College & University Technicians 46th Annual PTG Convention & Technical Institute

Humidity Control in the Institutional Environment

Period 1

Whole Building Humidity Control Systems

By

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Whole Building Humidity Control Systems

- How does it fit into the modern HVAC System?
- How do whole building system work?
- What does humidity control add to utility bills?
- How much do they cost to include / retrofit?

How does it fit into the modern HVAC System

Basic Terminology

HVAC

- ***Heating, Ventilating, and Air Conditioning systems.***

Air Handling Unit-

- ***A device to condition air. Consists of a fan and casing. Can include , cooling coils, heating coils, filters, dampers, and humidity control equipment.***

Outside Air-(OA)

- *The ambient air outside the structure. Temperature and humidity levels are dependent on weather patterns for the specified area.*

Humidity

- *Gaseous mixture of air and water vapor(humidity). Water vapor (humidity), being a gas occupies space along with the other gases comprising the air.*

- In the HVAC engineering **air** is considered as being made up of only two components- **Dry air** and **water vapor**.
- The properties of **air** remain relatively unchanged as the temperature of the air rises and falls.
- The **water vapor**, on the other hand, may undergo considerable alteration as the temperature changes, including changes of state (condensing and freezing). Substantial amounts of energy are involved in these transformation.

Relative Humidity (RH)

- *Describes* ***the wetness or dryness of air at a given*** temperature and pressure.
- **RH tells** us the **amount of moisture present** in the air at a given temperature compared **to what the air could hold at that temperature if it were saturated** and is expressed as a **percentage**.
- If **temperature rises 1^{0}F** with moisture content remaining the same the **RH goes down~2%**.
- If the **temperature drops 1^{0}F** with the moisture content remaining the same the **RH goes up ~2%**.

Absolute Humidity, Humidity Ratio, and Specific Humidity

- Each of these terms is **expressed as number that describes** a **unit weight of water vapor associated with a unit weight of dry air**. (grains or lbs of moisture/lb of dry Air)

Duct Equivalent Relative Humidity

- ***This is the relative humidity of a duct air stream at a given temperature as compared to the relative humidity of the space served which is usually at a different temperature***

Dry Bulb Temperature

- *The temperature of air indicated by any type of thermometer or thermocouple that has not been affected by evaporation or radiation.*
-

Wet Bulb Temperature

- *Expression of the temperature of the air when a wick or sock wetted with water encases the sensing element of a dry bulb thermometer and air is passed over it at a velocity of 700 ft per minute or more. The drier the air the greater is the cooling caused by evaporation and, therefore, the lower the wet bulb temperature.*

Dew-Point Temperature

- *The saturation temperature corresponding to the humidity ratio and pressure of a given moist-air state. It is the surface temperature at which moisture begins to condense on the surface. The more humid the air, the higher the due-point temperature. Conversely, the dryer the air, the lower the dew-point temperature. Air at 100 RH.*

Vapor Migration

- *In a mixture of water vapor and dry air, the water vapor exerts it own vapor pressure an will migrate from areas of higher vapor pressure to areas of lower vapor pressure. This migration occurs regardless of air movement. It is important to keep this phenomenon in mind when designing humidification for buildings or spaces within buildings. It may be necessary to consider the use of building materials having vapor barrier qualities in order to prevent loss of moisture, condensation and/or frost formation within the walls of the structure. Resulting in damage.*

Latent Heat

- *Latent means hidden. In HVAC usage, latent commonly refers to change of state, which is the heat involved in fusion (freezing water or melting ice) or vaporization (creating water vapor) condensation with no change in temperature. For water, fusion requires 144 btu per pound and vaporization and condensation requires 970 BTU per pound. These values, which are for sea-level atmospheric pressure, vary as pressure changes. Latent heat is not the same for all substances.*

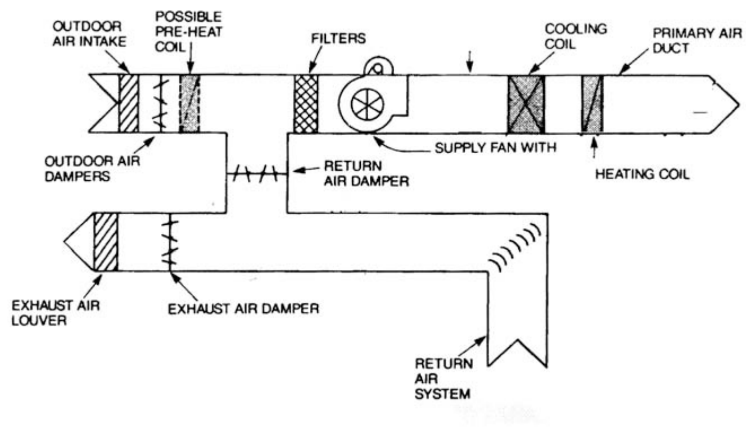
Sensible Heat

- *Sensible means that which can be sensed. In HVAC usage, it refers to the heat required to cause a change in temperature. The change is detected or sensed by the use of a thermometer*

Air handling unit- Can be a single piece of equipment in small installations to field assembled components in large installations.

- **Basic system includes Fan and Casing**
- **Supplementary items-**
- ***Cooling Coils to remove heat***
- ***Heating Coils to add heat***
- ***Filters to clean the air***
- ***Control valves to regulate the amount of heat removed or added to system***
- ***Dampers to control the flow of air***
- ***Sensors used to supply feedback to the system controller***
- ***Controller used to control set-points and sequences. Normally control valves and dampers in system. Can also provide information to other system controllers for monitoring and trending operation.***

How Do Systems Work



Typical System

Controlling Temperature-Heat removal

Function of removing the sensible heat dissipated in the space.

Sources-

Solar heat gain through glass, radiant heat from walls/roof heated by sun, people, lights, and outside air.

Each space's temperature gain is dependent on its heat gain and the sensible cooling is provided by the volume of air and temperature difference below the set-point temperature.

Whole Building A/C
How Do Systems Work

TRANE AIR CONDITIONING MANUAL

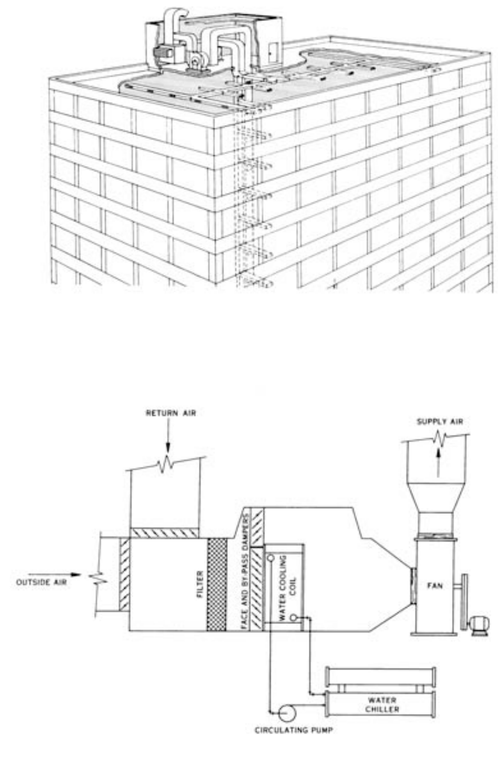
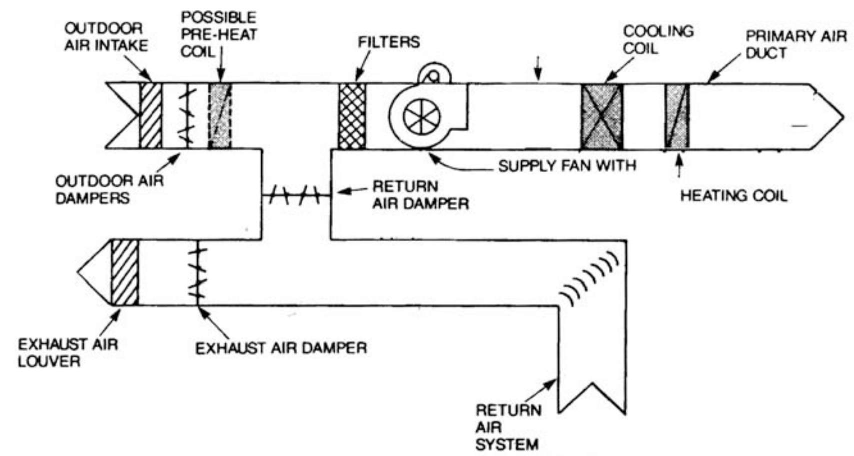


FIGURE 10-BP

SYSTEM WITH CENTRAL FAN, WATER COOLING COIL, FILTERS, DISTRIBUTING DUCT WORK, REFRIGERATION UNIT FOR CHILLING COLD WATER, CIRCULATING PUMP, FACE AND BYPASS DAMPERS FOR CONTROL AND CONTROLS.

