4.401/4.464 Environmental Technologies in Buildings

Christoph Reinhart

L04 Wind, Temperature and Relative Humidity

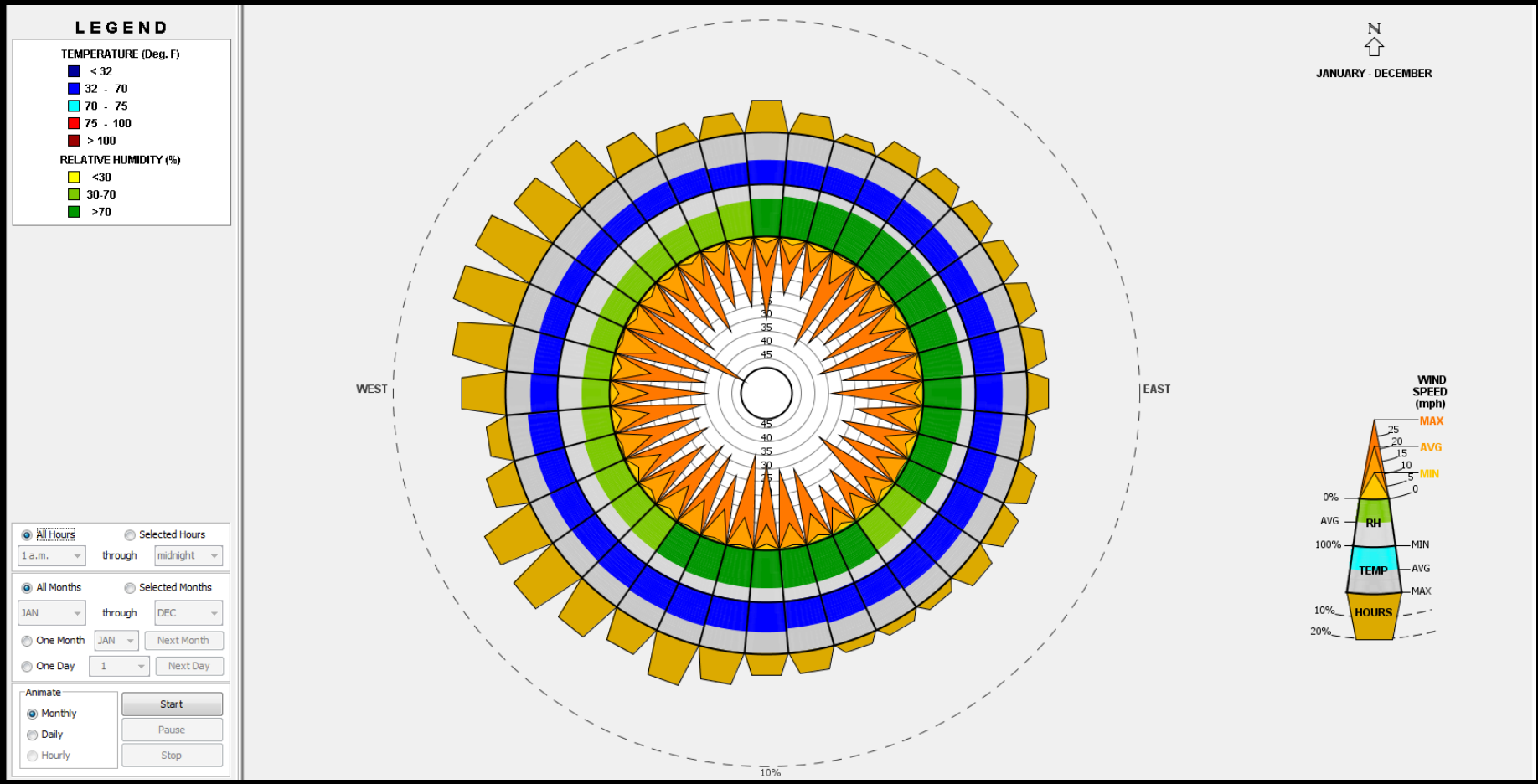
Wind

Measuring Wind

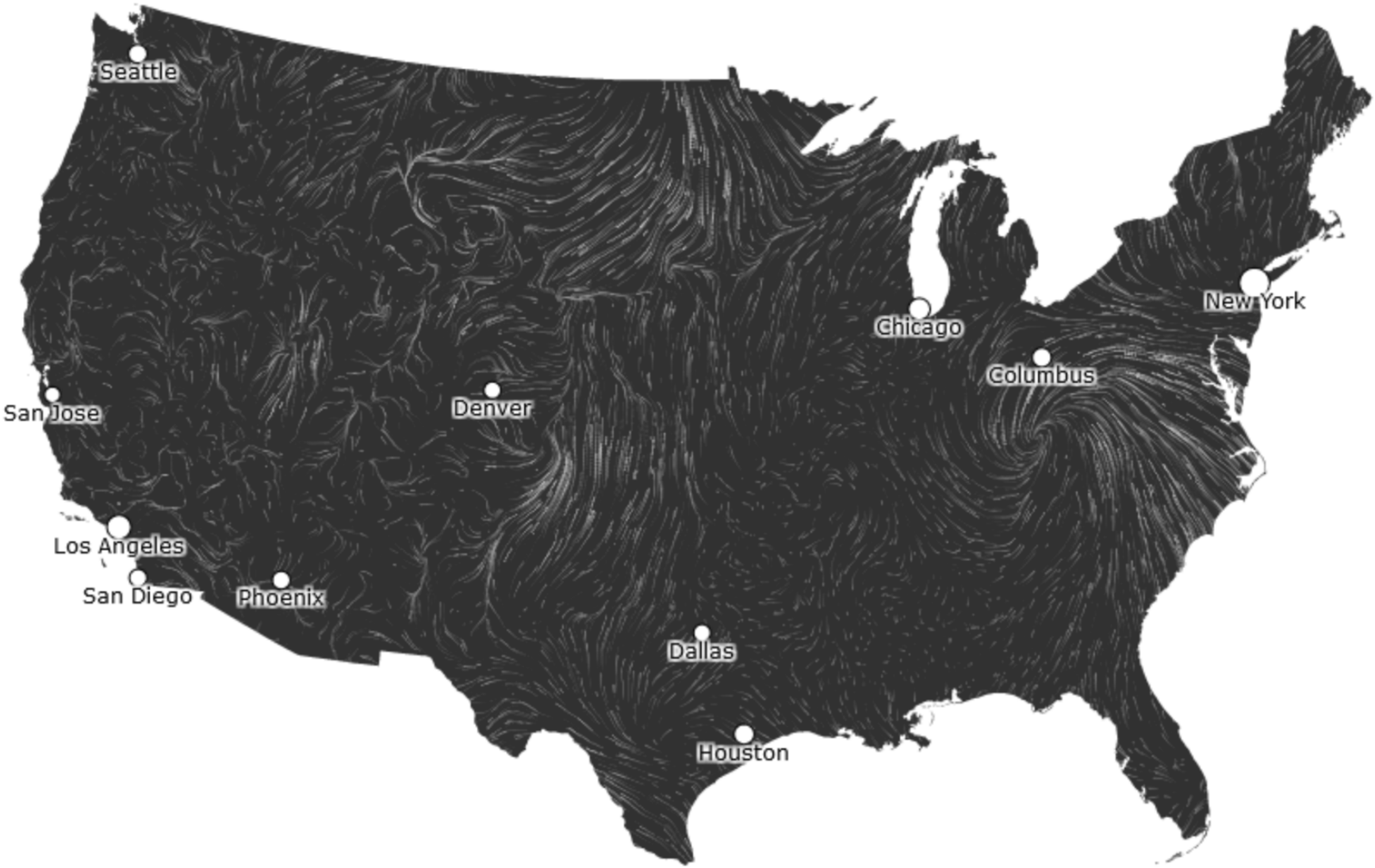
Wind speed [km/h or m/s]

Wind direction [degree]

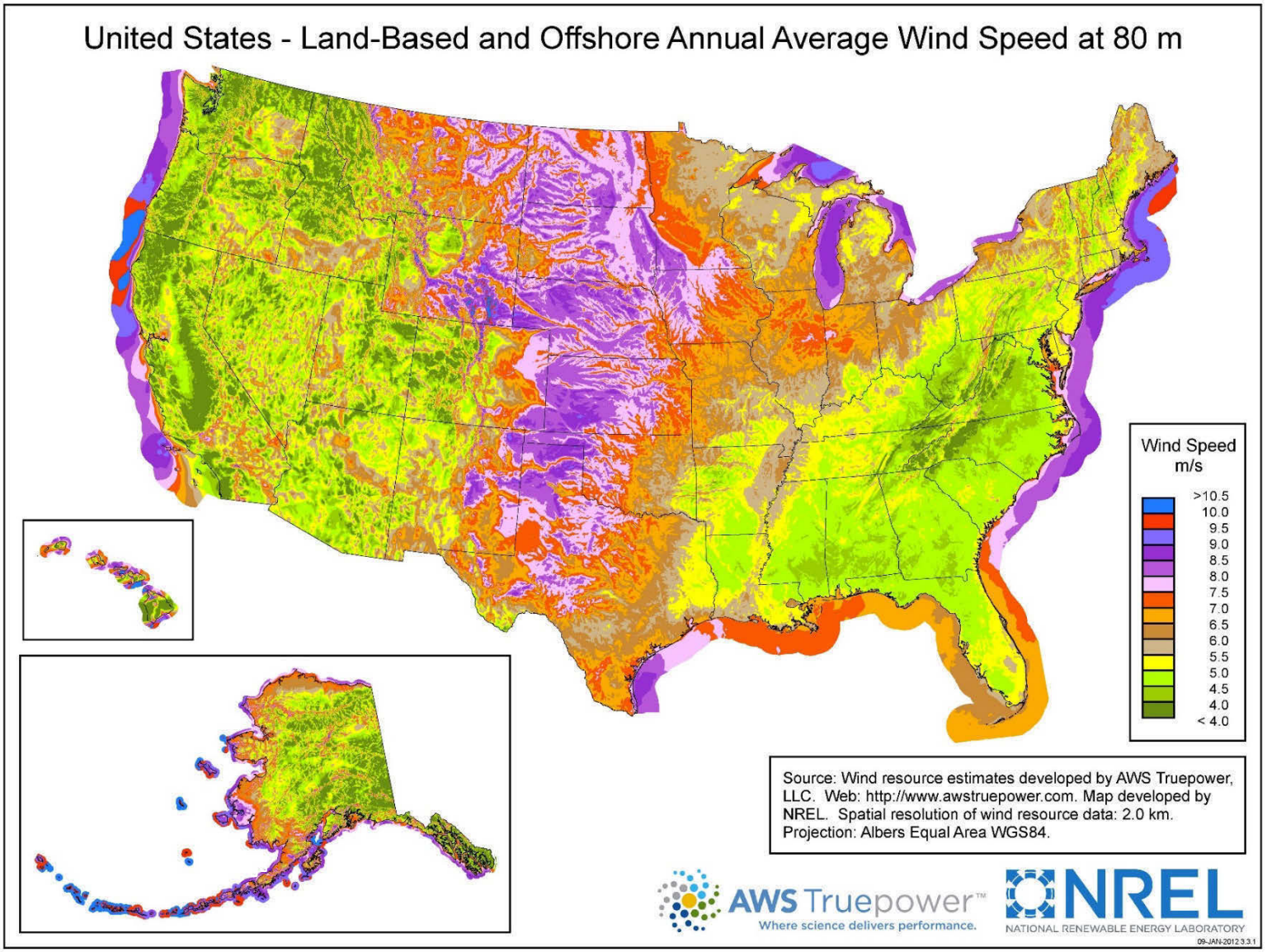
Prevailing Winds at Logan Airport



Wind Wheel generated using Climate Consultant software.



Data source: National Digital Forecast Database



Public domain image courtesy of NREL.

Wind Turbine Types

2 MW rated capacity | $3-4 million installed

10 kW rated capacity | $50,000 - $80,000

- Commercial turbine have a rated capacity from 0.5 to 8 MW at a diameter 30 m to 150 m and a hub height of 220 m.
- Residential turbines have a rated capacity under 30 kW, rotor diameters of 1 m to 15 m and a hub height up to 40 m.
- Total annual energy yield depends on a site's capacity factor which is usually in the 15% to 20% range.

Wind Turbine Types Analysis

Annual Energy = Rated Capacity x 8760 h x Capacity Factor

Annual Energy = 2 MW x 8760 x 15% = 2.6 million kWh

Corresponds to the annual energy use of ~200 homes.

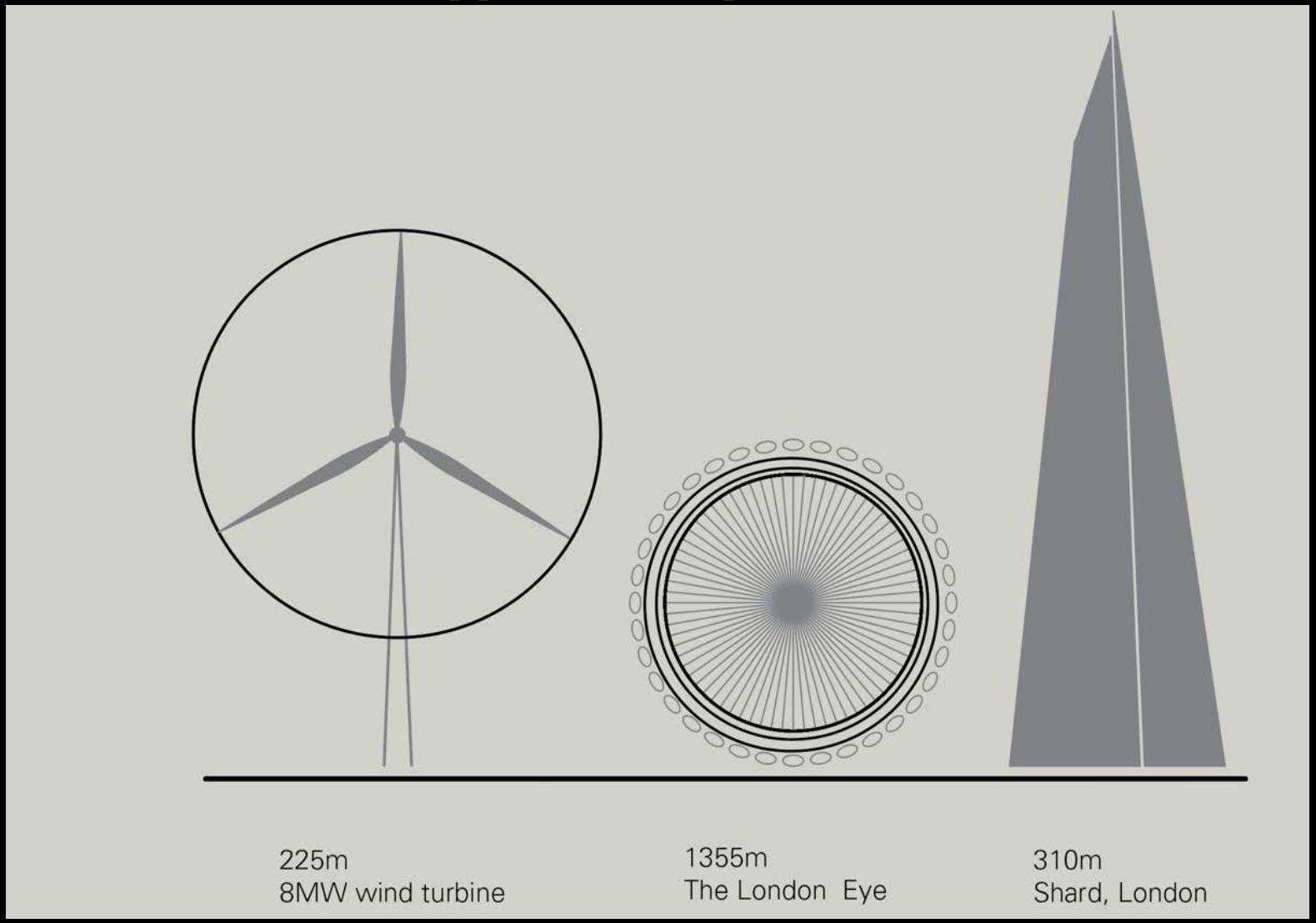
Upfront cost = $15,000 to $20,000 per home

Annual Energy = 10 kW x 8760 x 15% = 13,000 kWh

Corresponds to the annual energy use of ~1household (10 000 kWh).

