ENGS 44

SUSTAINABLE DESIGN

In Search of Indoor Comfort

Benoit Cushman-Roisin
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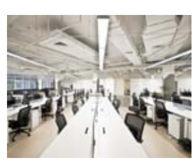
Fact: People spend 90% of their time being indoors.

Questions:

What is comfort?
How do you define it?

Is this room comfortable?

or



or

Elements of the answer

- Fresh air (as opposed to stale)
  → Good level of oxygen → Sufficient air exchange with outside

- Not too hot and not too cold
  → Control of temperature

- Not too dry and not too humid
  → Control of relative humidity

- Good amount of light, but no excess and no glare
  → Enough light, preferably diffuse

- Human dimension to the context
  → Appropriate geometric dimensions, pleasing shapes and colors

There are many more intangible aspects to comfort.

Formal definition of thermal comfort
(ASHRAE* Standard 55-2013 *Thermal Environmental Conditions for Human Occupancy*)

Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment.

A definition of comfort in general (not just thermal) may then be:

Comfort is that condition of mind which expresses satisfaction with one's environment.

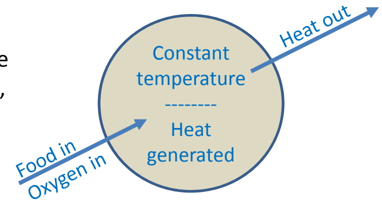
* ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers
(Only engineers could come up with such a name!)

Let's first focus on the thermal part because it is not only essential but also most easily comprehended.

Our body's thermostat is set at 98.6°F (37°C), and we generate heat by our metabolism and muscular activities:

Activity	Heat produced (in Watts)	Heat produced (in BTUs/hour)
Sleeping	100	340
Light work	200	680
Walking	300	1020
Jogging	800	2720

To remain at its constant temperature, the body has to eliminate the heat generated, somehow and at a rate equal to its production, in average.



Thermal Comfort

The human body has ways to adjust (increase or decrease) its heat loss, for example by bringing more or less blood to vessels right under the skin or by changing the total amount of blood in the body, with more blood produced under warmer conditions to expel heat more effectively.

Sweating and the resulting evaporation is another physiological mechanism to expel heat, but it is not one that we would call comfortable.

Thus, we can feel thermally comfortable within a range of temperatures, but that this range is limited.

Experience reveals that the comfort range for most people extends from 68°F (20°C) to 78°F (25°C).

Humidity Comfort

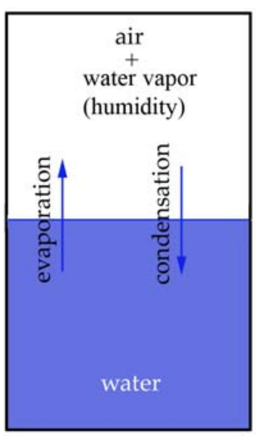
Likewise with humidity. Experience reveals that comfort is best achieved within a range of relative humidity.

Relative humidity (RH) is the fraction of water vapor that the air actually contains to the amount that it would contain at the point of condensation, expressed as a percentage. Thus, 0% corresponds to dry air, and 100% to maximally humid air for its temperature. Neither extreme is comfortable.

The minimum comfortable level of relative humidity is 20%. Below this, people complaint of dry nose, mouth, eyes, and skin, and there is an increase in respiratory illnesses. Furthermore, static electricity and shrinkage of wood are also problems cause by excessively low humidity.

The maximum comfortable level varies with the season.
- In summer, when the need to expel heat is more important, cooling by evaporation of body moisture is necessary, and RH is best kept below 60%.
- In winter, when getting rid of excess heat is hardly the case, a higher level of humidity can be tolerated, and the maximum RH level is 80%.

Humidity Limit as a Function of Temperature



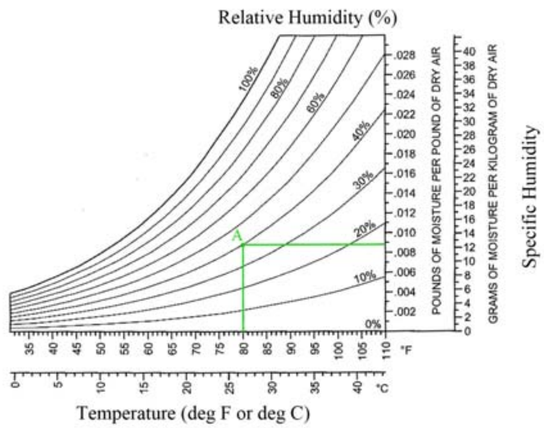
When water is exposed to air, some water evaporates and contributes to a certain level of humidity in the air. An equilibrium is eventually reached, and the amount of humidity (= mass of water vapor per mass of air) remains a constant. This level of humidity is the maximum possible level. Any higher level would cause condensation of water vapor back into liquid water.

