



Kohta Ueno  
**Monuments Builder Group:  
 Top 10 Building Science Problems**  
 September 17, 2018




# Background




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## About BSC


- Massachusetts-based consulting firm
- Founded by Joseph Lstiburek (“Dr. Joe”)
- Forensics
- Design reviews
- Construction admin
- <https://buildingscience.com/>




**Forensic Investigations**  
 BSC began its practice and established its reputation in building science by investigating problems related to the durability and performance of building. Forensic investigations of performance problems such as mold, rot, decay, odors, uncontrolled humidity, and poor indoor air quality remain a critical part of our practice, especially with the increasing complexity of architectural designs and the continuous development of more advanced (and often more moisture sensitive) building materials.




**Building Performance and Enclosure Consulting**  
 BSC provides whole building design assistance in the preliminary design and design development phases, as well as detail review and specific system design through the development of the contract documents. During construction we schedule site visits as needed to observe the installation of mock-ups, specific building systems, and any complicated details, as well as to respond to any unanticipated field conditions or design changes.




**Commercial Architecture**  
 BSC works on commercial projects typically begins with either a forensic investigation of a known problem or with a general building envelope condition survey to determine the areas of the building that may be deteriorating and in need of repair. The field investigation is followed with the development of prioritized repair recommendations, typically utilizing several approaches that clients may select depending on their constraints and preferences.



**Residential Architecture**  
 As a full service architecture firm with a prodigious understanding of building science, material science, and energy efficiency, BSC takes a multi-disciplinary team approach to design comfortable, durable, healthy, and energy efficient buildings. Our work includes both new construction and retrofit projects that start with schematic design and are taken through construction documents, bidding, permitting, construction administration and post-construction monitoring.




**Education and Training**  
 BSC regularly conducts workshops and seminars that cover both fundamental and advanced building science topics. We are frequently invited to present our research in academic and professional conferences across the country. The recent and upcoming seminars and workshops by the BSC team, visit our Events page.



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## Topics

- Stucco problems over OSB (and CMU)
- Sweating mechanicals in vented attics and closets
- Make up air for big kitchen range hoods
- Make up air for big fireplaces
- Building wraps vs fluid applied vs fully adhered vs ZIP/taped sheathings



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## Topics

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- 6. Air leakage, blower doors, and spray foam
- 7. Indoor swimming pools and spas
- 8. Wood floors on concrete slabs
- 9. Ventilation and over ventilation
- 10. HRVs vs ERVs and dehumidifiers



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## Stucco Problems

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## Stucco on Frame Construction

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## Stucco on Frame Failures

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### Stucco on Frame Failures



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### Stucco on Frame Failures



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### Stucco on Frame Failures



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### Adhered Stone ("Lumpy Stucco")



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### Adhered Stone (“Lumpy Stucco”)



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### Adhered Stone (“Lumpy Stucco”)



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### “Perfect Storm” of Stucco Failures

- Change from plywood sheathings to OSB sheathings
- Changes in the properties of building papers and water resistant barriers (WRB's)
- Higher levels of thermal resistance
- Use of interior plastic vapor barriers
- Changes in the properties of stucco renderings



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### OSB Manufacturing



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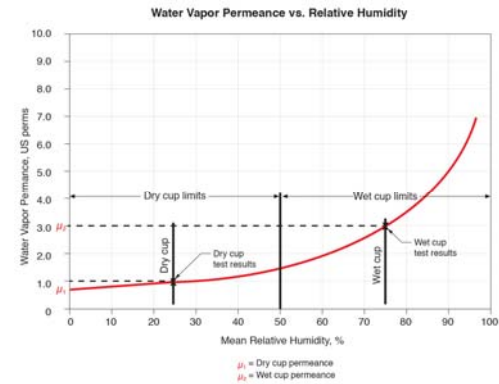
## OSB Manufacturing



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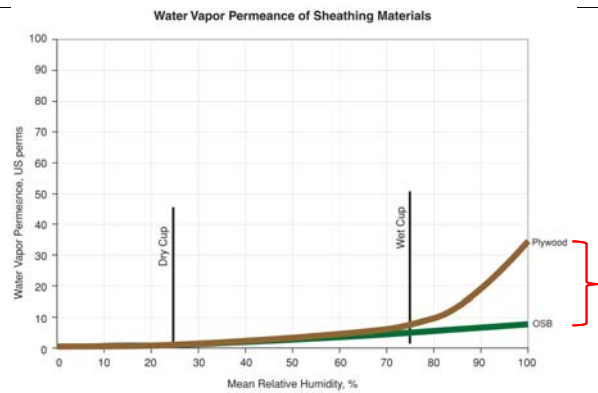
## Vapor Permeance-Dry & Wet Cup



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## Plywood vs. OSB



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## Plywood vs. OSB



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### Water "Lateral Redistribution"

- Plywood: inward, outward, lateral movement

The diagram illustrates a cross-section of a plywood sheathing panel. A large blue arrow labeled "Penetrating Water" points upwards from the bottom center. From this point, multiple blue arrows radiate outwards in all directions (up, down, left, right, and diagonally), indicating the lateral redistribution of water. The top surface of the plywood is labeled "Sheathing".

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### Water "Lateral Redistribution"

- OSB: much less redistribution, inward/outward drying

The diagram illustrates a cross-section of an OSB sheathing panel. A large blue arrow labeled "Penetrating Water" points upwards from the bottom center. From this point, blue arrows primarily point horizontally inward and outward, with fewer arrows pointing vertically or diagonally, indicating less lateral redistribution compared to plywood. The top surface of the OSB is labeled "Sheathing".

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Joseph Lstiburek - Rain Control

### Stucco-to-Paper Bond

The first photograph shows a close-up of a stucco wall with a jagged, broken edge where the stucco has separated from the underlying paper. A hand is pointing to this area. The second photograph shows a man holding up a piece of paper that has been pulled away from a wall, with a dark, wet residue on the paper. The third photograph shows a hand applying a piece of paper to a wall, demonstrating the application process.

