Vantage Pro Technical Reference

Davis Instruments
3465 Diablo Ave.
Hayward, CA 94545
Created: 9/11/01

Calculations of Derived Variables

The following parameters do not have any sensors or circuitry. They are calculated from measured variables. Any conditions that affect the functions of the measurements that are used to calculate these variables will affect the readings of these variables. This includes the Setup Screen settings.

Note: In each case unless otherwise noted, the software uses the exact formula and the console uses a lookup table that closely approximates the formula.

Wind Chill

Parameters Used: Outside Air Temperature and Wind Speed

What is it:
Wind chill takes into account how the speed of the wind affects our perception of the air temperature. Our bodies warm the surrounding air molecules by transferring heat from the skin. If there's no air movement, this insulating layer of warm air molecules stays next to the body and offers some protection from cooler air molecules. However, wind sweeps that comfy warm air surrounding the body away. The faster the wind blows, the faster heat is carried away and the colder the environment feels.

The new formula was adopted by both Environment Canada and the U.S. National Weather Service to ensure a uniform wind chill standard in North America. The formula is supposed to more closely emulate the response of the human body when exposed to conditions of wind and cold than the old formula did.

Formulas:
Older versions of software (Versions 5.0 and earlier) and firmware (Vantage firmware revisions before Sept. 7, 2001 and all non-Vantage products including Echo) are based on the following formula (Siple and Passel, 1945):

$$0.0817 * (3.71V^{0.5} + 5.81 – 0.25V) * (T – 91.4) + 91.4$$

where V is the wind speed in mph and T is the outside air temperature in °F. Wind speeds above 55 mph are set to 55 mph. For wind speeds below 5 mph or temperatures above 91.4°F, the wind chill is set equal to the air temperature.

Newer product revisions (WeatherLink version 5.1 and Vantage Pro consoles with Sept 7, 2001 firmware and later) are based on the following formula:

$$35.74 + 0.6215T - 35.75 * (V^{0.16}) + 0.4275T * (V^{0.16})$$

As with the old formula, any place where the result yields a wind chill temperature greater than the air temperature, the wind chill is set equal to the air temperature. This always occurs at wind speeds of 0 mph or temperatures above 76°F. This also occurs at lower wind speeds with temperatures between 0°F and 76°F.

The new formula takes into account the fact that wind speeds are measured "officially" at 10 meters (33 feet) above the ground, but the human is typically only 5 to 6 feet (2 meters) above the ground. So, anemometers still need to be mounted as high as possible (e.g., rooftop mast) to register comparable wind speed readings and wind chill values.

The Vantage Pro console uses the "10-minute average wind speed" to determine wind chill, which is updated once per minute. When 10-minute of wind speed data is unavailable, it uses a running average until 10-minutes worth of data is collected. The Vantage Pro software uses the 10-minute average wind speed also. If it is unavailable, it uses the current wind speed (which updates every 2.5 to 3 seconds). All other products use the current wind speed to determine wind chill.

The reason an average wind speed is employed in the Vantage Pro to calculate wind chill is as follows: The human body has a high heat capacity, thus high wind speeds have no effect on the body's thermal equilibrium. So, an average wind speed provides a more accurate representation of the body's response than an instantaneous reading. Also, "official" weather reports (from which wind chill is calculated) provide average wind speed, so using an average wind speed more closely matches the results that are seen in weather reports.

REFERENCES

"Media Guide to NWS Products and Services", National Weather Service Forecast Office, Monterey, CA, 1995.

"New Wind Chill Temperature Index", Office of Climate, Water and Weather Services, Washington, DC, 2001.

Siple, P. and C. Passel, 1945. Measurements of Dry Atmospheric Cooling in Subfreezing Temperatures. *Proc. Amer. Philos. Soc.*

Heat Index

Parameters Used: Outside Air Temperature and Outside Humidity

What is it:
Heat Index uses temperature and relative humidity to determine how hot the air actually "feels." When humidity is low, the apparent temperature will be lower than the air temperature, since perspiration evaporates rapidly to cool the body. However, when humidity is high (i.e., the air is saturated with water vapor) the apparent temperature "feels" higher than the actual air temperature, because perspiration evaporates more slowly.

Formulas:
Older versions of software and the display console using the following methodology. This formula is based upon the lookup table presented by Steadman (1979). The Davis implementation simply extends the range of use of this table to make it usable at temperatures beyond the scope of the table. Some of this extension is based on the table adapted by the US National Weather Service. The GroWeather and EnviroMonitor systems do not display a value beyond the scope of the Steadman table. All other products that display this value either:

- Set values at temperatures below the scope of the table to the air temperature
- Extend the readings using a best-curve fit above and below the air temperature scope of the table. The low temperature cutoff is when the heat index for the given combination of temperature and humidity is 14°C or 57.2°F or below. This corresponds to a vapor pressure of 16 hPa. Heat Indices are set equal to the air temperature or 57.2°F, whichever is less, below these values. (The 14°C cutoff corresponds to the equivalent dewpoint at average testing laboratory conditions.)

WeatherLink software version 5.2 uses the above methodology with the following exceptions for values below an air temperature of 68°F:

- The values use a variable baseline to which the Heat Index is either above or below the air temperature.
- The values are loosely derived from the methodology outlined by Steadman in his 1998 paper (referenced below). Thus, air temperatures below 50°F follow this 1998 procedure. Air temperatures above 68°F follow his procedure outlined in 1979 (since the US NWS continues to use this). Davis has made a smooth transition between the two methods between 50°F and 68°F.

The formula Davis uses is also used by the US National Weather Service. Heat Index can also be used to determine indoor comfort levels.

The following table is used for the software. The console table only differs in that whole degrees are used for memory space conservation. Blank spaces indicate where the value is undetermined. Filler numbers have been substituted in some cases to indicate that the Heat Index is very high at these values.

Note: Heat Index has also been referred to as "Temperature-Humidity Index" and "Thermal Index" in some Davis products.

Heat Index Console Table

Air Temp (ºF)	Relative Humidity % 0	10	20	30	40	50	60	70	80	90	100
57	57	57	57	57	57	57	57	57	57	57	57
58	57	57	57	57	57	57	57	57	57	57	58
59	57	57	57	57	57	57	57	57	57	58	59
60	57	57	57	57	57	57	57	58	59	59	60
61	57	57	57	57	57	57	58	59	60	60	61
62	57	57	57	57	58	58	59	60	61	62	62
63	57	57	57	58	59	60	60	61	62	63	64
64	57	57	58	59	60	61	61	62	63	64	65
65	58	58	59	60	61	62	63	63	64	65	66
66	59	60	60	61	62	63	64	65	66	66	67
67	60	61	62	62	63	64	65	66	67	68	68
68	61	63	63	64	66	66	68	68	70	70	70
69	63	64	65	65	67	67	69	69	71	71	72
70	65	65	66	66	68	68	70	70	72	72	74
71	66	66	67	67	69	69	71	71	73	73	75
72	67	67	68	69	70	71	72	72	74	74	76
73	68	68	69	71	71	73	73	74	75	75	77
74	69	69	70	72	72	74	74	76	76	76	78
75	70	71	71	73	73	75	75	77	77	78	79
76	71	72	73	74	74	76	76	78	79	80	80
77	72	73	75	75	75	77	77	79	81	81	82
78	74	74	76	76	77	78	79	80	82	83	84
79	75	75	77	77	79	79	81	81	83	85	87
80	76	76	78	78	80	80	82	83	85	87	90
81	77	77	79	79	81	81	83	85	87	89	93
82	78	78	80	80	82	83	84	87	89	92	96
83	79	79	81	81	83	85	85	89	91	95	99
84	79	80	81	82	84	86	87	91	94	98	103
85	80	81	81	83	85	87	89	93	97	101	108
86	81	82	82	84	86	88	91	95	99	104	113
87	82	83	83	85	87	90	93	97	102	109	120
88	83	84	84	86	88	92	95	99	105	114	131
89	84	84	85	87	90	94	97	102	109	120	144
90	84	85	86	89	92	95	99	105	113	128	146
91	84	86	87	91	93	96	101	108	118	136	
92	85	87	88	92	94	98	104	112	124	144	
93	86	88	89	93	96	100	107	116	130	143	
94	87	89	90	94	98	102	110	120	137		
95	88	90	91	95	99	104	113	124	142		
96	89	91	93	97	101	107	117	128			
97	90	92	95	99	103	110	121	132			
98	90	93	96	100	105	113	125	137			
99	90	94	97	101	107	116	129	140			
100	91	95	98	103	110	119	133	145			
101	92	96	99	105	112	122	137				
102	93	97	100	106	114	125	142				
103	94	98	102	107	117	128	148				
104	95	99	104	109	120	132	153				
105	95	100	105	111	123	136					
106	95	101	106	113	126	139					
107	96	102	107	115	130	143					
108	97	103	108	117	133	146					
109	98	104	110	119	137						
110	99	105	112	122	142						
111	100	106	113	125	147						
112	100	107	115	128	153						
113	100	108	117	131	158						
114	101	109	119	134							
115	102	110	121	136							
116	103	111	123	140							

Air Temp (ºF)	Relative Humidity % 0	10	20	30	40	50	60	70	80	90	100
117	104	112	125	143							
118	105	113	127	146							
119	106	114	129	150							
120	107	116	131	154							
121	108	117	132								
122	108	118	134								
123	108	120	136								
124	110	122	138								
125	111	123	139								
126	112	125	140								
127	113	126	142								
128	115	128	144								
129	116	129	145								
130	117	131	147								
131	118	133									
132	118	134									
133	119	136									
134	119	137									
135	120	139									
136	121	141									
137	122	143									
138	123	146									
139	124	148									
140	125	151									