Single Zone AHU



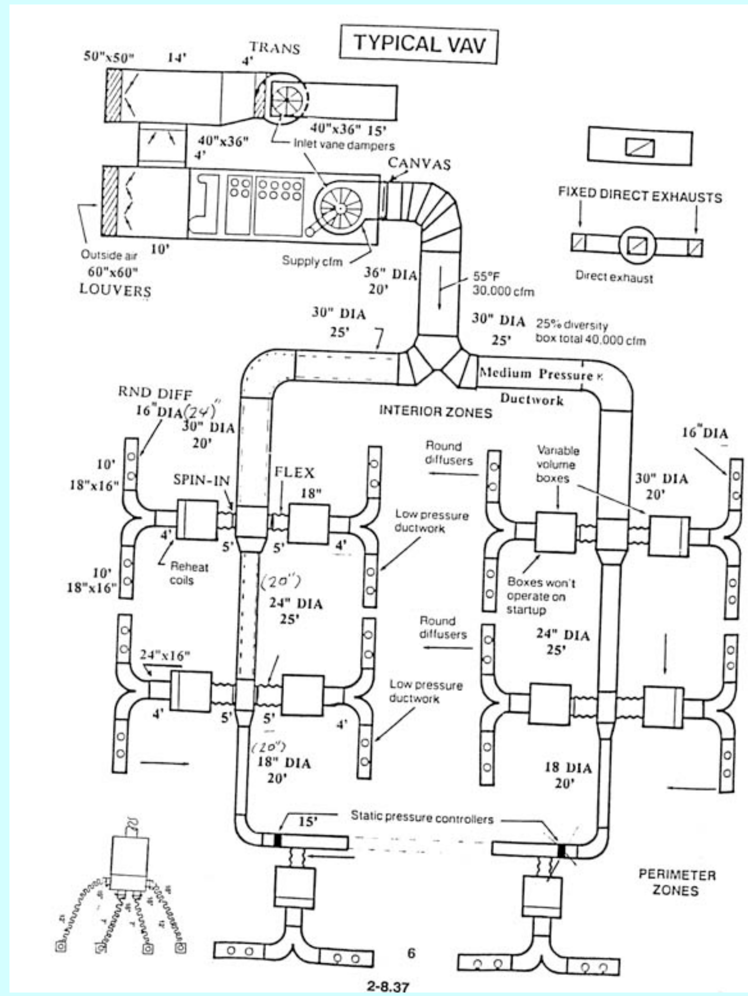
Typical System

- Basic System

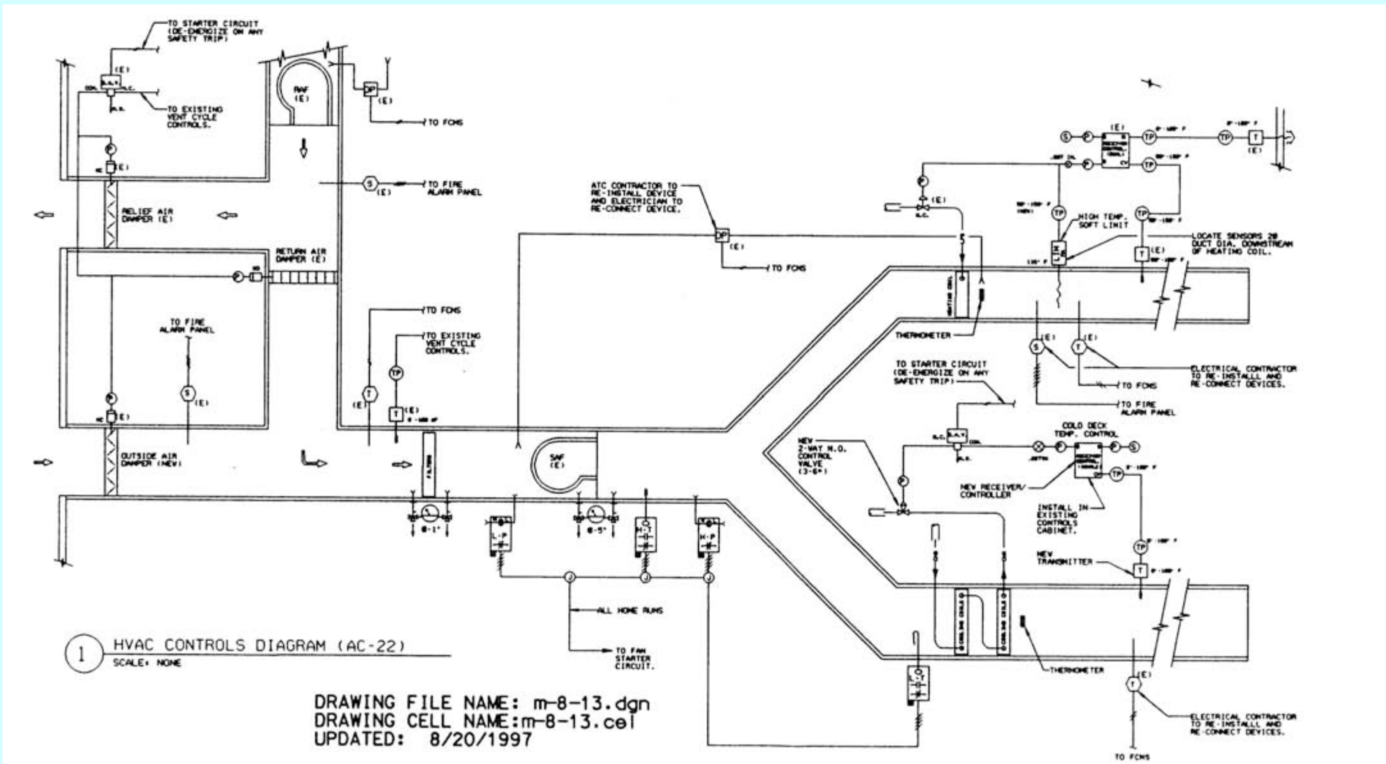
Variable Air Volume Multiple Zone AHU

Each area has it's own thermostat for temperature control.

Single AHU for cooling with supplemental heating on exterior zones.