At equilibrium, the water vapor is said to be saturated, and relative humidity is said to be at 100%.

This level of saturation varies with temperature. For example,
at 40^{o}F, it is 0.006 pound of water vapor per pound of dry air,
at 80^{o}F, it is 0.023 pound of water vapor per pound of dry air.

In most common indoor situations, there is no significant amount of water exposed. (Typical exceptions are kitchens and bathrooms when in use and, of course, indoor swimming pools.)

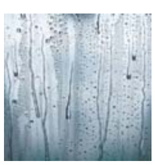
If the amount of humidity exceeds the saturation level, vapor condenses and forms droplets of water on surfaces. Surfaces get wet, and we call that moisture. Moisture in buildings is not good because persistent moisture leads to mold.

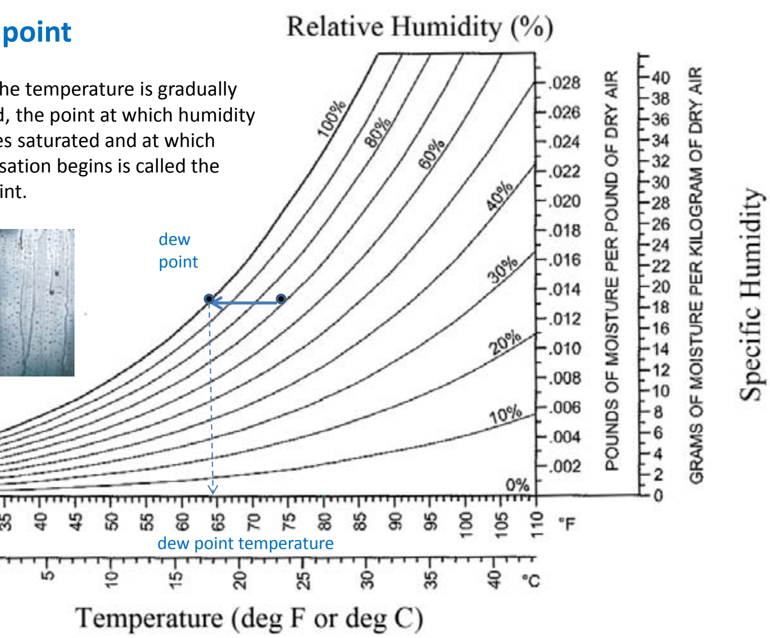


If the amount of humidity is lower than the saturation level, and if there is no exposed water to bring water vapor to the saturated state, the level of humidity lies somewhere between zero and saturation. This amount is measured as a % of the saturation value.

Dew point

When the temperature is gradually lowered, the point at which humidity becomes saturated and at which condensation begins is called the dew point.





