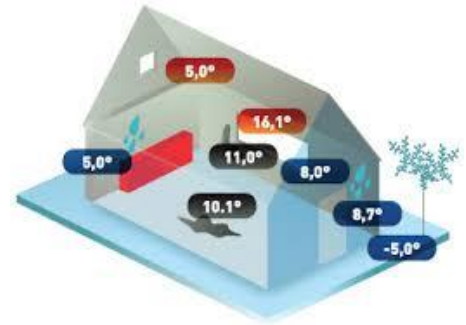
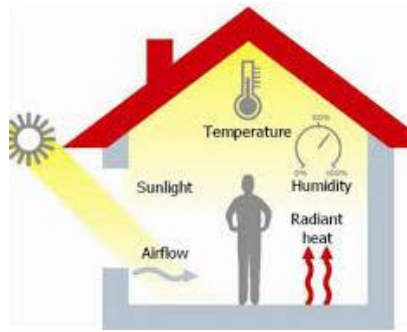


CIVIL 212

Indoor Climate

Fall 2024



Psychometrics

Heat Transfer in Buildings

19 September, 2024



Human-Oriented Built Environment Lab

Website: hobel.epfl.ch

Twitter: [@licinadusan](https://twitter.com/licinadusan)



EPFL

Asst. Prof. Dusan Licina, Ph.D.

School of Architecture, Civil and

Environmental Engineering

École polytechnique fédérale de Lausanne

dusan.licina@epfl.ch

Last time we covered...

- Definitions of Indoor Environmental Quality and, more specifically, Indoor Climate



- Traditionally, we have been thinking of **Climate** as environment **outside buildings**; however, **we spend majority of our time indoors...** recall the Corsi code!

79

70

50

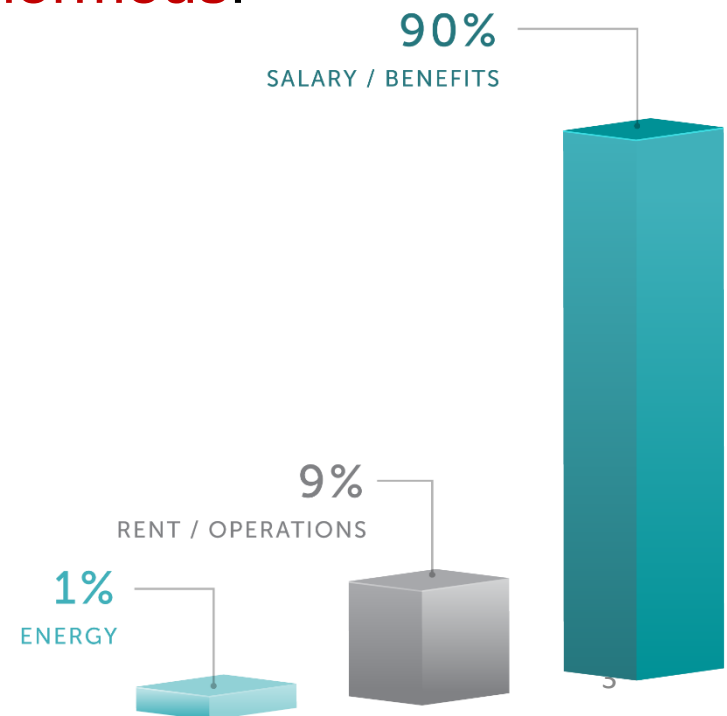
26

5

4

Last time we covered...

- What happens when you don't understand indoor climate?
 - ... you negatively influence building energy use, energy costs, greenhouse gas and other pollutant emissions, thermal comfort, indoor air quality, productivity and health
- Implications of indoor climate are **enormous!**
 - Health and well-being
 - Cognitive performance
 - Energy and ecology
 - Cost



Today's objectives...

- Heat, Air and Moisture Fundamentals
- Psychometric Chart Fundamentals
 - Exercise
- Heat Transfer in Buildings
- Course Assignment Overview



Heat, air and moisture – states of matter

- Gas
 - Molecules with high level of kinetic energy
 - Velocity $\propto$ temperature and partial pressure
 - Essentially no resistance to changing shape or volume
- Liquid:
 - Remove sufficient energy from a gas (or compress it sufficiently) and the strength of attraction between molecules will become stronger than kinetic energy of the moving molecules $\rightarrow$ liquid
 - Little resistance to changing shape; does resist changing volume
- Solid
 - Removing even more energy slows movement of molecules until intra-molecular forces begin to dominate $\rightarrow$ solid
 - Resistance to changing shape and volume
- Plasma (compound stripped of electrons)

Heat and energy basics

- **Sensible energy**

- Energy used to increase the velocity or vibrations of molecules (i.e., temperature)
- No phase change

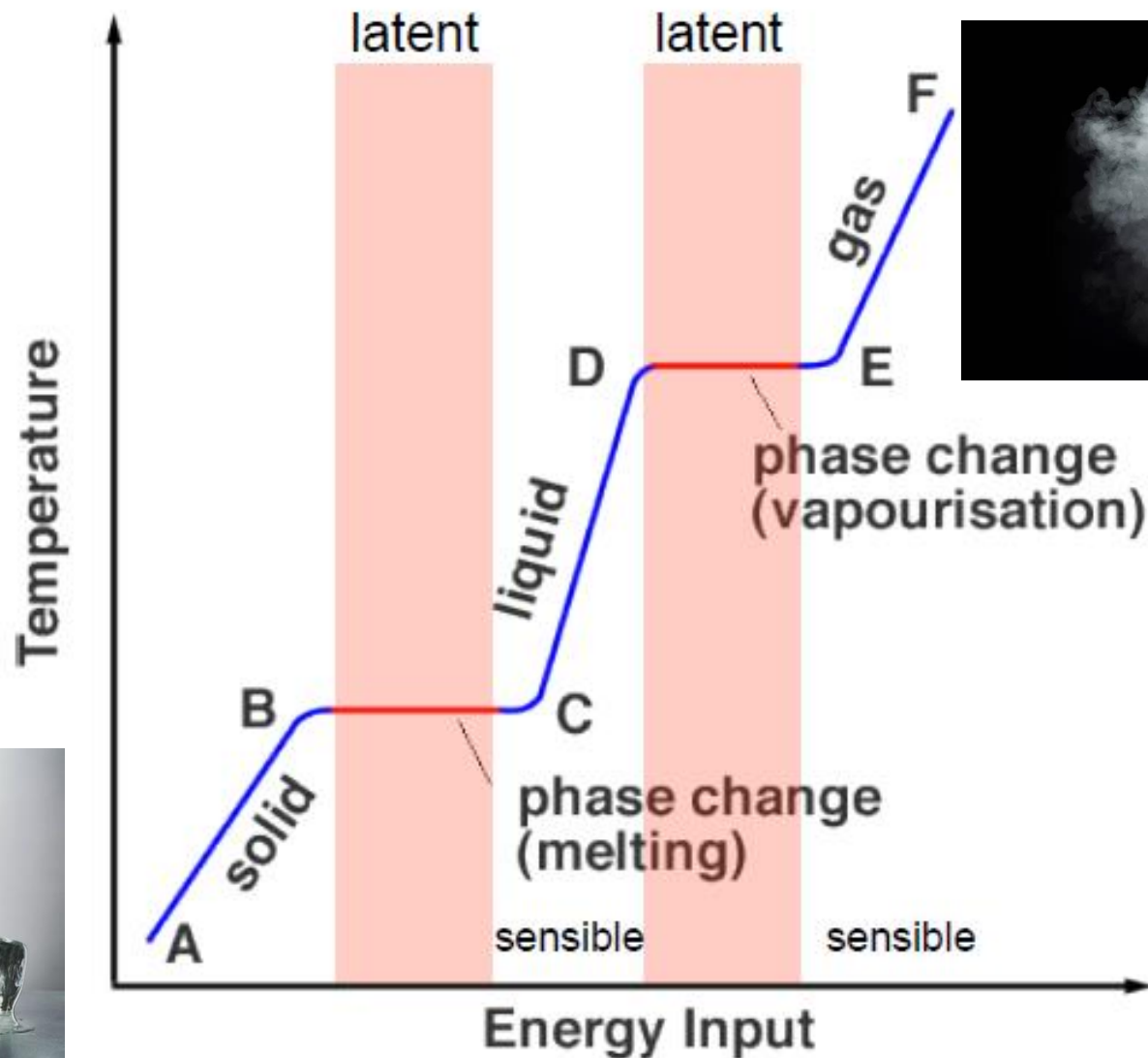
- **Specific heat capacity:**

- Sensible energy required to raise a unit mass of material one unit of temperature

- **Latent energy**

- The material-specific amount of energy given off (or taken up) during a state change
- Solid to liquid: heat of fusion
- Liquid to gas: heat of vaporization

Heat and energy basics



Air

- What chemical species are in “clean” dry air?



Composition of the Atmosphere

Species	MW (g/mol)	%
Nitrogen	28	78
Oxygen	32	21
Water vapor	18	<4
Argon	40	0.9
Carbon dioxide	44	0.04
Many minor species – <0.001%		

- Density at standard conditions, $\rho = 1.205 \text{ kg/m}^3$
- Dynamic (absolute) viscosity, $\mu = 1.81 \times 10^{-4} \text{ g/cm/s}$
- Kinematic viscosity, $\nu = 0.15 \text{ cm}^2/\text{s}$

Does water vapor increase or decrease air density?

Importance of units!

- In building engineering, both SI and IP (inch-pound) units are used
 - Sorry for that!
 - IP: Typically used in USA, UK, Australia, India, Malaysia, New Zealand...
 - SI (Metric units): Used in most of the world.
- Good news!
 - Many countries are slowly transitioning towards a single system – SI
 - We will be mostly using SI units.
- What to convert IP to SI?
 - Just google “IP to SI – ashrae” to download free conversion tool in excel file

Important definitions: Energy

- Definition: Capacity of a system to do work
 - We use this term a lot
 - Primary units: Joules, kWh or BTU (or MMBTU = 10^6 BTU)
- Forms of energy:
 - Thermal, radiant (inc. solar), nuclear, geothermal, hydrocarbon
 - Embodied or embedded energy
 - Embedded energy is the energy required to extract resources, manufacture, and transport a product
- Energy use depends on the rate of energy use and the time/duration of operation
 - Rate of energy use = Power (Rate at which energy is produced or consumed) – don't mix these two.

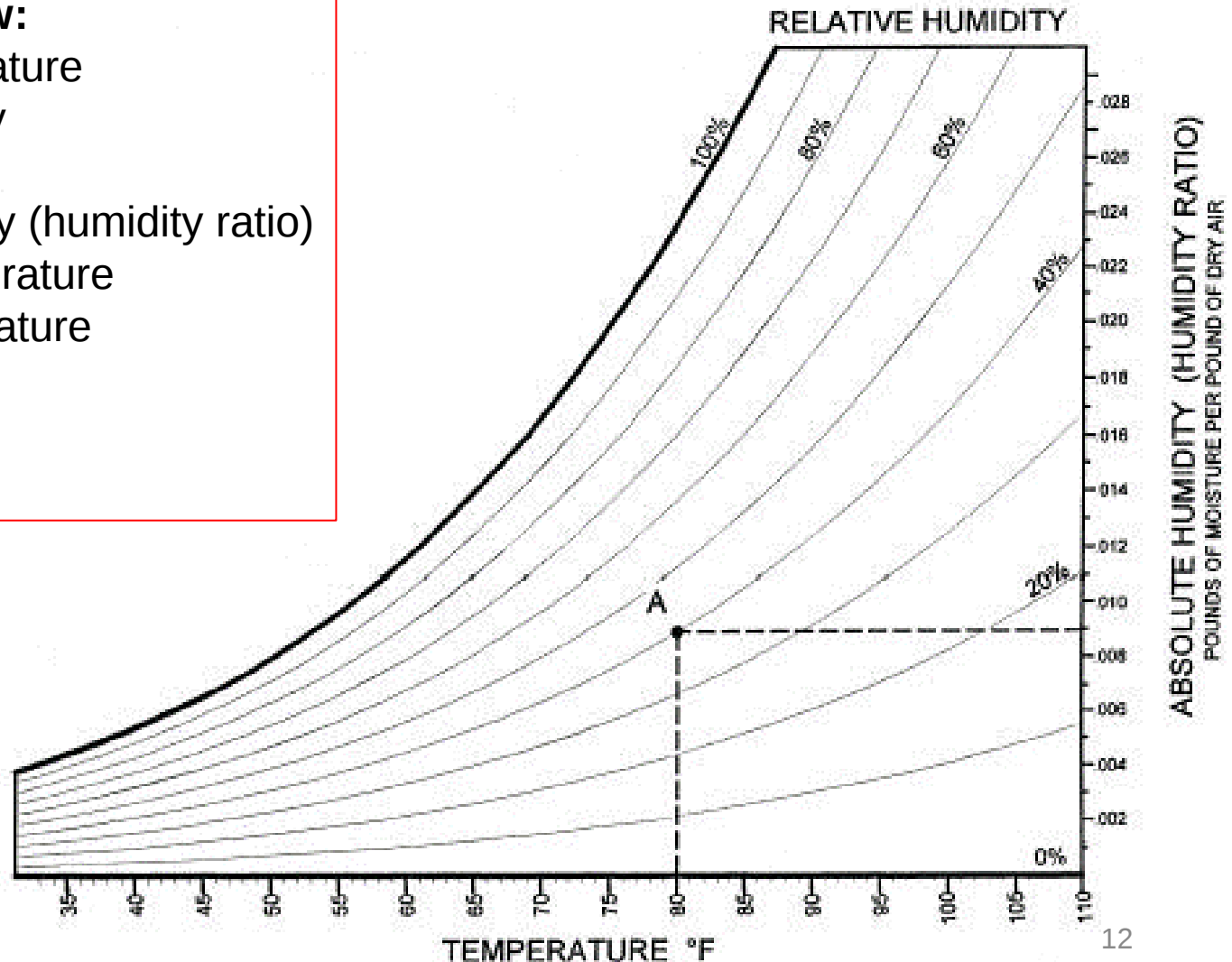
Psychrometric chart

- There are two ways to describe thermodynamic property of the air:
 - With equations and tables (tedious...)
 - Graphically using **psychrometric chart**
- Psychrometric chart
 - Two parameters are needed to define a state point
 - From a state point, we can get all other quantities
- We can do this calculation without a chart
 - Online there are many “digital” psychrometric charts available
 - You can create your own
 - Best source is ASHRAE Fundamentals (Chapter 6)