Dual Duct-Constant Volume, Variable Volume



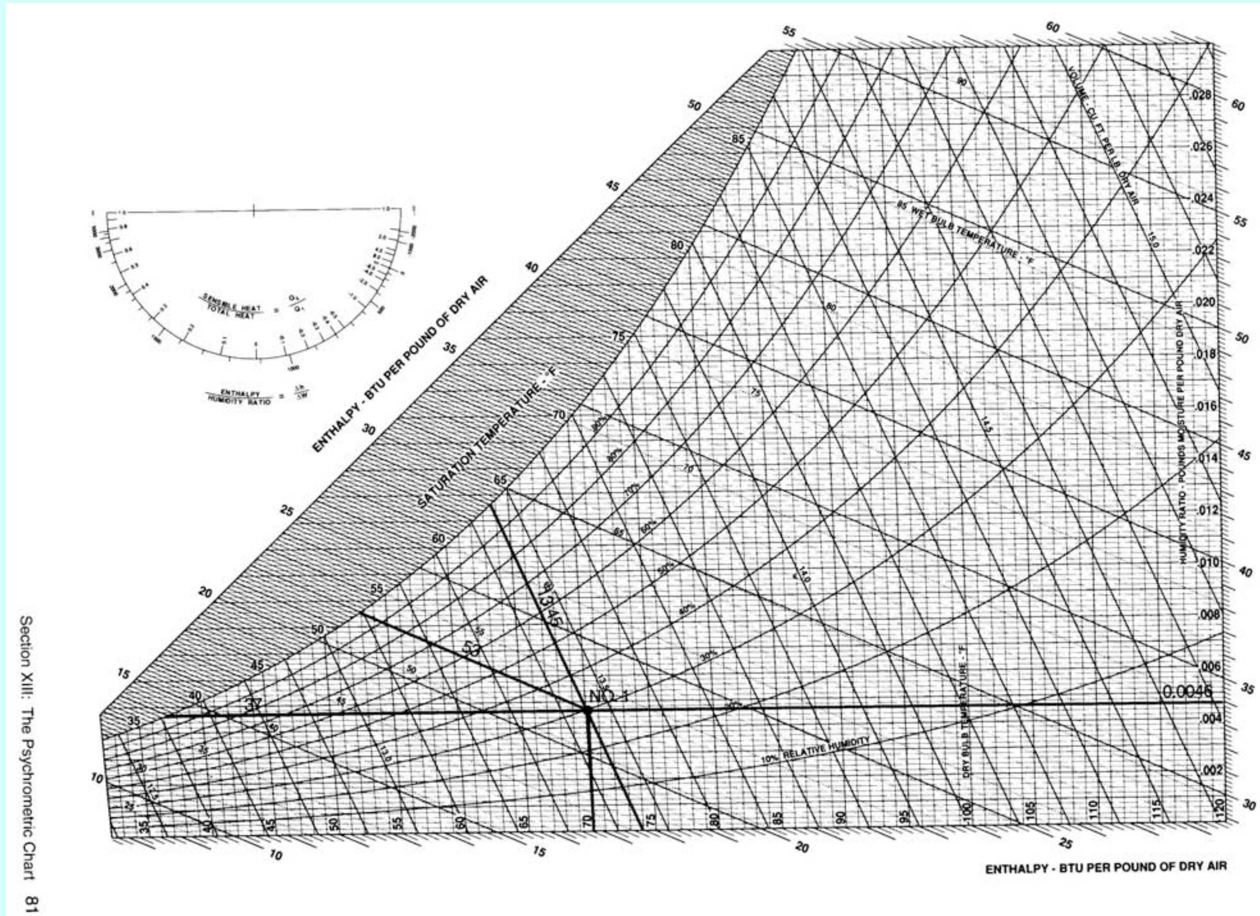
Basic requirements of HVAC Systems

- Supply a balanced volume of air at a temperature and moisture content to balance any heat gains or losses in the space and maintain the RH at the desired level.

Psychrometric Chart

- Added heat moves point to right
- Remove heat moves point left

- Added moisture moves point up.
- Remove moisture moves point down

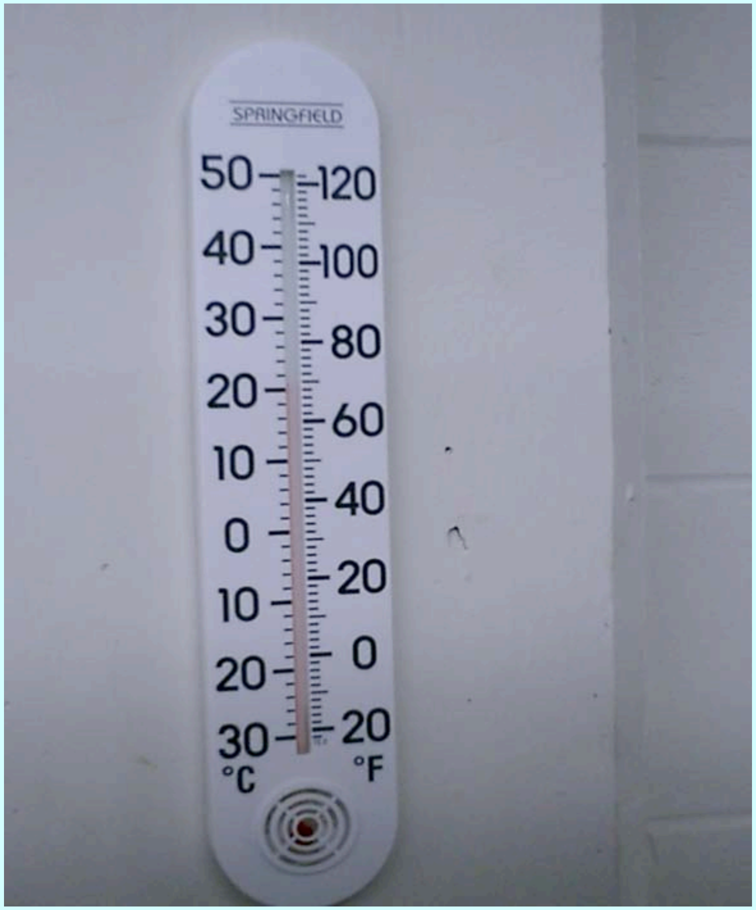


RH is curved lines up and to left

Dewpoint horizontal

Basic Control
Temperature- Sensible reading of a Thermometer

- Add heat and temperature goes up.
- Remove heat and temperature goes down.
- Thermostat senses change and sends signal to add or remove heat.



RH Control
Humidity- Causes change in characteristic of Sensor

- Change in size
- Change in Capacitance
- Senses change in wet bulb sensor. (wet sock over thermometer sensing bulb.

Humidity Sensors Properties

Table 13-1: Humidity sensor properties

Type of Sensor	Sensor Category	Method Of Operation	Approx. Range	Uses	Approx. Accuracy
Psychrometer	Evaporative cooling	Temeperature measurement of wet bulb	32 to 180°F	Measurement, standard	±3 to ±7% RH
Adiabatic Saturation Psychrometer	Evaporative cooling	Temeperature measurement of thermodynamic wet bulb	40 to 85°F	Measurement, standard	±0.2 to ±2% RH
Cilled Mirror	Dew point	Optical determination of moisture formation	-110 to 200°F dp	Measurement, control, meteorology	±0.4 to ±4°F
Heated Saturated Salt Solution	Water vapor pressure	Vapor pressure depression in salt solution	-20 to 160°F dp	Measurement, control, meteorology	±3°F
Hair	Mechanical	Dimensional change	5 to 100% RH	Measurement, control	±5%RH
Nylon	Mechanical	Dimensional change	5 to 100% RH	Measurement, control	±5%RH
Dacron Thread	Mechanical	Dimensional change	5 to 100% RH	Measurement	±7%RH
Goldbeater's Skin	Mechanical	Dimensional change	5 to 100% RH	Measurement	±7%RH
Cellulosic Materials	Mechanical	Dimensional change	5 to 100% RH	Measurement, control	±5%RH
Carbon	Mechanical	Dimensional change	5 to 100% RH	Measurement	±5%RH
Dunmore Type	Electrical	Impedence	7 to 98% RH at 40 to 140°F	Measurement, control	±1.5%RH
Ion Exchange Resin	Electrical	Impedence or capacitance	10 to 100% RH at -40 to 190°F	Measurement, control	±5%RH
Porous Ceramic	Electrical	Impedence or capacitance	Up to 400°F	Measurement, control	±1 to ±1.5% RH
Aluminum Oxide	Electrical	Capacitance	5 to 100% RH	Measurement, control	±3%RH
Aluminum Oxide	Electrical	Capacitance	-110 to 140°F dp	Trace moisture measurement, control	±2°F dp
Electrolytic Hygrometer	Electrical	Capacitance			
Coulometric	Electrical cell	Electrolyzes due absorbed moisture	1 to 1000 ppm	Measurement	
Infrared Laser Diode	Electrical	Optical diodes	0.1 to 100 ppm	Trace moisture measurement	±0.1 ppm
Surface Acoustic Wave	Electrical	SAW attenuation	85 to 98% RH	Measurement, control	±1% RH
Piezoelectric	Mass sensitive	Mass changes due to absorbed moisture	-100 to 0°F	Trace moisture measurement, control	±2 to ±10°F dp
Radiation Absorption	Moisture absorption	Moisture absorption of UV or IR radiation	0 to 180°F dp	Measurement, control, meterology	±4°F dp, ±5% RH
Gravimetric	Direct measurement of mixing ratio	Comparison of sample gas with dry airstream	120 to 20,000 ppm mixing ratio	Primary standard, research and laboratory	±0.13% of reading
Color Change	Physical	Color changes	10 to 80% RH	Warning device	±10% RH

