AD-A007 676

WORLD-WIDE EXTREMES OF HUMIDITY WITH TEMPERATURES BETWEEN 85 AND 120 DEG. F

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5 December 1974

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1 REPORT NUMBER AFCRL-TR-74-0603	2 GOVT ACCESSION NO.	3 RECIPIENT'S CATALOG NUMBER AD-AC07 676
4 TITLE (and Subtitle) WORLD-WIDE EXTREMES OF HUMIDITY WITH TEMPERATURES BETWEEN 85° AND 120°F		5 TYPE OF REPORT & PERIOD COVERED Scientific. Interim. 6 PERFORMING ORG REPORT NUMBER AFSG No. 296
7 AUTHOR(s) René V. Cormier		8 CONTRACT OR GRANT NUMBER(s)
9 PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Cambridge Research Laboratories (LK) Hanscom Air Force Base Bedford, Mass. 01731		10 PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 86240205 62101F
11 CONTROLLING OFFICE NAME AND ADDRESS Air Force Cambridge Research Laboratories (LK) Hanscom Air Force Base Bedford, Mass. 01731		12 REPORT DATE 5 December 1974 13 NUMBER OF PAGES 16
14 MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15 SECURITY CLASS (of this report) Unclassified 15a DECLASSIFICATION DOWNGRADING SCHEDULE
16 DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited.		
17 DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18 SUPPLEMENTARY NOTES		

19 KEY WORDS (Continue on reverse side if necessary and identify by block number)

Climatology	Climatic extremes	Persian Gulf
Design criteria	MIL-STD-210B	Joint extremes
Humidity, high	MIL-E-38453A	Combined environments
Temperature, high	Dew point, high	Air conditioning design
Military specification	Abadan, Iran	

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

Design of certain Air Force systems intended for world-wide usage requires knowledge of the possible joint extremes of high temperatures with high humidity. Previous studies have addressed themselves to this problem, but the statistics reported therein were not presented in terms of joint occurrence frequencies. This study presents joint values of temperature (to 120°F) and dew point (to 93°F) equalled or exceeded from 0.1 to 80 percent of the time (hours) in the world's severest joint high-temperature, high-humidity environment (Abadan, Iran). These values are compared with the joint

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) high-temperature, high-humidity criteria presented in Military Specification MIL-E-38453A. This comparison indicates that the use of MIL-E-38453A can lead to overdesign at temperatures above 120°F and to underdesign at lower temperatures.

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World-Wide Extremes of Humidity With Temperatures Between 85° and 120° F

1. INTRODUCTION

The design of air conditioning systems intended for world-wide usage requires knowledge of the joint extremes of high temperature with high humidity possible in the world's hottest and most humid regions. Military Specification MIL-E-38453A[1] (Figure 1 thereof) purports such information, but its validity is not known and needs to be determined.[2]

The recently issued B revision to MIL-STD-210 contains some information on high humidity extremes with high temperature.[3] However, the information was developed so as to present extremes of high humidity with concurrent high temperature rather than the converse, and as a result, temperatures are limited to 105°F.

(Received for publication 4 December 1974)

1. Department of the Air Force (1971) Military Specification Environmental Control, Environmental Protection and Engine Bleed Air Systems, Aircraft, General Specification for MIL-E-38453A, 2 Dec. 1971, Air Force Systems Command (SDDP), Washington, D.C. 20334.

2. Dean, R.E. (1973) Coordination of 4th Revision of MIL-STD-210, U.S. Air Force Headquarters Aeronautical Systems Division (ASD/WE), Wright-Patterson Air Force Base, Ohio, letter dated 2 August 1973 to Electronic Systems Division (DRD), Hanscom Air Force Base, Bedford, Mass.

3. Department of Defense (1973) Military Standard Climatic Extremes for Military Equipment MIL-STD-210B, 15 December 1973, Standardization Division, Office of the Assistant Secretary of Defense (I&L), Washington, D.C. 20305.

This shortcoming was noted, and a study to determine joint high-temperature, high-humidity extremes for temperatures up to 120°F was recommended by one of the reviewers[2] of draft MIL-STD-210B.