The psychrometric chart and
Defining the comfort zone on it

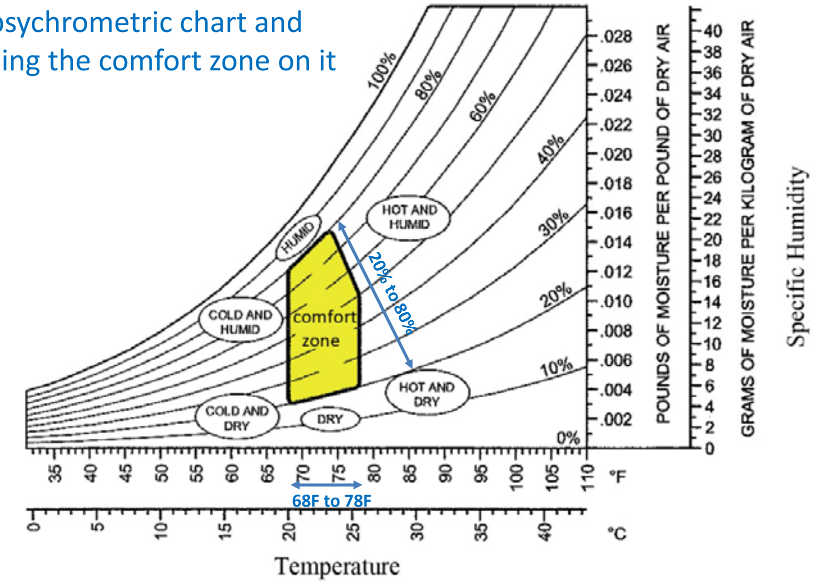
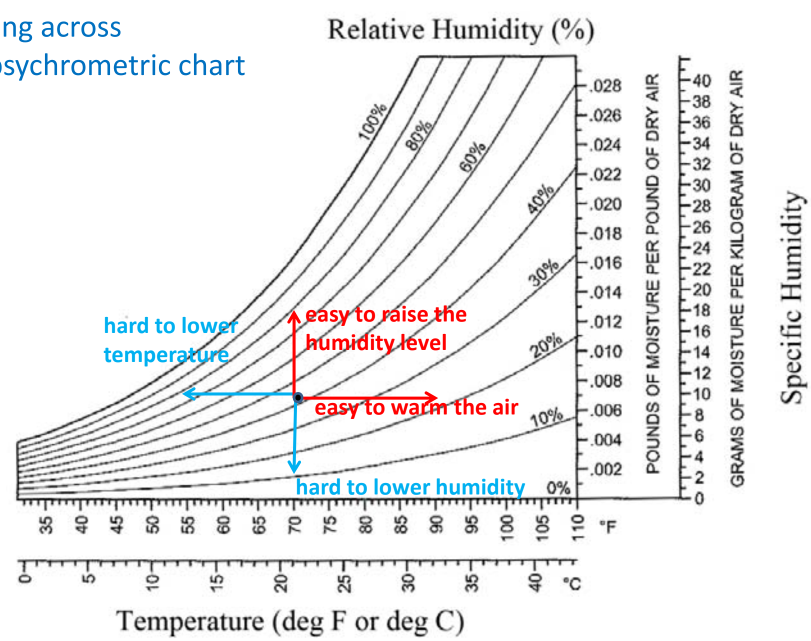


Figure 4.8a The comfort zone and various types of discomfort outside that zone are shown on this psychrometric chart.