Heat Index Software Table

Air	Relative Humidity %																				
Temp (°F)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
-57	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0	-57.0
-56	-56.1	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0	-56.0
-55	-55.1	-55.1	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0	-55.0
-54	-54.1	-54.1	-54.1	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0	-54.0
-53	-53.1	-53.1	-53.1	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0	-53.0
-52	-52.1	-52.1	-52.1	-52.1	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0	-52.0
-51	-51.1	-51.1	-51.1	-51.1	-51.1	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0	-51.0
-50	-50.1	-50.1	-50.1	-50.1	-50.1	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0	-50.0
-49	-49.1	-49.1	-49.1	-49.1	-49.1	-49.1	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0
-48	-48.1	-48.1	-48.1	-48.1	-48.1	-48.1	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0	-48.0
-47	-47.1	-47.1	-47.1	-47.1	-47.1	-47.1	-47.1	-47.0	-47.0	-47.0	-47.0	-47.0	-47.0	-47.0	-47.0	-47.0	-47.0	-47.0	-47.0	-47.0	-47.0
-46	-46.1	-46.1	-46.1	-46.1	-46.1	-46.1	-46.1	-46.1	-46.0	-46.0	-46.0	-46.0	-46.0	-46.0	-46.0	-46.0	-46.0	-46.0	-46.0	-46.0	-46.0
-45	-45.1	-45.1	-45.1	-45.1	-45.1	-45.1	-45.1	-45.1	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0	-45.0
-44	-44.1	-44.1	-44.1	-44.1	-44.1	-44.1	-44.1	-44.1	-44.1	-44.0	-44.0	-44.0	-44.0	-44.0	-44.0	-44.0	-44.0	-44.0	-44.0	-44.0	-44.0
-43	-43.1	-43.1	-43.1	-43.1	-43.1	-43.1	-43.1	-43.1	-43.1	-43.0	-43.0	-43.0	-43.0	-43.0	-43.0	-43.0	-43.0	-43.0	-43.0	-43.0	-43.0
-42	-42.1	-42.1	-42.1	-42.1	-42.1	-42.1	-42.1	-42.1	-42.1	-42.0	-42.0	-42.0	-42.0	-42.0	-42.0	-42.0	-42.0	-42.0	-42.0	-42.0	-42.0
-41	-41.1	-41.1	-41.1	-41.1	-41.1	-41.1	-41.1	-41.1	-41.1	-41.1	-41.0	-41.0	-41.0	-41.0	-41.0	-41.0	-41.0	-41.0	-41.0	-41.0	-41.0
-40	-40.1	-40.1	-40.1	-40.1	-40.1	-40.1	-40.1	-40.1	-40.1	-40.1	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
-39	-39.1	-39.1	-39.1	-39.1	-39.1	-39.1	-39.1	-39.1	-39.1	-39.1	-39.1	-39.0	-39.0	-39.0	-39.0	-39.0	-39.0	-39.0	-39.0	-39.0	-39.0
-38	-38.1	-38.1	-38.1	-38.1	-38.1	-38.1	-38.1	-38.1	-38.1	-38.1	-38.1	-38.0	-38.0	-38.0	-38.0	-38.0	-38.0	-38.0	-38.0	-38.0	-38.0
-37	-37.1	-37.1	-37.1	-37.1	-37.1	-37.1	-37.1	-37.1	-37.1	-37.1	-37.1	-37.0	-37.0	-37.0	-37.0	-37.0	-37.0	-37.0	-37.0	-37.0	-37.0
-36	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.0	-36.0	-36.0	-36.0	-36.0	-36.0	-36.0	-36.0	-36.0
-35	-35.1	-35.1	-35.1	-35.1	-35.1	-35.1	-35.1	-35.1	-35.1	-35.1	-35.1	-35.1	-35.0	-35.0	-35.0	-35.0	-35.0	-35.0	-35.0	-35.0	-35.0
-34	-34.1	-34.1	-34.1	-34.1	-34.1	-34.1	-34.1	-34.1	-34.1	-34.1	-34.1	-34.1	-34.1	-34.0	-34.0	-34.0	-34.0	-34.0	-34.0	-34.0	-34.0
-33	-33.1	-33.1	-33.1	-33.1	-33.1	-33.1	-33.1	-33.1	-33.1	-33.1	-33.1	-33.1	-33.1	-33.0	-33.0	-33.0	-33.0	-33.0	-33.0	-33.0	-33.0
-32	-32.1	-32.1	-32.1	-32.1	-32.1	-32.1	-32.1	-32.1	-32.1	-32.1	-32.1	-32.1	-32.1	-32.0	-32.0	-32.0	-32.0	-32.0	-32.0	-32.0	-32.0
-31	-31.1	-31.1	-31.1	-31.1	-31.1	-31.1	-31.1	-31.1	-31.1	-31.1	-31.1	-31.1	-31.1	-31.0	-31.0	-31.0	-31.0	-31.0	-31.0	-31.0	-31.0
-30	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.1	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0
-29	-29.2	-29.1	-29.1	-29.1	-29.1	-29.1	-29.1	-29.1	-29.1	-29.1	-29.1	-29.1	-29.1	-29.1	-29.0	-29.0	-29.0	-29.0	-29.0	-29.0	-29.0
-28	-28.2	-28.2	-28.1	-28.1	-28.1	-28.1	-28.1	-28.1	-28.1	-28.1	-28.1	-28.1	-28.1	-28.1	-28.0	-28.0	-28.0	-28.0	-28.0	-28.0	-28.0
-27	-27.2	-27.2	-27.1	-27.1	-27.1	-27.1	-27.1	-27.1	-27.1	-27.1	-27.1	-27.1	-27.1	-27.1	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0
-26	-26.2	-26.2	-26.2	-26.1	-26.1	-26.1	-26.1	-26.1	-26.1	-26.1	-26.1	-26.1	-26.1	-26.1	-26.1	-26.0	-26.0	-26.0	-26.0	-26.0	-26.0
-25	-25.2	-25.2	-25.2	-25.2	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0
-24	-24.2	-24.2	-24.2	-24.2	-24.2	-24.1	-24.1	-24.1	-24.1	-24.1	-24.1	-24.1	-24.1	-24.1	-24.1	-24.0	-24.0	-24.0	-24.0	-24.0	-24.0
-23	-23.2	-23.2	-23.2	-23.2	-23.2	-23.1	-23.1	-23.1	-23.1	-23.1	-23.1	-23.1	-23.1	-23.1	-23.1	-23.0	-23.0	-23.0	-23.0	-23.0	-23.0
-22	-22.2	-22.2	-22.2	-22.2	-22.2	-22.2	-22.1	-22.1	-22.1	-22.1	-22.1	-22.1	-22.1	-22.1	-22.1	-22.1	-22.0	-22.0	-22.0	-22.0	-22.0
-21	-21.2	-21.2	-21.2	-21.2	-21.2	-21.2	-21.1	-21.1	-21.1	-21.1	-21.1	-21.1	-21.1	-21.1	-21.1	-21.1	-21.0	-21.0	-21.0	-21.0	-21.0
-20	-20.2	-20.2	-20.2	-20.2	-20.2	-20.2	-20.2	-20.1	-20.1	-20.1	-20.1	-20.1	-20.1	-20.1	-20.1	-20.1	-20.0	-20.0	-20.0	-20.0	-20.0
-19	-19.2	-19.2	-19.2	-19.2	-19.2	-19.2	-19.2	-19.1	-19.1	-19.1	-19.1	-19.1	-19.1	-19.1	-19.1	-19.1	-19.0	-19.0	-19.0	-19.0	-19.0
-18	-18.2	-18.2	-18.2	-18.2	-18.2	-18.2	-18.2	-18.2	-18.1	-18.1	-18.1	-18.1	-18.1	-18.1	-18.1	-18.1	-18.0	-18.0	-18.0	-18.0	-18.0
-17	-17.2	-17.2	-17.2	-17.2	-17.2	-17.2	-17.2	-17.2	-17.1	-17.1	-17.1	-17.1	-17.1	-17.1	-17.1	-17.1	-17.0	-17.0	-17.0	-17.0	-17.0
-16	-16.3	-16.2	-16.2	-16.2	-16.2	-16.2	-16.2	-16.2	-16.2	-16.1	-16.1	-16.1	-16.1	-16.1	-16.1	-16.1	-16.1	-16.0	-16.0	-16.0	-16.0
-15	-15.3	-15.3	-15.2	-15.2	-15.2	-15.2	-15.2	-15.2	-15.2	-15.1	-15.1	-15.1	-15.1	-15.1	-15.1	-15.1	-15.1	-15.0	-15.0	-15.0	-15.0
-14	-14.3	-14.3	-14.3	-14.2	-14.2	-14.2	-14.2	-14.2	-14.2	-14.2	-14.1	-14.1	-14.1	-14.1	-14.1	-14.1	-14.1	-14.0	-14.0	-14.0	-14.0
-13	-13.3	-13.3	-13.3	-13.2	-13.2	-13.2	-13.2	-13.2	-13.2	-13.2	-13.1	-13.1	-13.1	-13.1	-13.1	-13.1	-13.1	-13.0	-13.0	-13.0	-13.0
-12	-12.3	-12.3	-12.3	-12.3	-12.2	-12.2	-12.2	-12.2	-12.2	-12.2	-12.2	-12.1	-12.1	-12.1	-12.1	-12.1	-12.1	-12.0	-12.0	-12.0	-12.0
-11	-11.3	-11.3	-11.3	-11.3	-11.3	-11.2	-11.2	-11.2	-11.2	-11.2	-11.2	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.0	-11.0	-11.0	-11.0
-10	-10.3	-10.3	-10.3	-10.3	-10.3	-10.2	-10.2	-10.2	-10.2	-10.2	-10.2	-10.1	-10.1	-10.1	-10.1	-10.1	-10.1	-10.0	-10.0	-10.0	-10.0
-9	-9.3	-9.3	-9.3	-9.3	-9.3	-9.3	-9.2	-9.2	-9.2	-9.2	-9.2	-9.2	-9.1	-9.1	-9.1	-9.1	-9.1	-9.1	-9.0	-9.0	-9.0
-8	-8.4	-8.3	-8.3	-8.3	-8.3	-8.3	-8.3	-8.2	-8.2	-8.2	-8.2	-8.2	-8.1	-8.1	-8.1	-8.1	-8.1	-8.1	-8.0	-8.0	-8.0
-7	-7.4	-7.4	-7.3	-7.3	-7.3	-7.3	-7.3	-7.2	-7.2	-7.2	-7.2	-7.2	-7.1	-7.1	-7.1	-7.1	-7.1	-7.1	-7.0	-7.0	-7.0
-6	-6.4	-6.4	-6.4	-6.3	-6.3	-6.3	-6.3	-6.3	-6.2	-6.2	-6.2	-6.2	-6.2	-6.1	-6.1	-6.1	-6.1	-6.1	-6.0	-6.0	-6.0
-5	-5.4	-5.4	-5.4	-5.3	-5.3	-5.3	-5.3	-5.3	-5.2	-5.2	-5.2	-5.2	-5.2	-5.1	-5.1	-5.1	-5.1	-5.1	-5.0	-5.0	-5.0
-4	-4.4	-4.4	-4.4	-4.4	-4.3	-4.3	-4.3	-4.3	-4.3	-4.2	-4.2	-4.2	-4.2	-4.1	-4.1	-4.1	-4.1	-4.1	-4.0	-4.0	-4.0
-3	-3.4	-3.4	-3.4	-3.4	-3.4	-3.3	-3.3	-3.3	-3.3	-3.2	-3.2	-3.2	-3.2	-3.2	-3.1	-3.1	-3.1	-3.1	-3.0	-3.0	-3.0
-2	-2.5	-2.4	-2.4	-2.4	-2.4	-2.3	-2.3	-2.3	-2.3	-2.3	-2.2	-2.2	-2.2	-2.2	-2.1	-2.1	-2.1	-2.1	-2.0	-2.0	-2.0
-1	-1.5	-1.5	-1.4	-1.4	-1.4	-1.4	-1.3	-1.3	-1.3	-1.3	-1.2	-1.2	-1.2	-1.2	-1.1	-1.1	-1.1	-1.1	-1.0	-1.0	-1.0
0	-0.5	-0.5	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0
1	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.0
2	1.5	1.5	1.5	1.5	1.6	1.6	1.6	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	2.0	2.0
3	2.4	2.5	2.5	2.5	2.6	2.6	2.6	2.6	2.7	2.7	2.7	2.7	2.8	2.8	2.8	2.9	2.9	2.9	2.9	3.0	3.0
4	3.4	3.4	3.5	3.5	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.8	3.8	3.9	3.9	3.9	3.9	4.0	4.0
5	4.4	4.4	4.5	4.5	4.5	4.5	4.6	4.6	4.6	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.9	4.9	4.9	5.0	5.0
6	5.4	5.4	5.4	5.5	5.5	5.5	5.6	5.6	5.6	5.7	5.7	5.7	5.7	5.8	5.8	5.8	5.9	5.9	5.9	6.0	6.0
7	6.3	6.4	6.4	6.4	6.5	6.5	6.5	6.6	6.6	6.6	6.7	6.7	6.7	6.8	6.8	6.8	6.9	6.9	6.9	7.0	7.0
8	7.3	7.3	7.4	7.4	7.5	7.5	7.5	7.6	7.6	7.6	7.7	7.7	7.7	7.8	7.8	7.8	7.9	7.9	7.9	8.0	8.0
9	8.3	8.3	8.4	8.4	8.4	8.5	8.5	8.5	8.6	8.6	8.6	8.7	8.7	8.8	8.8	8.8	8.9	8.9	8.9	9.0	9.0
10	9.3	9.3	9.3	9.4	9.4	9.4	9.5	9.5	9.6	9.6	9.6	9.7	9.7	9.7	9.8	9.8	9.9	9.9	9.9	10.0	10.0
11	10.2	10.3	10.3	10.3	10.4	10.4	10.5	10.5	10.5	10.6	10.6	10.7	10.7	10.7	10.8	10.8	10.8	10.9	10.9	11.0	11.0
12	11.2	11.2	11.3	11.3	11.4	11.4	11.4	11.5	11.5	11.6	11.6	11.6	11.7	11.7	11.8	11.8	11.8	11.9	11.9	12.0	12.0
13	12.2	12.2	12.2	12.3	12.3	12.4	12.4	12.5	12.5	12.5	12.6	12.6	12.7	12.7	12.7	12.8	12.8	12.9	12.9	13.0	13.0
14	13.1	13.2	13.2	13.3	13.3	13.3	13.4	13.4	13.5	13.5	13.6	13.6	13.7	13.7	13.7	13.8	13.8	13.9	13.9	14.0	14.0
15	14.1	14.1	14.2	14.2	14.3	14.3	14.4	14.4	14.5	14.5	14.5	14.6	14.6	14.7	14.7	14.8	14.8	14.9	14.9	15.0	15.0
16	15.1	15.1	15.1	15.2	15.2	15.3	15.3	15.4	15.4	15.5	15.5	15.6	15.6	15.7	15.7	15.8	15.8	15.9	15.9	16.0	16.0
17	16.0	16.1	16.1	16.2	16.2	16.3	16.3	16.4	16.4	16.5	16.5	16.6	16.6	16.7	16.7	16.8	16.8	16.9	16.9	17.0	17.0
18	17.0	17.0	17.1	17.1	17.2	17.2	17.3	17.3	17.4	17.4	17.5	17.5	17.6	17.6	17.7	17.7	17.8	17.8	17.9	17.9	18.0
19	17.9	18.0	18.0	18.1	18.1	18.2	18.3	18.3	18.4	18.4	18.5	18.5	18.6	18.6	18.7	18.7	18.8	18.8	18.9	18.9	19.0
20	18.9	18.9	19.0	19.1	19.1	19.2	19.2	19.3	19.3	19.4	19.4	19.5	19.6	19.6	19.7	19.7	19.8	19.8	19.9	19.9	20.0
21	19.8	19.9	20.0	20.0	20.1	20.1	20.2	20.2	20.3	20.4	20.4	20.5	20.5	20.6	20.7	20.7	20.8	20.8	20.9	20.9	21.0
22	20.8	20.9	20.9	21.0	21.0	21.1	21.2	21.2	21.3	21.3	21.4	21.5	21.5	21.6	21.6	21.7	21.8	21.8	21.9	21.9	22.0
23	21.7	21.8	21.9	21.9	22.0	22.1	22.1	22.2	22.2	22.3	22.4	22.4	22.5	22.6	22.6	22.7	22.7	22.8	22.9	22.9	23.0
24	22.7	22.8	22.8	22.9	23.0	23.0	23.1	23.1	23.2	23.3	23.3	23.4	23.5	23.5	23.6	23.7	23.7	23.8	23.9	23.9	24.0
25	23.6	23.7	23.8	23.8	23.9	24.0	24.0	24.1	24.2	24.3	24.3	24.4	24.5	24.5	24.6	24.7	24.7	24.8	24.9	24.9	25.0
26	24.6	24.7	24.7	24.8	24.9	24.9	25.0	25.1	25.1	25.2	25.3	25.4	25.4	25.5	25.6	25.6	25.7	25.8	25.9	25.9	26.0
27	25.5	25.6	25.7	25.7	25.8	25.9	26.0	26.0	26.1	26.2	26.3	26.3	26.4	26.5	26.6	26.6	26.7	26.8	26.9	26.9	27.0
28	26.5	26.5	26.6	26.7	26.8	26.8	26.9	27.0	27.1	27.2	27.2	27.3	27.4	27.5	27.5	27.6	27.7	27.8	27.8	27.9	28.0
29	27.4	27.5	27.6	27.6	27.7	27.8	27.9	28.0	28.0	28.1	28.2	28.3	28.4	28.4	28.5	28.6	28.7	28.8	28.8	28.9	29.0
30	28.3	28.4	28.5	28.6	28.7	28.8	28.8	28.9	29.0	29.1	29.2	29.3	29.3	29.4	29.5	29.6	29.7	29.8	29.8	29.9	30.0