Other studies have addressed themselves to the problem of high humidity and high temperature on a world-wide basis, but these investigations do not present temperature-humidity statistics in terms of joint occurrence frequencies. Salmela and Grantham[4] present humidity extremes exceeded 1, 5, 10 and 20 percent of the time with typical temperatures for the world's most humid locations. Dodd[5] presented median dew points and dew point ranges associated with temperatures of 109°F and higher at 17 locations selected primarily on the basis of high temperature. Moreover, Dodd[6] presented lowest, median, and highest temperature classes associated with dew point classes at 78 stations noted for having high dew points (greater than 76°F).

All the aforementioned studies indicate that the coastal regions surrounding the Persian Gulf, Gulf of Aden, and the Red Sea have the world's severest joint high-temperature, high-humidity environment. For instance, on 24 July 1953 at 1400 hours in Abadan, Iran, located at the head of the Persian Gulf (30°20'N, 48°18'E), it was 119°F with a dew point of 85°F! *

Unfortunately, only a limited (and certainly unrepresentative) number of stations in this area of the globe have taken hourly temperature and humidity observations for a sufficient period of time to establish reliable values of the percentage of time that high temperature and concurrent high humidity exceed a given threshold value. Of these stations, Abadan has the most extreme high-temperature, high-humidity environment.[4, 5, 6] And at Abadan, July is the most humid month. †

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*This was determined from data described in a subsequent paragraph.

† August has slightly higher maximum humidities with temperatures at and below 113°F, but median humidity values at all temperatures are considerably lower than in July.[5]

4. Salmela, H.A., and Grantham, D.D. (1972) Diurnal Cycles of High Absolute Humidity at the Earth's Surface, AFCRL-72-0587, Air Force Cambridge Research Laboratories, Hanscom Air Force Base, Bedford, Mass.

5. Dodd, A.V. (1966) Simultaneous Occurrence of High Temperature and High Dewpoints, Technical Report 66-55-ES, U.S. Army Natick Laboratories, Natick, Mass.

6. Dodd, A.V. (1969) Areal and Temporal Occurrence of High Dewpoints and Associated Temperatures, Technical Report 70-4-ES, U.S. Army Natick Laboratories, Natick, Mass.

2. METHODOLOGY AND RESULTS

A computer listing used in this study was comprised essentially of hourly temperature and humidity data (wet-bulb temperature, dew point, and relative humidity) ordered by decreasing temperature for Abadan (WMO Station 40831); the information was collected during the period 1949-1955 (2972 observations), and obtained from the U.S. Army Natick Laboratory for a previous study. From such a temperature-ordered listing, it is straightforward to determine the humidity (dew point) distributions associated with selected temperatures. The dew points associated with selected temperatures of 120°, 115°, 110°, 105°, 100°, 95°, 90°, and 85°F were ordered from smallest to largest, and plotted on probability paper using the following customary plotting rule:[7]

$$P(i) = (i - 3/8)/(N + \frac{1}{4}),$$

where in this case P(i) is the relative frequency with which the dew point associated with a selected temperature is equalled or exceeded; P(i) × 100 is the percent of time that the ith dew point is equalled or exceeded when a given temperature occurs; i is the numerical increasing sequence associated with each dew point in the dew points ordered from smallest to largest for a given temperature; and N is the number of dew point observations associated with each selected temperature T. To increase the dew point sample for the selected temperature T, dew points associated with selected temperatures ± 2°F were actually used to construct the ordered listing. For each selected temperature (±2°F), a smoothed line was drawn through the P(i) versus dew point points on the probability paper and this was used as an estimate of the true distribution. The dew points equalled or exceeded 1, 5, 10, and 20 percent of the time for each temperature (±2°F) are given in Table 1.

Table 1 includes two other measures of humidity in addition to dew point, wet-bulb temperature (T_w) determined on a log p skew T thermodynamic diagram from the temperature and the dew point assuming standard pressure (1013.2 mb), and relative humidity determined on the psychometric calculator ML-429 UM using temperature and dew point assuming standard pressure. An alternative presentation to Table 1 is given in Table 2. Here are given the relative frequencies* with which selected threshold dew points (D_t) from 45.0 to 92.5°F (in increments

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* For percent of time, multiply by 100.

