The HERS Associate and Taking the Performance Path

Module 1 – Fundamentals of Building Science

Presented by:
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I wonder if they have beer?

Jeez, what a nerd!
Introductions

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About Southface

• Building a Regenerative Economy,
  Responsible Resource Use & Social Equity
  Through a Healthy Built Environment for All
  www.southface.org
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Module Learning Objectives – Building Science Fundamentals

- Understand the concept of houses are systems
- Master Heat flow
- Appreciate Air movement
- Comprehend Moisture transport
- Learn from real world application
The house as a system

A house is a system made up of interrelated parts:
- The building thermal envelope
- The weather barrier
- Space conditioning
- Ventilation
- Lighting & appliances & plumbing
- The site and neighboring homes

- All efficiency measures should take occupants into account (e.g., air sealing & ventilation)

Building Science:

- Employ scientific principles from a variety of fields that govern building performance
- Optimize building performance and understand, predict, prevent and correct building failures
- Systems approach to houses
- Physics of:
  - Heat: Flows from hot to cold
  - Air: Flows from high pressure to low
  - Moisture: Flows from wet to dry (liquid and vapor)

A. Hot-Humid
B. Mixed-Humid
C. Cold & Colder
D. Hot-Dry
E. Mixed-Dry
F. Marine
Occupants – Question 1

In your opinion, how much impact do the occupants have on building performance?

• A. < 10%
• B. Between 10 & 15%
• C. I don’t know but I think it’s a lot

Building Science: Heat transfer

• Heat is a form of energy
• Heat moves from hot to cold
• 3 methods of heat transfer:
  • **Radiation:**
    Heat emits from a hot surface or hot object, e.g. hot coals
  • **Conduction:**
    Heat moves through a material by contact, e.g. the grill grates
  • **Convection:**
    Heat energy carried by a fluid, e.g. the air inside the covered grill
Heat transfer: Radiation

• **Radiation** is the movement of heat from a hot surface to a cooler surface with nothing solid or opaque in between.
Mean radiant temperature

- When the surfaces in the home (walls, floors, ceilings, windows, and doors), are different than the room air temperature, additional body heat can be lost or gained through radiation.
- This can have a major impact on comfort

\[(T_h^4 - T_l^4) = (660^4 - 550^4) = (190\text{Billion} - 91\text{Billion}) = 100\text{Billion}\]

Heat transfer: Conduction

- **Conduction** is heat flowing through a solid material (insulation slows conduction)
Heat transfer: Convection

**Convection** is the transfer of heat caused by the movement of a fluid, like water or air (air barriers slow convection)

Convective Loop

- Air movement due to temperature and pressure gradients
- Air rises along warm surface and falls along cold surface
- Creates circular movement of air within enclosed space (wall cavity, band between floors, even a room within living space!)
- Increases heat flow and can reduce insulation effectiveness
Question 2

On the following slide, a section of an attic on a hot afternoon is featured. Describe the dominant type of heat transfer for each segment described. Answer choices:

- Conduction (solid)
- Convection (air)
- Radiation (surfaces)

Knowledge Check

Heat Transfer Problem – Question 2

Your Choices:
- Radiation
- Conduction
- Convection

1 → 2 = __________

2 → 3 = __________

3 → 4 = __________

5 → 6 → 7 = __________
Spray foam rooflines

There are multiple ways of defining the building thermal envelope.
What’s the advantage when a home’s envelope is defined by the roof, not the flat ceiling?

Thermal Boundary

• Limits heat transfer between inside and outside.
• Identified by the presence of insulation.
• The location of insulation in relation to other building components is critical to its effectiveness.
• Even small areas of missing insulation are very important.
• Voids of 7% can reduce effective R-value by half.

Graphic developed for the US DOE WAP Standardized Curriculum
Building Thermal Envelope

Example 1: Attic, Conditioned space, Garage, Basement/vented crawl space.

Example 2: Vaulted conditioned space, Garage, Important air sealing location, Basement (conditioned or indirectly-conditioned).

Example 3: Conditioned space, Indirectly-conditioned space.

- Although these three homes look identical from the outside, each has defined the building thermal envelope differently.