Psychrometric chart

Key terms to know:

1. Dry bulb temperature
2. Relative humidity
3. Saturation
4. Absolute humidity (humidity ratio)
5. Dew point temperature
6. Wet bulb temperature
7. Density
8. Specific volume
9. Enthalpy



Psychrometric chart: In-class exercise

- Lets take the example of typical comfortable indoor conditions:
 - Moist air at 22 °C dry-bulb temperature
 - With 50% relative humidity

Find the following:

- the humidity ratio, W
- dew point temperature, T_{dew}
- wet-bulb temperature, T_{wb}
- specific volume, v
- dry air density, ρ
- enthalpy, h



ASHRAE PSYCHROMETRIC CHART NO.1

NORMAL TEMPERATURE

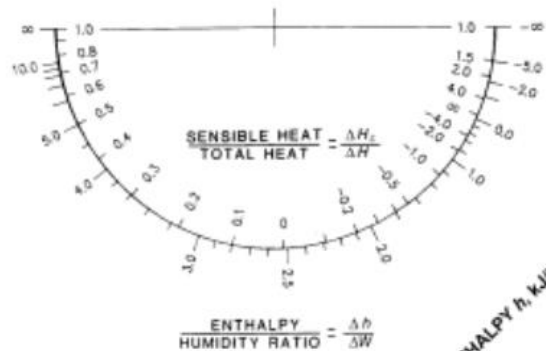
SEA LEVEL

BAROMETRIC PRESSURE:

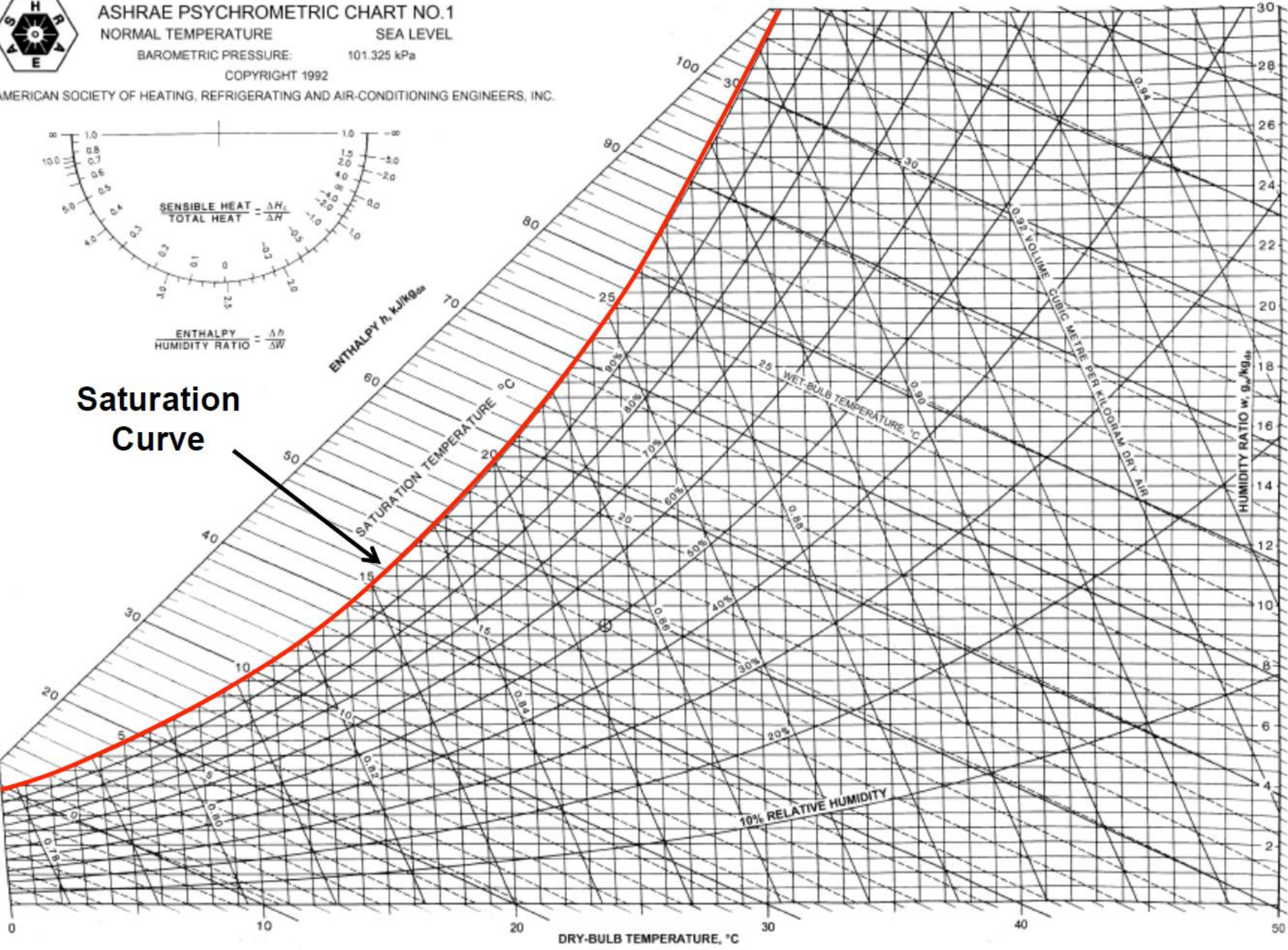
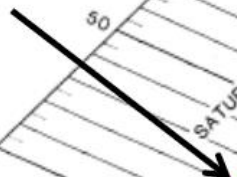
101.325 kPa

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**Saturation
Curve**





ASHRAE PSYCHROMETRIC CHART NO.1

NORMAL TEMPERATURE

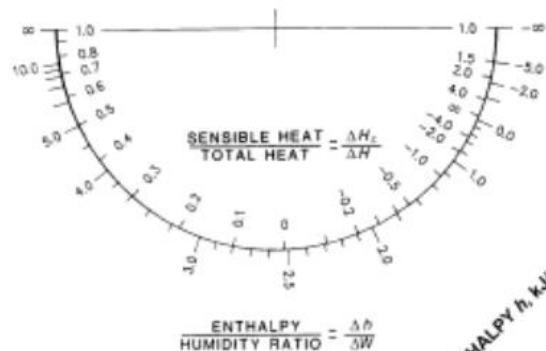
SEA LEVEL

BAROMETRIC PRESSURE:

101.325 kPa

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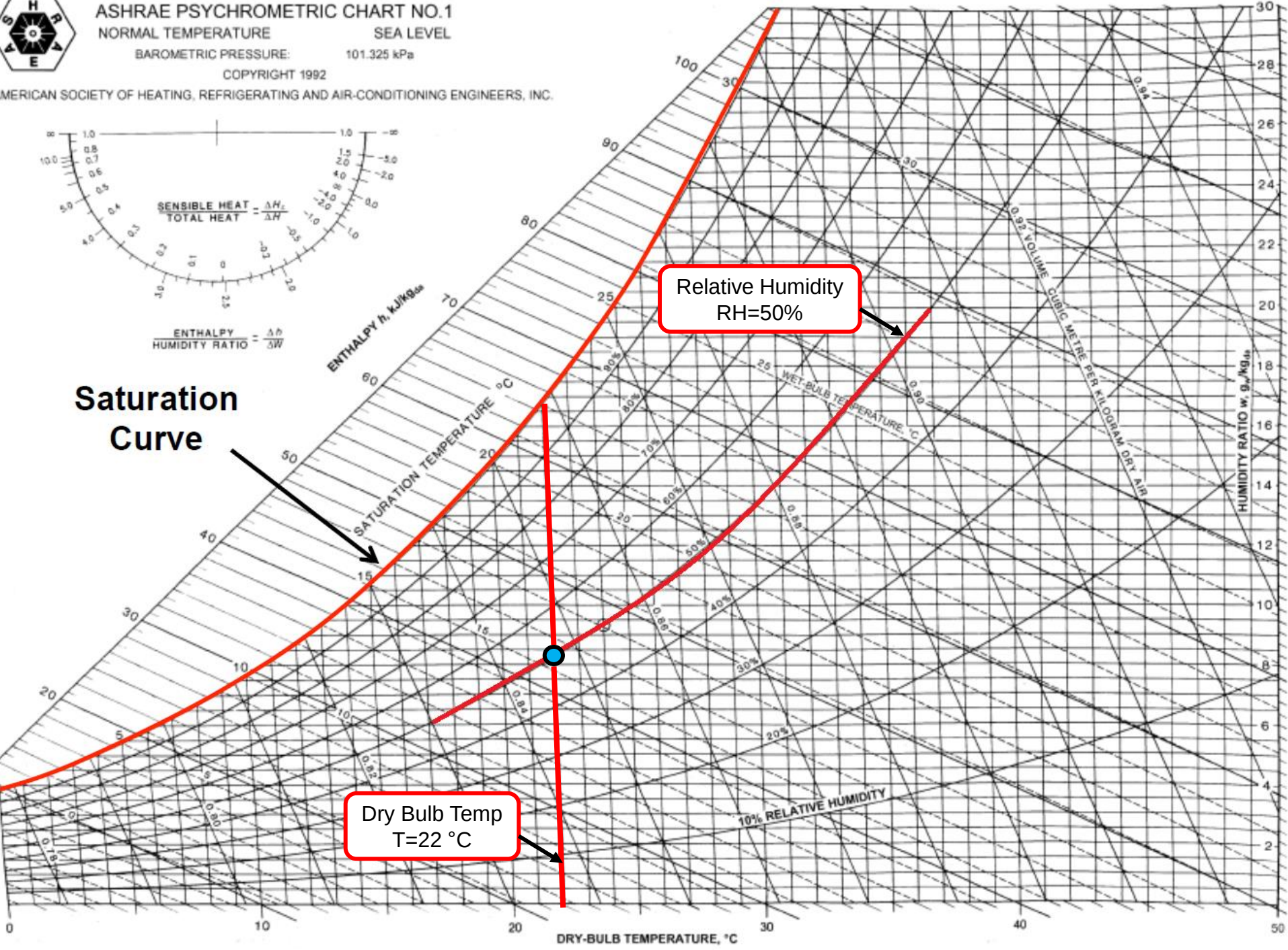
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Saturation Curve

Relative Humidity
RH=50%

Dry Bulb Temp
T=22 °C





ASHRAE PSYCHROMETRIC CHART NO.1

NORMAL TEMPERATURE

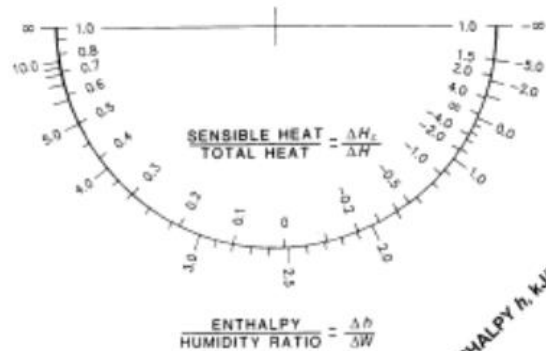
SEA LEVEL

BAROMETRIC PRESSURE:

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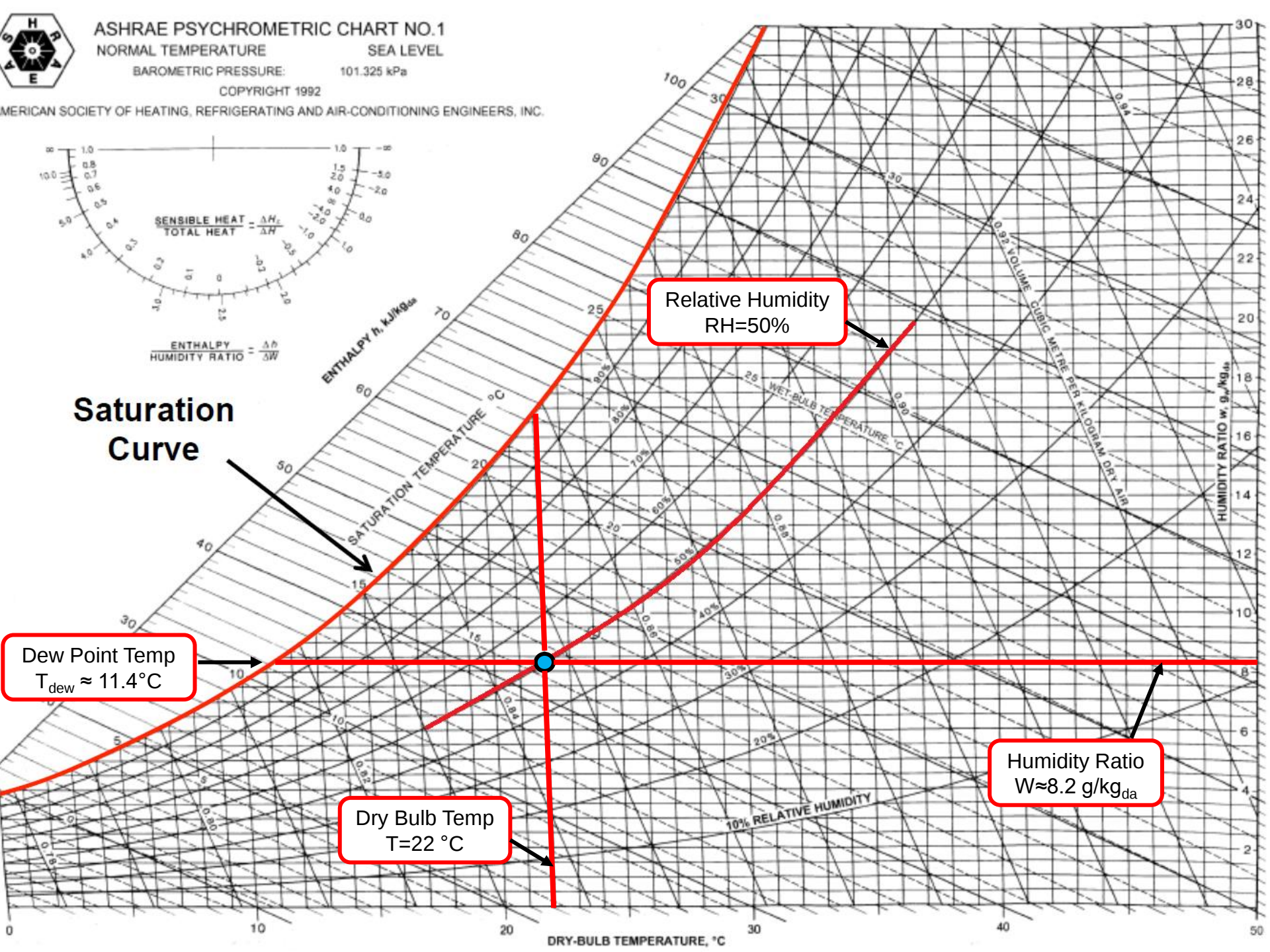
Saturation Curve

