THE HUMISERY AND OTHER MEASURES OF SUMMER DISCOMFORT

by

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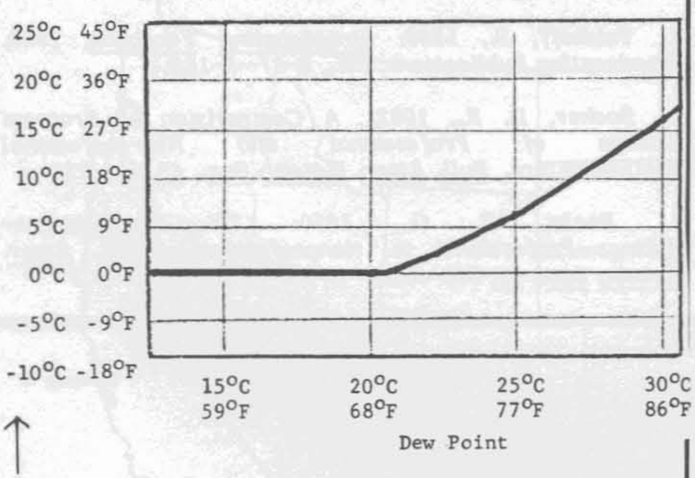
1. INTRODUCTION

Westerner: "I've been in temperatures near 100 degrees many times back home, but I've never been hotter than I am visiting your 90 degree weather."

Easterner: "It's not the heat, it's the humidity."

The Easterner in this conversation is attempting to explain the Westerner's discomfort by telling why it feels so much hotter than it is. The Easterner's explanation is fairly reasonable as far as it goes, but of course, it does not provide a measurement. How does the Westerner feel in the Easterner's weather? Suppose it is 90 degrees with a dew point of 77 degrees Fahrenheit (relative humidity, 66 percent)? Does it feel like 95°F, 100°F, 105°F?

Figure 1. Humisery Index Adjustment Due to Humidity



A number of attempts have been made to provide such an estimate similar to the way the wind chill provides an estimate of winter discomfort (see Section 3 below). Unfortunately, although the wind chill is firmly established with the public, none of the summer measures have gained anything of the wind chill's general acceptance. It is appropriate to examine the reasons for this situation.

2. WHY THE WIND CHILL INDEX WORKS

Perhaps the strongest appeal of the wind chill index is its intuitive fit with experience. When the wind chill index is -50°F, people feel cold even with heavy clothing. Another characteristic of the wind chill is its simplicity to the public. It is a number that is always lower than the temperature and is identical with the temperature at low wind speeds. A final characteristic is its use of all the factors which both prevail over populated areas and which contribute to discomfort. In this case, there are two: temperature and wind. Perhaps if any of the summer discomfort measures had the same characteristics, they would be equally acceptable to the public.

3. THE SUMMER INDICES

Various summer discomfort measures have been proposed since at least the 1920's.

Figure 2. Humisery Index Adjustment Due to Wind

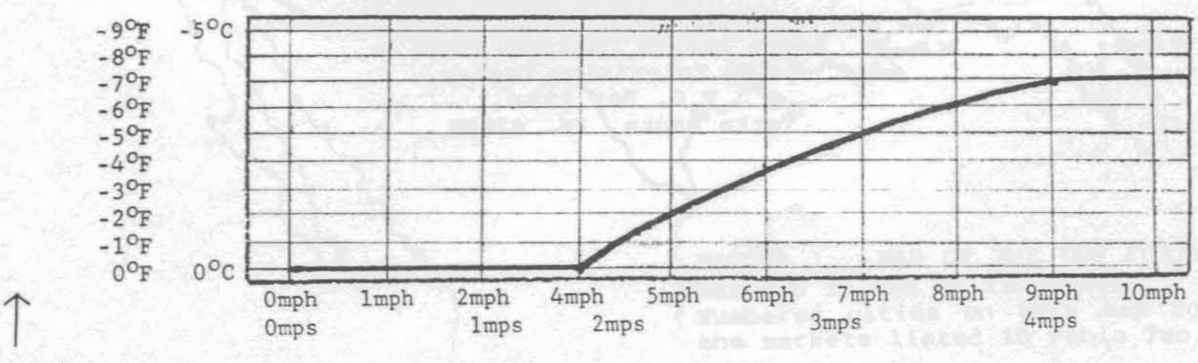
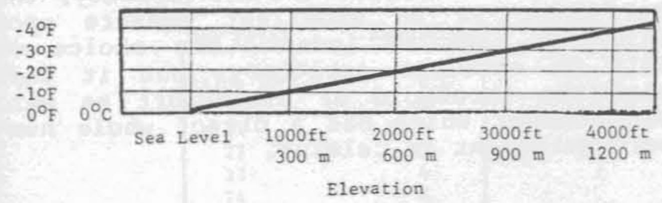