Heat Index Software Table

Air	Relative Humidity %																				
Temp (°F)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
31	29.3	29.4	29.5	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.1	30.2	30.3	30.4	30.5	30.6	30.7	30.8	30.8	30.9	31.0
32	30.2	30.3	30.4	30.5	30.6	30.7	30.8	30.9	31.0	31.0	31.1	31.2	31.3	31.4	31.5	31.6	31.7	31.8	31.9	31.9	32.0
33	31.2	31.2	31.3	31.4	31.5	31.6	31.7	31.8	31.9	32.0	32.1	32.2	32.3	32.4	32.5	32.6	32.7	32.8	32.8	32.9	33.0
34	32.1	32.2	32.3	32.4	32.5	32.6	32.7	32.8	32.9	33.0	33.1	33.2	33.3	33.4	33.5	33.5	33.6	33.7	33.8	33.9	34.0
35	33.0	33.1	33.2	33.3	33.4	33.5	33.7	33.8	33.9	34.0	34.1	34.2	34.3	34.4	34.5	34.6	34.7	34.8	34.9	35.0	35.1
36	34.0	34.1	34.2	34.3	34.4	34.5	34.6	34.7	34.8	34.9	35.0	35.1	35.2	35.3	35.4	35.6	35.7	35.8	35.9	36.0	36.1
37	34.9	35.0	35.1	35.2	35.3	35.4	35.6	35.7	35.8	35.9	36.0	36.1	36.2	36.3	36.4	36.6	36.7	36.8	36.9	37.0	37.1
38	35.8	35.9	36.1	36.2	36.3	36.4	36.5	36.6	36.8	36.9	37.0	37.1	37.2	37.3	37.4	37.6	37.7	37.8	37.9	38.0	38.1
39	36.8	36.9	37.0	37.1	37.2	37.4	37.5	37.6	37.7	37.8	38.0	38.1	38.2	38.3	38.4	38.6	38.7	38.8	38.9	39.0	39.2
40	37.7	37.8	37.9	38.0	38.2	38.3	38.4	38.5	38.7	38.8	38.9	39.0	39.2	39.3	39.4	39.5	39.7	39.8	39.9	40.1	40.2
41	38.6	38.7	38.9	39.0	39.1	39.3	39.4	39.5	39.6	39.8	39.9	40.0	40.2	40.3	40.4	40.6	40.7	40.8	40.9	41.1	41.2
42	39.5	39.7	39.8	39.9	40.1	40.2	40.3	40.5	40.6	40.8	40.9	41.0	41.2	41.3	41.4	41.6	41.7	41.8	42.0	42.1	42.2
43	40.5	40.6	40.7	40.9	41.0	41.2	41.3	41.4	41.6	41.7	41.9	42.0	42.2	42.3	42.4	42.6	42.7	42.9	43.0	43.1	43.3
44	41.4	41.6	41.7	41.9	42.0	42.1	42.3	42.4	42.6	42.7	42.9	43.0	43.2	43.3	43.5	43.6	43.8	43.9	44.1	44.2	44.4
45	42.3	42.5	42.6	42.8	42.9	43.1	43.3	43.4	43.6	43.7	43.9	44.0	44.2	44.3	44.5	44.6	44.8	44.9	45.1	45.2	45.4
46	43.3	43.4	43.6	43.7	43.9	44.1	44.2	44.4	44.5	44.7	44.9	45.0	45.2	45.3	45.5	45.6	45.8	46.0	46.1	46.3	46.4
47	44.2	44.3	44.5	44.7	44.8	45.0	45.2	45.3	45.5	45.7	45.8	46.0	46.2	46.3	46.5	46.7	46.8	47.0	47.2	47.3	47.5
48	45.1	45.3	45.4	45.6	45.8	46.0	46.1	46.3	46.5	46.7	46.8	47.0	47.2	47.3	47.5	47.7	47.9	48.0	48.2	48.4	48.6
49	46.0	46.2	46.4	46.6	46.8	46.9	47.1	47.3	47.5	47.7	47.8	48.0	48.2	48.4	48.6	48.7	48.9	49.1	49.3	49.5	49.6
50	47.0	47.2	47.3	47.5	47.7	47.9	48.1	48.3	48.5	48.7	48.8	49.0	49.2	49.4	49.6	49.8	50.0	50.1	50.3	50.5	50.7
51	47.6	47.8	48.0	48.2	48.4	48.6	48.9	49.1	49.3	49.5	49.7	49.9	50.1	50.3	50.5	50.7	50.9	51.0	51.2	51.4	51.6
52	48.3	48.5	48.7	48.9	49.1	49.3	49.6	49.9	50.1	50.3	50.5	50.8	51.0	51.2	51.4	51.6	51.8	52.0	52.2	52.3	52.5
53	49.0	49.2	49.4	49.6	49.9	50.1	50.4	50.7	50.9	51.2	51.4	51.6	51.9	52.1	52.3	52.5	52.7	52.9	53.1	53.3	53.4
54	49.7	49.9	50.1	50.4	50.6	50.9	51.2	51.5	51.8	52.0	52.3	52.6	52.8	53.0	53.3	53.5	53.7	53.9	54.1	54.2	54.4
55	50.4	50.6	50.9	51.1	51.4	51.6	52.1	52.4	52.7	52.9	53.2	53.5	53.7	54.0	54.2	54.5	54.7	54.9	55.1	55.2	55.4
56	51.2	51.3	51.6	51.9	52.2	52.4	52.9	53.2	53.5	53.8	54.1	54.4	54.7	55.0	55.2	55.4	55.7	55.9	56.1	56.2	56.4
57	51.9	52.1	52.4	52.7	53.0	53.2	53.8	54.1	54.5	54.8	55.1	55.4	55.7	56.0	56.2	56.5	56.7	56.9	57.1	57.2	57.4
58	52.7	52.9	53.2	53.5	53.8	54.1	54.7	55.0	55.4	55.7	56.0	56.4	56.7	57.0	57.2	57.5	57.8	57.9	58.1	58.3	58.4
59	53.4	53.6	54.0	54.3	54.6	54.9	55.6	55.9	56.3	56.7	57.0	57.4	57.7	58.0	58.3	58.5	58.8	59.0	59.2	59.4	59.5
60	54.2	54.4	54.8	55.1	55.5	55.8	56.5	56.9	57.3	57.7	58.0	58.4	58.7	59.1	59.4	59.6	59.9	60.1	60.3	60.4	60.6
61	55.1	55.3	55.7	56.0	56.3	56.7	57.4	57.8	58.3	58.7	59.0	59.4	59.8	60.2	60.4	60.7	61.0	61.2	61.4	61.5	61.7
62	55.9	56.1	56.5	56.9	57.2	57.6	58.4	58.8	59.3	59.7	60.1	60.5	60.8	61.3	61.5	61.8	62.2	62.3	62.5	62.7	62.8
63	56.7	56.9	57.4	57.7	58.1	58.5	59.3	59.8	60.3	60.7	61.1	61.6	61.9	62.4	62.7	62.9	63.3	63.5	63.7	63.8	64.0
64	57.6	57.8	58.3	58.6	59.0	59.4	60.3	60.8	61.3	61.8	62.2	62.7	63.1	63.5	63.8	64.1	64.5	64.6	64.8	65.0	65.1
65	58.5	58.7	59.2	59.6	60.0	60.4	61.3	61.8	62.4	62.8	63.3	63.8	64.2	64.7	65.0	65.3	65.7	65.8	66.0	66.2	66.3
66	59.4	59.6	60.1	60.5	60.9	61.3	62.4	62.9	63.4	63.9	64.4	64.9	65.3	65.8	66.2	66.5	66.9	67.0	67.3	67.4	67.5
67	60.3	60.5	61.1	61.5	61.9	62.3	63.4	63.9	64.5	65.1	65.6	66.1	66.5	67.0	67.4	67.7	68.1	68.3	68.5	68.6	68.8
68	61.2	61.5	62.0	62.6	63.1	63.8	64.4	65.0	65.6	66.2	66.7	67.2	67.7	68.2	68.6	68.9	69.3	69.5	69.7	69.9	70.0
69	62.4	62.9	63.3	63.8	64.3	64.8	65.4	66.0	66.6	67.1	67.6	68.0	68.4	68.9	69.4	70.0	70.5	70.8	71.0	71.3	71.9
70	64.0	64.1	64.5	65.0	65.5	65.9	66.4	66.9	67.3	67.8	68.3	68.7	69.2	69.7	70.1	70.6	71.1	71.5	72.0	72.5	73.5
71	65.4	65.5	65.9	66.4	66.8	67.3	67.7	68.2	68.6	69.1	69.6	70.0	70.5	70.9	71.4	71.8	72.3	72.8	73.2	73.7	74.7
72	66.7	66.8	67.2	67.6	68.1	68.6	69.1	69.6	70.1	70.6	71.1	71.5	71.9	72.3	72.7	73.0	73.4	73.8	74.2	74.8	75.6
73	68.0	68.1	68.6	69.2	69.7	70.2	70.7	71.2	71.7	72.1	72.5	73.0	73.4	73.7	74.1	74.5	74.8	75.1	75.5	75.8	76.6
74	69.2	69.5	69.8	70.3	71.0	71.7	72.3	72.7	73.1	73.4	73.7	74.2	74.7	75.2	75.6	75.9	76.0	76.2	76.4	77.0	77.6
75	70.4	71.2	71.7	72.1	72.5	72.9	73.3	73.8	74.2	74.7	75.1	75.5	75.9	76.3	76.7	77.1	77.5	78.0	78.4	78.7	78.8
76	71.5	72.5	73.1	73.6	74.1	74.3	74.5	74.8	75.1	75.6	76.0	76.3	76.7	77.2	77.8	78.4	78.9	79.2	79.5	80.0	80.3
77	72.6	73.7	74.6	75.2	75.5	75.7	75.8	76.0	76.2	76.5	76.8	77.3	77.8	78.3	78.9	79.5	80.0	80.6	81.0	81.5	82.2
78	73.6	73.8	74.6	75.4	75.9	76.2	76.4	76.7	77.1	77.6	78.0	78.5	78.9	79.4	80.0	80.6	81.4	82.1	82.8	83.4	84.4
79	74.6	74.7	75.1	75.6	76.1	76.7	77.2	77.8	78.2	78.7	79.2	79.6	80.1	80.7	81.3	82.0	82.8	83.7	84.7	85.8	86.8
80	75.6	75.7	76.1	76.5	77.0	77.5	78.0	78.5	79.0	79.6	80.1	80.7	81.3	82.0	82.7	83.6	84.5	85.6	86.8	88.1	89.6
81	76.5	76.6	77.0	77.5	77.9	78.4	79.0	79.5	80.0	80.6	81.2	81.9	82.7	83.5	84.4	85.4	86.5	87.8	89.2	90.7	92.5
82	77.4	77.5	77.9	78.4	78.9	79.5	80.1	80.7	81.3	81.9	82.6	83.4	84.2	85.2	86.3	87.5	88.9	90.4	92.1	93.9	95.7
83	78.3	78.5	79.1	79.6	80.0	80.4	81.0	81.8	82.7	83.5	84.2	84.9	85.7	86.9	88.4	90.1	91.7	93.1	94.8	97.3	99.2
84	79.1	79.9	80.6	80.8	81.0	81.5	82.3	83.3	84.3	85.1	85.8	86.6	87.7	89.2	90.9	92.7	94.5	96.1	98.0	100.5	103.1
85	80.0	80.9	81.6	81.7	81.8	82.4	83.2	84.2	85.1	86.0	86.8	87.9	89.4	91.1	92.9	94.6	96.4	98.4	100.9	104.1	107.6
86	80.8	81.8	82.5	82.6	82.8	83.4	84.3	85.3	86.2	87.1	88.2	89.7	91.5	93.4	95.3	97.0	98.8	101.2	104.5	108.6	113.2
87	81.6	82.6	83.3	83.5	83.7	84.3	85.2	86.2	87.4	88.6	90.1	91.8	93.6	95.6	97.5	99.6	102.1	105.4	109.8	114.9	120.5
88	82.4	83.3	83.7	84.0	84.4	84.9	85.7	86.8	88.1	89.7	91.4	93.1	94.9	96.8	99.0	101.4	104.4	108.5	114.2	121.9	130.4
89	83.1	83.6	83.7	84.4	85.2	86.0	87.0	88.3	90.0	91.9	93.7	95.4	97.3	99.6	102.3	105.5	109.2	113.8	120.9	132.0	144.2
90	83.9	84.2	85.5	86.2	86.6	87.4	89.0	89.9	91.2	93.3	95.1	97.4	99.8	102.8	105.8	109.4	113.3	120.3	127.1	142.9	163.4
91	84.7	85.1	86.4	87.2	87.6	88.6	90.2	91.2	92.9	95.1	97.1	99.7	102.3	105.6	109.0	113.4	118.2	126.5	135.1	156.6	190.2
92	85.4	86.0	87.3	88.2	88.6	89.8	91.4	92.6	94.5	96.9	99.1	102.1	104.9	108.6	112.3	117.8	123.6	133.7	144.3	173.2	227.3
93	86.2	86.9	88.2	89.2	89.7	91.0	92.7	94.0	96.3	98.8	101.2	104.6	107.7	111.7	115.7	122.7	129.7	141.7	155.1	193.3	277.7
94	86.9	87.7	89.1	90.2	90.7	92.3	94.0	95.4	98.1	100.8	103.4	107.2	110.7	114.9	119.4	128.0	136.6	150.8	167.6	217.4	345.5
95	87.6	88.6	90.0	91.3	91.8	93.6	95.3	97.0	100.0	102.9	105.7	110.0	113.8	118.4	123.4	134.0	144.4	161.1	182.2	246.0	435.4
96	88.4	89.5	90.9	92.3	93.0	95.0	96.6	98.6	102.0	105.1	108.1	112.9	117.1	122.1	127.5	140.5	153.1	172.7	199.0	279.9	552.9
97	89.1	90.4	91.8	93.3	94.1	96.3	98.0	100.3	104.0	107.3	110.6	116.0	120.6	125.9	131.9	147.7	162.8	185.6	218.5	319.6	704.8
98	89.8	91.2	92.7	94.4	95.3	97.8	99.5	102.1	106.1	109.6	113.2	119.2	124.3	130.0	136.6	155.6	173.7	200.0	241.0	365.8	898.6
99	90.6	92.1	93.7	95.5	96.5	99.2	101.0	103.9	108.3	112.0	115.9	122.6	128.2	134.3	141.6	164.3	185.9	216.0	266.9	419.2	---
100	91.3	93.0	94.6	96.6	97.8	100.7	102.6	105.9	110.6	114.6	118.8	126.2	132.3	138.9	146.8	173.8	199.3	233.8	296.5	480.6	---
101	92.1	93.9	95.5	97.6	99.1	102.2	104.2	108.0	113.0	117.2	121.7	130.0	136.6	143.7	152.4	184.2	214.2	253.3	330.5	550.7	---
102	92.8	94.8	96.4	98.8	100.4	103.7	105.9	110.2	115.5	119.9	124.8	134.0	141.2	148.8	158.3	195.6	230.7	274.8	369.1	630.3	---
103	93.5	95.6	97.4	99.9	101.8	105.3	107.7	112.6	118.0	122.7	128.1	138.1	146.1	154.2	164.6	208.0	248.8	298.4	413.1	720.2	---
104	94.3	96.5	98.3	101.0	103.2	107.0	109.5	115.0	120.7	125.7	131.4	142.5	151.2	159.9	171.3	221.5	268.6	324.1	462.9	821.3	---
105	95.0	97.4	99.3	102.2	104.6	108.6	111.4	117.6	123.5	128.7	134.9	147.1	156.6	165.9	178.4	236.1	290.2	352.2	519.2	934.4	---
106	95.8	98.3	100.3	103.4	106.0	110.3	113.4	120.3	126.4	131.9	138.6	152.0	162.3	172.3	186.0	251.9	313.8	382.6	582.6	---	---
107	96.5	99.2	101.3	104.6	107.5	112.1	115.6	123.1	129.4	135.2	142.4	157.1	168.4	179.1	194.0	269.1	339.4	415.5	653.8	---	---
108	97.3	100.1	102.3	105.8	109.0	113.9	117.8	126.1	132.5	138.7	146.4	162.5	174.8	186.3	202.6	287.5	367.2	451.1	733.6	---	---
109	98.1	101.1	103.3	107.0	110.6	115.8	120.1	129.3	135.7	142.3	150.6	168.2	181.6	193.9	211.7	307.5	397.1	489.4	822.7	---	---
110	98.8	102.0	104.3	108.3	112.2	117.7	122.5	132.6	139.1	146.0	155.0	174.3	188.8	202.0	221.4	328.9	429.4	530.5	922.0	---	---
111	99.6	102.9	105.4	109.6	113.8	119.7	125.0	136.1	142.6	149.9	159.5	180.6	196.4	210.5	231.8	351.8	464.1	574.5	---	---	---
112	100.4	103.8	106.5	110.9	115.4	121.7	127.7	139.7	146.3	154.0	164.3	187.3	204.4	219.6	242.8	376.4	501.3	621.6	---	---	---
113	101.2	104.8	107.6	112.2	117.1	123.8	130.5	143.6	150.1	158.2	169.3	194.3	213.0	229.3	254.6	402.7	541.1	671.8	---	---	---
114	102.0	105.7	108.7	113.6	118.8	125.9	133.4	147.6	154.0	162.6	174.5	201.8	222.1	239.5	267.1	430.8	583.6	725.2	---	---	---
115	102.8	106.7	109.9	115.0	120.6	128.1	136.5	151.7	158.2	167.2	179.9	209.7	231.7	250.4	280.6	460.8	628.8	782.0	---	---	---

Air	Relative Humidity %																				
Temp (°F)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
116	103.6	107.6	111.0	116.4	122.4	130.4	139.7	156.1	162.5	172.0	185.6	218.0	241.9	262.0	294.9	492.6	676.9	842.2	---	---	---
117	104.4	108.6	112.2	117.9	124.2	132.7	143.0	160.7	166.9	176.9	191.6	226.7	252.8	274.4	310.3	526.5	727.9	905.8	---	---	---
118	105.3	109.6	113.5	119.4	126.0	135.1	146.6	165.5	171.6	182.1	197.8	236.0	264.3	287.5	326.7	562.4	781.9	973.1	---	---	---
119	106.1	110.6	114.7	120.9	127.9	137.6	150.3	170.5	176.4	187.6	204.3	245.9	276.6	301.5	344.3	600.5	839.1	---	---	---	---
120	106.9	111.6	116.0	122.4	129.9	140.1	154.2	175.7	181.5	193.2	211.1	256.3	289.7	316.4	363.1	640.8	899.4	---	---	---	---
121	107.8	112.6	117.3	124.0	131.9	142.8	158.2	181.1	186.8	199.1	218.3	267.3	303.6	332.2	383.2	683.3	962.9	---	---	---	---
122	108.6	113.6	118.7	125.6	133.9	145.5	162.5	186.7	192.2	205.3	225.8	278.9	318.4	349.2	404.9	728.3	---	---	---	---	---
123	109.5	114.6	120.0	127.3	136.0	148.3	167.0	192.6	198.0	211.7	233.7	291.3	334.1	367.2	428.1	775.6	---	---	---	---	---
124	110.4	115.6	121.4	129.0	138.1	151.2	171.6	198.7	203.9	218.4	241.9	304.3	350.9	386.5	453.0	825.5	---	---	---	---	---
125	111.3	116.6	122.9	130.7	140.3	154.2	176.5	205.1	210.2	225.4	250.5	318.2	368.8	407.1	479.8	877.9	---	---	---	---	---
126	112.1	117.7	124.4	132.5	142.6	157.3	181.6	211.7	216.7	232.7	259.6	332.9	387.9	429.1	508.5	932.9	---	---	---	---	---
127	113.0	118.8	125.9	134.3	144.9	160.5	187.0	218.6	223.4	240.4	269.1	348.5	408.3	452.7	539.5	990.7	---	---	---	---	---
128	113.9	119.8	127.5	136.1	147.3	163.9	192.6	225.7	230.5	248.4	279.1	365.1	430.1	477.8	572.8	---	---	---	---	---	---
129	114.8	120.9	129.1	138.0	149.8	167.3	198.5	233.1	237.9	256.7	289.5	382.7	453.3	504.8	608.7	---	---	---	---	---	---
130	115.8	122.0	130.7	139.9	152.3	170.9	204.6	240.8	245.6	265.4	300.5	401.4	478.2	533.7	647.4	---	---	---	---	---	---
131	116.7	123.1	132.4	141.9	155.0	174.6	211.0	248.7	253.7	274.6	312.1	421.3	504.8	564.6	689.1	---	---	---	---	---	---
132	117.6	124.2	134.1	143.9	157.7	178.4	217.7	257.0	262.1	284.1	324.2	442.5	533.3	597.8	734.1	---	---	---	---	---	---
133	118.5	125.3	135.9	146.0	160.5	182.4	224.6	265.5	270.9	294.1	337.0	465.0	563.8	633.4	782.7	---	---	---	---	---	---
134	119.5	126.5	137.7	148.1	163.5	186.6	231.9	274.3	280.1	304.6	350.4	488.9	596.4	671.7	835.2	---	---	---	---	---	---
135	120.4	127.6	139.6	150.3	166.6	190.9	239.5	283.4	289.7	315.5	364.5	514.4	631.5	712.7	892.0	---	---	---	---	---	---
136	121.4	128.8	141.5	152.5	169.8	195.4	247.4	292.8	299.7	327.0	379.3	541.6	669.0	756.9	953.4	---	---	---	---	---	---
137	122.4	129.9	143.5	154.7	173.1	200.0	255.6	302.5	310.2	339.0	394.9	570.6	709.4	804.3	---	---	---	---	---	---	---
138	123.3	131.1	145.5	157.0	176.6	204.9	264.2	312.6	321.2	351.6	411.3	601.6	752.7	855.4	---	---	---	---	---	---	---
139	124.3	132.3	147.5	159.4	180.2	210.0	273.1	323.0	332.8	364.7	428.6	634.6	799.2	910.4	---	---	---	---	---	---	---
140	125.3	133.5	149.7	161.8	184.1	215.3	282.4	333.7	344.8	378.6	446.8	669.8	849.2	969.6	---	---	---	---	---	---	---
141	126.3	134.7	151.8	164.3	188.1	220.9	292.0	344.7	357.4	393.0	466.0	707.5	903.0	---	---	---	---	---	---	---	---
142	127.3	135.9	154.1	166.8	192.3	226.6	302.1	356.1	370.6	408.2	486.2	747.7	960.9	---	---	---	---	---	---	---	---
143	128.3	137.2	156.3	169.4	196.7	232.7	312.5	367.8	384.5	424.2	507.6	790.7	---	---	---	---	---	---	---	---	---
144	129.3	138.4	158.7	172.0	201.3	239.1	323.4	379.9	399.0	440.9	530.0	836.7	---	---	---	---	---	---	---	---	---
145	130.3	139.7	161.1	174.7	206.2	245.7	334.6	392.3	414.2	458.5	553.8	886.0	---	---	---	---	---	---	---	---	---
146	131.4	141.0	163.5	177.4	211.4	252.8	346.3	405.1	430.1	476.9	578.8	938.7	---	---	---	---	---	---	---	---	---
147	132.4	142.3	166.1	180.2	216.8	260.1	358.5	418.2	446.9	496.3	605.3	995.2	---	---	---	---	---	---	---	---	---
148	133.4	143.6	168.6	183.1	222.6	267.9	371.1	431.8	464.4	516.6	633.2	---	---	---	---	---	---	---	---	---	---
149	134.4	144.9	171.3	186.0	228.6	276.0	384.2	445.7	482.8	538.0	662.7	---	---	---	---	---	---	---	---	---	---
150	135.5	146.3	174.0	189.0	235.0	284.7	397.7	460.0	502.1	560.5	693.9	---	---	---	---	---	---	---	---	---	---
151	136.6	147.6	176.8	192.1	241.8	293.8	411.8	474.7	522.4	584.1	726.8	---	---	---	---	---	---	---	---	---	---
152	137.6	149.0	179.6	195.2	248.9	303.4	426.3	489.8	543.7	609.0	761.7	---	---	---	---	---	---	---	---	---	---
153	138.7	150.4	182.5	198.4	256.4	313.7	441.4	505.3	566.1	635.1	798.6	---	---	---	---	---	---	---	---	---	---
154	139.8	151.8	185.5	201.6	264.4	324.5	457.0	521.2	589.6	662.6	837.6	---	---	---	---	---	---	---	---	---	---
155	140.9	153.2	188.6	205.0	272.8	336.1	473.1	537.5	614.3	691.6	878.9	---	---	---	---	---	---	---	---	---	---
156	142.0	154.6	191.7	208.4	281.7	348.4	489.8	554.2	640.3	722.1	922.7	---	---	---	---	---	---	---	---	---	---
157	143.0	156.1	194.9	211.8	291.1	361.5	507.1	571.4	667.7	754.3	969.1	---	---	---	---	---	---	---	---	---	---
158	144.2	157.5	198.2	215.3	301.0	375.6	524.9	589.0	696.4	788.1	---	---	---	---	---	---	---	---	---	---	---
159	145.2	159.0	201.5	218.9	311.5	390.7	543.4	607.0	726.7	823.8	---	---	---	---	---	---	---	---	---	---	---
160	146.4	160.5	204.9	222.6	322.6	406.9	562.4	625.5	758.5	861.5	---	---	---	---	---	---	---	---	---	---	---
161	147.5	162.0	208.5	226.4	334.3	424.4	582.1	644.4	792.1	901.2	---	---	---	---	---	---	---	---	---	---	---
162	148.6	163.5	212.0	230.2	346.7	443.4	602.4	663.7	827.4	943.0	---	---	---	---	---	---	---	---	---	---	---
163	149.7	165.0	215.7	234.1	359.8	463.9	623.4	683.6	864.6	987.2	---	---	---	---	---	---	---	---	---	---	---
164	150.8	166.6	219.4	238.0	373.6	486.2	645.1	703.9	903.9	---	---	---	---	---	---	---	---	---	---	---	---
165	151.8	168.2	222.6	242.1	378.0	494.1	667.4	732.3	945.2	---	---	---	---	---	---	---	---	---	---	---	---
166	152.9	169.7	225.8	246.2	382.4	502.2	690.4	762.1	988.8	---	---	---	---	---	---	---	---	---	---	---	---
167	153.9	171.3	229.1	250.4	386.9	510.5	714.2	793.3	---	---	---	---	---	---	---	---	---	---	---	---	---
168	155.0	173.0	232.4	254.7	391.5	519.1	738.7	826.1	---	---	---	---	---	---	---	---	---	---	---	---	---
169	156.0	174.6	235.7	259.1	396.2	527.9	763.9	860.5	---	---	---	---	---	---	---	---	---	---	---	---	---
170	157.1	176.3	239.1	263.5	401.0	537.0	789.9	896.6	---	---	---	---	---	---	---	---	---	---	---	---	---
171	158.1	177.9	242.6	268.1	405.9	546.3	816.7	934.5	---	---	---	---	---	---	---	---	---	---	---	---	---
172	159.2	179.6	246.1	272.7	410.9	555.9	844.2	974.3	---	---	---	---	---	---	---	---	---	---	---	---	---
173	160.3	181.3	249.6	277.4	415.9	565.8	872.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---
174	161.3	183.0	253.2	282.2	421.1	576.0	901.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---
175	162.4	184.8	256.8	287.0	426.4	586.5	931.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---
176	163.4	186.5	260.5	292.0	431.8	597.3	962.7	---	---	---	---	---	---	---	---	---	---	---	---	---	---
177	164.5	188.3	264.3	297.1	437.4	608.4	994.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---
178	165.6	190.1	268.1	302.2	443.0	619.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
179	166.6	191.9	271.9	307.4	448.8	631.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
180	167.7	193.7	275.8	312.8	454.6	643.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
181	168.7	195.6	279.7	318.2	460.6	656.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
182	169.8	197.5	283.7	323.7	466.7	669.2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
183	170.9	199.4	287.8	329.3	473.0	682.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
184	171.9	201.3	291.8	335.0	479.4	696.2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
185	173.0	203.2	296.0	340.8	485.9	710.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
186	174.1	205.1	300.2	346.7	492.5	724.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
187	175.1	207.1	304.4	352.7	499.3	739.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
188	176.2	209.1	308.7	358.8	506.3	755.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
189	177.2	211.1	313.0	365.0	513.3	771.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
190	178.3	213.1	317.4	371.3	520.6	787.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
191	179.4	215.1	321.8	377.7	528.0	804.7	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
192	180.4	217.2	326.3	384.3	535.5	822.2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
193	181.5	219.3	330.8	390.9	543.2	840.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
194	182.5	221.4	335.4	397.6	551.1	858.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
195	183.6	223.5	340.0	404.4	559.1	878.1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
196	184.6	225.6	344.6	411.4	567.3	897.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
197	185.7	227.8	349.3	418.4	575.7	918.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
198	186.7	230.0	354.1	425.6	584.3	939.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
199	187.8	232.2	358.9	432.8	593.0	961.2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
200	188.8	234.4	363.8	440.2	602.0	983.7	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Heat Index Software Table