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### Stucco on Wood Frame Walls

The diagram shows a cross-section of a wall assembly. On the exterior side, there is a "Flashing" at the base, followed by "Engineered wood sheathing (OSB)". The wall itself consists of a "Timber frame" with "Cavity insulation" between the studs. On the interior side, there is "Interior gypsum li". The exterior finish is labeled as "Three-coat hand-coat stucco rendering" and "Two layers of building paper (concealed barrier)".

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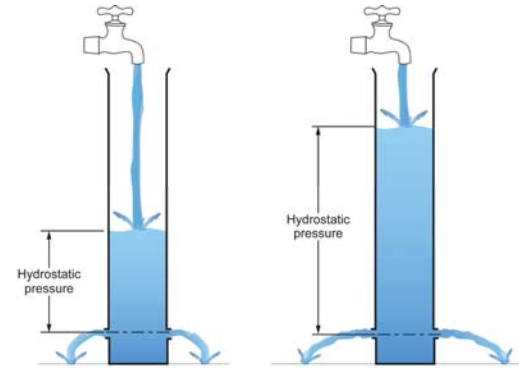
### Paper-Backed Lath



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### Hydrostatic Pressure



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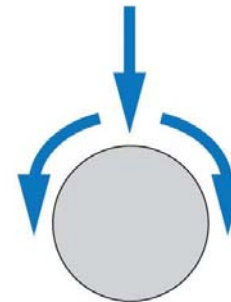
### Hockey Pucks & Hydrostatic Pressure



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### Hockey Pucks & Hydrostatic Pressure



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### Hockey Pucks & Hydrostatic Pressure

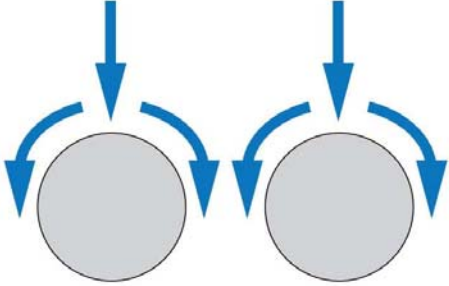


Diagram illustrating hydrostatic pressure using two hockey pucks. Two downward-pointing blue arrows represent the force of water above. From the top of each puck, two curved blue arrows point outwards, representing the lateral expansion of water under pressure.

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### Hockey Pucks & Hydrostatic Pressure

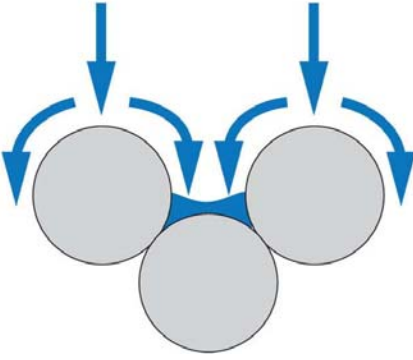



Diagram illustrating hydrostatic pressure using three hockey pucks. Two downward-pointing blue arrows represent the force of water above. From the top of each puck, two curved blue arrows point outwards, representing the lateral expansion of water under pressure.

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### Hockey Pucks & Hydrostatic Pressure



Photograph of a brick wall showing significant mortar erosion and crumbling bricks, illustrating the effects of hydrostatic pressure.

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### Hockey Pucks & Hydrostatic Pressure

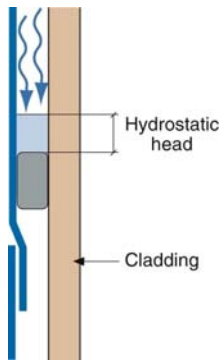
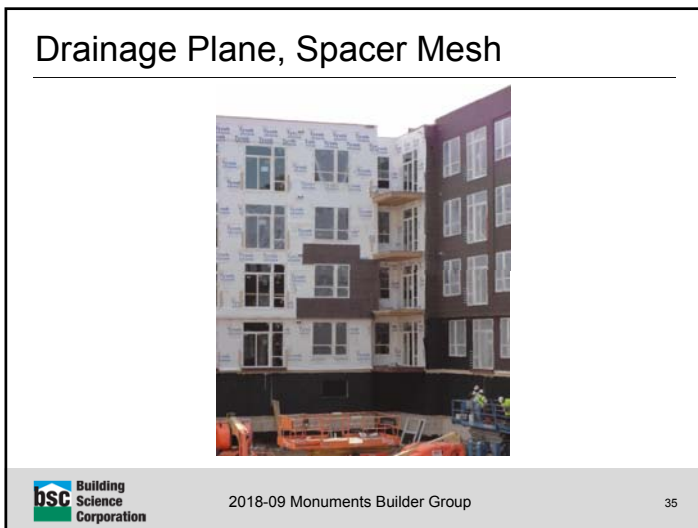
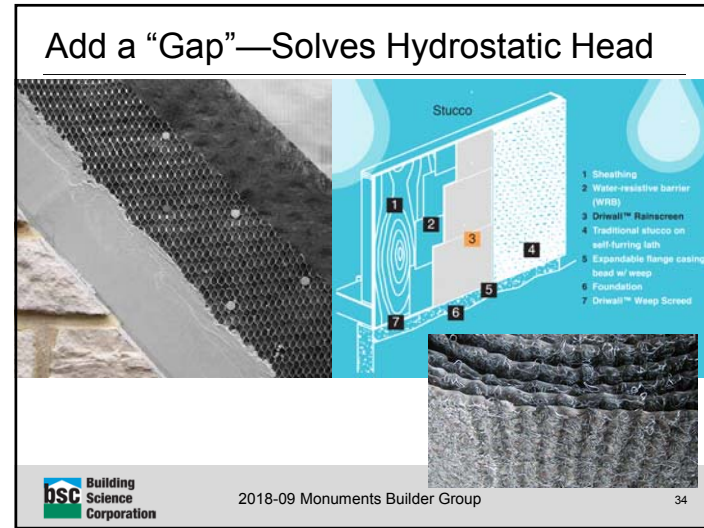
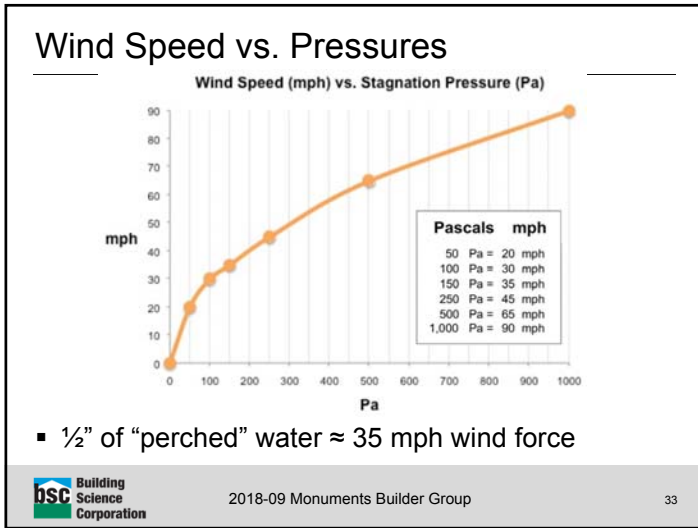


