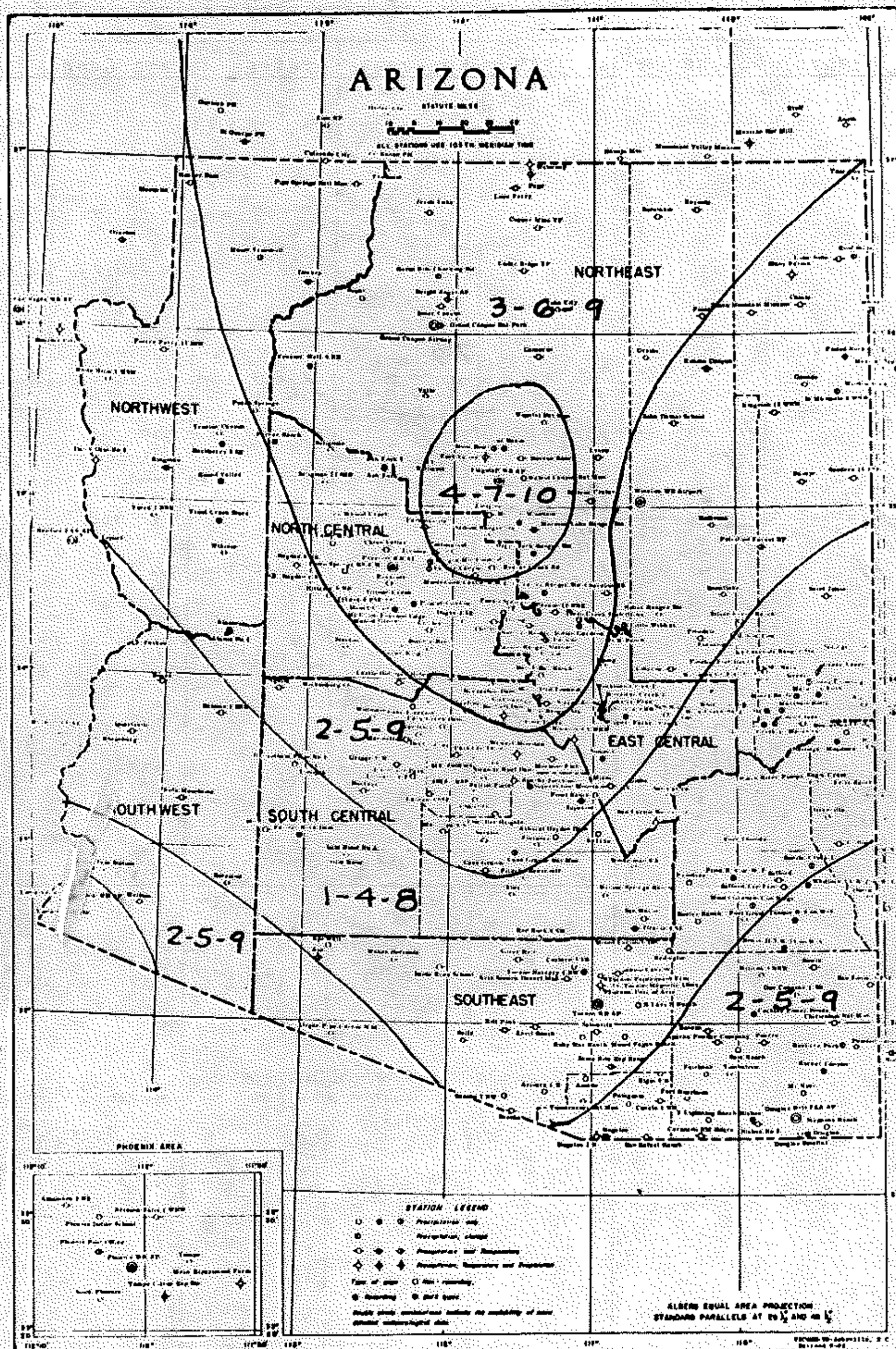

Figure 2. Differences between Median of Extremes and 0.1, 0.5, and 2.0% design dry bulb temperatures