Air	Relative Humidity %																				
Temp (°F)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
201	189.9	236.7	368.7	447.7	611.1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
202	190.9	238.9	373.6	455.3	620.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
203	191.9	241.2	378.6	463.0	630.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
204	193.0	243.5	383.6	470.9	639.7	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
205	194.0	245.9	388.7	478.8	649.7	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
206	195.0	248.2	393.8	486.9	659.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
207	196.1	250.6	399.0	495.1	670.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
208	197.1	253.0	404.2	503.4	680.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
209	198.1	255.4	409.5	511.8	691.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
210	199.1	257.8	414.8	520.4	702.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
211	200.2	260.3	420.2	529.0	714.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
212	201.2	262.8	425.6	537.8	725.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
213	202.2	265.3	431.0	546.8	737.7	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
214	203.2	267.8	436.5	555.8	749.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
215	204.2	270.4	442.0	565.0	762.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
216	205.2	273.0	447.6	574.3	775.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
217	206.2	275.6	453.2	583.7	787.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
218	207.2	278.2	458.9	593.3	801.2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
219	208.2	280.8	464.6	603.0	814.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
220	209.2	283.5	470.4	612.8	828.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
221	209.9	286.2	476.2	622.8	842.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
222	211.2	288.9	482.0	632.9	857.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
223	212.2	291.6	487.9	643.1	872.2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
224	213.2	294.4	493.8	653.5	887.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
225	214.2	297.2	499.8	664.0	902.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
226	215.1	300.0	505.8	674.6	918.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
227	216.1	302.8	511.8	685.4	935.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
228	217.1	305.7	517.9	696.3	951.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
229	218.0	308.6	524.1	707.4	968.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
230	219.0	311.5	530.2	718.6	986.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
231	220.0	314.4	536.5	729.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
232	220.9	317.4	542.7	741.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
233	221.9	320.3	549.0	753.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
234	222.8	323.4	555.4	764.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
235	223.8	326.4	561.7	776.7	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
236	224.7	329.4	568.1	788.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
237	225.6	332.5	574.6	801.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
238	226.6	335.6	581.1	813.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
239	227.5	338.8	587.6	825.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
240	228.4	341.9	594.2	838.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
241	229.3	345.1	600.8	851.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
242	230.2	348.3	607.5	864.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
243	231.2	351.5	614.2	877.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
244	232.1	354.8	620.9	890.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
245	233.0	358.1	627.7	904.2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
246	233.9	361.4	634.5	917.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
247	234.8	364.8	641.3	931.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
248	235.6	368.1	648.2	945.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
249	236.5	371.5	655.1	959.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
250	237.4	374.9	662.1	973.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

REFERENCES

Steadman, R.G., 1979: The Assessment of Sultriness, Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science. *Journal of Applied Meteorology, July 1979*

"Media Guide to NWS Products and Services", National Weather Service Forecast Office, Monterey, CA, 1995.

Quayle, R.G. and Steadman, R.G., 1998: The Steadman Wind Chill: An Improvement over Present Scales. *Weather and Forecasting, December 1998*

Dewpoint

Parameters Used: Outside Air Temperature and Outside Humidity

What is it:
Dewpoint is the temperature to which air must be cooled for saturation (100% relative humidity) to occur, providing there is no change in water content. The dewpoint is an important measurement used to predict the formation of dew, frost, and fog. If dewpoint and temperature are close together in the late afternoon when the air begins to turn colder, fog is likely during the night. Dewpoint is also a good indicator of the air's actual water vapor content, unlike relative humidity, which is air temperature dependent. High dewpoint indicates high vapor content; low dewpoint indicates low vapor content. In addition a high dewpoint indicates a better chance of rain and severe thunderstorms. Dewpoint can be used to predict the minimum overnight temperature. Provided no new fronts are expected overnight and the afternoon Relative Humidity >=50%, the afternoon's dewpoint gives an idea of what minimum temperature to expect overnight. Since condensation occurs when the air temperature reaches the dewpoint, and condensation releases heat into the air, reaching the dewpoint halts the cooling process.

Formula:
The following method is used to calculate dewpoint:

$v = RH*0.01*6.112 * \exp [(17.62*T)/(T + 243.12)]$,

this equation will provide the vapor pressure value (in pressure units) where T is the air temperature in C and RH is the relative humidity.

Now dewpoint, Td, can be found:

Numerator = $243.12*(\ln v) – 440.1$

Denominator = $19.43 – \ln v$

Td = Numerator/Denominator

This equation is an approximation of the Goff & Gratch equation, which is extremely complex. This equation is one recommended by the World Meteorological Organization for saturation of air with respect to water.

REFERENCES

"Guide to Meteorological Instruments and Methods of Observation". World Meteorological Organization, Geneva, Switzerland, 6th Ed. 1996.

"Smithsonian Meteorological Tables". Smithsonian Institution Press, Washington, DC, 4th Ed. 1968.

THSW Index

Parameters Used: Temperature, Humidity, Solar Radiation, Wind Speed, Latitude & Longitude, Time and Date

What is it:
Like Heat Index, the THSW Index uses humidity and temperature to calculate an apparent temperature. In addition, THSW incorporates the heating effects of solar radiation and the cooling effects of wind (like wind chill) on our perception of temperature.

Formula:
The formula was developed by Steadman (1979). The following describes the series of formulas used to determine the THSW or Temperature-Humidity-Sun-Wind Index. Thus, this index indicates the level of thermal comfort including the effects of all these values.

This Index is calculated by adding a series of successive terms. Each term represents one of the three parameters: (Humidity, Sun & Wind). The humidity term serves as the base from which increments for sun and wind effects are added.

The Vantage Pro calculation is an improvement over the THSW Index in the Health EnviroMonitor because the Health system:

- only calculates THSW Index when air temperature is at or above 68°F.
- assumes the sky is clear.
- assumes the elevation is sea level.

Humidity

The first term is humidity. This term is determined in the same manner as the Heat Index. This term serves as a base number to which increments of wind and sun are added to come up with the final THSW Index temperature.

Note: Heat Index has also been referred to as "Temperature-Humidity Index" and "Thermal Index" in some Davis products

Wind

The second term is wind. This term is determined in part by a lookup table (for temperatures above 50°F) and in part by the wind chill calculation.

- At 0 mph, set this term equal to zero.
- For temperatures at or above 70°F and wind speeds above 40 mph, set the wind speed equal to 40 mph and use the table.
- For temperatures at or above 130°F, set this term equal to zero.
- For temperatures below 50°F:
    - For the display console: use the wind chill calculation as the base temperature.
    - For the WeatherLink software (version 5.2 and higher): use the new heat index formula (as described in the heat index section) as the base temperature and calculate the wind chill increment using the difference between the air temperature and wind chill (which is always a negative number).

The resulting value is the wind term, which will be added to the humidity term and subsequently the sun term as indicated below.
Note 1: older console versions of product that use the old wind chill formula (see wind chill section) have a different table for temperatures between 50°F and 70°F.
Note 2: The WeatherLink software (version 5.2) does not include the sun term in its calculation. It shows the result as the "THW Index" or Temperature-Humidity-Wind Index. This value indicates the "apparent" temperature in the shade due to these factors.

Increment (°F) for Wind in THSW Index									
Temp (°F)	Wind Speed (mph)								
	0	5	10	15	20	25	30	35	40
50	0	-2	-4	-5	-6	-7	-8	-9	-9
55	0	-1	-3	-5	-6	-7	-8	-9	-9
60	0	-1	-3	-5	-6	-7	-8	-9	-9
65	0	0	-3	-5	-6	-7	-8	-9	-9
70	0	0	-2	-4	-5	-6	-7	-8	-9
75	0	0	-2	-3	-4	-5	-6	-7	-7
80	0	0	-1	-2	-3	-5	-5	-6	-6
85	0	0	-1	-2	-3	-3	-4	-4	-4
90	0	0	0	-1	-2	-2	-2	-2	-2
95	0	0	0	0	0	0	1	1	1
100	0	0	0	0	1	2	3	3	3
105	0	0	0	1	2	3	4	5	5
110	0	0	0	2	3	4	5	5	6
115	0	0	0	1	2	3	4	6	6
120	0	0	0	1	1	2	3	4	4
125	0	0	0	0	0	1	1	1	1
130	0	0	0	0	0	0	0	0	0

Increment (°F) for Wind in THSW Index															
Temp (°F)	Wind Speed (mph)														
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
50	-9	-10	-11	-12	-12	-13	-13	-14	-14	-15	-15	-15	-16	-16	-16
55	-9	-10	-10	-11	-11	-12	-12	-13	-13	-13	-13	-14	-14	-14	-14
60	-9	-10	-10	-10	-11	-11	-11	-11	-12	-12	-12	-12	-12	-12	-12
65	-9	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-10	-11	-11	-11
70	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9

Sun

The third term is sun. This term, Qg, is actually a combination of four terms (direct incoming solar, indirect incoming solar, terrestrial, and sky radiation). The term depends upon wind speed to determine how strong an effect it is (discussed later).

It is assumed that a flat, fixed position sensor is being used as in the Vantage Pro Plus system.

$Qg = Q1 + Q2 + Q3 - Q4$

Direct Incoming Solar Radiation Term ($Q1$)

First, calculate what the solar radiation reading would be if the sensor were tilted normal to the sun. The following parameters are calculated in the same manner as for the ET formula (see ET section).

- Sky cover, c
- Solar Zenith Angle, θ

Solar radiation normal to the sun, $Q_n = (5E\text{-}06\theta^3 - 0.0002\theta^2 + 0.0029\theta + 1)*Q$,

Where Q is the measured solar radiation value and θ is the solar zenith angle in degrees (as determined above)
Otherwise, if the c is greater than 60%, $Q_n = Q$.

Next, direct incoming solar, Q_d, is determined from Q_n,

$Q_d = 0.9 * (1 - c^2) * Q_n$, where c is the cloud cover fraction calculated as before,

Finally, $Q1 = 0.56 * F * Q_d$

Where F is the projected area body factor.
If $70° >= \theta >= 2°$, $F = 0.386 - 0.0032*(90 - \theta)$, ($\theta$ is in degrees in the formula),
If $\theta < 2°$, $F = 0.110$
If $\theta > 70°$, $F = 0.325$

Indirect Incoming Solar Radiation Term ($Q2$)

$Q_i = 0.1 * (1 - c^2) * Q_n$, where Q_n is the normal solar radiation & c is the cloud cover fraction (as determined in $Q1$ above)

$Q2 = 0.224 * Q_i$

Terrestrial Radiation ($Q3$)

$Q3 = 0.028 * Q$, where Q is the directly measured solar radiation and is used in this case.

Sky Radiation ($Q4$)

$Q4 = 150\,[1 - c^2\,(0.50 - 0.0043\phi)] * [1 - 0.62 * \exp(-0.108Z) - 0.16 * (vp\text{^}0.5)]$,

Where c is the cloud cover fraction calculated as before, ϕ is the station's latitude in degrees, Z is the station's elevation in **kilometers**, and vp is the vapor pressure (in kPa),

$vp = RH*0.01*0.6112 * \exp[(17.62*T)/(T + 243.12)]$, where RH is the outdoor relative humidity expressed as a percent & T the air temperature in **°C**.

From the resulting Q_g, if the wind speed is < 7 mph, then the sun term in THSWI (in ° F) is $0.101 * Q_g$,

Otherwise, the sun term is $(1.10Q_g)/(8 + 0.45v)$, where v is the wind speed in mph.