Heat Flow Calculations
Conduction Heat Flow Calculations

• Heat transfer through a solid object: the formula for calculating transmission heat loss is:

\[ q = U \times A \times \Delta T \]

• \( q \) = heat flow (Btu/hr)
• \( U \) = inverse of R-Value \([U=1/R, \; R=1/U]\) (Btu/hr ft\(^2\)°F)
  
  \( U \) is referred to as the Conductance or Thermal Transmittance
• \( A \) = area (square feet)
• \( \Delta T \) = temperature difference across component (°F)

Conduction Example

• Low R-value (R-5)
  
  \( (1/5) \times 500 \times (70-20) = 5,000 \) Btu/hr

High R-value (R-10)

\( (1/10) \times 500 \times (70-20) = 2,500 \) Btu/hr

Total = 7,500 Btu/hr
### Gross Wall Area Example

- Dimensions: 25' x 15' x 9'
- Walls are R = 13
- Outdoor temperature: 95°F
- Indoor temperature: 75°F

\[ q = U \times A \times \Delta T \]

<table>
<thead>
<tr>
<th>R</th>
<th>U</th>
<th>Area</th>
<th>Delta T</th>
<th>q</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>0.077</td>
<td>360</td>
<td>20</td>
<td>554 Btu/hr</td>
</tr>
</tbody>
</table>

### Net Wall Area Example

- Dimensions: 25' x 15' x 9'
- Walls are R = 13
- Outdoor temperature: 95°F
- Indoor temperature: 75°F
- Door is 20 s.f.
- R = 2

\[ q = U \times A \times \Delta T \]

<table>
<thead>
<tr>
<th>Wall</th>
<th>R</th>
<th>U</th>
<th>Area</th>
<th>Delta T</th>
<th>q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>13</td>
<td>0.077</td>
<td>280</td>
<td>20</td>
<td>4318 Btu/hr</td>
</tr>
<tr>
<td>Door</td>
<td>2</td>
<td>0.5</td>
<td>20</td>
<td>20</td>
<td>2008 Btu/hr</td>
</tr>
<tr>
<td>Window</td>
<td>0.55</td>
<td>60</td>
<td>20</td>
<td>660 Btu/hr</td>
<td></td>
</tr>
</tbody>
</table>

\[ \frac{1}{13} \times 360 \times 20 = 554 \]
Convection Heat Flow

• Heat transfer through a fluid (liquid or gas) – usually air. For air, the formula for calculating convective heat transfer is

\[ q = 1.08 \times \text{CFM} \times \Delta T \] = convective heat flow (Btu/hr)

• CFM = Cubic Feet per Minute of air being transported
• \( \Delta T \) = temperature difference of entering air and ambient air (°F)

Example:
A supply fan delivers 50 cfm of OA into a 75°F home when the ambient is 90°F. Sensible heat added is \[ q = 1.08 \times 50 \times (15) = 810 \text{ Btu/hr} \]

Conduction - Question 3

• Which of these is NOT needed to calculate heat transfer?
  a) Area
  b) Delta T
  c) U-Factor
  d) Material Density

   d) Material Density
Insulation Coverage is Key!

Attic Stairs
Attic pull-down stairs efficiency retrofit

Attic Hatch

Before

After
• Attic scuttle hole efficiency retrofit

• Whole house fan insulated cover efficiency retrofit
Keeping Attics Cool

- Dark, asphalt shingles are excellent solar collectors (unfortunately)
- One option is to reduce the solar gain into an attic by using a less absorptive roofing material such as an ENERGY STAR shingle or metal roof with reflective coating

Radiant Barriers

- All materials give off, or emit, energy by thermal radiation as a result of their temperature.
- Radiant barriers work by reducing heat transfer by thermal radiation between the roof and the rest of the attic.
- According to the Oak Ridge National Lab, radiant barriers can reduce cooling bills by 2-10 percent.
Radiant Barrier Installation

• Radiant barriers can be installed four ways:

  1. Along top chord of truss
  2. Against the roof deck (with an air space)
  3. As part of the roof decking assembly (foil or spray-on product)
  4. On top of ceiling insulation

• RB decking is easiest for new construction
• Perforated products permit the decking to “breath,” allowing the passage of moisture