ARIZONA SOUTH CENTRAL

ANNUAL MAXIMUM TEMPERATURES

	Alhambra	Apache Jn	Bartlett Dm	Buckeye	Carefree	Casa Grnde
125						
124						
123						
122						
121						
120				/		
119				////		
118			/	////		/
117	///		/	///// /	/	
116	/	//	///// //	///		//
115	//	///	/	///// /	/	///// /
114	///// //	///	///// ///			///// /
113	////	//	////			/
112	////	//	//		//	/////
111	//				/	/
110	/	//			///	
109		//	112		/	
108			109		///	
107	112	112	105		/	
106	109	109		115		
105	10	105		112		113
104				108	107	110
103					104	106
102					101	
101						
100						
99						
98						
97						
96						
95						
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93						
92						
91						
90						

Figure 3. Typical tabulation of annual maximum temperatures for Arizona localities, with dry bulb design temperatures at 0.1, 0.5, and 2.0% levels

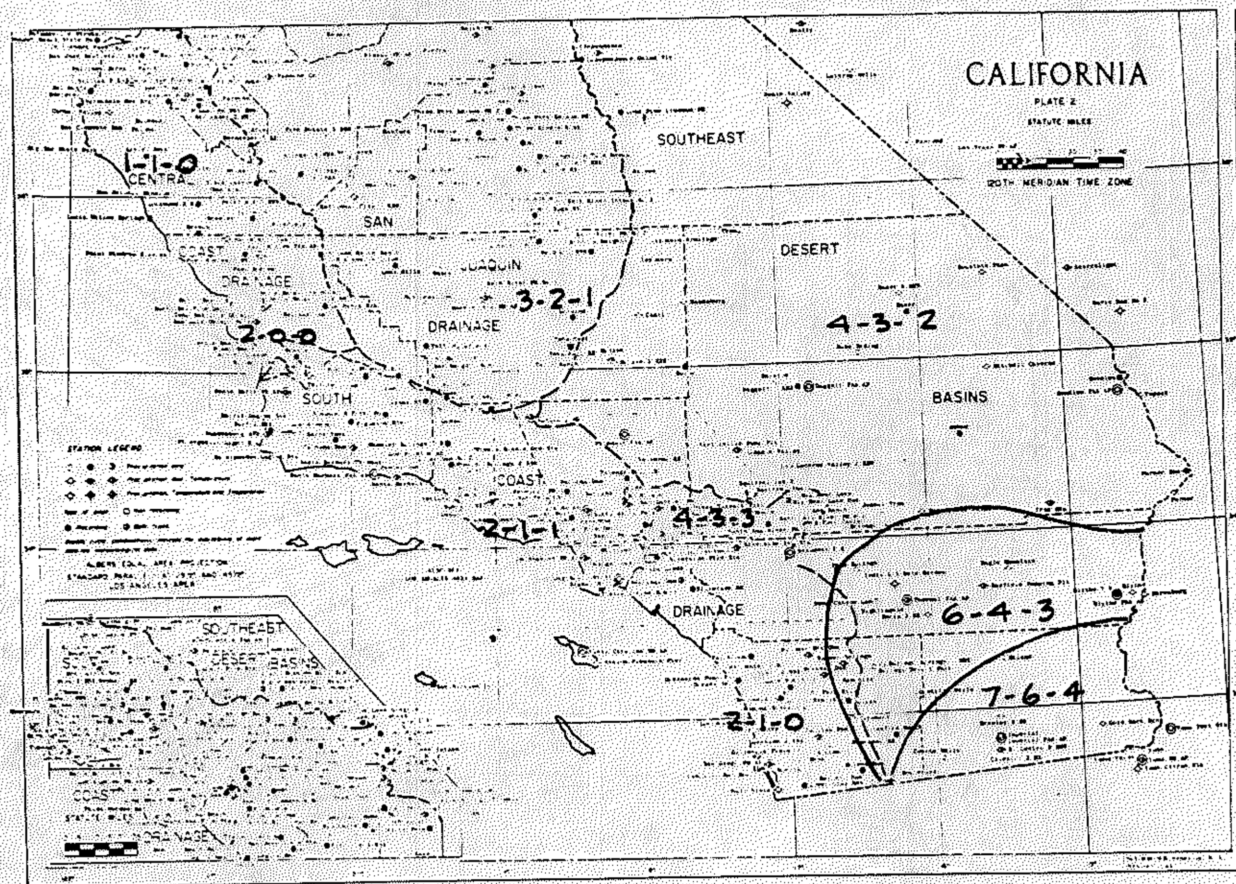

Figure 4. DWB-MCWB, Southern California

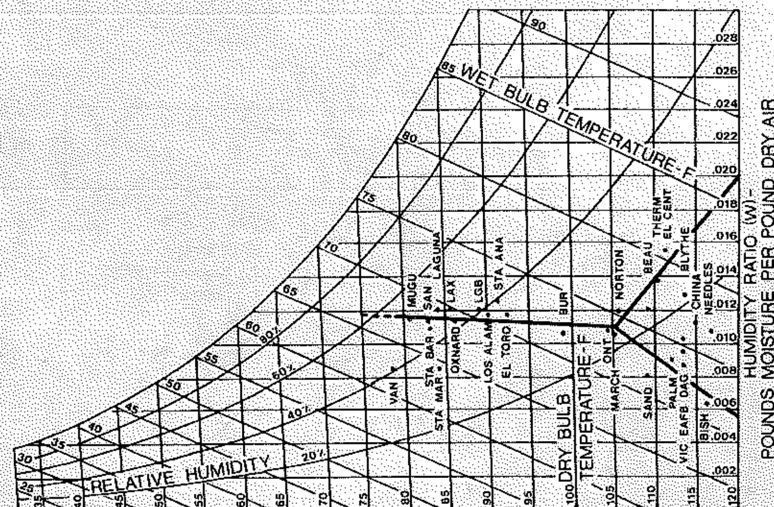

Figure 5. Design dry bulb and wet bulb relations for Southern California at 0 elevation