Upfront cost = $50,000 to $80,000 per home

Wind Turbine Types Analysis



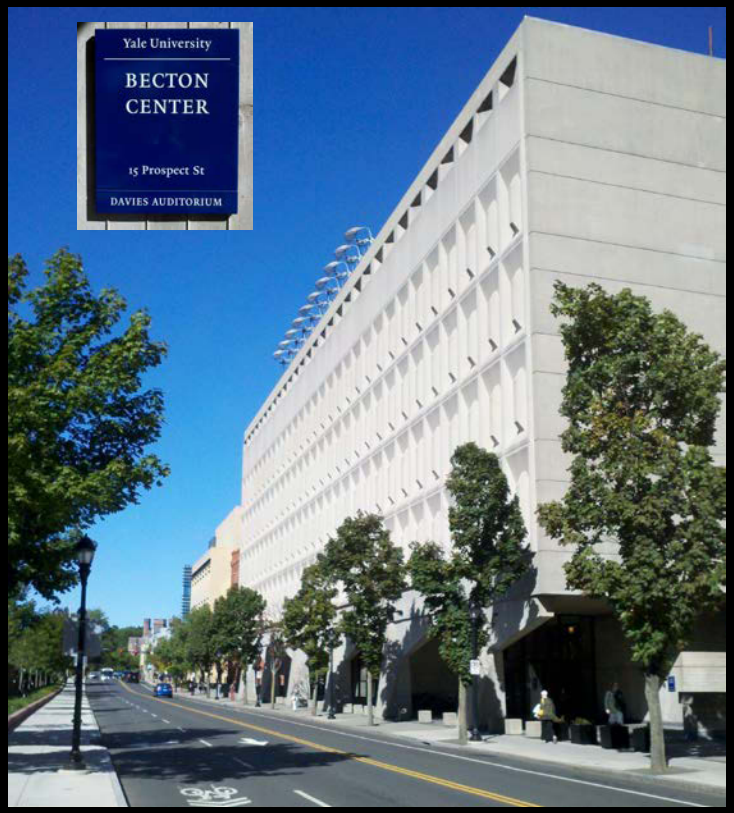
In 2016, 6% of US electricity came from wind power (US Energy Information Administration; https://www.eia.gov/electricity/data.php)

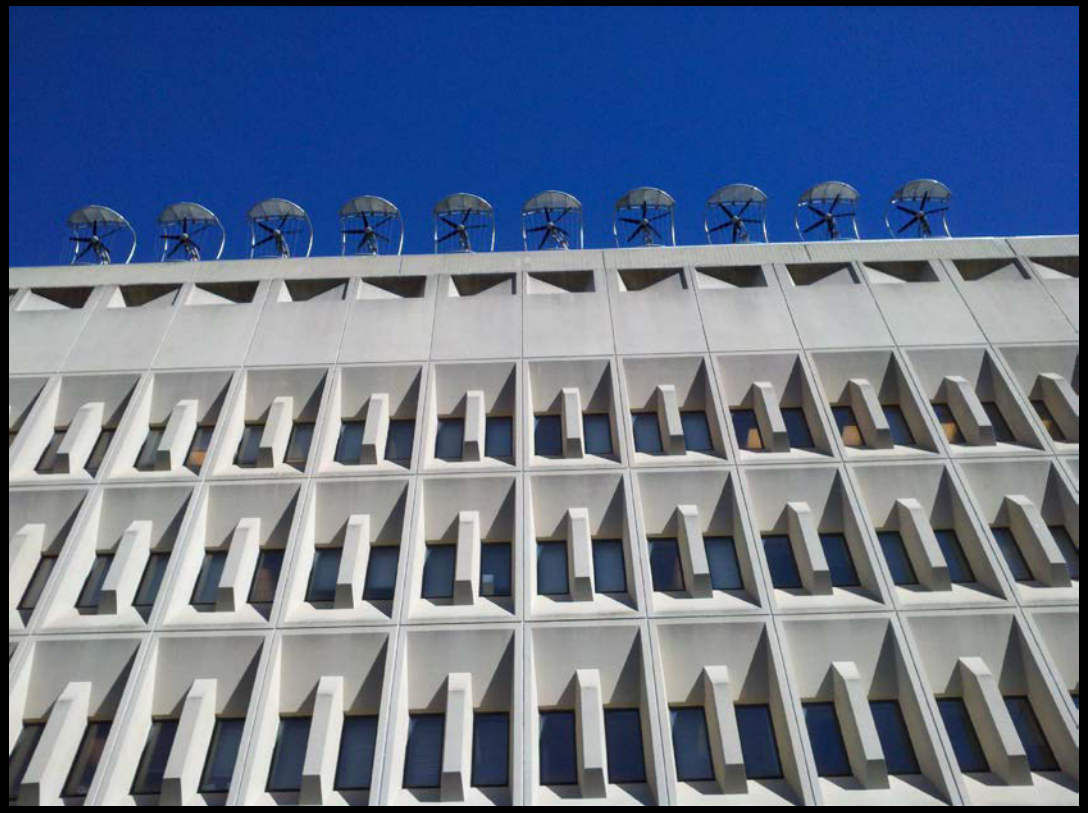
Bahrain World Trade Center

Architecture: Atkins
Wind turbines: Danish company Norwin A/S (225 kW)

Is this a good idea?

Building Integrated Wind Power



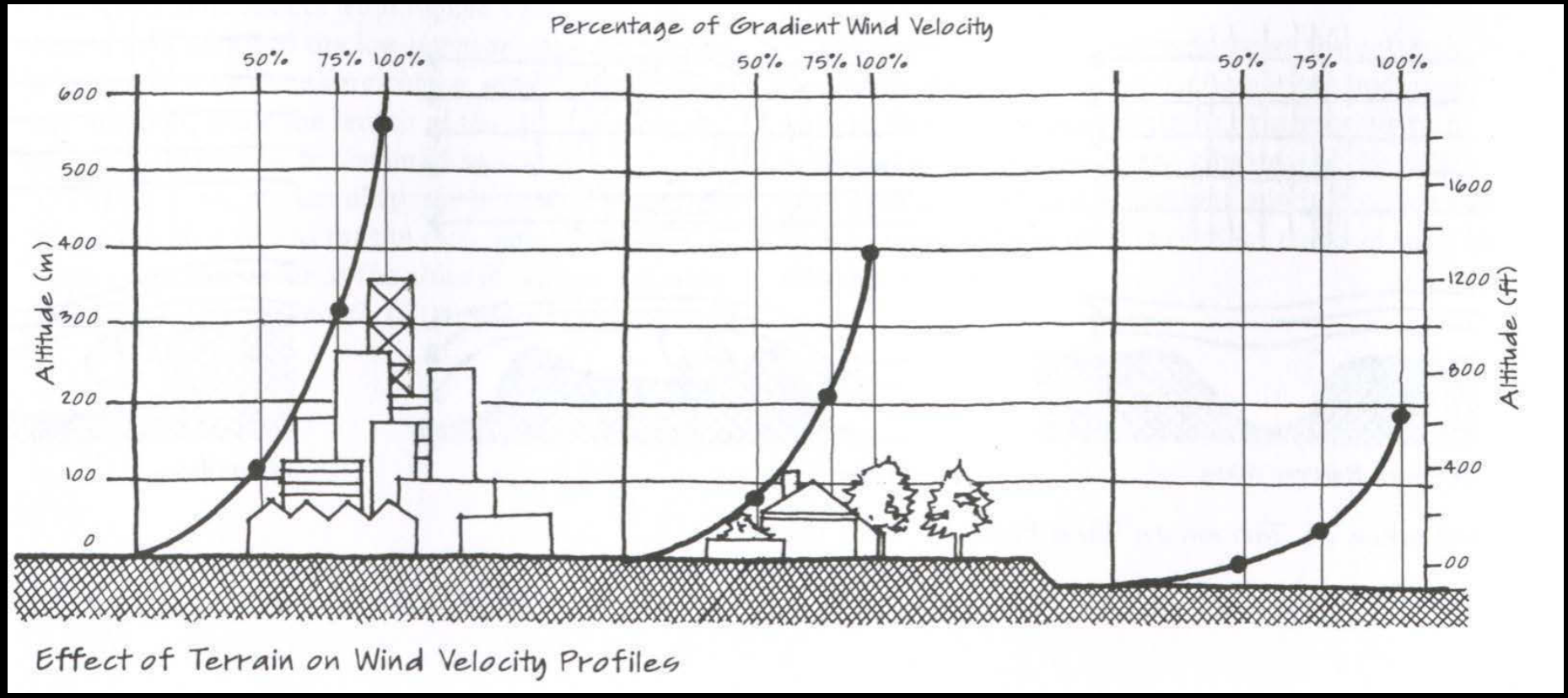


Becton Center, Yale University

- It is generally difficult to predict the electricity gains from building integrated wind turbines due to unknown and complicated/turbulent local wind patterns.
- Other concerns associated with this technology are economy of scale issues (small wind turbine versus large ones) and well as noise and structural stress cause by these systems
- At the building level PV is comparable in price but at less maintenance cost and disturbance.

Review article: Alex Wilson, 2009, "The Folly of Building-Integrated Wind," *Environmental Building News*, URL: https://www2.buildinggreen.com/article/folly-building-integrated-wind

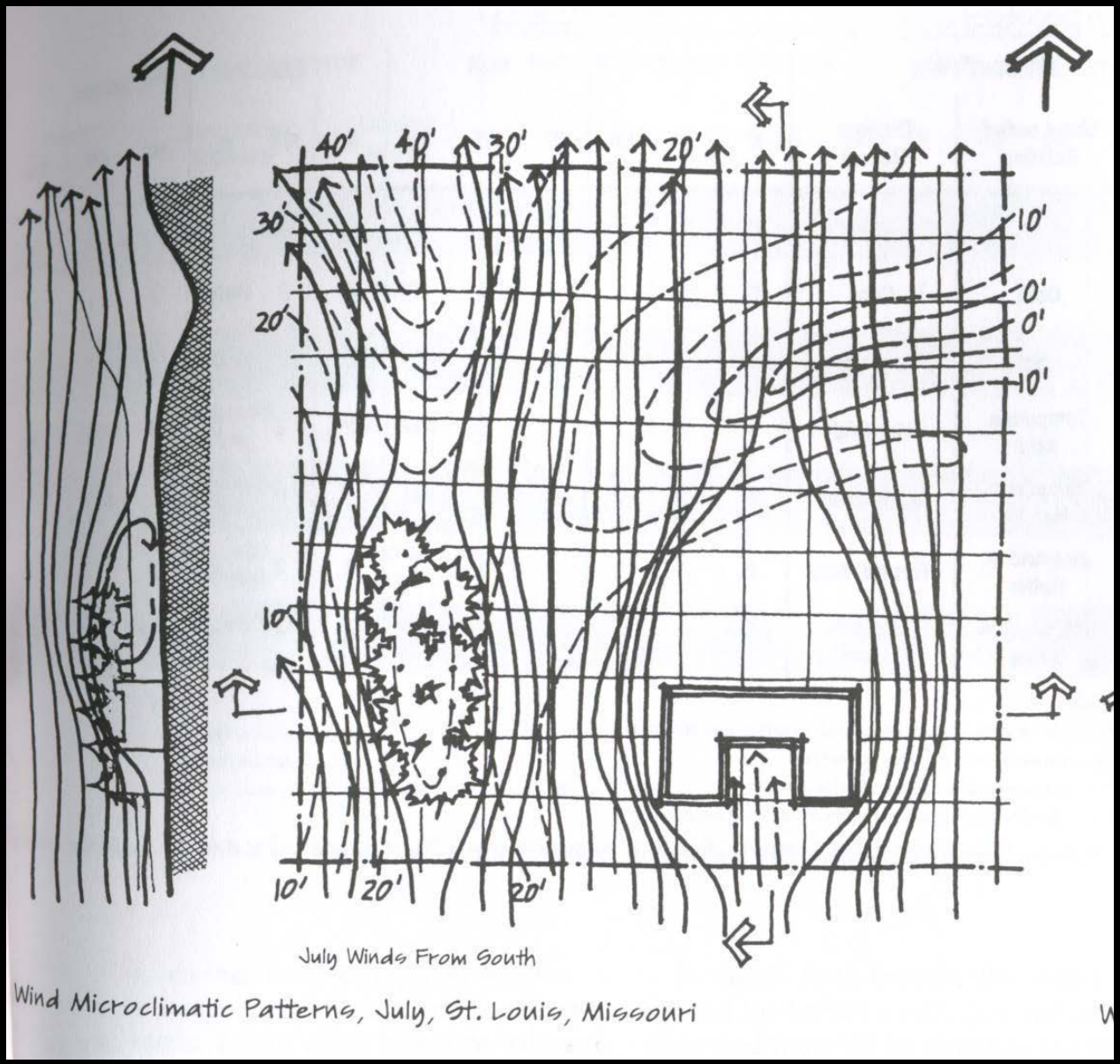
Effect of Terrain on Wind Velocity Profiles



Source: *Sun, Wind & Light*, Brown and DeKay. Courtesy of John Wiley & Sons. Used with permission.

- Graph is only qualitative and should be used with caution.

Microclimatic Wind Patterns



Source: *Sun, Wind & Light*, Brown and DeKay. Courtesy of John Wiley & Sons. Used with permission.

Pressure Coefficients

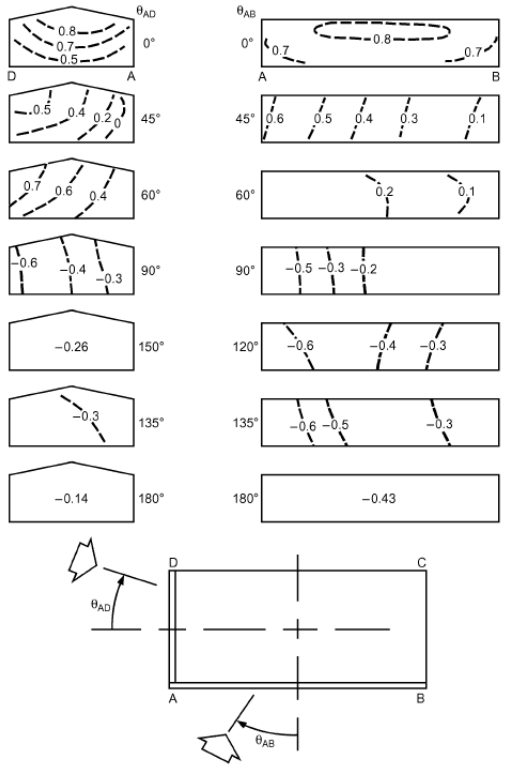


Fig. 5 Local Pressure Coefficients for Walls of Low-Rise Building with Varying Wind Direction
(Holmes 1986)

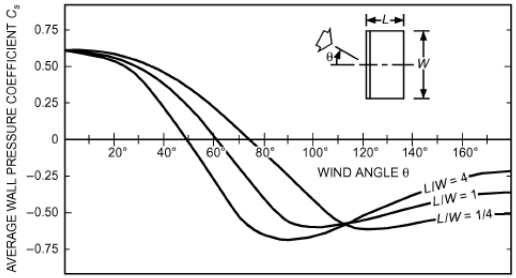


Fig. 7 Surface-Averaged Wall Pressure Coefficients for Tall Buildings
(Akins et al. 1979)

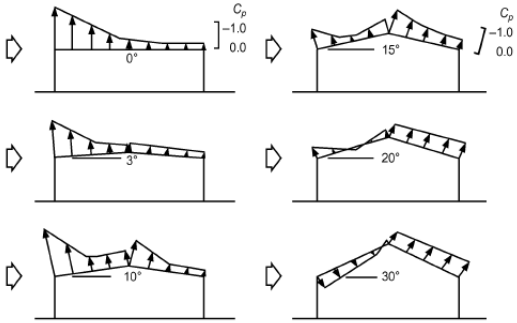


Fig. 8 Local Roof Pressure Coefficients for Roof of Low-Rise Buildings
(Holmes 1986)

- Wind Pressure : $P_{wind} = 0.5 * \text{mass-density}_{air} * C_p * \text{velocity}_{air}^2$
- C_p = pressure coefficient onto building façade, a pressure coefficient quantifies the interaction of wind with structure.
- Pressure coefficients are used to calculate wind loads and wind-induced air flow through naturally ventilated buildings.

Temperature & Relative Humidity

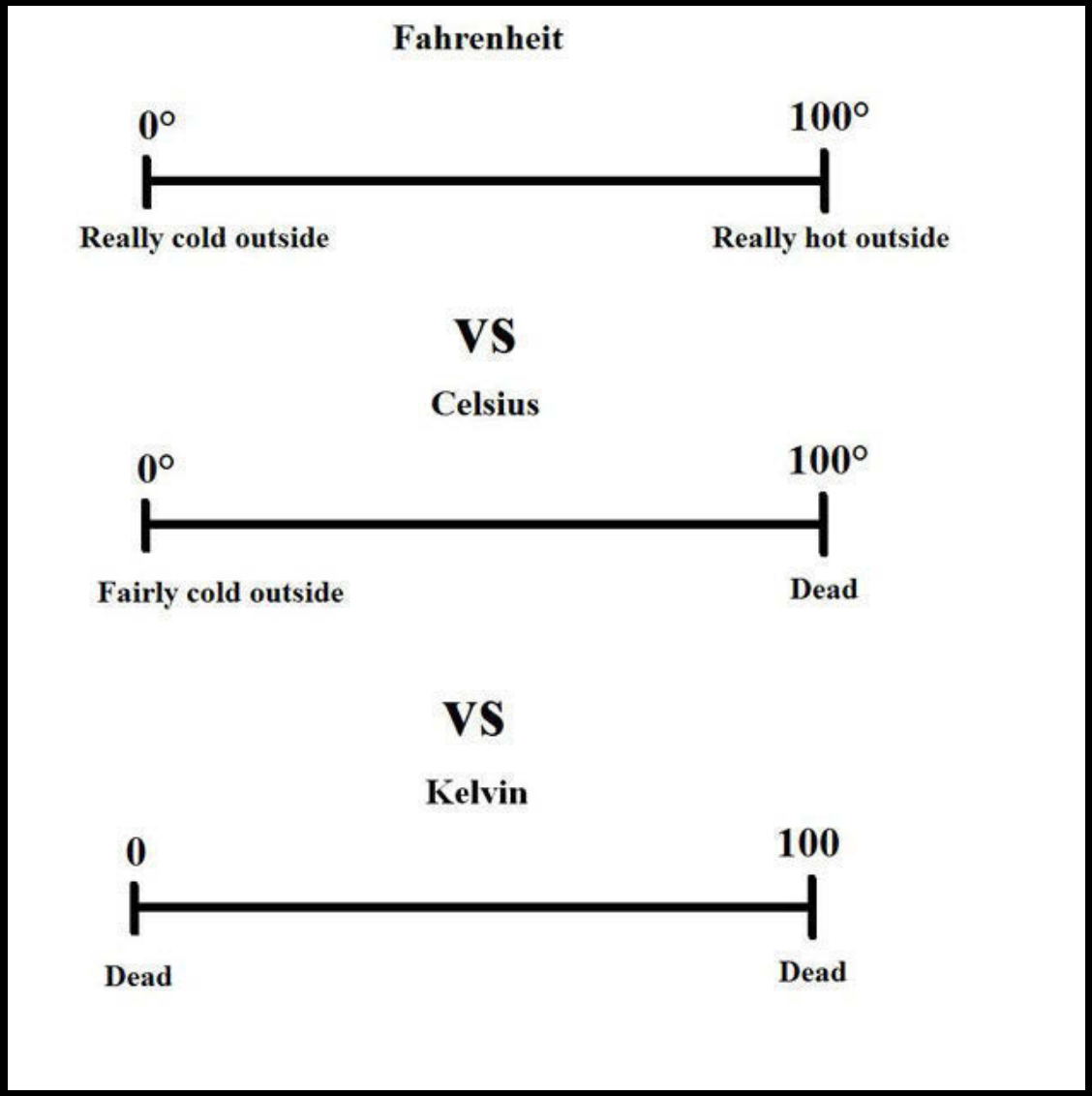
Temperature Units

°F =(9/5 x °C)+32
1724 Daniel Gabriel Fahrenheit

°C =5/9 x (°F -32)
1742 Anders Celsius

K = °C + 273
1848 Lord Kelvin

But... ☺

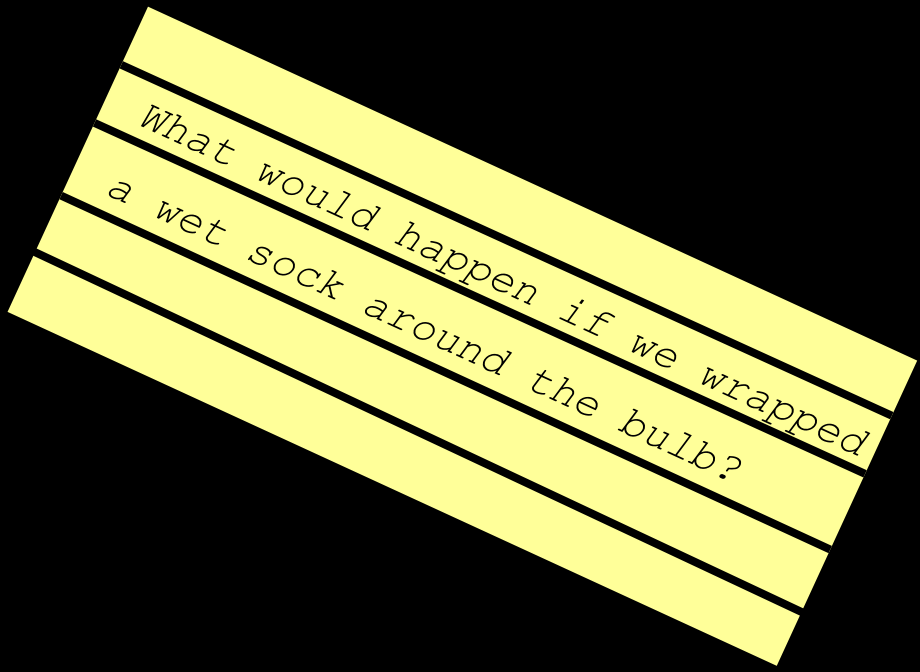


"Fahrenheit uses its digits more efficiently than Centigrade."