REFERENCES

Steadman, R.G., 1979: The Assessment of Sultriness, Part II: Effects of Wind, Extra Radiation and Barometric Pressure on Apparent Temperature. *Journal of Applied Meteorology, July 1979*.

"Media Guide to NWS Products and Services", National Weather Service Forecast Office, Monterey, CA, 1995.

Quayle, R.G. and Steadman, R.G., 1998: The Steadman Wind Chill: An Improvement over Present Scales. *Weather and Forecasting, December 1998*

Barometric Pressure

What is it:
The weight of the air that makes up our atmosphere exerts a pressure on the surface of the earth. This pressure is known as atmospheric pressure. Generally, the more air above an area, the higher the atmospheric pressure, this, in turn, means that atmospheric pressure changes with altitude. For example, atmospheric pressure is greater at sea-level than on a mountaintop. To compensate for this difference and facilitate comparison between locations with different altitudes, atmospheric pressure is generally adjusted to the equivalent sea-level pressure. This adjusted pressure is known as barometric pressure. In reality, the Vantage Pro measures atmospheric pressure. When entering the location's altitude in Setup Mode, the Vantage Pro calculates the necessary correction factor to consistently translate atmospheric pressure into barometric pressure.

Barometric pressure also changes with local weather conditions, making barometric pressure an extremely important and useful weather forecasting tool. High pressure zones are generally associated with fair weather while low pressure zones are generally associated with poor weather. For forecasting purposes, however, the absolute barometric pressure value is generally less important than the change in barometric pressure. In general, rising pressure indicates improving weather conditions while falling pressure indicates deteriorating weather conditions.

Parameters Used: Outside Air Temperature, Outside Humidity, Elevation, Atmospheric Pressure

Formula:
Simply,

$P_{SL} = P_S * (R)$,

where P_{SL} is sea level pressure, P_S is the unadjusted reading sensed by the Davis barometer, and R is the reduction ratio, which is determined as follows:

First, Tv (virtual temperature in the "fictitious column of air" extending down to sea-level) can be determined as follows. The result is in degrees Rankine, which is similar to Kelvin except it uses a Fahrenheit scale divisions rather than Celsius scale divisions:

$Tv = T + 460 + L + C$,

where T is the average between the current outdoor temperature and the temperature 12 hours ago (in Fahrenheit) in whole degrees. L is the typical lapse rate, or decrease in temperature with height (of the "fictitious column of air"), as calculated by:

$L = 11\ Z/8000$,

where L is a constant value with units in °F. Z is elevation, which must be entered in feet.

The current dewpoint value and the station elevation are necessary to compute C. C is the correction for the humidity in the "fictitious column of air". It is determined from a lookup table (provided in the attached table). The table consists of dewpoints in °F every 4°F and elevations in feet every 1500 feet. Linear interpolation is performed to obtain the correct reduced pressure value. For dewpoints below –76°F, C = 0; for dewpoints above 92°F, a dewpoint of 92°F is assumed.

Now, Tv can be determined. From this, the following can be computed:

Exponent = $[Z/(122.8943111*Tv)]$

Once this exponent is computed, R can be computed from the following:

R = 10^[Exponent].

Thus, $P_{SL} = P_S * (R)$ can be calculated. Pressure can be in any units (R is dimensionless) and still yield the correct value.

This procedure is designed to produce the correct reduced sea-level pressure as displayed. This requires the user to know their elevation to at least ±10 feet to be accurate to every .01” Hg or ±3 feet to be accurate to every 0.1 mb/hPa.

This is a simplified version of the official U.S. version in place now.   The accepted method is to use lookup tables of ratio reduction values keyed to station temperature. These are based on station climatology. These values are unavailable for every possible location where a Davis user may have a station, thus this approach is not suitable.

It should be noted that if a sensor’s pressure readings require adjustment, the user can adjust either the uncorrected or the final reading to match the user's reference, as appropriate. If the user chooses to measure uncorrected atmospheric pressure or use another reduction method, they should set their elevation to zero. Subsequently, output data using the VantageLink can be read by or exported to another application and converted as desired.

The calibration of the sensor is a separate one time function performed on the unit during the manufacturing process. It is a completely independent operation from the calculation the Vantage Pro console makes to display a reading corrected to sea-level. It is described in a separate section. The calibration is done to ensure the sensor reads uncorrected or raw atmospheric pressure (not barometric pressure) properly. Any properly functioning unit will read the uncorrected atmospheric pressure within specifications. However, limits in the displayable range of the bar value may prevent the user from setting an incorrect elevation for their location. That is, a user at sea-level, may see a dashed reading if they set their unit to 5000' elevation or vice-versa. So, the best way to tell if a unit is functioning properly, is:

- use a reference that has been adjusted to indicate sea-level pressure and setting the Vantage Pro console to the proper elevation or
- use a reference that is reading the raw, uncorrected atmospheric pressure and set the Vantage Pro console elevation to zero

and verify that these readings are comparable.

REFERENCE

"Smithsonian Meteorological Tables". Smithsonian Institution Press, Washington, DC, 4th Ed. 1968.

"Federal Standard Algorithms for Automated Weather Observing Systems used for Aviation Purposes". Office of the Federal Coordinator for Meteorological Services and Supporting Research, Washington, DC, 1988

Rain Total

Unlike previous Davis systems, the Vantage Pro comes with only one type of rain collector. It is equipped with a 0.01" rain collector. All Vantage Pros physically measure in increments of 0.01 in. The system has a prevision for other types should they be added in the future.

The Vantage Pro is pre-configured for this type of rain collector. In the series of "Setup Screens", there is one for "Rain Collector". Simply press the DONE key to move to the next screen. By default, it should be set to ".01" Rain Collector". If it isn't, use the "+" and "-" arrow keys to select this type.

The rain display's units may be changed from inches to millimeters by pressing 2ND, then the UNITS key while in "Current Screen" mode with one of the rain fields selected. If millimeters is displayed, the console converts from inches to mm. If display millimeters is displayed, the counter will occasionally skip a reading due to rounding.

Rain Rate

Parameters Used: Rain Total (actually, rain rate is a measured variable in the sense that it is measured by the ISS and transmitted to the display console, whereas all other calculated variables are determined by the console from data received from the ISS.)

Formula:

Under normal conditions (see packet sequencing below) rain rate data is sent with a nominal interval of 10 to 12 seconds. Every time a rain tip or click occurs, a new rain rate value is computed (from the timer values) and the rate timers are reset to zero.

Rain rate is calculated based on the time between successive tips of the rain collector. The rain rate value is the highest rate since the last transmitted rain rate data packet. (Under most conditions, however, a rain tip will not occur every 10 to 12 seconds.)

If there have been no rain tips since the last rain rate data transmission, then the rain rate based on the time since that last tip is indicated. This results in slowly decaying rate values as a rain storm ends, instead of showing a rain rate which abruptly drops to zero. This results in a more realistic representation of the actual rain event.

If this time exceeds roughly 15 minutes, than the rain rate value is reset to zero. This period of time was chosen because 15 minutes is defined by the U.S. National Weather Service as intervening time upon which one rain "event" is considered separate from another rain "event". This is also the shortest period of time that the Umbrella will be seen on the display console after the onset of rain.

REFERENCES

"Surface Weather Observations and Reports ". Office of the Federal Coordinator for Meteorological Services and Supporting Research, Washington, DC, 1998

UV Index

INTRODUCTION

Ultraviolet (UV) radiation can cause health damage in many ways --
- to the skin: burning, premature aging, and possible skin cancer
- to the eyes: possible cataracts and other disorders
- to the body's immune system.

This Note discusses the interpretation of the Health EnviroMonitor® and Vantage Pro system's UV readings in terms of possible skin damage. One should, however, be aware of the other hazards and minimize exposure to UV.

The UV SPECTRUM

UV radiation is divided into three spectral regions: UV-A, wavelengths of 400 to 320 nanometers (nm); UV-B, 320 to 280 nm; and UV-C, 280 to 100 nm.

The earth's atmosphere absorbs wavelengths shorter than 290 nm (UV-C). UV-B rays pose the greatest risk of skin cancer. Some UV-A radiation is needed by the human body for the synthesis of vitamin D, but excessive amounts cause aging, wrinkling, and loss of elasticity of the skin, and they contribute to skin cancer and cataracts.

The Erythemal Action Spectrum (EAS) was defined by McKinlay and Diffey (1987) and has been accepted by the Commission Internationale de l'Eclairage (CIE) as the standard representation of the average skin response to UV-B and UV-A. The skin is 100 times more sensitive to radiation at 298 nm than to that at 319 nm.

UV MEASUREMENTS

The Health EnviroMonitor and Vantage Pro system displays two types of UV measurement: **Intensity**, the strength of UV radiation at the moment of measurement, and **Dose**, the total UV energy measured over a period of time.

INTENSITY

The UV intensity at a given instant is usually defined in one of three ways:
- The scientific measure of UV irradiance is usually given in units of Watts per square meter.
- The UV Index has been defined to give a more-easily-remembered set of units, ranging from 1 to 15.
- The intensity may also be defined as a Dose-rate, MEDs per hour.

The Health EnviroMonitor and Vantage Pro calculate and display the Index and Dose-rate.

<u>UV Index</u>. The Index was first defined by Environment Canada and has since been adopted by the World Meteorological Organization. In the U.S. the Environmental Protection Agency (EPA) has categorized the Index values as follows:

0 to 2, Minimal
3 to 4, Low
5 to 6, Moderate
7 to 9, High
10 and higher, Very High.

The Index is equal to the EAS-weighted irradiance (in Watts/m²) x 40. An Index of 10 is equivalent to an EAS-weighted irradiance of 0.25 W/m². The relationship between Index value and estimated time for sunburn is discussed below.

The Index value published by the U.S. National Weather Service is a forecast of the next day's noontime UV intensity (see Long, et al). The Index value displayed by the Health EnviroMonitor and Vantage Pro is the result of a real-time measurement.

Dose-rate. The Dose-rate is expressed in MEDs per hour, where a MED is the Minimum Erythemal Dose, the amount of sun exposure which causes barely perceptible skin sunburn redness (erythema). The MED and its scale factor are discussed below under DOSE.

For a MED scale factor of 1.0 (the base, or default, value) a Dose-rate of 4.3 MEDs per hour is equivalent to an Index of 10. Stated another way, the base MED rate is 3/7 of the Index value.

DOSE

As mentioned above, the MED, or Minimum Erythemal Dose, is the integral, or summation, of UV intensity over a period of time; it is the amount of EAS-weighted energy which causes barely perceptible redness to appear within 24 hours in previously-unexposed skin. The Health EnviroMonitor and Vantage Pro calculate the dose by performing a real-time integration of EAS-weighted intensity.

The base MED is equal to 21 mJ/cm^2 of EAS-weighted UV energy.

It's obvious that not all skin types have the same sensitivity to sunlight. The following sections discuss the interpretation of dose information for various skin types.

SKIN TYPES

The EPA has defined four skin phototypes to help individuals interpret UV data for their own sensitivities; these definitions are shown in Table 1a. Within each skin type a range of sensitivities are found; some

Table 1a. Description of Four Skin Phototypes (Source: EPA -017)

SKIN PHOTOTYPE		SKIN COLOR IN UNEXPOSED AREA	TANNING HISTORY
1	Never Tans, Always Burns	Pale or milky white; alabaster	Develops red sunburn; painful swelling; skin peels.
2	Sometimes Tans, appears; Usually Burns	Very light brown; sometimes freckles	Usually burns; pinkish or red coloring can gradually develop light brown tan.
3	Usually Tans, Sometimes Burns	Light tan, brown, or olive; distinctly pigmented	Rarely burns; shows moderately rapid tanning response.
4	Always Tans, Rarely Burns	Brown, dark brown, or black	Rarely burns; shows very rapid tanning response.

Table 1b. Description of Six Skin Types (Source: Environment Canada)

SKIN TYPE	CHARACTERISTICS	TANNING HISTORY
I	Blond hair, blue or green eyes, very light skin.	Always burns easily, never tans
II	Light to medium hair, eyes, and skin.	Always burns easily, tans minimally.
III	Medium hair, dark eyes, medium skin.	Burns moderately, tans gradually.
IV	Dark hair and eyes, light brown skin.	Burns minimally, always tans well.
V	Dark hair and eyes, very dark skin.	Rarely burns, tans profusely.
VI	Dark hair and eyes, very dark skin.	Never burns, deeply pigmented.

people will experience sunburn more quickly than others of the same phototype. Environment Canada has defined six skin types, as defined in Table 1b.

DOSE TO BURN

It must be remembered that reflected UV can play a large role in sun-burning, and the UV sensor may not be in a position to measure all the reflected radiation to which an individual -- one sitting beside a swimming pool, for example -- might be exposed. That person, then, could be receiving a larger dose than the weather station's measurement would indicate.

Table 2a. Suggested MED Scale Factor Ranges (four skin types)

SKIN PHOTOTYPE (EPA)		SCALE FACTORS
1	Never Tans, Always Burns	1.0 to 1.4
2	Sometimes Tans, Usually Burns	0.7 to 1.0
3	Usually Tans, Sometimes Burns	0.5 to 0.7
4	Always Tans, Rarely Burns	0.3 to 0.5

Table 2b. Description of Six Skin Types (Source: Environment Canada)

SKIN TYPE (Environment Canada)		SCALE FACTOR
I	Always burns easily, never tans	1.4
II	Always burns easily, tans minimally	1.0
III	Burns moderately, tans gradually	0.7
IV	Burns minimally, always tans well	0.6
V	Rarely burns, tans profusely.	0.5
VI	Never burns, deeply pigmented.	0.4

TIME TO BURN

To estimate the length of exposure time that will cause sunburn one can divide the Dose to Burn by the current Dose Rate. For example: 0.8 MEDs ÷ 3.2 MEDs/hour = 0.25 hour = 15 minutes.

The above Time to Burn equation must be used with caution. The Dose Rate can be expected to change during the dose period, so the Time to Burn will change. If, for example, the dose period is begun before solar noon the Dose Rate will probably increase during the period, so the Time to Burn will be shortened.

Similarly, if the initial Dose Rate is observed during a period of cloudiness or overcast skies, the subsequent Dose Rates and Time to Burn will be quite different if the sky clears.

REFERENCES

Environmental Protection Agency, 1994: Experimental UV Index. EPA 430-F-94-017, -018, and –019.

Long, C. S., et al: Ultraviolet Index Forecasts Issued by the National Weather Service. *Bulletin of the American Meteorological Society, April 1996.*

McKinlay, A. F., and B. L. Diffey, 1987: A reference spectrum for ultraviolet-induced erythema in human skin. *Human Exposure to Ultraviolet Radiation: Risks and Regulations.* W. F. Passchier and B. F. Bosnajakovic, eds., Elsevier, 83-87.

Moon Phase

Parameters Used: Latitude, Longitude, Time and Date, Time Zone, Daylight Savings Time Setting

Sufficient accuracy is obtained from the following formula for i, the phase angle:

$i = 180° - D - 6.289° \sin M' + 2.1° \sin M - 1.274° \sin (2D - M') - 0.658° \sin 2D$

where

- D is the mean elongation of the moon (the maximum angular distance between the earth and the moon)
- M' is the moon's mean anomaly (angular distance, measured from where the moon is closest to the earth in its orbit, if it moved around the earth at a constant angular velocity)
- M is the sun's mean anomaly (angular distance, measured from where the earth is closest to the sun in its orbit, if it moved around the earth at a constant angular velocity)

and the terms in the equation provide increasing amounts of mean accuracy to calculate the phase angle as follows (hr:min):

- D = 20:57
- $6.289° \sin M'$ = 8:35
- $2.1° \sin M$ = 4:26
- $1.274° \sin (2D - M')$ = 1:56
- $0.658° \sin 2D$ = 0:38

Note: these equations assume that the sun and moon both revolve around the earth, for simplicity. However, when addressing the positions in orbit, it is actually the earth revolving around the sun, so this should be understood when trying to understand the physical meaning described in the definitions.

The equations for D, M' and M are as follows:

D = 297.8501921 + 12.19074911**days*
M' = 134.9633964 + 13.06499295**days*
M = 357.52911 + 0.985600281**days*,

Where *days* (in days and fractions of days) is the number of days since Jan 1st, 2000 at 12:00 UTC

Local time needs to be converted to UTC in order to be used in the formulas:

UTC = Local Time - Time Zone Offset (including adding one hour for daylight savings if and when in use)

The phase angle is modified so that it can be used to determine whether the moon is waxing (illuminated portion increasing in size) or waning (decreasing in size):

If i >= 180°, then $k = 1 - (k / 2)$

Now, the phase angle can be used to determine which phase the moon is in:

$i = (i * 8) + 0.5$

The result is interpreted as follows:
0 = New Moon, 1 = Waxing Crescent, 2 = First Quarter, 3 = Waxing Gibbous, 4 = Full Moon,
5 = Waning Gibbous, 6 = Last Quarter, 7 = Waning Crescent

Bulletin Graphic

k is the fraction of the moon's disk that is illuminated. It is used to draw the moon phase icon in the Bulletin.

