Advanced Residential Building Science

- Introduction to HAM
  - Heat flows
  - Air flows
  - Moisture flows

- Readings
  - HF: Chapter 2 => 2.1 to 2.3 (review)
  - HF: Chapter 4 => 4.1 to 4.21 (review)
  - HPE: Chapter 1, 2, 3 (intro only)

Introduction to HAM

- Heat Flows
  - Transmission losses/gains
  - Air exchange losses/gains
  - Solar gains
  - Internal gains
- Air Flows
  - Paths
  - Pressures
- Moisture Flows
  - Liquid
    - gravity
    - capillarity
  - Vapor
    - diffusion
    - air transport

Airflow - The Basics

Air Flows in Buildings

- Simple in concept, but very challenging in practice!
- For air to move from one location to another there must be a pathway (or hole) and a pressure
- In fixed volume buildings, air in must equal air out

Airflow - The Basics

Pathways are

- Unintentional
  - leaks and holes
- Intentional
  - windows & doors
  - ports & ducts

Airflow - The Basics

Pressures

- Natural
  - wind
  - stack
- Mechanical
  - combustion venting
  - exhaust fans/devices
  - supply fans/devices
  - forced air systems
    - leaks
    - imbalances

Heat - Fundamentals

- Heat *always* goes from hot (more energy) to cold (less energy)

- Modes of Heat Transfer
  - Conduction
  - Convection
  - Radiation

Heat - The Basics

Heat moves through the building envelope in two distinct ways:

- Transmission losses/gains
  - through the opaque ceilings, walls, floors
  - through windows and doors
- Air exchange losses/gains
  - infiltration & exfiltration
  - exhaust devices
  - combustion equipment
  - ventilation

Heat - The Basics

Envelope Losses/Gains (Loads)

- Transmission
- Air exchange
- Solar gains
- Internal gains

Heat - The Basics

Loads vs. Purchased Energy

– Building load comparisons
  - heating
  - cooling

– The changing role of
  - solar gains
  - internal gains

Basics of Heat Loss/Gain

- U-Value
  - The U-value of a material refers to how well the material will conduct heat (energy)
  - It is the transfer of heat, expressed in
    - Btu/hr-sq.ft.-^{o}F
- R-value
  - The R-value of a material refers to resistance to the flow of heat (energy) for that material
  - It is resistance to heat flow, expressed in
    - hr-sq.ft.-^{o}F/Btu

Basics of Heat Loss/Gain

R-values and U-values are reciprocal. The relationship between U-values and R-values can be shown mathematically like this:

U-value = 1/R-value

and

R-value = 1/U-value

Basics of Heat Loss/Gain

Using the appropriate formulas, we can calculate the heat (energy) losses from a building

- There is a calculation to find heat loss through the building envelope
  - we call these **transmission losses**
- There is a separate calculation to find heat loss from air movement in and out of the building
  - we call these **air exchange losses**

Basics of Heat Loss/Gain

Heat Loss Calculation: Transmission

Rate of Heat Loss = U-value x A x ΔT

Where the rate of heat loss is defined as U and

A = area (square feet)

ΔT = temperature difference

U-value = conductance (Btu/hr-sq.ft.-°F)

Note: The rate of heat loss will be in Btu/hr

Basics of Heat Loss/Gain

Heat Loss Calculation: Air Infiltration

Rate of Heat Loss $= 0.018 \times \text{cfm} \times 60 \times \Delta T$

or $= 0.018 \times \text{ACH} \times \text{volume} \times \Delta T$

where:

ΔT = temperature difference
cfm = cubic feet per minute
ACH = air changes per hour
0.018 = the amount of heat (in Btus) it takes to heat 1 cu.ft. of air 1 ^{o}F

Note. The rate of heat loss is in Btu/hr

Moisture - Overview

- States of moisture
  - Solid
  - Liquid
  - Gas
  - Adsorbed
- Moisture transfer
  - Liquid
  - Vapor
- Wetting vs. Drying

Moisture - The Basics

Moisture States:

Solid

Liquid (Absorbed)

Vapor (Adsorbed)

Moisture States - Solid

Ice is generally not an issue in residential construction, except for

- wind-driven snow in attics
- attic frost
- water entry resulting from ice dams
- freeze-thaw action in absorbent materials

Moisture States - Liquid

Liquid water sources and transport are usually the most damaging in residential construction, both above and below grade, and can cause