Figure 3. Humisery Index Adjustment Due to Elevation



Contribution to Humisery Index

Considering them one at a time, they are the "temperature-humidity index" (2), the "apparent temperature" (3), and the "Humiture" (4). Comparing them against the "wind chill" index standard will give some idea of their nature.

3.a The Temperature-Humidity Index

This index was the result of experiments which attempted to establish what combinations of heat and humidity gave equivalent feelings of discomfort. Perhaps the greatest barrier to acceptance is its lack of intuitive fit with experience. This index is set up such that at 70°F, few people are uncomfortable and at 80°F, nearly everybody is uncomfortable. The necessity of a double translation from index to percentage of people feeling uncomfortable to personal feeling of discomfort is a severe handicap. The index also does not consider wind or elevation. It continues to register, declining even at very low dew points, way outside the range of usefulness.

3.b The Apparent Temperature

The apparent temperature is the result of experiments and judgments about discomfort based on clothing and physiology. The index also predicts heat stress risk. The intuitive fit of this index is very good; however it does not have a base and thus the apparent temperature occasionally drops below the actual temperature.

A somewhat lesser problem is that apparent temperature is strongly based on relative humidity, a notoriously variable parameter. For example, in the case of the humid day previously noted (90°F temperature, 77°F dew point), a 1 degree decline in temperature will, at that dewpoint, cause more than a 1 percent increase in relative humidity. Because of its variability, relative humidity is considered a poor factor for use in calculating indices.

3.c The Humiture Index

This index also provides a good intuitive fit with discomfort but suffers from the same lack of basis as does the apparent temperature. Its most striking feature is its computational simplicity. One equation of humiture is that it is equal to temperature plus dew point minus 65°F (or 18° Celsius). It frequently is less than temperature, however, and perhaps more seriously, it also continues to decline even at very low dew points. Wind and elevation are not considered in this index.

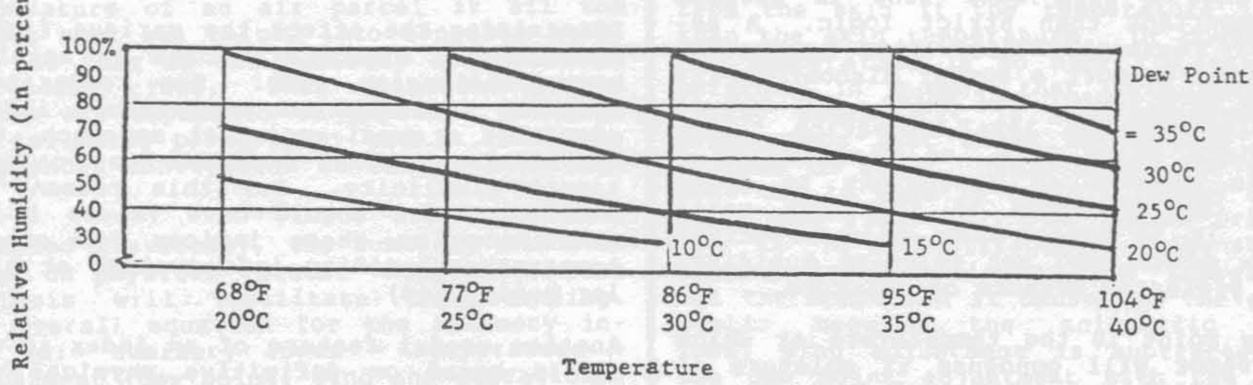
Notwithstanding these minor weaknesses, it must be admitted that each of these indices gives information about heat and humidity that is no less meaningful than the wind chill index. Indeed, it may be only a lack of a strong public education campaign that is keeping the indices out of general practice.