$k = (1 + \cos i)/ 2$

k is a number between zero and one that indicates how much of the moon's disk should be drawn as lit. It indicates the "terminator's" (boundary between light and dark face) position on the observed face of the moon.

k can also be interpreted as listed below
0.00 = New Moon
0.25 = First Quarter
0.50 = Full Moon
0.75 = Last Quarter

REFERENCE

Meeus, Jean: "Astronomical Algorithms". Willman-Bell, Richmond, VA, 2nd Ed. 1998.

Description of ET, Reference ET, and the Crop Coefficient

Evapotranspiration (ET) is the amount of water that moves from the ground (and plants on the ground) to the atmosphere through both evaporation and transpiration. It is primarily important to people who are monitoring plant growth and associated water usage.

Measuring actual ET for a given location requires the measurement of weather variables at different heights at the same location and is beyond the capabilities of the current Davis weather stations. Instead, a single set of weather data measurements (described in detail below) are used to calculate a Reference ET (ET_o). ET_o is the amount of ET that is expected at a location with specified reference conditions under the actual weather conditions. The two most common reference conditions used for agricultural purposes are the grass reference – well watered grass that completely shades the ground, is uniformly clipped to a few inches in height – and the alfalfa reference – similar to the grass reference with alfalfa instead of grass, and a different height. The Davis ET calculations all calculate ET_o for a grass reference.

To determine actual ET from a reference ET_o, multiply the ET_o by a crop coefficient (K_c). The crop coefficient accounts for the type of plant, the maturity of the plant, and may include local factors such as soil type. Davis Instruments does not supply crop coefficients. It is up to the individual user to determine what K_c is appropriate. See below for a list of some sources. It is very important, when selecting K_c to make sure that the coefficient is for use with a grass reference. Do not use coefficients that were derived from alfalfa referenced ET_o.

The different Davis ET_o calculations

There are three ways that ET is calculated by Davis weather stations. They differ in how the weather data values are gathered and in how Net Radiation is calculated. The three methods are: GroWeather calculated on the console, GroWeather calculated on a PC, and Vantage Pro (calculated on the console). In all methods, hourly ET values are calculated from hourly averages of weather variables. The differences arise from differences in the computational abilities of the GroWeather station, Vantage Pro station and a PC.

Data Sampling and variables required for Calculation

The GroWeather console calculated ET_o samples Temperature, Humidity, Wind Speed, Solar Radiation over a one hour period. This sampling is independent of sampling undertaken for the creation of archived data records. At the end of the hour, the arithmetic mean is calculated for each value by dividing the sum of the sampled data values by the number of samples taken. The number of samples is tracked for each sensor independently in case some sensors are not connected for some part of the period. In addition, the raw Barometer value (i.e. not corrected for altitude) at the end of the hour is read.

The temperature is calculated in tenths of a degree F, the humidity is calculated in tenths of a percent, wind speed is calculated in miles per hour, solar radiation is calculated in watts per square meter, and atmospheric pressure is read in thousandths of an inch of mercury. All arithmetic is in integers. Values that use fractions are represented by multiplying by an appropriate value. The formulas given below that use functions more complicated than addition, subtraction, multiplication, and division are calculated with table lookups with linear interpolation where appropriate.

The GroWeather PC calculated ET_o uses data from the historical archived data to calculate the average temperature, humidity, wind speed, solar radiation; and the final atmospheric pressure. In addition, the software uses the latitude, longitude, and time zone settings set in the Station Configuration dialog.

The Vantage calculated ET_o takes samples of Temperature, Wind Speed, and Solar Radiation over a one hour period and derives an average value in a manner similar to the GroWeather console. Instead of sampling the humidity and deriving an “average humidity” for the hour, each time the temperature is sampled, the value of the saturation vapor pressure and actual water vapor pressure are calculated from the current values of temperature and humidity and sampled. These vapor pressure values (in kPa) are used to compute the average saturation vapor pressure and the average water vapor pressure for the hour. The Vantage has the capability to perform floating point arithmetic.

General ET_o Calculation

For the most part, these equations are applicable to all 3 calculation methods. Where they differ they are marked as follows: (GWc) applies to the GroWeather Console calculation, (GWpc) applies to the GroWeather PC calculation, and (VP) applies to the Vantage calculation

Measured Variables

T_F mean air temperature in tenths of a degree Fahrenheit
U_{MPH} mean wind speed in whole miles per hour
R_s mean solar radiation in whole Watts per square meter
H mean humidity in percent (value is between 0 and 100). (GWc and GWpc only)
P_{in} atmospheric air pressure (not corrected for elevation) at the end of the hour; thousandths of inches of mercury.

Calculated Values
(unit conversions)

T_C mean temperature in Celsius

$$T_c = (T_F - 32) * 5/9$$

T_K mean temperature in Kelvin

$$T_K = T_C + 273.16$$

P_{kPa} atmospheric pressure in kPa

$$P_{kPa} = P_{in} * 33.864$$

$U_{m/s}$ mean wind speed in meters per second

$$U_{m/s} = U_{MPH} * 0.44704$$

R_n average net radiation over the hour as described in the next section. Watts per square meter

e_a saturation water vapor pressure in kPa

$$e_a = 0.6108 * e^{\left(\frac{17.27 * T_C}{T_C + 237.3}\right)}$$

e_d actual water vapor present

Δ

$$e_d = e_a * \frac{H}{100}$$

Δ slope of the saturation vapor curve at T_C

$$\Delta = \frac{e_a}{T_K} * \left(\frac{6790.4985}{T_K} - 5.02808\right)$$

γ psychometric constant

$$\gamma = 0.000646 * (1 + 0.000946 * T_C) * P_{kPa}$$

W weighting factor that expresses the relative contribution of the radiation component

$$W = \frac{\Delta}{\Delta + \gamma}$$

F the wind function indicates the amount of energy that the wind contributes towards ET. There are two functions, one for day (solar radiation > 0) and one for night.

$$F_d = 0.030 + 0.0576 * U_{m/s}$$

$$F_n = 0.125 + 0.0439 * U_{m/s}$$

λ latent heat of vaporization. Used to convert net radiation in Watts per square meter into the amount of water evaporated in mm

$$\lambda = 694.5 * (1 - 0.000946 * T_C)$$

ET_o the hourly potential ET in mm

$$ET_o = W * \frac{R_n}{\lambda} + (1 - W) * (e_a - e_d) * F$$

Formulas for Net Radiation

Solar radiation is the primary source of energy that drives evapotranspiration, but what is important is the net radiation, incoming radiation minus outgoing radiation, at all wavelengths.

The Davis solar radiation sensor measures incoming radiation in the visible portion of the spectrum. From this we must subtract out the component that is reflected off the plant leaves. This value is called the albedo (α).

In addition to the radiation in the visible spectrum, we must also take account of the longer wavelength thermal radiation. This is modeled as black-body radiation coming from three sources at the measured air temperature. The first source is the portion of the sky that does not contain clouds, the second source is the portion of the sky containing clouds, and the third source is the ground radiating into the sky. The first two sources are incoming radiation and the third is outgoing radiation. In order to determine the relative contributions of source one and two, we need to calculate the percentage of the sky that is covered by clouds.

The cloud cover fraction is estimated by comparing the actual mean solar radiation received against the amount we would have received if the sky was clear. In order to calculate the clear sky radiation, it is necessary to calculate the height of the sun above the horizon (solar altitude angle). The altitude of the sun depends, in turn, on the latitude, longitude, day of the year, and time of the day.

Net Radiation on the GroWeather Console

ET_o calculated by the GroWeather console assumes a simple relationship between solar radiation and net radiation.:

$$R_n = 0.5625 * R_s$$

The constant 0.5625 was chosen by examining several 15 day sets of ET_o data from CIMIS weather stations in July and May 1994. For each data set, the total ET_o was calculated using several scale factors. It was found that calculated ET_o was equal to the reported ET_o for scale factors between about 0.535 and 0.5875. Any value in this range would have produced a value within 10 percent of the correct value. Later, a whole year's worth of data from a single station was analyzed and this criteria was found to be true only between April and September. From October through March, lower scale factors are required (as low as 0.24 in January) and therefore the ET_o calculated on the GroWeather console is too high.

Net Radiation on the GroWeather calculated on the PC

Here are the equations used in the GroWeatherLink software (version 1.2) to calculate net radiation

Input values

Lat_d Latitude of the station (N is positive) in degrees

Lon_d Longitude of the station (E is positive) in degrees

TZ timezone of the station (difference in time between the local civil time and UTC, PST = -8.0) in hours

DOY Day of the year (between 1 and 365)

D_l serial number of the day (number of days since Jan 1, 1900

$Time_l$ local civil time in minutes after midnight (0 – 1439)

Note that this is the time and date of the middle of the hour.

D_{UTC} the date in Greenwich at the same instant as $Time_l$ in days since Jan 1, 1900

$Time_{UTC}$ the time in Greenwich at the same instant as $Time_l$ in minutes

$$Time_{GMT} = Time_l - (TZ * 60)$$

if $Time_{GMT} < 0$

$$D_{GMT} = D_l - 1$$

$$Time_{GMT} = Time_{GMT} + 1440$$

if $Time_{GMT} \geq 1440$

$$D_{GMT} = D_l + 1$$

$$Time_{GMT} = Time_{GMT} - 1440$$

otherwise

$$D_{GMT} = D_l$$

Astronomical Values

D_{J2000} number of days (with fractions) since J2000.0 (i.e. 1/1/2000 12:00 noon)

$$D_{J2000} = \left(D_{GMT} - D_{12/31/1999}\right) - 1.5 + \frac{Time_{GMT}}{1440}$$

L' mean solar longitude in radians

$$L' = \left(280.46 + 0.98564742 * D_{J2000}\right) * \frac{\pi}{180}$$

M mean solar anomaly in radians

$$M = \left(357.528 + 0.985600273 * D_{J2000}\right) * \frac{\pi}{180}$$

L_{ecl} solar ecliptic longitude in radians

$$L_{ecl} = \begin{pmatrix} L'_{\deg} \\ + \left(1.915 - 0.00000013142\right) * \sin(M) \\ + 0.2 * \sin(2 * M) \end{pmatrix} * \frac{\pi}{180}$$

ϵ obliquity of the ecliptic in radians

$$\varepsilon = \left(23.439 + 0.0000003559 * D_{J2000}\right) * \frac{\pi}{180}$$

δ solar declination in radians

$$\delta = \sin^{-1}\left(\sin\left(L_{ecl}\right) * \sin(\varepsilon)\right)$$

Equation of Time

A_1 angle 1 in radians

$$A_1 = \left(0.98561 * DOY - 4.02\right) * \frac{\pi}{180}$$

A_2 angle 2 in radians

$$A_2 = \left(1.9712 * DOY - 8.04\right) * \frac{\pi}{180}$$

θ angle Theta in radians

$$\theta = \begin{pmatrix} 9.122 + 0.98561 * DOY \\ + 1.915 * \sin(A_1) + 0.014 * \cos(A_1) \\ + 0.02 * \sin(A_2) \end{pmatrix} * \frac{\pi}{180}$$

Q quadrant of Θ (1 to 5)

Φ Another angle in degrees

$$\phi = \tan^{-1}\left(\frac{\tan(\theta)}{0.91747}\right) * \frac{180}{\pi}$$

Now put Φ in the same quadrant as θ

if $\phi < 0$

$$\phi = \phi + Q * 90$$

otherwise

$$\phi = \phi + (Q - 1) * 90$$

Eqt equation of time (the difference between mean noon and true solar noon) in minutes

$$Eqt = 36.486 + 3.94244 * DOY - 4 * \phi$$

LTO Local Time Offset takes into account the difference between the station's longitude and the standard longitude of the timezone. It also takes care of the fact that we want Noon (instead of Midnight) to be zero. In minutes of time

$$LTO = \left(\frac{Lon_d}{15} - TZ + 12\right) * 60$$

HA hour angle of the sun (noon is zero) in radians

$$HA = \left(\frac{LTO + Eqt + Time_l}{4}\right) * \frac{\pi}{180}$$

h_r solar altitude angle in radians

$$h_r = \sin^{-1}\begin{pmatrix} \sin(Lat) * \sin(\delta) + \\ \cos(Lat) * \cos(\delta) * \cos(HA) \end{pmatrix}$$

h_d solar altitude angle in degrees

$$h_d = h_r * \frac{180}{\pi}$$

Cloud Cover

c cloud cover factor. Fraction of the sky covered by clouds (between 0.0 and 1.0)

if $h_d < 10$

Use the previous value for c

Otherwise, use the following equations:

G_{sc} Solar constant (extraterrestrial radiation, normal to the sun at 1 AU) in Watts per square meter

$$G_{sc} = 1367$$

R_a clear sky global radiation in Watts per square meter

$$R_a = \left(0.79 - \frac{3.75}{h_d}\right) * G_{sc} * \sin(h_r)$$

Make sure that R_s is <= R_a then calculate:

$$c = \left(1.333 - 1.333 * \frac{R_s}{R_a}\right)^{0.294}$$

Make sure c is between 0.0 and 1.0.

Albedo

I extraterrestrial radiation

$$I = G_{sc} * \sin(h_r)$$

α albedo (percent of visible light reflected from plant surface

$$if\ \frac{R_s}{I} < 0.375$$

$$\alpha = 0.26$$

otherwise

$$\alpha = 0.00158 * h_d + 0.386 * e^{(-0.0188 * h_d)}$$

e_{d-mb} water vapor pressure in millibars

$$\mathrm{e}_{d,mb} = \mathrm{e}_d * 10$$

$\varepsilon_a(0)$ clear sky emissivity

$$\varepsilon_a(0) = 1.08 * \left(1 - e^{-\left(\mathrm{e}_{d,mb}^{\left(\frac{T_k}{2016}\right)}\right)}\right)$$

σ Stefan Boltzmann constant that relates blackbody radiation to temperature.

$$\sigma = 5.67 * 10^{-8}\ W\ m^{-2}\ K^{-4}$$

R_c Net radiation in Watts per square meter

$$R_n = 0.89 * \left((1-\alpha) * R_s + (\varepsilon_a(0) * (1-c) + c - 0.98) * \sigma T_k^4\right)$$

Net Radiation on the GroWeather calculated on the Vantage

Here are the equations used in the Vantage to calculate net radiation

Input values

Lat_d Latitude of the station (N is positive) in degrees

Lon_d Longitude of the station (E is positive) in degrees

Z_f station altitude in feet

TZ timezone of the station (difference in time between the local civil time and UTC, PST = -8.0) in hours

D_l serial number of the day (number of days since Jan 1, 1900

$Time_l$ local civil time in minutes after midnight (0 – 1439)

Note that this is the time and date of the middle of the hour.

