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Acquisition and evaluation of thermal standard data

Paul F. Krause

MARCH 1980

U.S. ARMY CORPS OF ENGINEERS
ENGINEER TOPOGRAPHIC LABORATORIES
FORT BELVOIR, VIRGINIA 22060

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A Naval Weapons Center (NWC) thermal standard was installed at Fort Belvoir, VA, and monitored for a year. Extreme temperatures of 129°F and 113°F occurred at the top surface and center of the thermal standard, respectively. Data were compared to thermal standard data from prior investigations. Methodologies involving data display, sampling strategies, and predictive capabilities were examined. The original predictive equation was examined, and it was found that a derivation was more suitable at Fort Belvoir, indicating that geographic and/or climatic limitations to certain analytical methods could exist.

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PREFACE

Each year, a great amount of money is spent conducting tests to determine the effects of heating and cooling on military materiel stored in the open. If it were possible to correlate the test data with climatic data so the climatic data could be used to predict the probable effects at a proposed storage site, the money spent conducting tests could be saved, and reliable operational information could be provided to the people responsible for logistical support to units in the field. This study was undertaken to determine the response temperatures of a Naval Weapons Center (NWC) *thermal standard* at Fort Belvoir, Virginia, and to determine whether predictive methodologies developed during testing in areas of extreme climatic conditions could be applied reliably to a site at a moderate, midlatitude location. Besides its specific results, this study contributes to a larger thermal standard investigation being conducted jointly by the Naval Weapons Center, China Lake, California, and Brigham Young University, Provo, Utah.

Appreciation is extended to MSGT Earl Rook and SSGT Mark Noe, Detachment 2, 5th Weather Squadron, Davison Army Airfield, Fort Belvoir, Virginia, for providing selected climatological data; to NOAA, Test and Evaluation Division, Sterling, Virginia, and Dr. W. H. Klein, Smithsonian Radiation and Biology Laboratory, Rockville, Maryland, for providing solar radiation information; and to Messrs. Regis Orsinger, Edward Trelinskie, and Michael Eastwood, MGI Systems Division, U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia for assistance rendered in computer operations.

The work reported on was done under DA Project 4A161101A91D, Task 01, Work Unit ~~0~~075, "Acquisition and Evaluation of Thermal Standard Data."

The work was performed during 16 June 1978 to 15 June 1979 under the supervision of H. S. McPhilimy, Group Leader, Environmental Effects Group; M. Gast, Chief, MGI Systems Division, and Kent T. Yoritomo, Director, Geographic Sciences Laboratory.

COL Daniel L. Lycan, CE was Commander and Director and Mr. Robert P. Macchia was Technical Director of the Engineer Topographic Laboratories during the study and report preparation.

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. Customary Units of Measurement used in this report can be converted to metric (SI) as follows:

Multiply	By	To Obtain
inches	25.4	millimeter
feet	30.48	centimeter
miles	.6093	kilometer
pounds	0.4536	kilogram
ton, long	1.0160	metric ton
ton, short	0.9072	metric ton
gallon	3.785	liter
Fahrenheit degrees*	5/9	Celsius degrees, Kelvin

*To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula:

$$C = (5/9)\ (F-32)$$

To obtain Kelvin (K) readings, use formula:

$$K = (5/9)\ (F-32) + 273.15$$

CONTENTS

ILLUSTRATIONS

TABLES

ACQUISITION AND EVALUATION OF THERMAL STANDARD DATA

INTRODUCTION

When ordnance is to be stored in the open for a long time, information is needed on how it will be affected by temperature changes. One way to obtain such information is through long term surveillance programs, in which large quantities of instrumented test items are placed in an area and monitored for many years. To lower the cost of such a project, the Navy developed an inexpensive device that is intended to respond thermally to the natural environment as would certain sizes of ordnance and propulsion materiel. This device is the Naval Weapons Center (NWC) *thermal standard.* If tests are successful, the device could serve as a thermal analog to certain ordnance and propulsion items and as a predictive base for others.

This report is concerned with collection and analysis of thermal standard data from 16 June 1978 to 15 June 1979 at Fort Belvoir, Va. The report also includes comparisons with thermal standard responses obtained from prior studies in other areas of the world and an analysis of the methods used to evaluate and represent thermal standard data.

BACKGROUND

Thermal Standard Description ● The thermal standard is a 6-inch-diameter, stainless steel, spherical shell filled with a special rubber material.* As shown in figure 1, the sphere contains five copper-constantan thermocouples--four welded to the inside surface of the sphere and one positioned at the sphere's geometric center. The entire assembly stands 36 inches high.

*The absorptivity of the thermal standard is approximately 0.6. The thermal properties of the RTV 511 rubber filler are: thermal conductivity = 0.18 Btu/hr/ft/°F; density = 73.5 lbm/ft^3; and specific heat = 0.48 Btu/lbm/°F. (Richard D. Ulrich, *Evolution of the NWC Thermal Standard, Part 2. Comparison of Theory with Experiment*, NWC TP 4834, Part 2, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1971, p. 2.)

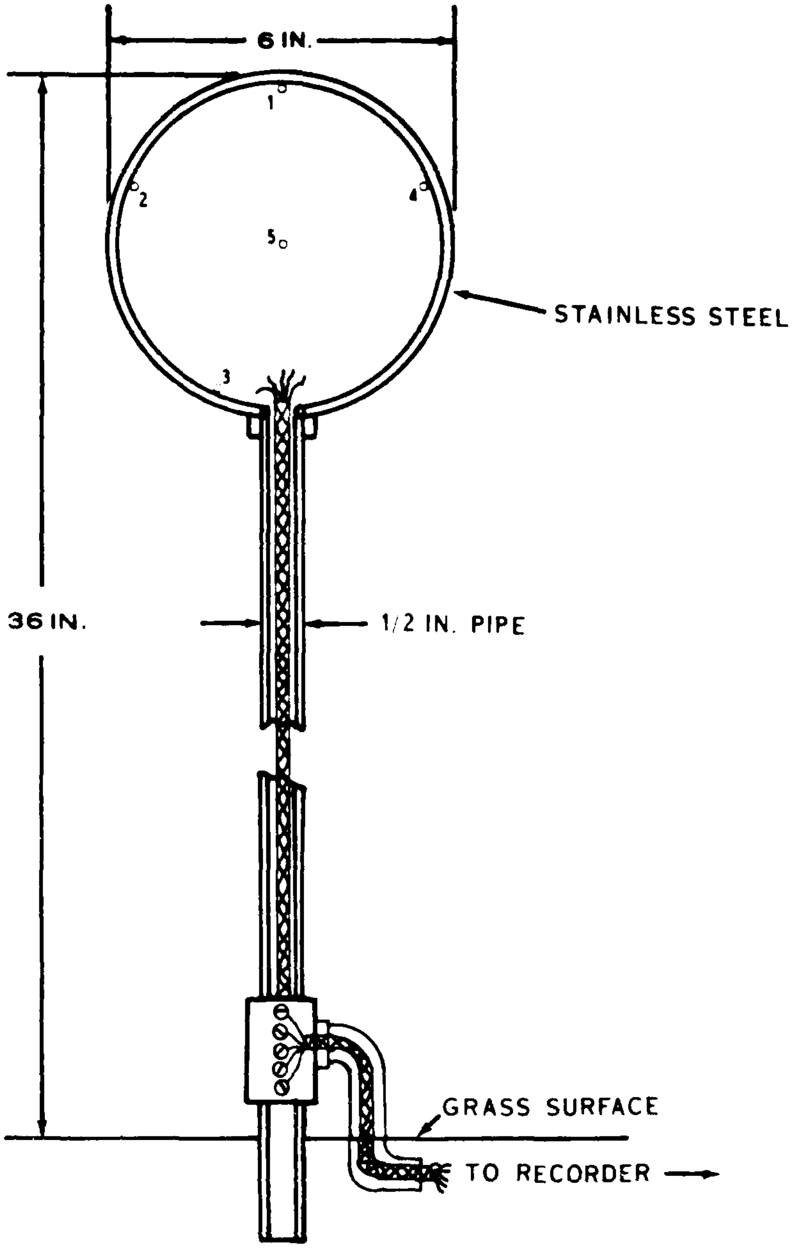

Figure 1. Schematic Drawing of the Thermal Standard.

The thermal standard is situated in a secure, grassy test area about 100 feet south of Building 2591, Fort Belvoir, Va. (figure 2). This area has an elevation of approximately 85 feet. Data from the thermal standard were gathered continuously from 16 June 1978 to 15 June 1979 and printed on a recording potentiometer in Building 2591.

Meteorological Data ● The following meteorological elements were measured directly at the test site or obtained from outside sources when measurements at the site were not available or where certain measurements were not possible:

Air Temperature. Ambient air temperature was measured twice each hour by a thermocouple in an aspirated radiation shield on a micromet mast arm at the 4-foot level. The mast is situated approximately 10 feet NNE of the thermal standard emplacement (figure 3). Air temperatures were gathered continuously during the study period on the same recorder used for the thermal standard data.

Windspeed. A 3-cup anemometer at the 5-foot level on the same micromet mast (figure 3) provided data from 1 January 1979 to 15 June 1979. For the period prior to 1 January 1979, wind data were obtained from Davison Army Airfield (approximately 2.5 miles SSW of the thermal standard test area). These data were adjusted by a ratio to represent windspeeds at the test site.

Solar Radiation. Hourly values of solar radiation were obtained from NOAA, Test and Evaluation Division, Sterling, Va. (25 miles NW of the thermal standard test site) and from the Smithsonian Radiation and Biology Laboratory, Rockville, Md. (28 miles NNE of the test site).

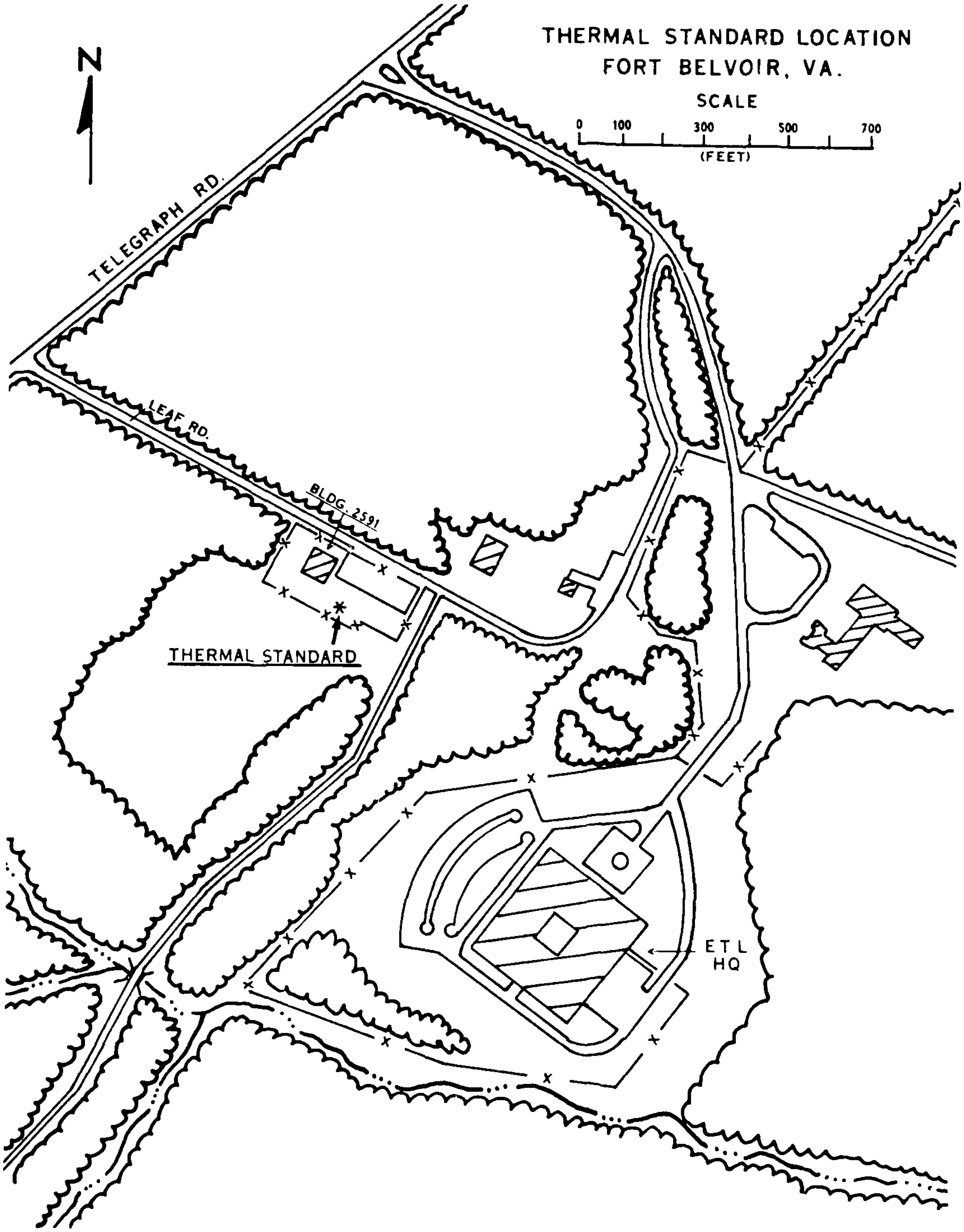

Figure 2. Location of the thermal Standard at Fort Belvoir, Va.