Diagram illustrating hydrostatic pressure on a wall. A vertical blue line with wavy arrows represents water. A horizontal blue line indicates the water level. A vertical brown line represents the wall. A horizontal arrow points from the water level to the wall, labeled "Hydrostatic head". A horizontal arrow points from the wall to the right, labeled "Cladding".

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## Stucco Application



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## Adhered Stone Veneer



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## Stone Veneer Rainscreen Options



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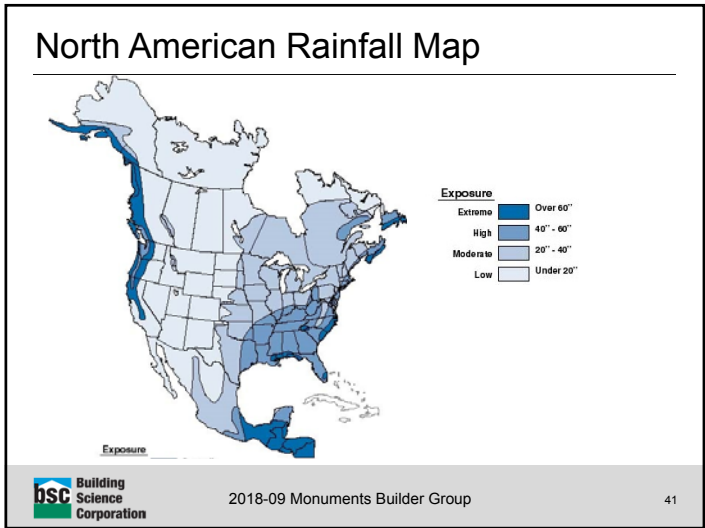
## Stucco Recommendations...

- Provide a 3/8 inch air space behind all stucco in regions where it rains more than 20 inches per year
- Provide a 3/8 inch air space behind all stucco over three stories
- Don't install interior vapor barriers



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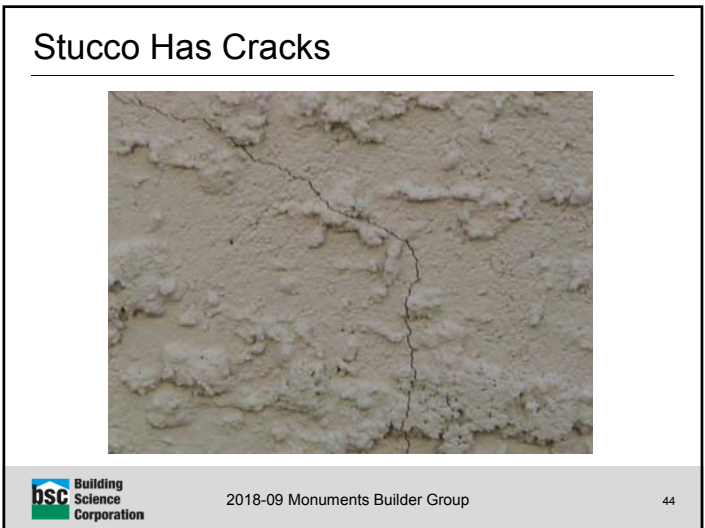
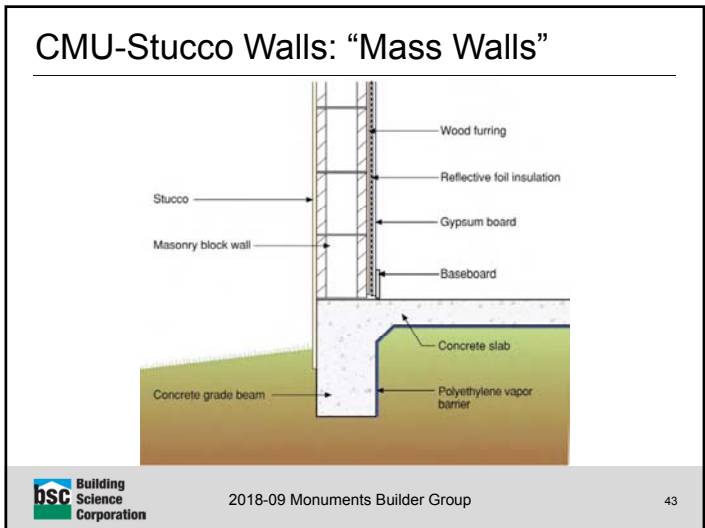


## CMU Wall Stucco

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### Stucco Has Cracks



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### Water Testing (RILEM Tube)



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### Water Testing (Spray Rack)



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### Water Testing (Spray Rack)



