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DIURNAL CYCLES OF HIGH ABSOLUTE HUMIDITY AT THE EARTH'S SURFACE

Henry A. Salmela, et al

Air Force Cambridge Research Laboratories
L. G. Hanscom Field, Massachusetts

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Diurnal Cycles of High Absolute Humidity at the Earth's Surface

HENRY A. SALMELA
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II

Abstract

Previous studies of high humidities at the earth's surface are reviewed as an introduction for the purpose of formulating recommendations for absolute humidity extremes for MIL-STD-210B. Four typical diurnal cycles of dew point and temperature for periods of extremely humid conditions are described. Hourly data from Abadan, Iran were used as the basis for the 1 percent High Absolute Humidity Extreme for design operations. This cycle includes 24 hours of dew point equal to or greater than 84°F, 7 hours of which are 88°F. The recommended Withstanding High Absolute Humidity Extreme for MIL-STD-210B was based on data from the tropical coastline location, Belize, British Honduras. It is comprised of 30 days in which the dew point cycles between 79°F and 83°F.

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1. INTRODUCTION

Military equipment designers are well aware of the problems produced by high humidities. Near the earth's surface, the problems include corrosion, fungus and bacterial growth, electronic circuitry breakdowns, air conditioning loads, etc. Effects on humans of high humidities associated with high temperatures include heat rash and heat prostration which can result from engaging in little or negligible activity. These adverse effects of high humidities and high temperatures on both men and materials have long been recognized.

This present study and a companion study for the upper air (Grantham and Sissenwine, 1970) have been specifically designed to implement the revision of MIL-STD-210A, "Climatic Extremes for Military Equipment." The calculated risk philosophy usually applied in the derivation of MIL-STD-210B extremes for which military equipment should be designed to operate is to specify values which are exceeded 1 percent of the time in the most extreme climatic area and month. When a climatic element has a strong diurnal cycle, such 1 percent extremes are shown in a cycle with related elements. Also included in MIL-STD-210B will be extremes that must be withstood without irreversible damage even though operations are not required during their occurrence. An example of this is wind speeds

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associated with hurricanes or typhoons. The calculated risk philosophy usually applied for deriving "withstanding" criteria is to specify annual maxima which have only 10 percent probability of occurrence in the planned field life of equipment, usually 2, 5, 10 or 25 years.

These two MIL-STD-210B studies supplement other recent studies on humidity. An earlier AFCRL and ETAC report (Gringorten, et al, 1966) presents percentile distributions of humidity from the earth's surface up to a pressure altitude of 400 mb, at about 7 km. The data for this report were obtained from records of 1500 surface stations and 400 upper-air stations. Another study (Landsberg, 1964) includes world maps showing the mean vapor pressure (directly related to dew points) based on the data from 2300 stations. A third study (Dodd, 1969) gives the frequency of occurrence of high dew points and high temperatures in graphical form, and tables of joint probability of high dew points and high temperatures for many of these stations. Dodd's paper also has maps indicating the monthly variation of occurrences of high dew points for 215 stations around the world between latitudes 40°N and 40°S. However, none of these reports present absolute humidity in diurnal cycles with temperature which are based upon actual hourly observations when the 1 percent absolute humidity extreme occurs.

Two categories of equipment design problems exist which are related to high absolute humidities. First, there are problems associated with high diurnal maxima moisture content (absolute humidity, dew point or vapor pressure—all of which have a one-to-one correspondence) and with high temperature. Second, there are problems associated with nearly continuous high absolute humidity with only moderately high temperatures so that the equipment is always in nearly saturated air. The first category, high moisture content, is of primary concern in the operation of equipment. The second category, high relative humidity, is usually related to corrosion and fungus growth during long term exposure, a withstanding problem. Parallel high relative humidity cycles appear in a related U.S. Army document (Department of Army, 1969).