- initiation of biological deterioration
- initiation of mold/mildew growth
- staining, leaching, efflorescence
- dimensional changes in materials
- enhanced freeze-thaw damage

Moisture States - Vapor

- Water vapor will rarely create a problem as long as it stays in the vapor state

- However…
  - it frequently contributes to durability and indoor air quality problems when it migrates and condenses on susceptible materials
  - it can raise the moisture content of materials by adsorption and cause dimensional changes
  - at very high relative humidity it can sustain mold growth

Moisture States - Vapor

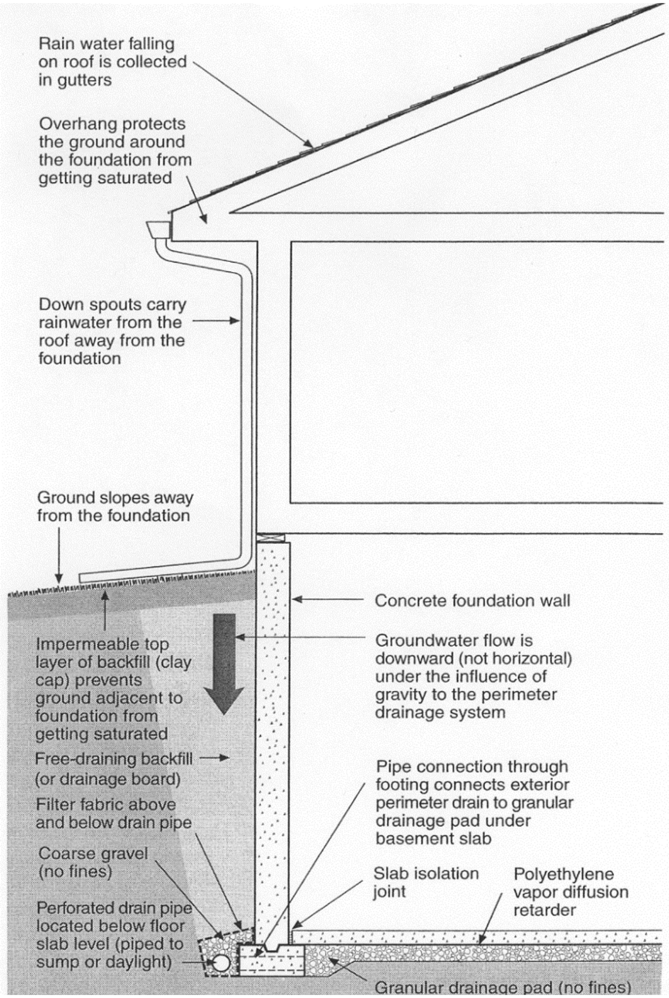
But, remember….

– Vapor drying is the main method of removing moisture from materials

Moisture Transport - Liquid

Gravity (Bulk Water)

- Above Grade
  - roof leaks
  - window/door leaks
  - wall penetrations
  - saturated materials
- Below Grade
  - surface drainage
  - saturated soils



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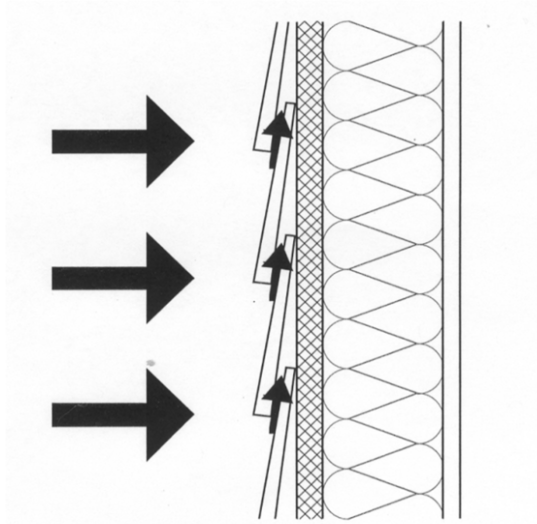
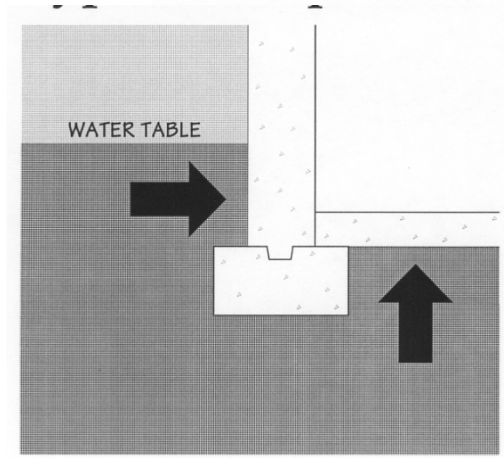
Moisture Transport - Liquid