Relative Humidity
RH=50%

Dew Point Temp
 $T_{dew} \approx 11.4^\circ\text{C}$

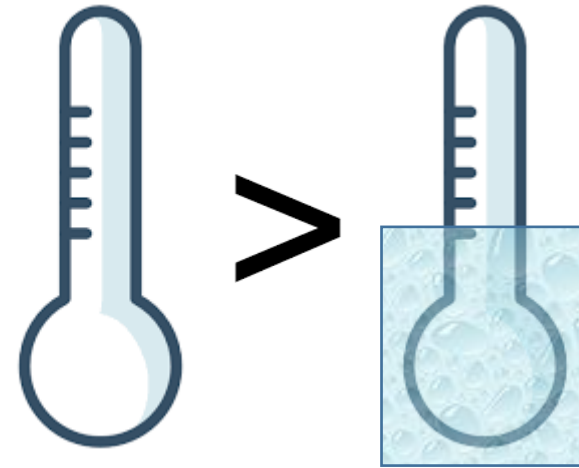
Dry Bulb Temp
 $T=22^\circ\text{C}$

Humidity Ratio
 $W \approx 8.2 \text{ g/kg}_{da}$



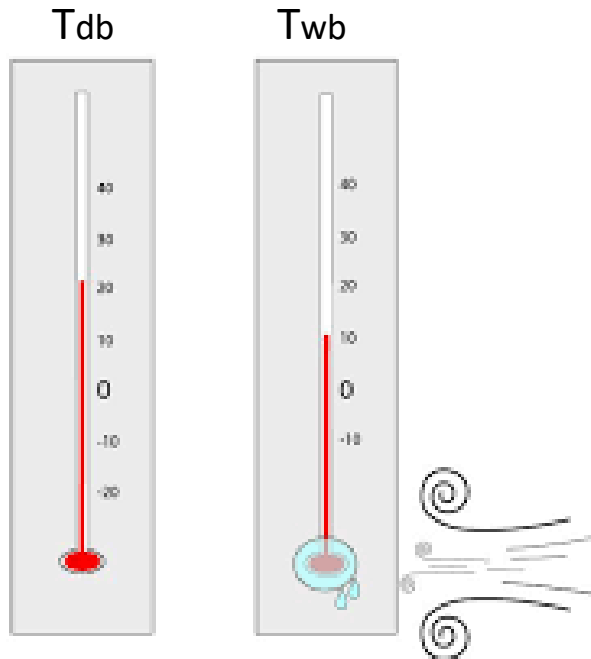
Which T do you expect to be higher?

- dry-bulb temperature, T_{db}
- wet-bulb temperature, T_{wb}



- Wet-bulb T is lower than dry-bulb T:
 - Evaporating moisture removes heat from thermometer bulb
 - Wet-bulb temperature is the theoretical minimum temperature which may be achieved by purely evaporative cooling of a wetted surface
 - The higher the humidity
 - Smaller difference between wet-bulb and dry-bulb temperature

A note of T_{db} vs T_{wb}



- T_{wb} is the lowest temperature that can be reached using the evaporation of water only
- Logic behind: T_{wb} is measured by a standard thermometer located under the shade, but with its bulb wrapped in a cotton wick whose bottom is submerged in a container of water. Exposing the wick to wind causes the water to evaporate. Evaporation processes causes the bulb to cool down. A value representing the wet-bulb temperature is then obtained in the thermometer.

- When air is below the saturation level, that is, when the relative humidity is below 100%, T_{wb} is always lower than T_{db} . The evaporation is reduced when the air contains more water vapor. For relative humidity of 100, $T_{wb}=T_{db}$
- The difference T_{db} and T_{wb} is an indication of the potential of evaporative cooling systems. The human body uses this principle (evaporative cooling) through perspiration. That's why high humidity will cause discomfort for human body.



ASHRAE PSYCHROMETRIC CHART NO.1

NORMAL TEMPERATURE

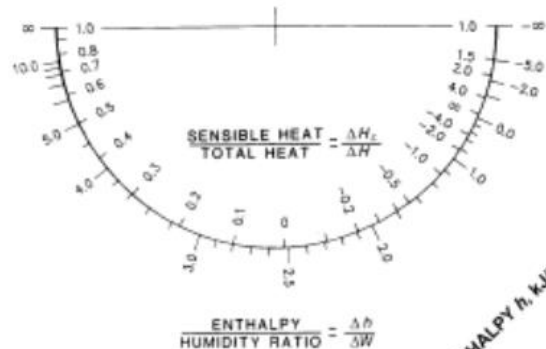
SEA LEVEL

BAROMETRIC PRESSURE:

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Saturation Curve

Dew Point Temp
 $T_{dew} \approx 11.4^\circ\text{C}$

Dry Bulb Temp
 $T = 22^\circ\text{C}$

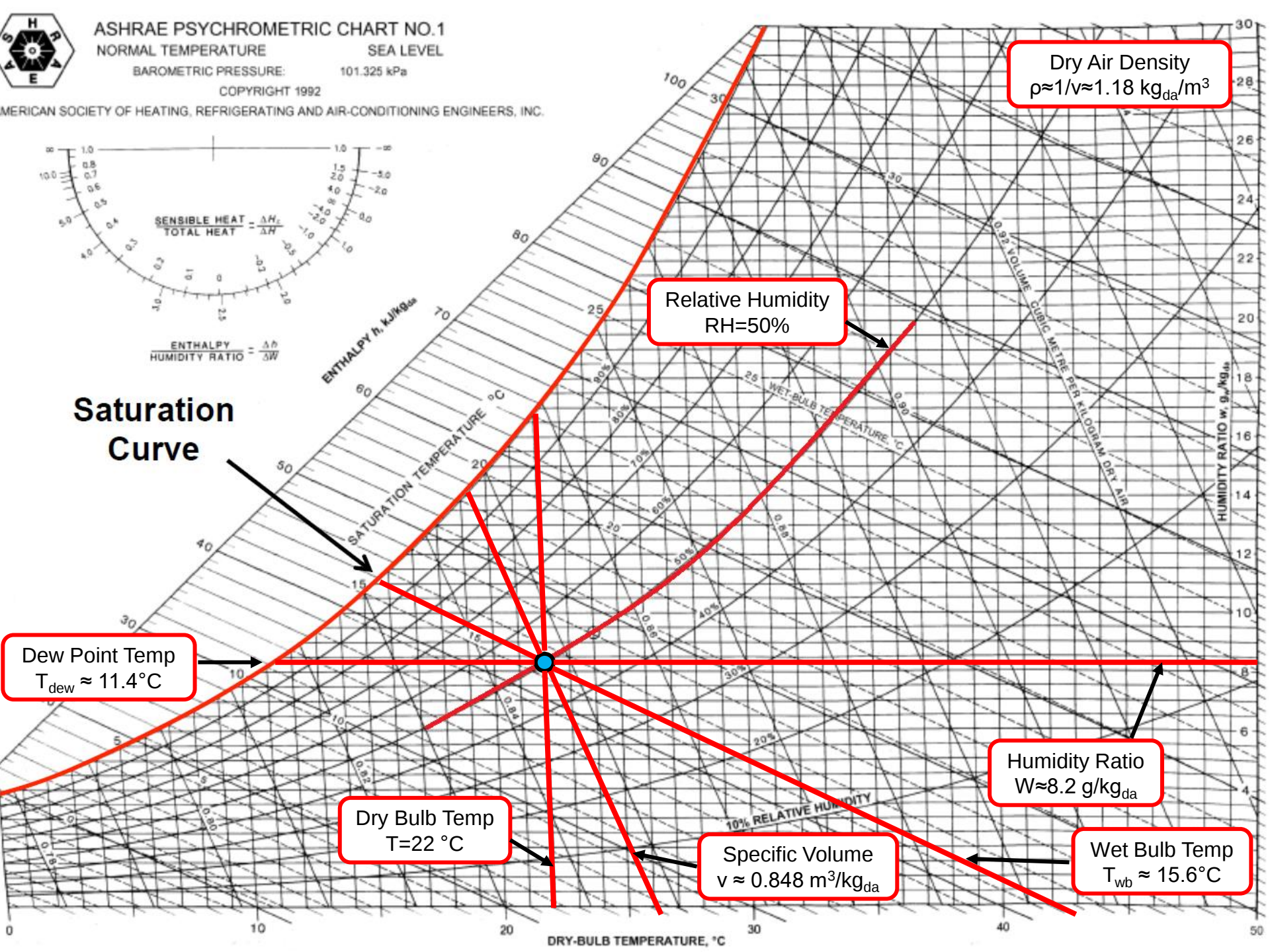
Specific Volume
 $v \approx 0.848 \text{ m}^3/\text{kg}_{da}$

Wet Bulb Temp
 $T_{wb} \approx 15.6^\circ\text{C}$

Humidity Ratio
 $W \approx 8.2 \text{ g/kg}_{da}$

Relative Humidity
 $RH = 50\%$

Dry Air Density
 $\rho \approx 1/v \approx 1.18 \text{ kg}_{da}/\text{m}^3$





ASHRAE PSYCHROMETRIC CHART NO.1

NORMAL TEMPERATURE

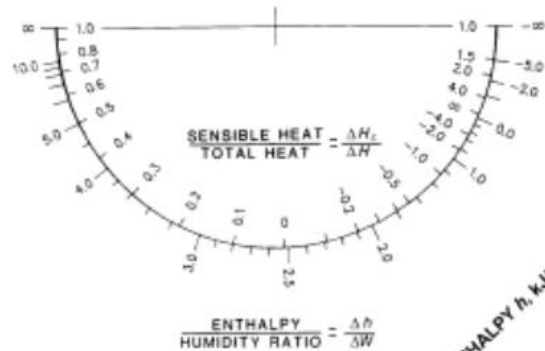
SEA LEVEL

BAROMETRIC PRESSURE:

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Saturation Curve

Enthalpy
 $h \approx 44 \text{ kJ/kg}_{da}$

Dew Point Temp
 $T_{dew} \approx 11.4^\circ\text{C}$

Dry Bulb Temp
 $T = 22^\circ\text{C}$

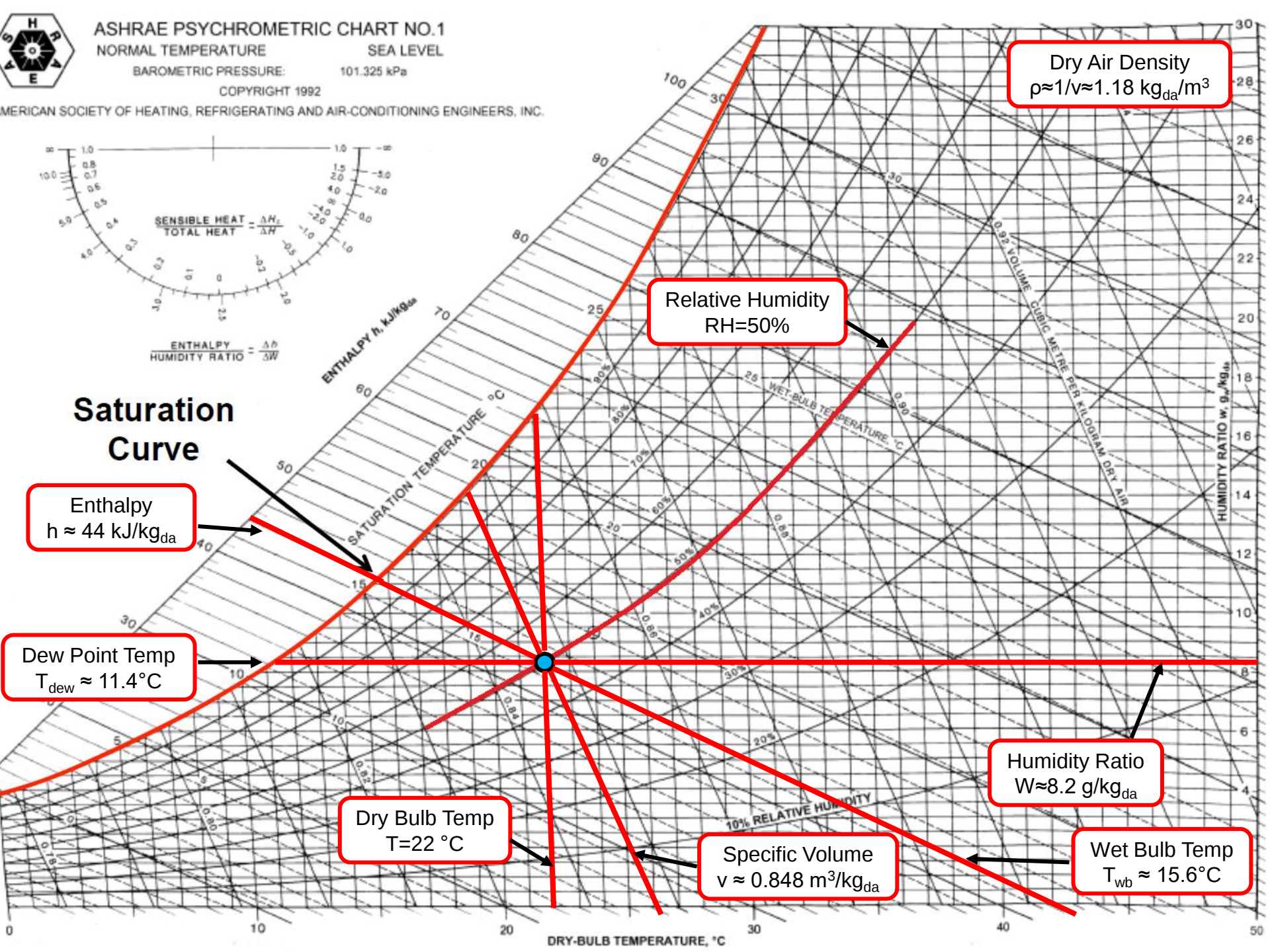
Specific Volume
 $v \approx 0.848 \text{ m}^3/\text{kg}_{da}$