In natural environments, the maximum dew point cannot exceed the surface temperature of the body of water producing water vapor. A search for high sea-surface temperatures reveals that such areas are surrounded by or in close proximity to hot desert land areas. Of primary interest are the coastal regions of the Persian Gulf, Gulf of Aden, and the Red Sea. Over the Persian Gulf dew point temperatures of 86°F are exceeded 5 percent of the time (Gringorten, et al, 1966). In shallow marsh lands, such as surrounds the port of Abadan, Iran, surface water temperatures can reach about 95°F (Watt, 1967) and dew points can approach this value when the air motions are light and off the water. Other areas of possible extreme humidities are found in the Bay of Bengal and the Gulfs of Mexico and

California. Tropical areas covered by jungle canopies do not attain such high dew points (greater than 85°F) for as significant a portion of the time as t'e coastal desert areas, but they may have higher monthly mean dew points, near 0°F, because of a very small diurnal range.

2. DATA

In addition to the publications outlined above, data for this paper came from four sources: (1) microfilm of daily weather records for Dhahran, Arabia and Abadan, Iran; (2) tabulations of temperature and their associated dew points for Abadan and Bahrein, Arabia (some Abadan tabulations overlapped the microfilm tabulation); (3) tabulations of cumulative relative frequency of dew points for Bahrein and Sharjah, Arabia and for Khanpur, India (prepared for an earlier study of high humidities); and, (4) listings of observations made at 6-hour intervals at Belize, British Honduras. Table 1 provides the geographical and observational details for the data mentioned above. Most of the data were directly obtained from the Data Processing Division ETAC, U.S. Air Force, but tabulations for source (2) were obtained from the U.S. Army Natick Laboratories. They had been originally processsed by the National Climatic Center (formerly the National Weather Records Center) at Asheville, North Carolina.

3. REPRESENTATIVE HUMIDITY CYCLES

Each of the four figures described below is a composite of five days which were chosen as typical patterns of dew point and temperature cycles during periods of extreme humidity. The prerequisite for the daily cycles which make up each composite was that the dew point must have reached or exceeded 84°F. These daily cycles fell into two general patterns for each of the two selected locations—Dhahran, Arabia, and Abadan, Iran. For each general pattern, five daily cycles were then averaged into the "typical" patterns of extremely high humidities which are described below.

Figure 1 shows a composite of five 24-hour cycles of temperature and dew point for Dhahran, Arabia when the dew point is high and rather steady. For most of the diurnal cycles, the dew point ranges from 82 to 85°F except lowering to 77°F at noon local standard time (LST). There is no pronounced peak in the dew point. The associated temperature follows the typical hot climate cycle except that the range is somewhat smaller. The minimum temperature, about 86°F occurs at 0600 LST and the maximum about 104°F at 1300 LST.

Table 1. Geographical and Observational Information for Selected Stations Where High Humidities are Recorded

Station	WMO Number	Lat.	Long.	Elevation (ft msl)	Period of Record	Approx. No. Observations	Data Source
Abadan, Iran	40831	30°22'N	48°15'E	36	1949-1955	2722	Dodd 1969, plus hourly listing but not 24 per day
Dhahran, Arabia	40416	24°16'N	50°10'E	69	1952-1961	3718	Dodd 1969, plus hourly listing but not 24 per day
Bahrein, Arabia	40427	23°41'N	58°35'E	20	1949-1953	107	ETAC 1 obs/day, 1600 LST
Sharjah, Arabia	40449	25°21'N	55°23'E	6	1949-1955	88	ETAC 1 obs/day, 1600 LST
Khanpur, Pakistan	41718	28°39'N	70°41'E	297	1954-1963	620	ETAC 2 obs/day, 0800 & 1700 LST
Belize, Br. Honduras	78584	17°31'N	88°21'W	3	1953-1954	169	ETAC 0000, 0600, 1200, and 1800 LST

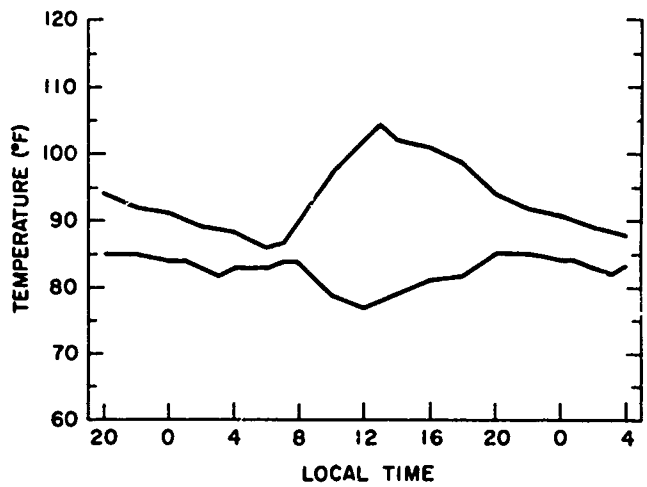

Figure 1. Composite of Five Daily Cycles of High Temperature and Dew Point for Dhahran, Iran. An example of a high, relatively steady dew point

