COLORADO FLOWER GROWERS ASSOCIATION

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HUMIDITY — A PRIMER FOR GREENHOUSE USE

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Humidity is a factor in greenhouses which often causes growers considerable grief. Humidity is important for these reasons:

1. The amount of water vapor in the air determines the lowest possible temperature to which air can be cooled in fan-and-pad systems.
2. The amount of water in the air determines the lowest possible temperature to which air, or a plant in the air, can be cooled without condensation and formation of fog or free water on leaves and flowers.
3. The amount of water, with other factors, determines the rate of water loss from plants, and, therefore, the amount of stress inside the plant. Stress directly influences the number of side breaks and stem length.
4. Many important diseases (Botrytis, mildew, bacterial blight, etc.) are directly influenced by humidity, and proper control of humidity is an important disease control measure.

Several growers have requested information on the effects of manipulating humidity for the control of powdery mildew on roses, efficiency of some of the newer cooling pad materials, and its effect on many of the plants grown in Colorado greenhouses. In order to approach the subject intelligently, we need to know some basic terms, ways of measuring water in air, and how humidity actually varies outside and inside greenhouses.

Terminology

Most people are familiar with relative humidity (RH). Unfortunately, RH is a human comfort index. Plants may not be comfortable at a humidity that suits us. Secondly, RH varies directly in relation to two factors: 1) The actual amount of water vapor in air, and 2) the air temperature or "dry bulb" temperature (T_p). This is because RH is calculated by dividing the actual amount of vapor present by the amount of vapor the air could hold if saturated at the same temperature, and multiplying by 100. The water air can hold at saturation is a direct function of temperature, increasing as temperature rises (Fig. 1). So, RH can decrease without any change in concentration of water, as temperature increases.

There are several ways to express absolute amounts of water vapor:

1. mixing ratio (pounds of water per pound of dry air),
2. specific humidity (pounds of water per pound of moist air),
3. absolute humidity (pounds of water per cubic yard of moist air),
4. vapor pressure (inches mercury (Hg), millimeters mercury or millibars),
5. dew point (degrees Farhenheit).

The first three are seldom used in greenhouse terminology. Vapor pressure is more common. As temperature increases, molecular motion increases in a direct relationship to temperature, and the average motion of all molecules hitting a surface results in an average pressure usually expressed as "inches of mercury" — or the pressure at the bottom of a column of mercury so many inches high. Barometric pressure, which is the sum of all the pressures of the individual gases in a column of air (oxygen, nitrogen, water, etc.) is also reported in the same units. "Dew point" is the most common expression of absolute amounts of water vapor. This is the temperature at which condensation occurs; the air is saturated. For example, the dry bulb temperature (T_p) may be 70°F, but T_d is 52°F. If the air temperature is lowered to 52°, water will condense. Dew point, then, is a primary factor in greenhouse operation as it tells the grower how much he can lower plant and air temperatures without having free water condense on his plants.

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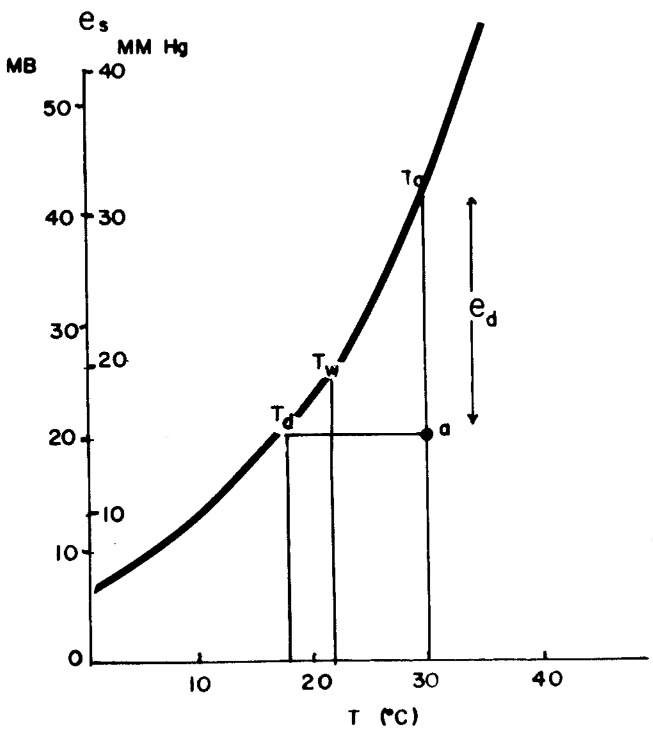

Fig. 1: Relationships between vapor pressure, dry bulb (T_p), wet bulb (T_w) and dew point (T_d).