• Attic catwalk / platform retrofit
• Attic radiant barrier retrofit

Air Leakage
Building Science: Air Movement

- Air moves from high pressure to low
- Air leakage requires
  - A hole or pathway
  - A pressure difference
- 3 forces cause pressure differences:
  - Wind
  - Stack
  - Fans

Air leakage

Air leakage requires two things:

- A hole (we can get rid of these)
- Pressure differences across that hole (we really can’t eliminate these)
  - The bigger the hole or higher the pressure difference, the more airflow.
  - To reduce airflow, we could lower the pressure difference or reduce the number of holes.
Air Leakage

- Airflow is measured in cubic feet per minute, also written as ft³/min, or CFM.
- 1 CFM out = 1 CFM in
- Airflow takes the path of least resistance.
- Air moves from high to low pressure areas.
- Warm air rises, cool air sinks.

Air Leakage: Pressure

Air flow is always from _____ to ______
Flow takes the path of least resistance
Air Leakage

**Ventilation** = Controlled air exchange

**Infiltration** = Air leaking in

**Exfiltration** = Air leaking out

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Air Leakage: Driving Forces

- Three forces create pressure differences in a home:
  - Wind
  - Stack Effect
  - Mechanical Fans
Driving Forces: Wind Effect

Wind creates a positive pressure on the windward side of the building. As it flows past, it creates a negative pressure on the leeward side.

Driving Forces: Stack effect

Warmer air rises and escapes out of the top of the house... ...which creates a suction that pulls in outside air at the bottom of the house.
Stack effect

- Function of
  - Building Height
  - Temperature difference

Driving Forces: Mechanical effect

Combustion Equipment & Exhaust Fans
Fans—Driving Forces for Infiltration

<table>
<thead>
<tr>
<th>Device</th>
<th>CFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bath</td>
<td>50</td>
</tr>
<tr>
<td>Range hood</td>
<td>150</td>
</tr>
<tr>
<td>Downdraft hood</td>
<td>500</td>
</tr>
<tr>
<td>&quot;Commercial&quot; Hood</td>
<td>1500</td>
</tr>
<tr>
<td>Dryer</td>
<td>200</td>
</tr>
<tr>
<td>Air Handler / ton</td>
<td>400</td>
</tr>
</tbody>
</table>

Make up air for large kitchen hoods

Details

- Motorized damper for make up air (not shown)
- Wire damper to open when fan operates

Figure 2: Capture the Effluent. The first thing we make sure is that the exhaust hood actually works to capture the effluent. The hood must overhang the cooking surface big-time. The absolute best approach is to use a backsplash hood with side panels and large overhangs on both sides and the front. Backsplash hoods can typically use 30% less exhaust to capture bad stuff compared to other hoods. Side panels can get you another 30% improvement. Note the direct makeup air using a modified backwall approach such that this makeup air is introduced at floor level. This direct makeup air introduced at floor level should never provide more than 60% to 70% of the hood exhaust. Why? Ah, we need a zone of negative pressure around the cooking surface. You don’t want to push the bad stuff; you want to pull the bad stuff.

http://www.youtube.com/watch?v=NsV9MB9bJeE
Driving Forces: mechanical effect

**Duct Leakage**
Duct leakage can create positive and negative pressures in different areas of the house.

The pressures associated with duct leaks can be larger and more significant because the driving force is stronger.
Driving Forces: mechanical effect

Room Pressure Imbalances

Master Bedroom
Utility Room
Kitchen
Whole-house return in hallway
Living Room
Bedroom
Bath

Design for Proper Return Path

Install sheet metal duct inside wall cavity

Grille located high in wall on bedroom side to avoid blockage by furniture

Cavity is sealed tight, drywall glued to studs and plates on both sides

Grille located low in wall on hallway side

Graphic developed for the US DOE WAP Standardized Curricula
Driving Forces: mechanical effect

• Use a Blower Door as a Controlled Driving Force

• Using the blower door depressurizes the house, drawing air through all the holes between inside and outside.

What is a Pascal?

A Pascal is the unit of pressure in the International System of Units. Named after French scientist Blaise Pascal (1623-1662), it is abbreviated Pa.