Figure 2, also for Dhahran, shows a typical cycle when the diurnal range of dew points is large. As in Figure 1, the temperature and dew point are out-of-phase, only in this case, to a much greater extent. The temperature ranges from a minimum of 86°F at 0600 LST to a maximum of 112°F at 1400 LST. The daily mean dew point for this cycle is 79.4°F as compared to 82.0°F for the steady high dew point cycle given in Figure 1.

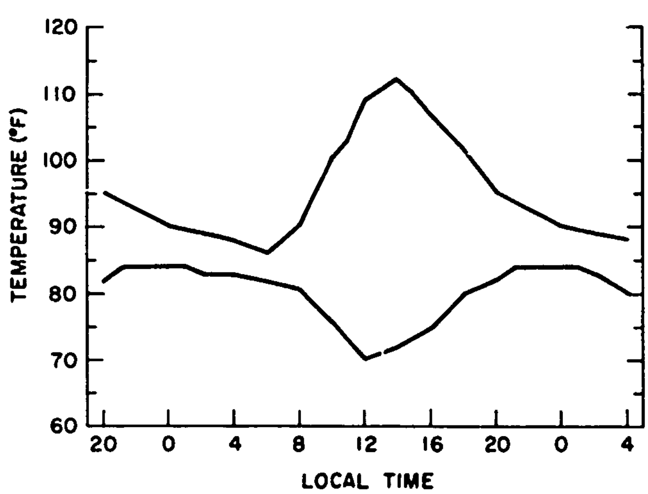

Figure 2. Composite of Five Daily Cycles of High Temperature and Dew Point for Dhahran, Iran. An example of a high, fluctuating dew-point cycle and its associated very hot temperature cycle

Figure 3 depicts a typical diurnal cycle when steady dew points are observed at Abadan, Iran. Its general shape differs from the steady, high dew-point cycle for Dhahran, mainly in that at near local noon the dew point increases slightly, whereas for Dhahran there is a slight decrease. Abadan's average dew point through the diurnal cycle is 85.3°F, higher than for Dhahran. The range of associated temperature is 87 to 106°F, but with a slightly higher maximum. The Abadan highest dew point and temperature occur somewhat later than at Dhahran, which may be the land-sea breeze effect; however, some of the difference may be due to adjusting to local time from GMT.

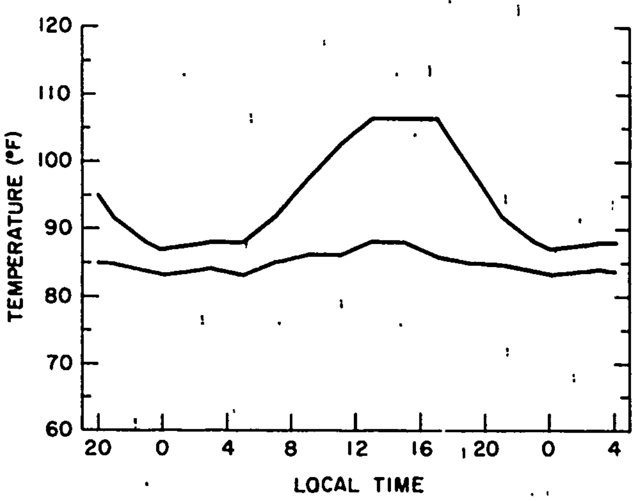

Figure 3. Composite of Five Daily Cycles of High Temperature and Dew Point for Abadan, Iran. An example of a very high, steady dew point.