7. Kimball, B.F. (1960) On the choice of plotting position on probability paper, J. Am. Stat. Assoc. 55:546-560.

Table 1. Humidities Equalled or Exceeded 1, 5, 10, and 20 Percent of the Time When Stated Temperatures (±2°F) Occur. (T_D = dew point in °F, T_w = wet-bulb temperature in °F, and RH = Relative Humidity in percent)

Temperature (± 2°F)	1 Percent			5 Percent			10 Percent			20 Percent		
	T_D	T_w	RH	T_D	T_w	RH	T_D	T_w	RH	T_D	T_w	RH
120	85	91	35	85	91	35	84	90	34	82	89	32
115	88	92	44	83	90	38	81	88	35	77	84	31
110	86	91	48	81	88	41	79	86	38	76	85	35
105	89	92	61	81	85	47	78	85	43	75	83	39
100	89	91	71	84	88	61	80	84	53	76	82	47
95	87	89	78	82	85	66	77	81	56	72	79	47
90	88	89	94	85	86	85	79	82	68	72	77	55
85	85	85	100	83	84	94	80	81	85	74	77	76

Table 2. Relative Frequencies (for percent of time, multiply by 100) with Which Selected Threshold Dew Points D_t are Equalled or Exceeded for the Different Temperature Ranges (T_i to $T_i + \delta T_i$)

T_i to $T_i + \delta T_i$ (°F)	D_t(°F)									
	45.0	47.5	50.0	52.5	55.0	57.5	60.0	62.5	65.0	67.5
118-122	.984	.970	.950	.920	.890	.850	.810	.750	.680	.610
113-117	.970	.960	.945	.925	.880	.835	.780	.710	.640	.570
108-112	.946	.918	.882	.840	.790	.740	.670	.610	.520	.440
103-107	.990	.972	.920	.870	.815	.740	.660	.570	.480	.410
98-102	.995	.992	.974	.930	.883	.825	.760	.680	.600	.510
93-97	.998	.993	.980	.940	.876	.790	.720	.640	.530	.410
88-92	.9987	.985	.870	.930	.870	.805	.720	.615	.500	.390
83-97	.9953	.993	.987	.950	.900	.850	.770	.670	.560	.420
	70.0	72.5	75.0	77.5	80.0	82.5	85.0	87.5	90.0	92.5
118-122	.550	.480	.420	.330	.240	.160	.016	0	0	0
113-117	.480	.380	.300	.190	.120	.055	.030	.013	.0002	0
108-112	.360	.280	.220	.160	.075	.032	.012	.001	.0001	0
103-107	.340	.270	.210	.140	.060	.045	.032	.023	.005	.0001
98-102	.400	.300	.220	.150	.097	.065	.036	.019	.005	.0001
93-97	.290	.190	.128	.095	.070	.045	.018	.006	.0017	.00035
88-92	.290	.130	.133	.110	.095	.080	.046	.012	.0001	0
83-87	.300	.230	.190	.150	.100	.050	.010	0	0	0

of 2.5°F) are equalled or exceeded for the different temperature ranges T_i to $(T_i + \delta T_i)$.

To determine the percentage of time that joint threshold values of high temperature (T_t) and concurrent high humidity/dewpoint (D_t) are equalled or exceeded $(T \geq T_t,\ D \geq D_t)$, one needs to determine the relative frequency,

$$P(T \geq T_t,\ D \geq D_t) = \sum_i p(\delta T_i) \cdot P(D \geq D_t \mid \delta T_i) \ , \qquad (1)$$

where T_i equals or exceeds threshold temperature T_t; $p(\delta T_i)$ is relative frequency with which the temperature (T_i) is within the range T_i to $(T_i + \delta T_i)$; and $P(D \geq D_t \mid \delta T)$ is the conditional relative frequency with which the dew point (D) equals or exceeds D_t when the temperature is within the range T_i to $(T_i + \delta T_i)$, that is, values given in Table 2.