Another major term is "wet bulb" temperature (T_W). This is the temperature that is reached by a thermometer whose bulb is enclosed by a wet surface under carefully defined conditions. Essentially, evaporative pads are wet surfaces and if they are 100% efficient, the air after passing through the pad should be at the wet bulb temperature.

The relationships between dry bulb, wet bulb, dew point, and vapor pressure are shown in Fig. 1. Assume that the dry bulb temperature as indicated is 30°C (86°F). If the air were saturated at that temperature (100% RH), the vapor pressure would be 1.241 inches Hg (about 40.6 mb at Denver's altitude), and the wet bulb and dew points would also be the same. However, in our climate, the air is often dry so that T_W is below the dry bulb and the dew point is even lower. In the example, the dew point is 18°C (64°F), or 0.595 in Hg. The relative humidity is:

$$\frac{0.595}{1.241} \times 100 = 46\% \text{ approximately.}$$

Determining humidity

The most common way for measuring humidity is by "psychrometric" methods. This is the measurement of wet and dry bulb temperatures under controlled conditions, and then referring to appropriate tables. Fig. 2 shows two types. By finding the difference between T_p and T_W and referring the Table 2, the relative humidity can be determined without calculation. If Table 3 is used, the dew point can be read directly. Fig. 3 is another means by which wet and dry bulb readings can be used to obtain relative humidity and also the mixing ratio. Quite often a special slide rule can be used to read RH directly and is supplied with the instruments shown in Fig. 2.

Table 1: Definitions important in working with humidity.

1. Absolute humidity (d_V)	The weight (mass) of water vapor per unit volume of moist air.
2. Barometric pressure	The uncorrected barometer reading, the total pressure of components in a column of air (at sea level, 760 mm Hg, or 29.92 inches mercury). (Roughly 25.0 in Hg at Denver).
3. Dew point (T_d)	The temperature at which any further cooling will cause water to condense from the air.
4. Dry bulb temperature (T_p)	Actual air temperature.
5. Mixing ratio (r)	The weight (mass) of water vapor per unit weight of dry air.
6. Psychrometry	Method of determining water content in a gas (air) by determining the difference between wet bulb and dry bulb temperatures.
7. Relative humidity (RH)	The ratio of the actual amount of water present to the amount of water that would be present if the air was saturated at the same temperature. Expressed as a percentage.
8. Specific humidity (q)	The weight (mass) of water vapor per unit weight of moist air.
9. Vapor pressure (3)	The pressure exerted by the water molecules in air. Sometimes referred to as "partial presure". The sum of all the pressures in a gas mixture (water, oxygen, nitrogen, CO_2, etc.) is equal to the barometric pressure.
10. Wet bulb temperature (T_W)	Temperature of an aspirated thermometer bulb encased by a wick saturated with water. It is the equilibrium temperature reached by an evaporating surface.