Relative Humidity

- Changes with temperature with no change in moisture content.
- 1 Degree temperature change produces ~2% RH change.
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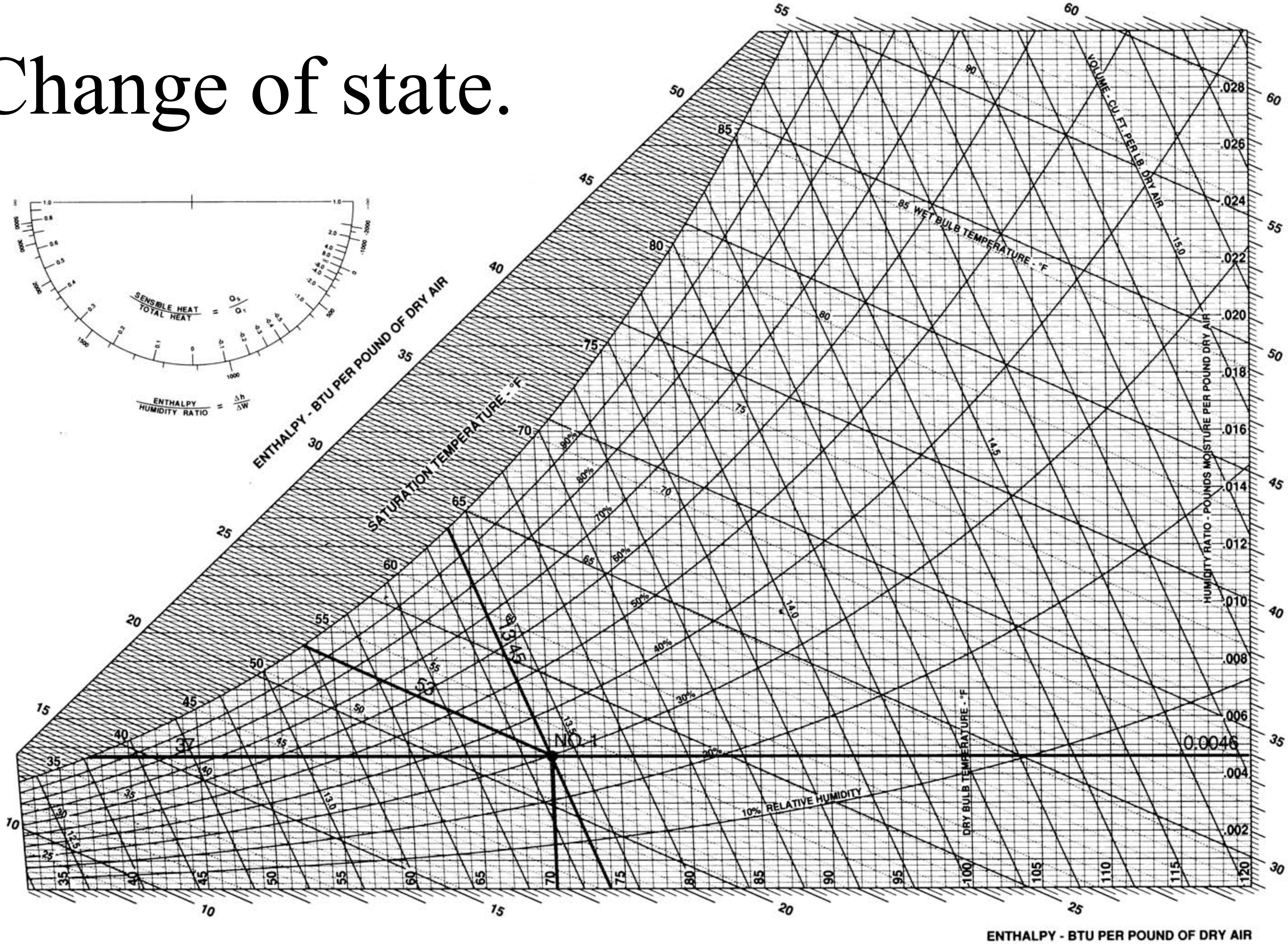
- Changes with increased moisture content of air with no change in temperature.
- 1 Degree of Change in due point produces at constant temperature ~2% in RH.

Change of state.



Vapor Migration

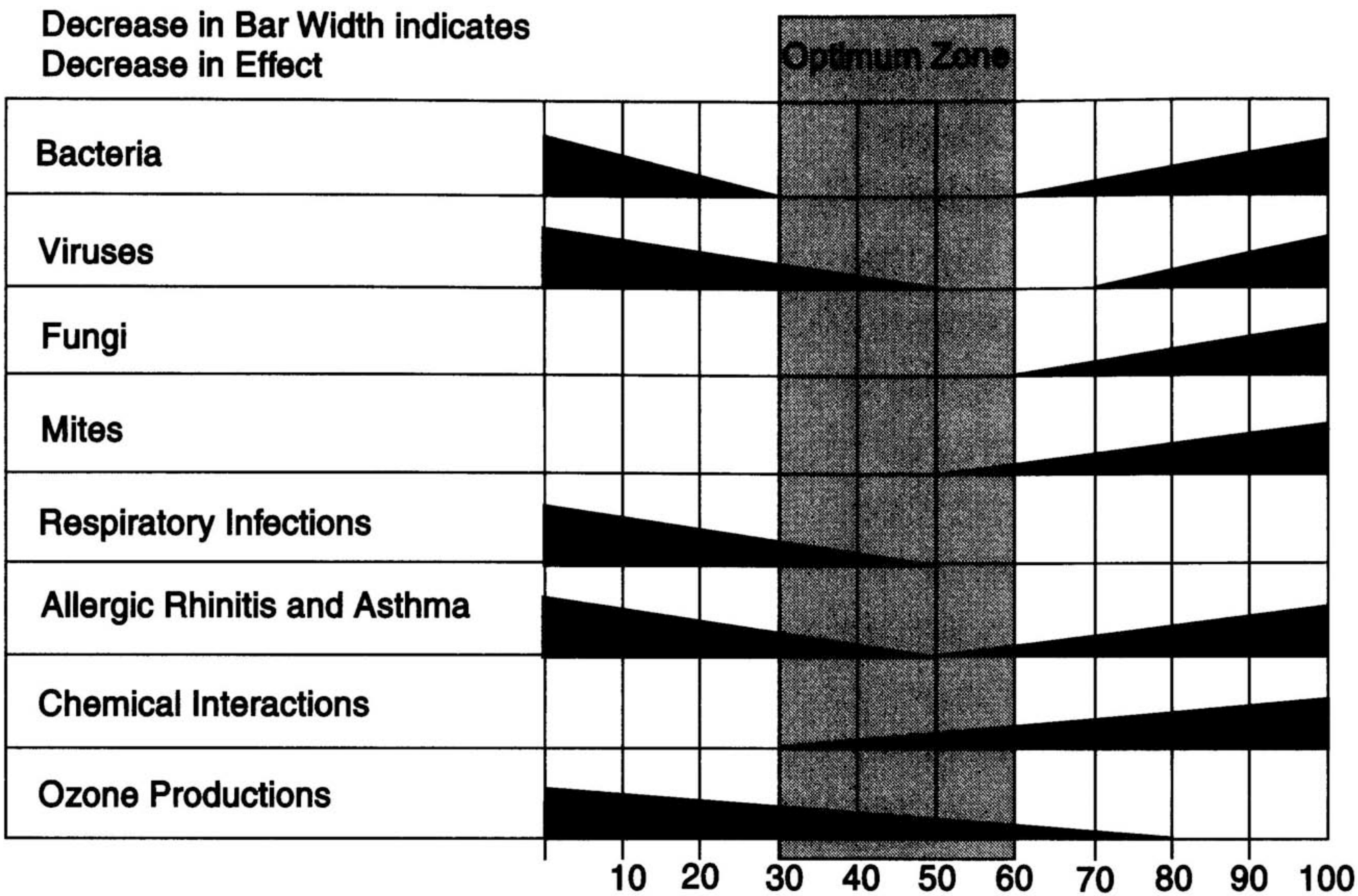
In a mixture of water vapor and dry air, the water vapor exerts it own vapor pressure an will migrate from areas of higher vapor pressure to areas of lower vapor pressure. This migration occurs regardless of air movement. It is important to keep this phenomenon in mind when designing humidification for buildings or spaces within buildings.
Air that mixes will seek a equilibrium in due point due point. If left untreated building air due point will be governed by the OA due point.

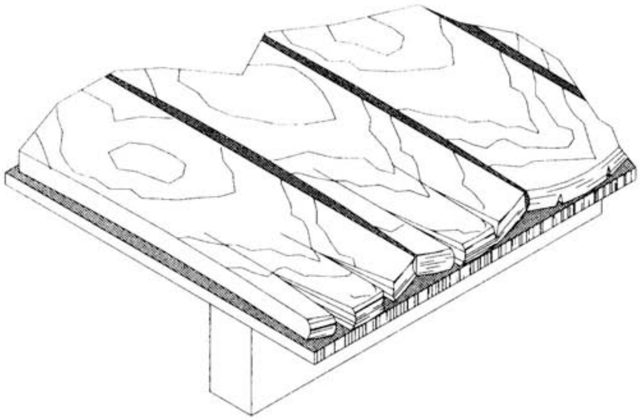
How does this effect hygroscopic materials

- Hygroscopic-Readily absorbing moisture, as from the atmosphere.
- Materials such as wood and building materials.

- Changes in weight.
- Changes in length and width.
- Changes in ability to support micro-organisms, grow mold, and deteriorate .