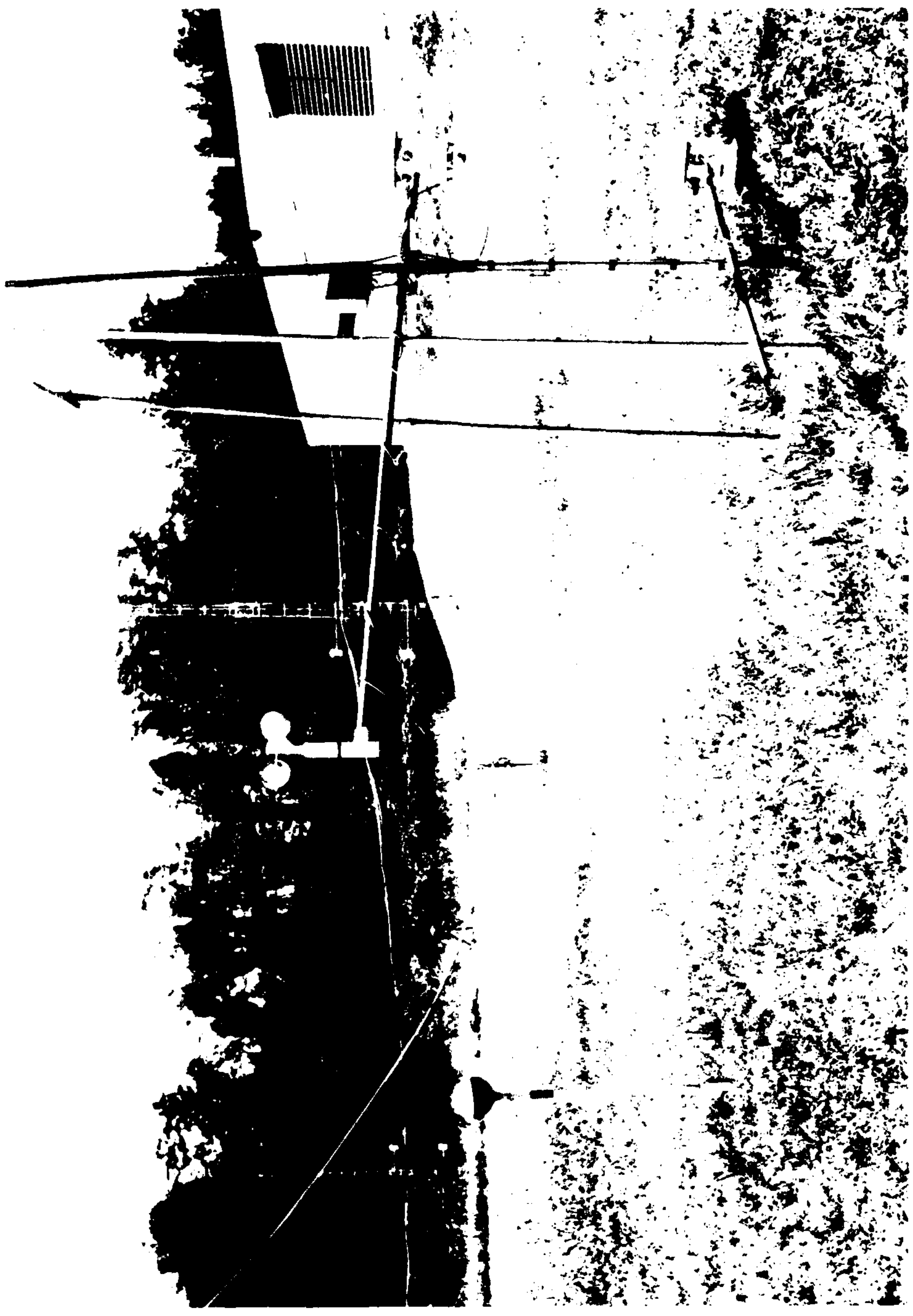

Figure 3. NWC Thermal Standard and Meteorological Instrumentation.

Previous Thermal Standard Investigations and Results • In a series of three reports, Ulrich[1,2] and Ulrich and Schafer[3] described the NWC thermal standard through the various phases of conception, laboratory and field experimentation, evaluation, and application. Beginning in the late 1960's,NWC thermal standards were placed next to instrumented ordnance items at many test sites within areas possessing extreme environmental conditions--desert, arctic, and tropics.* However, in 1978, thermal standards only were placed in other areas, including Atlanta, Ga., Lafayette, Ind., Provo, Utah, and Fort Belvoir, Va.

Some of the major finds and conclusions of Ulrich[4] and Ulrich and Schafer,[5] are summarized below:

1. The NWC thermal standard was shown to attain response temperatures that were similar to those attained on previously instrumented and similarly exposed ordnance items. The response of the thermal standard is "typical" of the response of ordnance in the 2- to 20-inch diameter range.

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[1]Richard D. Ulrich, *Evolution of the NWC Thermal Standard, Part 1. Concept*, NWC TP 4834, Part 1, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1970.

[2]Richard D. Ulrich, *Evolution of the NWC Thermal Standard, Part 2. Comparison of Theory with Experiment*, NWC TP 4834, Part 2, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1971.

[3]Richard D. Ulrich, and Howard Schafer, *Evolution of the NWC Thermal Standard, Part 3. Application and Evaluation of the Thermal Standard in the Field*, NWC TP 4834, Part 3, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1977.

[4]Richard D. Ulrich, *Evolution of the NWC Thermal Standard, Part 2. Comparison of Theory with Experiment*, NWC TP 4834, Part 2, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1971.

[5]Richard D. Ulrich and Howard Schafer, *Evolution of the NWC Thermal Standard, Part 3. Application and Evaluation of the Thermal Standard in the Field*, NWC TP 4834, Part 3, Brigham Young University for the Naval Weapons Center, China Lake Calif.,1977.

*Thermal Standards were or are now in operation in the following desert, arctic, and tropical locations: China Lake and Death Valley, Calif.; Israel; Richardson and Fort Greely, Alaska; Alert and Resolute Bay, Canada; Thailand; Philippines; Panama; and Australia.

2. The surface color of an item directly exposed to the natural environment determines, in a large measure, the item's thermal sensitivity. Painting items a light color is shown to be an effective method of keeping induced temperatures from becoming excessive.

3. The NWC thermal standard is amenable to analysis by theory. Laboratory investigations were conducted in which the thermal standard and thermal energy experts predicted the temperature responses of various ordnance items. The thermal standard method proved to be more accurate.

4. A prediction method whereby the maximum thermal standard surface temperature for each day could be determined by meteorological data was developed and proved to be fairly accurate. When perfected, this prediction method would enable the response temperatures of the thermal standard to be predicted in lieu of actual thermal standard emplacement.

5. The authors feel that the NWC thermal standard is of value as a tool in thermal environment instrumentation. Possible future uses envisioned (in addition to predicting the thermal response of ordnance) were in the realm of predicting thermal responses of other items (airplanes, ships, antennae, buildings, etc.) and functioning as a control device within environmental test chambers.

THERMAL STANDARD DATA -- FORT BELVOIR

Data Description ● Figure 4 shows the temperature profile for the thermal standard top surface and center and the ambient air for the data-gathering period at Fort Belvoir. Each daily maximum and minimum temperature is connected with a line so that the magnitude of the diurnal range becomes readily apparent. Means, extremes, and ranges for these data were extracted and appear in table 1. An inspection of figure 4 data indicates that relationships exist between the air temperature and the induced temperatures.*

To determine the degree of interrelationship between the air temperature and the temperatures attained by the thermal standard, one must prepare a distribution of corresponding daily maximum top surface and ambient air temperatures (figure 5). A distribution of the daily maximum thermal standard center and air temperatures was also prepared (figure 6).

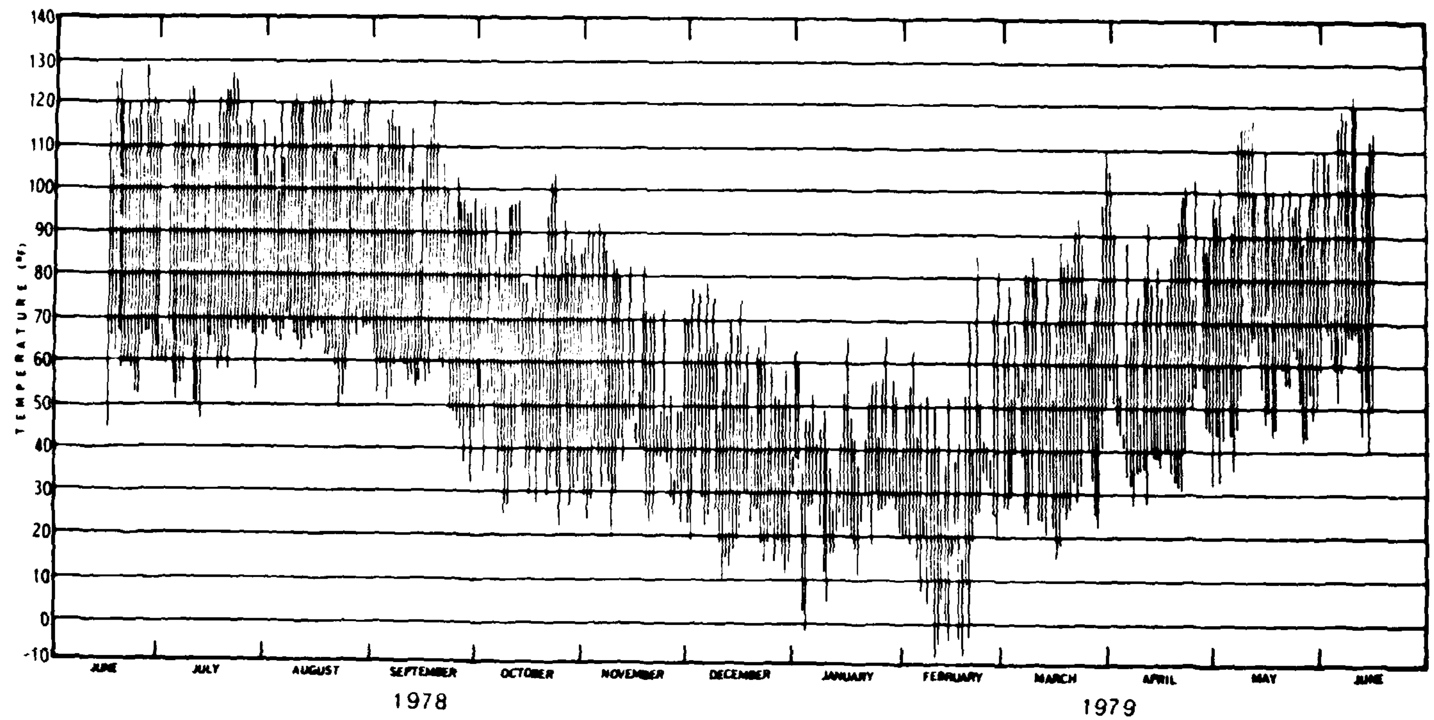
Both distributions illustrate that a strong positive linear relationship exists between air and induced temperatures (coefficient of correlation – $r = 0.96$ for top surface and air, and $r = 0.98$ for the center and the air). Naturally, the cluster of points in figure 6 is tighter and a degree of correlation higher because the center experiences less variation than the surface. It is also worth noting that at higher temperatures the data cluster more closely around the regression line. This fact might be significant since it would indicate that predictions from the regression lines in figures 5 and 6 could be made with a fairly high degree of accuracy at the higher temperatures.

*One of the most noticeable features of figure 4 is the extreme cold period during mid-February 1979. This particular February was the coldest on record for a number of surrounding stations, with temperatures averaging on the order of 10°F below normal. For more information, see the *Metropolitan Climatological Summaries, National Capital Area*, NOAA, February 1979.