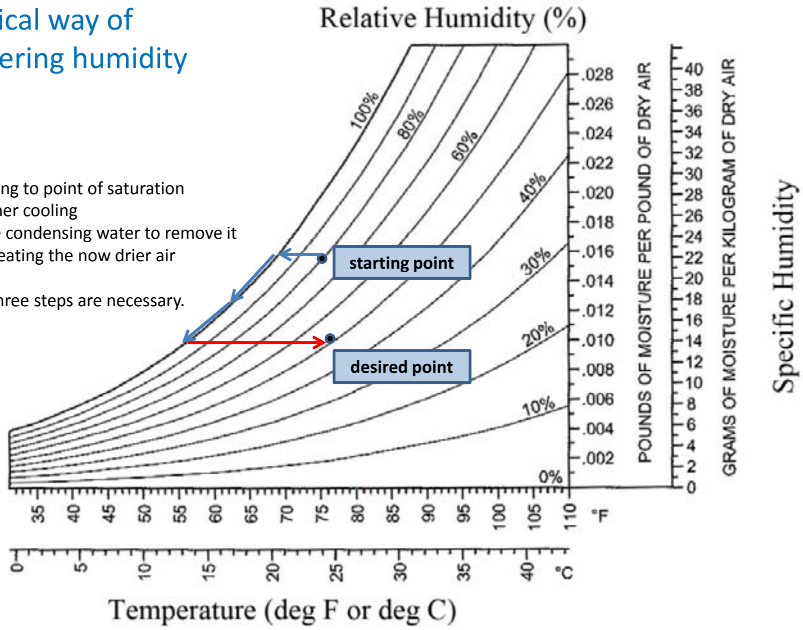
Moving across
the psychrometric chart



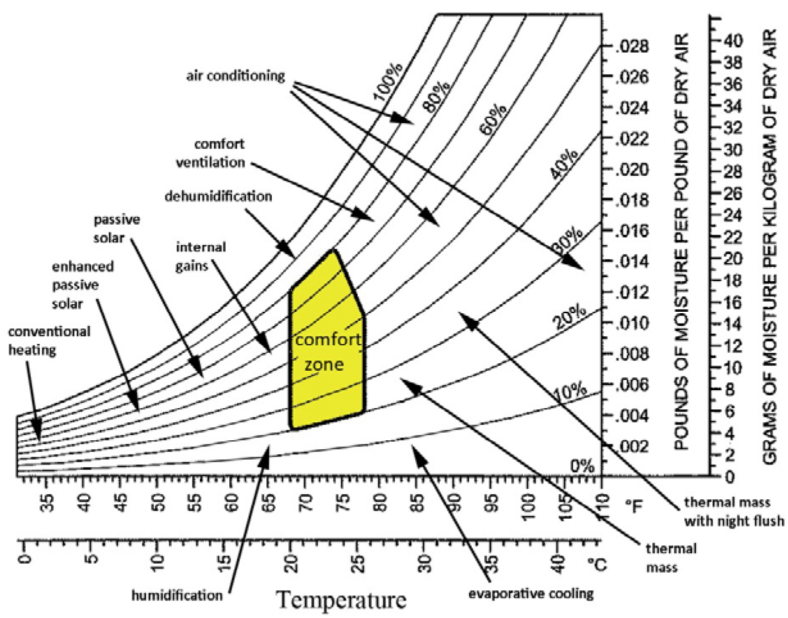
Typical way of lowering humidity

1. Cooling to point of saturation
2. Further cooling
   while condensing water to remove it
3. Re-heating the now drier air

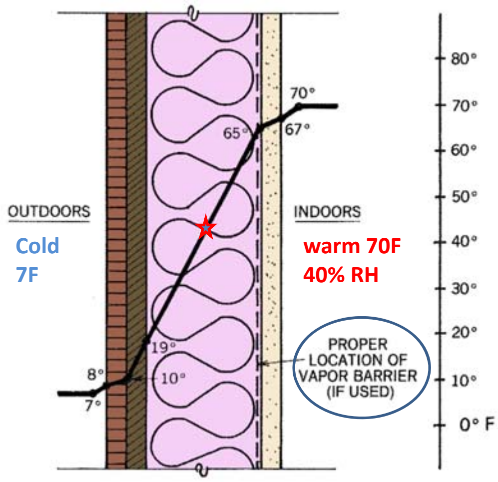
Thus, three steps are necessary.



Various methods and technologies to bring indoor air conditions into the comfort zone



Reaching dew point inside of a wall: Danger of condensation within the wall!



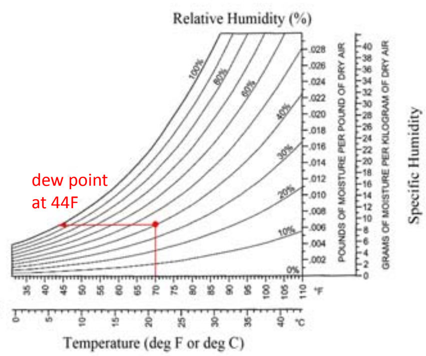


Figure 15.14c The graph of the thermal gradient, which is superimposed on a wall detail, clearly shows the temperature at each layer inside the construction. The dew-point temperature of the air determines if and where in the wall condensation will occur. Vapor barriers are recommended only in very cold climates.