Dry Bulb Temperature

The dry-bulb temperature of an air sample, as determined by an ordinary thermometer, the thermometer's bulb being dry. DBT is measured in Celsius or Fahrenheit.

On a microscopic scale, temperature can be defined as the average energy in each degree of freedom in the particles in a system.



Wet Bulb Temperature

The wet-bulb temperature is the temperature of an air sample after it has passed through a constant-pressure, ideal, adiabatic saturation process. In practice, this is the reading of a thermometer whose sensing bulb is covered with a wet sock evaporating into a rapid stream of the sample air.

The WBT is the same as the DBT when the air sample is saturated with water.

Dew point temperature (DPT) is the temperature at which a moist air sample at constant pressure would reach water vapor saturation, i.e. the water vapor begins to condense.

Relative Humidity

Hair hygrometer.

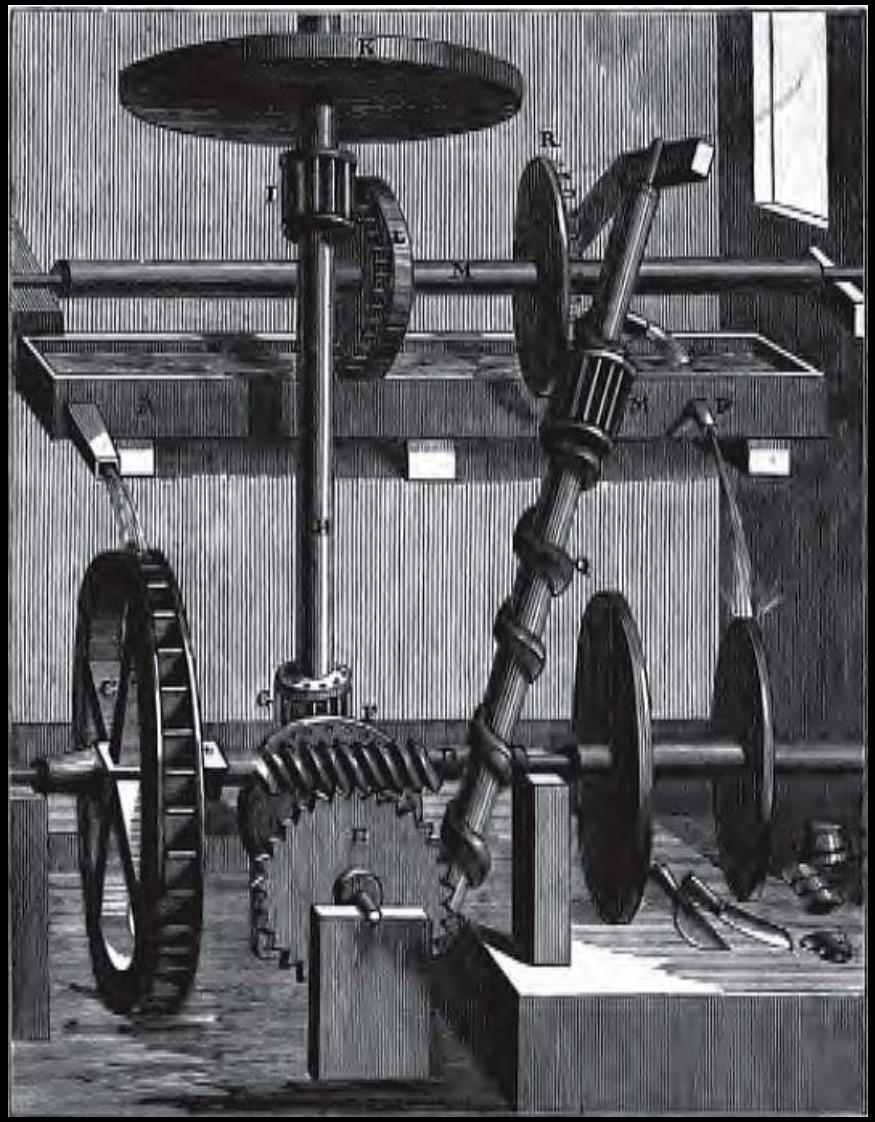
Relative Humidity (RH) is the ratio of the mole fraction of water vapor to the mole fraction of saturated moist air at the same temperature and pressure. RH is usually expressed as a percentage.

Absolute Humidity is the proportion of mass of water vapor per unit mass of dry air. AH is dimensionless, but is sometimes expressed as grams of water per kilogram of dry air (g/kg).

RH can be measured using a swing psychrometer. Modern sensors rely on resistive sensors (a polymer membrane whose resistance changes with temperature and RH).

Why do we obsess over moist air?

First Law of Thermodynamics



An engraving of Robert Fludd's 1618 "water screw" perpetual motion machine.
Public domain image courtesy of George A. Bockler on Wikipedia.

Energy can be converted from one form to another, but it is never created or destroyed.

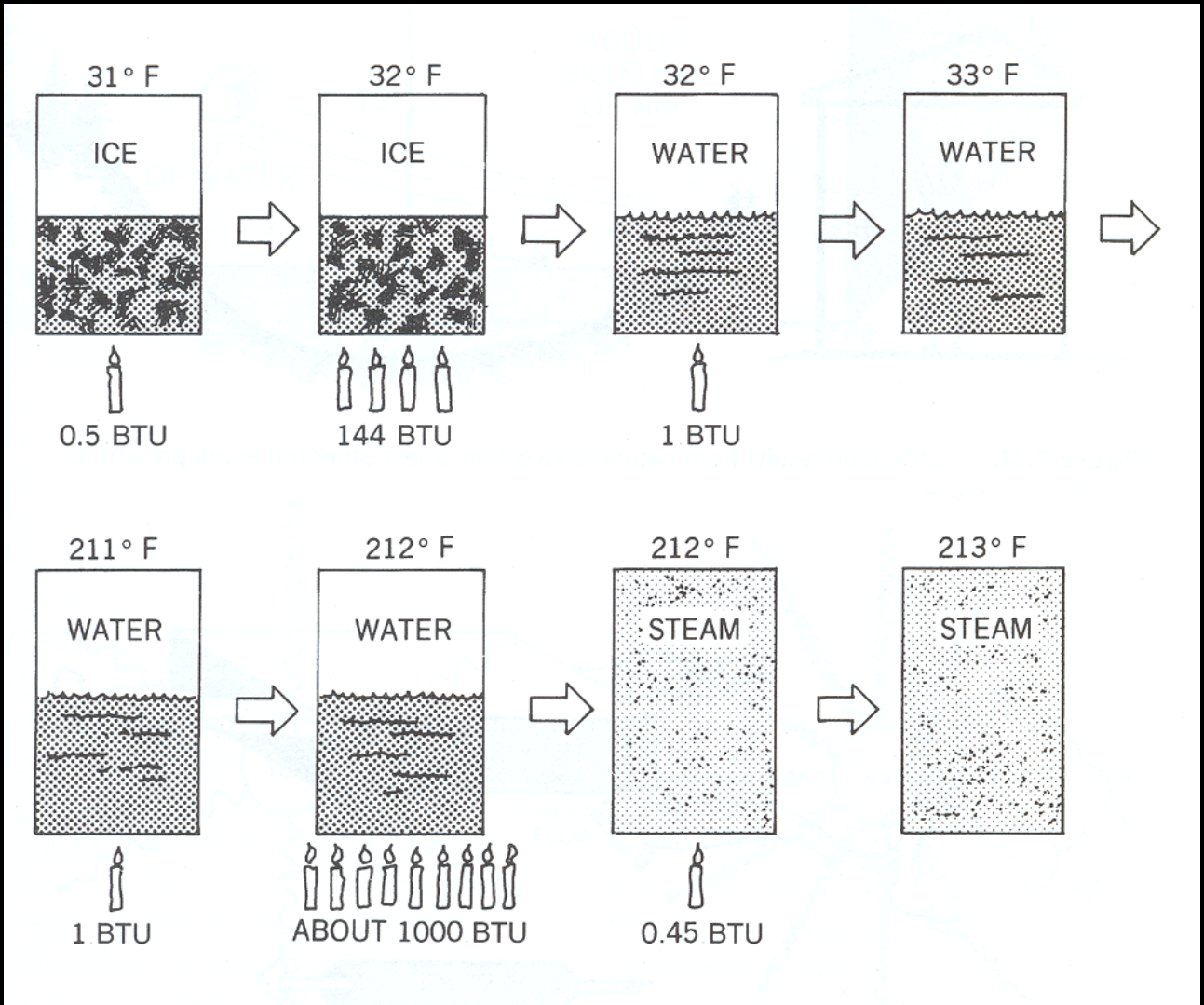
‘Heat’ (Internal Energy)

- Internal energy is a form of energy that is stored in a material as molecular motion (sensible energy) or that is associated with the phase of the material (latent energy).

- Sensible energy is measured in temperature.

- Latent energy is the amount of heat released or absorbed by a substance during a change of phase.

Internal Energy for Water



From Lechner, *Heating, Cooling, Lighting*. Courtesy of John Wiley & Sons. Used with permission.

How should we describe annual temperatue/RH?

CLIMAPLUS

Boston

outdoor climate | solar radiation

3030

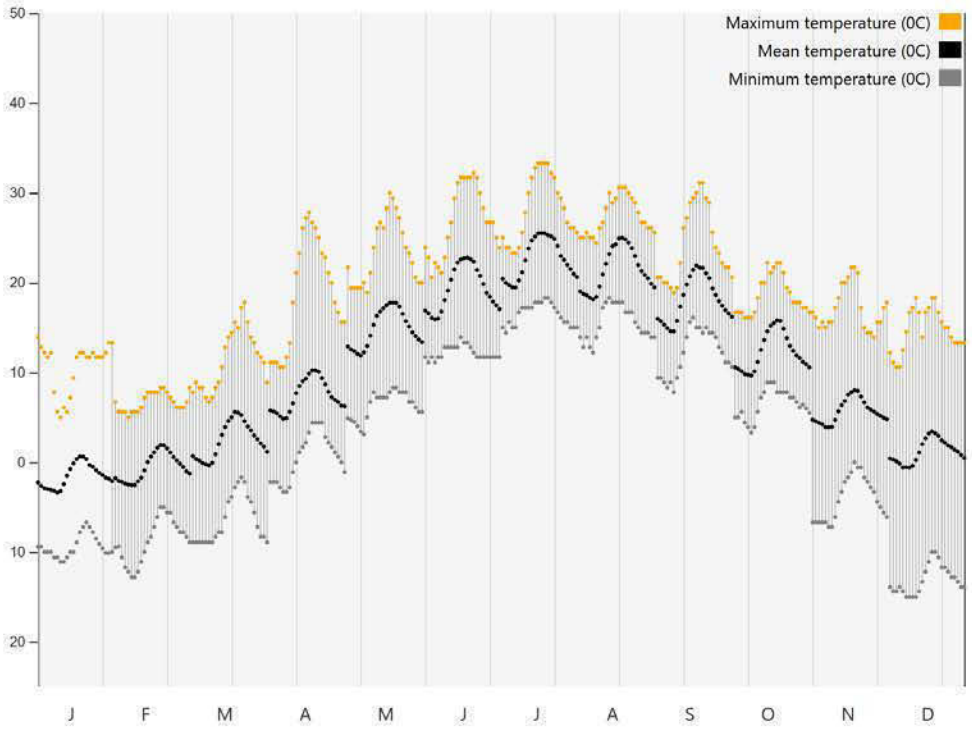
HDD18

1567

CDD10

5

Climate Zone



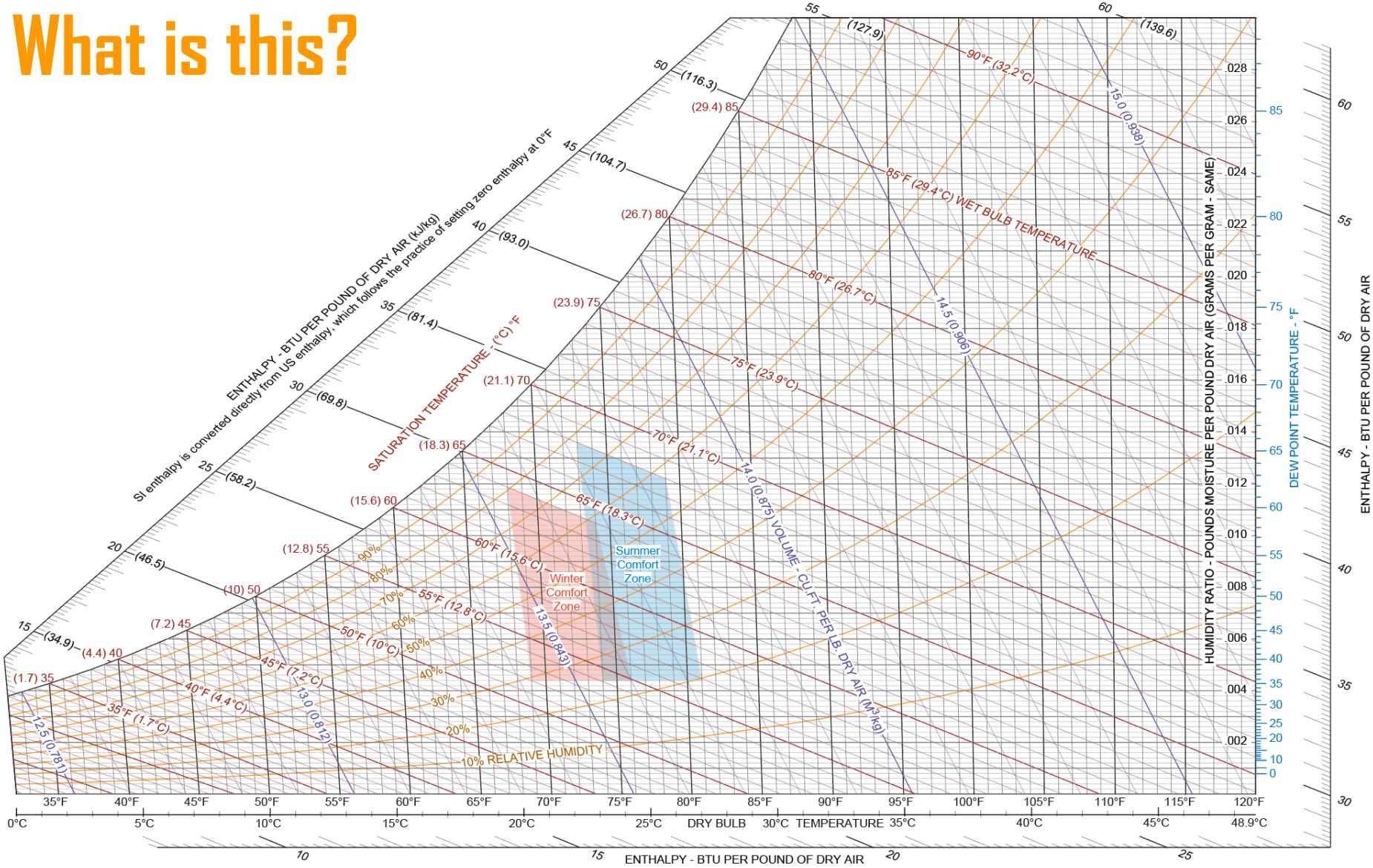
Outdoor Temperature

Hourly max, min and mean temperatures from each month in the year.

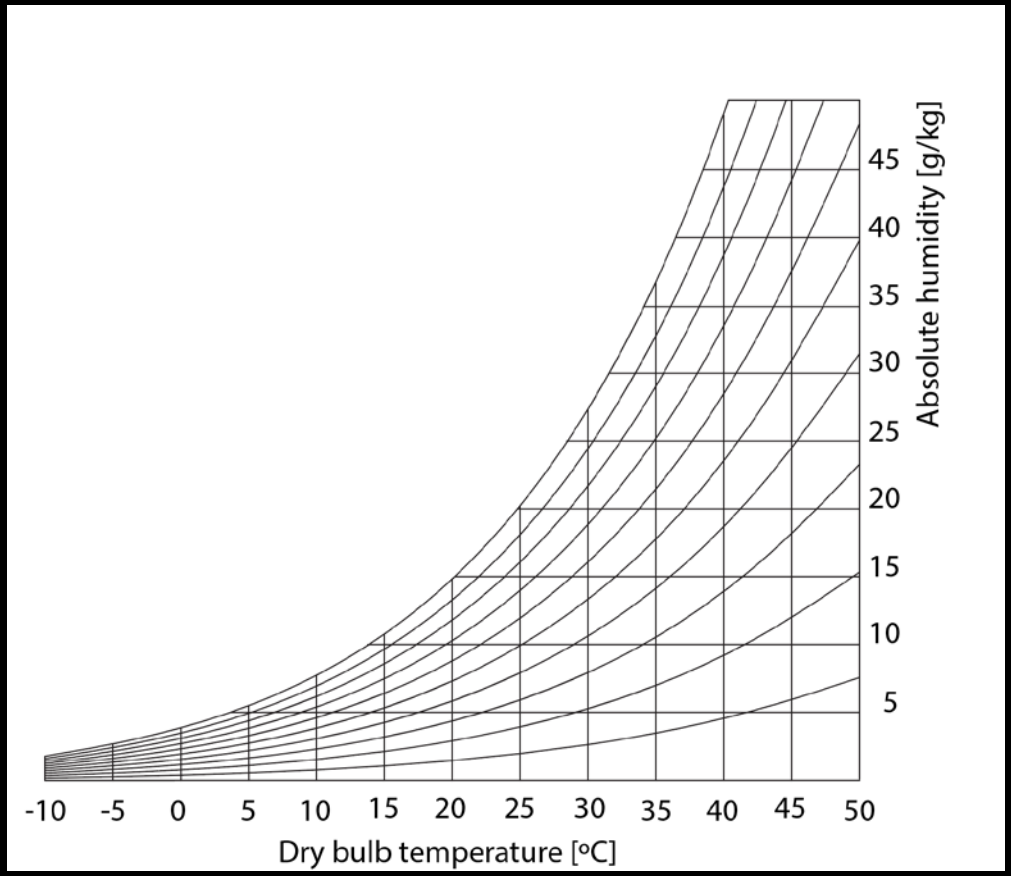
Source: Tool under development by Alpha Arsano

MIT SDLAB

What is this?