16June78-15June79	TOP SURFACE OF THERMAL STANDARD	CENTER OF THERMAL STANDARD	AMBIENT AIR
AVERAGE MAX TEMP. AVERAGE MIN TEMP. AVERAGE TEMP.	83.3°F 40.8°F 62.05°F	74.4°F 41.8°F 58.25°F	62.5°F 41.6°F 52.05°F
AVERAGE DIURNAL RANGE	42F°	33F°	21F°
MAXIMUM DIURNAL RANGE	74F°	67F°	43F°
EXTREME MAXIMUM TEMPERATURE EXTREME MINIMUM TEMPERATURE RANGE	129°F -9°F 138F°	113°F -9°F 122F°	95°F -10°F 105F°

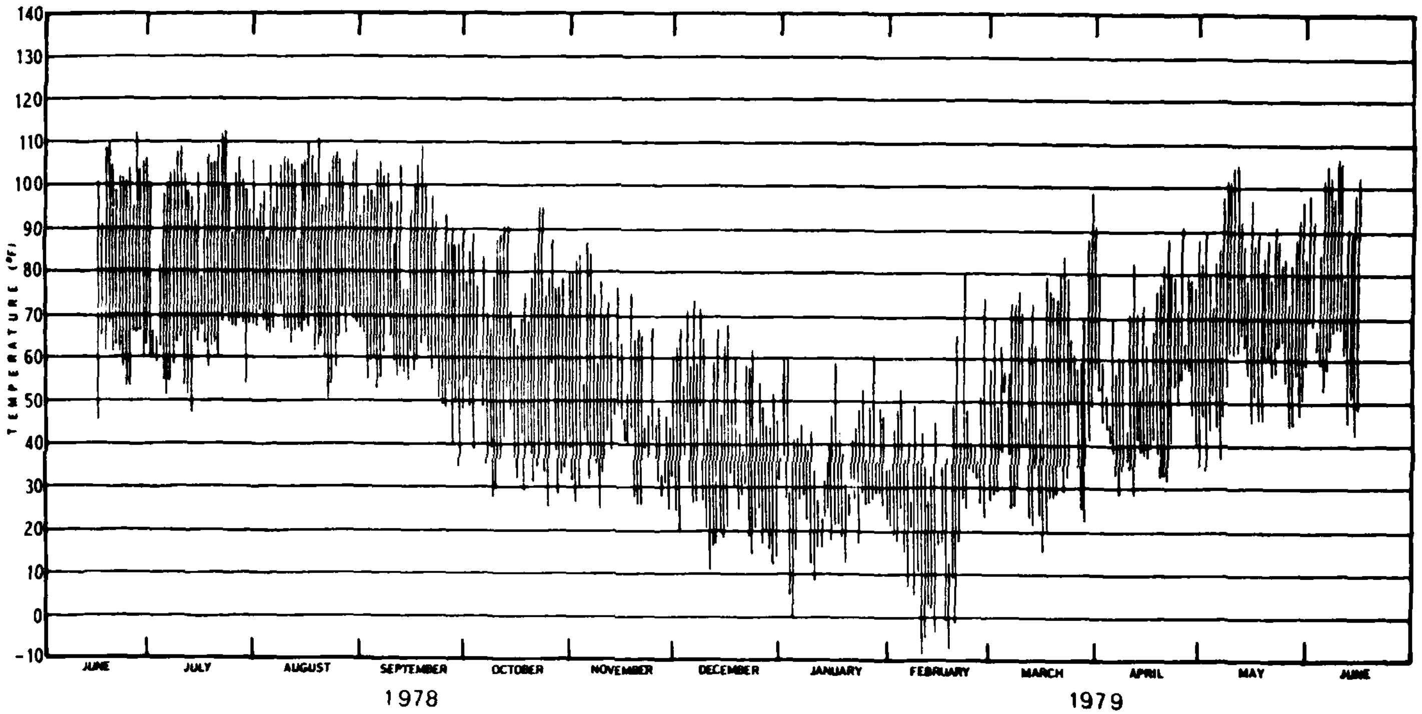
Table 1. Means, Extremes, and Ranges of Temperatures of the Thermal Standard and Ambient Air at Fort Belvoir, Va. (16 June 1978 – 15 June 1979).

a. Thermal Standard Top Surface (TC #1)

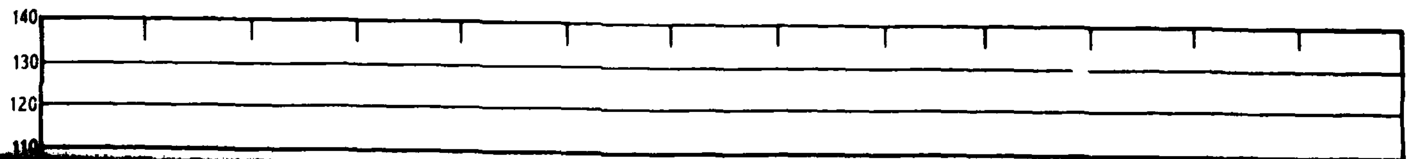


b. Thermal Standard Center (TC #5)

b. Thermal Standard Center (TC #5)



c. Ambient Air (TC #6)



c. Ambient Air (TC #6)

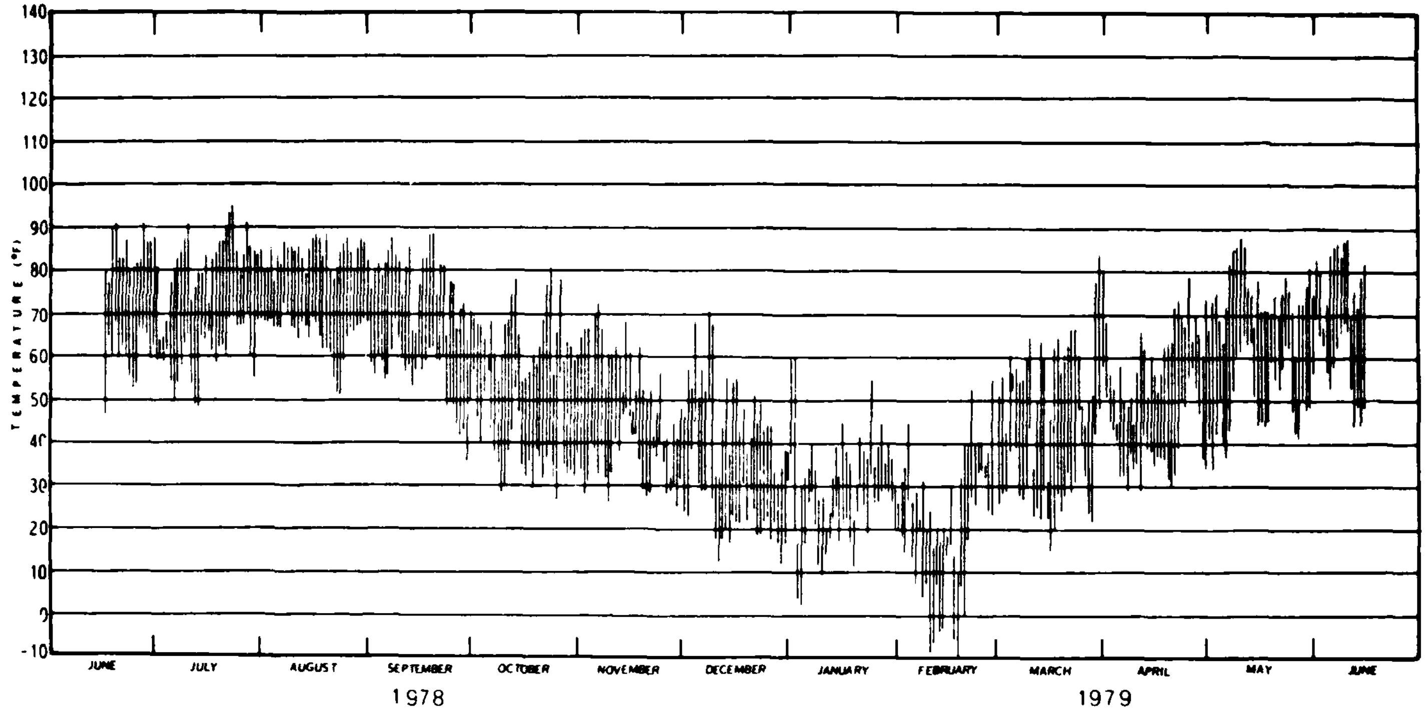


Figure 4. Temperature Profiles of Thermal Standard Top Surface and Center, and Ambient Air at Fort Belvoir, Va. (16 June 1978 -- 15 June 1979)

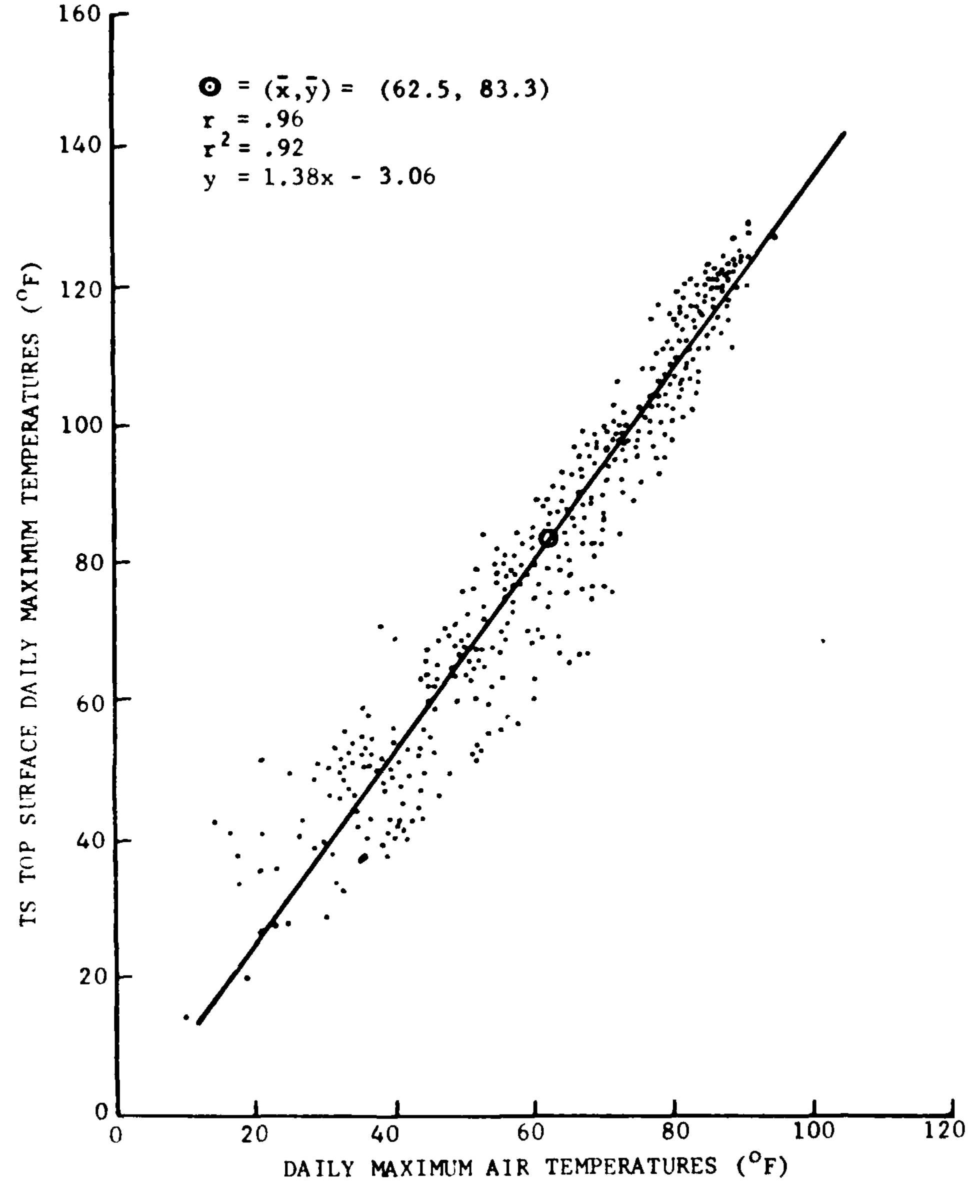


Figure 5. Daily Top Surface Maximum Temperatures and Daily Maximum Air Temperatures (16 June 1978 – 15 June 1979).