A diurnal cycle depicting a wide range of both dew point and temperature for Abadan is given in Figure 4. This cycle shows a very wide daily range for both parameters, which occurs mainly with winds of a northerly (off-shore) component. Another feature of this cycle is that dew point and temperature are in phase. The range of the dew point is from 68°F at 0500 LST to 87°F at about 1600 LST. The temperature range is from 82 to 112°F, or just a little more than the analagous cycle for Dhahran.

In a study by G.A. Watt (1968), the mean diurnal variation of dry- and wet-bulb temperatures for Sharjah and Bahrein, Arabia during July, August and September for the years 1962-1966 are given in graphic form. The mean monthly dry- and wet-bulb diurnal temperatures were used to derive dew points for the two

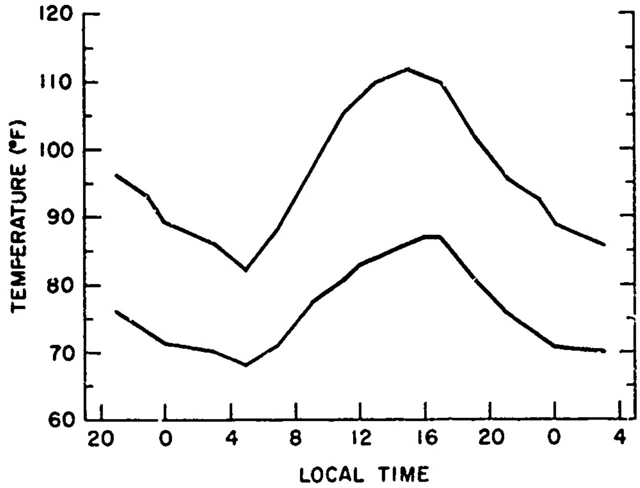

Figure 4. Composite of Five Daily Cycles of High Temperature and Dew Point for Abadan, Iran. An example of a high, fluctuating dew-point cycle and its associated very hot temperature cycle

stations for August (only slightly more humid than July). It was realized that the monthly mean dew point cannot be exactly determined from means of dry- and wet-bulb temperatures, but if the variability of the two latter parameters is small, the error in the mean dew point will also be small. The results are shown in Figure 5. The Bahrein temperature and dew point cycles are out of phase and follow closely the pattern that Dhahran had in Figure 1. This might be expected since they are geographically close. The Sharjah cycles are nearly in phase and display a greater variation with the lowest dew point occurring earlier in the day than at Bahrein.

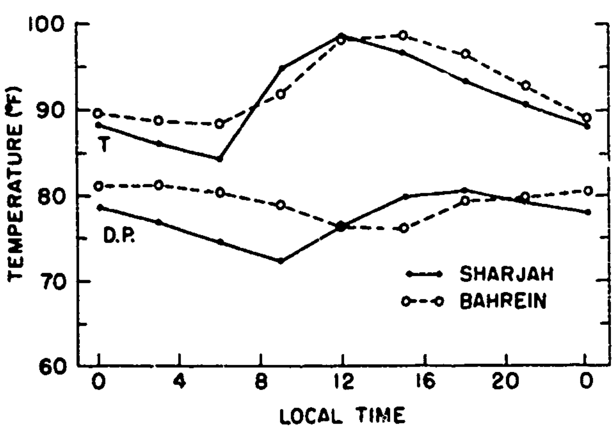

Figure 5. August Mean Monthly Dry-Bulb and Dew-Point Temperature Cycles for Sharjah and Bahrein, Arabia, Based on 1962-1966 Date (After Watt, 1968)

This section of the paper has demonstrated that patterns of the diurnal cycle of high dew point and their associated temperature vary considerably with station location and local condition. Even for coastal locations there is no set pattern which all high humidity regimes follow. For some, the dew point and temperature cycles are in phase with one another, for others, they are out of phase. There are also the cases where the dew point may be either relatively constant, or may fluctuate while the temperature follows a typical hot-climatic diurnal cycle.

4. RECOMMENDED DESIGN CRITERIA FOR MIL-STD-210B

4.1 Highest Recorded Absolute Humidity

The highest accepted absolute humidity observation, a dew point of 34°C (93.2°F), was recorded in July at Sharjah, Saudia Arabia, located on the western shore of the Persian Gulf.