D_{UTC} the date in Greenwich at the same instant as $Time_l$ in days since Jan 1, 1900

$Time_{UTC}$ the time in Greenwich at the same instant as $Time_l$ in minutes

$$Time_{GMT} = Time_l - (TZ * 60)$$

$$\text{if } Time_{GMT} < 0$$

$$D_{GMT} = D_l - 1$$

$$Time_{GMT} = Time_{GMT} + 1440$$

$$\text{if } Time_{GMT} \geq 1440$$

$$D_{GMT} = D_l + 1$$

$$Time_{GMT} = Time_{GMT} - 1440$$

otherwise

$$D_{GMT} = D_l$$

Astronomical Values

D_{J2000} number of days (with fractions) since J2000.0 (i.e. 1/1/2000 12:00 noon)

$$D_{J2000} = (D_{GMT} - D_{1/1/2000}) - 0.5 + \frac{Time_{GMT}}{1440}$$

L' mean solar longitude in radians

$$L' = (280.46646 + 0.98564736 * D_{J2000}) * \frac{\pi}{180}$$

M mean solar anomaly in radians

$$M = (357.52911 + 0.985600281 * D_{J2000}) * \frac{\pi}{180}$$

C equation of the center is the difference between the mean and true values of longitude and anomaly, in radians

$$C = \begin{pmatrix} (1.914602 - 1.3188 * 10^{-7}\ D_{J2000})\sin(M) + \\ (0.019993 - 2.765 * 10^{-9}\ D_{J2000})\sin(2M) \end{pmatrix} * \frac{\pi}{180}$$

ϵ obliquity of the ecliptic in radians

$$\varepsilon = 23.43929$$

δ solar declination in radians

$$\delta = \sin^{-1}(\sin(L' + C) * \sin(\varepsilon))$$

Equation of Time

e eccentricity of the earth's orbit

$$e = 0.016708634 - 0.0000000011509 * D_{J2000}$$

y intermediate value

$$y = \tan^2\left(\frac{\varepsilon}{2}\right)$$

Eqt_r equation of time (the difference between mean noon and true solar noon) in radians

$$Eqt_r = y\sin(2L) - 2e\sin(M) + 4ey\sin(M)\cos(2L)$$

Eqt_m equation of time in minutes

$$Eqt_m = Eqt_r * 4 * \frac{180}{\pi}$$

r distance between the earth and sun in AU

$$r = \frac{1.000001018 * (1 - e^2)}{1 + e * \cos(M + C)}$$

LTO Local Time Offset takes into account the difference between the station's longitude and the standard longitude of the timezone. It also takes care of the fact that we want Noon (instead of Midnight) to be zero in minutes of time

$$LTO = \left(\frac{Lon_d}{15} - TZ + 12\right) * 60$$

HA hour angle of the sun (noon is zero) in radians

$$HA = \left(\frac{LTO + Eqt + Time_l}{4}\right) * \frac{\pi}{180}$$

----

h_r solar altitude angle in radians

$$h_r = \frac{12}{\pi} * \left[\sin(Lat_r) * \sin(\delta) * \frac{\pi}{12} + \cos(Lat_r) * \cos(\delta) * \left(\sin\left(HA + \frac{\pi}{24}\right) - \sin\left(HA - \frac{\pi}{24}\right)\right)\right]$$

h_d solar altitude angle in degrees

$$h_d = h_r * \frac{180}{\pi}$$

Cloud Cover

c cloud cover factor. Fraction of the sky covered by clouds (between 0.0 and 1.0)

if $h_d < 10$

$$c = c_{saved}$$

Otherwise, use the following equations:

G_{sc} Solar constant (extraterrestrial radiation, normal to the sun at 1 AU) in Watts per square meter

$$G_{sc} = 1367$$

z_m station altitude in meters

$$z_m = z_f * 0.3048$$

Ra clear sky global radiation in Watts per square meter

$$R_a = \left(0.75 - \frac{z_m}{32}\right) * \frac{G_{sc}}{r^2} * \sin(h_r)$$

Make sure that R_s is <= R_a then calculate:

$$c = \left(1.333 - 1.333 * \frac{R_s}{R_a}\right)^{0.294}$$

Make sure that c is between 0.0 and 1.0, then calculate

c_{saved} cloud factor to use at night if this is the last hour with $h_d > 10$

$$c_{saved} = \mathrm{MAX}((c - 0.25), (0.0))$$

Albedo

I extraterrestrial radiation

$$I = \frac{G_{sc}}{r^2} * \sin(h_r)$$

α albedo (percent of visible light reflected from plant surface

$$if\ \frac{R_s}{I} < 0.375$$

$$\alpha = 0.26$$

otherwise

$$\alpha = 0.00158 * h_d + 0.386 * e^{(-0.0188 * h_d)}$$

$e_{d,mb}$ water vapor pressure in millibars

$$\mathrm{e}_{d,mb} = \mathrm{e}_d * 10$$

$\varepsilon_a(0)$ clear sky emissivity

$$\varepsilon_a(0) = 1.08 * \left(1 - e^{-\left(\mathrm{e}_{d,mb}^{\left(\frac{T_k}{2016}\right)}\right)}\right)$$

σ Stefan Boltzmann constant that relates blackbody radiation temperature.

$$\sigma = 5.67 * 10^{-8}\ W\ m^{-2}\ K^{-4}$$

R_c Net radiation in Watts per square meter

$$R_n = 0.89 * \left(\left(1-\alpha\right) * R_s + 0.98 * \left(\varepsilon_a(0) * \left(1-c\right) + c - 1\right) * \sigma T_k^4\right)$$

ACCURACY

These equations were modeled after the ones used by the California Irrigation Management Information System (CIMIS), a program run by the California Department of Water Resources. Therefore, the accuracy of the Davis ET_o calculations are made against the ET_o calculations made by CIMIS. Some of the differences between Davis and CIMIS ET_o calculated values are due to differences in resolution, rather than accuracy.

There are two major factors that cause differences between Davis and CIMIS ET_o calculations: differences in sensor measurements, and differences in net radiation values.

On the GroWeather, all wind averages are in one mile per hour increments, whereas CIMIS data has a higher resolution. The Vantage Pro measures wind speed in one mile per hour increments, but maintains a higher resolution for hourly averages.

As explained above, there are several different ways to calculate a hourly average vapor pressure and saturation vapor pressure values. The CIMIS method is to calculate and sample the vapor pressure value as described for the Vantage Pro. However, the saturation vapor pressure is calculated from the average temperature. This method will produce a saturation vapor pressure that is equal or lower than the average of the sampled saturation pressures.

The net radiation formula given above are all approximations of the formula CIMIS uses. CIMIS either directly measures net radiation, or uses a formula that includes a provision for an empirically derived cloud cover factor. CIMIS determines this factor either from data collected at the site over a four year period, or from other sites in the same region. Twelve factors are determined, one for each month.

REFERENCES

General reference on ET
Jensen, M .E., Burman, R. D., Allen, R. G., Editors (1990) "*Evapotranspiration and irrigation water requirements.*" ASCE Manuals and Reports on Engineering Practice No 70.

Paper describing CIMIS' equations and methodology
Snyder, R. L., Pruitt, W. O. (1992). "Evapotranspiration Data Management in California" *Irrigation & Drainage Session Proceedings/Water Forum '92 EE, HY, IR, WR, div/ASCE*

Paper describing the net radiation equations used by the GroWeather PC calculation
Dong, A, Grattan, S. R., Carroll, J. J., Prashar, C. R. K. (1992). "Estimation of net radiation over well-watered grass." *J. of Irrigation and Drainage Engineering*, Vol. 118, No. 3 ASCE

Web sites with useful information
CIMIS home page
http://wwwdpla.water.ca.gov/cgi-bin/cimis/cimis/hq/main.pl

Provides some guidelines for water requirements for growing landscape plants in California
http://wwwdpla.water.ca.gov/urban/conservation/landscape/wucols/index.html

Sunrise/Sunset

Parameters Used: Latitude, Longitude, Time and Date, Time Zone, Daylight Savings Time Setting

Sunrise and sunset is a matter of finding when, local time, the sun is on the horizon. The following equations describe the position of the sun in the sky:

Solar altitude, α, is the angular distance of the sun above the horizon, given by:

$\sin \alpha = \sin \phi \sin \delta + \cos \phi \cos \delta \cos h$

ϕ is latitude, δ is the declination angle of the sun, h is the hour angle

declination angle is the latitude on the earth at which the sun is directly overhead (south latitudes are indicated as a negative number)

hour angle is the non-negative angular distance east or west from directly overhead

These formulas indicate the true geometric position of the sun. When the sun is on the horizon (as in the case of sunrise and sunset), refraction by the atmosphere will alter the apparent position of the sun. Under average conditions, the sun will appear at the horizon when it is actually 34' (0.567°) below the horizon. Since sunrise and sunset is defined as when the upper half of the sun is visible on the horizon, and the radius of the sun when on the horizon is 16' (0.267°), sunrise and sunset are defined when the geometric position of the sun is 50' (0.833°) below the horizon. This is especially critical in polar regions.

The report also generates twilight times. There are three separate twilight times listed for both morning and evening:

Astronomical Twilight (Astro) is defined as the time at which the center of the sun is 18° below the horizon. At this time, stars and planets of sixth magnitude are visible directly above and generally there is no trace of twilight glow on the horizon. It's the time of complete darkness without an artificial light source.

Nautical Twilight (Naut) is defined as the time at which the center of the sun is 12° below the horizon. Distinguishing the outlines of objects on the ground is impossible past this point toward darkness, thus it marks the point at which navigation is impossible without an artificial light source.

Civil Twilight (Civil) is defined as the time at which the center of the sun is 6° below the horizon. At this time, stars and planets of first magnitude are visible and suspension of outdoor activities is required (on a clear day) without artificial lighting. Civil twilight is roughly 30 minutes long during the equinox.

The procedure to calculate any of these parameters is as follows. Details on the equations used and time convention and unit conversions follow this brief description:

1. First assume that a sunrise event occurred at 6:00 am local time, a sunset event at 6:00 pm local time. The equations used to describe the position of the sun already require a time, so we must make a first "guess" as to when the event will be.
2. Convert this local time to UTC time. The equations used to define the position of the sun (in this case, on the horizon) use UTC time.
3. Calculate the **declination** and subsequently the **hour angle** of the sun using this UTC time and the specified solar altitude of the given event.
4. Convert the resultant **hour angle** (which is in geometric coordinates) to UTC time.
5. Take the resultant UTC time to again *recalculate* the **declination** and subsequently the **hour angle** using this more accurate indication of the position of the sun.
6. Convert the resultant **hour angle** (which is in geometric coordinates) to UTC time.

To calculate the **hour angle** of the sun, *h*, at the given altitude (which is defined by sunrise/sunset or the twilight parameters), so rearranging the equation for the sun's altitude above for the hour angle, we get:

$$\cos h = \frac{\sin\alpha - \sin\phi \sin\delta}{\cos\phi\cos\delta}$$

If the result of this equation is undefined, that is, cos *h* > 1 or *h* < 1, then the event did not occur.

Otherwise, we can solve for $\cos^{-1}(h)$. The value of *h* here is an angle, which must be converted to a 24 hour time base. The procedure is as follows:
Convention: h = 0 = midnight, *h* = 90 = 6:00 am, *h* = 180 = noon, *h* = 270 = 6:00 pm
If h is determined to be a sunrise, then (180 – *h*)/15 is the value in hours (and fractions of hours), otherwise
If *h* is determined to be a sunset, then (180 + *h*)/15 is the value in hours (and fractions of hours)
The result is in **solar time**, which, in this convention, at Noon, the **mean sun** is at its highest point in the sky for the day, which can differ considerably from local time.

The sun's **declination** angle, δ**,** is determined as follows:

$\delta = \sin^{-1}(\sin T \sin \epsilon)$

$T = L + C$

$L = (280.46646 + 0.98564736 * days)$

$C = ((1.914602 - 0.00000013188 * days) * \sin M + (0.019993 - 0.000000002765 * days) * \sin 2M)$

$\epsilon = 23.43929°$

$M = (357.52911 + 0.985600281 * days)$

where *days* (including fractional days) is the number of days since Jan 1st, 2000, 12:00 UTC in UTC

T is the true anomaly of the sun (the angular distance between where the earth is closest to the sun is its orbit and the actual position in orbit)

L is the mean longitude of the sun (mean angular distance measured around the earth's orbit from the position at the time of equinox)

C is the center of the sun or the difference between the true, *T*, and mean, *M*, anomalies of the sun (determines the location of the sun resolving the differences between the actual position of the sun and the position the sun would have if the earth's angular motion were uniform)

M is the mean anomaly of the sun (same as true anomaly except it assumes the earth moves around the sun at a constant angular velocity), same as mean anomaly of the earth

ϵ is the obliquity of the earth (the amount the earth is tilted on its axis), which is constant for a century or so (It has an error in the year 2100 of only 0.013° when this constant is used.)

Note: these equations assume that the sun revolves around the earth, for simplicity. However, when addressing the positions in orbit, it is actually the earth revolving around the sun, so this should be understood when trying to understand the physical meaning described in the definitions.

Time Conversions

First, convert local mean solar time to local actual solar time. (Note: When calculating sunrise and sunset, the 6:00 am or 6:00 pm local time is considered actual solar time for simplicity. In the second iteration, when higher precision is needed, the result, local mean solar time, is corrected to actual solar time):

Actual Solar Time = Local Mean Solar Time – E

$E = y \sin 2L - 2e \sin M + 4ey \sin M \cos 2L$

where e is eccentricity of the earth's orbit (how much of an elliptical shape it has) as described below, and M is the sun's mean anomaly and L is the sun's mean longitude as described earlier

$e = 0.016708634 - 0.0000000011509 * days$

$y = \tan^2 (\epsilon / 2)$

where ϵ is obliquity as described earlier

The equation of time must be taken into account in order to determine the exact local time (as opposed to the local mean time). This specifies the difference between apparent time and mean time. Stated another way, it is the difference between the true position of the sun and the mean position of the sun. The mean sun assumes that its motion across the sky is uniform.

Then to convert to actual local solar time to local civil time (local civil time is refers to the time convention used by the public at large within a given time zone), take into account how far west or east of the "standard meridian" for their particular time zone. Fractions of minutes must be incorporated to avoid rounding errors. The **standard meridian** is determined as follows:

Standard Meridian = |(UTC Offset)| * 15

UTC Offset should include whether or not Daylight Savings Time is currently in use and be the absolute value or always positive value of the offset in this case.
Then, determine the offset from the standard meridian in hours:

Local Offset = (Standard Meridian - Longitude) / 15

Summarized, the formula for determining sunrise and sunset in local civil time:

Local Civil Time = Mean Solar Time – E + Local Offset

The Davis software further converts the results into UTC so a standard time base is used and thus, it is much easier to use any combination of Time Zone and latitude/longitude coordinates. Some may prefer to have the sunrise/sunset times in UTC. Others, for example, may want to determine what time it is in San Francisco when the sunrise in Tokyo occurs. Here is the relationship between UTC and local civil time:

UTC = Local Civil Time – UTC Offset

In general, UTC offsets are negative if the longitude is west, positive if east. The UTC Offset includes any corrections for Daylight Savings Time (if specified) and must be converted into hours and minutes as needed.

To convert between days, hours and minutes the following formulas may be used:

convert hours to days, hours / 24 convert minutes to days, minutes / 1440

convert days to hours, days * 24 convert minutes to hours, minutes / 60

convert days to minutes, days * 1440 convert hours to minutes, hours * 60

Retain fractional values to provide sufficient resolution, (e.g., days to 0.0001 resolution to obtain minutes)

REFERENCES

Meeus, Jean: "Astronomical Algorithms". Willman-Bell, Richmond, VA, 2nd Ed. 1998.

"Smithsonian Meteorological Tables". Smithsonian Institution Press, Washington, DC, 4th Ed. 1968.

WeatherLink Reports

NOAA Monthly Summary

General station information (Station Name, City, State, Units of Measure, etc.) appears at the top of the report. For each day in the report, you can view the following information (and a total for the month):

Day - Each row in the report shows information for a single day. The date for each row appears at the left of the row.
Mean Temperature - The mean temperature for the day. At the bottom of the column, the mean temperature for the month is displayed. The mean temperature is derived using all the Temp Out data values collected throughout the day. If "Calculate using integration method" is checked in the Degree-Day section of the NOAA setup dialog window, then the mean temperature is calculated by adding up all the temperature measurements for that day and then dividing by the number of samples. If "Calculate using integration method" is not checked in the NOAA setup, the mean temperature is the average of the daily high and low temperatures.
High Temperature & Time - The high temperature for the day and the time at which it occurred. At the bottom of the column, the highest temperature recorded during the month and the day on which it occurred is displayed. The time is the archive record time which contained the highest temperature for that day.
Low Temperature & Time - The low temperature for the day and the time at which it occurred. At the bottom of the column, the lowest temperature recorded during the month and the day on which it occurred is displayed. The time is the archive record time which contained the lowest temperature for that day.
Heating Degree-Days - The number of heating degree-days accumulated on each day. At the bottom of the column, the total heating degree-days accumulated during the month is displayed. Heating degree-days can be calculated using either the high/low summary or the integration methods.
Cooling Degree-Days - The number of cooling degree-days accumulated on each day. At the bottom of the column, the total cooling degree-days accumulated during the month is displayed. Cooling degree-days can be calculated using either the high/low summary or the integration methods.
Rain - The rainfall accumulated on each day. At the bottom of the column, the total rainfall accumulated during the month is displayed.
Average Wind Speed - The average wind speed for each day. At the bottom of the column, the accumulated average wind speed during the month is displayed.
High Wind Speed & Time - The high wind speed for each day and the time at which it occurred. At the bottom of the column, the highest wind speed for the month and the day on which it occurred is displayed.
Dominant Wind Direction - The dominant (a.k.a., prevailing) wind direction for the day. At the bottom of the column, the dominant wind direction for the month is displayed. The dominant wind direction is the wind direction that occurred most often throughout the day. In the event of a tie, the direction closest to the north going counter-clockwise around the wind rose is the result.

At the bottom of the report, the following monthly information is summarized:

Max >= 90°F (32°C) - The number of days on which the daily high temperature was 90°F (32°C) or above.
Max <= 32°F (0°C) - The number of days on which the daily high temperature was 32°F (0°C) or below.
Min <= 32°F (0°C) - The number of days on which the daily low temperature was 32°F (0°C) or below.
Min <= 0°F (-18°C) - The number of days on which the daily low temperature was 0°F (-18°C) or below.
Max Rain - The maximum daily rainfall during the month.
Days of Rain - The number of days on which rainfall exceeded 0.01" (0.2 mm), 0.1" (2 mm), or 1" (20 mm) is displayed.

Note: Max/Min thresholds are always in whole degrees. It’s therefore possible for the number of days in these last four items to be different, depending on whether you’re using US or metric units. For example, if there were a daily high registered between 89.6°F and 89.9°F the maximum would not count as >= 90°F; however, if you were using metric units, the maximum would count as >= 32°C (the equivalent of 90°F).

NOAA Yearly Summary

General station information (Station Name, City, State, Units of Measure, etc.) appears at the top of the report. Below the general information section are separate temperature, rainfall, and wind summary sections.

NOAA Yearly Temperature Summary

For each month in the NOAA Yearly Summary, you may view the temperature information listed below (and total and average for the year). The NOAA Yearly Summary also contains a rainfall and a wind summary section.