Figure 18-1: The Sterling bar graph





Floorboards buckle

Wallpaper seams open and gaps form

Libraries and Museums

Many priceless manuscripts, books, works of art, and other exhibited objects have been destroyed or badly damaged because they were not kept in a properly controlled atmosphere. The environmental conditions most suitable for these objects do not generally fall within the human comfort range.

In addition to housing books, libraries handle microfilms and many forms of electronic media records. Some also handle works of art. Microfilms and magnetic tape become too dry below 37% relative humidity, while paper survives best at an upper limit of 40%.

A variety of museum pieces are organic in nature and survive best at lower temperatures. Some museums rotate their collections between storage and display. While in storage, the temperature should be kept cooler than the comfort range.

Many art conservators firmly believe that maintaining a constant relative humidity is far more important than maintaining a constant temperature. Changes in RH, especially for such hygroscopic materials as wood and paper, can cause dramatic dimensional changes to objects composed of these materials. In fact, a change of 4% RH for certain moisture-absorbent wooden materials can cause an expansion across the grain equivalent to a change of 18°F, at a constant relative humidity. A change of 18°F would be extraordinary in a building with a working air conditioning system, whereas a 4% change in RH is usually considered *within spec* for most museum environmental control systems.

Equilibrium of Materials at different RH

Table 38-1: EMC % of wood

Dry Bulb °C	Dry Bulb °F	Relative Humidity 12%	25%	38%	51%	63%	72%
10	50	3	5.0	7.0	8.9	11.0	12.9
12.8	55	3	5.0	7.0	8.9	11.0	12.9
15.5	60	3.1	5.1	7.1	8.9	11.0	13.0
18.3	65	3.2	5.1	7.1	9.0	11.1	13.5
21.1	70	3.2	5.2	7.1	9.0	11.1	13.6
23.9	75	3.3	5.2	7.2	9.0	11.2	14.0
26.7	80	3.3	5.3	7.2	9.1	11.2	14.0

Table 31-1: Regain of various hygroscopic materials

CLASSIFICATION: NATURAL TEXTILE FABRICS		RELATIVE HUMIDITY								
MATERIALS:	DESCRIPTION:	10%	20%	30%	40%	50%	60%	70%	80%	90%
Cotton	Sea Island-roving	2.5	3.7	4.6	5.5	6.6	7.9	9.5	11.5	14.1
Cotton	American cloth	2.6	3.7	4.4	5.5	5.9	6.8	8.1	10.0	14.3
Cotton	Absorbent	4.8	9.0	12.5	15.7	18.5	20.8	22.8	24.3	25.8
Wool	Australian Merino - Skein	4.7	7.0	8.9	10.8	12.8	14.9	17.2	19.9	23.4
Silk	Raw Chevennes - Skein	3.2	5.5	6.9	8.0	8.9	10.2	11.9	14.3	18.3
Linen	Table cloth	1.9	2.9	3.6	4.3	5.1	6.1	7.0	8.4	10.2
Linen	Dry spun - yarn	3.6	5.4	6.5	7.3	8.1	8.9	9.8	11.2	13.8
Jute	Average of several grades	3.1	5.2	6.9	8.5	10.2	12.2	14.4	17.1	20.2
Hemp	Manila & sisal rope	2.7	4.7	6.0	7.2	8.5	9.9	11.6	13.6	15.7
CLASSIFICATION: RAYONS		RELATIVE HUMIDITY								
MATERIALS:	DESCRIPTION:	10%	20%	30%	40%	50%	60%	70%	80%	90%
Viscose nitro-cellulose	Average Skein	4.0	5.7	6.8	7.9	9.2	10.8	12.4	14.2	16.0
Cuprammonium cellulose acetate		0.8	1.1	1.4	1.9	2.4	3.0	3.6	4.3	5.3
CLASSIFICATION: PAPERS		RELATIVE HUMIDITY								
MATERIALS:	DESCRIPTION:	10%	20%	30%	40%	50%	60%	70%	80%	90%
M.F. newspring	Wood pulp - 24% ash	2.1	3.2	4.0	4.7	5.3	6.1	7.2	8.7	10.6
H.M.F. writing	Wood pulp - 3% ash	3.0	4.2	5.2	6.2	7.2	8.3	9.9	11.9	14.2
White bond	Rag - 1% ash	2.4	3.7	4.7	5.5	6.5	7.5	8.8	10.8	13.2
Comm. ledger	75% rag - 1% ash	3.2	4.2	5.0	5.6	6.2	6.9	8.1	10.3	13.9
Kraft wrapping	Coniferous	3.2	4.6	5.7	6.6	7.6	8.9	10.5	12.6	14.9
CLASSIFICATION: MISC. ORGANIC MATERIALS		RELATIVE HUMIDITY								
MATERIALS:	DESCRIPTION:	10%	20%	30%	40%	50%	60%	70%	80%	90%
Leather	Sole oak-tanned	5.0	8.5	11.2	13.6	16.0	18.3	20.6	24.0	29.2
Catgut	Racquet strings	4.6	7.2	8.6	10.2	12.0	14.3	17.3	19.8	21.7
Glue	Hide	3.4	4.8	5.8	6.6	7.6	9.0	10.7	11.8	12.5
Rubber	Solid tires	0.11	0.21	0.32	0.44	0.54	0.66	0.76	0.88	0.99
Wood	Timber (average)	3.0	4.4	5.9	7.6	9.3	11.3	14.0	17.5	22.0
Soap	White	1.9	3.8	5.7	7.6	10.0	12.9	16.1	19.8	23.8
Tobacco	Cigarette	5.4	8.6	11.0	13.3	16.0	19.5	25.0	33.5	50.0
CLASSIFICATION: FOODSTUFFS		RELATIVE HUMIDITY								
MATERIALS:	DESCRIPTION:	10%	20%	30%	40%	50%	60%	70%	80%	90%
White bread		0.5	1.7	3.1	4.5	6.2	8.5	11.1	14.5	19.0
Crackers		2.1	2.8	3.3	3.9	5.0	6.5	8.3	10.9	14.9
Macaroni		5.1	7.4	8.8	10.2	11.7	13.7	16.2	19.09	22.1
Flour		2.6	4.1	5.3	6.5	8.0	9.9	12.4	15.4	19.1
Starch		2.2	3.8	5.2	6.4	7.4	8.3	9.2	10.6	12.7
Gelatin		0.7	1.6	2.8	3.8	4.9	6.1	7.6	9.3	11.4
CLASSIFICATIONS: MISC. INORGANIC MATERIALS		RELATIVE HUMIDITY								
MATERIALS:	DESCRIPTION:	10%	20%	30%	40%	50%	60%	70%	80%	90%
Asbestos fiber	Finely divided	0.16	0.24	0.26	0.32	0.41	0.51	0.62	0.73	0.84
Silica gel		5.70	9.80	12.70	15.20	17.20	18.80	20.20	21.50	22.60
Domestic coke		0.20	0.40	0.61	0.81	1.03	1.24	1.46	1.67	1.89
Activated charcoal	Steam activated	7.10	14.30	22.80	26.20	28.30	29.20	30.00	31.10	32.70
Sulfuric acid	H_2SO_4	33.00	41.00	47.50	52.50	57.00	61.50	67.00	73.50	82.50

Dimensional Change in Woods

Table 12–5. Coefficients for dimensional change as a result of shrinking or swelling within moisture content limits of 6% to 14% (C_T = dimensional change coefficient for tangential direction; C_R = radial direction)