Nonetheless, considering in detail all the factors that make the wind chill acceptable, and applying them to the summer discomfort index, we should be able to produce a better notion of what an acceptable summer discomfort index should be like. I shall call this newly developed product the humisery index.

4. A NEW SUMMER INDEX - HUMISERY

Intuitively, a summer discomfort index should be in the 80s, 90s and 100s as people get more and more uncomfortable (when

Figure 4. Relationship of Temperature, Dew Point and Relative Humidity

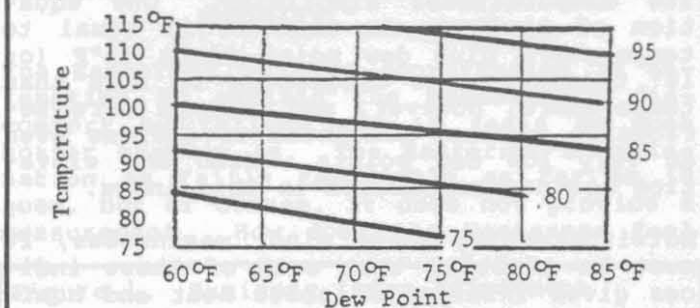


Note: Valid at 1000mb only, but relatively close at 950 mb.

working within the Fahrenheit scale). The index should also be higher as the air becomes more humid, stagnant or thicker (the last with lower elevation). Although shade conditions, clothing, pollution, physiology, and physical activity also influence discomfort, such factors vary so widely between individuals and within short distances that they cannot be used in an index.

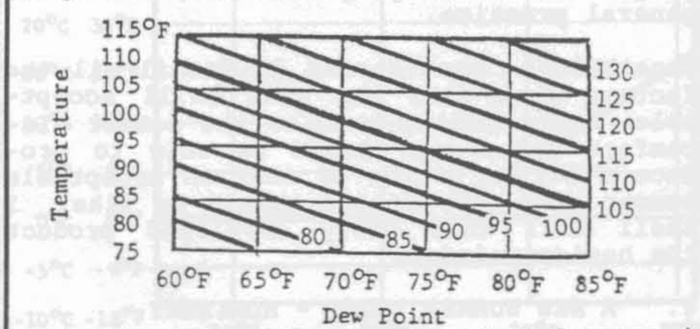
Determining a good base for a summer discomfort index must, of necessity be somewhat arbitrary or judgmental. The wind chill uses a 4 mph wind speed as its base, for example. Since 4 mph is a reasonable

Figure 5. Discomfort (Temperature-Humidity)



Note: Using dew point equation in Reference 2

Figure 6. Humiture



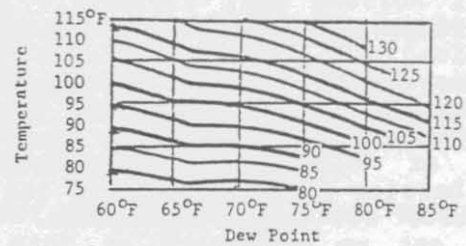
Note: From dew point equation in Reference 4.

brisk walking speed, then logically the wind chill index should actually be warmer than the air temperature when the wind is under 4 mph. The fact that it is not shows that a firm base line is perhaps more important than strict logic. A series of reasonable base line parameters that would support a summer discomfort index are 68°F (20°C) dew point, a 4 mph (2 mps) wind and sea level elevation. Thus dew points below 68°F, or winds below 4 mph are treated as equivalent to these values, as explained in the next paragraph. It is useful once more to stress why dew point, and not relative humidity, is the preferred measure of moisture.

The dew point is the temperature at which water vapor will condense if moisture is neither added nor subtracted during cooling. Over the course of a summer day, the dew point is unlikely to change much except in the unusual case of a swift frontal passage. Because of its stability, the dew point is an excellent measure upon which to base an index. The choice of 68°F is somewhat arbitrary, but it does seem the threshold of discomfort as well as a number which has a direct whole number equivalent in Celsius.

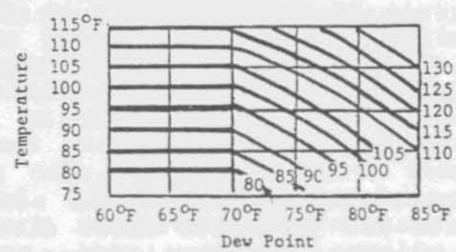
The 4 mph wind choice parallels the wind chill index wind speed base. The sea level elevation choice is defined on the basis that much of the population worldwide lives fairly close to that level.