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### Boroscope Camera Examination



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### Boroscope Camera Examination



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### Boroscope Camera Examination



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### Water Penetration Through Stucco



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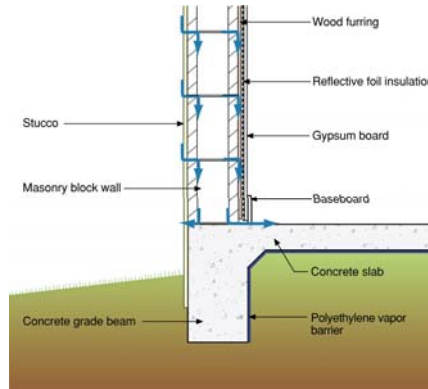
### Water Penetration Through Stucco



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### CMU-Stucco Wall Rain Penetration



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### CMU-Stucco Wall Rain Penetration

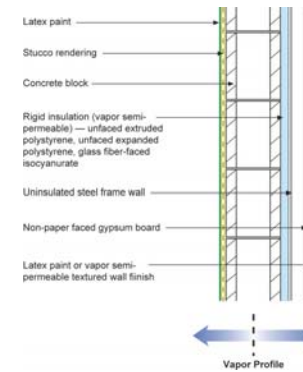
- Water penetrates then cannot dry out



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### Recommended Stucco-CMU Assembly

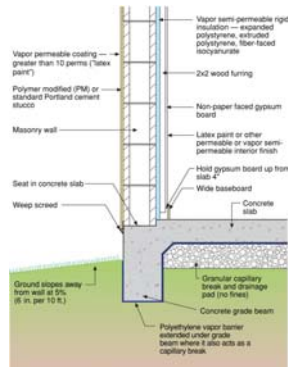


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Joseph Lstiburek

### Recommended Stucco-CMU Assembly

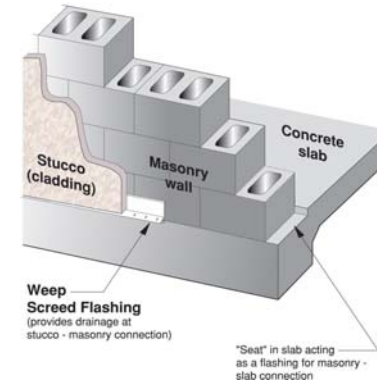


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Joseph Latburek

### Stucco-CMU "Seat" in Slab Edge



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### Stucco-CMU "Seat" in Slab Edge



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### Stucco-CMU Interior XPS Board



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### Frame-to-CMU Horizontal Joint

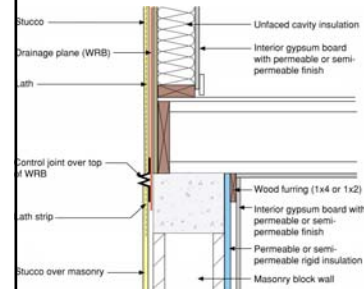


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### Frame-to-CMU Horizontal Joint

- Drained stucco to “mass” stucco wall connection



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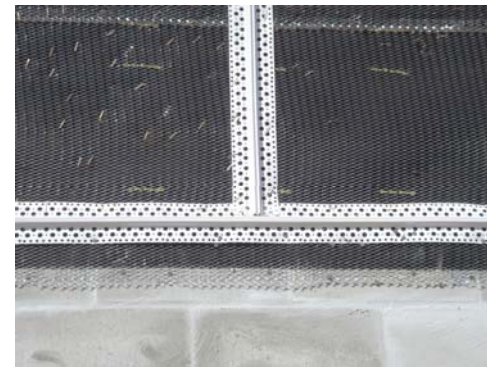
### Frame-to-CMU Horizontal Joint (Old)



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### Frame-to-CMU Horizontal Joint (Old)



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### Frame-to-CMU Horizontal Joint (Old)



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### Frame-to-CMU Horizontal Joint (Old)

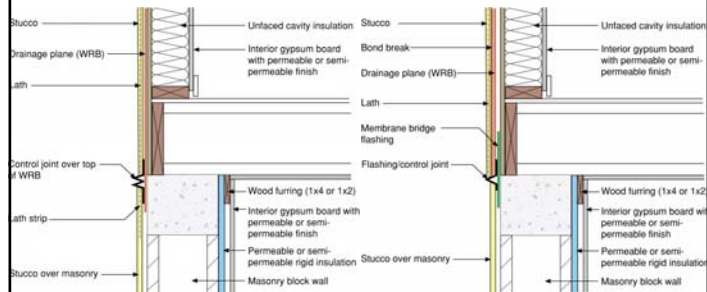


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### Frame-to-CMU Horizontal Joint

- Drained stucco to “mass” stucco wall connection



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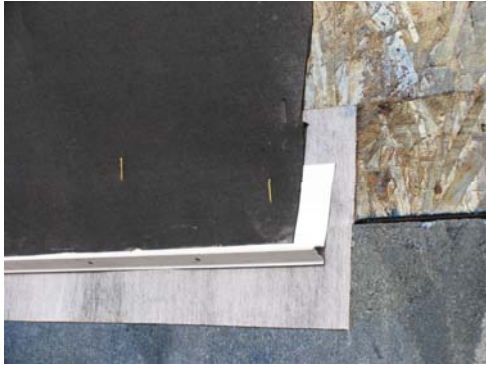
### Frame-to-CMU Horizontal Joint (New)



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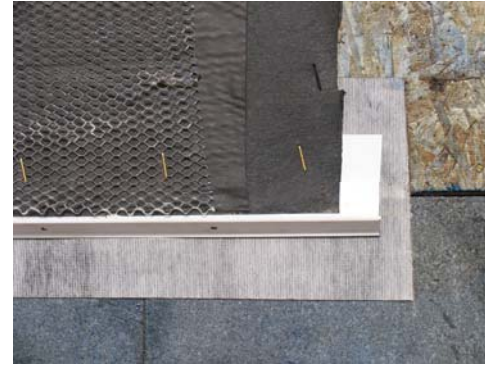
### Frame-to-CMU Horizontal Joint (New)