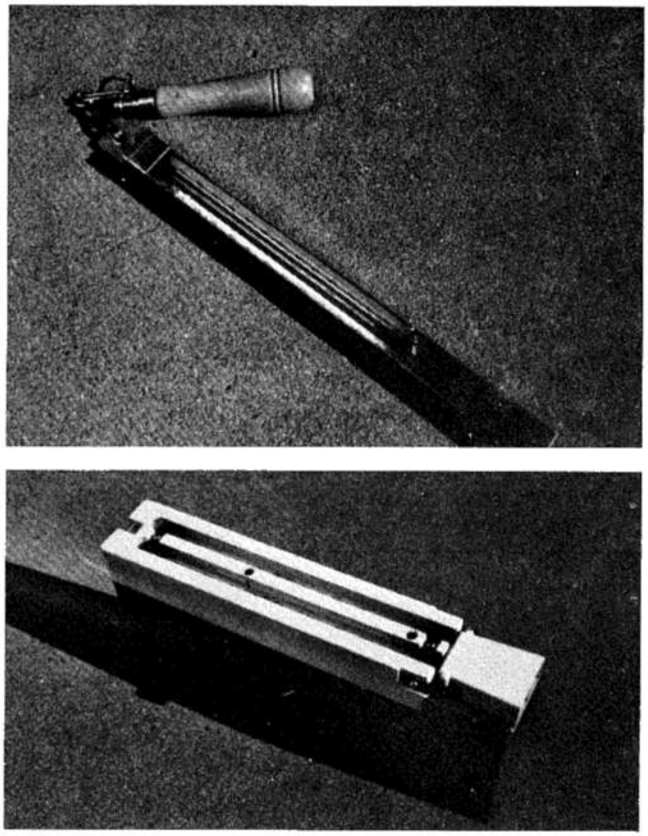

Fig. 2: Two examples of devices for determining humidity. The upper device is a sling psychrometer, costing between $10.00 and $20.00. The lower apparatus does not require whirling, but has its own fan motor. Cost ranges between $80.00 to $100.00. Readings obtained with these devices can be used in Tables 2 and 3 to determine relative humidity and dew point temperature.

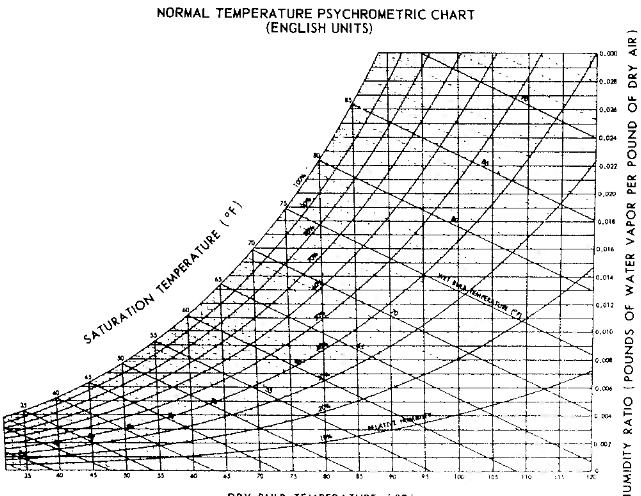

Fig. 3 Psychrometric chart for determining relative humidity and amount of water in air from wet and dry bulb temperatures. For example, presume that one obtains a dry bulb reading of 70°F and a wet bulb reading of 60°F. From 70 on the bottom line, move up vertically until reaching the intersection of the vertical 70 line and the diagonal 60 line. The relative humidity is approximately 57%.

Hair elements, paper elements other systems can be obtained to read relative humidity and dew point directly (Fig. 4). Unfortunately, most hair elements are seldom accurate to within ± 20%, and often suffer permanent shifts in calibration if subjected to extremes of humidity. If wet and dry bulb thermometers are utilized to obtain spot readings, the following guidelines should be used:

1. Use distilled water on the wick covering the wet bulb.
2. Use clean wicks.
3. Wet the wick only once during each reading.
4. The air movement over the wick must exceed 200 feet per minute.
5. The thermometers must be matched.
6. The thermometers should be protected from direct sunlight.
7. Take a series of thermometer readings over at least a 30 second period, or until the readings show no change. This may be as long as 60 seconds.

A direct reading hair element can be used for relative humidity as long as it is calibrated periodically with a good psychrometer, using the procedures above.

From wet and dry bulb readings, and Tables 2 and 3, the grower can gain an idea of:

1. Cooling efficiency.
2. Is the humidity too low for the crop during the day?
3. Is it likely that condensation will occur as temperatures drop in the evening?
4. Is the pad being turned off early enough in the afternoon?
5. Is watering being done too late in the afternoons?
6. When are outside conditions likely to be favorable for disease and what special precautions may be needed in ventilating or heating the greenhouse?
7. When should humidity be added to the greenhouse?
8. Are humidity controllers such as hair elements operating properly?