Figure 7. Apparent Temperature



Base on Figure 1 of Reference 3 and interpolation and conversion to dew point valid at sea level and 5.6 mph wind.

Figure 8. Humisery



From Figure 1-3 of this paper, valid at sea level and 5.6 mph wind.

Now that the base line of the humisery index has been chosen, the next matter is to detail the effects of conditions that represent more discomfort than the base lines.

Determining the effect the various factors have on the discomfort index is surely a most challenging task. The temperature-humidity and apparent temperature indices represent a quasi-empirical approach, with the humiture being modified for calculational simplicity. For this reason, the humisery index should have values in the same range as these indices (or similar temperature-humidity index values at similar humiseries).

Another useful feature of an index is that it is based on definitive physical values. A reasonable relation can be made to the rise in equivalent temperature (the

Table 1A. Moisture Adjustment (°C) to Humisery Based on Dew Point.

Dew Point	Adjustment
Below 20°C	0°C
20	0
21	1
22	3
23	4
24	6
25	7

Dew Point	Adjustment
26°C	9°C
27	11
28	13
29	14
30	16
31	18

Dew Point	Adjustment
Below 68°F	0°F
68	0
69	1
70	3
71	4
72	6
73	7
74	9
75	11
76	12

Dew Point	Adjustment
77°F	14°F
78	16
79	18
80	19
81	21
82	23
83	25
84	27
85	28
86	30

Table 1B. Moisture Adjustment (°F) to Humidity Based on Dew Point.

temperature of an air parcel if all the latent heat was turned into sensible heat) and the rise in the humisery index as the dew point rises. This relationship and others are explained in physical terms in the following paragraphs, and in the humisery index conversions in Tables 1 through 4.

As noted previously, the humisery index is based on physical values. Hopefully, such a basis will facilitate understanding. The overall equation for the humisery index is: Humisery index = temperature + adjustment (dew point, wind and elevation).

The adjustments are determined as follows:

At dew points above 68°F, (20°C), the dew point adjustment increases at 40 percent the rate that the equivalent temperature increases (see Figure 1). Obviously, one can call this a clumsy, reconciling assumption, even arbitrary. True, a judgment has been made. The alternative, however, is the huge expense of equipping laboratories, hiring experimental subjects, duplicating an enormous number of environmental conditions and normalizing extraneous factors. Frankly, it would stretch the bounds of credibility if one claimed success in this endeavor. Indeed, the apparent temperature and humiture index make no such claim, although vague reference to 'clothing science' etc., intrude there, too.

The clumsy compromise of 40 percent is based, however, on a number of physical arguments. The main argument has to do with evaporation. Evaporation of perspiration is believed to be the main mechanism by which the human body rids itself of heat during the summer. For example, high relative humidity is considered a primary inhibitor of evaporation. On the other hand, at lower temperatures, even very high relative humidities do not increase the feeling of heat very much. In fact, because water is such a good heat conductor, loss of heat at low temperatures becomes accelerated at high humidities. This is why hiking in the rain can produce hypothermia even at temperatures tens of degrees above freezing.

Obviously, the wind is an equally difficult factor to consider in the adjustment. The mechanism by which wind cools a body in summer is much different from the wind cooling mechanism in winter. The summer mechanism is the action of carrying away air molecules from the skin as they become saturated with water vapor due to body perspiration. The more wind, the more fresh unsaturated air is brought near the skin, thus increasing the rate of evaporation and cooling. Even without evaporation, the wind carries away heat from the skin if the temperature is less than the skin temperature. Of course, the air temperature is so near the skin temperature in summer that this effect is fairly small. It is the enhancement of evaporation that makes any breeze at all welcome on a hot, humid day. The adjustment due to wind is again a clumsy compromise (see Figure 2). As stated previously, it is scientifically reasonable to have a lower humisery than temperature, but the confusion it causes to the general public negates the scientific value. Thus, wind adjustment is subtracted from the dew point adjustment with the condition that remainders less than zero are set at zero.