Figure 1 shows the percentage of time that given threshold temperature (T_t) are equalled or exceeded at Abadan in July. This curve was drawn from

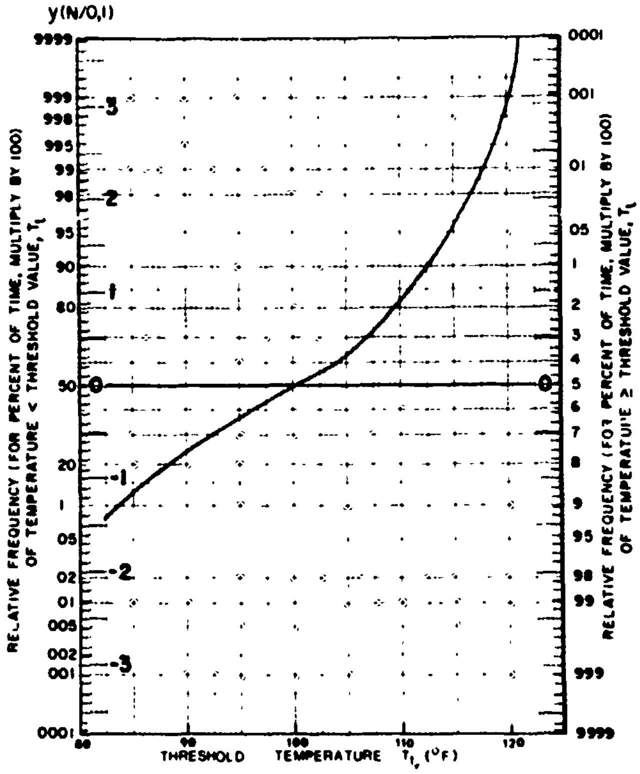

Figure 1. Relative Frequency (for percent of time, multiply by 100) of Hourly Temperatures at Abadan, Iran, in July

probabilities given by Dodd in Reference 5 for temperature 109°F and above, and in Reference 6 for temperatures below 109°F. The data used to establish these probabilities cover the same time period as the humidity data used in this study. From Figure 1, the relative frequencies with which the selected temperatures were equalled or exceeded, $P(T_i)$, were determined (see Table 3). Using this information, one can then obtain $p(\delta T_i)$, the relative frequency with which the temperature (T_i) is within the range T_i to ($T_i + \delta T_i$); this information is also given in Table 3. The relative frequencies of Table 3, $p(\delta T_i)$, are then cumulatively multiplied by the relative frequencies of each threshold dew point D_t of Table 2, $P(D \geq D_t \mid \delta T_i)$, according to Eq. (1), thereby producing Table 4. The joint relative frequencies in Table 4 were plotted on graph paper and isopleths for joint values of high temperature and high humidity equalled or exceeded from 0.1 to 80 percent of the time were drawn by interpolation. These isopleths are shown in Figure 2. The upper left-hand portion of Figure 2 has been clipped because of the physical impossibility of dew points greater than temperatures. These clipped dew points were the result of ordering the dew points by the 5° temperature ranges, as discussed previously.

It now remains to select the desired joint probability (percent of time equalled or exceeded) levels which would be useful in design and then to determine the dewpoints associated with the selected threshold temperatures for these levels from Figure 2. Recently issued MIL-STD-210B, as a result of recommendations made

Table 3. Relative Frequency with Which Selected Temperatures (T_i) are Equalled or Exceeded, $P(T_i)$, and Relative Frequency $p(\delta T_i)$ with Which Temperature (T_i) is within the Range Ti to Ti + δT_i (°F)

T_i	to	$T_i + \delta T_i$	$P(T_i)$	$p(\delta T_i)$
118	to	122	.01	.01
113	to	117	.092	.082
108	to	112	.28	.19
103	to	107	.42	.14
98	to	102	.55	.13
93	to	97	.69	.14
88	to	92	.81	.12
87	to	87	.92	.11