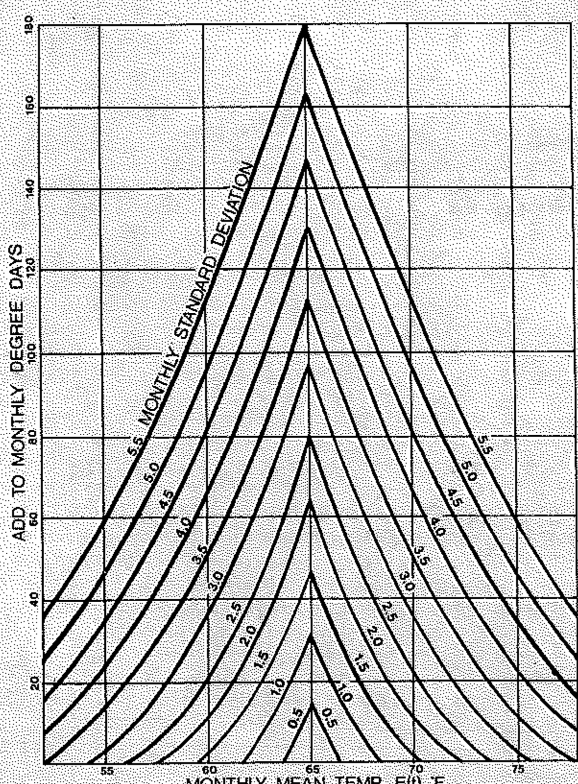

Figure 6. Additive constants for monthly degree days to 65° base

ARIZONA DESIGN TEMPERATURES

				Summer							Winter			
		Lat	Elev	Design Dry Bulb & Mean Coincident Wet Bulb			Outdoor Daily Range	Design Wet Bulb			Median of Extremes	0.2%	0.6%	Heating Degree Days
				0.1%	0.5%	2.0%		0.1%	0.5%	2.0%				
Aguila	b	34.0	2165	110/69	107/68	103/67	33	74	72	70	17	22	26	
Ajo	b	32.4	1763	111/70	108/69	104/68	26	75	73	72	28	33	36	1352
Alamo Dam	b	34.2	1290	113/71	110/70	106/69	34	75	74	72	18	23	27	
Alhambra	b	33.5	1135	112/71	109/70	105/69	32	76	75	73	23	27	30	
Alpine	b	33.8	8050	91/56	88/55	84/54	34	57	56	54	−13	−7	−3	7790
Anvil Ranch	b	32.0	2750	110/68	107/67	103/66	31	71	70	68	14	20	24	2027
Apache	b	31.7	5380	96/61	93/60	89/59	31	65	64	62	11	17	21	
Apache Junction	b	33.4	1720	112/70	109/69	105/68	30	74	73	71	27	31	34	
Apache Powder	b	31.9	3690	104/66	101/65	97/64	31	69	68	66	12	18	22	2644
Ash Fork	b	35.3	5325	99/62	96/61	93/60	36	66	64	62	2	9	15	4648
Avondale		33.3	1170	113/71	110/70	106/69	30	78	76	74	22	26	29	
Bagdad	b	34.6	3712	102/65	99/64	95/63	34	70	69	67	20	25	29	
Bartlett Dam	b	33.8	1650	112/70	109/69	105/68	29	74	73	71	26	31	35	1508
Beaver Creek RS	b	34.7	3820	103/65	100/65	97/64	28	69	68	66	15	22	28	
Beaver Dam	b	36.9	1875	113/70	110/69	106/68	35	74	72	70	16	21	25	
Benson	b	32.0	3675	104/66	101/65	97/64	31	69	68	66	13	19	22	2618
Betatakin	b	36.7	7286	92/57	89/57	86/57	31	61	59	57	0	6	10	6125
Bisbee	b	31.4	5020	97/62	94/61	90/60	25	66	65	63	20	26	30	
Black River Pumps	b	33.5	6040	97/61	94/60	90/59	29	63	62	60	−2	3	8	5202
Blue	b	33.6	5760	100/62	97/61	93/60	34	63	62	60	−3	3	7	
Blue Ridge RS	b	34.6	6810	91/58	88/57	85/56	29	62	61	59	−7	−1	3	
Bouse	b	34.0	930	115/71	112/71	108/70	34	76	75	73	17	22	26	1791
Bowie	b	32.3	3770	106/66	103/65	99/64	31	69	68	66	15	21	25	
Buckeye	b	34.4	870	115/72	112/71	108/70	33	76	75	73	21	25	28	1554
Burrus Ranch	b	35.3	6800	92/58	89/58	86/57	35	63	61	59	−11	−3	4	
Cameron	b	35.9	4165	103/65	100/64	97/63	31	69	67	65	3	10	16	
Canelo	b	31.6	4985	98/62	95/62	91/61	29	66	65	63	10	16	20	3677
Canyon de Chelly	b	36.2	5540	96/61	93/60	89/59	33	66	64	62	−5	1	5	
Carefree	b	33.8	2530	107/68	104/68	101/67	27	73	72	70	25	30	34	
Casa Grande	b	32.9	1415	113/71	110/70	106/69	32	75	74	72	23	28	31	1629
Casa Grande NM	b	33.0	1419	114/71	111/70	107/69	35	75	74	72	18	23	26	1680
Cascabel	b	32.3	3145	107/67	104/66	100/65	27	70	69	67	13	19	23	
Castle Hot Sprg	b	34.0	1990	110/69	107/69	103/68	30	74	73	71	26	31	35	
Chandler	b	33.3	1216	111/70	108/70	104/69	32	76	75	73	25	29	32	
Chandler Hts	b	33.2	1425	110/70	107/70	103/69	28	76	75	73	24	28	31	1535

Figure 7. Typical design temperatures