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### Frame-to-CMU Horizontal Joint (New)



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## Sweating Mechanicals- Vented Attics, Closets



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### Air Handlers in Attics

- Attics operate at outdoor dewpoint
- Hot humid climates-sweating




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### Sweating on Ductwork & Equipment

- Dripping, equipment longevity



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### Sweating on Ductwork & Equipment


- Dripping, mold growth



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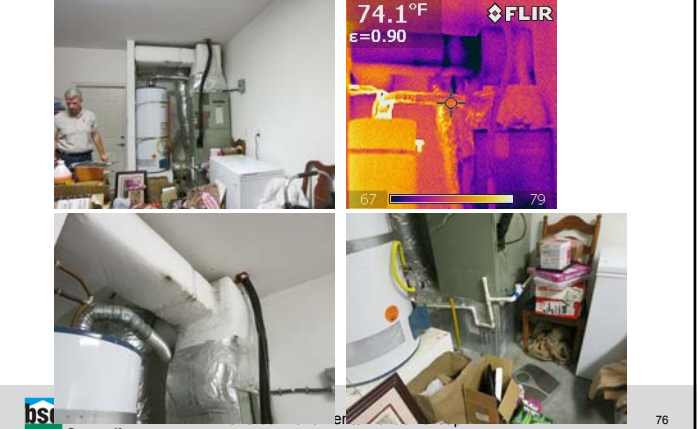
### Air Handlers In Garage/Garage Closet

- Cooler than an attic
- Outdoor dewpoint (often)—combustion air duct?
- Sweating sometimes worse (cooler surfaces)



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### Sweating Problems Worsen?



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### Return Grille (Not Supply Grille)

- Make closet dewpoint lower, but not much colder

Backdrafting and code problems if gas water heater

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### Move Mechanicals Inside?

- Sweating where duct penetrates ceiling
- Same solution as garage mechanical closet
- Insulated mechanical closets (sound isolation) → worse
- With return grille opening, closet will be negative pressure

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### Ceiling Duct Penetration

- Negative pressure will suck out of hot-humid attic
- Not flex... rigid collar best seal

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### “Landlocked” Closets

- Dripping from ceiling
- Better attic insulation, cooler closet ceiling
- “Dewpoint stratification,” little dehumidification

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### “Landlocked” Closets

- Add closet returns
- Undercut doors (return pathway)
- General humidity control measures (more later)



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### No Good Deed Goes Unpunished

- Air handlers inside
- Increase attic insulation
- Better windows
- Reducing cooling loads → cooling runs less → less dehumidification happens → moisture problems
- Higher ventilation rates (codes)
- Supplemental dehumidification: more later


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### Make-Up Air for Big Range Hoods

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### Why Makeup Air?

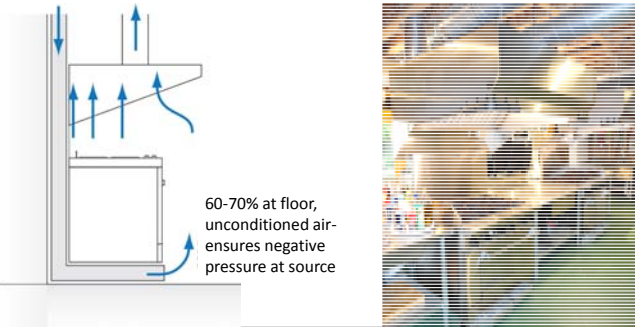
- Building code (M1503.4 Makeup Air Required when > 400 CFM)
- Backdrafting of combustion appliances & fireplaces
- Pull air from garage
- Whistling noises at windows & doors
- Motorized or gravity damper as option?



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### Make-Up Air Floor Level Supply

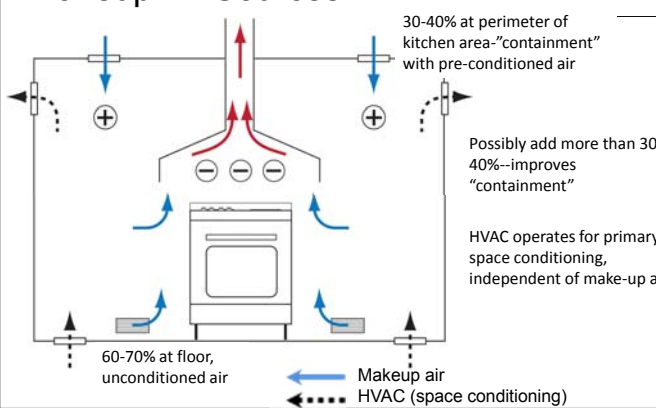
- Supply at floor, 60-70% unconditioned



60-70% at floor, unconditioned air-ensures negative pressure at source

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### Makeup Air Sources



30-40% at perimeter of kitchen area-“containment” with pre-conditioned air

Possibly add more than 30-40%--improves “containment”

HVAC operates for primary space conditioning, independent of make-up air

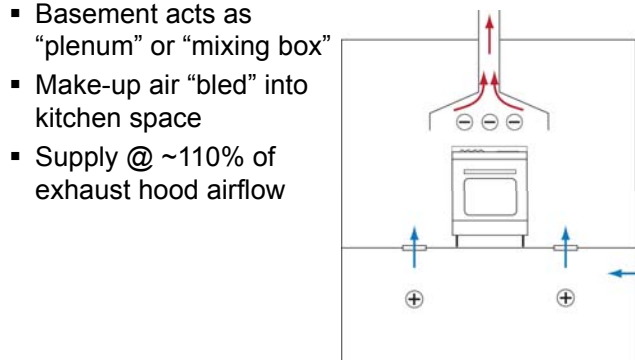
60-70% at floor, unconditioned air

Makeup air  
HVAC (space conditioning)

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### Smaller (~200 CFM) Make Up Air