Table 4. Relative Joint Frequency (for percent of time, multiply by 100) with which Joint Values of High Temperature and High Dew Point Equal or Exceed Given Threshold Values: $T \geq T_t$, $D \geq D_t$

	D_t (°F)									
T_t(°F)	45.0	47.5	50.0	52.5	55.0	57.5	60.0	62.5	65.0	67.5
118	.00984	.00970	.00950	.00920	.00890	.00850	.00810	.00750	.00680	.00610
113	.089	.088	.087	.085	.081	.077	.072	.065	.059	.053
108	.267	.261	.253	.243	.230	.216	.198	.180	.157	.136
103	.406	.397	.382	.365	.344	.320	.290	.260	.224	.193
98	.535	.526	.508	.486	.458	.427	.389	.349	.302	.259
93	.675	.665	.645	.617	.581	.538	.490	.438	.376	.317
88	.795	.783	.762	.729	.686	.634	.576	.512	.436	.363
83	.904	.892	.870	.833	.785	.728	.661	.586	.498	.410
	70.0	72.5	75.0	77.5	80.0	82.5	85.0	87.5	90.0	97.5
118	.00550	.00480	.00420	.00330	.00240	.00160	.00016	0	0	0
113	.045	.036	.029	.019	.012	.0061	.0026	.0011	.000016	0
108	.113	.089	.070	.049	.026	.012	.0049	.0013	.000035	0
103	.160	.126	.100	.069	.035	.018	.0094	.0045	.00074	.000014
98	.212	.165	.128	.088	.047	.027	.014	.0069	.0014	.000027
93	.253	.192	.146	.101	.057	.033	.017	.0078	.0016	.000076
88	.288	.214	.162	.115	.069	.043	.022	.0092	.0016	.000076
83	.321	.239	.183	.131	.080	.048	.023	.0092	.0016	.000076