Humidity Ratio
 $W \approx 8.2 \text{ g/kg}_{da}$

Wet Bulb Temp
 $T_{wb} \approx 15.6^\circ\text{C}$

Relative Humidity
RH=50%

Dry Air Density
 $\rho \approx 1/v \approx 1.18 \text{ kg}_{da}/\text{m}^3$



Enthalpy, h [J/kg] & Humidity ratio, W [g/kg_{da}]

- Enthalpy (from Psychrometric chart) =
 - Total energy in air [J/kg, BTU/lb]: Sensible + latent
 - Very valuable for calculations
- Sensible – Energy associated with temperature change
- Latent – Energy associated with moisture change (Often more important than sensible)

$$h = 1.006t + W(2501 + 1.86t)$$



$$W = 0.62198 \frac{p_w}{p - p_w}$$

Humidity ratio, W :

- Mass of water vapor/divided by mass of dry air
- Hard to measure directly

(p – total pressure; p_w – vapor pressure)

Psychrometric chart: In-class exercise

- Lets take an example of hot indoor conditions
 - Moist air at 30 °C dry-bulb temperature
 - Dew point temperature at 15 °C

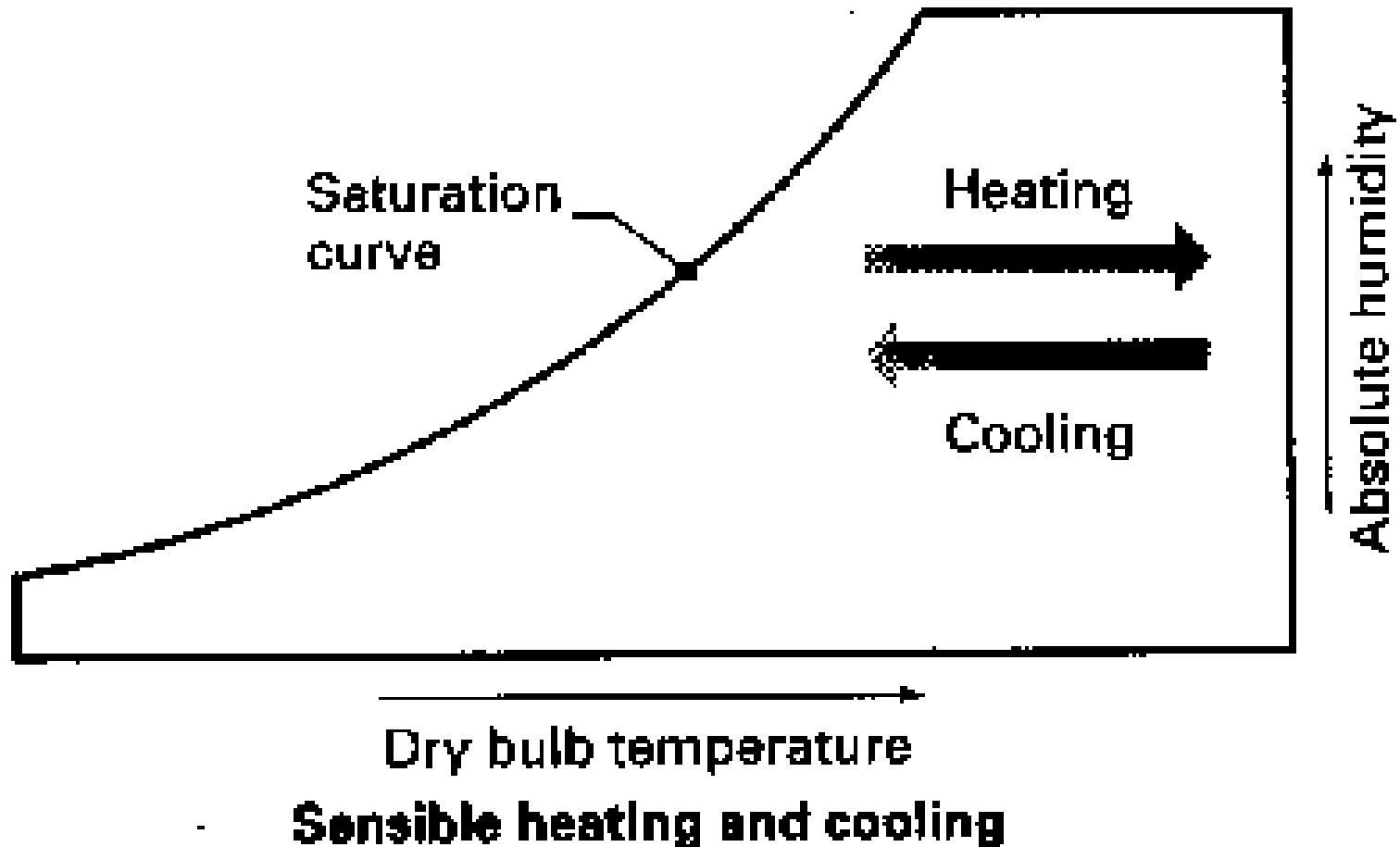
Find the following:

- the humidity ratio, W
- wet-bulb temperature, T_{wb}
- specific volume, v
- relative humidity, RH
- enthalpy, h

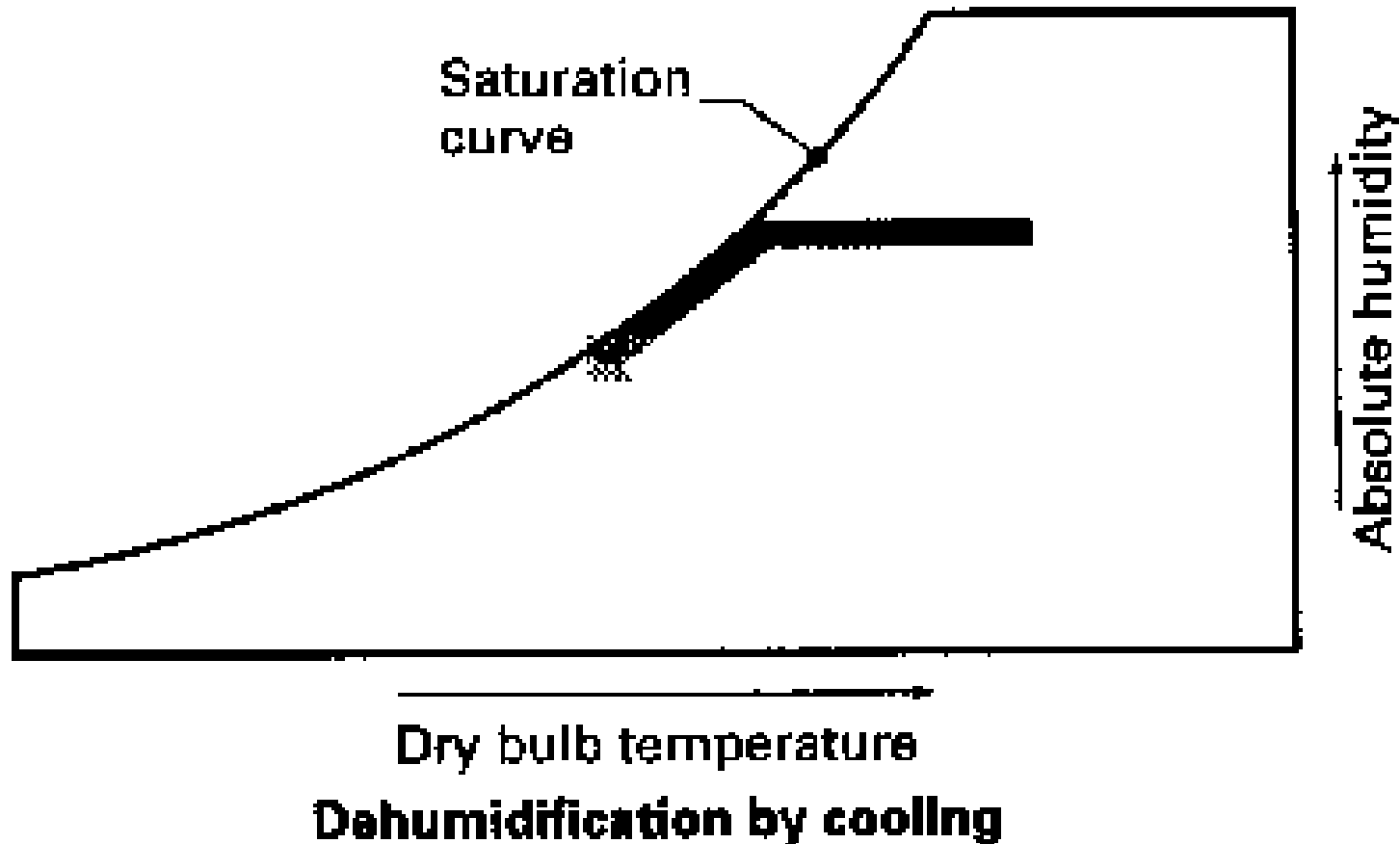
You can download the chart here:

<https://www.ashrae.org/File%20Library/Technical%20Resources/Bookstore/UP3/SI-1.pdf>