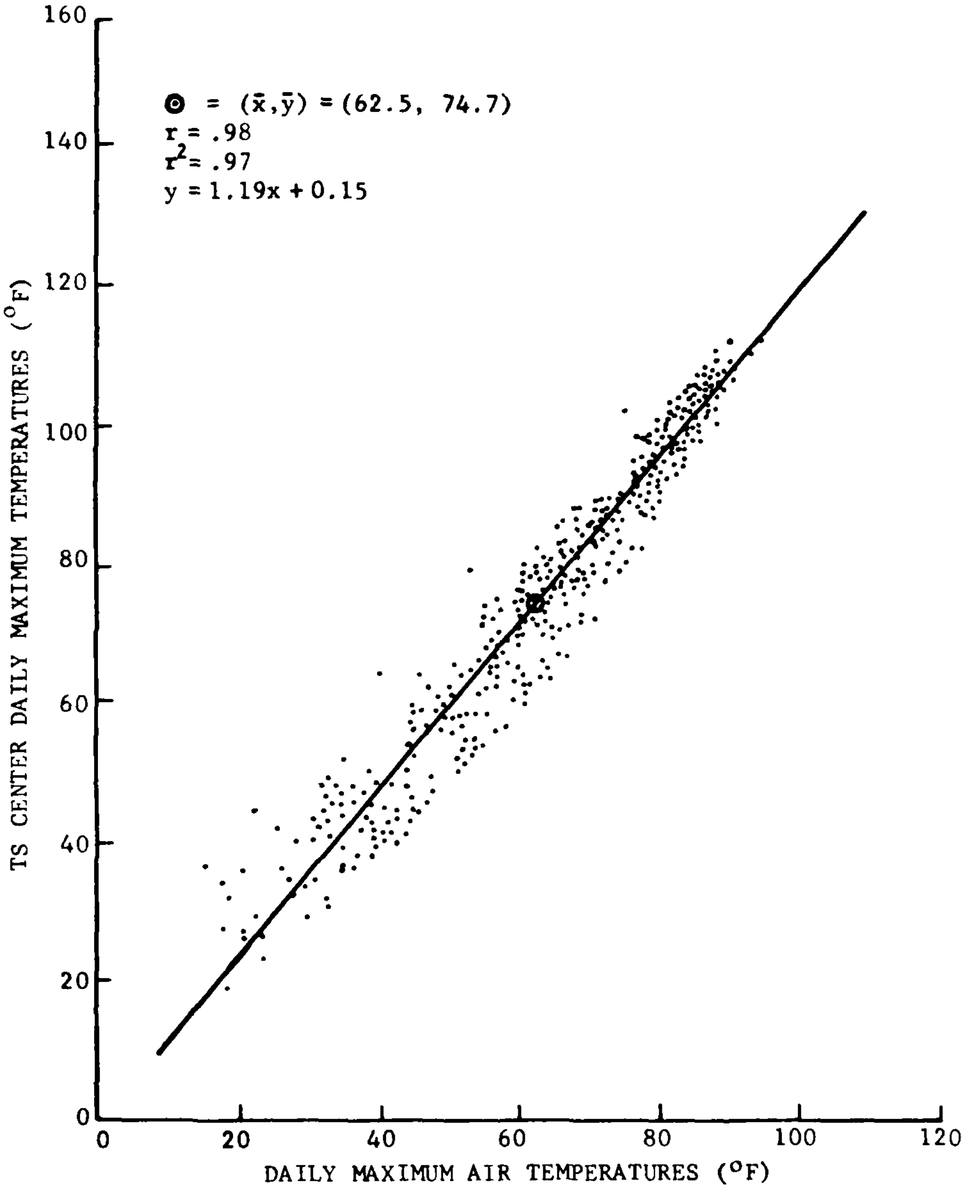


Figure 6. Daily Center Maximum Temperatures and Daily Maximum Air Temperatures (16 June 1978 – 15 June 1979).

Sampling Strategies and Data Analysis ● Since data from each measurement point can be extracted every hour (even every half-hour if so desired), the amounts of data can become quite voluminous after a long time. However, Ulrich and Schafer have illustrated that it is possible to represent large quantities of data with a relatively small sample.[6] Table 2 shows some of the sampling strategies that were examined and the percent of maximum error to be expected with each. As one illustration of this point, they compared a cumulative relative frequency curve generated with only a 10 percent sampling of the hourly data (n = 876) to a curve generated using the entire data population (N = 8760).[7] For all practical purposes, these curves, which appear in figure 7, are identical.

Hourly values of thermal standard and ambient air temperatures at Fort Belvoir were obtained on every 5th day throughout the data-gathering period. Since, as shown in table 2, the maximum error to be expected with a 20 percent sample (all hours every 5th day) is 1.4 percent, the distribution of every 5th day's hours can be considered to be quite representative of the data population. The cumulative relative frequency distributions of thermal standard top surface, center, and ambient air temperatures for every 5th consecutive day are presented in figure 8. These curves may be considered to be baseline curves at Fort Belvoir.*

[6] Richard D. Ulrich and Howard Schafer, *Evolution of the NWC Thermal Standard. Part 3. Application and Evaluation of the Thermal Standard in the Field*, NWC TP 4834, Part 3, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1977, pp. 28-47.

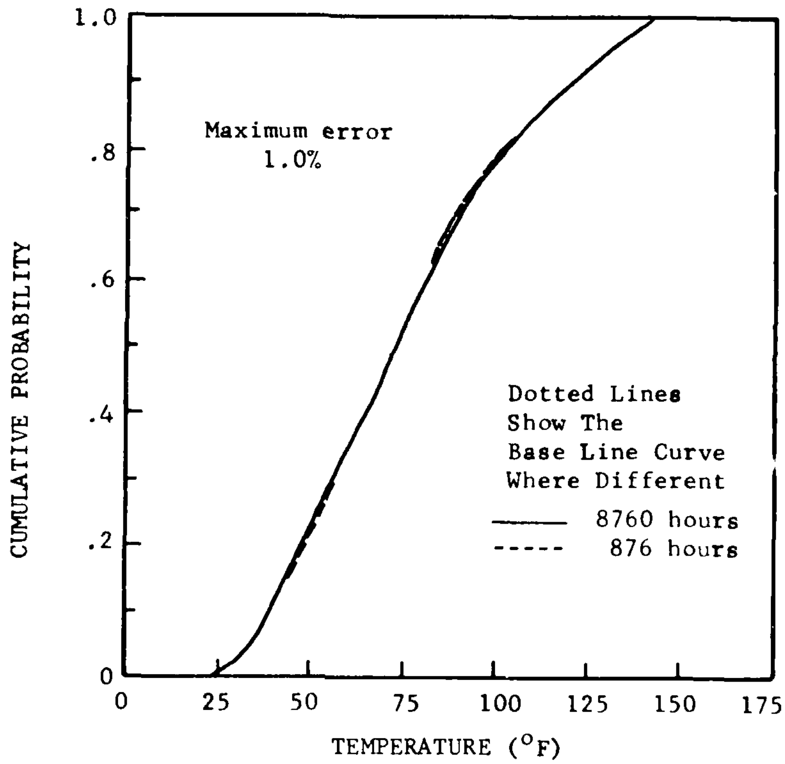
[7] Ibid, p. 28.

* The skewing of the three curves in their lowest 2-3 percent was due to the fact that the extreme cole days of February 1979 happened to fall on sampling days.

Data Graphed	% Data Used	% Maximum Error
Every other hour	50%	.25
Every 3rd hour	33%	.85
Every 5th hour	20%	.85
20% of hours randomly selected	20%	1.1
Every 7th hour	14%	1.0
Every 10th hour	10%	1.0
10% of hours randomly selected	10%	3.8
7% of hours randomly selected	7%	4.2
Every 20th hour	5%	1.7
5% of hours randomly selected	5%	3.1
Every 30th hour	3%	2.8
Every 50th hour	2%	4.2
100 random points plus year max and min	1%	5.0
Every other day	50%	.25
Every 3rd day	33%	.85
Every 4th day	25%	.85
Every 5th day	20%	1.4
20% of the days randomly selected	20%	2.0
Every 9th day	12%	3.6
Every 10th day	10%	1.7
10% of the days randomly selected	10%	1.9
Every 20th day	5%	3.6
5% of the days randomly selected	5%	4.7
Every 40th day	2%	5.6

Source: Richard D. Ulrich and Howard Schafer, *Evolution of the NWC Thermal Standard, Part 3: Application and Evaluation of the Thermal Standard in the Field*, NWC TP 4834, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1977, p. 29.

Table 2. Data Sampling Strategies and Sampling Error.



Source: Richard D. Ulrich and Howard Schafer, *Evolution of the NWC Thermal Standard, Part 3. Application and Evaluation of the Thermal Standard in the Field*, NWC TP 4834, Part 3, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1977.

Figure 7. Top Thermocouple, Thermal Standard, 1974, China Lake, Calif.

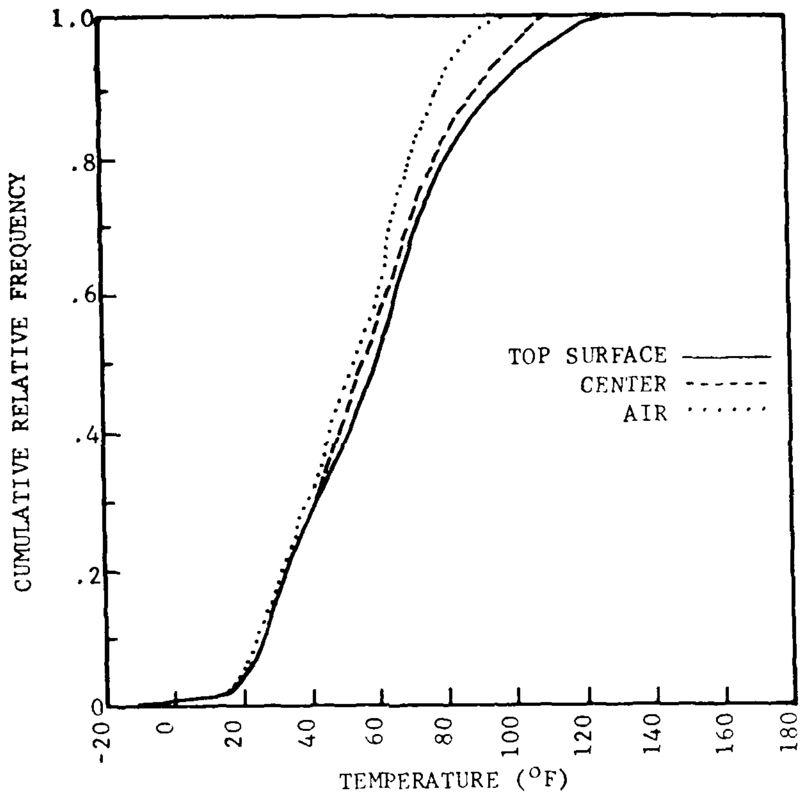


Figure 8. Frequency Distribution of Hourly Temperatures Every 5th Day at Fort Belvoir, Va. (16 June 1978 -- 15 June 1979).

In another effort to approximate thermal standard baseline curves, Ulrich and Schafer used a method based on the assumption that for most days the thermal standard responds in a rather definite temperature/time pattern.[8] The major variation in this pattern is the amplitude of the diurnal curve -- a function of the daily maximum and minimum temperature. When approximations of a thermal standard baseline curve were attempted using only daily maximum and minimum temperatures for a year, the results were unsatisfactory. However, it was discovered that a fairly accurate approximation of a thermal standard baseline curve could be created by a method wherein the temperature at every hour of the day is treated as a ratio of the diurnal range. In this way, for any maximum and minimum temperature, the remaining 22-hour temperatures could be approximated. Thus, from a year's daily maximum and minimum temperatures (n = 730), 8,760 hourly values can be generated, and frequency curves can be constructed.

To create this normalized diurnal curve, the temperatures for each separate hour of the day for every day throughout the year are summed and averaged. The formula for this operation is

$$(\text{temperature ratio})_i = \frac{(\sum T)_i - (\sum T)_{min}}{(\sum T)_{max} - (\sum T)_{min}}$$

where i is the ith hour, $(\sum T)_i$ is the sum over the ith hour for 365 days, $(\sum T)_{min}$ and $(\sum T)_{max}$ are the daily minimum and maximum sums.[9]

This procedure was performed by using actual hourly values for every 5th day at Fort Belvoir. The computed ratios appear in table 3 and in figure 9.* The curves in figure 9 are taken as representative of an entire year. They show the averaged progression of temperatures throughout the day for the three measurement points under consideration.

[8] Richard D. Ulrich and Howard Schafer, *Evolution of the NWC Thermal Standard, Part 3, Application and Evaluation of the Thermal Standard in the Field*, NWC TP 4834, Part 3, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1977, p. 30

[9] Richard D. Ulrich and Howard Schafer, *Evolution of the NWC Thermal Standard, Part 3, Application and Evaluation of the Thermal Standard in the Field*, NWC TP 4834, Part 3, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1977, p. 30.

* The hourly temperature ratios for Fort Belvoir correspond quite closely to those that were established for China Lake, Calif., (See Ulrich and Schafer, Part 3, p. 31.)