In a 10-year period of twice-daily observations for Khanpur, Pakistan, a dew point of 36°C (96.9°F) was once reported during the month of August. This 36°C dew point has not been accepted for two reasons. First, neither Khanpur nor any other known location has ever observed even a 35°C dew point. Second, and more importantly, its location makes it highly unlikely to have a water source to supply such high water-vapor pressure. (Either insufficient or excessive whirling of a sling psychrometer could account for a spurious high dew point.) Khanpur is located about 300 nmi northeast of Karachi (and the Arabian Sea) in the Indus River Valley. It is about 20 nmi from the main river, but has one or two small tributaries and a canal in close proximity; however, these are not believed likely to provide the water vapor necessary to produce such extreme humidities as reported for that location, especially since Khanpur is only 10 nmi north of the Thar Desert. One source of high humidity for this region, presented by Gringortem, et al (1966), is a tongue of moisture extending from the Bay of Bengal across Northern India into West Pakistan; but the 5 percent high dew-point values in this tongue are less than those around the Persian Gulf. As a point of interest, Khanpur has recorded two 34°C dew points: one in July and another in August, and even these are hard to accept because of the reasons stated above. However, this 34°C dew-point value has been observed at Sharjah.

4.2 Operations (1 Percent Extreme and Its Diurnal Dew Point-Temperature Cycle)

The upper portion of the cumulative frequency distributions for Dhahran, Abadan, Khanpur and Sharjah data are plotted on probability scale in Figure 6. Sharjah with its one-a-day observations, near noon, has a completely different

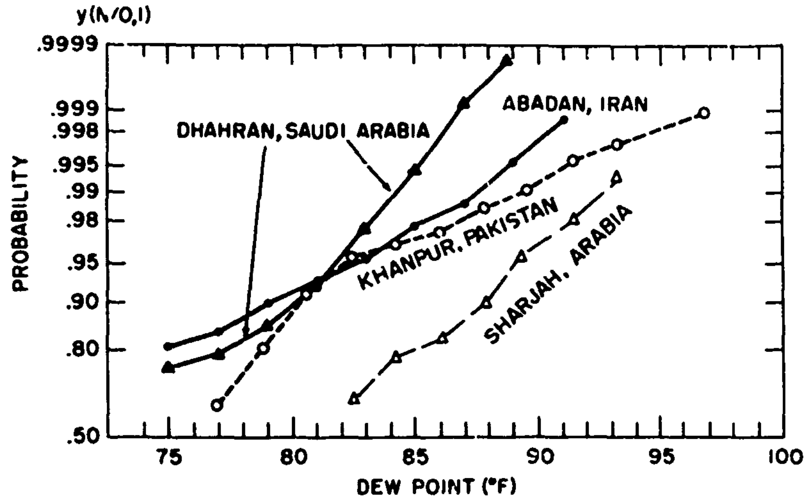

Figure 6. Cumulative Frequency Distributions (Upper Portions) for Dhahran, Abadan, Khanpur and Sharjah

distribution from the other stations. For all probabilities less than about 0.999, Sharjah shows the highest dew points; however, as outlined above this is a distribution of near-maximum, daily dew points. Khanpur shows higher dew points for probabilities greater than 0.999 but the distribution takes a peculiar bend above a 0.95 probability. This could be the result of combining the 0800 and the 1700 LST dew points where one time is near a minimum dew point and the other near a maximum. Of the two stations with hourly data, Dhahran and Abadan, Abadan has the highest dew points for probabilities greater than 0.94, but Dhahran has higher dew-point values for lesser probabilities. The 1, 5, 10 and 20 percent high extreme values derived from Figure 6 are presented in Table 2.

Table 2. Extremes of High Monthly Dew Points for Military Operations

Station	Absolute		1%		5%		10%		20%		Month
	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	
Sharjah, Arabia	34	93*	34	92	32	89	31	88	30	86	July
Abadan, Iran	33	91	31	88*	28	82	26	79	24	75	July & Aug
Belize, British Honduras	32	89	31	88	30	86*	29	84*	28	83*	Aug
Dhahran, Arabia	32	89	29	84	28	82	27	80	26	78	July & Aug
Khanpur, Pakistan	36	97	32	89	28	82	27	80	26	79	Aug

*Values to be used for design.