Pressure Driven Flow

- Above grade
  - wind-driven rain



- Below grade
  - rising water table



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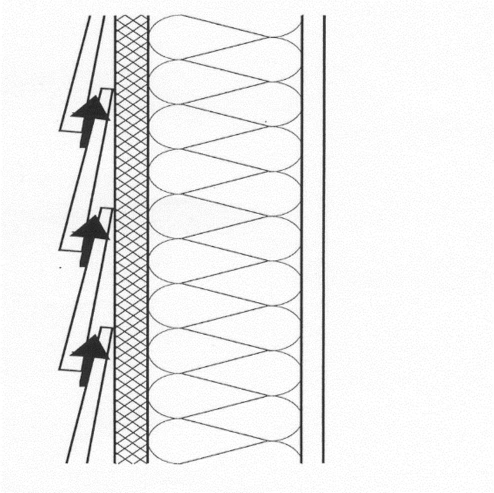
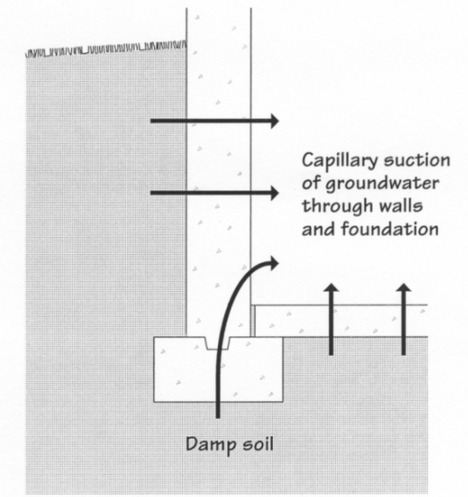
Moisture Transport - Liquid

Capillary Action

- Above grade
  - seams/joints
  - flashing



- Below grade
  - soils
  - footing/foundation
  - slab



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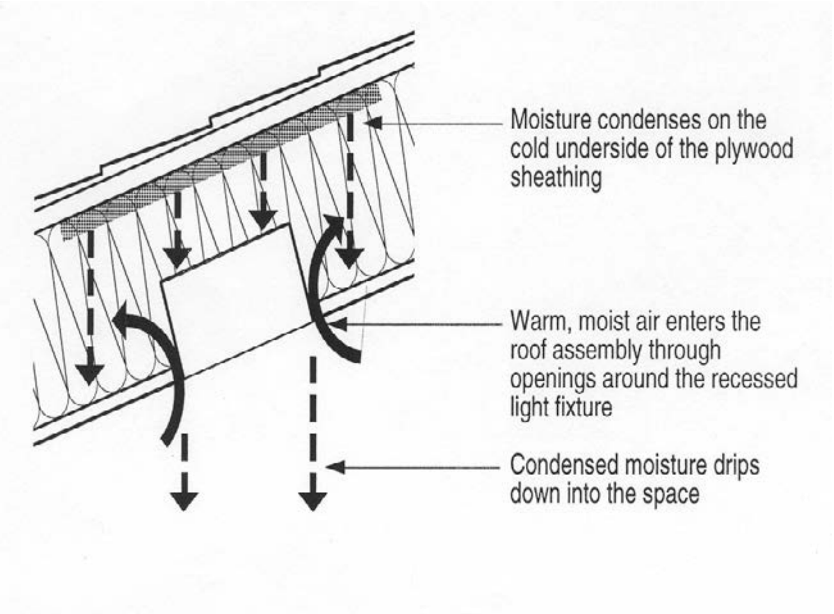
Moisture Transport - Vapor

Air Flow

– Above grade
  - interior/exterior moisture
  - air barrier integrity
  - indoor-outdoor pressures
– Below Grade
  - interior & soil moisture
  - air barrier integrity
  - basement-outdoor pressures