HOUR	TOP SURFACE	CENTER	AMBIENT AIR
00	.1068	.1792	.1423
01	.0750	.1357	.1300
02	.0570	.0977	.0995
03	.0394	.0738	.0697
04	.0197	.0434	.0298
05	.0041	.0226	.0116
06	.0000	.0026	.0000
07	.0574	.0000	.1126
08	.2223	.0593	.3065
09	.4525	.2116	.5374
10	.6827	.4117	.6899
11	.8527	.6139	.8141
12	.9499	.7705	.8882
13	.9879	.8831	.9492
14	1.0000	.9522	.9920
15	.9651	.9940	1.0000
16	.8870	1.0000	.9528
17	.7646	.9590	.8598
18	.6215	.8673	.6986
19	.4753	.7321	.5454
20	.3623	.5870	.4154
21	.2996	.4548	.3123
22	.2012	.3434	.2520
23	.1566	.2641	.2179

Table 3. Average Diurnal Temperature Ratios – Fort Belvoir, Va.

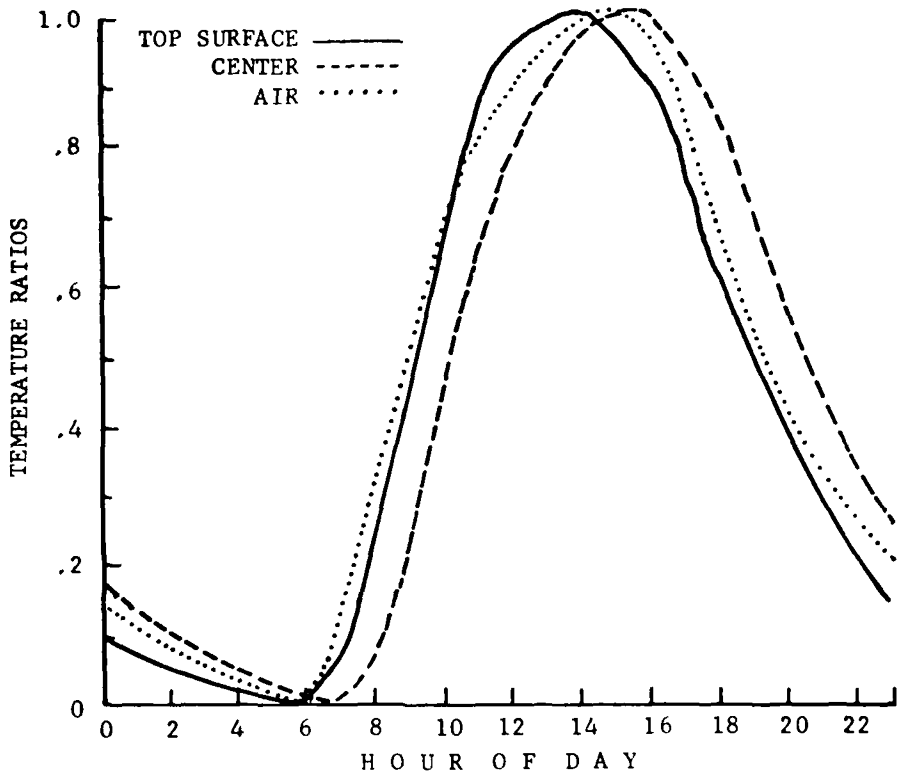


Figure 9. Normalized Curves of Temperature Ratios as a Function of Time of Day Based on Hourly Values Every 5th Day at Fort Belvoir, Va. (16 June 1978 -- 15 June 1979).

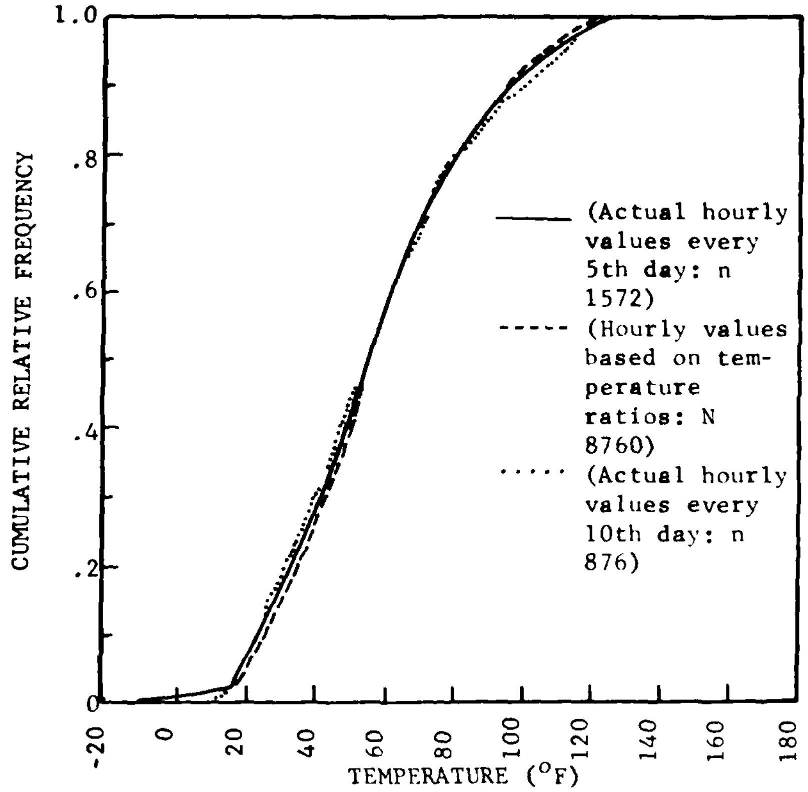


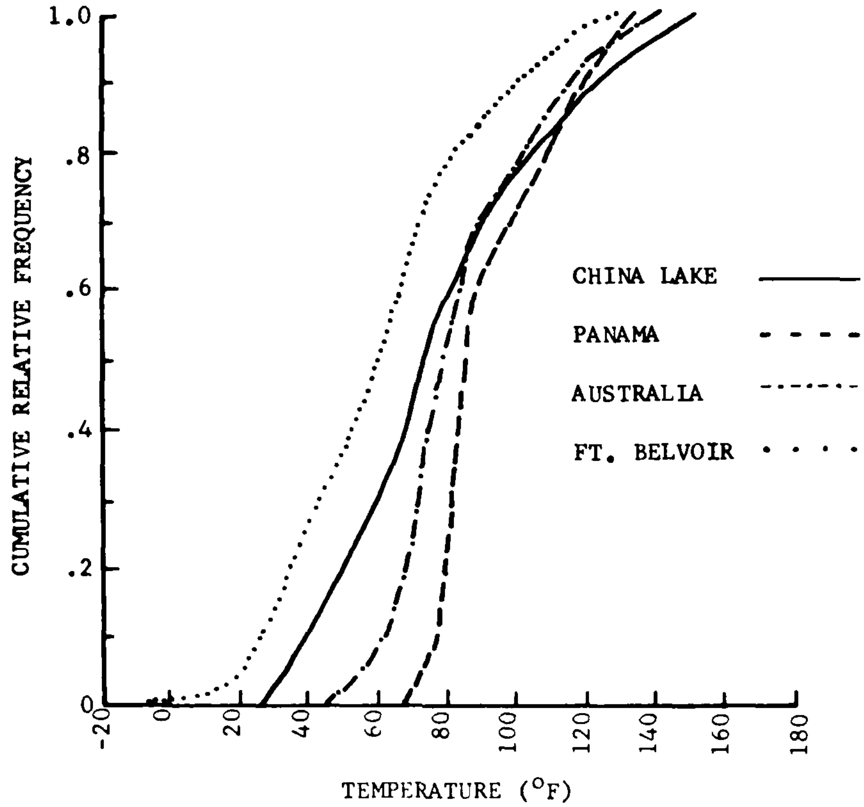
Figure 10. Thermal Standard Top Surface Temperatures at Fort Belvoir, Va. (16 June 1978 – 15 June 1979).

Figure 10 shows three cumulative relative frequency curves of thermal standard top surface temperatures for Fort Belvoir. Two curves are composed of actual hourly temperatures (every 5th and 10th day, respectively), and one curve was constructed based on the temperature ratios found in table 3 and is composed of the actual maximum and minimum temperatures for each day and the synthetic temperatures determined by the ratios. The three curves correspond quite closely with no more than 2 to 3 percent difference between the curves at any one point. Again, the exception is the lowest 3 percent of the curve constructed from the data for every 10th day's hours. The extreme cold days of February 1979 did not fall on a sampling day in this instance.

However, since the curves of actual temperatures and the curve of synthetic temperatures corresponded so closely, it was decided that the generation of similar curves of synthetic temperatures for the thermal standard center and the ambient air was not necessary. Hence, the aforementioned method whereby synthetic temperatures are derived by using actual daily maximum and minimum values and applying temperature ratios appears to be a reasonable procedure for obtaining representative baseline curves of thermal standard data. Once the ratios are established, a simple program can be set up on a desk calculator to obtain the synthetic temperatures from an actual maximum and minimum temperature.

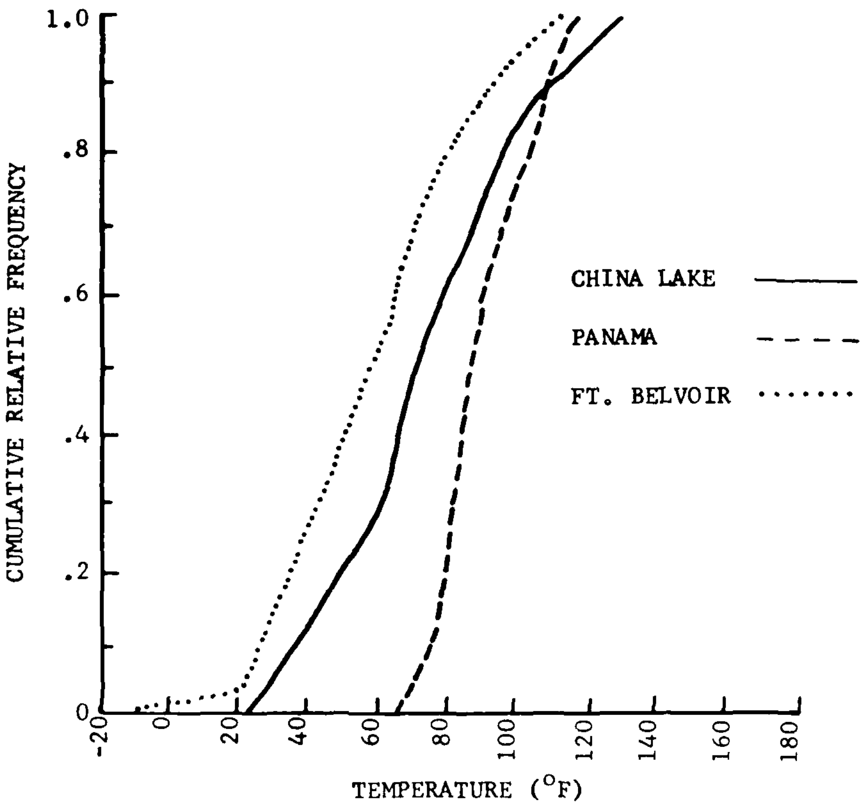
Once it was determined that the three curves appearing in figure 8 could serve as baseline curves for Fort Belvoir, it was decided to compare these curves to similar curves obtained from various prior investigations. In figures 11 and 12, the top surface and center thermal standard temperatures at Fort Belvoir are compared to those obtained from desert and tropical areas.* A visual examination of these curves reveals that the curve of Fort Belvoir data possesses a shape that is fairly consistent with the curve of China Lake data (although 10F° to 20F° cooler at each point along the curve). As one would expect, the two curves for the tropical locations exhibit a smaller annual range of temperature than do the more continental midlatitude stations.

*Figures 11 and 12 are taken from Ulrich and Schafer with the Fort Belvoir temperature data added to the original figures.



Source: Richard D. Ulrich and Howard Schafer, *Evolution of the NWC Thermal Standard, Part 3. Application and Evaluation of the Thermal Standard in the Field.* NWC TP 4834, Part 3, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1977.

Figure 11. Frequency Curves of Thermal Standard Top Surface Temperatures for Selected Locations.



Source: Richard D. Ulrich and Howard Schafer, *Evolution of the NWC Thermal Standard, Part 3. Application and Evaluation of the Thermal Standard in the Field*, NWC TP 4834, Part 3, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1977.

Figure 12. Frequency Curves of Thermal Standard Center Temperatures for Selected Locations.

PREDICTING THERMAL STANDARD TEMPERATURES

A Basic Predictive Equation ● Ulrich also investigated the prediction of daily maximum thermal standard top surface temperatures using meteorological data. If successful, this would mean that it would be possible to estimate the thermal response of the thermal standard for any place in the world based solely on local meteorological data. During investigations involving 229 days of data from China Lake, Calif., it was shown that the top surface maximum temperatures could be predicted with an accuracy of 13.5F° on more than 95 percent of the days.[10]

The formula[11] used in making the predictions was

$$\theta_{cal} = \alpha k q_{total} Z f(v)$$

where

θ_{cal} = excess temperature over noon air temperature
α = 0.6 (the absorptivity of the thermal standard)
k = 3.67 (thermal conductivity)
q_{total} = total daily radiation in langleys
$Z = \dfrac{\sum q_{max}}{\sum q_{total}}$ [$\sum q_{max}$ is the sum of the daily solar radiation maximums (hourly values) for the months, and $\sum q_{total}$ is the sum of the daily solar radiation totals for the month]
f(v) = the heat transfer coefficient (a function of windspeed)

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[10]Richard D. Ulrich, *Evolution of the NWC Thermal Standard, Part 2. Comparison of Theory with Experiment*, NWC TP 4834, Part 2, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1971.