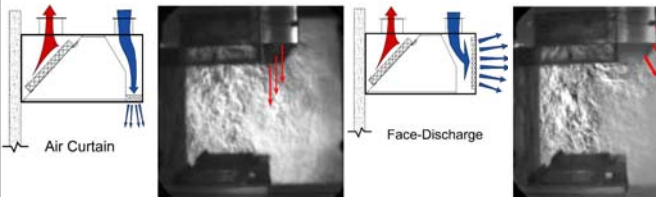
- Basement acts as “plenum” or “mixing box”
- Make-up air “bled” into kitchen space
- Supply @ ~110% of exhaust hood airflow



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### Supplying Make-Up Air

- Commercial Kitchens (CA Energy Commission)



Air Curtain

Face-Discharge

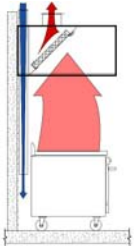
Figure 6. Schlieren image shows the thermal plume being pulled outside the hood by the air curtain.

Figure 7. Schlieren image shows the thermal plume being pulled outside the hood by a poorly engineered front face supply.

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### Supplying Make-Up Air

- Commercial Kitchens (CA Energy Commission)



Rear Discharge (Back Supply)

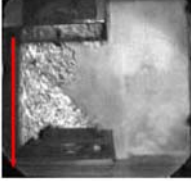


Figure 8. Schlieren image shows the thermal plume being pulled captured with backwall supply.

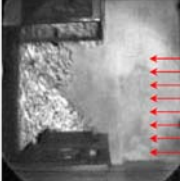



Figure 11. Schlieren image shows the plume being effectively captured when makeup air is supplied at low velocity from dis-  
placement diffusers.

At least 12" below cooking surface

No more than 60% of exhaust flow



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### Island-Style Range Hoods





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### Island-Style Range Hoods







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### Range Hood at Wall





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### Range Hood at Wall

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### Make-Up Air at Toe Kicks

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### Off-the-Shelf Heated Make-Up Air

- <http://www.fantech.net/product-range/fans-and-appurtenances/makeup-air-systems/>

Legend

1. Inline centrifugal fan
2. Filter cassette
3. Shut-off damper
4. Intake wall hood
5. Inline duct heater
6. Silencer
7. Fast clamps

- Hot climates: 1 ton/200 CFM of air

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### Off-the-Shelf Make-Up Air


- Interlock control with range hood
- Variable speed controller (if variable speed hood)
- Sizing heater (based on flow, outdoor Ts)

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# Make-Up Air for Fireplaces

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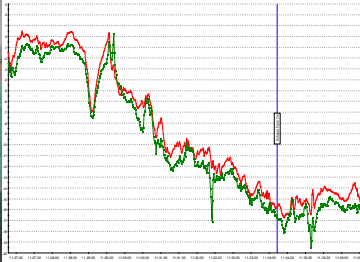
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## Wood Fireplaces

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- “Wood-powered exhaust fan”
- 400-600 CFM going up chimney (example below)
- Pressures/flow change with fire (start/dying down)





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## Wood Fireplaces

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- Attempt at combustion air: 6” duct
- Minimal effectiveness
- Need bigger duct, fan drive... or open window



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## Wood Burning Fireplaces

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Two types of fireplaces

**Open Face**



**Airtight**






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## Wood Burning Fireplaces

<h3>Open Face</h3> <ul style="list-style-type: none"> <li>▪ Exposed to interior space</li> <li>▪ Draws combustion air from inside</li> <li>▪ Chimney flue damper (iron usually, not well sealed)</li> <li>▪ Higher risk to occupants and structure if operated incorrectly</li> </ul>	<h3>Airtight</h3> <ul style="list-style-type: none"> <li>▪ Sealed combustion</li> <li>▪ OA duct connected to sealed firebox with damper.</li> <li>▪ No chimney flue</li> <li>▪ Low risk to occupants and structure if operated incorrectly</li> </ul>
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## Wood Burning Fireplace Challenges

- Makeup Air
  - How to supply makeup air in low leakage homes
  - Are intelligent controls necessary?
- Air Leaks (Open Face)
  - Leaky flue damper when not operating energy
  - Leaky fireplace assembly
- Other appliances that need makeup air?
  - Kitchen hood, clothes dryer




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## Wood Burning Fireplaces: Makeup Air

- Wood fireplace = 200-600 CFM
- Size makeup air duct according to flue?
- Fan to move makeup air?
  - Inline fan at makeup air duct
  - Exhaust fan at chimney cap
- How to operate makeup air?
- What about operator error:
  - Closing off makeup air too early? Can lead to re-entrainment of flue gases, CO poisoning
  - Startup problems can lead to smoke in house




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## Wood Burning Fireplaces: Makeup Air

- ASHRAE says: you need a fan
 

An inoperative fireplace is completely at the mercy of indoor/outdoor pressure differences caused by winds, building stack effects, and operation of forced-air heating systems or mechanical ventilation. Thus, the complaint of smoking during start-up can have complex causes seldom related to the chimney. Increasingly in new homes and especially in high-rise multiple family construction, fireplaces of normal design cannot cope with mechanically induced reverse flow or shortages of combustion air. It is mandatory in these circumstances to treat and design a fireplace as a constantly operating mechanical exhaust system, with induced-draft blowers (mechanical-draft systems) that can overpower other mechanized air-consuming systems, and can develop sufficient flow to avoid smoking and excessive flue temperatures.