Table 2A

Moisture Adjustment (°C) to Humisery Based on Relative Humidity

Temperature (Centigrade)	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
45°C	0°C	6°C	9°C	12°C	-	-	-	-	-	-	-	-	-	-	-	-
42	0	2	6	9	12°C	15°C	16°C	-	-	-	-	-	-	-	-	-
39	0	0	2	6	8	11	14	16°C	-	-	-	-	-	-	-	-
36	0	0	0	1	4	7	9	11	14°C	16°C	-	-	-	-	-	-
33	0	0	0	0	0	3	4	7	9	11	13°C	16°C	-	-	-	-
30	0	0	0	0	0	0	1	3	5	7	9	11	13°C	14°C	15°C	16°
27	0	0	0	0	0	0	0	0	0	2	5	6	8	9	10	11
24	0	0	0	0	0	0	0	0	0	0	0	1	3	4	5	6
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Relative Humidity (in percent)

Table 2B

Moisture Adjustment (°F) to Humisery Based on Relative Humidity

Moisture Adjustment (in Degrees Fahrenheit) to Humisery Based on Relative Humidity

Temperature (Fahrenheit)	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
115°F	2°F	8°F	15°F	22°F	-	-	-	-	-	-	-	-	-	-	-	-
110	0	4	11	18	24°F	-	-	-	-	-	-	-	-	-	-	-
105	0	0	6	14	20	25°F	30°F	-	-	-	-	-	-	-	-	-
100	0	0	1	6	11	14	21	26°F	30°F	-	-	-	-	-	-	-
95	0	0	0	0	4	8	14	18	22	27°F	30°F	-	-	-	-	-
90	0	0	0	0	0	2	6	10	14	18	22	25°F	29°F	-	-	-
85	0	0	0	0	0	0	0	3	6	10	14	18	20	23°F	25°F	29°
80	0	0	0	0	0	0	0	0	0	2	5	10	13	15	17	19
75	0	0	0	0	0	0	0	0	0	0	0	1	4	6	8	10

Relative Humidity (in percent)

Elevation is the last factor to be considered in the adjustment. It is not nearly as important as the other factors since most people live fairly near sea level, but it does make a difference. At high elevation (and low pressure) there are fewer molecules near a water surface; thus, there is less chance of condensation of vapor to replenish the water molecules lost to evaporation. In a near vacuum, vapor would rapidly disperse from around a water droplet and never condense back. It is partly this tendency to avoid the water stage that allows snow at high elevations to retain its powdery nature while snow at lower elevations gets packed more quickly (5).

Table 3A

Wind Adjustment to Humisery

Wind Speed (metres/second)	Adjustment
0 mps	0°C
1	0
2	0
3	-2
4	-3
5 or greater	-4

Table 3B

Wind Adjustment to Humisery

Wind Speed Miles/Hour	Adjustment
Under 4 mph	0°F
4	0
5	-2
6	-4
7	-5
8	-6
9	-7
10 mph or more	-7

Table 4A

Elevation Adjustment to Humisery

Elevation	Adjustment
Sea Level	0°C
300 metres	-1
600 metres	-1
900 metres	-2
1200 metres	-2
1500 metres	-3

Table 4B

Elevation Adjustment to Humisery

Elevation	Adjustment
Sea Level	0°F
1000 feet	-1
2000 feet	-2
3000 feet	-3
4000 feet	-4
5000 feet	-5

Table 5

Comparison of Summer Discomfort Indices

Narrative	Temp. °F	Dew Point °F	Relative Humidity	Temp. Humidity	Apparent Temp.	Humiture	Humisery
WARM	80						
Very Dry		50°F	35%	72	79	65	80
Dry		60	50	74	81	75	80
Humid		70	70	76	85	85	85
Very Humid		80	100	80	91	95	96
HOT	90						
Very Dry		50	26	77	88	75	90
Dry		60	36	79	91	85	90
Humid		70	50	81	96	95	95
Very Humid		80	70	85	106	105	106
VERY HOT	100						
Very Dry		50	18	81	98	85	100
Dry		60	26	83	102	95	100
Humid		70	34	85	106	105	105
Very Humid		80	52	89	115	115	116
Westerner's Visit East	90	77	66	84	103	102	101

Notes: Temperature Humidity Index from relative humidity equation (See Reference 2).
Apparent temperature from Figure 1 of Reference 3, assumes sea level and 5.6 mph.
Humiture from dew point equation of Reference 11.
Humisery from Tables 1-4B, sea level 5.6 mph.