[11]Richard D. Ulrich, *Evolution of the NWC Thermal Standard, Part 2. Comparison of Theory with Experiment*, NWC TP 4834, Part 2, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1971, pp. 33-36.

Table 4 contains the daily predictions of excess temperature (θ_{cal}), the actual measured excess temperature (θ_{exp}), and their differences from 16 June 1978 to 15 June 1979 at Fort Belvoir, Va. The noon air value was approximated in all cases since actual noon air values were not gathered on a regular basis.* Because two different sources of solar radiation data are used, the "Z" values are not constant during some of the months.

Annually, the distribution of differences between the actual temperature excess (θ_{exp}) and the predicted excess (θ_{cal}) found in table 4 had a mean of 2.52 and a standard deviation of 5.54. This translates into 95 percent of the predicted values falling into the range ±11F°. This is slightly better than the value obtained from China Lake (±13.5F°). On a monthly basis, the best predictions occurred during the winter, and the poorest during the summer. In fact, most predictions that were made on days with low radiation (summer included) were better than those made on days with high radiation loads. Predictions generated on days with greater windspeeds tended to be better than those made on days when the windspeeds were rather low.

Some of the excessive over- and under-predictions that appear in table 4 were examined. It was found that many of these that were approximately +10F° and greater could be explained by changes in cloud cover and/or windspeed that occurred during the immediate post noon period (1200 -- 1500 hours). Many other factors might also have some bearing on the accuracy of the predictions. One factor is that the absorptivity of the thermal standard can only be determined to 0.63 ± .06 (0.57 -- 0.69). Another factor is that the solar radiation values being used were from sources that were greater that 20 miles distant from the thermal standard test site. During the summer months, the locally isolated nature of many weather phenomena in this area can cause radiation values to differ greatly over very short distances. The rather sensitive nature of the equation to changes in windspeeds in the 2- to 5-knot range brought up another area of concern. About half of the wind data used in this study, and all of the wind data at China Lake, were extrapolated from other sources. In the case of Fort Belvoir, winds from a

*The average noon air value was determined to be approximately 3F° less than the daily maximum air temperature. This value was computed by inserting the average maximum and minimum air temperature found in table 1 into the temperature ratio formula and solving for the noon air ratio (0.8882) found in table 3.

DATE	Top Surface Max T ^oF	Noon Air T ^oF	q_{total} cal/cm^2/hr	Z $\left[\frac{\Sigma q_{max}}{\Sigma q_{total}}\right]$	wind speed, knots	θ_{cal} F^o	θ_{exp} F^o	Diff. F^o
Jun.'78								
16	116	77	587	.132	2	51.2	39	12.2
17	104	75	271	.132	3	19.7	29	-9.3
18	125	87	472	.132	2	41.1	38	3.1
19	128	88	501	.132	2	43.7	40	3.7
20	121	80	649	.135	2	57.8	41	16.8
21	111	80	393	.135	5	23.4	31	-7.6
22	120	84	555	.135	3	41.3	36	5.3
23	118	78	701	.135	3	52.2	40	12.2
24	117	78	640	.135	2	57.0	39	18.0
25	121	80	617	.135	3	45.9	41	4.9
26	107	81	355	.132	3	25.8	26	-0.2
27	129	88	605	.132	2	52.7	41	11.7
28	118	84	640	.132	5	37.2	34	3.2
29	123	84	637	.132	3	46.3	39	7.3
30	121	85	631	.132	4	42.1	36	6.1
Jul.'78								
1	118	78	601	.139	2	55.1	40	15.1
2	69	61	77	.139	2	7.1	8	-0.9
3	66	62	54	.139	2	5.0	4	1.0
4	98	66	291	.139	2	26.7	32	-5.3
5	..	..	..	..	..	..	..	..
6	116	78	579	.139	3	44.4	38	6.4
7	116	80	696	.134	5	41.0	36	5.0
8	118	83	547	.134	3	40.4	35	5.4
9	124	85	612	.134	2	54.1	39	15.1
10	124	88	534	.134	3	39.4	36	3.4
11	108	72	704	.134	4	47.7	36	11.7
12	115	74	733	.134	3	54.1	41	13.1
13	111	77	649	.139	4	45.6	34	11.6
14	102	77	299	.134	2	26.5	25	1.5
15	117	81	480	.134	2	42.5	36	6.5
16	84	70	152	.134	2	13.4	14	-0.6

Table 4 Comparison of Calculated and Experimental Values of Maximum Temperature Excess at Fort Belvoir, Va. (16 June 1978 – 15 June 1979)

DATE	Top Surface Max T ^oF	Noon Air T ^oF	q_{total} cal/cm^2/hr	Z $\left[\frac{\Sigma q_{max}}{\Sigma q_{total}}\right]$	wind speed, knots	θ_{cal} F°	θ_{exp} F°	Diff. F°
Jul.'78 (cont;)								
17	107	80	416	.139	4	27.7	27	0.7
18	122	82	540	.139	2	39.6	40	-0.4
19	119	84	560	.139	5	30.1	35	-4.9
20	124	84	599	.139	2	42.2	40	2.2
21	124	87	568	.139	3	36.7	37	-0.3
22	127	91	536	.139	4	32.2	36	-3.8
23	127	92	610	.139	5	31.6	35	-3.4
24	116	82	401	.139	3	29.8	34	-4.2
25	101	77	196	.139	2	21.6	24	-2.4
26	117	81	379	.139	2	32.0	36	-4.0
27	120	88	557	.139	4	33.0	32	1.0
28	116	83	466	.139	2	36.3	33	3.3
29	111	82	515	.139	5	28.6	29	-0.4
30	105	81	341	.139	3	27.0	24	3.0
31	117	82	406	.139	2	33.4	35	-1.6
Aug.'78								
1	108	77	261	.157	2	27.1	31	-3.9
2	105	78	211	.157	2	21.9	27	-5.1
3	113	83	424	.157	4	33.7	30	3.7
4	100	75	159	.157	2	16.5	25	-8.5
5	120	81	406	.148	2	39.7	39	0.7
6	108	79	420	.148	3	34.3	29	5.3
7	113	84	397	.148	3	32.4	29	3.4
8	121	83	497	.148	2	48.6	38	10.6
9	123	83	508	.148	2	49.6	40	9.6
10	121	82	505	.148	3	41.2	39	2.2
11	120	83	542	.148	3	44.2	37	7.2
12	113	80	338	.148	2	33.0	33	0.0
13	97	77	252	.148	4	18.9	20	-1.1
14	123	83	485	.148	2	47.4	40	7.4
15	123	85	447	.148	3	36.5	38	-1.5
16	123	86	523	.148	2	51.1	37	14.1
17	121	85	598	.148	4	44.7	36	8.7

Table 4. Continued.

DATE	Top Surface Max T ^oF	Noon Air T ^oF	q_{total} cal/cm^2/hr	Z $\left[\frac{\sum q_{max}}{\sum q_{total}}\right]$	wind speed, knots	θ_{cal} F^o	θ_{exp} F^o	Diff. F^o
Aug.'78 (cont;)								
18	119	81	570	.148	2	55.7	38	17.7
19	127	86	576	.148	3	47.0	39	8.0
20	109	77	619	.148	5	40.3	32	8.3
21	111	76	632	.148	4	47.3	35	12.3
22	119	79	560	.157	3	48.4	40	8.4
23	123	82	517	.157	2	53.6	41	12.6
24	122	84	542	.148	3	44.2	38	6.2
25	120	85	447	.148	2	43.7	35	8.7
26	116	82	432	.148	2	42.2	34	8.2
27	104	78	227	.148	3	18.5	26	-7.5
28	114	83	372	.148	2	36.3	31	5.3
29	120	85	481	.157	4	38.2	35	3.2
30	122	84	299	.148	2	29.2	38	-8.8
31	102	80	214	.148	2	20.9	22	-1.1
Sep.'78								
1	99	74	400	.158	4	32.0	25	7.0
2	112	78	523	.158	5	36.4	34	2.4
3	111	80	421	.158	3	36.7	31	5.7
4	109	77	475	.158	4	38.0	32	6.0
5	117	80	550	.158	3	47.9	37	10.9
6	119	82	522	.158	2	54.4	37	17.4
7	115	85	475	.158	5	33.0	30	3.0
8	115	81	413	.158	2	43.0	34	9.0
9	111	80	309	.158	2	32.2	31	1.2
10	99	72	306	.158	3	26.6	27	0.4
11	107	79	385	.158	4	30.8	28	2.8
12	115	83	407	.158	3	35.4	32	3.2
13	83	64	150	.158	2	16.5	19	-2.5
14	84	64	201	.158	3	17.5	20	-2.5
15	103	75	426	.158	4	34.0	28	6.0
16	111	81	426	.158	3	37.1	30	7.1

Table 4. Continued.

DATE	Top Surface Max T °F	Noon Air T °F	q_{total} cal/cm^2/hr	Z $\left[\frac{\Sigma q_{max}}{\Sigma q_{total}}\right]$	wind speed, knots	θ_{cal} F°	θ_{exp} F°	Diff. F°
Sep.'78 (cont;)								
17	117	81	390	.158	2	40.7	36	4.7
18	121	86	433	.158	2	45.1	35	10.1
19	111	86	427	.158	4	34.1	25	9.1
20	96	72	205	.158	2	21.4	24	-2.6
21	107	79	347	.158	2	36.1	28	8.1
22	101	79	176	.158	5	12.2	22	-11.8
23	76	62	180	.158	3	15.7	14	1.7
24	95	75	263	.158	3	22.9	20	2.9
25	104	74	331	.155	3	28.3	30	-1.7
26	98	64	451	.155	2	46.1	34	12.1
27	99	78	425	.155	5	29.0	21	8.0
28	96	70	411	.155	4	32.2	26	6.2
29	96	63	442	.155	3	37.8	33	4.8
30	..	..	..	..	..	..	..	..
Oct.'78								
1	..	..	..	..	..	..	..	..
2	97	66	382	.168	5	28.2	31	-2.8
3	98	65	393	.171	3	37.0	33	4.0
4	85	62	236	.168	2	26.2	23	3.2
5	69	58	79	.168	2	8.8	11	-2.8
6	97	66	395	.168	4	33.6	31	2.6
7	83	58	305	.168	8	20.3	25	-4.7
8	77	52	249	.168	5	18.4	25	-6.6
9	89	58	425	.168	3	39.3	31	8.3
10	97	65	403	.168	2	44.7	32	12.7
11	98	66	401	.168	3	37.1	32	5.1
12	98	72	354	.168	4	30.1	26	4.1
13	99	76	334	.168	3	30.9	23	7.9
14	79	62	187	.168	3	17.3	17	0.3
15	79	52	328	.168	4	27.9	27	0.9

Table 4. Continued.

DATE	Top Surface Max T °F	Noon Air T °F	q_{total} cal/cm^2/hr	Z $\left[\frac{\Sigma q_{max}}{\Sigma q_{total}}\right]$	wind speed, knots	θ_{cal} F°	θ_{exp} F°	Diff. F°
Oct.'78 (cont;)								
16	71	53	121	.168	2	13.4	18	4.6
17	74	54	204	.168	2	22.6	20	2.6
18	83	58	351	.168	7	24.6	25	0.4
19	75	57	214	.168	3	19.8	18	1.8
20	85	60	338	.168	5	25.0	25	0.0
21	95	66	360	.168	3	33.3	29	4.3
22	103	74	348	.168	3	32.2	29	3.2
23	105	78	305	.168	4	25.9	27	1.1
24	81	52	364	.168	2	40.4	29	11.4
25	85	63	349	.168	8	23.3	22	1.3
26	94	76	168	.168	4	14.3	18	-3.7
27	84	57	348	.168	5	25.7	27	-1.3
28	89	61	333	.168	3	30.8	28	2.8
29	85	60	318	.168	4	27.0	25	2.0
30	79	57	318	.168	6	23.5	22	1.5
31	85	58	321	.168	3	29.7	27	2.7
Nov.'78								
1	88	62	292	.180	5	23.1	26	-2.9
2	92	64	329	.180	3	32.6	28	4.6
3	91	64	294	.180	2	34.9	27	7.9
4	56	51	93	.180	7	7.0	5	2.0
5	94	67	295	.180	2	35.1	27	8.1
6	91	70	270	.180	5	21.4	21	0.4
7	87	64	145	.180	2	17.2	23	5.8
8	62	51	147	.180	4	13.4	11	2.4
9	84	58	296	.180	3	29.4	26	3.4
10	82	58	238	.180	3	23.6	24	-0.4
11	80	60	209	.180	2	24.8	20	4.8
12	70	57	123	.180	3	12.2	13	-0.8

Table 4. Continued.