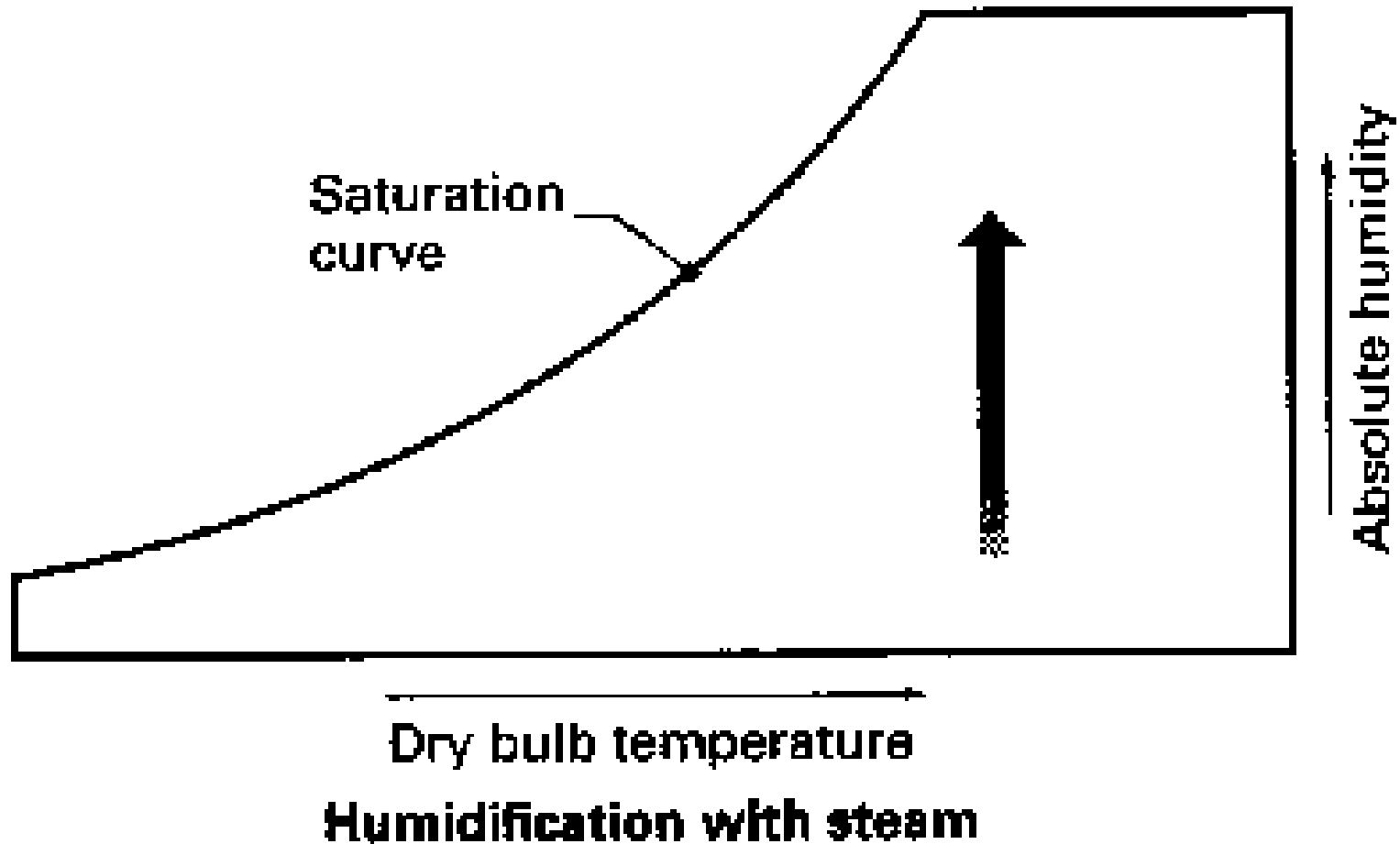
Processes useful for indoor climate



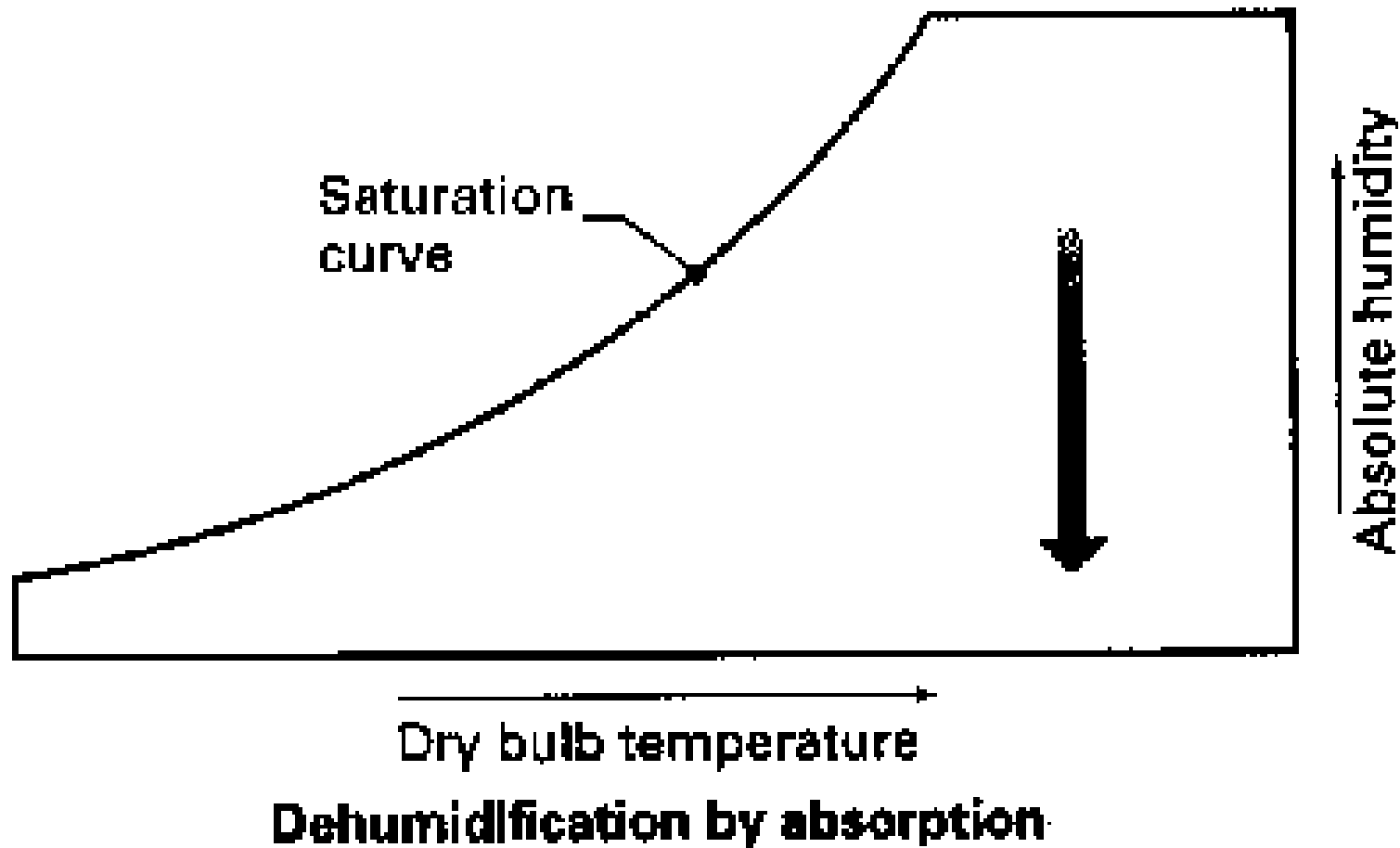
Processes useful for indoor climate



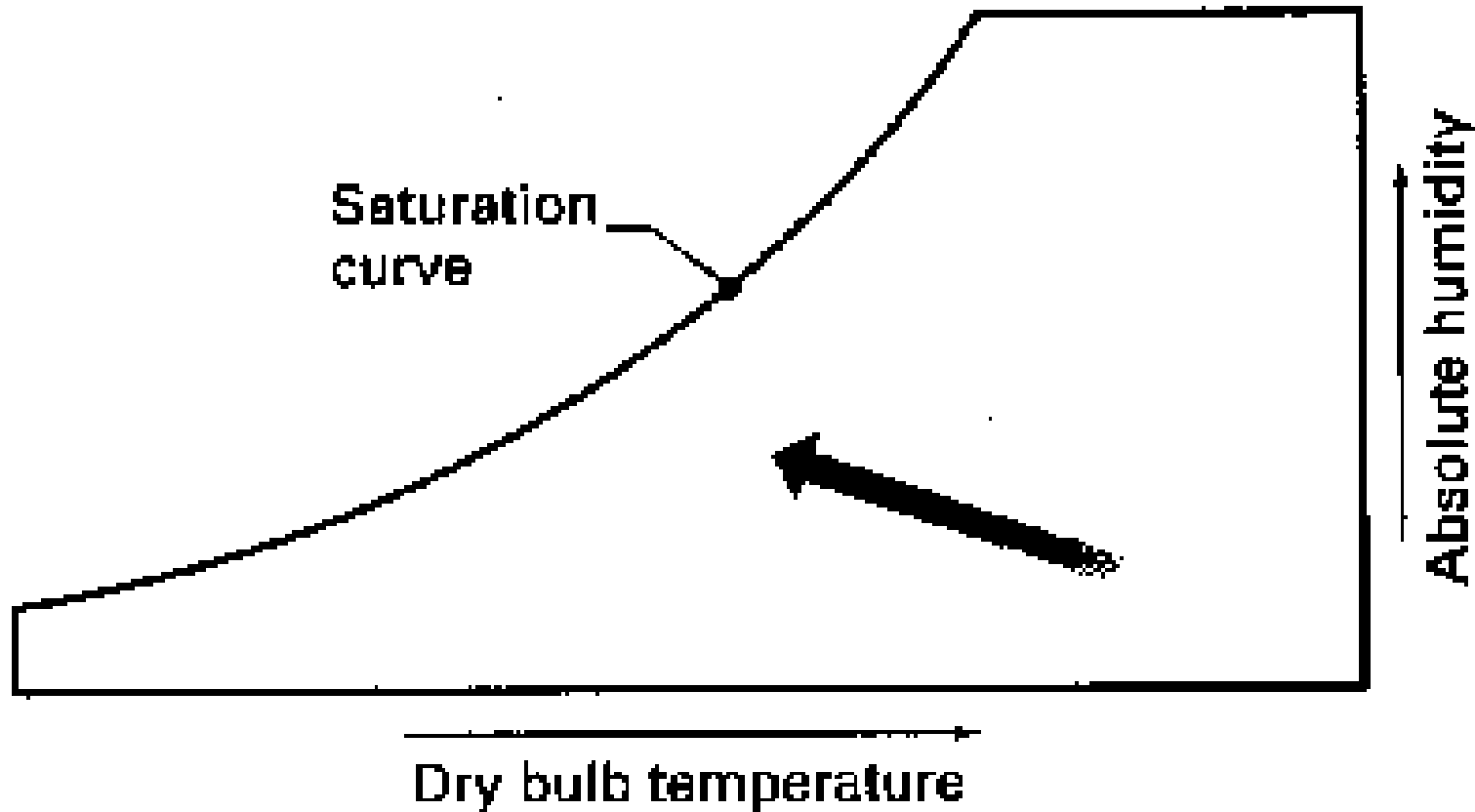
Processes useful for indoor climate



Processes useful for indoor climate



Processes useful for indoor climate



Humidification by evaporative cooling

Psychrometric chart: Homework #1

- Condensation on windows when taking a shower
 - How cold does it have to be outside for condensation to form on windows?

Assumptions:

- windows are the same temperature as outside air
- dry-bulb temperature, $T_{db} = 27\text{ °C}$
- relative humidity, $RH = 80\%$



You can download the chart here:

<https://www.ashrae.org/File%20Library/Technical%20Resources/Bookstore/UP3/SI-1.pdf>

Psychrometric chart: Homework #2

By using psychrometric chart, complete the following table of values for a moist air:

Dry bulb temp °C	Wet bulb temp °C	Specific enthalpy kJ/kg	Specific volume m ³ /kg	% saturation	Moisture content kg/kg
40°C	-	-	-	-	0.01
40°C	20°C	-	-	-	-
40°C	-	-	-	30%	-
15°C	-	-	0.82	-	-
25°C	15°C	-	-	-	-
30°C	-	30	-	-	-
50°C	-	120	-	-	-

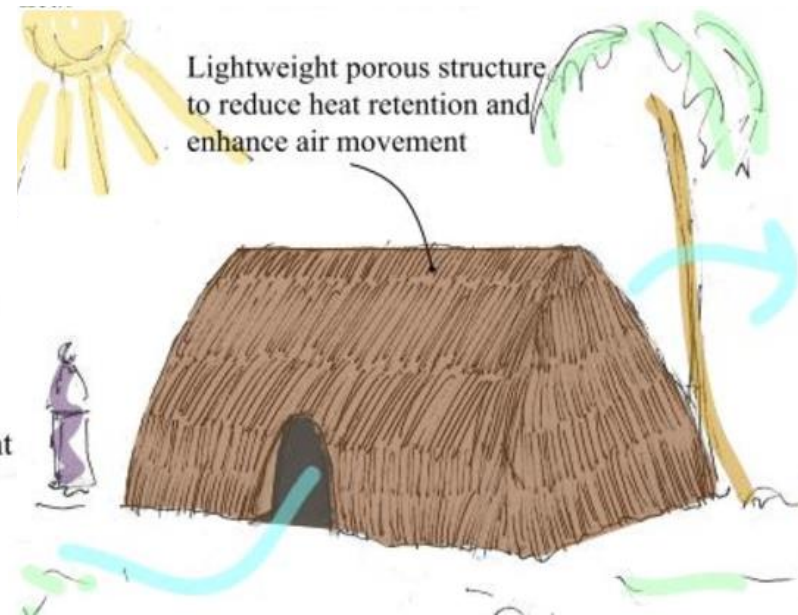
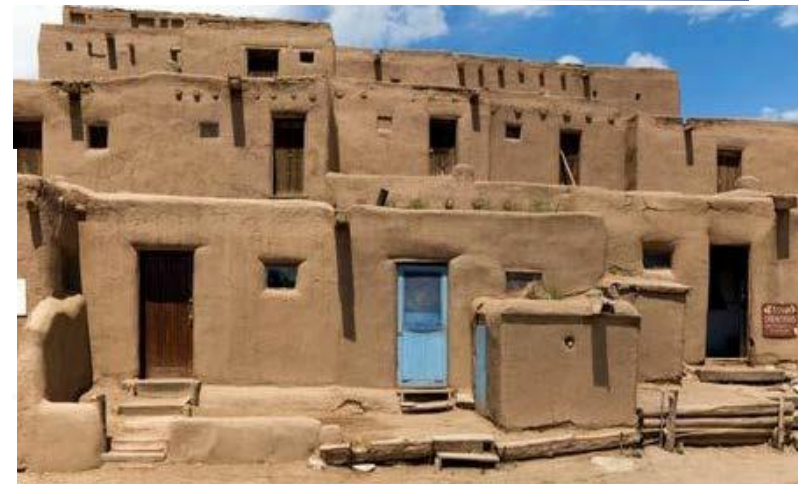
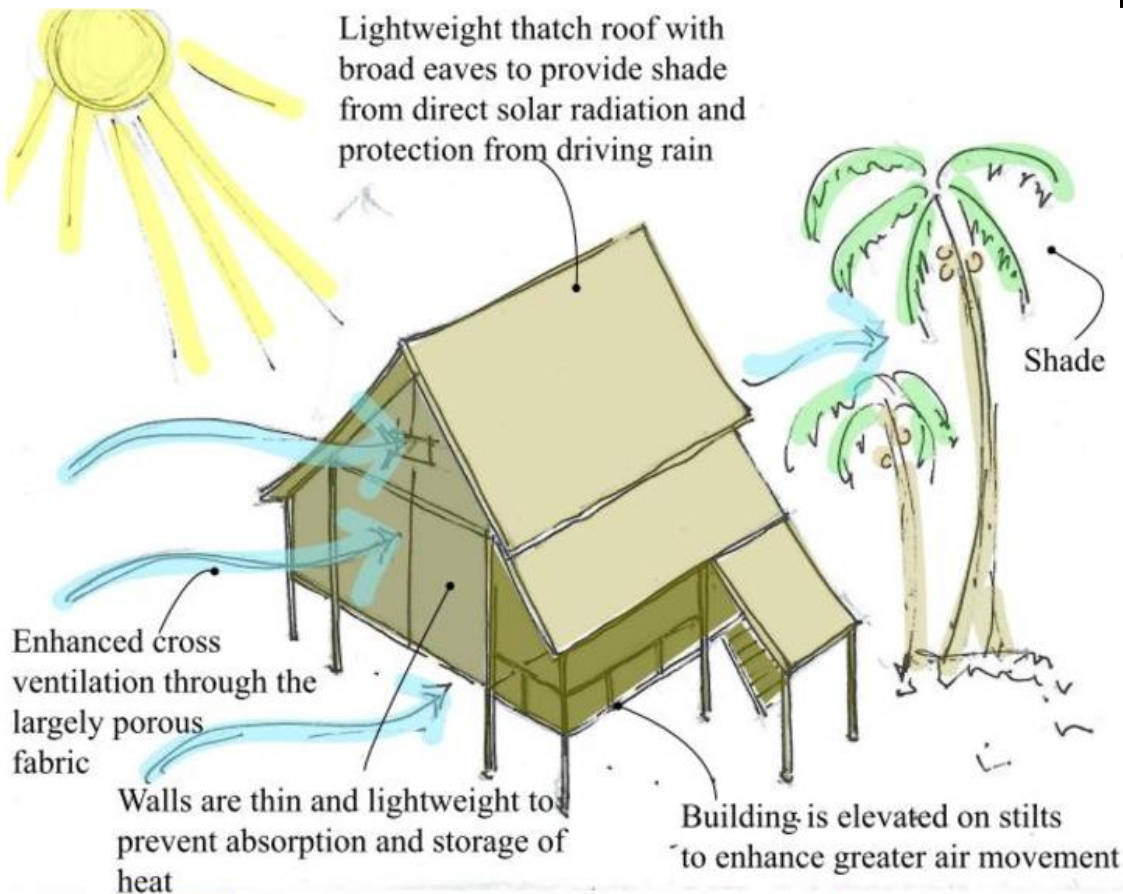
You can download the chart here:

<https://www.ashrae.org/File%20Library/Technical%20Resources/Bookstore/UP3/SI-1.pdf>

Any questions?