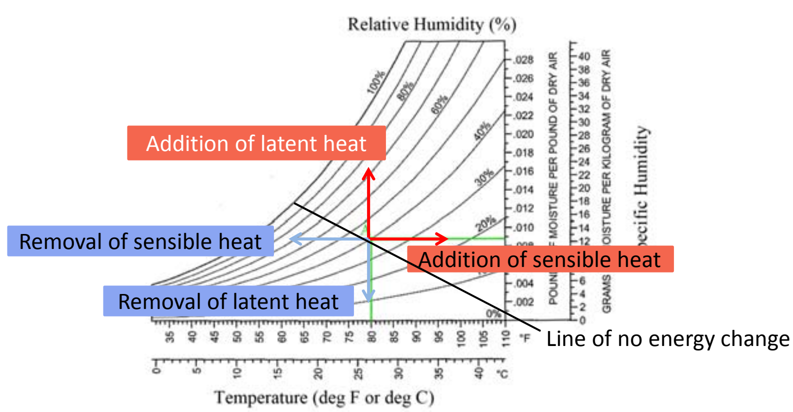
Energy Considerations

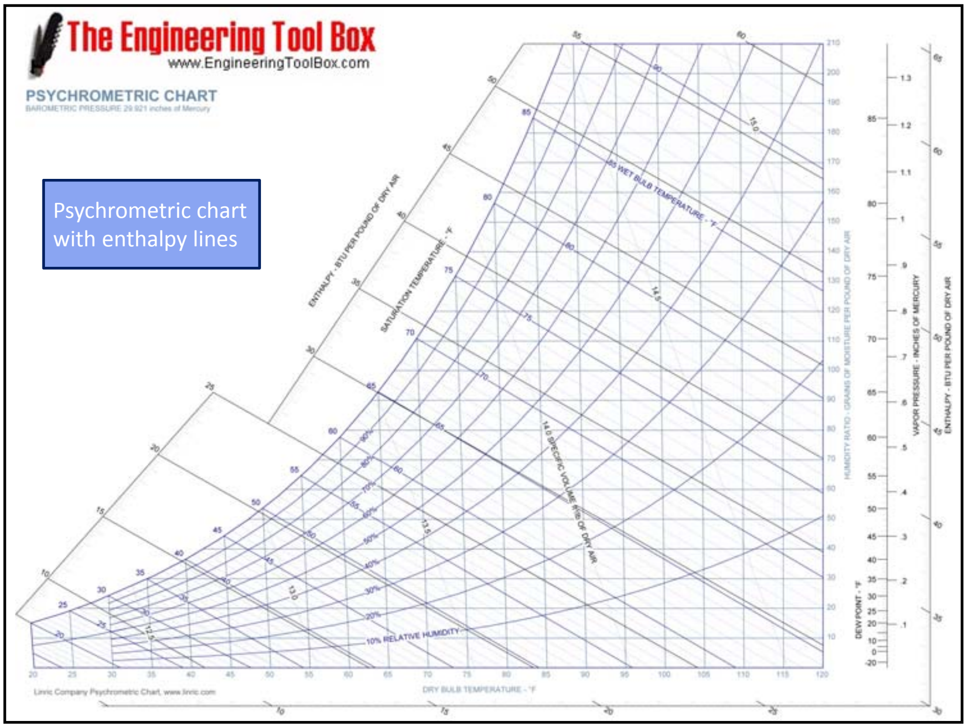
It takes energy to change the temperature of the air:
- Input for heating
- Removal for cooling.

} called sensible heat

Likewise, it takes energy to vary the humidity of the air:
- Input to vaporize liquid water into vapor
- Removal to condense vapor into liquid.

} called latent heat





An important side note: Notion of **ENTHALPY**

When a manipulation of air is done at constant pressure (here, atmospheric pressure), it is accompanied by a change of volume. The pressure force times a displacement creates mechanical work. Work is expanded by the air during dilation, and work is taken by the air during contraction.

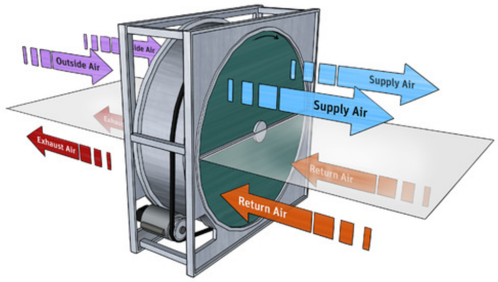
Mechanical work is a form of energy, and this must be added to the sensible and latent heat forms of energy.

When mechanical work is added to heat, the total energy quantity is called enthalpy.

The concept of enthalpy is often misunderstood, and it is very common to hear HVAC* engineers speak about energy when they mean only heating/cooling and enthalpy when they include humidity. The latent heat associated with humidity is NOT what makes energy become enthalpy. What makes energy become enthalpy is the fact that the change occurs at constant pressure rather than at constant volume.

(* HVAC = Heating, Ventilation and Air Conditioning)

The enthalpy wheel



The slowly turning wheel absorbs and rejects heat. It is also covered by a desiccant that absorbs and rejects humidity.

In the case of indoor heating, the exhausting air is warmer and more humid than the outside air. The lower part of the wheel absorbs both heat and humidity. When this half of the wheel has rotated to become the upper part, it imparts its heat and humidity to the cold and dry air entering from the outside. The net effect: The air has been changed, but about 85% of its heat and humidity has been recycled.