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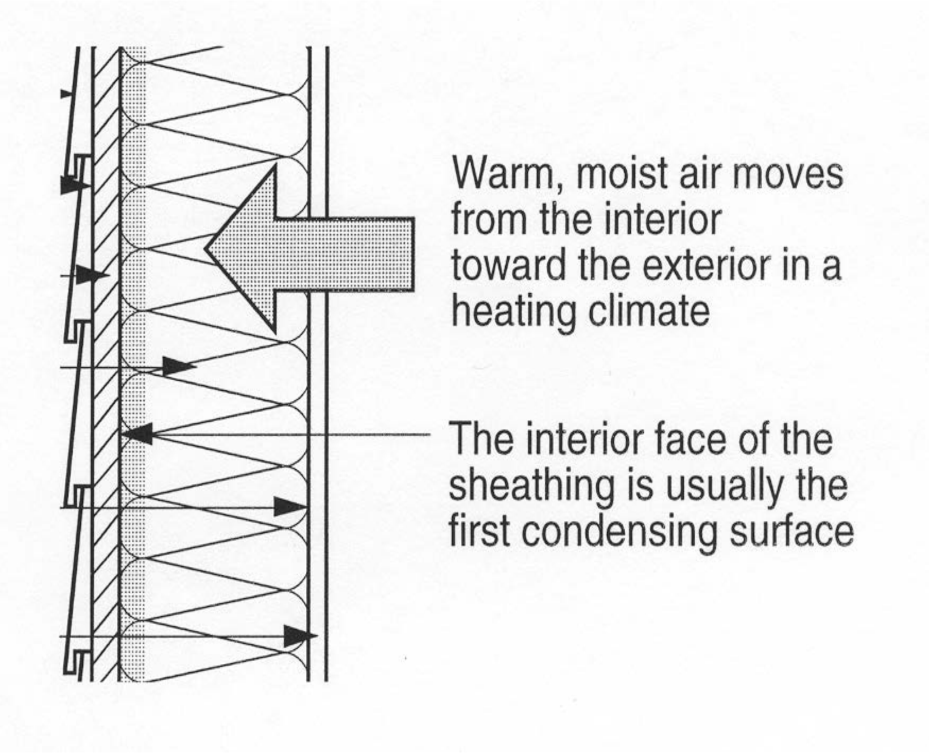
Moisture Transport - Vapor

Diffusion

- Above grade
  - vapor pressure gradient
    - outward in heating
    - inward in cooling
  - permeability
- Below grade
  - vapor pressure gradient
    - lower wall and slab is usually inward
    - upper wall is similar to above grade
  - permeability



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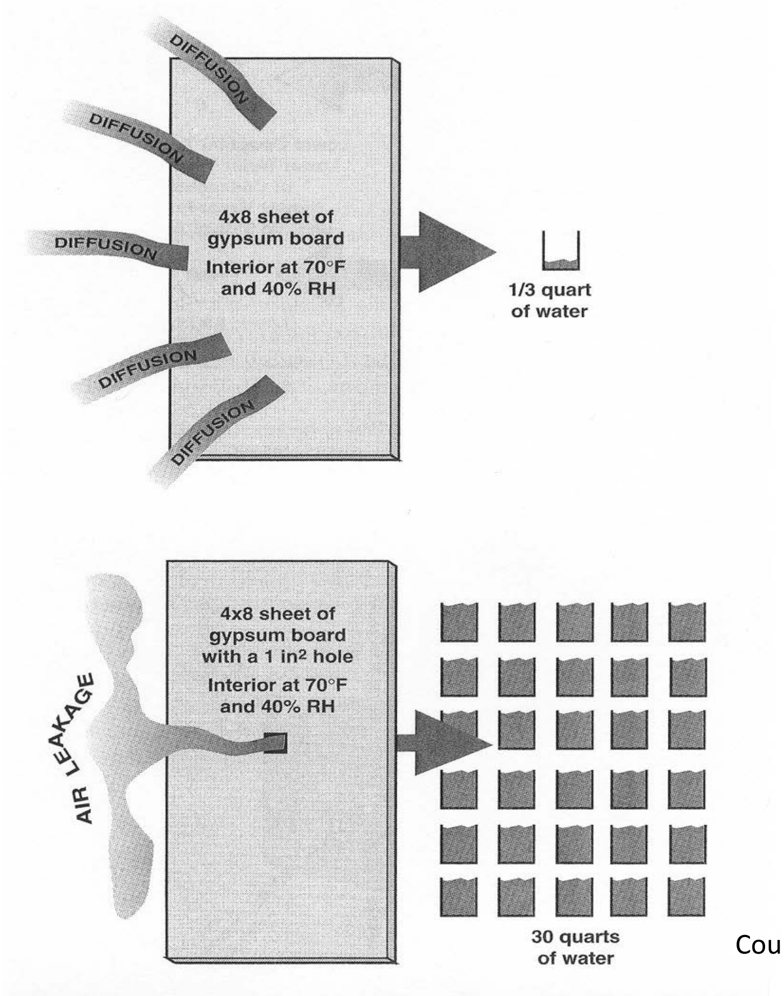
Moisture Transport - Vapor