The adjustment to elevation (Figure 3) is hence a very modest one. Once again, since the humisery is never lower than temperature, the elevation adjustment is subtracted from the dew point (or dew point minus wind) adjustment with the condition that remainders less than zero are set to zero.

For example, if the dew point adjustment were 10, the wind adjustment -5 and the elevation adjustment were -1, the total adjustment would be 10 - 6 = 4. In the case of a dew point adjustment of 4 and the wind and elevation adjustments as before, the total adjustment would be 4 - 6 = -2, set to 0.

Although the dew point is a better index of moisture than relative humidity because of smaller variability, it is not a value the public knows. See the chart in Figure 4 for conversion of temperature and relative humidity into dew point.

5. COMPARISON OF INDICES

To see how the various summer discomfort indices compare, a tabular comparison is useful. Table 5 shows how the different indices change on days ranging from warm to very hot and from very dry to very humid.

A number of notes on Table 5 are necessary. For one thing, it is given in the Fahrenheit scale (6). In addition, a wind speed (5.6 mph) and elevation (sea level) must be assumed to calculate the apparent temperature and humisery. The other two indices are, as explained before, not influenced by these factors. Table 5 does, however, illustrate the fact that the Humisery Index does not continue to decrease under very dry conditions (the others do) while it increases with very humid conditions at roughly the same rate as apparent temperature and humidity.

Table 6

Comparative Mean July - August Humiseries

	July	August
SOUTHEAST (most uncomfortable)		
Port Arthur, TX	91	94
Corpus Christi, TX	91	93
Houston, TX	87	94
Victoria, TX	89	91
Lake Charles, LA	90	90
Apalachiola, FL	87	90
New Orleans, LA	88	89
Key West, FL	88	89
Shreveport, LA	88	88
Tallahassee, FL	86	89
SOUTHEAST (other large cities)		
Atlanta, GA	78	77
Memphis, TN	82	80
Miami, FL	84	87
Dallas, TX	85	86
WEST & SOUTHWEST		
Yuma, AZ	94	93
Las Vegas, NV	89	87
Bakersfield, CA	84	82
Honolulu, HI	80	81
OTHERS (East, Midwest, PR)		
Kansas City, MO	77	77
St. Louis, MO	79	77
San Juan, PR	81	81
Newark, NJ	76	75
Washington (Natl) DC	79	77

Generally speaking, the tendency of the humiture index to continue to decrease with lower and lower dew point is shown by Table 5. Also pronounced is the tendency of the 'apparent temperature' to exceed the other indices in very hot conditions while just barely continuing to decrease with low dew points. The most obvious point of Table 5 is that the humisery does not decrease with dew point reduction from 60°F to 50°F. For this reason, the humisery is only slightly lower in very hot and dry conditions (which might be thought of as the Westerner's native climate) than it is in the Eastern humidity. The other indices show greater differences between the Western and Eastern condition. This weakness of the humisery index is necessary in order to retain the "never lower than temperature" characteristic.

The graphic differences between the indices are shown in Figures 5 through 8. Each figure shows how the index varies with temperature and dew point. An inspection shows that the temperature-humidity and humiture index bears a distinctly linear relationship to dew point. The apparent temperature relationship to dew point is nonlinear. It is also irregular in that its slope increases and decreases with increasing dew points. This observation is caused by the fact that the index itself is based on relative humidity. On a similar chart, with a horizontal axis of relative humidity, the relationship would be nonlinear but regular. The humisery index is also nonlinear in its relationship to dew point and temperature (above 68°F dew point) but is regular with the slope changing in a smooth manner. The effect of the baseline dew point on humisery is also obvious in the graph.

One additional observation is that the two more empirical indices (temperature-humidity and apparent temperature) seem to differ from each other as much as the indices based on physical reasoning (humiture and humisery).

6. CLIMATIC FACTORS

A climatology based on humisery rather than temperature provides some interesting insights into the interaction of temperature and other variables as they account for summer discomfort. The July mean temperature and humisery and August mean temperature and humisery are shown in Figures 9 and 10, respectively (7). These figures show only the Southeast since elsewhere