1 Pa = 1 Newton of force applied over 1 square meter.

50 Pascals (0.2” w.c.) is approximately the same as a 20 mph wind blowing on all six surfaces of a house.

1 inch of water column = 248 Pascals
Blower Door – Question 4

A blower door is used to depressurize a house to -50 Pa. While the fan is running, the water in a sink’s P-trap will...

a. Be pushed downward by 0.2”
b. Stay the same – it wouldn’t move
c. Rise up (towards the house) by 0.2”
d. Rise up (towards the house) by 1”

ANSWER: c. Water in trap will rise up 0.2” towards the house

Managing Water Vapor

- Another reason to limit air flow in a home is to reduce moisture intrusion.
- Even a small hole can allow a large amount of water vapor into the building.
Air Barrier Installation

Air Barrier

- Limits airflow between inside and outside.
- The IECC defines the air barrier as materials assembled and joined together to limit air leakage.
- Should be collocated with the thermal boundary
- New homes – wall sheathing
  Old homes – wall interior finish
Air Seal Exterior Sheathing

- No unsealed gaps
- Tape or caulk sheathing seams / penetrations
- Caulk or glue to framing

- Seal to framing, top plate, bottom plate
- Seal window & door openings
- Seal all penetrations

Shower/Tub on Exterior Wall

Photo courtesy of Anthony Cox
Shower/Tub on Insulated Wall

• Coordinate with your subcontractors so that insulation and air sealing details are not missed before it is too late!

Plumbing and wiring

Install insulation and sealed air barrier behind tub (required)
Cantilevered floor

Didn’t Install Blocking
(Just Covered Over With Insulation)

Fiberglass does not stop airflow!
Garage Separation

Cantilevered floor
The blocking above the bearing wall helps to define the home’s air barrier, so each piece of blocking needs to be sealed at the perimeter with caulk or canned spray foam. As long as both layers of rigid foam are installed with attention to airtightness, this type of cantilevered floor performs well.

Diagram courtesy of Green Building Advisor

1½-in. rigid insulation

Continuous bead of sealant

Cover foam with plywood, fiber cement, or other solid soffit material.

Framing Blocked and Sealed
Penetrations Sealed

Garage on Other Side of Wall

Good!!!
Cantilever support wall

Duct Shafts

Cap chases with rigid material and seal tight around ducts or flue pipes
Duct Shafts

- Sealed with foam
- Chase capped with OSB material
- Penetrations in Top Plate Sealed

Recessed Lights

- Standard Can Light
- Airtight and IC Rated

- All recessed luminaires shall be labeled as having an air leakage rate not more than 2.0 cfm tested at 75 pa
- All recessed luminaires shall be sealed with a gasket or caulk between the housing and the interior wall or ceiling covering
Air Sealing After Drywall

- Top plate to drywall (interior wall cavities often connect to attic)
- HVAC, plumbing and electrical penetrations

Sill (bottom) plate

Bottom Plate Sealed (but batt installation fails!)
Sill (bottom) plate

- Dirty carpet on **exterior** wall indicates leak at wall sill plate
- On **interior** wall indicates wall leaking to attic

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**Air Sealing 101 - No BIG Holes!**

- First, cover with sheet material and seal
- Then insulate
Air Sealing - Tubs

Looking for Leaks

Plumbing pipe and dirty insulation are clues... that an attic bypass is allowing air flow through the insulation.

Photo courtesy of the US Department of Energy
Sealing Attic penetrations

Changes in Ceiling Height

The interior wall cavities act as a chimney that robs the house of heat and conditioned air.
Changes in Ceiling Height

Sealing Attic Kneewalls

An attic kneewall has unconditioned attic space on one side and conditioned space on the other
ATTIC KNEEWALLS

(Want higher R-value with attic- side air barrier)

No Blocking under Attic Kneewalls
KNEEWALL – PICS SHOWS NEED FOR BLOCKING & SHEATHING

Proper Blocking under Attic Kneewalls
Sealing ducts with mastic

Sealing wall hvac boots
Building Science: Moisture transport

- Moisture moves from wet to dry
- Liquid water flows downhill (but can be wicked up)
- Water vapor diffuses from high concentration to lower concentration
- Air movement can carry lots of humidity
Forms of Moisture flow