Species	Dimensional change coefficient[a] C_R	C_T	Species	Dimensional change coefficient[a] C_R	C_T
Hardwoods					
Alder, red	0.00151	0.00256	Honeylocust	0.00144	0.00230
Apple	0.00205	0.00376	Locust, black	0.00158	0.00252
Ash, black	0.00172	0.00274	Madrone, Pacific	0.00194	0.00451
Ash, Oregon	0.00141	0.00285	Magnolia, cucumbertree	0.00180	0.00312
Ash, pumpkin	0.00126	0.00219	Magnolia, southern	0.00187	0.00230
Ash, white	0.00169	0.00274	Magnolia, sweetbay	0.00162	0.00293
Ash, green	0.00169	0.00274	Maple, bigleaf	0.00126	0.00248
Aspen, quaking	0.00119	0.00234	Maple, red	0.00137	0.00289
Basswood, American	0.00230	0.00330	Maple, silver	0.00102	0.00252
Beech, American	0.00190	0.00431	Maple, black	0.00165	0.00353
Birch, paper	0.00219	0.00304	Maple, sugar	0.00165	0.00353
Birch, river	0.00162	0.00327	Oak, black	0.00123	0.00230
Birch, yellow	0.00256	0.00338	Red Oak, commercial	0.00158	0.00369
Birch, sweet	0.00256	0.00338	Red oak, California	0.00123	0.00230
Buckeye, yellow	0.00123	0.00285	Red oak: water, laurel, willow	0.00151	0.00350
Butternut	0.00116	0.00223	White Oak, commercial	0.00180	0.00365
Catalpa, northern	0.00085	0.00169	White oak, live	0.00230	0.00338
Cherry, black	0.00126	0.00248	White oak, Oregon white	0.00144	0.00327
Chestnut, American	0.00116	0.00234	White oak, overcup	0.00183	0.00462
Cottonwood, black	0.00123	0.00304	Persimmon, common	0.00278	0.00403
Cottonwood, eastern	0.00133	0.00327	Sassafras	0.00137	0.00216
Elm, American	0.00144	0.00338	Sweet gum	0.00183	0.00365
Elm, rock	0.00165	0.00285	Sycamore, American	0.00172	0.00296
Elm, slippery	0.00169	0.00315	Tanoak	0.00169	0.00423
Elm, winged	0.00183	0.00419	Tupelo, black	0.00176	0.00308
Elm, cedar	0.00183	0.00419	Tupelo, water	0.00144	0.00267
Hackberry	0.00165	0.00315	Walnut, black	0.00190	0.00274
Hickory, pecan	0.00169	0.00315	Willow, black	0.00112	0.00308
Hickory, true	0.00259	0.00411	Willow, Pacific	0.00099	0.00319
Holly, American	0.00165	0.00353	Yellow-poplar	0.00158	0.00289
Softwoods					
Baldcypress	0.00130	0.00216	Pine, eastern white	0.00071	0.00212
Cedar, yellow	0.00095	0.00208	Pine, jack	0.00126	0.00230
Cedar, Atlantic white	0.00099	0.00187	Pine, loblolly	0.00165	0.00259
Cedar, eastern red	0.00106	0.00162	Pine, pond	0.00165	0.00259
Cedar, Incense	0.00112	0.00180	Pine, lodgepole	0.00148	0.00234
Cedar, Northern white[b]	0.00101	0.00229	Pine, Jeffrey	0.00148	0.00234
Cedar, Port-Orford	0.00158	0.00241	Pine, longleaf	0.00176	0.00263
Cedar, western red[b]	0.00111	0.00234	Pine, ponderosa	0.00133	0.00216
Douglas-fir, Coast-type	0.00165	0.00267	Pine, red	0.00130	0.00252
Douglas-fir, Interior north	0.00130	0.00241	Pine, shortleaf	0.00158	0.00271
Douglas-fir, Interior west	0.00165	0.00263	Pine, slash	0.00187	0.00267
Fir, balsam	0.00099	0.00241	Pine, sugar	0.00099	0.00194
Fir, California red	0.00155	0.00278	Pine, Virginia	0.00144	0.00252
Fir, noble	0.00148	0.00293	Pine, western white	0.00141	0.00259

Estimation Using Dimensional Change Coefficient

The change in dimension within the moisture content limits of 6% to 14% can be estimated satisfactorily by using a dimensional change coefficient based on the dimension at 10% moisture content:

$$\Delta D = D_I\left[C_T(M_F - M_I)\right] \qquad (12\text{–}2)$$

where ΔD is change in dimension, D_I dimension in units of length at start of change, C_T dimensional change coefficient tangential direction (for radial direction, use C_R), M_F moisture content (%) at end of change, and M_I moisture content (%) at start of change.

Values for C_T and C_R, derived from total shrinkage values, are given in Table 12–5. When $M_F < M_I$, the quantity $(M_F - M_I)$ will be negative, indicating a decrease in dimension; when greater, it will be positive, indicating an increase in dimension.

As an example, assuming the width of a flat-grained white fir board is 232 mm (9.15 in.) at 8% moisture content, its change in width at 11% moisture content is estimated as

$$\Delta D = 232[0.00245(11 - 8)]$$
$$= 232(0.00735)$$
$$= 1.705 \text{ mm}$$

$$\Delta D = 9.15[0.00245(11 - 8)]$$
$$= 9.15[0.00735]$$
$$= 0.06725 \text{ or } 0.067 \text{ in.}$$

Then, dimension at end of change

$$D_I + \Delta D = 232 + 1.7 \qquad (= 9.15 + 0.067)$$
$$= 233.7 \text{ mm} \qquad (= 9.217 \text{ in.})$$

The thickness of the same board at 11% moisture content can be estimated by using the coefficient $C_R = 0.00112$.

Wood Equilibrium Moisture Content in Outdoors in several US Locations

Table 12–1. Equilibrium moisture content of wood, exposed to outdoor atmosphere, in several U.S. locations in 1997

		Equilibrium moisture content[a] (%)											
State	City	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AK	Juneau	16.5	16.0	15.1	13.9	13.6	13.9	15.1	16.5	18.1	18.0	17.7	18.1
AL	Mobile	13.8	13.1	13.3	13.3	13.4	13.3	14.2	14.4	13.9	13.0	13.7	14.0
AZ	Flagstaff	11.8	11.4	10.8	9.3	8.8	7.5	9.7	11.1	10.3	10.1	10.8	11.8
AZ	Phoenix	9.4	8.4	7.9	6.1	5.1	4.6	6.2	6.9	6.9	7.0	8.2	9.5
AR	Little Rock	13.8	13.2	12.8	13.1	13.7	13.1	13.3	13.5	13.9	13.1	13.5	13.9
CA	Fresno	16.4	14.1	12.6	10.6	9.1	8.2	7.8	8.4	9.2	10.3	13.4	16.6
CA	Los Angeles	12.2	13.0	13.8	13.8	14.4	14.8	15.0	15.1	14.5	13.8	12.4	12.1
CO	Denver	10.7	10.5	10.2	9.6	10.2	9.6	9.4	9.6	9.5	9.5	11.0	11.0
DC	Washington	11.8	11.5	11.3	11.1	11.6	11.7	11.7	12.3	12.6	12.5	12.2	12.2
FL	Miami	13.5	13.1	12.8	12.3	12.7	14.0	13.7	14.1	14.5	13.5	13.9	13.4
GA	Atlanta	13.3	12.3	12.0	11.8	12.5	13.0	13.8	14.2	13.9	13.0	12.9	13.2
HI	Honolulu	13.3	12.8	11.9	11.3	10.8	10.6	10.6	10.7	10.8	11.3	12.1	12.9
ID	Boise	15.2	13.5	11.1	10.0	9.7	9.0	7.3	7.3	8.4	10.0	13.3	15.2
IL	Chicago	14.2	13.7	13.4	12.5	12.2	12.4	12.8	13.3	13.3	12.9	14.0	14.9
IN	Indianapolis	15.1	14.6	13.8	12.8	13.0	12.8	13.9	14.5	14.2	13.7	14.8	15.7
IA	Des Moines	14.0	13.9	13.3	12.6	12.4	12.6	13.1	13.4	13.7	12.7	13.9	14.9
KS	Wichita	13.8	13.4	12.4	12.4	13.2	12.5	11.5	11.8	12.6	12.4	13.2	13.9
KY	Louisville	13.7	13.3	12.6	12.0	12.8	13.0	13.3	13.7	14.1	13.3	13.5	13.9
LA	New Orleans	14.9	14.3	14.0	14.2	14.1	14.6	15.2	15.3	14.8	14.0	14.2	15.0
ME	Portland	13.1	12.7	12.7	12.1	12.6	13.0	13.0	13.4	13.9	13.8	14.0	13.5
MA	Boston	11.8	11.6	11.9	11.7	12.2	12.1	11.9	12.5	13.1	12.8	12.6	12.2
MI	Detroit	14.7	14.1	13.5	12.6	12.3	12.3	12.6	13.3	13.7	13.5	14.4	15.1
MN	Minneapolis–St.Paul	13.7	13.6	13.3	12.0	11.9	12.3	12.5	13.2	13.8	13.3	14.3	14.6
MS	Jackson	15.1	14.4	13.7	13.8	14.1	13.9	14.6	14.6	14.6	14.1	14.3	14.9
MO	St. Louis	14.5	14.1	13.2	12.4	12.8	12.6	12.9	13.3	13.7	13.1	14.0	14.9
MT	Missoula	16.7	15.1	12.8	11.4	11.6	11.7	10.1	9.8	11.3	12.9	16.2	17.6
NE	Omaha	14.0	13.8	13.0	12.1	12.6	12.9	13.3	13.8	14.0	13.0	13.9	14.8
NV	Las Vegas	8.5	7.7	7.0	5.5	5.0	4.0	4.5	5.2	5.3	5.9	7.2	8.4
NV	Reno	12.3	10.7	9.7	8.8	8.8	8.2	7.7	7.9	8.4	9.4	10.9	12.3
NM	Albuquerque	10.4	9.3	8.0	6.9	6.8	6.4	8.0	8.9	8.7	8.6	9.6	10.7
NY	New York	12.2	11.9	11.5	11.0	11.5	11.8	11.8	12.4	12.6	12.3	12.5	12.3
NC	Raleigh	12.8	12.1	12.2	11.7	13.1	13.4	13.8	14.5	14.5	13.7	12.9	12.8
ND	Fargo	14.2	14.6	15.2	12.9	11.9	12.9	13.2	13.2	13.7	13.5	15.2	15.2
OH	Cleveland	14.6	14.2	13.7	12.6	12.7	12.7	12.8	13.7	13.8	13.3	13.8	14.6
OK	Oklahoma City	13.2	12.9	12.2	12.1	13.4	13.1	11.7	11.8	12.9	12.3	12.8	13.2
OR	Pendleton	15.8	14.0	11.6	10.6	9.9	9.1	7.4	7.7	8.8	11.0	14.6	16.5
OR	Portland	16.5	15.3	14.2	13.5	13.1	12.4	11.7	11.9	12.6	15.0	16.8	17.4
PA	Philadelphia	12.6	11.9	11.7	11.2	11.8	11.9	12.1	12.4	13.0	13.0	12.7	12.7
SC	Charleston	13.3	12.6	12.5	12.4	12.8	13.5	14.1	14.6	14.5	13.7	13.2	13.2
SD	Sioux Falls	14.2	14.6	14.2	12.9	12.6	12.8	12.6	13.3	13.6	13.0	14.6	15.3
TN	Memphis	13.8	13.1	12.4	12.2	12.7	12.8	13.0	13.1	13.2	12.5	12.9	13.6
TX	Dallas–Ft.Worth	13.6	13.1	12.9	13.2	13.9	13.0	11.6	11.7	12.9	12.8	13.1	13.5
TX	El Paso	9.6	8.2	7.0	5.8	6.1	6.3	8.3	9.1	9.3	8.8	9.0	9.8
UT	Salt Lake City	14.6	13.2	11.1	10.0	9.4	8.2	7.1	7.4	8.5	10.3	12.8	14.9
VA	Richmond	13.2	12.5	12.0	11.3	12.1	12.4	13.0	13.7	13.8	13.5	12.8	13.0
WA	Seattle–Tacoma	15.6	14.6	15.4	13.7	13.0	12.7	12.2	12.5	13.5	15.3	16.3	16.5
WI	Madison	14.5	14.3	14.1	12.8	12.5	12.8	13.4	14.4	14.9	14.1	15.2	15.7
WV	Charleston	13.7	13.0	12.1	11.4	12.5	13.3	14.1	14.3	14.0	13.6	13.0	13.5
WY	Cheyenne	10.2	10.4	10.7	10.4	10.8	10.5	9.9	9.9	9.7	9.7	10.6	10.6