Grantham and Sissenwine (1970) suggested Sharjah, Arabia as having the highest world-wide 1 percent high dew point, 33.6°C (92.5°F). This extreme was based on 88 once-daily, 1200 GMT observations during the month of July for the years 1949 to 1953. However, it was later noted that the 1200 GMT (1600 local time) is near the maximum of the diurnal humidity cycle for Sharjah (Watt, 1968) as shown in Figure 5. Consequently this 33.6°C, 1 percent high dew point more nearly represents a distribution of daily maximum dew points rather than a distribution of hourly dew points and was therefore rejected. Also rejected, after much consideration, was the distribution of 620 July observations for Khanpur, West Pakistan. The Khanpur observations were taken twice daily, 0300 and 1200 GMT (0800 and 1700 LST), over the 10-year period from 1954 to 196?. The 1 percent extreme dew point for Khanpur in the most humid month, August, was 31.7°C (89°F). However, it was decided that in addition to the factors outlined in the previous section, the fact that the observations were taken at 0800 and 1700 LST would bias the upper portion of the distribution toward higher values.

A world-wide 1 percent high absolute humidity, dew point of 31°C (88°F), was determined from 2722 hourly July observations for Abadan, Iran. This was accepted as the 1 percent extreme for the most humid area and month applicable to operational extremes for MIL-STD-210B. The 5-, and 10- percentile high dew points at Abadan are 82 and 79°F (only slightly lower than those for Khanpur, as shown in Table 2). Abadan, surrounded by marshlands on the northern tip of the Persian Gulf, is ideally situated for allowing the already hot waters from the Gulf to be heated further in the shallow marshlands to provide extremely high water-vapor pressures.

A tabulation of nearly hourly July and August observations at a second Abadan location were also available for the war years 1944 and 1945. No significantly high dew points for this period of record were noted, apparently because the location was further inland. The dew point gradient near the coast is very steep, with high humidities occurring immediately along the water. Dodd (1969) states that in such desert locations the maximum dew points a few miles inland can be 20°F lower than along the coast.

The 1 percent high dew point of 88°F observed at Abadan has now been established. The equipment designer now needs to know what is the typical diurnal temperature-dew point cycle during which such an extreme will occur. Of the two high humidity cycles for Abadan described in Section 3, the first case, a constant high dew-point cycle (Figure 3) is considered more severe for the operation of equipment sensitive to absolute high humidity and temperature. The two consecutive days of 25 and 26 July 1953 are typical of this temperature-dew point cycle (see Figure 7). The temperature ranges between 87 and 105°F and the dew point

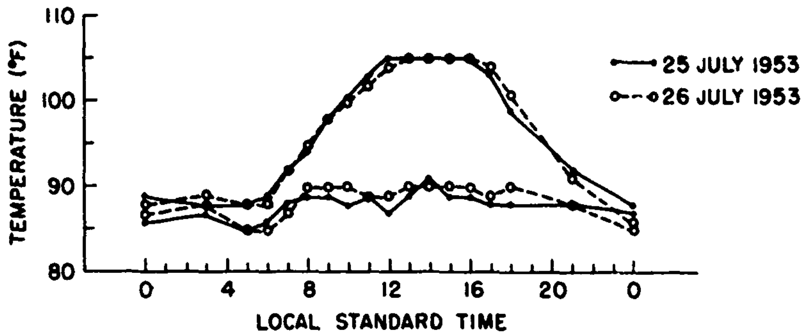

Figure 7. Hourly Temperatures and Dew Points for Two Consecutive Days of Very High Humidities at Abadan, Iran

ranges between 85 and 91°F. In the synthesized cycle (refer to Figure 8 and Table 3) the 1 percent extreme dew point of 88°F persists for seven hours (1 percent of the month). Values are 84°F or higher for the full 24-hour cycle (about 3 percent of the month), which also conforms to the dew point frequency distribution for the most humid month, July (August is almost as humid), in Abadan. Also shown in Table 3 is the resulting relative humidity cycle and the associated solar radiation cycle. The solar radiation values are from "Port High Relative Humidity Cycle–Clear Skies" (Crutcher, et al, 1970).