Climate-responsive architecture



Evolution of buildings



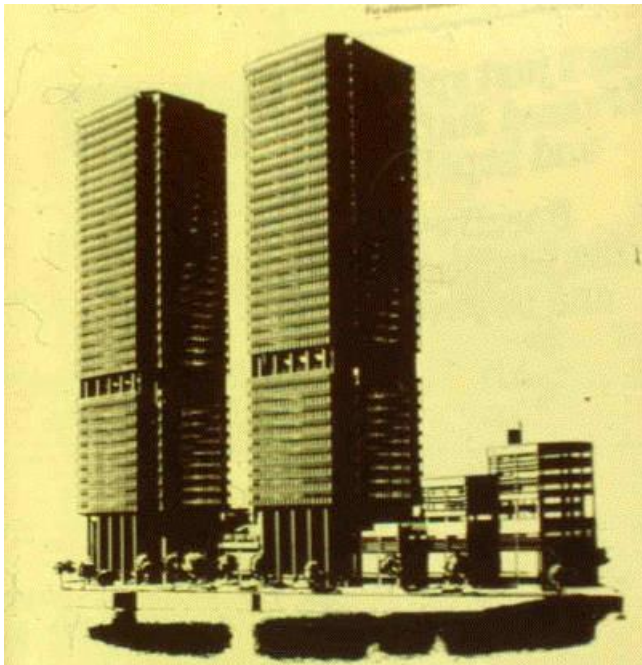
Climate (envelope)
dominated



Internal-load
dominated



Evolution of big skyscrapers



**ON THE NILE, THE THAMES OR THE
YORKSHIRE OUSE?**
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headquarters building for Thomas Cook at Peterborough.

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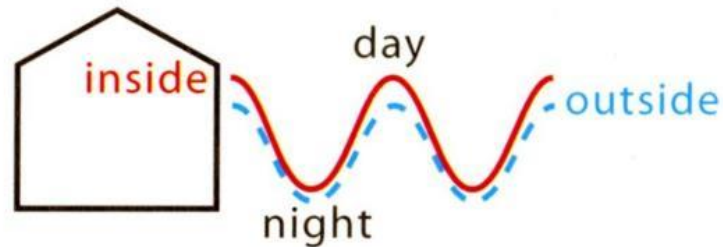


(Sources: Carrier advertisement, Flickr.com)

Impact of thermal mass on indoor climate

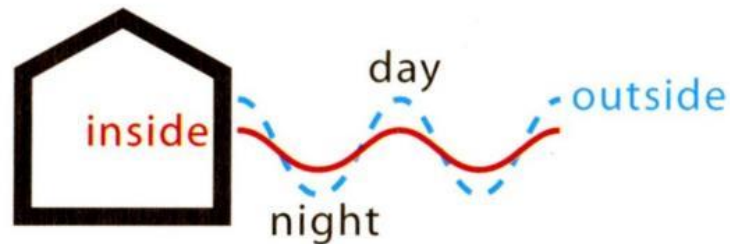
A Tent climate

Temperature follows the outdoor climate



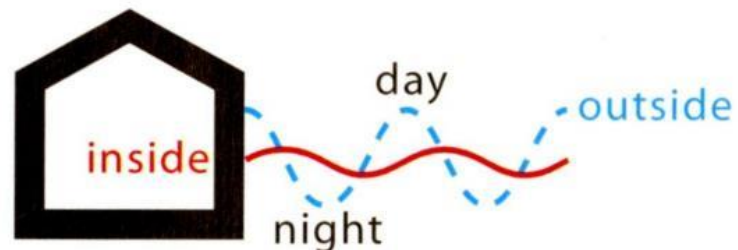
B Cabin climate

Quickly warm and cold



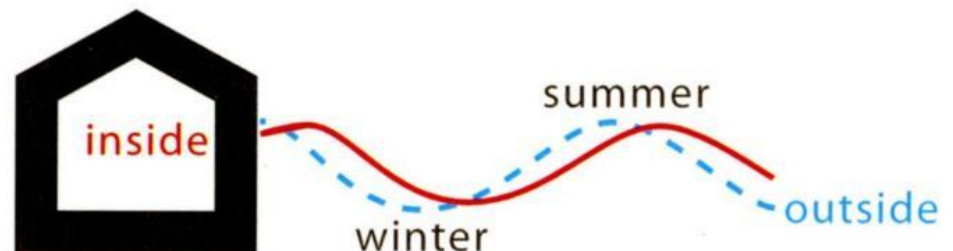
C Stone house climate

Phase offset variation across the day



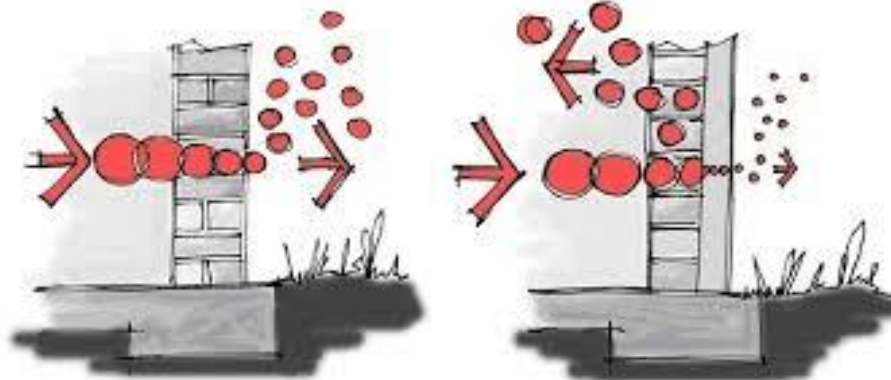
D Cave climate

Phase offset variation across the year



Heat transfer in buildings

- Transfer of thermal energy between objects with different T
- Knowing heat transfer is important because:
 - We can select and size HVAC equipment to provide indoor comfort
 - Estimate building energy use and operating costs
 - Understand trade-offs in energy efficient design



- **SIA 380/1**: Swiss standard for heat balances in the building

A few basic notes before we start...

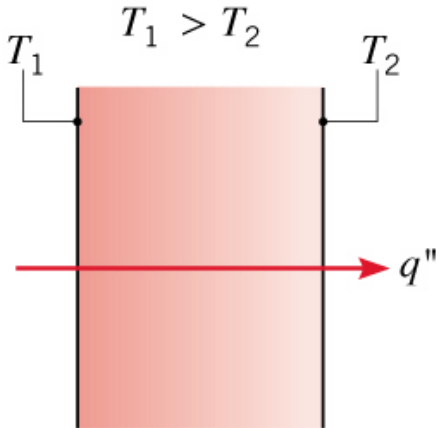
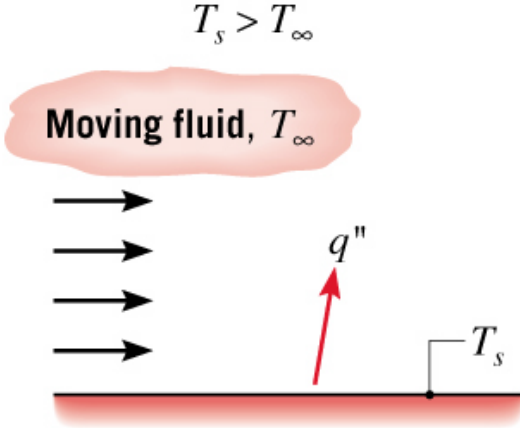
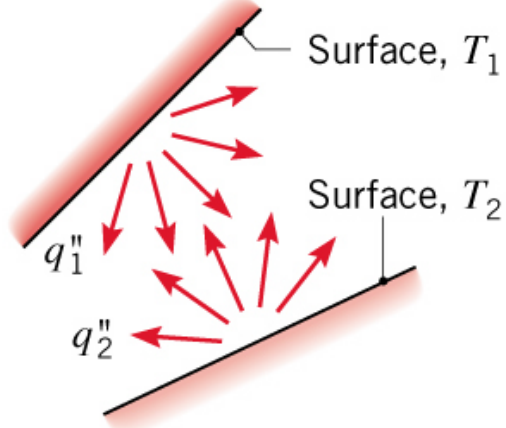
- Heat flow can be transient or steady-state
 - Transient (temperature & heat flow vary w/ time)
 - Steady-state (temperature & heat flow don't vary w/ time)
 - Choice depends on what problem you're investigating
- Heat flow occurs in 1, 2, and 3-dimensions
 - In almost all real situations, heat flow occurs in 3-D
 - 1-D is often acceptable from a practical standpoint

And one more thing: Units of heat transfer

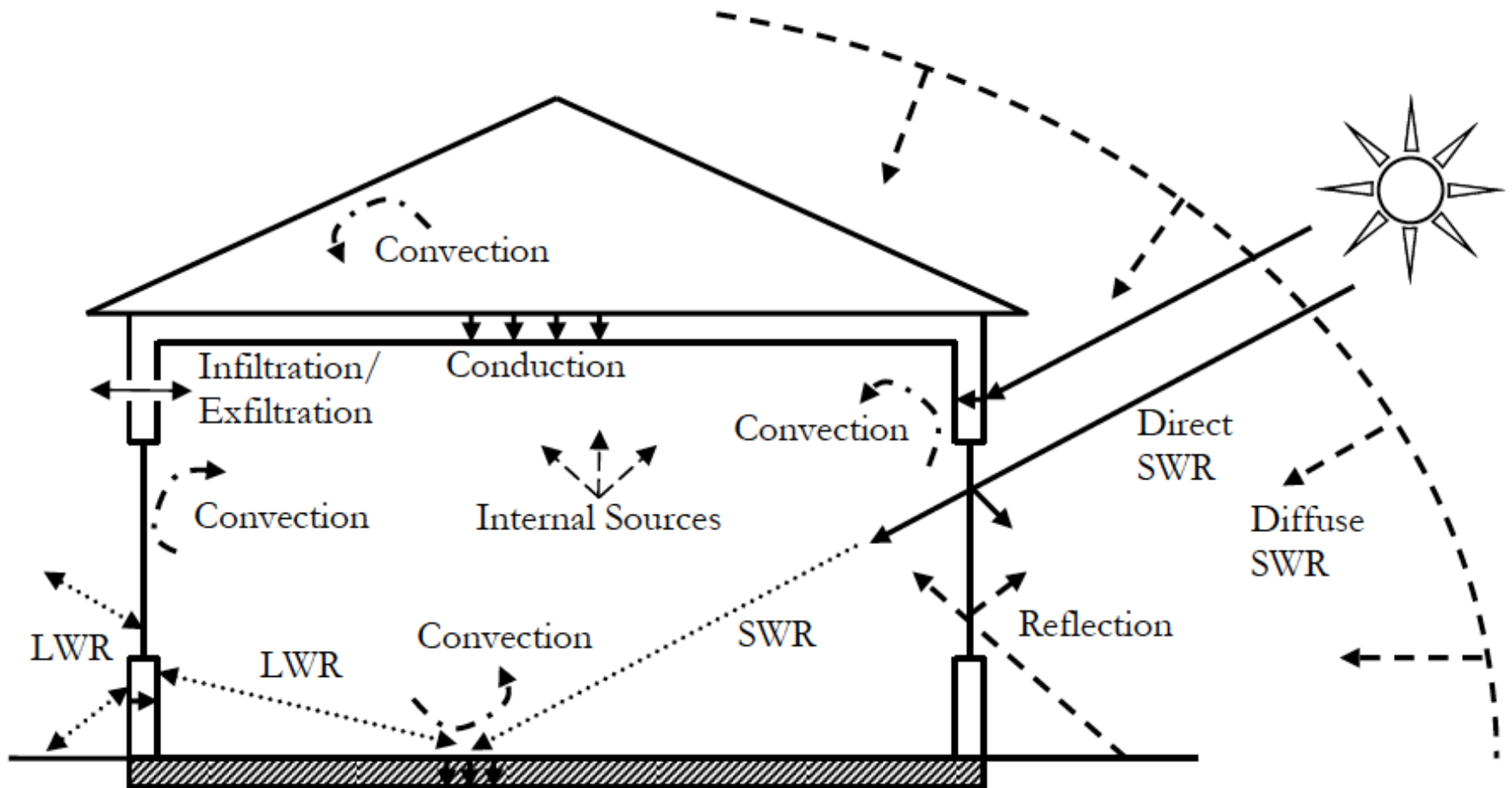
- We denote the total rate of heat energy transfer by the symbol Q
 - It is a rate of energy transfer (i.e., a power)
 - So the units are W (J/s) or Btu/h ($1 \text{ W} = 3.41 \text{ Btu/h}$)
- We denote the rate of heat transfer per unit area by the symbol q
 - By definition $q = Q/A$, where A is the area through which the heat is moving
 - The units of q are W/m^2 [or $\text{Btu}/(\text{h}\cdot\text{ft}^2)$]
 - Using q instead of Q makes it easier to compare the thermal properties of assemblies without regard to the actual size of them