[a]EMC values were determined from the average of 30 or more years of relative humidity and temperature data available from the National Climatic Data Center of the National Oceanic and Atmospheric Administration.

Humidifier Technologies

Isothermic

Electrode and Immersed Element

Direct and Indirect Steam

Gas Fired Steam

Adiabatic

Air / Water Atomizer

Airless Atomizer

“Isothermic”

- Internal Energy Exchange
- Heat added to water prior to being added to air stream
- Air temperature rise is due to heat loss of equipment and not in absorption of moisture.

Isothermic Equipment

Figure 102-1: Steam heated secondary steam boiler

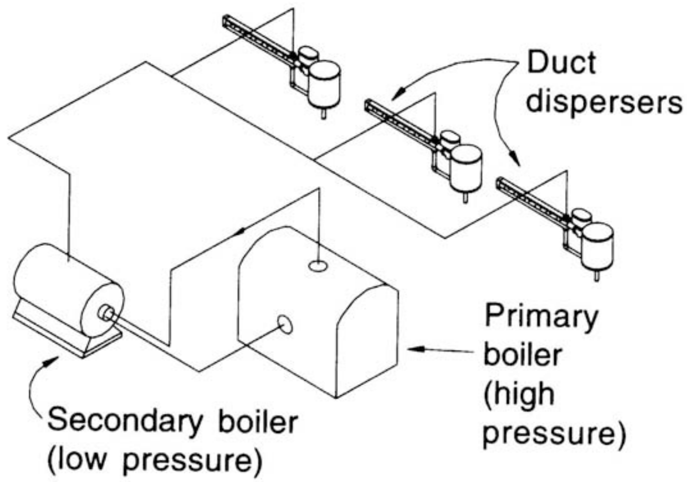


Figure 103-1: Electric heated vapor generator

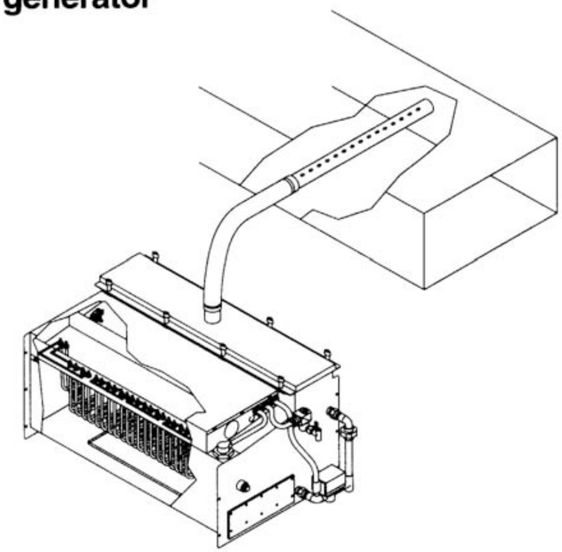
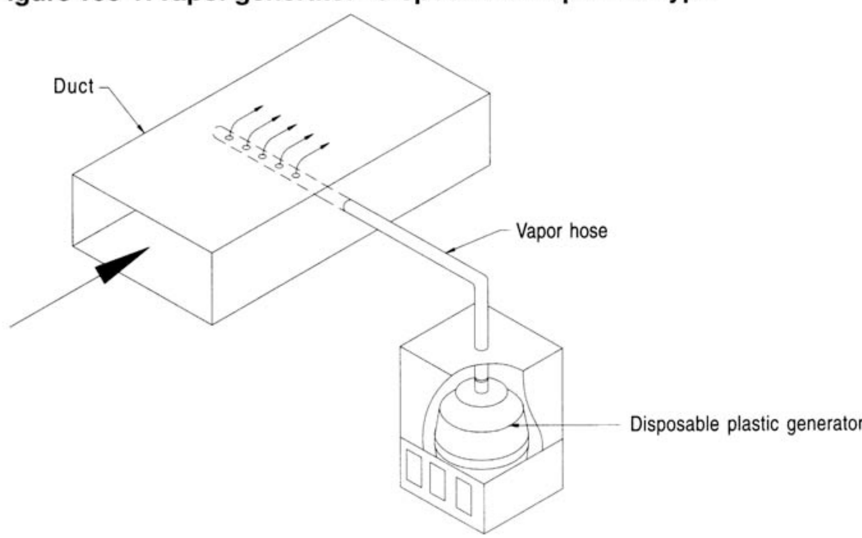


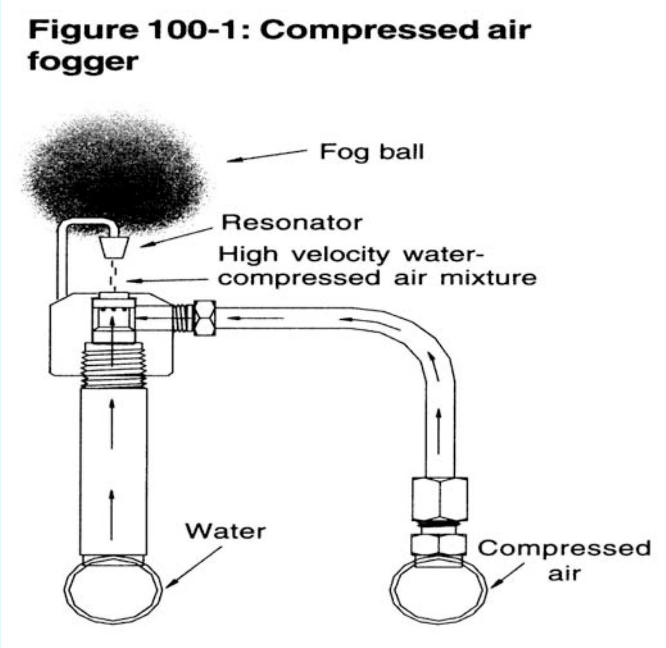
Figure 106-1: Vapor generator - disposable evaporator type