Year & Month - Each row in the report shows information for a single month. The month and year appear at the left of the row.
Mean Max - The mean maximum temperature for the month. At the bottom of the column, the mean maximum temperature for the year is displayed.
Mean Min - The mean minimum temperature for the month. At the bottom of the column, the mean minimum temperature for the year is displayed.
Mean - The mean temperature for the month. At the bottom of the column, the mean temperature for the year is displayed.
Departure From Norm - The amount by which the mean temperature departed from normal for the month. At the bottom of the column, the amount by which the mean temperature departed from normal for the year is displayed.
Heating Degree-Days - The number of heating degree-days accumulated during each month. At the bottom of the column, the total heating degree-days accumulated during the year is displayed. Heating degree-days can be calculated using either the high/low summary or the integration methods.
Cooling Degree-Days - The number of cooling degree-days accumulated during each month. At the bottom of the column, the total cooling degree-days accumulated during the year is displayed. Cooling degree-days can be calculated using either the high/low summary or the integration methods.
High Temperature & Date - The highest temperature for the month and the date on which it occurred. At the bottom of the column, the highest temperature recorded during the year and the month in which it occurred is displayed.
Low Temperature & Date - The lowest temperature for the month and the date on which it occurred. At the bottom of the column, the lowest temperature recorded during the year and the month in which it occurred is displayed.
Max >= 90°F (32°C) - The number of days on which the high temperature was 90°F (32°C) or above during the month. At the bottom of the column, the total number of days on which the high temperature was 90°F (32°C) or above during the year is displayed.
Max <= 32ºF (0°C) - The number of days on which the high temperature was 32°F (0°C) or below during the month. At the bottom of the column, the total number of days on which the high temperature was 32°F (0°C) or below during the year is displayed.
Min <= 32°F (0°C) - The number of days on which the low temperature was 32°F (0°C) or below during the month. At the bottom of the column, the total number of days on which the low temperature was 32°F (0°C) or below during the year is displayed.
Min <= 0°F (-18°C) - The number of days on which the low temperature was 0°F (-18°C) or below during the month. At the bottom of the column, the total number of days on which the low temperature was 0°F (-18°C) or below during the year is displayed.

Note: Thresholds are always in whole degrees. It’s therefore possible for the number of days in these last four items to be different, depending on whether you’re using US or metric units. For example, if there were a daily high registered between 89.6 and 89.9°F the maximum would not count as >= 90°F; however, if you were using metric units, the maximum would count as >= 32°C (the equivalent of 90°F).

NOAA Yearly Rainfall Summary

For each month in the NOAA Yearly Summary, you can view the rainfall information listed below (and total and average for the year). The NOAA Yearly Summary also contains a Temperature and a Wind summary section.
Year & Month - Each row in the report shows information for a single month. The month and year appear at the left of the row.
Total - The total rainfall for the month. At the bottom of the column, the total rainfall for the year is displayed.
Departure From Norm - The amount by which the total rainfall departed from normal for the month. At the bottom of the column, the amount by which the total rainfall departed from normal for the year is displayed.
Maximum Observation Day & Date - The highest daily rainfall total during the month and the date on which it occurred. At the bottom of the column, the highest daily rainfall total during the year and the month during which it occurred are displayed.
Days of Rain Over .01 in (0.2 mm) - The number of days on which total rainfall exceeded 0.01" (0.2 mm) during the month. At the bottom of the column, the number of days on which rainfall exceeded 0.01" (0.2 mm) during the year is displayed.
Days of Rain Over .1 in (2 mm) - The number of days on which total rainfall exceeded 0.1" (2 mm) during the month. At the bottom of the column, the number of days on which rainfall exceeded 0.1" (2 mm) during the year is displayed.
Days of Rain Over 1.0 in (20 mm) - The number of days on which total rainfall exceeded 1" (20 mm) during the month. At the bottom of the column, the number of days on which rainfall exceeded 1" (20 mm) during the year is displayed.

NOAA Yearly Wind Summary

For each month in the NOAA Yearly Summary, you may view the wind information listed below (and an average for the year). The NOAA Yearly Summary also contains a temperature and a rainfall summary section.
Year & Month - Each row in the report shows information for a single month. The month and year appear at the left of the row.
Average - The average wind speed for the month. At the bottom of the column, the average wind speed for the year is displayed.
High & Date - The high wind speed for the month and the date on which it occurred. At the bottom of the column, the highest wind speed recorded during the year and the month in which it occurred is displayed.
Dominant Direction - The dominant (a.k.a., prevailing) wind direction for the month. At the bottom of the column, the dominant wind direction during the year is displayed. The dominant wind direction is the wind direction that occurred most often throughout the month. In the event of a tie, the direction closest to the north going counter-clockwise around the wind rose is the result.

Heating & Cooling Degree-Days

Although degree-days are most commonly used in agriculture, they are also useful in building design and construction, and in fuel use evaluation. The construction industry uses heating degree-days to calculate the amount of heat necessary to keep a building, be it a house or a skyscraper, comfortable for occupation. Likewise, cooling degree-days are used to estimate the amount of heat that must be removed (through air-conditioning) to keep a structure comfortable. Just like growing degree-days, heating and cooling degree-days are based on departures from a base temperature. 65ºF is almost always used as this base.

One heating degree–day is the amount of heat required to keep a structure at 65ºF when the outside temperature remains one degree below the 65ºF threshold for 24 hours. One heating degree–day is also the amount of heat required to keep that structure at 65ºF when the temperature remains 24°F below that 65ºF threshold for 1 hour.

Likewise, one cooling degree–day is the amount of cooling required to keep a structure at 65ºF when the outside temperature remains one degree above the 65ºF threshold for 24 hours. One cooling degree–day is also the amount of cooling required to keep that structure at 65ºF when the temperature remains 24°F above that 65ºF threshold for 1 hour.

Depending on the calculation method, both heating and cooling degree-days can accumulate in the same day. Also, note that there are no negative degree-days. If the temperature remains below the threshold, there is no degree-day accumulation.

Heating and Cooling degree-days may be calculated by either the **High/Low method** or the **Integration method**.

Below are some representative heating and cooling degree-day totals from different parts of the United States.

Barrow, Alaska		Key West, Fla.	
Heating degree days	20,370	Heating degree days	68
Cooling degree days	0	Cooling degree days	4,820
Kansas City, Mo.		Hilo, Hawaii	
Heating degree days	5,326	Heating degree days	0
Cooling degree days	1,388	Cooling degree days	3,134
Bismarck, N.D.		Yuma, Ariz.	
Heating degree days	8,932	Heating degree days	983
Cooling degree days	499	Cooling degree days	4,244

Table data source: Williams, Jack. 1995. The USA TODAY Weather Almanac.

Growing Degree Days

Because temperature plays an important part in the rate of development of plants and many diseases and pests (especially insects), a measurement including the accumulation of heat with passing time is necessary to predict maturation. Growing degree-days provide a measure for calculating the effect of temperature on the development of plants and pests. One growing degree-day is the amount of heat that accumulates when the temperature remains one degree above the base developmental threshold for 24 hours. One growing degree–day is also the amount of heat that accumulates when the temperature remains 24° above the base threshold for 1 hour. Note that there are no negative degree-days. If the temperature remains below the threshold, there is no degree-day accumulation.

Unlike strict time predictions of plant or pest development, growing degree-day predictions hold true regardless of location or temperature fluctuations. As long as you know the number of degree-days necessary for plant/pest development, you may use degree-days as an accurate predictor. For example, you may know that it takes, in general, three weeks for a specific pest to develop. What you will find, however, is that the pest may take 4 weeks to develop in cooler weather and only 2 weeks to develop in warmer weather. The time prediction can be off by up to a week by looking at time alone, while the degree–day prediction should result in far greater accuracy.

Degree-Day Calculation Methods

The WeatherLink software uses the outside temperature data in conjunction with the base and upper thresholds entered for each crop/pest to calculate degree-days. You can choose between three possible methods for calculating degree-days: the growing degree-day cutoff method, the high/low method or the integration method.

Growing degree-day cutoff method

If you select the cutoff method, the software uses the highest and lowest temperatures for a given day to calculate the average for that day. Note, however, that if the low temperature is below the base threshold, the software uses the base threshold as the low temperature when calculating the average temperature for the day. In addition, if the high temperature is above the upper threshold, the software uses the upper threshold as the high temperature when calculating the average temperature. For this method to work, you must have entered the upper and lower thresholds.

The difference between the average temperature and the base threshold is assumed to be the number of degree-days accumulated on that day. (For example, if the average of the highest and lowest temperatures was 24° above the base threshold, the software would assume 24 degree-days for the entire day.

Note: Unless 15 hours worth of records exist in the database for that day (from midnight to 3pm, for example), the software will not calculate degree-days for that day.

High / Low method

If you select the high/low method, the software uses the highest temperature and the lowest temperature for a given day to calculate the average temperature for that day. The difference between the average temperature and the base threshold are assumed to be the number of degree-days accumulated on that day. For example, if the average of the highest and lowest temperatures is 24° above the base threshold, the software assumes 24 degree–days for the entire day.

Note: Unless 15 hours worth of records exist in the database for that day (from midnight to 3pm, for example), the software will not calculate degree-days for that day.

Integration method

If you select the integration method, the software calculates degree–days using the average temperature for an interval and the interval time. For example, if the average temperature during a 15 minute interval was 24° above the base threshold, the software would calculate 0.25 degree-days during that interval (24 * 15 minutes in interval/1440 minutes per day). The number of degree-days during each interval are added together to arrive at a degree-day total. This method calculates degree-day totals more accurately than the high/low method.

Temperature-Humidity Hours Report

Certain pests (in particular, some molds) develop most aggressively under specific combinations of temperature and humidity. Each pest can be expected to emerge when a specific number of temperature/humidity hours has accumulated. Temperature/Humidity hours, therefore, can be used to select the optimum time for application of preventative measures. The use of pesticides can be minimized and, when needed, used more efficiently and effectively. For more information, contact your local agricultural agent or university agricultural extension.

The temperature-humidity hours report contains the following information:

Name, Start Date, Thresholds - The report shows the name, start date, and the thresholds you entered.
Days Occurred - The report shows the number of days on which temperature-humidity hours accumulated.
Total for prior 3 days - The report shows the number of temperature-humidity hours accumulating on each of the past 3 days.
Development Total - The report shows the development total you entered.
Hours to Go - The report shows the total temperature-humidity hours left before the development total is reached.
Days to Go - The report shows the expected number of days before the development total is reached. This calculation is based on the average number of temperature-humidity hours during the last three complete days.

Soil Temperature Hours Report

Soil temperature hours can be used to monitor the relative portion of time that soil temperature is above freezing (or some other threshold) in order to select a time to plant. For more information, contact your local agricultural agent or university agricultural extension.

The soil temperature hours report contains the following information:

Total - The total number of soil temperature hours accumulating during the selected period of time.
Start Date, End Date, Threshold - The report shows the start and end dates and the threshold you entered.
Hours for the last 15 days - The report shows the number of soil temperature hours accumulating on each of the past 15 days.

Chilling Requirement Report

Certain fruit trees bear best when temperatures drop below specific levels for specific amounts of time during the dormant season. Chilling requirements provide a measure of this dormancy. For more information, contact your local agricultural agent or university agricultural extension.

The software calculates the number of hours of chilling for the selected period and displays that information at the bottom of the dialog box.

Bright Sunshine Hours Report

This report is only available in version 5.2 of the WeatherLink for Vantage Pro software.

WeatherLink can calculate the total hours of bright sunshine during any given period. To do so, you must enter a solar energy threshold above which is considered "bright sunshine". The default is 100 W/m2. WeatherLink calculates the amount of time the solar energy was above the threshold and reports that amount of time as the hours of daylight.

WeatherLink calculates and displays the hours of daylight accumulated between the start and end dates. The report is opened into Window's Notepad, from which you can print or copy the information. The report shows the total hours of daylight that occurred during the selected period of time, the selected start and end dates for the report and the solar radiation threshold used to determine "daylight", and the hours of daylight which occurred on each of the last 15 days of the report time period.

Leaf Wetness Hours Report

This report is only available in version 5.2 of the WeatherLink for Vantage Pro software.

You may track the number of hours during which temperature fell within a certain range and a leaf wetness threshold was exceeded.

The software calculates leaf wet hours and displays that information. The report is opened into Windows' Notepad from which you may copy or print the report information. The report shows the total leaf wet hours during the selected period, the start and end dates and the temperature and wetness the thresholds you entered, and the total leaf wet hours for each of the past 30 days.

Total ET Report

This report is only available in version 5.2 of the WeatherLink for Vantage Pro software.

You may calculate the total ET (evapotranspiration) which has occurred since a specified start date using a single K factor for the entire period.

Crop-specific K factors allow you to calculate evapotranspiration rates more accurately by allowing you to factor in the different transpiration rates of different crops at different stages in the growth cycle. A K factor of 1.0 is used for well watered grass that completely covers the ground and is uniformly clipped to a few inches in height. If a crop transpires more or less then average then the K factor is adjusted up or down. A K factor of 1.25 is used if the crop transpires 25% more than grass. A K factor of 0.80 is used if the crop transpires 20% less than grass. More information on ET K factors can be found at the following URL:
http://lawr.ucdavis.edu/coopextn/biometeorology/evapotranspiration/CropCoef/crop_coefficients.htm

The software calculates ET for the selected period and displays that information. The report is opened into Windows' Notepad from which you may copy or print the report information. The report shows the total ET since the start date, the start and end dates and the K factor you entered, and the total ET on each of the last 30 days.

Note: Do not use a K factor of 1.00 for alfalfa.

Fuel Demand Report

This report is only available in version 5.2 of the WeatherLink for Vantage Pro software.

The software includes a versatile fuel demand feature which allows you to track fuel demand for a hundreds of customers. The list shows all entered fuel customers. The check box at the bottom of the screen allows you to select the method by which the software calculates heating degree-day totals. By default, the software calculates heating degree-days using the average temperature for an interval and the interval time. For example, if the average temperature during a 15 minute interval was 75°F, the software would calculate 2.5 degree-hours during that interval for a base threshold of 65°F (10° * 15 minutes / 60 minutes). The number of degree-hours during each interval since the start date are added together to arrive at a heating degree-day total for use in estimating fuel usage.

You may select (by checking the check box) to have the software use the high/low method for calculating heating degree-days instead. In this method, the software uses the highest temperature and the lowest temperature to calculate the average temperature for each day. It then calculates heating degree-days by multiplying the number of degrees by which this "average" exceeds the heating degree day threshold by 24 hours.

To view an estimate of the remaining fuel for a customer, open the customer’s record and choose Estimate. The software calculates the heating degree-days since the last reading date (using the heating degree day threshold entered from the software) and calculates fuel usage based on this number of degree days. The estimated fuel used is subtracted from the number of gallons at the last reading to arrive at an estimate of the number of gallons remaining. The estimated gallons left is shown at the bottom of the dialog box.

Fuel Demand K factors allow you to calculate fuel demand more accurately by factoring in the different fuel consumption rate each customer has for a given number of heating degree-days. A K factor of 1.0 is used when degree days equals fuel consumption. If a customer uses more or less fuel then the K factor is adjusted up or down. The Fuel Demand report will also calculate the K factor based on past usage, and also allows you to edit the K factor if you wish.

WeatherLink Data Types

Parameter	Data Type	Size (bytes)	Sample Rate
Inside Temp	Current or Average	2	1 minute
Outside Temp	Current or Average	2	10-12 secs.
Hi Outside Temp	Highest	2	10-12 secs.
Low Outside Temp	Lowest	2	10-12 secs.
Inside Hum	Current	1	1 minute
Outside Hum	Current	1	50-60 secs.
Barometer	Current	2	15 minutes
Wind Speed	Average	2	2.5-3 secs.
Hi Wind Speed	Highest	2	2.5-3 secs.
Direction of Hi Wind		1	2.5-3 secs.
Wind Direction	Dominant (prevailing)	1	2.5-3 secs.
Wind Run	Total	Not stored	Calculated
Wind Chill	Average	Not stored	Calculated
Rain	Total	2	10-12 secs.
Rain Rate	Highest	2	10-12 secs.
Dewpoint	Current	Not stored	Calculated
Heat Index	Current	Not stored	Calculated
THW Index	Current	Not stored	Calculated
Solar Radiation	Average	2	50-60 secs.
Solar Energy	Total	Not stored	Calculated
Hi Solar Rad*	Highest	2	50-60 secs.
UV Radiation	Average	1	50-60 secs.
UV Dose	Total	Not stored	Calculated
Hi UV Index*	Highest	1	50-60 secs.
Heating Degree Days	Total	Not stored	Calculated
Cooling Degree Days	Total	Not stored	Calculated
ET	Total	1	1 hour
Leaf Wetness*	Current	1	62.5-75 secs.
Soil Moisture	Current	1	62.5-75 secs.
Leaf Temperature*	Current	1	62.5-75 secs.
Soil Temperature	Current	1	62.5-75 secs.
ISS Data Packets Received	Total	2	2.5-3 secs.
ISS Reception	Current	Calculated	Calculated
Archive Interval	Not Logged**	1	1 minute

*Available only with Revision B firmware in the display console

**value is stored in the WeatherLink database on the computer