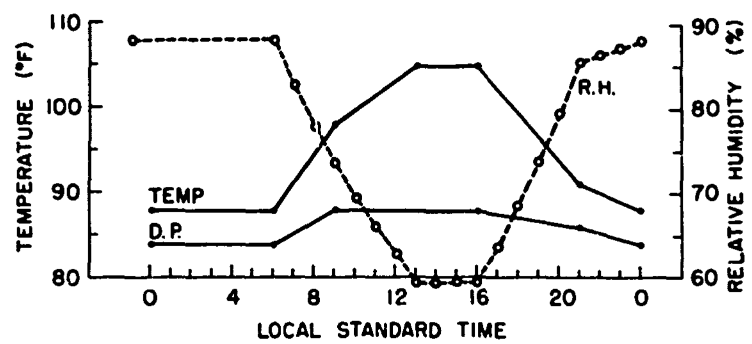

Figure 8. Diurnal Cycle of Dew Point, Temperature and Relative Humidity Associated With the 1 Percent High Absolute Humidity Operational Extreme (which is a dew point of 88° in a coastal desert location, Abadan, Iran)

The highest monthly 5, 10, and 20 percent dew points are not found in locations where the 1 percent high is located because of high fluctuations in coastal desert humidity regimes. These are found in moist tropical regions where dew points are somewhat lower but nearly constant. As shown in Table 2, the 5, 10,

Table 3. Diurnal Cycle of Dew Point, Temperature, Relative Humidity, and Solar Insolation Associated With the 1 Percent High Absolute Humidity Operational Extreme (a dew point of 88°F in a coastal desert location)

Time (LST)	Dew Point (°F)	Temperature (°F)	Relative Humidity (%)	Insolation* Btu $ft^{-2}h^{-1}$
0000-0500	84	88	88	0
0600	84	88	88	15
0700	linear	linear	83	100
0800	increase to	increase to	78	177
0900	88	98	73	251
1000	88	linear	70	302
1100	88	increase,	66	328
1200	88	to	63	343
1300	88	105	60	317
1400	88	105	60	280
1500	88	105	60	225
1600	88	105	60	147
1700			64	66
1800	linear	linear	69	4
1900	decrease to	decrease to	74	0
2000			79	0
2100	86	91	85	0
2200	linear	linear	86	0
2300	decrease to	decrease to	87	0
0000	84	88	88	0

*Solar radiation values from "Port High Relative Humidity Cycle—Clear Skies" (Crutcher, et al, 1970)

and 20 percent dew-point extremes are 30°C (86°F), 29°C (84°F), and 28°C (83°F) respectively, as determined from Belize, British Honduras data. Even the 1 percent value is as high as that for Abadan, but the temperatures are considerably less.

4.3 Withstanding Extremes

The general MIL-STD-210B philosophy for withstanding extremes for most meteorological elements has been to determine that extreme expected to occur with 10 percent risk within the projected lifetime of the equipment being designed. However, the withstanding extremes of absolute humidity present a different problem in that a one-time, short-duration occurrence of maximum humidity may not have the detrimental effect on equipment that a somewhat lower humidity would have for an extended period of exposure.

It was thought that such an extended period of extreme humidity was found for Dhahran, Arabia for the 30 days between 21 July to 19 August 1957, when dew points for 1 percent of the hours were above 87°F, 10 percent above 84 and 20 percent above 83. However, when the 30-day period was averaged for each hour, no hour of the day exceeded an 80°F dew point. Even considering medians of the hourly values, only for two hours, 2200 and 2300 LST, did the median dew point reach as high as 81.5°F. This example illustrates the fact that areas having extremely high dew points for shorter periods of time are not necessarily the same areas where equipment will have to withstand prolonged periods of sustained high dew points.

The highest sustained absolute humidities were found at Belize, British Honduras for the month of August. For the years 1953 and 1954, the average daily temperature-dew point cycle for August (based on 6-hour interval data) is shown in Figure 9. On the assumption that monthly values of temperature and dew point in the tropics will vary only slightly from year to year, the August 1953 period was synthesized to produce a 30-day Withstanding High Absolute Humidity Cycle as given in Table 4 and shown in Figure 10. Such conditions are found in coastal, moist tropical locations and are approximately duplicated for a month. Adjacent months will experience only slightly less humid extremes.