Three dominant modes of heat transfer

- **Conduction:** transfer of heat resulting from intermolecular transfer of kinetic energy in solids liquids and gases
- **Convection:** transfer of heat resulting from larger-scale fluid motion (can be in liquid or in gas)
- **Radiation:** transfer of heat by means of electromagnetic waves

Conduction through a solid or a stationary fluid	Convection from a surface to a moving fluid	Net radiation heat exchange between two surfaces
 Conduction	 Convection	 Radiation

In reality: combined heat transfer modes

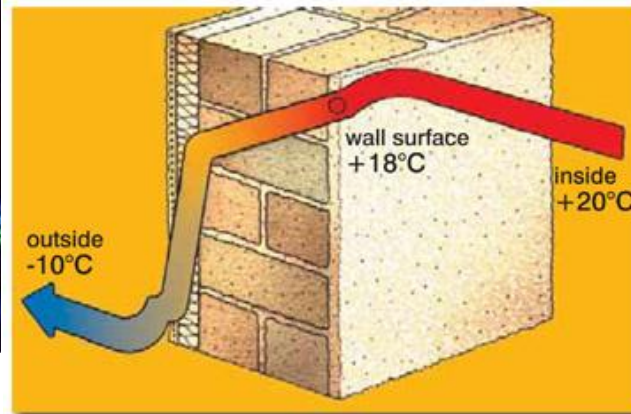


Heat transfer: Conduction

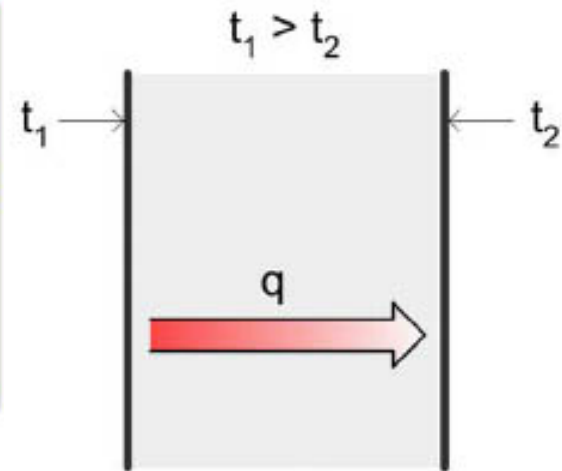
- Conductive heat transfer is heat transfer through direct molecular contact. It is basically the transfer of thermal momentum between atoms or molecules and follows Fourier's Law
 - Similar to electrical conduction in solid objects
- Occurs in the direction from high to low temperature
- Example: Heat gain through opaque walls in summer



IR image of conductive losses in home



(Source: Images from Google)



Heat transfer: Conduction

- Conduction follows Fourier's Law

$$q = -k \cdot \nabla T = -k \left(\frac{\partial T}{\partial x} + \frac{\partial T}{\partial y} + \frac{\partial T}{\partial z} \right)$$

heat flux per
unit area [W/m²]

thermal conductivity
[W/m·K]

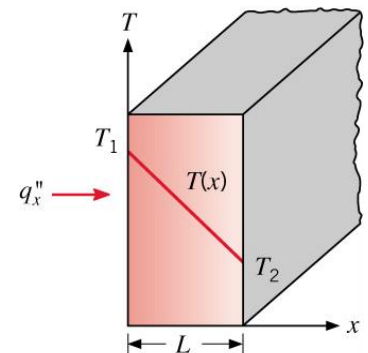
"The time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area, at right angles to that gradient, through which heat flows."

- For 1-D problems, this becomes: $q = -k \frac{\partial T}{\partial x} \quad \left[\frac{W}{m^2} \right]$
- To get total heat flow, Q [W], simply multiply q [W/m²] by A [m²]:

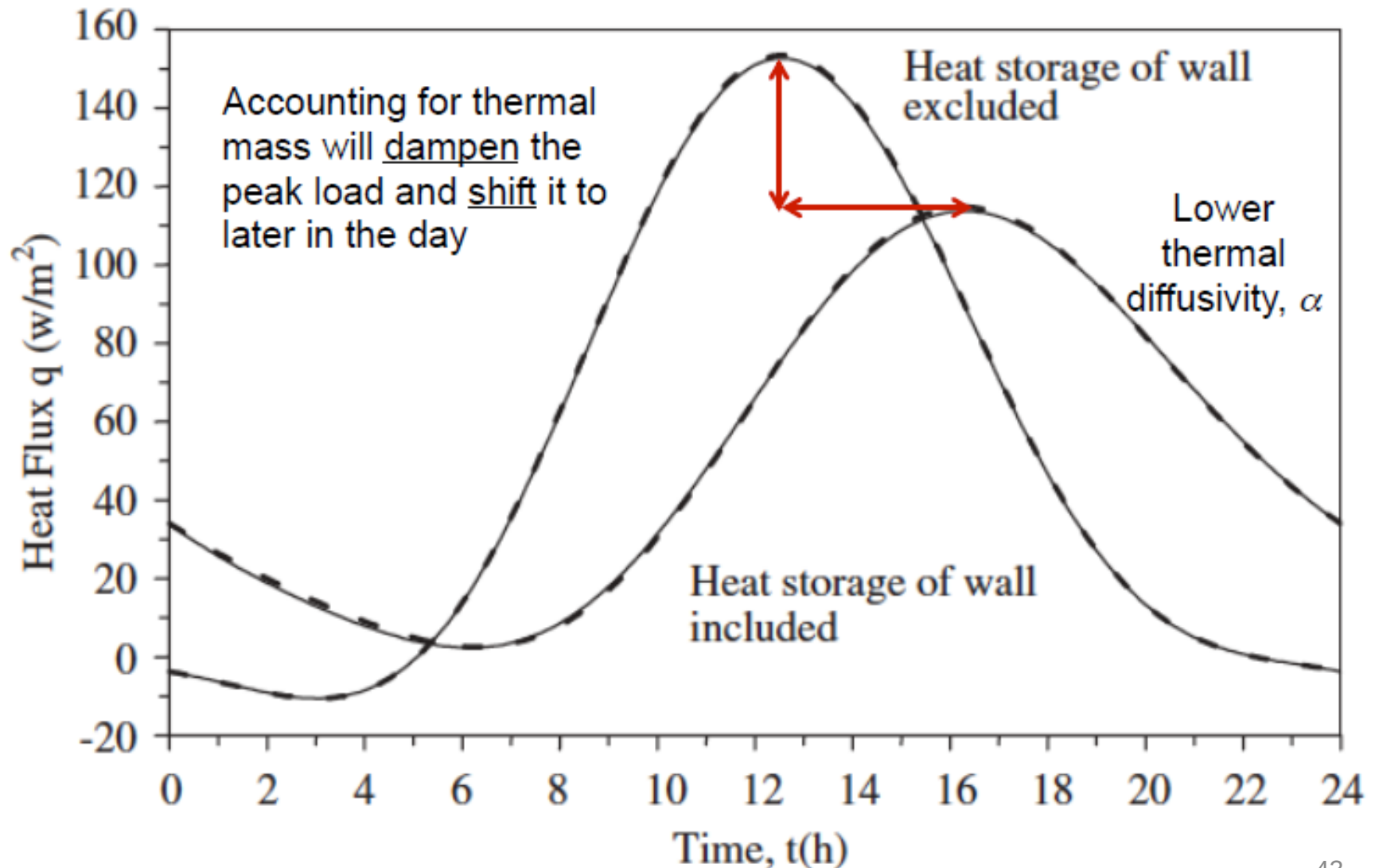
$$Q = q \cdot A = A \cdot \frac{k}{L} (T_1 - T_2)$$

Note 1: Here T_1 and T_2 are the surface temperatures but keep in mind that heat will always flow from high to low temperature.

*Note 2: k/L represents **U value**, which is thermal conductance [W/m²K]*

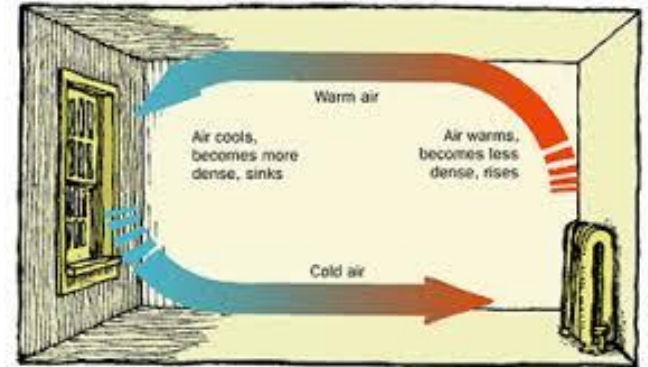
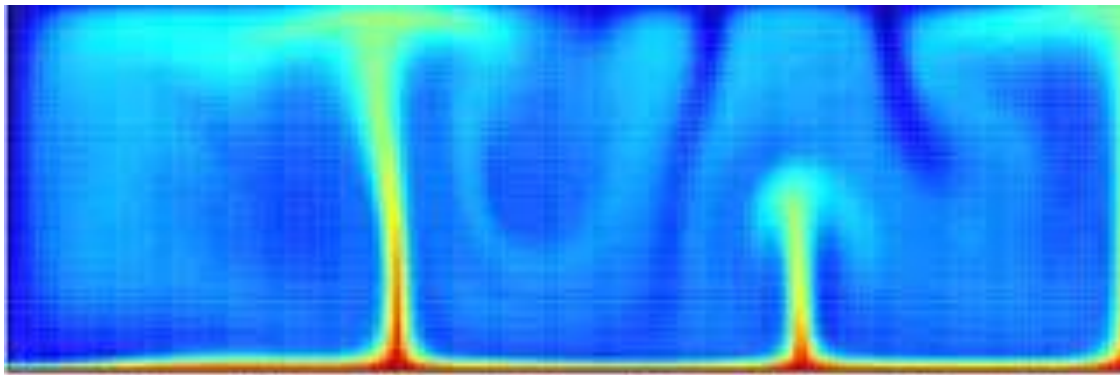


Accounting for the impact of thermal mass



Heat transfer: Convection

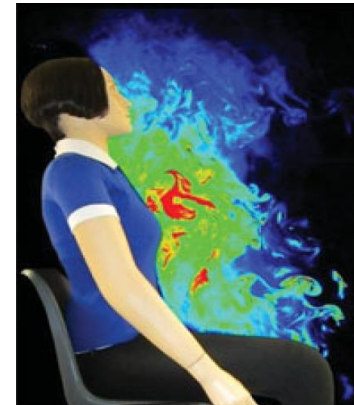
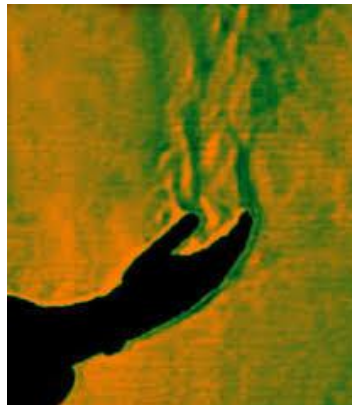
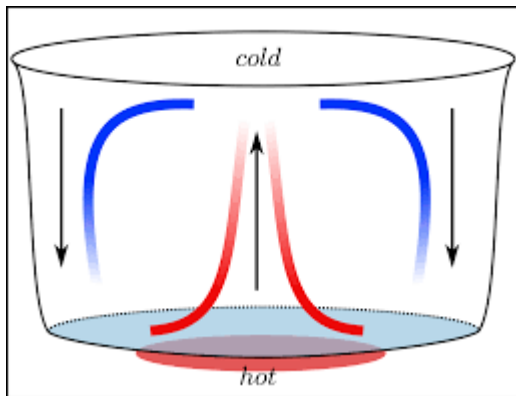
- Result of larger-scale motions of a fluid, either liquid or gas
- Increases with the higher velocity of fluid flow
- Also increases with higher temperature difference
- Example: Using a fan to cold down person's skin and remove heat



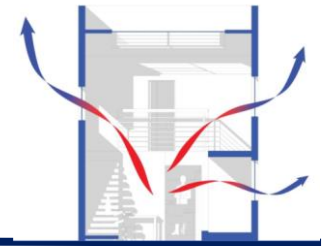
Heat transfer: Convection

Two main types of convective heat transfer in buildings:

- “**Advection**” (or bulk convection)
 - The transport of heat between fluids by fluid flow (e.g. air or water)
 - Example: Ventilation air supply cools down the room air
- What we most refer to as “**convection**”
 - Convective heat transfer between a surface and a fluid
 - Example: heat transfer from the human skin to surrounding air



Advection (bulk convection)



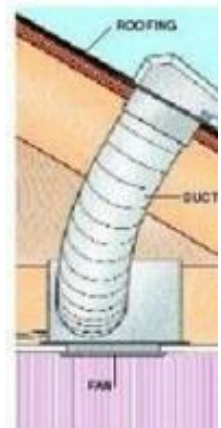
- It's more direct compared to convection between surfaces and fluids
- Air has the capacity to store heat, so air flowing into or out of a control volume (building) also carry heat with it

$$Q_{bulk} = \dot{m} C_p \Delta T \quad [W] = \left[\frac{kg}{s} \cdot \frac{J}{kg \cdot K} \cdot K \right]$$

Mass flow rate of fluid (kg/s) specific heat capacity of fluid [J/(kgK)]

- Do-it-yourself:

- If it's 22 °C inside the apartment and 5 °C outside, what is the rate of heat loss via advection (bulk convection) during this condition?
 - Assume that mechanical fan which you have in the bathroom operates at an airflow rate of 170 m³/h.