There are a number of factors influencing humidity in greenhouses:

1. Outside absolute humidity or dew point varies seasonally, with low dew points in the winter and high in the summer. During the winter, the greenhouse will tend to dry out more even with ventilators closed.
2. Wet pads add water to the incoming air so that the rise in relative humidity results from both a dry bulb temperature decrease (cooling) and additional water in the air (higher dew point).
3. During the day, plants lose water through their stomates at a rate dependent upon light intensity. This will raise dew point, and increase relative humidity if the dry bulb temperature remains the same. During the night, with closed stomates, some evaporation from the soil surfaces will occur, but will be very slight compared with the day-time addition.
4. Spray type irrigation systems will tend to increase dew point and relative humidity. If watered late in the afternoon, evaporation from wet soil surfaces will cause a rapid increase in relative humidity as temperatures decrease into the night.
5. Natural gas unit heaters will increase humidity if exhausted into the house for CO_2. A major product of combustion is water.
6. Air infiltration through cracks in the greenhouse will influence humidity. Plastic covered houses tend to be very tight. However, steam heated glass and fiberglass houses with no internal forced air circulation can have very low infiltration rates under

calm conditions. Combustion units in the greenhouse tend to increase infiltration rates. Large greenhouses will have a lower infiltration rate than small greenhouses. Outside temperatures near or below 0°F will tend to reduce infiltration because the cracks freeze shut.

7. The outside air temperature, if low enough, will cause condensation on the inner surfaces of greenhouses. This is essentially dehumidification, which can be increased by internal, forced-air circulation.

8. Note, that as inside temperature drops to the night setting, relative humidity will increase regardless of whether the dew point stays the same. The opposite will occur in the morning. If extreme high humidities, or condensation, are to be avoided, some of the water vapor must be removed prior to temperature set-back. This can be done in the summer by drying out the house; in the winter, condensation on the roof, heating, and some infiltration will perform a dehumidification cycle more or less automatically.

Table 2: Relative humidity, percent, for a barometric pressure of 25.0 inches mercury.

Air temperature (°F) (T_p)	Depression of wet bulb thermometer (T_p - T_w)												
	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0
45	93	87	80	73	67	61	55	49	43	37	32	26	20
46	93	87	81	74	68	62	56	50	44	38	33	27	22
47	93	87	81	74	68	62	57	51	45	39	34	29	23
48	94	87	81	75	69	63	57	52	46	40	35	30	24
49	94	88	81	75	69	64	58	52	47	42	36	31	26
50	94	88	82	76	70	64	59	53	48	43	38	33	28
51	94	88	82	76	71	65	60	54	49	44	39	34	29
52	94	88	83	77	71	66	60	55	50	45	40	35	30
53	94	88	83	77	71	66	61	56	51	46	41	36	32
54	94	88	83	77	72	67	62	67	52	47	42	37	33
55	94	89	83	78	72	67	62	57	53	48	43	38	34
56	94	89	83	78	73	68	63	58	53	49	44	39	35
57	94	89	84	78	73	68	63	59	54	49	45	40	36
58	95	89	84	79	74	69	64	59	55	50	46	41	37
59	95	90	84	79	74	69	65	60	56	51	46	42	38
60	95	90	85	79	74	70	65	61	56	52	47	43	39
61	95	90	85	80	75	70	66	61	57	52	48	44	40
62	95	90	85	80	75	71	66	62	57	53	49	45	41
63	95	90	85	80	76	71	67	62	58	54	49	45	42
64	95	90	85	81	76	72	67	63	59	54	50	46	42
65	95	90	86	81	76	72	68	63	59	55	51	47	43
66	95	90	86	81	77	72	68	64	60	56	52	48	44
67	95	90	86	81	77	73	68	64	60	56	52	48	45
68	95	91	86	84	77	73	69	65	61	57	53	49	45
69	95	91	86	82	78	73	69	65	61	57	54	59	46
70	95	91	86	82	78	74	70	66	62	58	54	51	49
71	96	91	87	82	78	74	70	66	62	59	55	51	48
72	96	91	87	83	78	74	70	66	61	59	55	52	48
73	96	91	87	83	79	75	71	67	63	60	56	52	49
74	96	91	87	83	79	75	71	67	63	60	56	53	49
75	96	91	87	83	79	75	71	68	64	60	57	53	50
76	96	91	87	83	79	75	72	68	64	61	57	54	51
77	96	91	87	83	79	76	72	68	65	61	58	54	51
78	96	92	88	84	80	76	72	69	65	62	58	55	52
79	96	92	88	84	80	76	72	69	66	62	59	55	52
80	96	92	88	84	80	76	73	69	66	62	59	56	53
82	96	92	88	84	81	77	73	70	67	63	60	57	54
84	96	92	88	85	81	77	74	71	67	64	61	58	55
86	96	92	89	85	81	78	74	71	68	65	61	58	55
88	96	92	89	85	82	78	75	72	68	65	62	59	56
90	96	92	89	85	82	79	75	72	69	66	63	60	57