Table 4. Withstanding High Absolute Humidity (Dew Point) With Associated Temperature, Resulting Relative Humidity and Insolation

Time (LST)	Dew Point (°F)	Temperature (°F)	Relative Humidity (%)	Insolation* (Btu ft^{-2} H^{-1})
0000	80.0	83.0	91	0
0300	79.5	82.0	92	0
0600	79.0	81.0	94	15
0900	81.0	83.5	92	200
1200	83.0	86.0	91	307
1500	82.0	85.0	91	252
1800	81.0	84.0	91	73
2100	80.5	83.5	91	0

Note: Interpolate linearly between listed times.
*Solar radiation cycle estimated by using Moon (1940) for moist tropics.

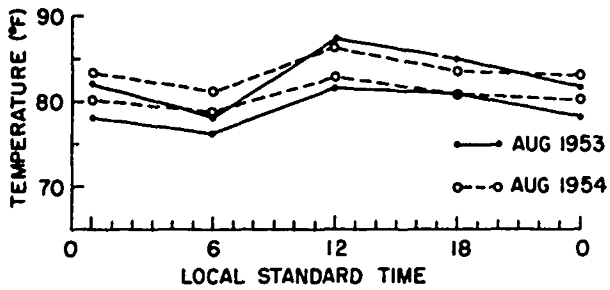

Figure 9. Average Diurnal Temperature Dew-Point Cycle (based on 6 hour interval data) for August 1953 and 1954 for Belize, British Honduras

5. SUMMARY

Four typical diurnal cycles of dew point and temperature for periods of extremely humid conditions have been described. Each pattern was a composite of five, 24-hour temperature-dew point cycles. Two typical patterns were taken from Abadan, Iran and from Dhahran, Arabia, both coastal desert locations on the Persian Gulf.

At Abadan, the dew point cycle appears to be in phase with the temperature, that is, with the maximum and minimum dew points occurring at the same time as the maximum and minimum temperatures, respectively. The first patterr shows a large amplitude humidity cycle with dew points ranging from about 68 to 87°F while temperature ranges from 82 to 112°F. The second pattern at Abadan shows a relatively small amplitude cycle with dew points ranging from 83 to 88°F and a smaller temperature range, 87 to 107°F.

At Dhahran, the dew point amplitudes are slightly less but the chief difference as compared with Abadan is that the temperature and the dew point cycles are out of phase, that is, the maximum dew point occurs at the time of minimum temperature, and vice versa.

The Abadan data were used as the basis for the 1 percent High Absolute Humidity Extreme for operational design. This is recommended for MIL-STD-210B in the synthesized cycle shown in Figure 8 and given in Table 3. This cycle includes 24 hours of dew points equal to or greater than 84°F, 7 hours of which are at 88°F.

The recommended Withstanding High Absolute Humidity Extreme for MIL-STD-210B was based on data from the tropical coastline location, Belize, British Honduras. It is comprised of 30 days in which the dew point cycles between 79 and 83°F in phase with a temperature cycle ranging from 81 to 86°F as shown in Figure 10 and given in Table 4. Such conditions are found in coastal, moist

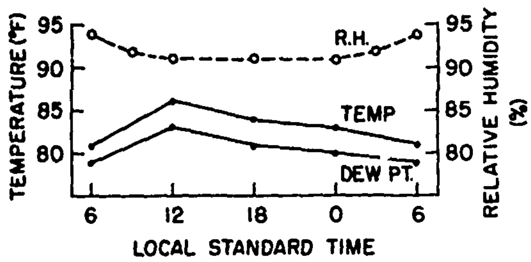

Figure 10. Withstanding High Absolute Humidity (Dew Point) With Associated Temperature, Resulting Relative Humidity and Insolation. Such conditions are found in coastal, moist tropical locations and are approximately duplicated for a month. Adjacent months will experience slightly less humid extremes

tropical locations and are approximately duplicated for a month. Adjacent months will experience only slightly less humid extremes.

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