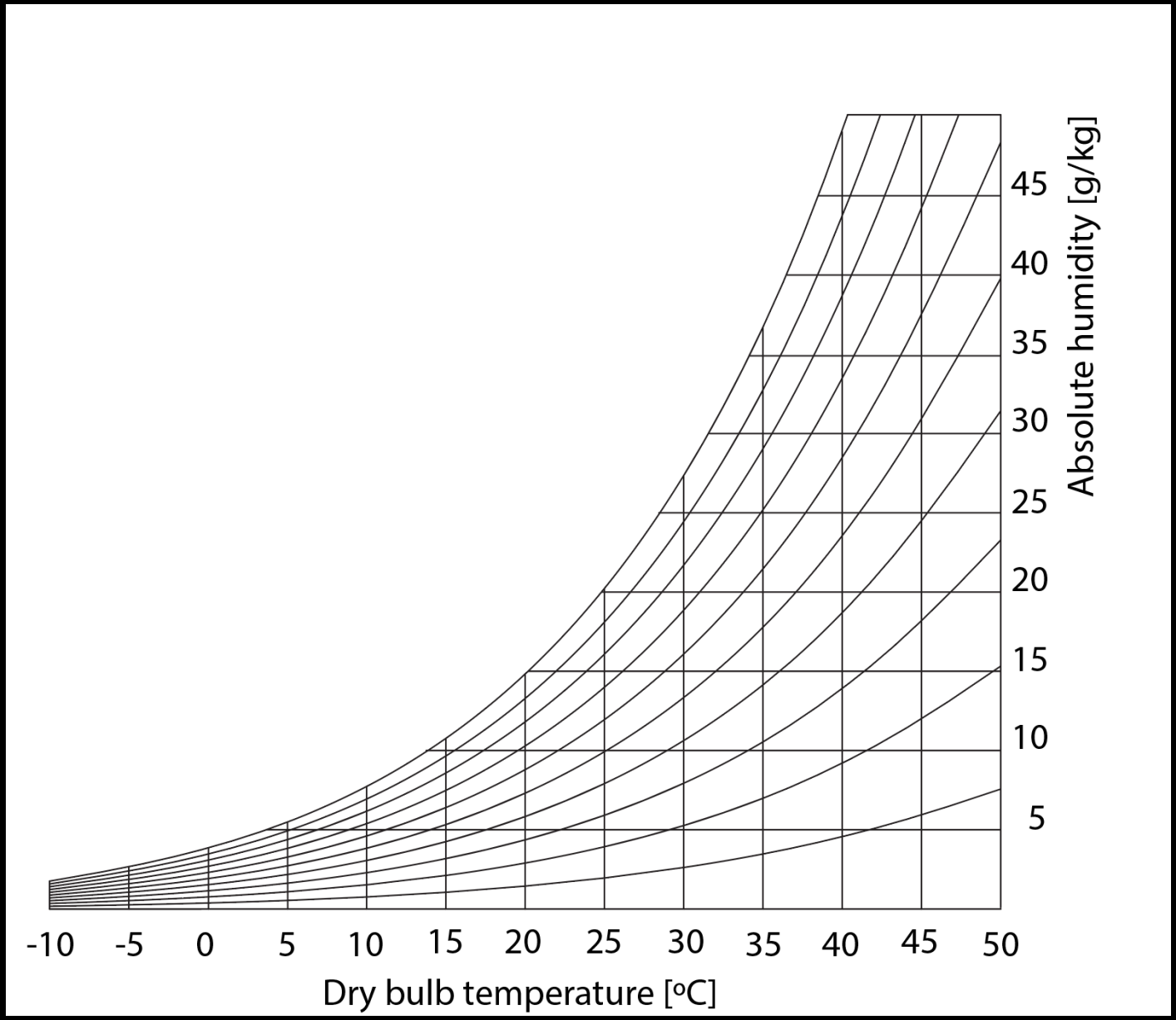


Psychrometric Chart

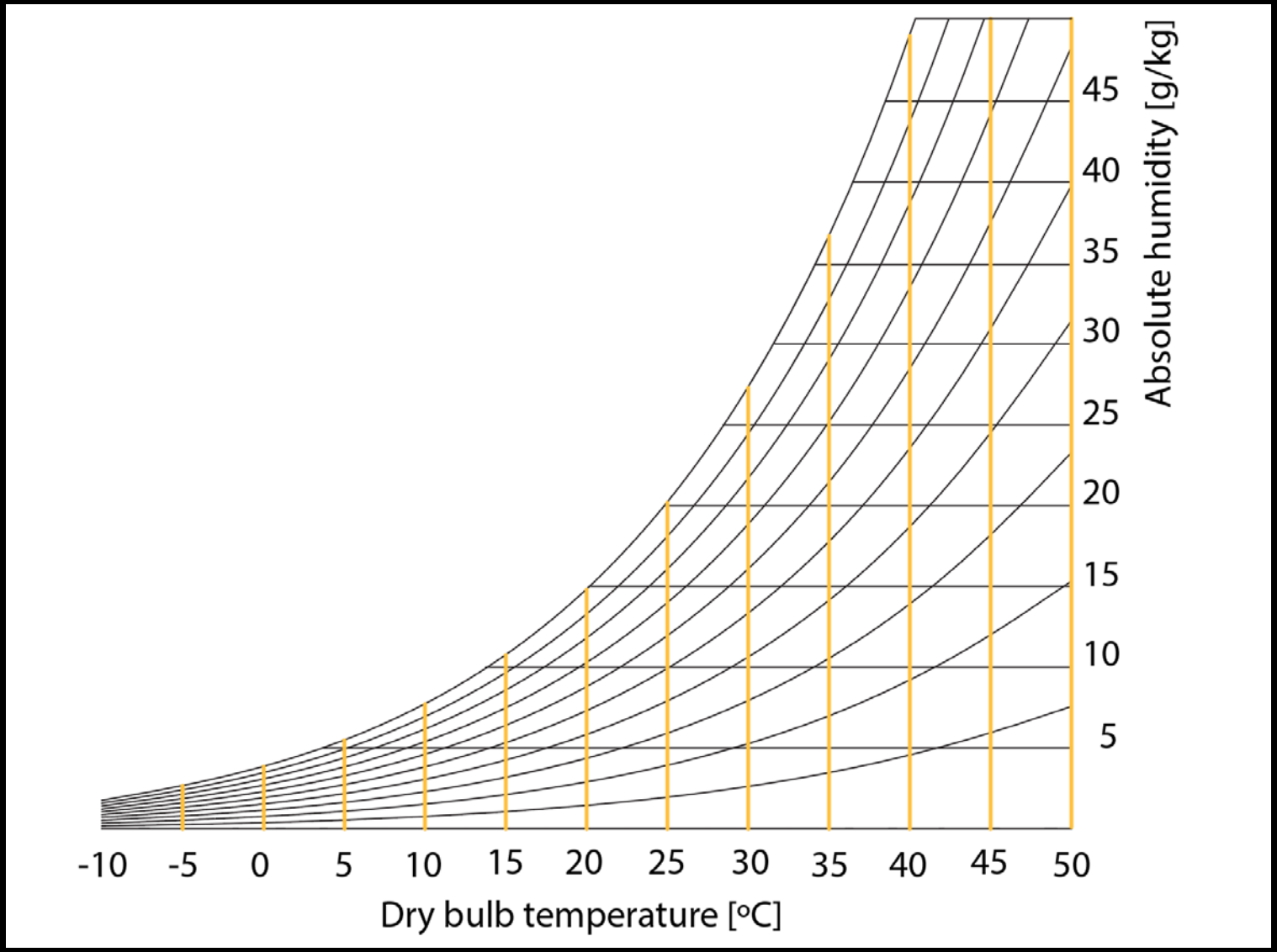


- A psychrometric chart is a graph of the physical properties of moist air at a constant pressure (usually at sea level).
- The value of the psychrometric chart is the fact that if two independent properties of a given unit of moist air are known, other key physical properties can be determined.
- The psychometric chart is the HVAC engineer's, bioclimatic architect's best friend.

Psychrometric Chart

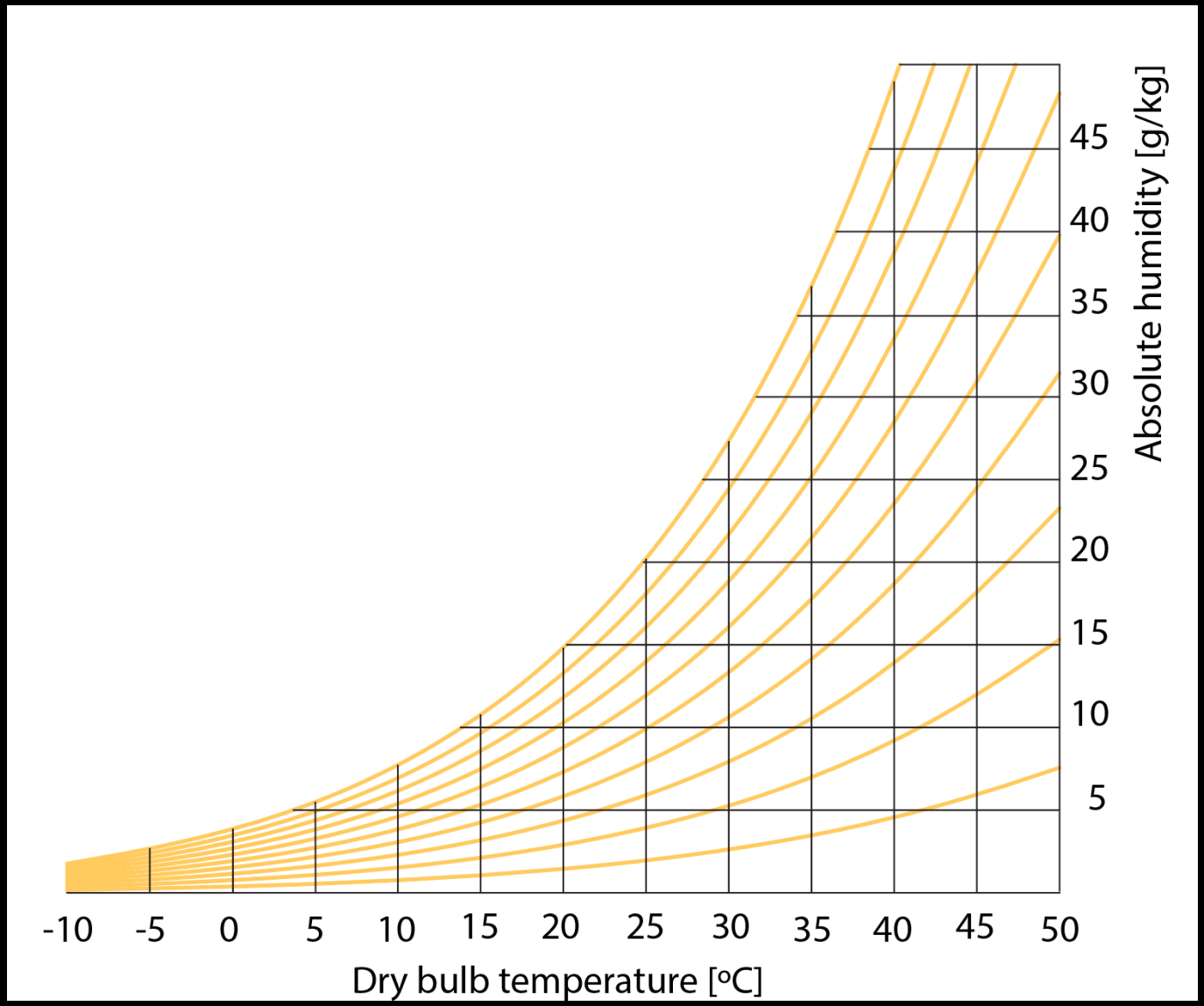


Psychrometric Chart



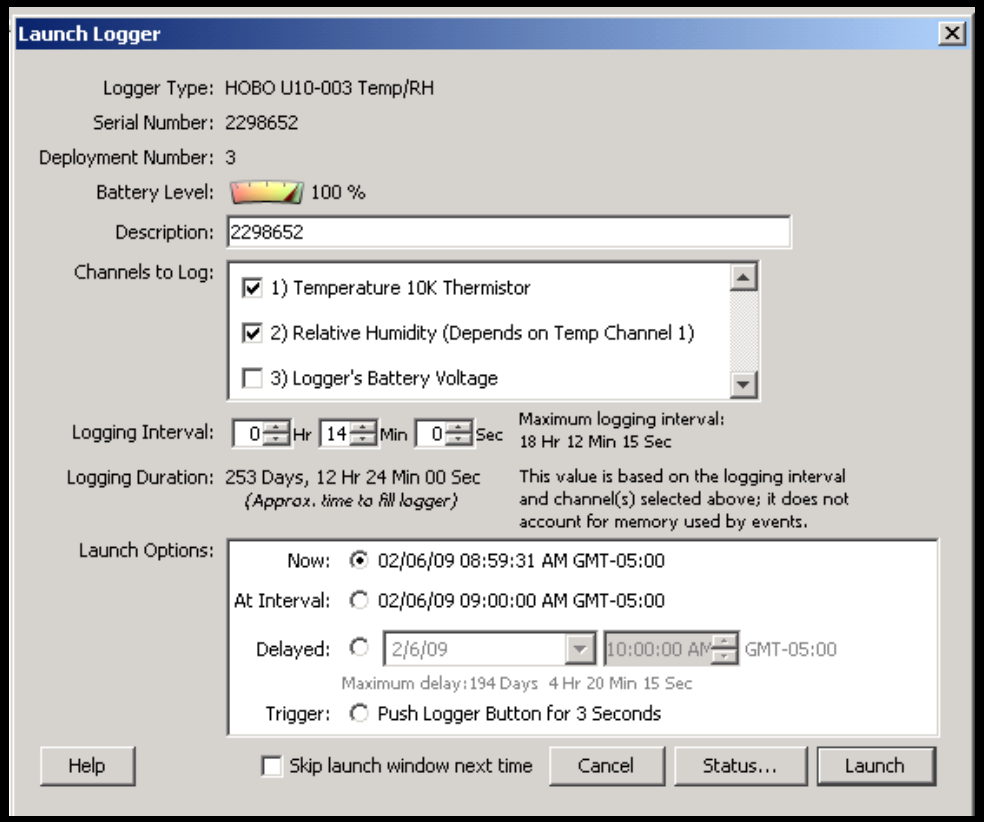
- Highlighted lines correspond to constant dry bulb temperatures.

Psychrometric Chart



- Highlighted lines correspond to constant relative humidity states.

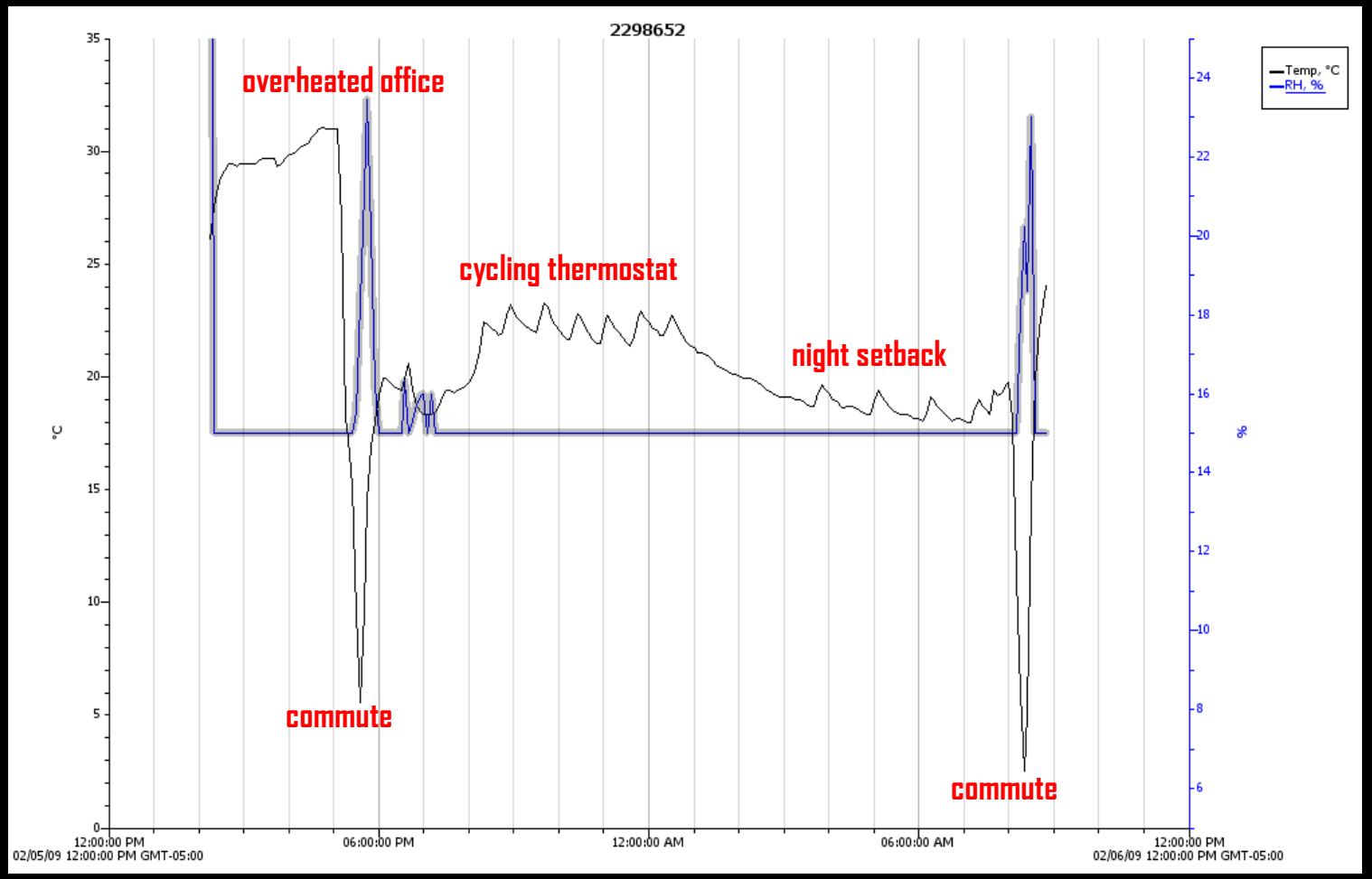
Let's HOBO...