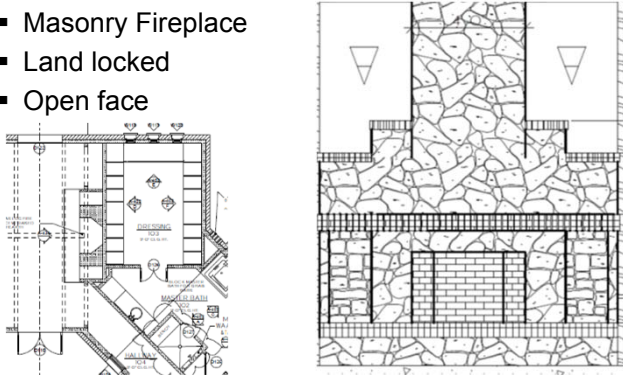


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### Wood Burning Fireplace Example

- Masonry Fireplace
- Land locked
- Open face

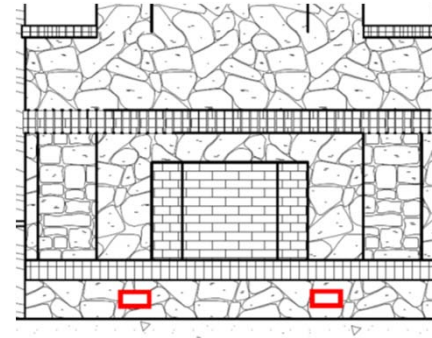


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### Outside air makeup

- Makeup air register location

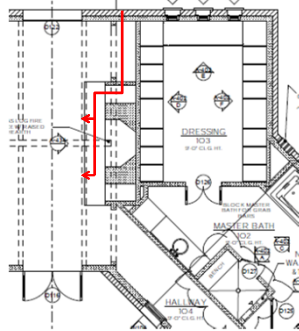


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### Outside air makeup

- Makeup air duct & fan



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### Sizing Make Up Air

- Calculate flue size based on open face of fireplace
- Supply airflow to achieve 0.8 feet per second (fps) velocity target
- Then start dialing in airflows
- More complicated with more fireplaces
- Chimney top fan (“pulling”) possibly safer approach



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### Wood Burning Fireplaces: Makeup Air

- Chimney top fans—effective solution, always out
- Issues: planning, access, noise complaints
- Still requires fine-tuning



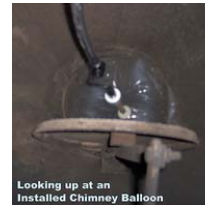
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### Wood Burning Fireplace: Air Leaks

#### Air Leaks (Open Face)

- Flue damper must seal well
- One option is an inflatable bladder
- <http://www.chimneyballoon.us/>



Looking up at an Installed Chimney Balloon

Fireplace Condition	Results in cfm
Damper open / No Damper	1720
Glass Doors closed only	1323
Damper closed only	1470
Damper closed & Glass doors closed	1280
Chimney Balloon installed only	1250



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### Wood Burning Fireplace: Air Leaks

- 24/7/365 inside-to-outside hole
- Height of chimney worsens leakage problems
- Inward in summer, outward in winter



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## Housewraps vs. Self-Adhered vs. Fluid-Applied...



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### Housewrap (Residential)



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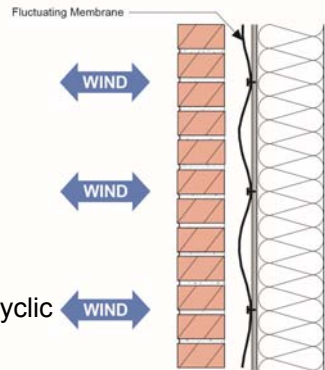
### Housewrap (Commercial)



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### Billowing Housewrap



- Is it really an air barrier (network airflow)?
- Potential damage from cyclic loading



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### Vapor-Impermeable Adhered Membrane



- Cold climate + no exterior insulation = danger



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### Vapor-Permeable Adhered Membrane



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### Self-Adhered Membranes

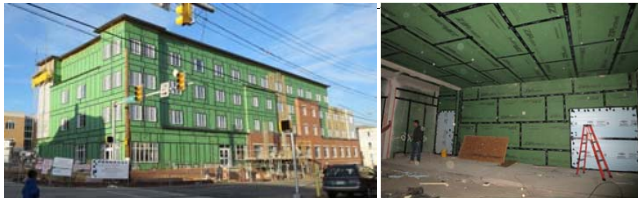


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- Self-sealing
- Air leakage improvement; no blow-off/billowing
- No 'hidden path' water leakage/bypass
- Reverse laps not as critical

### Taped Sheathings (WRB Surface)



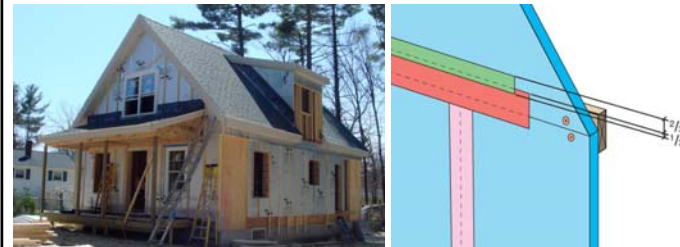
- Fast dry-in
- Airtightness
- Reliance on adhesive vs. laps? Surface prep
- Rigid foam insulation too



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### Taped Joints (Foam Sheathing)



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- Membrane-type flashing tape at joints
- Horizontals more important than verticals

## Fluid-Applied WRBs



- “Housewrap in a can” (GBA Column)
- Continuous water control
- Airtightness
- Can be applied with air gun (paint sub)
- Issues: surface prep, application temperature, substrate condition, etc.



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### Reverse Lap Termination



- “Termination mastic” at reverse lap condition

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### Air Leakage, Blower Doors, and Spray Foam

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### Air Barrier Systems

- Function: to stop airflow through enclosure
- ABS can be placed anywhere in the enclosure
- Must be strong enough to take wind gusts (code requirement)
- Many materials are air impermeable, but most systems are not airtight

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### Why Not Build Air-Leaky?