Solution to the previous problem

- If it's 22 °C inside the apartment and 5 °C outside, what is the rate of heat loss via advection (bulk convection) during this condition?
 - Assume that mechanical fan which you have in the bathroom operates at an airflow rate of 170 m³/h.

$$Q_{bulk} = \dot{m} C_p \Delta T$$

Mass flow rate of fluid (kg/s) specific heat capacity of fluid [J/(kgK)]

$$[W] = \left[\frac{kg}{s} \cdot \frac{J}{kg \cdot K} \cdot K \right]$$

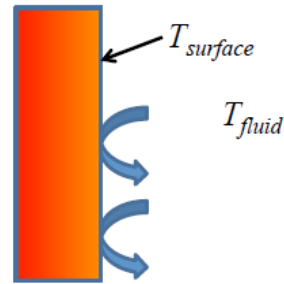
c_p = specific heat of air (1.006 kJ/kg K)
 ρ = density of air (1.202 kg/m³)
 ΔT = temperature difference (°C or K)

$$\dot{m} = 170 \frac{m^3}{h} \cdot 1.202 \frac{kg}{m^3} = 204.34 \frac{kg}{h} = 0.0567 \frac{kg}{s}$$

$$Q_{bulk} = \dot{m} C_p \Delta T = 0.0567 \frac{kg}{s} \cdot 1.006 \frac{kJ}{kg K} \cdot 17K = 0.97 \frac{kJ}{s} \approx 1kW$$

Convection (between a surface and a fluid)

- When a fluid comes in contact with a surface at a different temperature
- We use a heat transfer coefficient, h_{conv} , to relate the rate of heat transfer to the difference between the solid surface temperature, $T_{surface}$, and the temperature of the fluid far from the surface, T_{fluid}



$$q_{conv} = h_{conv}(T_{fluid} - T_{surface}) \quad \left[\frac{W}{m^2} \right]$$

convective heat transfer coefficient $[W/(m^2 \cdot K)]$

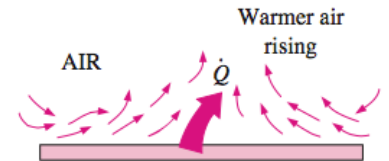
fluid temperature far enough not to be affected by $T_{surface}$

- To get Q , simply multiply by surface area, A

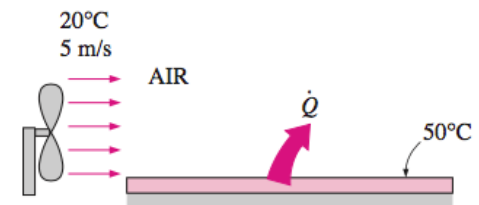
$$Q_{conv} = h_{conv} \cdot A(T_{fluid} - T_{surface}) \quad [W]$$

Two types of surface/fluid convection

- **Natural (or free) convection:** Results from density differences in the fluid caused by contact with the surface to or from which the heat transfer occurs
 - **Buoyancy** is the main driver (temperature dependent density differences)
 - Example: The circulation of air in a room caused by the presence of a solar-warmed window or wall (without a mechanical system) is a manifestation of natural/free convection

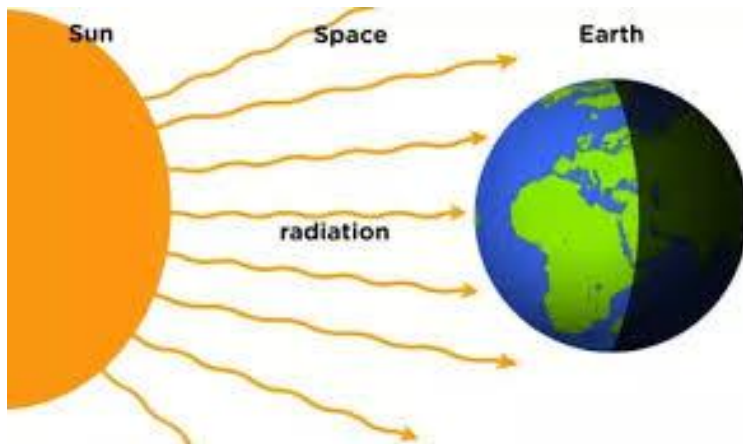


- **Forced convection:** Results from a force external to the problem (other than gravity or other body forces) moves a fluid past a warmer or cooler surface
 - Usually much higher velocities and more random and chaotic flow
 - Driven by mechanical forces (e.g. fans and wind)
 - Example: Heat transfer between cooling coils and an air stream



Heat transfer: Radiation

- Electromagnetic wave exchange between 2 surfaces at different temperatures
- It must be absorbed by the surface to produce internal energy
- Example: Short wave radiation from the Sun to the Earth, and long wave radiation from the Earth to the atmosphere.



Heat transfer: Radiation

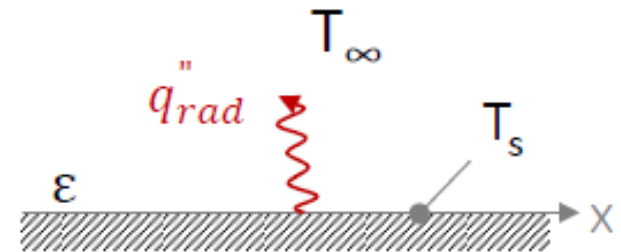
- All objects above absolute zero radiate electromagnetic energy according to: $q_{rad} = \varepsilon \cdot \sigma \cdot T^4$

where ε is emissivity, σ is Stefan-Boltzmann constant = $5.670 \times 10^{-8} \text{ [W/m}^2 \cdot \text{K}^4]$, and T is absolute temperature in Kelvin

- General surface-to-air radiation:

$$q_{rad} = \frac{Q_{rad}}{A} = \varepsilon \cdot \sigma \cdot (T_{surface}^4 - T_{\infty}^4)$$

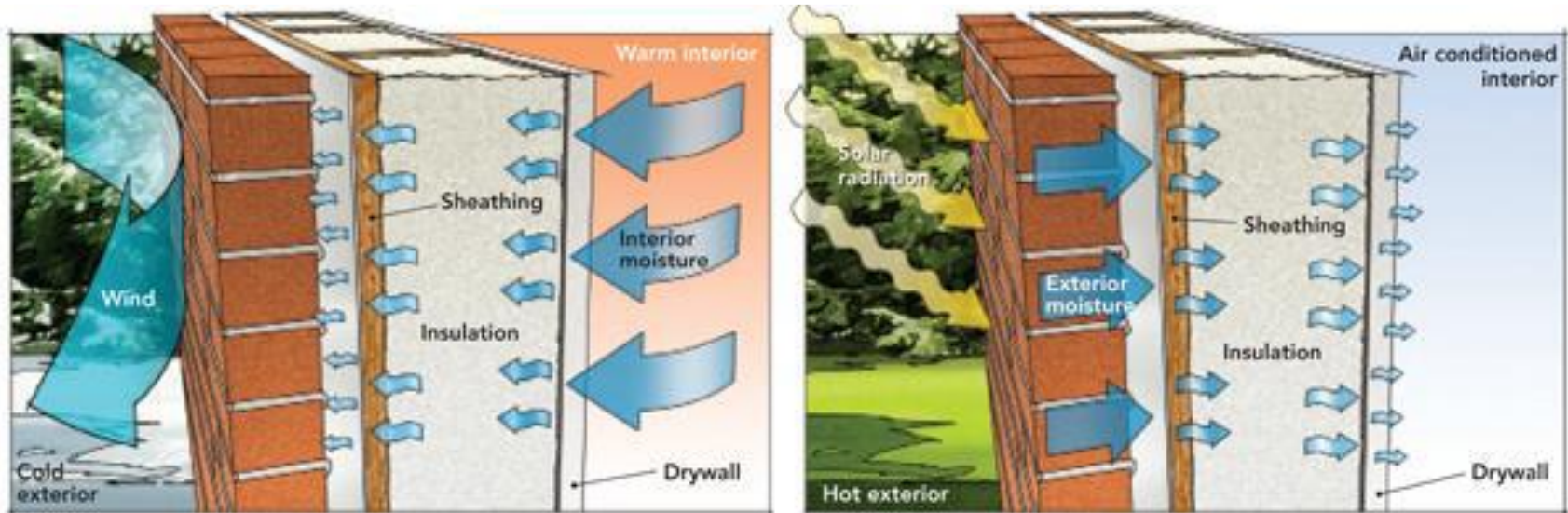
Emissivity (ε) represents effectiveness of the surface in emitting energy as *thermal (infrared) radiation*, can have a value from 0 (shiny mirror) to 1 (blackbody). Real surfaces emit less radiation than ideal “black” ones. For most common building materials (e.g. brick, concrete, wood), emissivity is around 0.9.



Surface	Emittance 50–100 °F
A small hole in a large box, sphere, furnace, or enclosure	0.97 to 0.99
Black nonmetallic surfaces such as asphalt, carbon, slate, paint, paper	0.90 to 0.98
Red brick and tile, concrete and stone, rusty steel and iron, dark paints (red, brown, green, etc.)	0.85 to 0.95
Yellow and buff brick and stone, firebrick, fire clay	0.85 to 0.95
White or light-cream brick, tile, paint or paper, plaster, whitewash	0.85 to 0.95
Window glass	0.90 to 0.95
Bright aluminum paint; gilt or bronze paint	0.40 to 0.60
Dull brass, copper, or aluminum; galvanized steel; polished iron	0.20 to 0.30
Polished brass, copper, monel metal	0.02 to 0.05
Highly polished aluminum, tin plate, nickel, chromium	0.02 to 0.04

Also useful to know: Moisture transfer

- Moisture transfer is the transfer of water vapor into and through the enclosure (and within building)
- We want to understand and control moisture transfer because unwanted moisture can:
 - Increase latent heating/cooling load
 - Cause deterioration of the building enclosure
 - Create conditions amenable to mold growth



Moisture transfer

- From high temperature to low temperature
 - Driven by thermal gradient
- From high humidity to low humidity
 - Driven by concentration gradient
- Carried with air
 - Driven by air leakage into/through enclosure
- Need to ensure that moist air does not contact and condense on cold elements within the enclosure
 - Chemical deterioration and corrosion
 - Deterioration due to freezing
 - Mold and mildew
 - Staining/damage to interior finishes

Any questions?



Course project instructions

- Project objective:
 - to deepen your familiarity on contemporary indoor climate issues and trends, as well as to encourage you to think about this topic in a broader scientific and societal context, introduce you to the writings of leading experts in the field, and give you practice of oral presentation of short, interesting and visually stimulating slides
- One important deliverable:
 - Oral presentation on the same selected topic (**due 12th or 19th December**) + PDF of the slides (**due 20th December**)
 - There used to be a blog post of a selected topic as an additional deliverable but not anymore

Course project instructions

- You are expected to address at least these points:
 - Title and authors/presenters
 - Motivation and process - Why did you select this topic and how did you find the relevant literature
 - Introduction - Facts about the topic selected (e.g., specific air pollutant)
 - Technical challenges including the effect on humans and influencing factors in buildings
 - Remedial actions - What can we do to improve the situation?
 - Conclusions
 - References
- You will be working in groups of **6-7 students**
 - **10 groups of 6 students + 2 groups of 7 students**
 - I will let you choose the group members
 - You can already start thinking about it
 - See next slide to fill an online form and define groups
 - Each of you is expected to contribute equally to the project effort

Course project topics (see syllabus)

- Importance of Building Massing and Orientation for Indoor Climate
- Thermal Resistance of Building Façade and Indoor Climate
- How Has Architectural Evolution Impacted Indoor Climate?
- Passive versus Active: What Matters More for Securing Good Indoor Climate?
- Air Humidity and Indoor Air Quality
- Impact of Indoor Air Quality on Human Productivity
- Thermal Comfort and Human Productivity
- Impact of Indoor Climate on Human Health
- Influence of Indoor Environment on Sleep Quality
- Human Productivity and Energy Use – Are These in Conflict?
- How will Climate Change Impact Indoor Climate?
- Role of Occupant Behavior on Indoor Climate Control
- Indoor Particles: Sources & Exposure
- Why does Mold Grow and How to Remediate it?
- How to Prevent Condensation in Buildings?
- Overheating of Buildings: Why we Should Tackle Overheating Early in the Design Process?
- Cooling of Buildings Without Air-Conditioning: Feasible or Not?
- Review of Post Occupancy Evaluation (POE) Tools
- Methods to Assess Indoor Climate: Pros and Cons
- IoT and Low-Cost Air Quality Sensors - Is this the future?
- Do Green Buildings Have Better Indoor Climate?
- Mechanical or Natural Ventilation?
- Air Infiltration in Buildings: A Friend or a Foe?
- Novel Ventilation Strategies for Commercial Buildings
- Emerging HVAC Filtration and Air Cleaning Technologies
- Role of Indoor Climate in Combating the Spread of Airborne Virus
- Personalized Ventilation – Is This a Future?
- Strategies to Achieve Thermal Comfort for All – How Well Can We Engineer It?

Topic selection due : 03 October 2024

- You will provide the full name of students from your group and the name of the proposed (selected) topic this

online form:

https://docs.google.com/forms/d/e/1FAIpQLSffWYFmHJnDxYZVnNC7zrONhcHzSPx8z4bYyOeak6dv-2hVEXQ/viewform?usp=pp_url

- Otherwise, I will assign the student members and the topic

Course project instructions

- General requirements on oral presentation:
 - All images, text and graphics must be clear and legible (no blurry images).
 - All images, graphics, data, quotes, etc. that you did not create yourself must be properly cited.
 - Your group's presentation has a 12-minute time limit. This will be followed by a short Q&A session.
 - All work must be submitted (by 20th Dec) in PDF form via email on time for full credit.
 - The file should be named according to the following convention:
GroupX_Title of the presentation.
- Additional information in the course syllabus

Any questions?



Next time...

- Human thermal comfort:
 - Thermal comfort fundamentals
 - Human body heat balance
 - Factors affecting thermal comfort
 - Local thermal discomfort
 - Quiz time



(Source: NY Times)