HOBOware

What do you think the current inside and outside temperatures and relative humidities are?

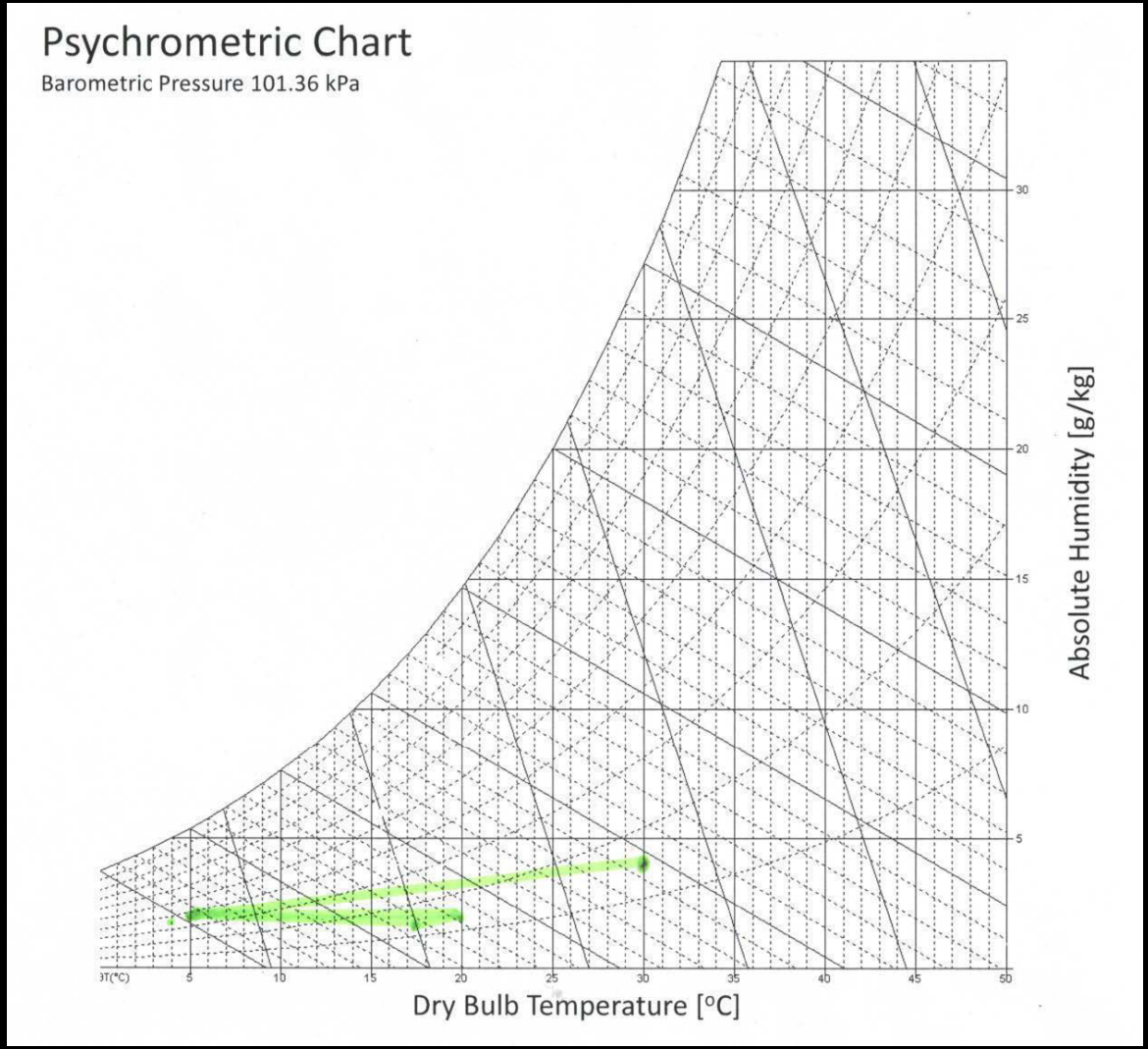
Assignment 3 - Example



Carry a HOBO around with you all day.

Be bold. Go places but please do not break the sensors ☺.

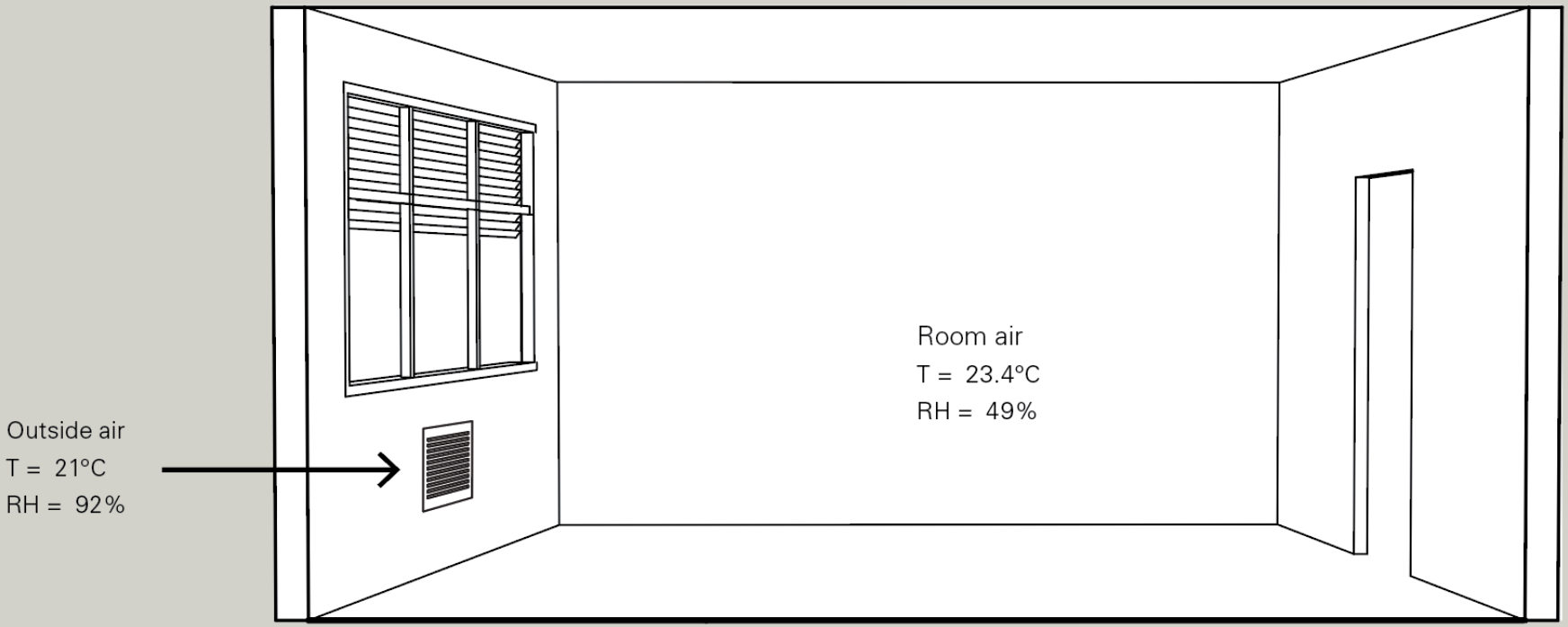
Assignment 3 - Example



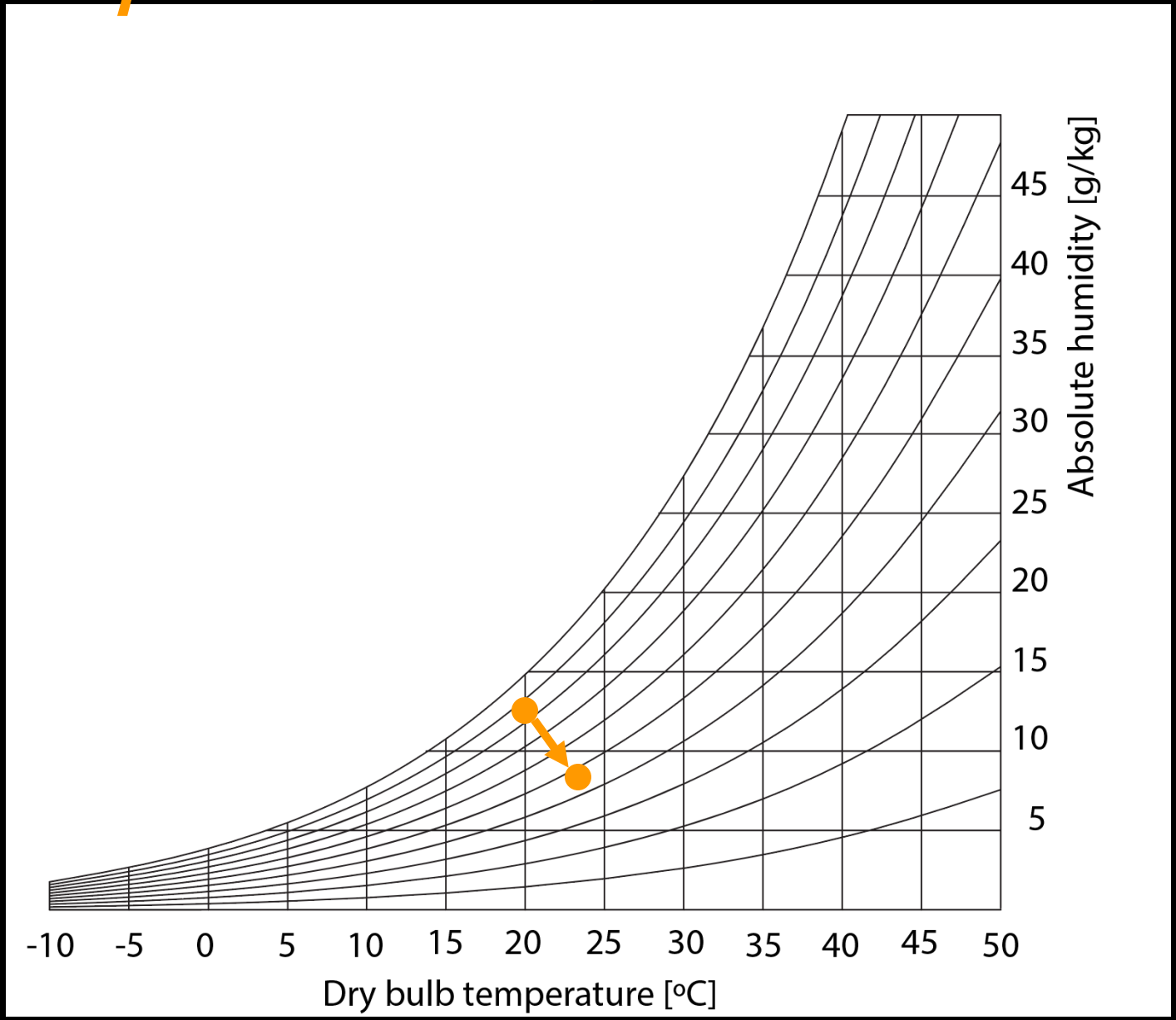
Print your day on the psychrometric chart.

Interpret your findings.

Indoor and Outdoor Environmental Conditions on an Early Fall Morning

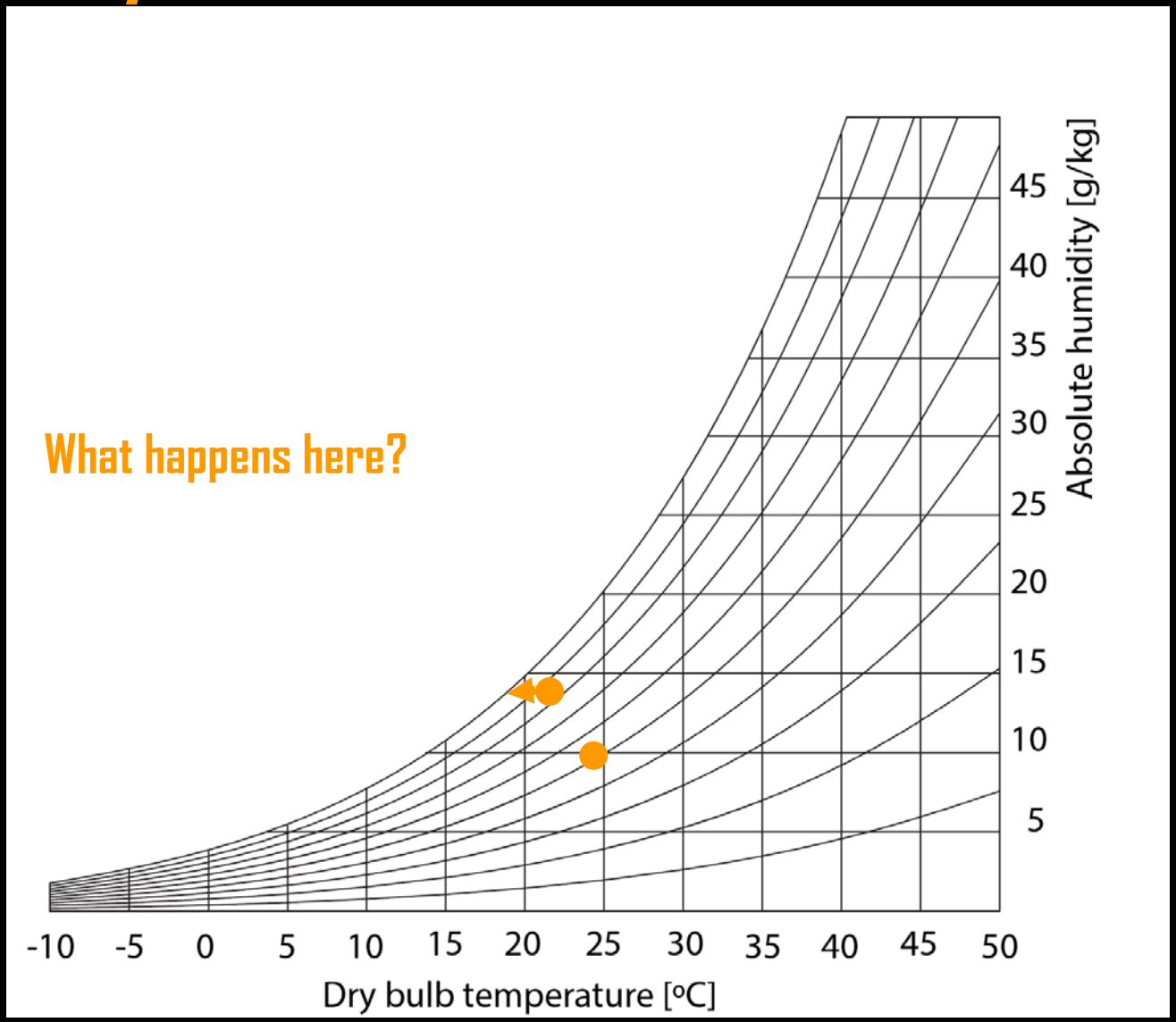


Psychrometric Chart



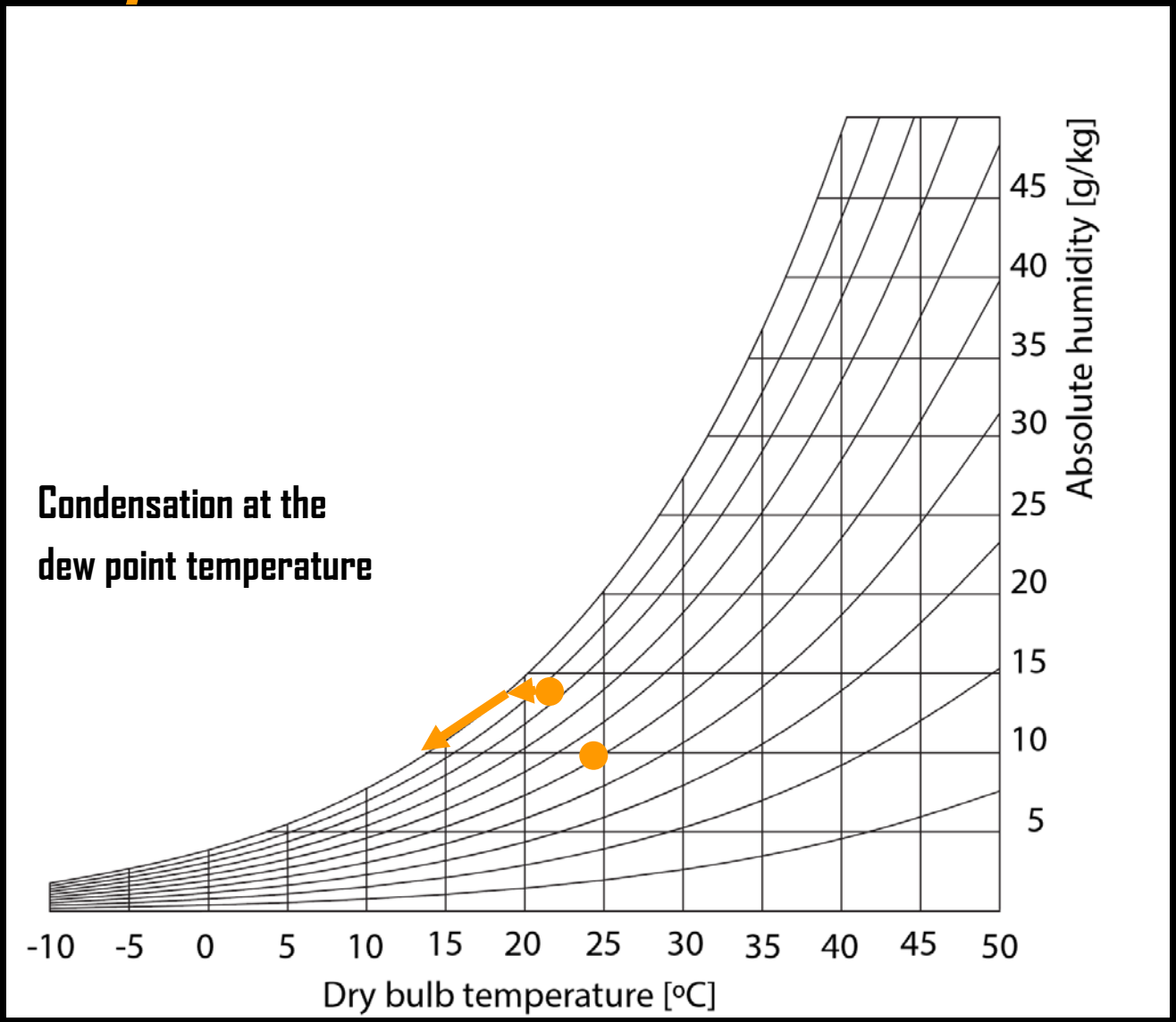
We are heating the air and reducing water content. How does MIT do this?