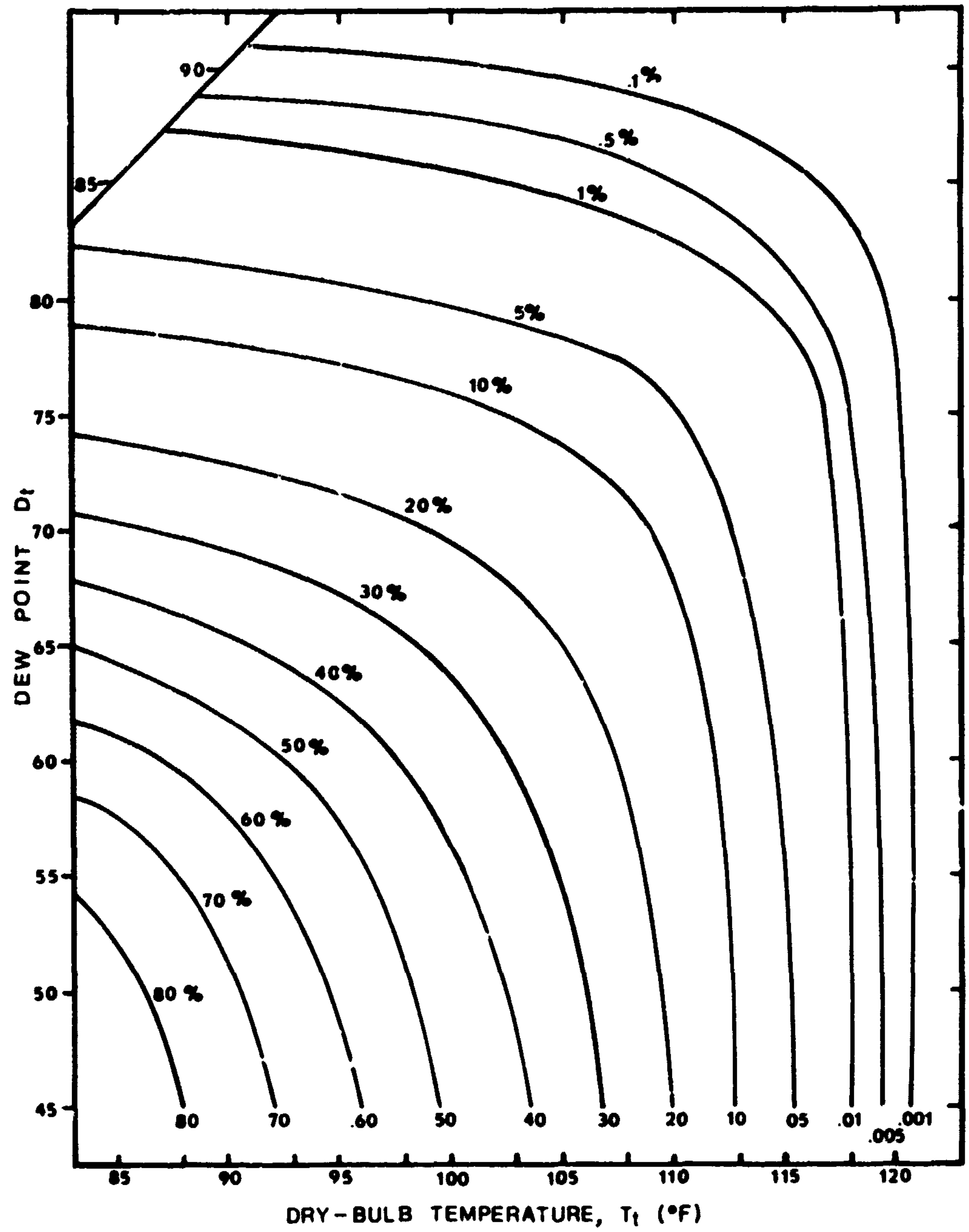

Figure 2. Joint Values of High Temperature (to 120°F) and High Humidity Which are Equalled or Exceeded 0.1, 0.5, 1, 5, 10, 20, 30, 40, 50, 60, 70, and 80 Percent of the Time (Hours) of the Most Severe Month in the World's Severest Joint High-Temperature, High-Humidity Environment

by the Joint Chiefs of Staff,[8] gives values equalled or exceeded only 1 percent of the time (hours) of the most severe month for design of most equipment.[3] However, the Joint Chiefs of Staff also stated[8] that equipment whose operational failure could endanger life should be designed so as to result in a percentage of time of inoperability which is as close to zero as practically possible. Therefore, this study presents the 1 percent of time joint high-temperature, high-humidity extremes for normal design, and the 0.1 percent joint values for more stringent designs. In addition, since it sometimes may be technologically impossible or economically not cost effective to design for the 1 percent extreme, this study also presents the 5, 10, and 20 percent joint extremes as guidance in selecting less stringent criteria. These values as well as the 0.1 and 1 percent joint are given in Table 5. At the higher temperatures, it was not always possible to establish joint values for the higher percentages because of the limiting infrequency of such conditions. Wet-bulb temperatures and relative humidities in Table 5 were determined as discussed in Section 2.

Table 5. Joint Values of High Temperature (to 120°F) and High Humidity Which are Equalled or Exceeded 0.1, 1, 5, 10, and 20 Percent of the Time (Hours) of the Most Severe Month in the World's Severest Joint High-Temperature, High-Humidity Environment (T_D = Dew Point in °F, T_W = Wet-Bulb Temperature in °F, and RH = Relative Humidity in Percent

Temperature (°F)	0.1 Percent			1 Percent			5 Percent			10 Percent			20 Percent		
	T_D	T_W	RH	T_D	T_W	RH	T_D	T_W	RH	T_D	T_W	RH	T_D	T_W	RH
120	78	87	28	+	+	+	+	+	+	+	+	+	+	+	+
115	88	93	44	81	89	35	71	82	25	+	+	+	+	+	+
110	88	92	51	82	88	42	76	84	35	68	79	27	45	69	12
105	90	93	63	84	88	52	78	84	43	74	82	37	65	76	28
100	90	92	73	86	89	65	80	84	53	76	82	47	70	78	38
95	91	92	88	87	88	77	81	84	64	77	81	56	71	77	46
90	90	90	100	87	88	91	81	84	75	78	81	68	73	78	57
85	85	85	100	85	85	100	82	83	91	79	81	82	74	77	69

+ Equalled or exceeded joint values do not occur this often.