Adapted from U.S. Dept. Commerce, Weather Bureau, Psychometric Tables, W.B. No. 235, 1941.

Table 3: Temperature of the dew point (T_d) from psychrometric measurement of wet and dry bulb temperature, for a barometric pressure of 25.0 inches mercury.

Air temperature (°F) (T_p)	Vapor pressure (in Hg)	Depression of wet bulb thermometer (T_p - T_w)												
		1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0
44	.287	42	40	38	36	34	32	29	26	23	20	16	12	6
46	.310	44	42	40	38	36	34	31	29	26	23	20	16	11
48	.334	46	44	42	40	38	36	34	31	29	26	23	19	16
50	.360	48	47	45	43	41	38	36	34	31	29	26	23	19
52	.387	50	49	47	45	43	41	39	36	34	31	29	26	23
54	.417	52	51	49	47	45	43	41	39	36	34	31	29	26
56	.448	54	53	51	49	47	45	43	41	39	37	34	32	29
58	.482	56	55	53	51	50	48	46	44	42	39	37	34	32
60	.517	59	57	55	54	52	50	48	46	44	42	40	37	35
62	.555	61	59	57	56	54	52	50	49	47	45	42	40	38
64	.595	63	61	60	58	56	55	53	51	49	47	45	43	41
66	.638	65	63	62	60	58	57	55	53	52	50	48	46	43
68	.684	67	65	64	62	61	59	57	56	54	52	50	48	46
70	.732	69	67	66	64	63	61	60	58	56	54	53	51	49
72	.783	71	69	68	66	65	63	62	60	59	57	55	53	51
74	.838	73	71	70	68	67	66	64	62	61	59	57	56	54
76	.896	75	73	72	71	69	68	66	65	63	62	60	58	56
78	.957	77	75	74	73	71	70	68	67	65	64	62	60	59
80	1.022	79	77	76	75	73	72	70	69	68	66	64	63	61
82	1.091	81	79	78	77	75	74	70	71	70	68	67	65	64
84	1.163	83	81	80	79	78	76	72	73	72	70	69	67	66
86	1.241	85	83	82	81	80	78	74	76	74	73	71	70	68
88	1.322	87	86	84	83	82	80	76	78	76	75	73	72	70
90	1.408	89	88	86	85	84	82	78	80	78	77	76	74	73

Adapted from U.S. Dept. Commerce, Weather Bureau, Psychrometric Tables, W.B. No. 235, 1941.

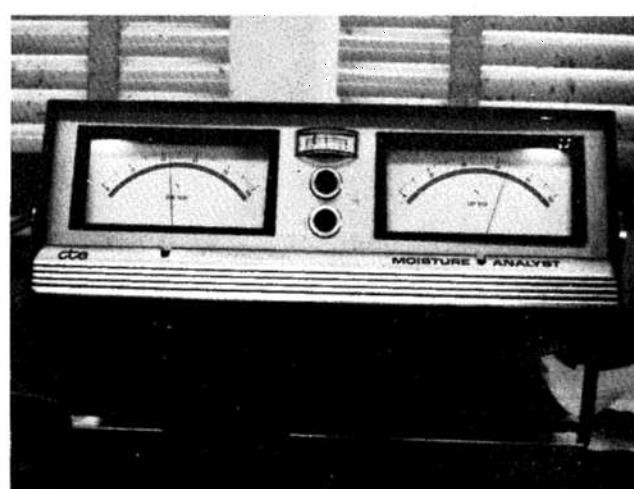

Fig. 4: Left: Typical hair element for direct reading of relative humidity. Recorder costs approximately $300.00.

Right: Expensive system for measuring dew point directly.