<table>
<thead>
<tr>
<th>LIQUID</th>
<th>VAPOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bulk</strong></td>
<td><strong>Diffusion</strong></td>
</tr>
<tr>
<td>Liquid water (rain,</td>
<td>Molecules of water</td>
</tr>
<tr>
<td>drainage, plumbing</td>
<td>moving through</td>
</tr>
<tr>
<td>leaks)</td>
<td>porous materials</td>
</tr>
<tr>
<td><strong>Capillarity</strong></td>
<td><strong>Infiltration</strong></td>
</tr>
<tr>
<td>Wicking through</td>
<td>Moisture laden air</td>
</tr>
<tr>
<td>porous materials</td>
<td>brought into the</td>
</tr>
<tr>
<td>(concrete, wood,</td>
<td>house</td>
</tr>
<tr>
<td>paper drywall,</td>
<td></td>
</tr>
<tr>
<td>fiberglass and</td>
<td></td>
</tr>
<tr>
<td>cellulose insulation)</td>
<td></td>
</tr>
</tbody>
</table>

Managing Bulk Moisture

- Foundation waterproofing
- Proper site drainage
  - Gutters channel water away from foundation
- Drainage planes with proper flashing in walls allows water to escape (e.g. behind brick)
Encountering Bulk Moisture

Managing Bulk Moisture

Foundation waterproofing
- Plastic under slab
  - Gravel base under plastic
- Waterproofing foundation wall
  - Drainage mat, dimpled with filter, then backfill
- Footing
  - Wrap footing in plastic – tie into other plastic and waterproofing
  - OR waterproof top of footing before stem wall is poured
- Foundation drain tile
  - Adjacent to footing (better than on top)
  - Routed to daylight or sump pump
- Positive exterior drainage
  - Gutters, downspouts, grading slopes away from foundation
Bulk Moisture – foundation waterproofing

- Spray on waterproofing plus drainage board

Dimpled drainage mat with filter

Drainage system

Plastic wrapped beneath footing

Managing Bulk Moisture

- Proper site drainage is crucial
Bulk Moisture Control

- Proper site drainage
  - Swales
  - Positive slope grading
  - French drains
Bulk Moisture Control

• Proper site drainage
  • Swales
  • Positive slope grading
  • French drains
Encountering Water Vapor

Diffusion Through Surface

Both water vapor and air molecules pass through.

Convection Through Holes

Air flow

Both water vapor and air molecules pass through.

Managing Water Vapor

Water Vapor Movement

The measurement of the permeability of a material is its Perm Rating.
Vapor Diffusion Retarders

Appropriate measures for moisture control are essential!

Moisture – Question 5

• Which of these is not one of the four forms of moisture transport?
  1. Bulk
  2. Capillarity
  3. Air Movement
  4. Diffusion
  5. Flux Capacitance

**Flux Capacitance**
Psychrometrics

Moisture: Some Definitions

- **Psychrometrics**: The measurement of water vapor and heat in an air sample
- **Absolute humidity**: The ratio of the mass of water vapor to the mass of dry air in a given volume of air at a given temperature - the amount of moisture in the air (grains)
- **Relative humidity**: is the percent of moisture absorbed in the air compared to the maximum amount possible (the amount of moisture in the air in relation to the amount of moisture the air could hold at that temperature)
- **Dew Point**: The temperature at which water vapor condenses into liquid (related to absolute humidity)
Moisture Vapor content

• Ideal Health & Comfort is ~50% RH at room temperature (~72°F)

• Building decay 100% RH
• Interior Mold RH > 70%
• Dust Mites RH > 50%
• Viruses RH < 40%
• Static electricity, dry sinus RH < 25%

Temperature and Relative Humidity

• Warm air can hold more moisture than cold air
Psychrometric Chart

- As temperature goes up, RH goes down

Room Temperature Example

Find 75°F and 50% Relative Humidity.
Record the grains: _______°F
What is the Dew Point? _______°F
This air is then heated to 90°F. What happens to the relative humidity? _______%
What is the RH? _______%
This air is now cooled to 60°F. What happens to the relative humidity? _______%
What is the relative humidity? _______%
Example Problem – Winter

Find 40°F and 90% Relative Humidity.
Record the grains: 30
What is the Dew Point? 38°F

This air is then heated to 70°F. What happens to the relative humidity? ↓
What is the RH? 28%

This air is now cooled to 38°F. What happens to the relative humidity ↑?