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8. Sissenwine, N., and Cormier, R.V. (1974) Synopsis of Background Material for MIL-STD-210B, Climatic Extremes for Military Equipment, AFCRL-TR-74-0052, Air Force Cambridge Research Laboratories, Hanscom Air Force Base, Bedford, Massachusetts

3. VALIDITY OF MIL-E-38453A

As mentioned in Section 1, the validity of Figure 1 in Military Specification MIL-E-38453A needs to be determined. Figure 3 is a reproduction of the pertinent portion of Figure 1. The heavy dark two-segment line is the design envelope specified in MIL-E-38453A. The smooth curves are the 0.1, 1, 5, and 10 percent design envelopes based on the data contained in Table 5. One can see that from a dry-bulb temperature of near 85°F to near 103°F, design criteria specified by MIL-E-38453A are equalled or exceeded between approximately 1 and 5 percent of the time; from near 103° to 116°F, the criteria are equalled or exceeded between 5 and 10 percent of the time; from 116° to near 120°F, between 5 and 1 percent of the time; and beyond near 120°F, between 1 and 0.1 percent of the time. With the design philosophy promulgated in MIL-STD-210B as a basis (that is, designing equipment intended for world-wide usage to values equalled or exceeded only 1 percent of the time [hours] of the most severe month in the most severe area), the use of criteria in MIL-E-38453A leads to moderate underdesign for temperatures between 85° and 103°F, considerable underdesign between 103° and 116°F, slight underdesign between 115° and 120°F, and slight overdesign beyond 120°F.

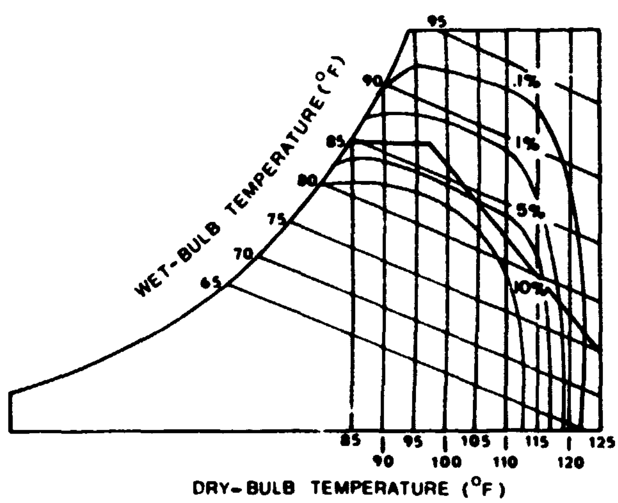

Figure 3. Reproduction of Figure 1 from MIL-E-38453A Showing Current High-Temperature, High-Humidity Envelope with Superimposed 0.1, 1, 5, and 10 Percent Design Envelopes Determined in This Study

4. RECOMMENDATIONS

Based on the foregoing, it is recommended that the curve in Figure 3 labelled 1 percent replace the design criteria currently in Figure 1 of MIL-E-38453A.

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1. Department of the Air Force (1971) Military Specification Environmental Control, Environmental Protection and Engine Bleed Air Systems, Aircraft, General Specification for MIL-E-38453A, 2 Dec. 1971, Air Force Systems Command (SDDP), Washington, D.C. 20334.
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3. Department of Defense (1973) Military Standard Climatic Extremes for Military Equipment MIL-STD-210B, 15 December 1973, Standardization Division, Office of the Assistant Secretary of Defense (I&L), Washington, D.C. 20305.
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7. Kimball, B.F. (1960) On the choice of plotting position on probability paper, J. Am. Stat. Assoc. 55:546-560.
8. Sissenwine, N., and Cormier, R.V. (1974) Synopsis of Background Material for MIL-STD-210B, Climatic Extremes for Military Equipment, AFCRL-TR-74-0052, Air Force Cambridge Research Laboratories, Hanscom Air Force Base, Bedford, Mass.