DATE	Top Surface Max T ^oF	Noon Air T ^oF	q_{total} cal/cm^2/hr	Z $\left[\frac{\sum q_{max}}{\sum q_{total}}\right]$	wind speed, knots	θ_{cal} F^o	θ_{exp} F^o	Diff. F^o
Nov.'78 (cont;)								
13	52	49	19	.180	2	2.3	3	0.7
14	83	66	236	.180	8	16.9	17	-0.1
15	70	59	47	.180	2	5.6	11	-5.4
16	46	44	24	.180	4	2.2	2	0.2
17	53	50	26	.180	3	2.6	3	-0.4
18	83	60	257	.180	7	20.2	23	-2.8
19	73	50	228	.180	3	22.6	23	-0.4
20	73	48	233	.180	2	27.7	25	2.7
21	72	50	170	.180	2	20.2	22	-2.2
22	46	39	45	.180	3	4.5	7	-2.5
23	49	45	29	.180	2	3.4	4	-0.6
24	73	54	202	.180	8	14.4	19	-4.6
25	48	38	116	.180	10	7.9	10	-2.1
26	53	39	117	.180	7	8.8	14	-5.2
27	33	30	30	.180	2	3.6	3	0.6
28	50	42	85	.180	3	8.4	8	0.4
29	49	39	94	.180	2	11.2	10	1.2
30	71	46	173	.180	2	20.6	25	-4.4
Dec.'78								
1	70	44	214	.192	2	27.1	26	1.1
2	78	55	165	.192	2	20.9	23	-1.1
3	60	50	90	.192	5	11.4	10	1.4
4	76	66	93	.192	5	7.9	10	-2.1
5	63	48	144	.192	2	18.3	15	3.3
6	79	55	206	.192	2	26.1	24	2.1
7	65	50	123	.192	2	15.6	15	0.6
8	76	68	71	.192	3	7.5	8	-0.5
9	66	65	21	.192	4	2.0	1	1.0
10	47	30	219	.192	6	18.0	17	1.0

Table 4. Continued.

DATE	Top Surface Max T ^oF	Noon Air T ^oF	q_{total} cal/cm^2/ hr	Z $\left[\frac{\Sigma q_{max}}{\Sigma q_{total}}\right]$	wind speed, knots	θ_{cal} F^o	θ_{exp} F^o	Diff. F^o
Dec.'78 (cont;)								
11	55	30	211	.192	2	26.7	25	1.7
12	63	42	140	.192	4	13.6	21	-7.4
13	70	53	214	.192	7	17.2	17	0.2
14	51	35	215	.192	8	16.4	16	0.4
15	67	52	180	.192	4	17.5	15	2.5
16	76	53	199	.192	8	15.1	13	2.1
17	56	41	169	.192	10	12.3	15	-2.7
18	60	46	202	.192	5	17.1	14	3.1
19	49	36	122	.192	6	10.0	13	-3.0
20	40	39	23	.192	3	2.4	1	1.4
21	65	49	182	.192	6	15.0	16	-1.0
22	63	42	207	.192	3	21.9	21	0.9
23	69	47	193	.192	4	18.7	22	-3.3
24	43	41	29	.192	2	3.7	2	1.7
25	60	42	175	.192	6	14.4	18	-3.6
26	53	42	132	.192	3	14.0	11	3.0
27	52	31	213	.192	5	18.0	21	-3.0
28	50	29	214	.192	6	17.6	21	-3.4
29	59	32	208	.192	2	26.4	27	0.6
30	51	36	137	.192	4	13.3	15	-1.7
31	38	36	18	.192	4	1.7	2	-0.3
Jan.'79								
1	63	58	24	.200	7	2.0	5	-3.0
2	60	58	14	.200	10	1.1	2	-0.9
3	34	15	222	.200	8	17.6	19	-1.4
4	47	28	222	.200	8	17.6	19	-1.4
5	47	30	132	.200	3	14.5	17	-2.5
6	53	32	126	.200	3	13.9	21	-7.1
7	41	38	26	.200	3	2.9	3	-0.1
8	45	32	130	.200	8	10.3	13	-2.7
9	49	25	226	.200	3	24.9	24	0.9

Table 4. Continued.

DATE	Top Surface Max T ^oF	Noon Air T ^oF	q_{total} cal/cm^2/hr	Z $\left[\frac{\sum q_{max}}{\sum q_{total}}\right]$	wind speed, knots	θ_{cal} F^o	θ_{exp} F^o	Diff. F^o
Jan.'79 (cont;)								
10	39	26	126	.200	3	13.9	13	0.9
11	36	18	124	.200	4	12.5	18	-5.5
12	27	21	64	.200	3	7.1	6	1.1
13	33	30	36	.200	4	3.6	3	0.6
14	42	37	69	.200	6	5.9	5	0.9
15	53	30	238	.200	5	21.0	23	-2.0
16	66	42	182	.200	2	24.0	24	0.0
17	47	36	55	.200	2	7.3	11	-3.7
18	43	34	241	.200	15	14.8	9	-4.2
19	36	20	143	.200	3	15.8	16	0.2
20	29	28	20	.200	2	2.6	1	1.6
21	43	41	38	.200	8	3.0	2	1.0
22	51	36	161	.200	10	12.2	15	-2.8
23	55	34	193	.200	5	17.0	21	-4.0
24	56	52	23	.200	5	2.0	4	-2.0
25	43	32	116	.200	12	8.2	11	-2.8
26	56	37	238	.200	8	18.9	19	-0.1
27	66	42	257	.200	6	22.1	24	-1.9
28	40	33	24	.200	3	2.6	7	-4.4
29	55	37	204	.200	10	15.5	18	-2.5
30	53	34	254	.200	13	16.7	19	-2.3
31	39	27	143	.200	6	12.3	12	0.3
Feb.'79								
1	41	24	260	.172	9	17.7	17	0.7
2	51	29	295	.172	6	21.8	22	-0.2
3	55	32	158	.172	2	17.9	23	-5.1
4	63	42	218	.172	3	20.7	21	-0.3
5	43	24	307	.172	9	20.9	19	1.9
6	51	26	267	.172	2	30.3	25	5.3
7	27	20	19	.172	3	1.8	7	-5.2
8	53	29	293	.172	4	25.5	24	1.5

Table 4. Continued.

DATE	Top Surface Max T ^oF	Noon Air T ^oF	q_{total} cal/cm^2/hr	Z $\left[\frac{\sum q_{max}}{\sum q_{total}}\right]$	wind speed, knots	θ_{cal} F^o	θ_{exp} F^o	Diff. F^o
Feb.'79 (cont;)								
9	41	18	301	.172	4	26.2	23	3.2
10	50	22	275	.172	3	26.1	28	-1.9
11	41	14	297	.172	3	28.2	27	1.2
12	27	18	99	.172	6	7.3	9	-1.7
13	37	15	235	.172	4	20.4	22	-1.6
14	52	18	251	.172	2	28.5	34	-5.5
15	20	16	42	.172	3	4.0	4	0.0
16	38	28	119	.172	4	10.4	10	0.4
17	42	12	376	.172	3	26.2	30	-3.8
18	15	7	86	.172	5	6.5	8	-1.5
19	53	30	318	.172	7	22.8	23	-0.2
20	70	37	299	.172	2	34.0	33	1.0
21	41	37	51	.172	4	4.4	4	0.4
22	85	50	350	.172	2	39.7	35	4.7
23	51	37	85	.172	2	9.7	14	-4.3
24	42	38	59	.172	4	5.1	4	1.1
25	41	38	40	.172	4	3.5	3	0.5
26	38	33	37	.172	4	3.2	5	-1.8
27	72	36	268	.172	2	30.4	36	-5.6
28	82	52	390	.172	4	33.9	30	3.9
Mar.'79								
1	67	49	171	.157	3	14.8	18	-3.2
2	78	53	373	.157	4	29.6	25	4.6
3	53	41	100	.157	2	10.4	12	-1.6
4	69	58	81	.157	2	8.4	11	-2.6
5	59	54	42	.157	3	3.6	5	-1.4
6	57	55	74	.157	4	5.9	2	3.9
7	81	52	363	.157	3	31.4	29	2.4
8	81	53	346	.157	2	35.9	28	7.9
9	85	57	384	.157	3	33.2	28	5.2

Table 4. Continued.

DATE	Top Surface Max T ^{o}F	Noon Air T ^{o}F	q_{total} cal/cm^2/hr	Z $\left[\frac{\Sigma q_{max}}{\Sigma q_{total}}\right]$	wind speed, knots	θ_{cal} F°	θ_{exp} F°	Diff. F°
Mar.'79 (cont;)								
10	81	62	166	.157	2	17.2	19	-1.8
11	55	32	347	.157	8	21.6	23	-1.4
12	69	47	422	.157	6	28.4	22	6.4
13	80	61	396	.157	10	23.7	19	4.7
14	70	58	177	.157	5	12.2	12	0.2
15	52	29	477	.157	10	28.5	23	5.5
16	69	43	466	.157	5	32.2	26	6.2
17	88	60	460	.157	5	31.8	28	3.8
18	83	62	453	.157	8	28.2	21	7.2
19	85	54	471	.157	4	37.4	31	6.4
20	83	58	477	.157	6	32.1	25	7.1
21	91	60	456	.157	4	36.2	31	5.2
22	94	64	466	.157	4	37.0	30	7.0
23	88	64	417	.157	7	27.3	24	3.3
24	77	58	103	.157	2	10.7	19	-8.3
25	65	46	254	.157	4	20.2	19	1.2
26	68	42	376	.157	8	23.4	26	2.6
27	76	47	277	.157	4	22.0	29	7.0
28	79	49	504	.157	4	40.0	30	10.0
29	97	75	433	.157	8	27.0	22	5.0
30	108	81	365	.157	3	31.5	27	4.5
31	105	77	318	.157	2	33.0	28	5.0
Apr.'79								
1	90	65	155	.147	2	15.0	25	-10.0
2	63	53	80	.147	2	7.8	10	-2.2
3	53	50	74	.147	4	5.5	3	2.5
4	44	42	32	.147	5	2.1	2	0.1
5	83	55	403	.147	6	25.4	28	-2.6
6	67	47	554	.147	10	31.0	20	11.0
7	69	46	562	.147	8	32.8	23	9.8

Table 4. Continued.

DATE	Top Surface Max T ^oF	Noon Air T ^oF	q_{total} cal/cm^2/hr	Z $\left[\frac{\sum q_{max}}{\sum q_{total}}\right]$	wind speed, knots	θ_{cal} F^o	θ_{exp} F^o	Diff. F^o
Apr.'79 (cont;)								
8	76	48	269	.147	3	21.8	28	-6.2
9	47	42	54	.147	2	5.2	5	0.2
10	81	54	573	.147	10	32.1	27	5.1
11	93	63	520	.147	6	32.8	30	2.8
12	79	61	189	.147	4	14.1	18	-3.9
13	52	49	66	.147	4	4.9	3	1.9
14	83	58	531	.147	8	31.0	25	6.0
15	76	54	298	.147	8	17.4	22	-4.6
16	67	50	154	.147	6	9.7	17	-7.3
17	79	54	350	.147	4	26.0	25	1.0
18	85	60	599	.147	10	33.5	25	8.5
19	88	61	591	.147	9	34.4	27	7.4
20	93	61	593	.147	4	44.1	32	12.1
21	99	69	573	.147	6	36.1	30	6.1
22	102	72	378	.147	2	36.7	30	6.7
23	86	67	227	.147	3	18.4	19	-0.6
24	76	65	158	.147	4	11.7	11	0.7
25	103	76	432	.147	5	28.0	27	1.0
26	66	62	115	.147	10	6.4	4	2.4
27	90	67	211	.147	4	15.7	23	-7.3
28	87	63	376	.147	3	30.5	24	6.5
29	89	58	540	.147	5	34.9	31	3.9
30	99	71	584	.147	5	37.8	28	9.8
May '79								
1	95	64	662	.144	6	40.9	31	9.9
2	102	70	629	.144	4	45.8	32	13.8
3	89	72	191	.144	4	13.9	17	-3.1
4	81	66	126	.144	2	12.0	15	-3.0
5	91	61	660	.144	5	41.8	30	11.8
6	95	69	563	.144	7	33.9	26	7.9
7	112	79	610	.144	4	44.4	33	11.4
8	115	82	582	.144	4	42.4	33	9.4

Table 4. Continued.