“Adiabatic”

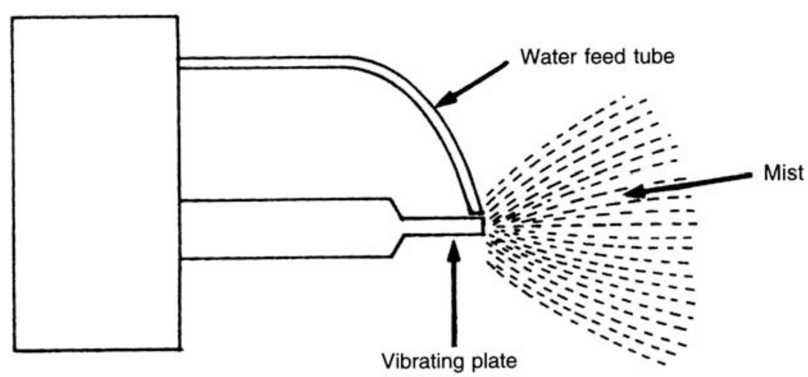
- External Energy Exchange
- Energy for conversion of state from liquid to vapor taken from air stream. Air temperature drops as moisture is added at the rate of ~1000 BTUs/lb. of water

Adiabatic Equipment



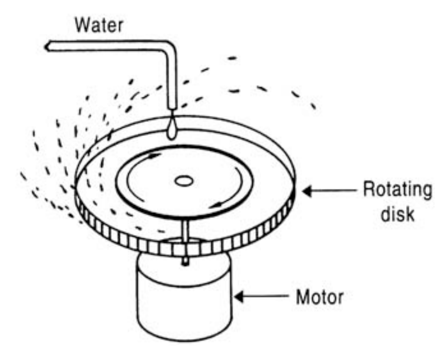
Adiabatic Equipment

Figure 101-2: Ultrasonic humidifier



- Droplet size critical to absorption.
- .3 to 10 micron available. Some equipment can provide only 20 micron and above.
- Not all can modulate output and are on or off.

Figure 99-1: Centrifugal atomizing humidifier



the other hand, they are less expensive than foggers.

How much moisture needs to be added?

(Simplified)

- Dominated by OA Conditions.
- Minimum is around 1 air change per hour.Unoccupied-25 CFM/Person Occupied
- Sq. ft of building times height=Volume in cubic ft
- Cubic ft/60 minutes for Cubic ft/min(CFM)
- Difference in moisture between Temp/RH of outdoor air and indoor desired condition.
- Multiply by CFM/100

Table 71-1: Pounds of moisture per hour per 100 cfm

Air Temperature		Percentage of Saturation											
°C	°F	30%	35%	40%	45%	50%	55%	60%	65%	70%	80%	90%	100%
-29	-20	.043	.05	.057	.064	.071	.078	.064	.093	.099	.114	.13	.14
-23	-10	.074	.085	.097	.11	.121	.134	.147	.159	.171	.20	.22	.24
-18	0	.121	.142	.162	.184	.204	.223	.245	.265	.285	.33	.36	.40
-12	10	.20	.232	.266	.30	.332	.364	.40	.434	.465	.54	.59	.66
-7	20	.32	.374	.430	.494	.535	.583	.635	.695	.758	.86	.96	1.05
-1	30	.50	.585	.67	.75	.84	.92	1.0	1.09	1.17	1.34	1.49	1.65
4	40	.74	.84	.96	1.08	1.20	1.31	1.45	1.53	1.68	1.98	2.20	2.43
10	50	1.05	1.24	1.40	1.58	1.76	1.93	2.12	2.30	2.46	2.83	3.16	3.49
13	55	1.26	1.47	1.68	1.90	2.10	2.30	2.53	2.74	2.94	3.37	3.76	4.16
16	60	1.49	1.74	1.98	2.24	2.50	2.72	2.99	3.24	3.48	4.00	4.46	4.93
18	65	1.75	2.04	2.32	2.63	2.92	3.20	3.50	3.80	4.06	4.73	5.27	5.82
20	68	1.96	2.28	2.60	2.84	3.26	3.56	3.19	4.24	4.55	5.23	5.84	6.05
21.1	70	2.05	2.40	2.74	3.10	3.44	3.75	4.12	4.46	4.80	5.56	6.20	6.45
21.7	71	2.15	2.50	2.85	3.21	3.55	3.90	4.29	4.65	5.00	5.74	6.40	7.07
22.2	72	2.20	2.58	2.94	3.32	3.68	4.03	4.44	4.80	5.15	5.91	6.60	7.29
22.8	73	2.28	2.66	3.03	3.43	3.80	4.16	4.57	4.95	5.31	6.12	6.83	7.54
23.3	74	2.37	2.75	3.13	3.54	3.93	4.31	4.74	5.14	5.51	6.32	7.05	7.78
23.9	75	2.42	2.84	3.23	3.65	4.06	4.45	4.86	5.28	5.65	6.55	7.27	8.03
25.0	77	2.58	3.02	3.42	3.82	4.33	4.73	5.13	5.63	6.04	6.94	7.75	8.55
26.7	80	2.84	3.3	3.75	4.20	4.75	5.19	5.63	6.18	6.62	7.62	8.50	9.38
29.4	85	3.32	3.88	4.39	4.91	5.56	6.07	6.59	7.23	7.75	8.92	9.95	10.98
32.2	90	3.74	4.37	4.95	5.53	6.25	6.84	7.43	8.15	8.73	10.03	11.20	12.37
35.0	95	4.50	5.25	6.00	6.75	7.50	8.25	9.00	9.75	10.50	12.00	13.50	15.00
37.8	100	5.14	5.99	6.85	7.70	8.56	9.42	10.27	11.13	12.00	13.69	15.41	17.12
40.6	105	5.93	6.92	7.90	8.89	9.88	10.87	11.86	12.85	13.83	15.82	17.79	19.77
43.3	110	6.66	8.00	9.14	10.28	11.43	12.57	13.71	14.85	16.00	18.28	20.57	22.85
48.9	120	8.95	10.44	11.93	13.42	14.91	16.40	17.90	19.39	20.88	23.86	26.85	29.83
54.4	130	11.46	13.37	15.28	17.19	19.10	21.01	22.92	24.83	26.74	30.56	34.38	38.20
60.0	140	14.67	17.12	19.56	22.01	24.45	26.89	29.34	31.78	34.26	39.12	44.01	48.90
65.6	150	18.60	21.70	24.80	27.90	31.00	34.10	37.20	40.30	43.40	49.60	55.80	62.00
71.1	160	23.34	27.23	31.12	35.01	38.90	42.79	46.68	50.57	54.46	62.24	70.02	77.80
76.7	170	29.07	33.92	38.76	43.61	48.45	53.29	58.14	63.00	67.80	77.52	87.20	96.90
87.8	190	43.80	51.10	58.40	65.70	73.00	80.30	87.60	94.90	102.20	116.80	131.40	146.00
93.3	200	53.50	62.40	71.32	80.24	89.15	98.07	107.00	115.90	124.80	142.60	160.50	178.30

How much moisture needs to be added?

Examples

- Building -100'X100'X14'=140,000 Cubic Ft.
- 140,000/60=2,333 CFM
- Outdoor Condition-20 Degrees F@ 70%--.758 lb/ 100 CFM
- Indoor Desired Condition-70 Degrees F@50%--3.44 lb/100 DFM
- ----------------------Occupied--------------------
- 3.44-.758=2.68 lb/100 X (2,333/100)=62 lbs/hr
- 280 peopleX25 CFM/person=7280 CFM Req.
- 7280/2333=3.12   3.12X62=193 lbs/hr

Cost for energy

- Per Hour
- Energy~1000 BTU/lb. of water X62=62,000 BTUH
- To
- 1000 BTU/lb. of water X193=193,000 BTUH
- Per Day (Times 24)—1,488,000 BTU to 4,632,000 BTU per day.435 kw to 1,356 kw/day
- $35 to $110 per day electric.

Added Cost

- Standby losses
- Maintenance
- Space allowance for equipment
- Replacement cost.

Installation Cost

- New Project Cost ~Institutional 100 year Building
- \$150 to \$225/ sq. ft Building not including land.
- Mechanical and Electrical Construction Cost 1/3 to ½ the cost With Humidification adding \$1 to \$2 Per Square Foot
- Self Contained in space equipment-\$50/lb per hour capacity on 10 to 200 lb/hour equipment.

Questions... ?

…thank you !