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Moisture Control - General

Over some critical period

- drying must exceed wetting
- material storage provides the buffer

Moisture - Storage

Storage as a Buffer

- Because a perfect envelope is not realistic, wetting will occur
- Ample storage must be provided until drying can be completed
  - concrete/masonry walls provide a lot of storage
    - original EIFS was over mass walls and it worked
  - steel frame and fiberglass provide almost no storage
  - wood framing and sheathing provide limited storage
  - some evidence that cellulose board or insulation can act as a hygric buffer for short wetting periods

Remember, water stored (adsorbed or absorbed) must leave as a vapor!

Indoor Air Quality - Fundamentals

- Indoor pollutant concentration is a function of …
  - source strength (source type, emissions rate, transport)
  - removal rate (ventilation, filtration, diffusion, sinks)

- Indoor air quality has been demonstrated to be many times worse than outdoor air quality

Indoor Air Quality - The Basics

IAQ and Health

- Health impacts
  - Acute
  - Chronic
- Occupant sensitivities
  - Age
  - General health
  - Exposure
    - Dose
    - Duration

Indoor Air Quality - The Basics

- External
  - Outdoor air
  - Attached garages
  - Loading docks
  - Soil gas
- Internal
  - Building materials
  - Combustion equipment
  - Occupant
  - Occupant activities
    - Cooking
    - Cleaning
    - Hobbies
  - Furnishings
  - Mold and other biologicals

Indoor Air Quality - The Basics

Pollutant Avoidance Strategies

- Elimination
  - don’t bring it in
  - remove it
- Encapsulation
  - seal it (another material or paint, varnish, sealer)

Indoor Air Quality - The Basics

Pollution Removal Strategies

- Point source removal
  - dedicated ventilation (bath fan, kitchen hood, etc)
  - spot filtration (free standing unit)
- General pollutant removal
  - whole house ventilation
  - general filtration (via air handling system)

Building Science Review

- Key Building Science Principles
  - Heat goes from _____ to _____ .
  - Water vapor goes from _____ to _____ .
  - Water vapor goes from _____ to _____ .
  - Air in _____ _____ air out (and vice versa).
  - Air must have a _____ and a _____ to flow.
  - ____ the rain (and the soil)
  - Most of the action is at _____ and _____ .
  - Gas concentration (pollutants, water vapor, etc.) is a function of
    _______ _______ and _______ _______ .

Building Science Review

In the end..

______ , ______ , and ______ flows will drive the performance of the system!

Building Science - Applications

You are thinking about putting carpet on your basement slab…

- Good idea or bad idea?
- What might happen?
- Can it be done?

Building Science - Applications

You are thinking it might be a good idea to replace your old furnace with a high-efficiency sealed combustion model….

- Good idea or bad idea?
- What might happen?
- Can it be done?

Building Science - Applications

You are remodeling your kitchen and thought it might be nice to add a downdraft range vent….

– Good idea or bad idea?

– What might happen?

– Can it be done?

Building Science - Applications

You are suspicious that you water heater is not venting properly so you decide to add a combustion air duct to the outdoors….

– Good idea or bad idea?

– What might happen?

– Can it be done?

Building Science - Applications

Water is dripping off your windows in winter and you've been told you simply need to add mechanical ventilation….

- Good idea or bad idea?
- What might happen?
- Can it be done?

Building Science - Applications

You decided to remodel the basement and want to add interior insulation to the block walls….

- Good idea or bad idea?
- What might happen?
- Can it be done?

In Summary

Questions and Discussion

Preview for Next Class

- Intro to Building Enclosures (Envelope)
  - Built facilities
  - Building enclosure functions
- Thermal Comfort
  - Interior design conditions

- Readings
  - HPE Chapter 2 & 3 (intro)
  - HF: Chapter 9.1 to 9.23

Building Science Principles

- Heat goes from warm to cold
- Water vapor goes from more to less
- Water vapor goes from warm to cold
- Air in must equal air out (and vice versa)
- Airflow requires pressure and a path
- Drain the rain (and the soil)
- Most of the action is at surfaces and connections
- Gas concentration (pollutants, water vapor, etc.) is a function of source strength and removal rate (ventilation)

=> Heat, air, and moisture flows drive performance!