What is the relative humidity? 99%

Summer Temperature Example

Find 80°F and 80% Relative Humidity.
Record the grains: 123
What is the Dew Point? 73°F

This air is then heated to 95°F. What happens to the relative humidity? ↓
What is the RH? 50%

This air is now cooled to 75°F. What happens to the relative humidity? ↑
What is the relative humidity? 95%
Questions 6 - Psychrometrics

“Cold air is very **dry** air”
Which can hold more moisture, warm air or cold air? **warm**
If a cubic foot of air is heated, what happens to the RH? **↓**

If a cubic foot of air is cooled, what happens to the relative humidity? **↑**
Misting 75F water vapor into 75F air will cause the RH to **↑**?
Adding a desiccant to a humid closet will cause the RH to **↓**?

“As temperature goes up,” “RH goes down” “... & vice versa”

Questions 6 – Psychrometrics, cont.

If a cubic foot of air held exactly 1/3 of the water vapor that it theoretically could hold, the relative humidity would be? **33**%

Because a person’s body cools via sweat evaporation, humid air generally feels **less** comfortable in the summer.

Air that is too **dry (cold)** in the winter is uncomfortable and can lead to chapped lips, nosebleeds, and static electricity.

Mold generally starts to grow at **70**% RH
Practical applications

Moisture transport
Drainage Planes and Cladding
Cladding – Brick Veneer

- Water shedding surface
- Gap / air space

Brick Veneer

- Weeps are critical
Rain Screen / Drainage Pane

Housewrap: Details are Critical

“Rain Screen / Drainage Pane”

“Housewrap: Details are Critical”

“Top Sash after trim removed”

“Rotten Header”

“Windows (incorrectly) have flange over housewrap”

“See WRB factsheet for more details”

“The bitterness of poor quality remains long after the sweetness of low price is forgotten” - Benjamin Franklin
Housewrap as a Weather Barrier

Managing Bulk Moisture – flashing

Flashing must be integrated with wall and roof drainage plane surfaces
No Weather Barrier

- Rotted siding
  - Air leakage
  - Wicking

Alternative WR Barriers

- WRB pre-attached to sheathing
Fluid-Applied Weather Resistive Barrier

Retrofit: Lap Siding nailed directly to studs

Plywood on boarded up doorway
Siding Drainage Plane Retrofit

Siding Drainage Plane Retrofit
Install Structural Insulated Sheathing (SIS)

Set Nails in SIS
Seal Seams of SIS

Prep for Furring Strips
3” Insect Screen Before Furring

3/16” PT Furring Strips (with lower end primed)
Aligns with Wall Studs and Covers Top Half of Insect Screen
Bottom of Screen Folded Up & Stapled

Ready for Siding ...
Siding Caulked At Edge, Not At Butt Joints

Floating Butt Joint With Flashing
3/16” Gap Between Siding & WRB

Siding Installation
Siding Drainage Plane Retrofit

Siding Drainage Plane Retrofit
Kitchen hood exhaust penetration

Siding Drainage Plane Retrofit
Constructing a system

Siding Drainage Plane – New Construction
Question 7 Moisture (Setup)

On the following slide, 4 different moisture scenarios are described. Define the likely method of transport.

Answer choices:

- **Bulk** (liquid flow)
- **Capillarity** (liquid wicking)
- **Air Movement** (infiltration humidity)
- **Diffusion** (molecular movement)

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Question 7: Moisture Scenarios

1. A homeowner notes that their house is on a hillside and digs a shallow swale to divert flow around their foundation.

2. After taking a shower, a homeowner runs an exhaust fan for 30 minutes to remove the moisture.

3. A homeowner notes that the bottom 6” of the drywall in the garage has some mold growing on it (even though the plumbing line leak that flooded the garage last month was vacuumed up fairly quickly).

4. A homeowner notes that plastic installed over their crawlspace ground frequently has water droplets underneath it.

Answer choices:

- **Bulk** (liquid flow)
- **Capillarity** (liquid wicking)
- **Air Movement** (humidity)
- **Diffusion** (molecular movement)
Questions?

Thank you!
mikeb@southface.org

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• June 18th - Combustion Safety
• July 16th - HVAC Load Calcs
• Aug 20th - High Performance Design

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