Psychrometric Chart



When moist air is heated or cooled it moves horizontally along a line of constant air humidity.

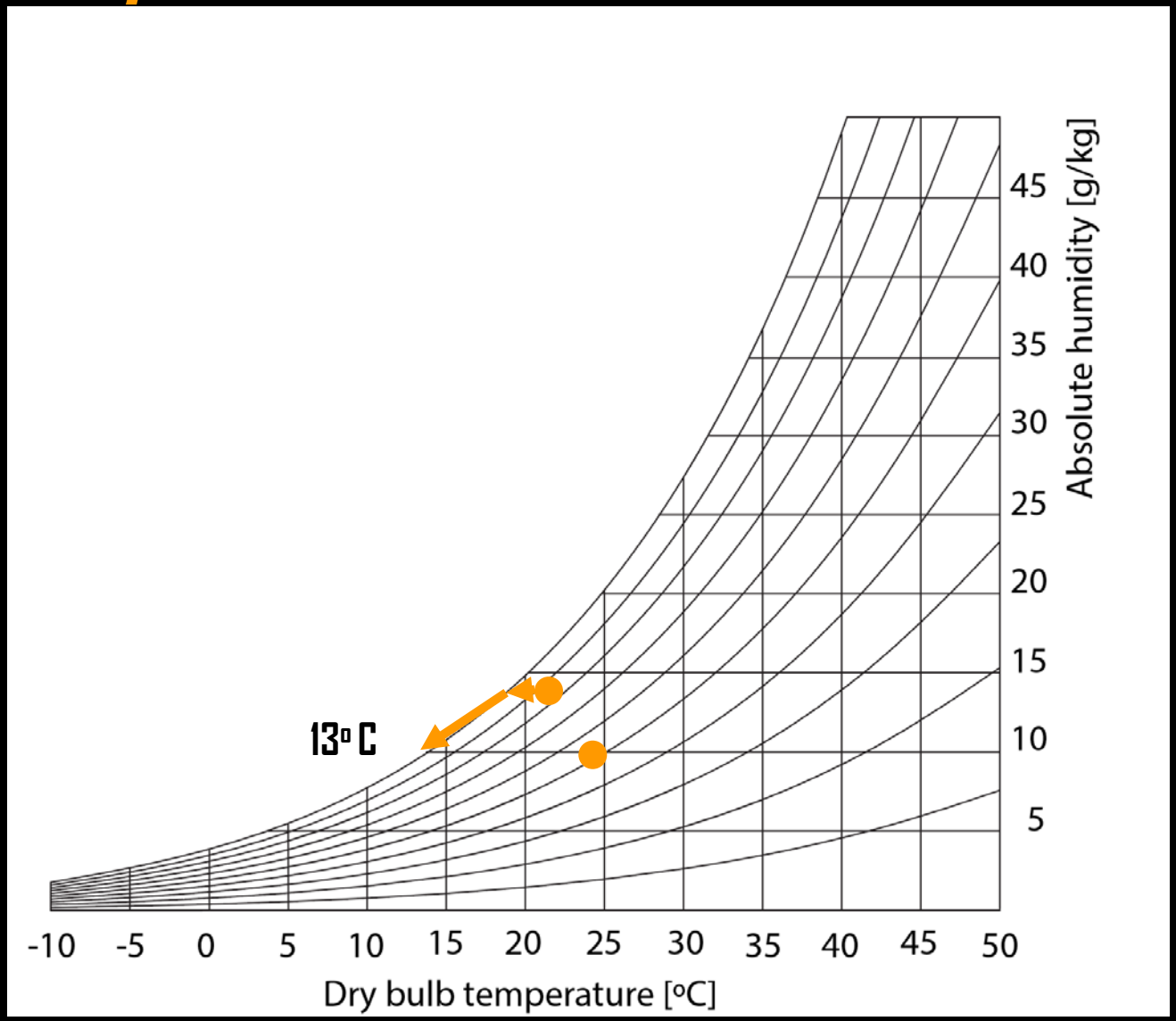
Psychrometric Chart



When air is cooled below the dew point temperature water vapor begins to condense; the air is 'dried'/ dehumidified. The drying process adds a latent load to the cooling process.


CHARLOTTE PIPE

Psychrometric Chart



In our example we have to dry to 13° C to reach the desired temperature/RH combination in the room. We often overcool and reheat. Usully you also have to account for internal loads.

Latent Load

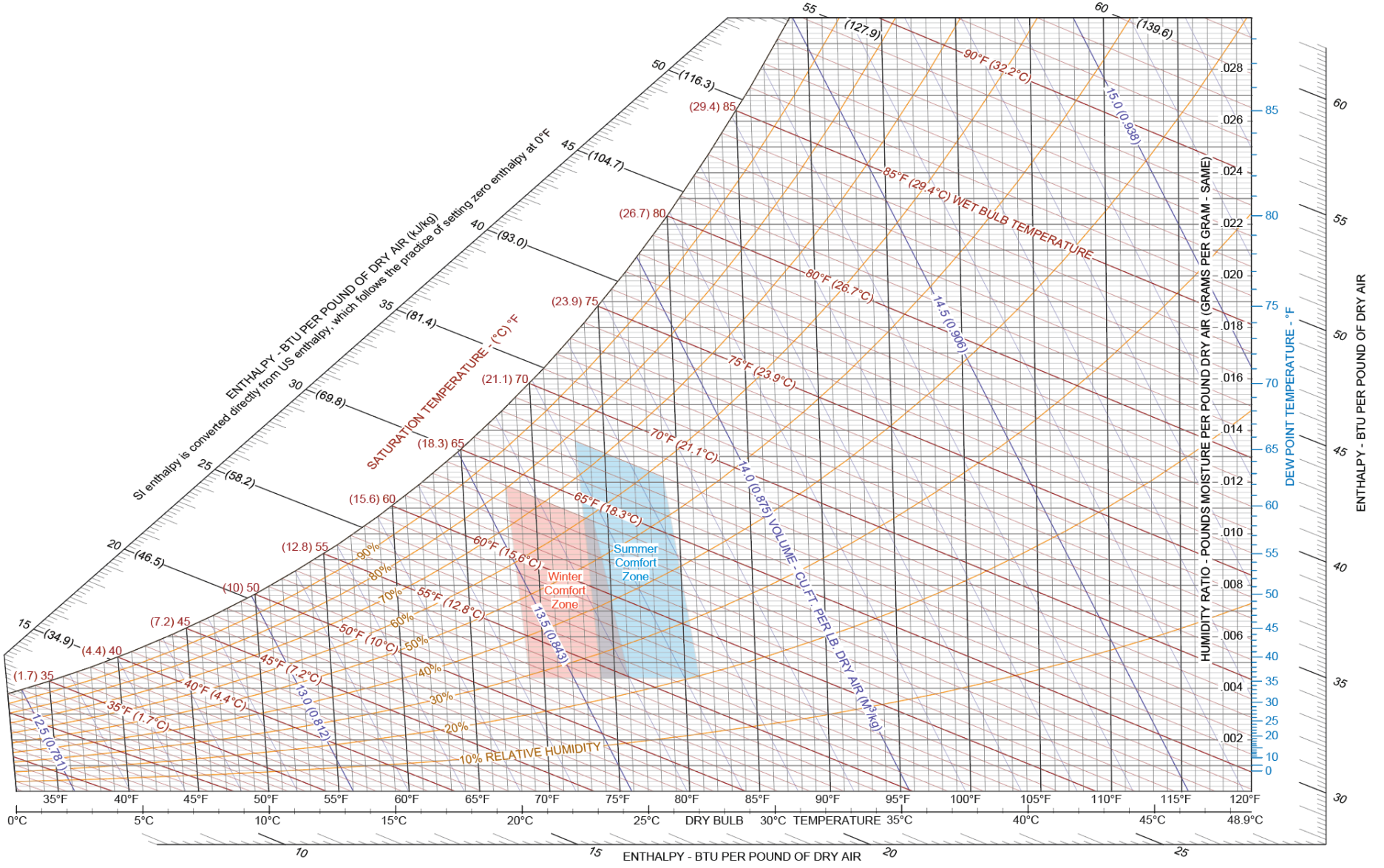
- Cooling required to remove unwanted moisture from an air-conditioned space.

Sensible Load

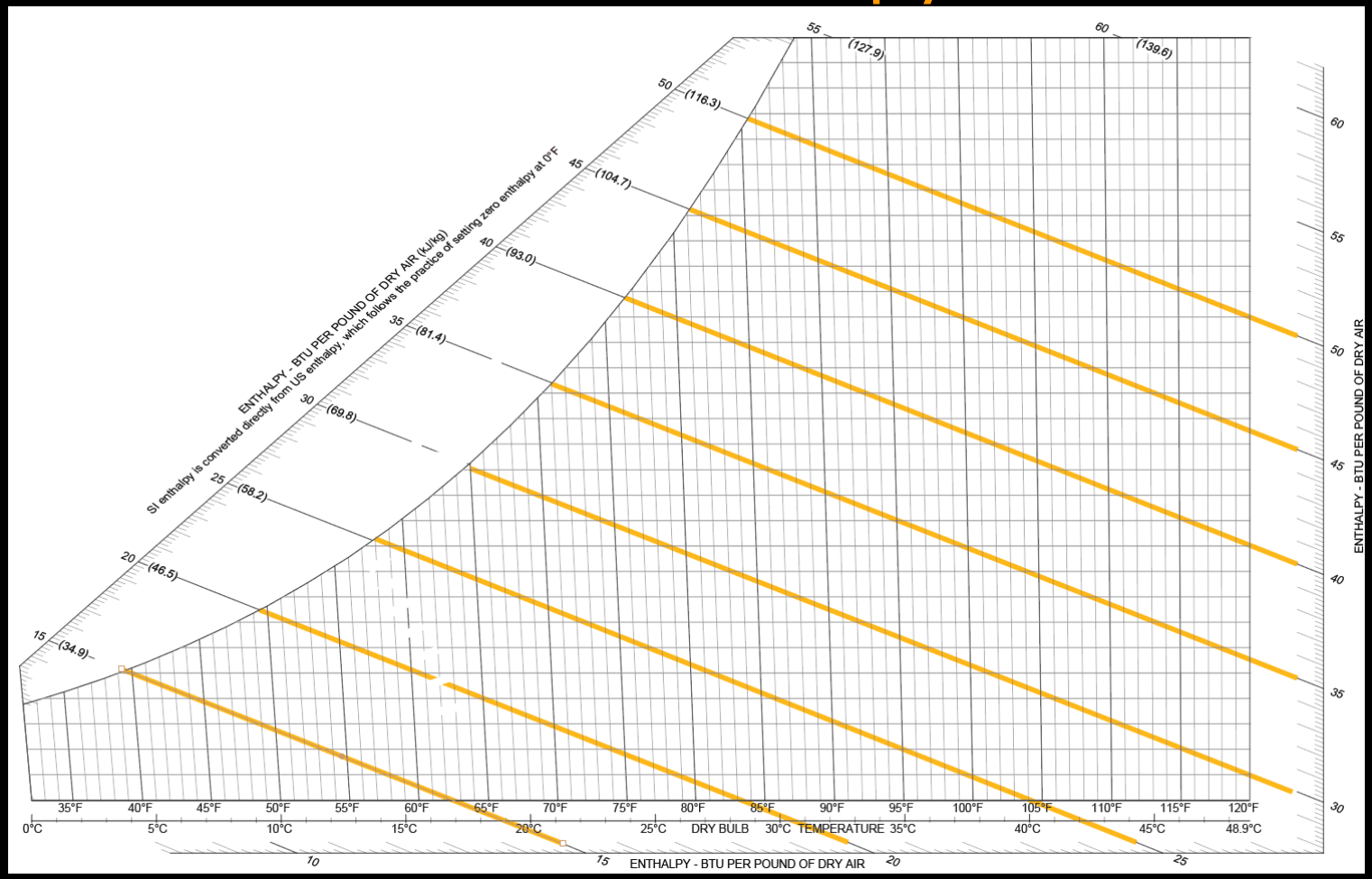
- Cooling required to cool the air in a space and remove heat from solar gains, electric lighting and other electronic internal gains.

What is the cooling load on the HVAC unit?

Let's consult the enthalpy lines.

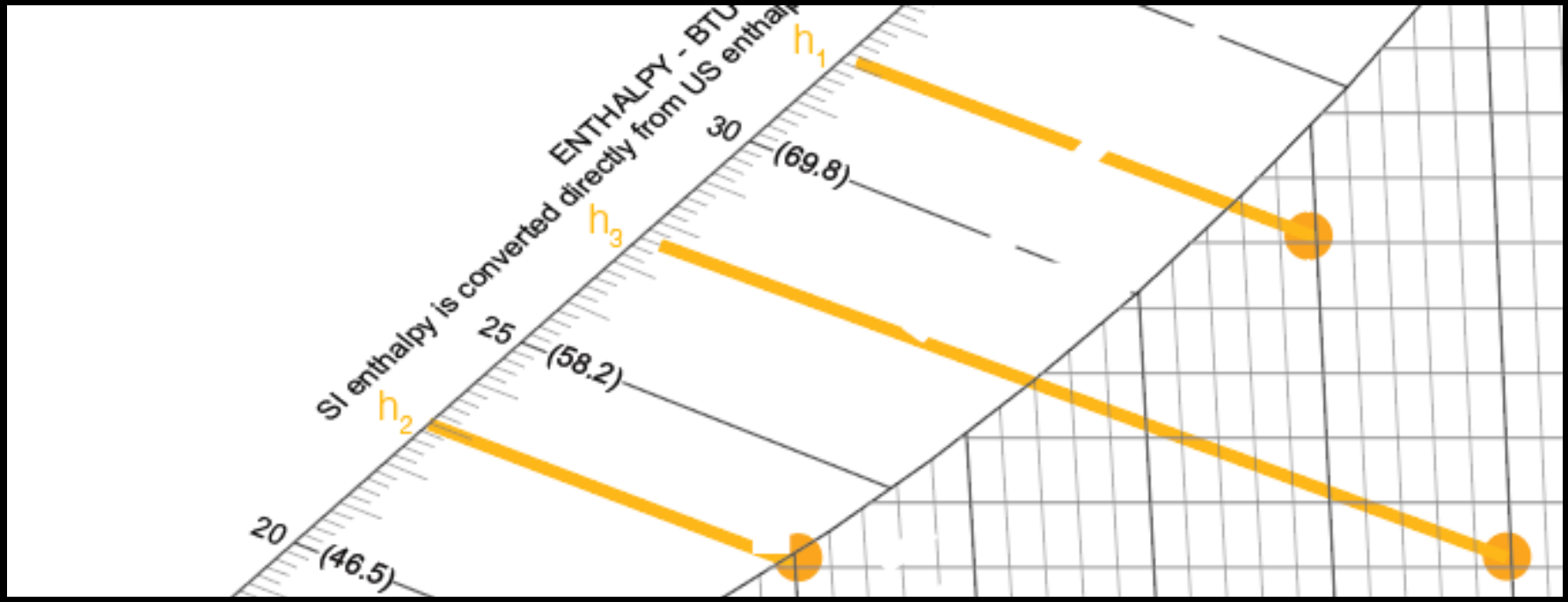


Let's consult the Enthalpy lines.



- Enthalpy (h) is the energy content of moist air. It consists of sensible heat (dry bulb temperature) and latent heat (vaporized moisture content).
- Measure in units of kJ/kg or BTU/lb. Used to calculate the energy needed to change the condition of air with 1 BTU/lb = 2.326 kJ/kg

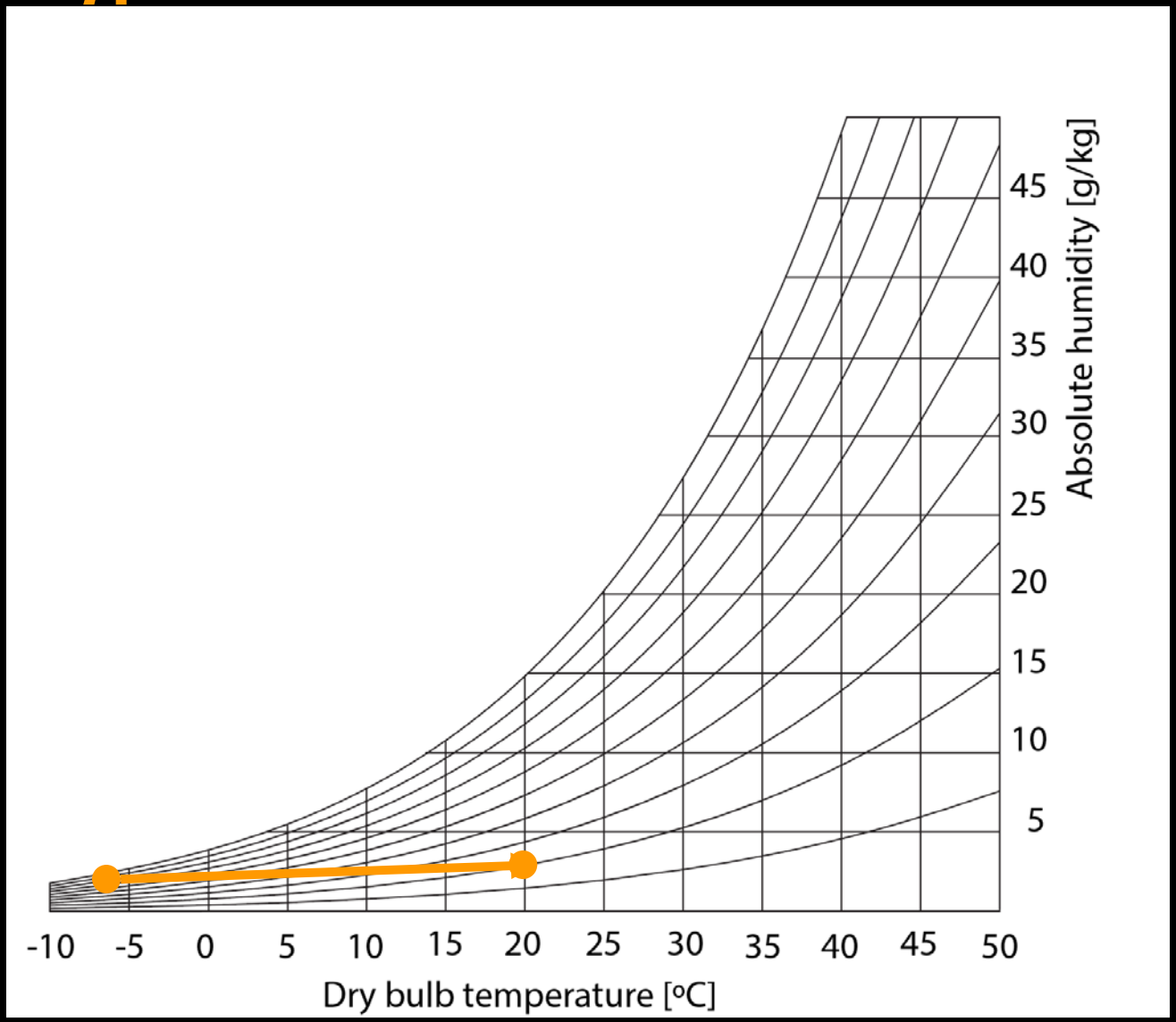
Heating and Cooling Loads



- We are cooling from h_1 to h_2 and heating from h_2 to h_3.
- $h_2 - h_1$= 23 BTU/lb - 32 BTU/lb = - 9 BTU/lb ~ -29 kJ/kg (negative for cooling)
- $h_3 - h_2$= 27.5 BTU/lb – 23 BTU/lb = 4.5 BTU/lb ~ 10 kJ/kg (positive for heating)

- The load is ~2/3 latent and 1/3 sensible.
- Please note that for this example we ignored internal loads.