DATE	Top Surface Max T ^oF	Noon Air T ^oF	q_{total} cal/cm^2/hr	Z $\left[\frac{\Sigma q_{max}}{\Sigma q_{total}}\right]$	wind speed, knots	θ_{cal} F^o	θ_{exp} F^o	Diff. F^o
May '79 (cont;)								
9	115	83	600	.144	4	43.7	32	11.7
10	117	85	545	.144	4	39.7	32	7.7
11	117	83	541	.144	3	42.9	34	8.9
12	110	74	302	.144	2	28.7	26	2.7
13	97	72	147	.144	2	14.0	25	-9.0
14	89	65	305	.144	2	29.0	24	5.0
15	110	75	533	.144	2	50.7	35	15.7
16	99	68	713	.144	6	44.0	31	13.0
17	101	69	699	.144	5	44.3	32	12.3
18	92	68	385	.144	3	30.5	24	6.5
19	94	68	524	.144	6	32.4	26	6.4
20	100	71	372	.144	2	35.4	29	6.4
21	85	67	188	.144	2	17.9	18	-0.1
22	101	72	529	.144	5	33.5	29	4.5
23	95	76	249	.144	4	18.1	19	-0.9
24	92	73	237	.144	6	14.6	19	-4.4
25	100	68	381	.144	2	36.2	32	4.2
26	81	58	286	.144	2	27.2	23	-5.8
27	92	70	310	.144	4	22.6	22	0.6
28	99	70	261	.144	3	20.7	29	-8.3
29	108	74	539	.144	4	39.3	34	5.3
30	109	78	662	.144	5	42.0	31	11.0
31	91	72	272	.144	3	21.6	19	2.6
Jun.'79								
1	110	80	381	.136	3	28.6	30	-1.4
2	105	77	447	.136	4	30.7	28	2.7
3	71	64	71	.136	3	5.3	27	-1.7
4	95	70	405	.136	4	27.9	25	2.9
5	115	81	599	.136	4	41.2	34	7.2
6	119	83	497	.136	3	37.2	36	1.2

Table 4. Continued.

DATE	Top Surface Max T ^{o}F	Noon Air T ^{o}F	q_{total} cal/cm^2/hr	Z $\left[\frac{\Sigma q_{max}}{\Sigma q_{total}}\right]$	wind speed, knots	θ_{cal} F^{o}	θ_{exp} F^{o}	Diff. F^{o}
Jun.'79 (cont;)								
7	118	84	469	.136	4	32.2	34	-1.7
8	108	81	465	.136	3	34.9	27	7.9
9	123	85	607	.136	2	54.5	38	16.5
10	120	85	433	.136	2	38.9	35	3.9
11	87	67	406	.136	5	24.3	20	4.3
12	102	73	724	.136	5	43.3	29	14.3
13	107	69	645	.136	4	44.4	38	6.4
14	112	76	721	.136	3	54.0	36	18.0
15	114	79	700	.136	4	48.2	35	13.2

Table 4. Continued.

sensor at the 12-foot level at an airfield were extrapolated to represent winds at the thermal standard test site -- a location sheltered by trees and a building, and for the most part lower than the surrounding terrain. Thus, errors of a few knots are inherent during this extrapolation process. An error of a few knots in the windspeed, especially on days with a high solar load, can easily mean a difference of 10F° to 20F° between predicted values of θ_{cal}. For example, on a day with a q_{total} of 700 ly, the difference between a θ_{cal} computed with a 2-knot wind and one computed with a 5-knot wind is about 19F°.

A Derivation of the Prediction Equation ● In an effort to discover if better estimates of excess temperature (θ_{cal}) could be obtained for Fort Belvoir, an empirical derivation of the basic prediction equation was constructed. This derivation equation* was

$$\theta_{cal} = \frac{[(q_{total})(Z)]^{\alpha}}{.h}\left(\frac{1}{1 + \omega^2 \tau_c^2}\right)^{1/2}$$

where

q_{total} = total daily radiation in langleys

Z = $\dfrac{\sum q_{max}}{\sum q_{total}}$

α = the absorptivity of the thermal standard

$.h$ = heat transfer coefficient x 0.1 (a function of windspeed)

$\left(\dfrac{1}{1 + \omega^2 \tau_c^2}\right)^{1/2}$ = attenuation factor (a function of windspeed) [ω is frequency, and τ_c is the time constant]

*For an explanation and graphic illustration of the elements of this equation, see Ulrich, Part 2, pp. 4-10.

Overall, the derivation proved to be a more accurate predictor when applied to the data at Fort Belvoir. The derivation yielded a mean of 1.24 and a standard deviation of 3.05; whereas, the basic equation provided a mean of 2.52 and a standard deviation of 5.54 when applied to the Fort Belvoir data. In addition, during days with high solar radiation loads and low windspeeds, the excessive over-predictions evident during application of the basic equation were not manifested when this derivation was employed.

To compare the results obtained from both predictive equations to the actual thermal standard, top surface temperatures at Fort Belvoir, one must construct frequency curves (figure 13). The curve of actual values was taken from figure 10 and comprises 8,760 temperatures – actual daily maximum and minimum temperatures, plus those obtained by using the temperature ratios of table 3. The curves for the basic equation and derivation were constructed by using the predicted top surface values and the actual minimum air temperature for each day. The minimum air temperature is a good approximation of the minimum thermal standard, top surface temperature, and it would be the value used in lieu of actual thermal standard data. The remaining temperatures for each prediction were found by using again the temperature ratio method.

For the most part, the curves in figure 13 are almost identical through the lower 70 percent. In the upper 30 percent, the curve of actual values and the curve from the derivation of the predictive equation are identical; whereas, the curve composed of values from the basic equation exhibits a 1 to 2 percent difference from the other two curves. This difference, expressed in temperature, translates into 1F° to 2F° increasing to 5F° to 10F° towards the uppermost part of the distributions.

It would appear that the derivation of the basic equation is a better predictor at Fort Belvoir. However, the derivation proved to be less than desirable when it was applied to the data from China Lake, Calif., as excessive under-predictions resulted. This was especially evident during the summer months. It would seem that both of these equations could possess geographic and/or climatic limitations in their applicability. Only further investigations, involving these and other equations with thermal standard data bases from various climatic regions will confirm or negate this assumption.

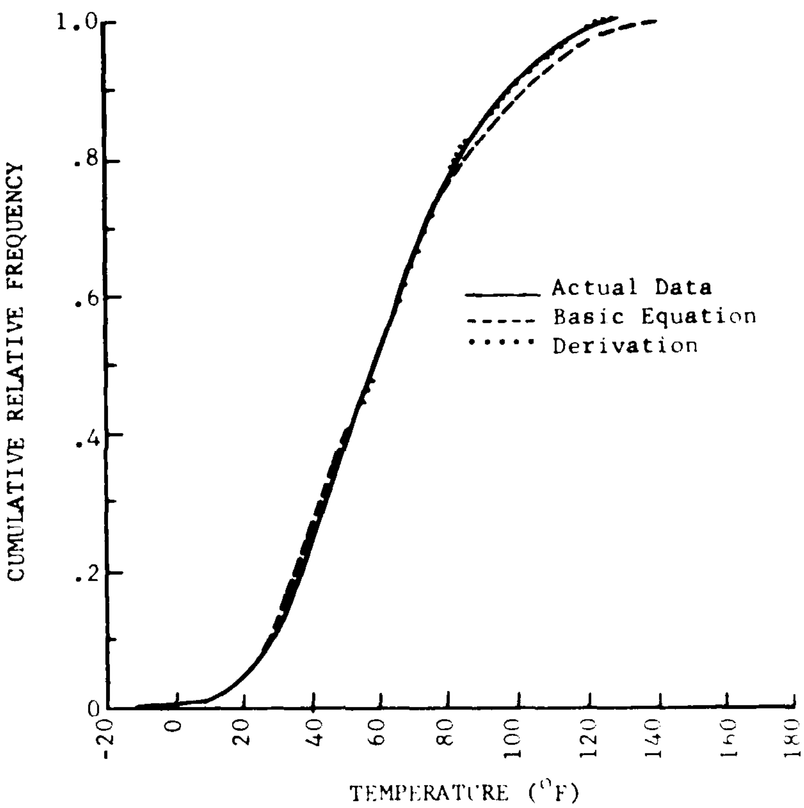

Figure 13. Frequency Distributions of Actual and Predicted Thermal Standa
Top Surface Temperatures at Fort Belvoir, Va
(16 June 1978 – 15 June 1979).

Predictive Relationships ● Two other predictive trials were performed. The first involved predicting the center daily maximum temperature when both the surface daily maximum and ambient air maximum temperatures are known. The second involved predicting the top surface maximum temperature when the center maximum and ambient air maximum temperatures are known.

The simple equation used for this process was

$$\frac{T_c - T_a}{T_s - T_a} = \text{Predictive Ratio}$$

where T_c, T_a, and T_s are yearly mean values for the thermal standard center, the ambient air, and the thermal standard top surface temperatures.

The predictive ratio at Fort Belvoir was computed at 0.587. When the actual daily maximum thermal standard surface temperatures and the daily maximum air temperatures were inserted in the formula, it was found that the center daily maximum temperature could be predicted to within 2.5F° of actual values on about 95 percent of the days. The predictive ratio at China Lake was 0.375, and the center maximum temperature was predicted to within 2F° on all but one of the days.[12] The lower predictive capability at Fort Belvoir is assumed to be weather related, i.e., cloudiness, rainfall, etc. Obtaining the top surface maximum temperature from the predictive ratio yielded a capability of estimating to within 3.5F° of actual top surface temperatures on 95 percent of the days.

The predictive techniques examined above show promise as useful tools in determinating ordnance response temperatures. Further work should stress the application of these techniques to all available thermal standard data bases to determine the nature and extent of possible geographic or climatic restrictions in their usage. Once perfected, it should be possible to create approximations of thermal standard baseline curves for any area of the world. From these approximations, the thermal response nature of ordnance and possibly other items can be estimated.

[12] Rich, E. D. Ulrich. *Evolution of the NWC Thermal Standard, Part 2, Comparison of* [illegible] *with Experiment*. NWC TP 4834, Part 2, Brigham Young University for the Naval Weapons Center, China Lake, Calif., 1971, p. 29.

DISCUSSION

The predictive equation developed by Ulrich proved to be a fair predictor of the daily top surface maximum temperature. This equation performed excellently during the cooler months and on days with low to moderate solar radiation loads, but during periods of high radiation and low windspeeds it over-predicted excessively in many instances. An empirical derivation of this basic predictive equation was examined and found to predict with great accuracy at Fort Belvoir. Predictions for China Lake, Calif., using the derivation, however, proved to be less than satisfactory. Both equations, as well as others, should be examined further to determine if there are geographic or climatic limitations to their usage, and the extent of these limitations.

The nature of the meteorological inputs into the predictive equation can present some problems. Ideally, windspeed, solar radiation, and temperature data should be gathered at the test site, as extrapolation of data from one place to another can contain uncertainty and probable error. The prediction equation is extremely sensitive to small changes in windspeed in the 2- to 5-knot range. If windspeeds cannot be gathered at the actual test site, then extreme care must be exercised during extrapolation. If the equation is being applied to an area for which no windspeed data exist, or only data in a grossly summarized form, then perhaps a series of curves should be generated. In each curve the predicted thermal values during the high-sun periods would be based on a single windspeed value (e.g. 2, 4, 6 knots).

Solar radiation data for most of the world are tenuous and sketchy, if available at all. Furthermore, the accuracy of available measurements is debatable. If solar radiation data are not obtained at the test site or available from a nearby station, then data from an analogous station or set of stations should be selected, keeping in mind any local factors that may enhance or attenuate incoming radiation at the test site (e.g., elevation, cloudiness, pollution, etc.).

Noon air temperatures, although easily available for first-order stations in the United States, are not always available from foreign sources. A reworking of the prediction equation to accept daily maximum air temperature instead of noon air temperature would remedy this situation, as the daily maximum temperature is a value that appears more frequently in published form. Another possibility would be to estimate the average diurnal time temperature cycle by climatic or geographic region. In this fashion, once the daily maximum temperature for a location was obtained the noon air temperature can be approximated fairly accurately.

CONCLUSIONS

1. The frequency curves of thermal standard top surface and center temperatures at Fort Belvoir possess a shape similar to those for China Lake, California, although they are 10°F to 20°F cooler at all points along the curves.

2. The regression equations appear to be good predictors (especially at high temperatures), but their usage is most likely limited to geographic and climatic areas similar to Fort Belvoir.

3. More research is needed on the response of NWC thermal standards in other areas of the world (e.g. Europe, the Middle East, and Korea), and a thorough analysis of the data and of the analytical methodologies should be made to determine if there is a limitation to this technique.

4. Once the prediction equation or set of equations is perfected, it will be possible to provide reliable temperature response profiles to developers, designers, and testers of materiel.

5. The results of this research indicate there is a high probability that a set of prediction equations with practical application can be developed.

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