Typical Winter Situation

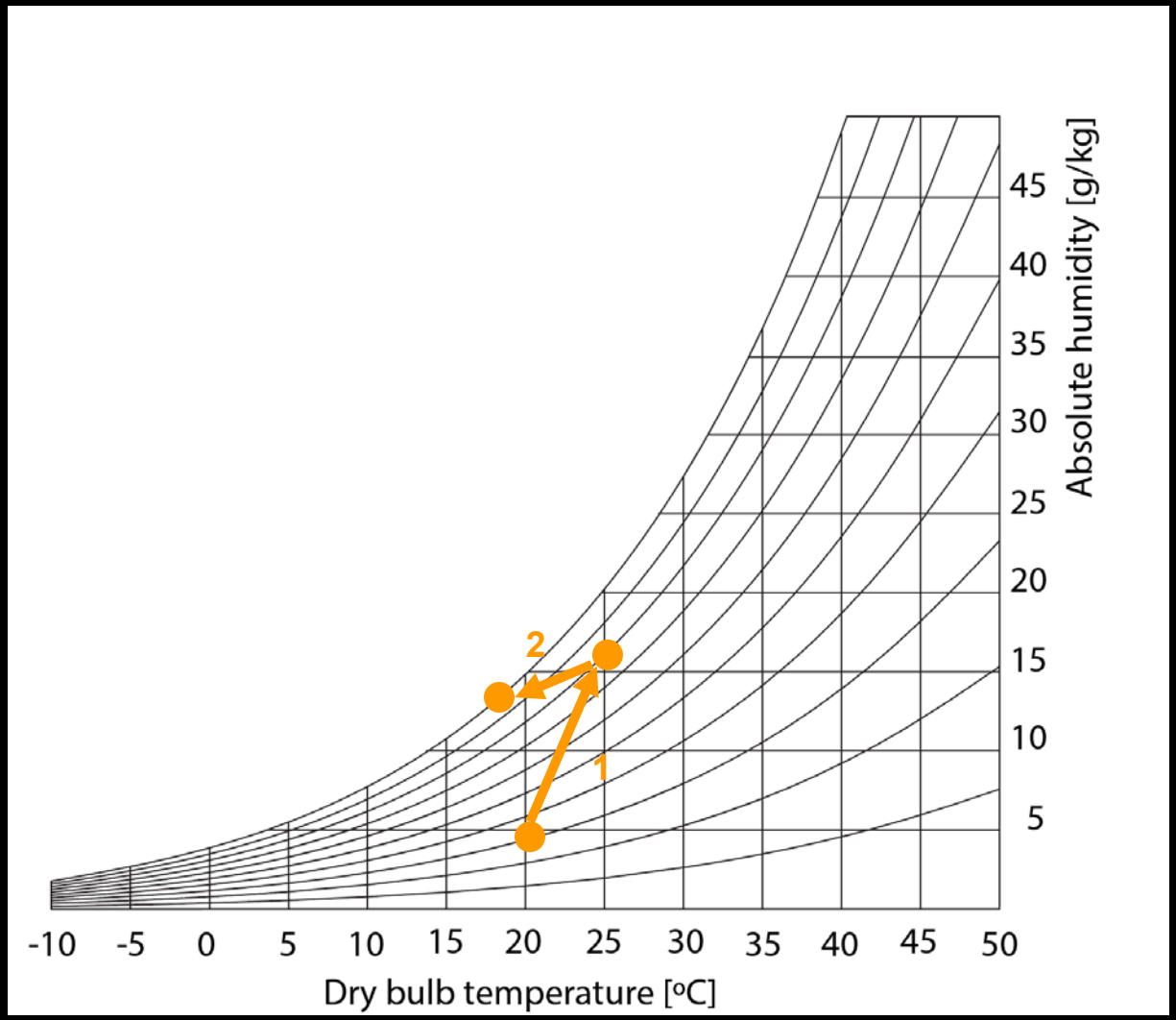


- Heating outside air in winter is very dry. This is why we recirculate air in residential buildings.
- Where is the fresh air coming from? Where is the moisture coming from?

Quiz

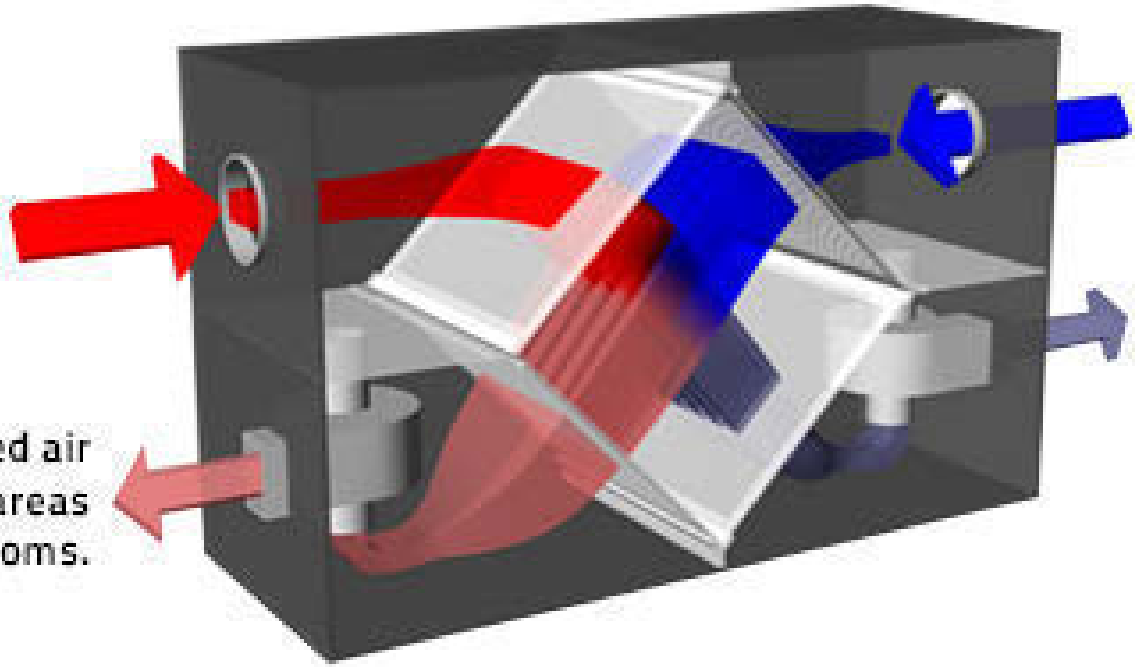
- You just weather-stripped your apartment, i.e. reduced the amount of uncontrolled air exchange with the outside via cracks in the building envelope. On a cold day, is it going to be wetter or dryer than before in your apartment?

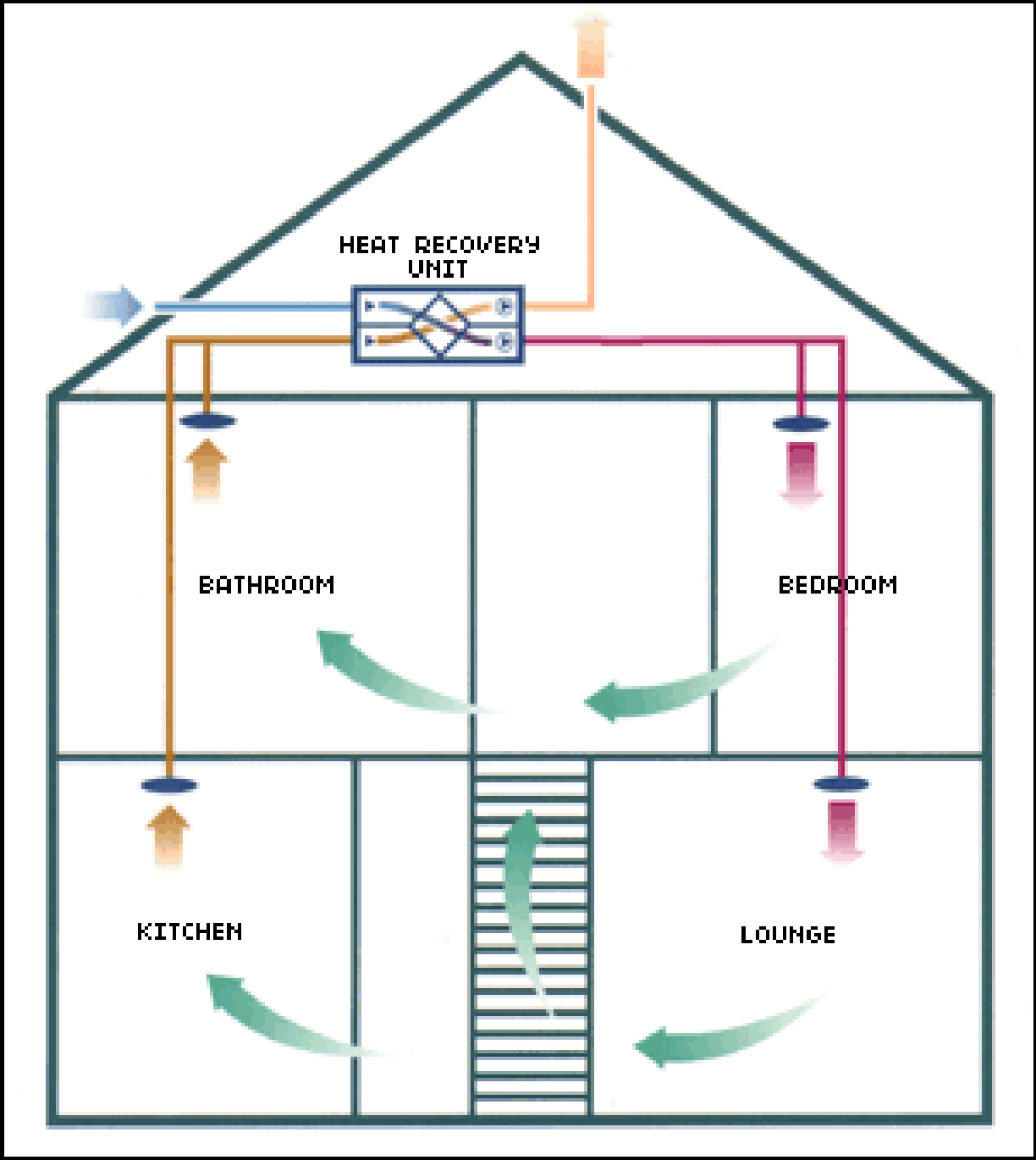
What happens when you cook, take a shower?



1. Your kitchen/bathroom gets more humid and warmer.
2. Water condenses in cold corners and may trigger mold growth. What do you do?
3. Buy exhaust fans for kitchen and all bathrooms.

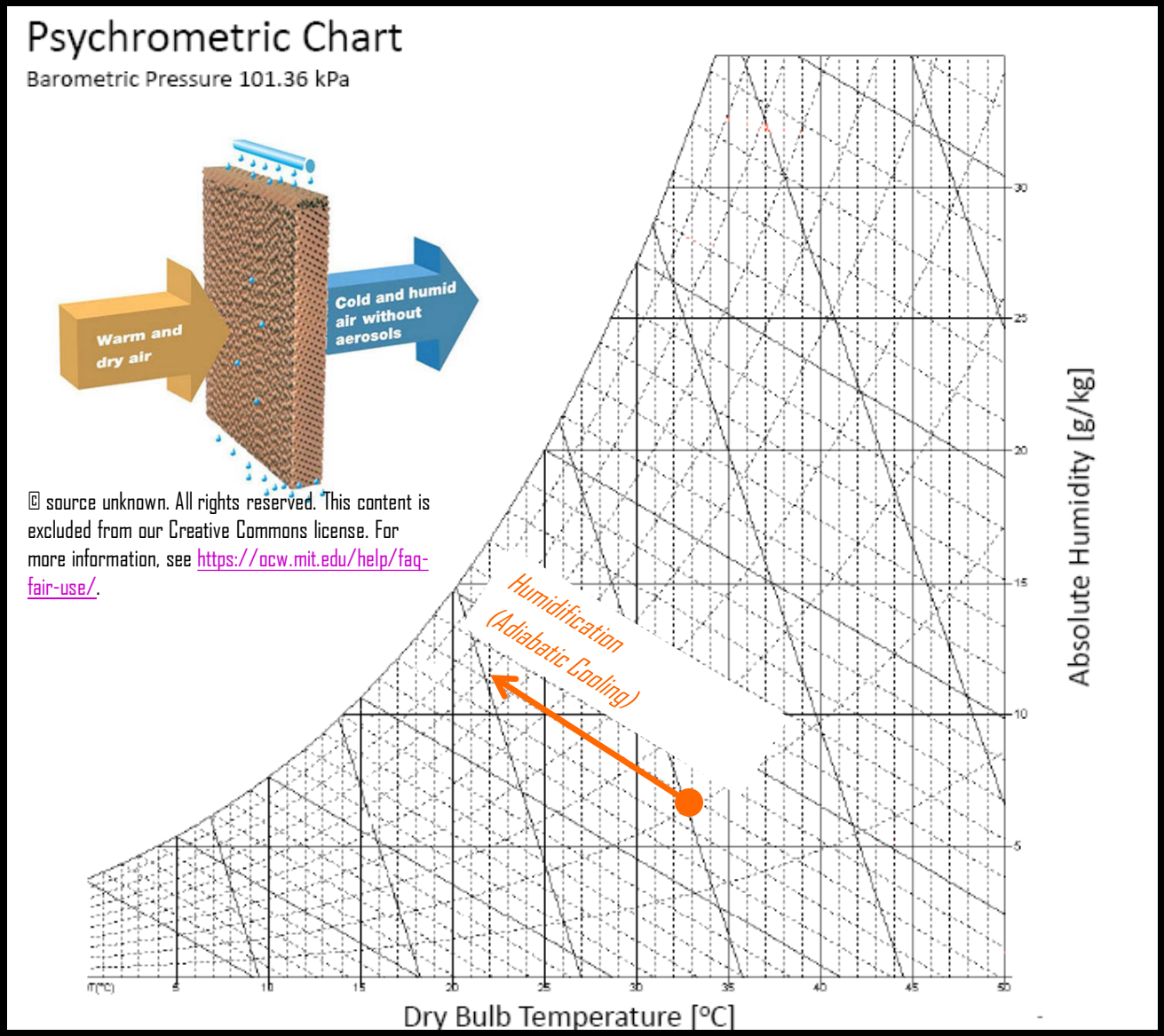
How Heat Recovery Ventilators Work





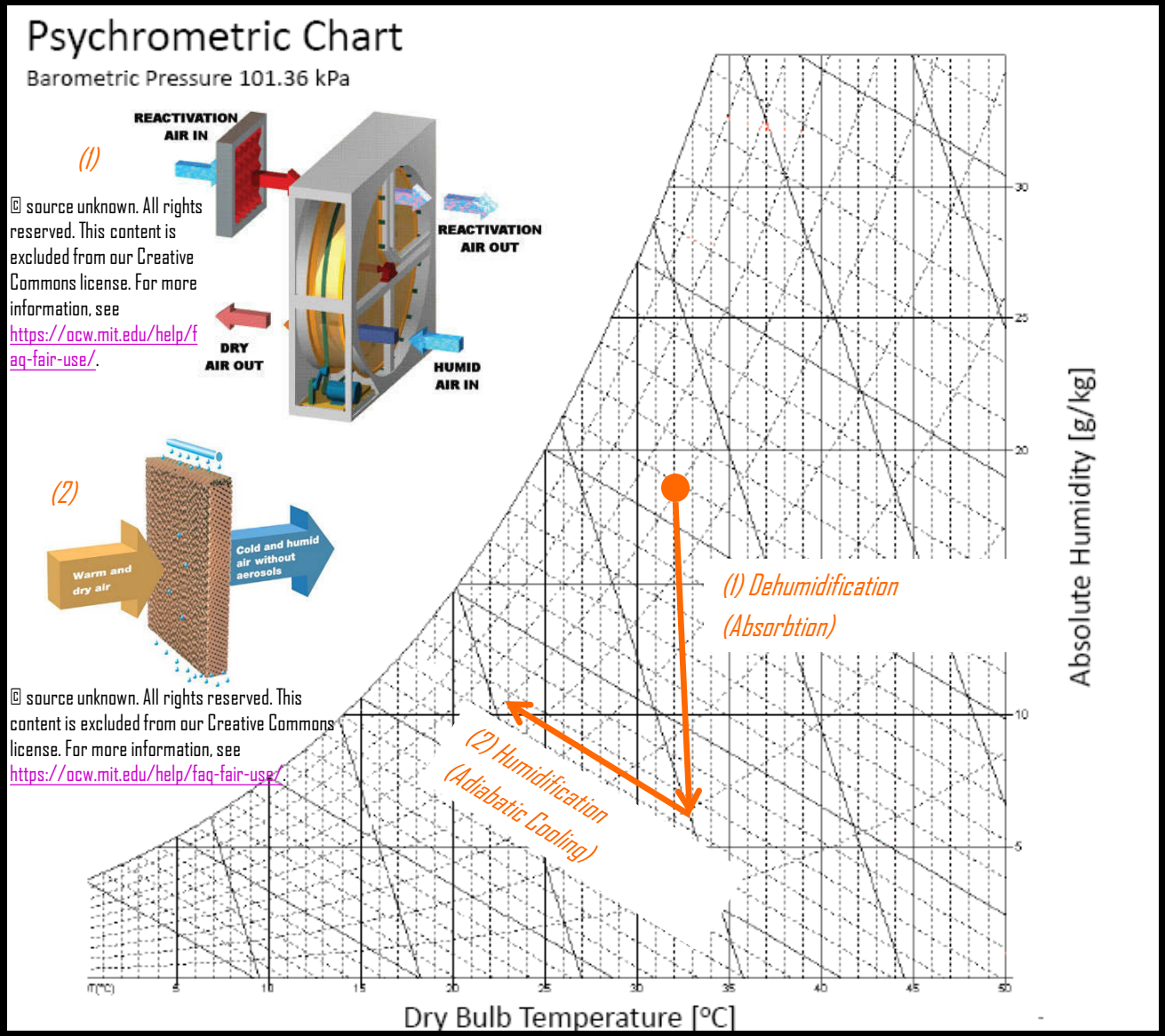
What is happening?

Adiabatic Cooling



Dry air can be adiabatically cooled by adding water.

Adiabatic Processes

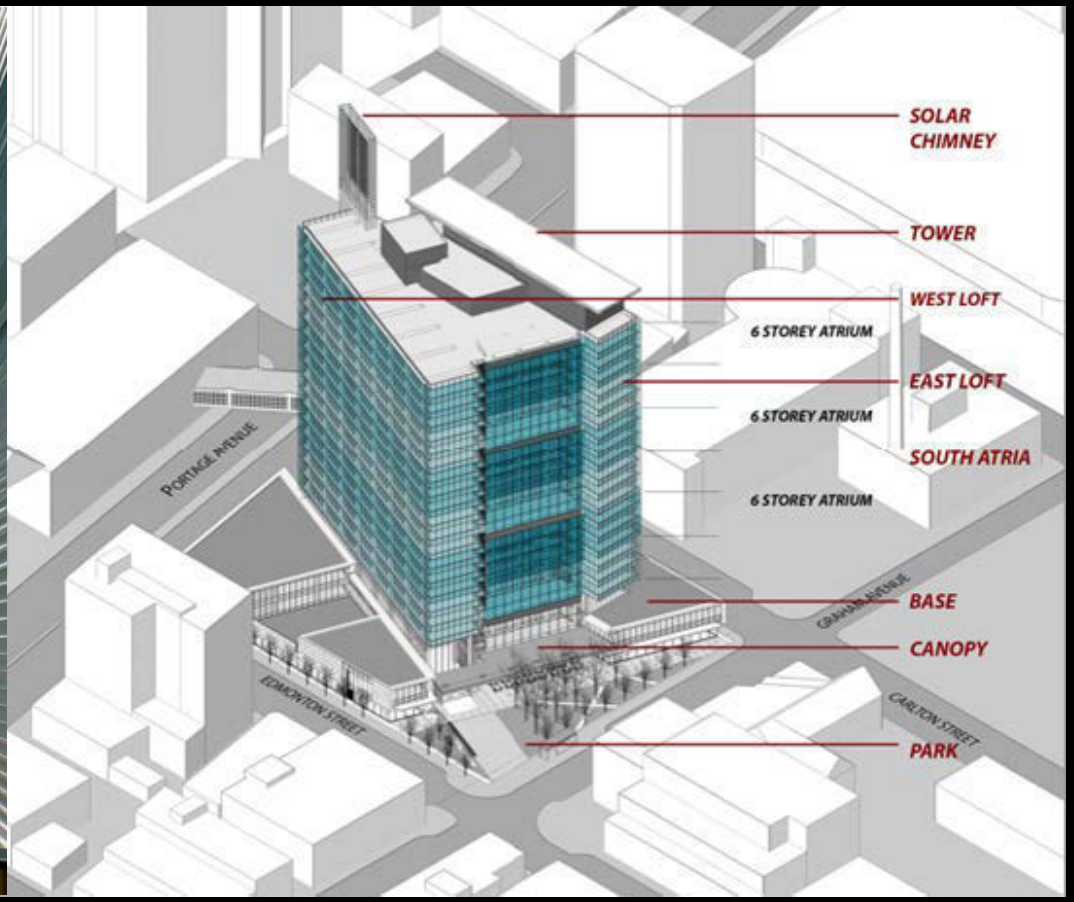


Moist air can be dried using an sorbent wheel.

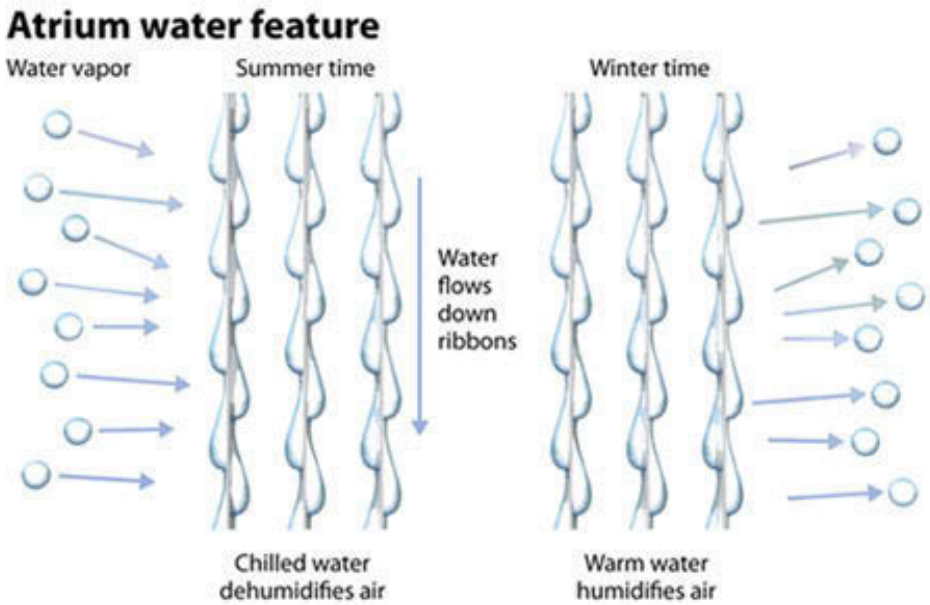
Manitoba Hydro Building

Architecture: Bruce Kawabara;
Climate Concept: Transsolar
Completed 2009
Floor area: ~650,000 ft2
Measured savings 65% compared to MNECB

Manitoba Hydro Building



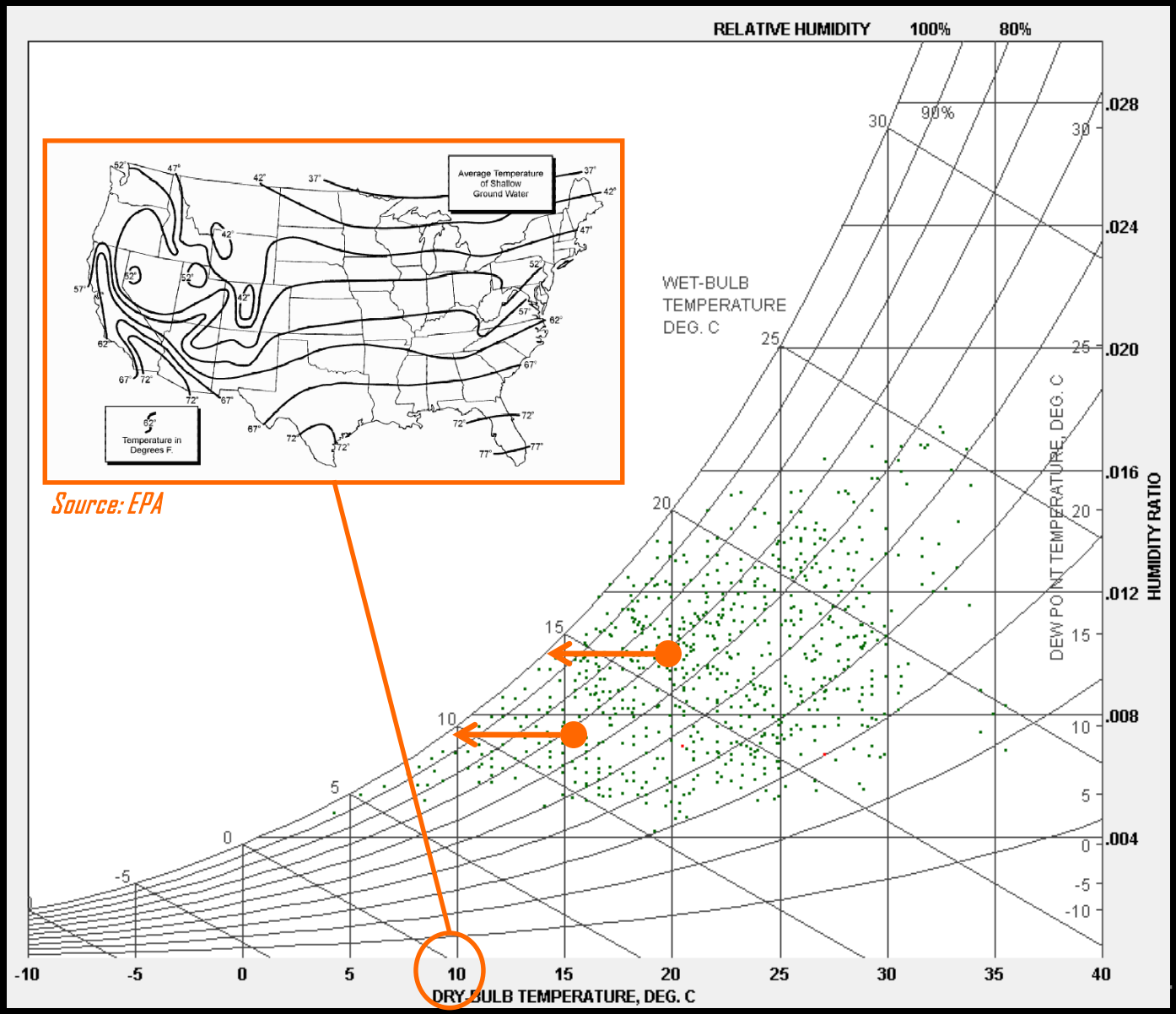
Manitoba Hydro Building



In-Class Exercise

Psychrometric Chart in DIVA/Archsim

Winnipeg in Summer



SDLAB

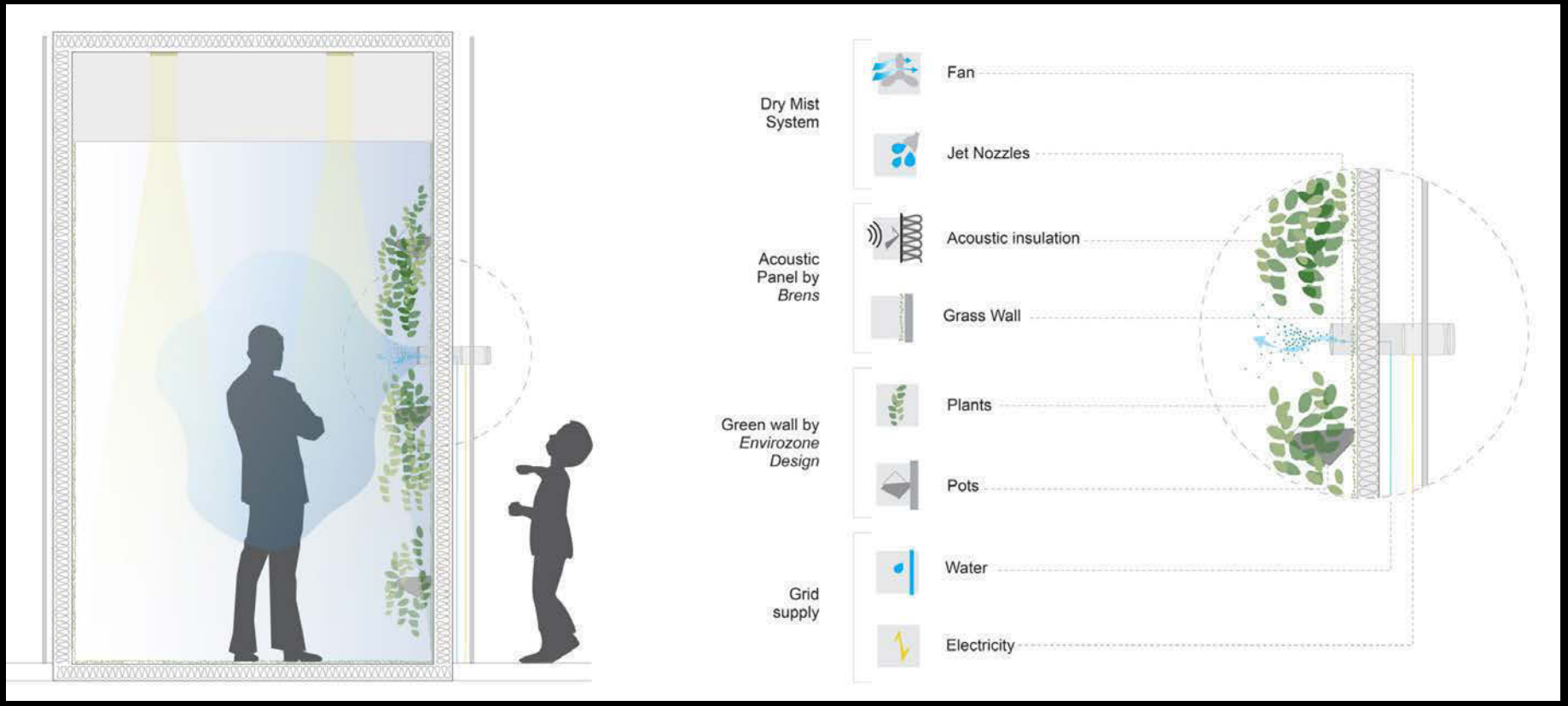
Reversío at EDIT Toronto 2017

https://transsolar.com/projects/reversio

"Induce a feeling of being outdoors while actually being inside [...] by playing with the human senses:"

- Absence of the typical acoustic reverberation; walking on grass; green walls combined with dry mist, diffuse light from above

Reversío at EDIT Toronto 2017

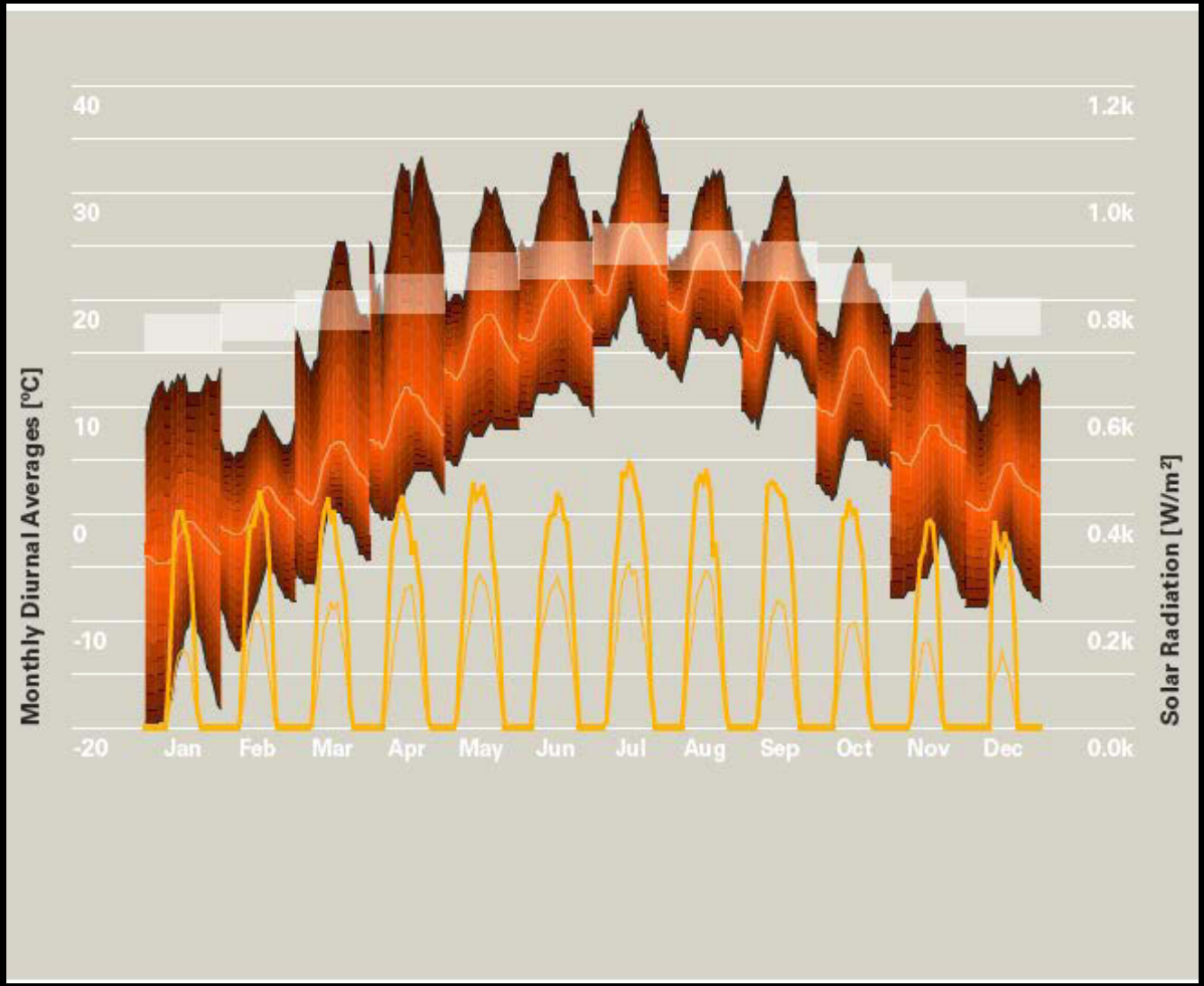


https://transsolar.com/projects/reversio

Reversío at EDIT Toronto 2017

https://transsolar.com/projects/reversio

Questions?


Monthly Diurnal Averages [°C]
40
30
20
10
0
-10
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1.2k
1.0k
0.8k
0.6k
0.4k
0.2k
0.0k
Solar Radiation [W/m²]

4.401/4.464 Environmental Technologies in Buildings Fall 2018