- Code requirements (2012 IECC onward)
- Problems with “too tight”?
  - Typically a lack of air change/ventilation problem
  - Design and product solutions available
- Problems with air leaky
  - Unpredictable where leaks are, how big
  - Comfort complaints
  - Humidity problems
  - **Moisture damage (inward or outward air leakage)**

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## Air Barrier Systems: Requirements

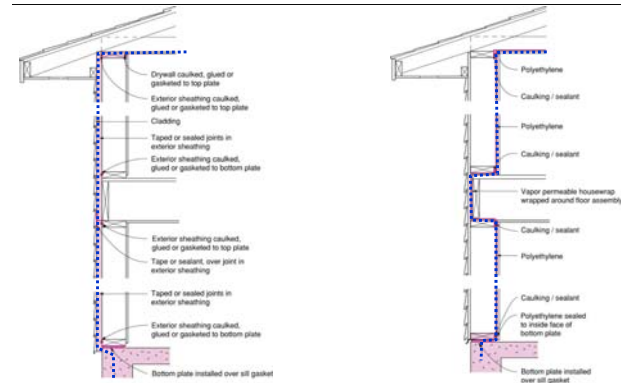
- Continuous
  - primary need, common failure
- Strong
  - designed for full wind load
- Durable
  - critical component - repair, replacement
- Stiff
  - control billowing, pumping
- Air Impermeable
  - (may be vapour permeable)



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## Air Barriers: "Trace the line"



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## Polyethylene as Air/Vapor Barrier

- Potential problems with AC, definitely not in South

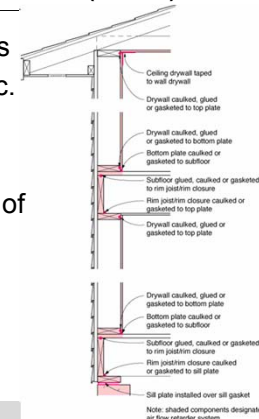


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## The Airtight Drywall Approach (ADA)

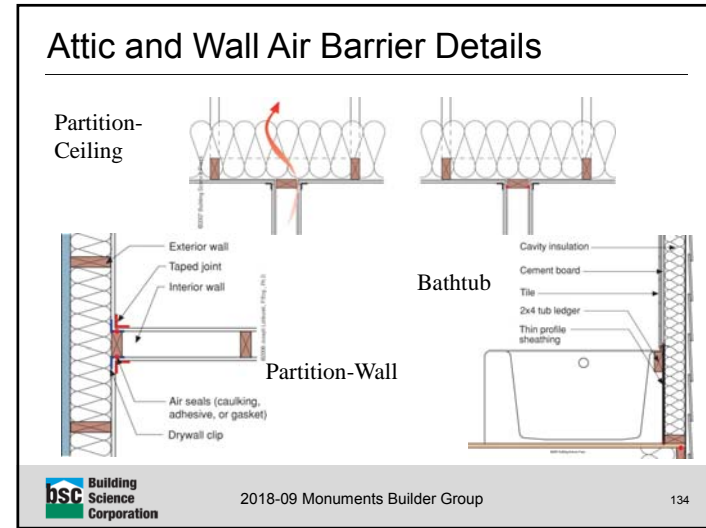
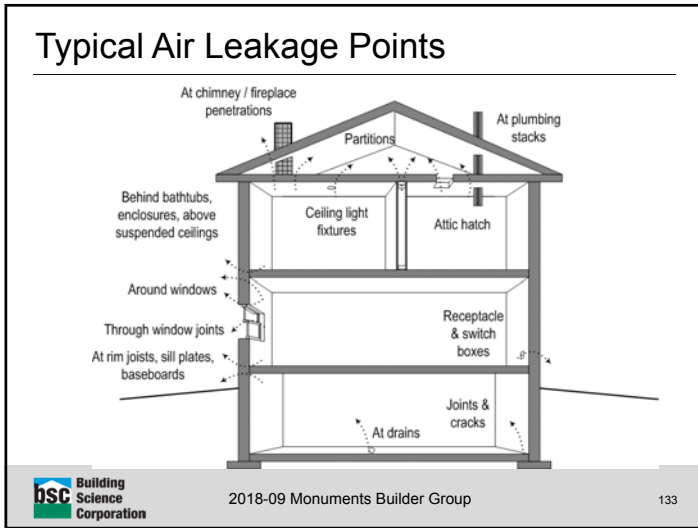
- Use drywall, framing members
- Seal with sealant, gaskets, etc.
- Is stiff, strong
- Often easier to ensure quality
- Widely applicable to all forms of commercial, residential
- Allows choice of vapor permeance



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### Air Sealing at Components

- E.g., windows and walls; other openings and penetrations
- Low expansion foam, membrane flashing tapes, sealants, etc.

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### Window Air Sealing

- Air barrier “wraps” into window rough opening
- Seal window to rough opening “wrap”
- Tooled sealant & backer rod: excellent results

Wall fluid or sheet applied WRB

Line rough opening with self-adhered membrane flashing

Wall fluid or sheet applied WRB

Membrane gas flashing returned up at back sash angle

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### Window Air Sealing

- Seal window to rough opening "wrap"
- Air seal, weather seal, and "beauty bead"

Jamb  
Full interior and exterior backer rod and sealant joint between the window and the membrane lined rough opening

Exterior sealant beauty bead between composite metal cladding and window

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### Window Air Sealing with Clips

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### Window Air Sealing with Clips

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### Air Leakage Testing

- 2009 IECC does not have testing requirement
- 2012 IECC onward requires 3 or 5 ACH 50

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### Air Leakage Testing

FLIR

FLIR

136.9

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### Spray Foam as an Air Barrier

Drywall caulked, glued or gasketed to top plate

Exterior sheathing caulked, glued or gasketed to top plate

Clacking

Taped or sealed joints in exterior sheathing

Exterior sheathing caulked, glued or gasketed to bottom plate

Exterior sheathing caulked, glued or gasketed to top plate

Tape or sealant, over joint in exterior sheathing

Taped or sealed joints in exterior sheathing

Exterior sheathing caulked, glued or gasketed to bottom plate

Bottom plate installed over sill gasket

Note: shaded components designate air barrier system

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### Spray Foam as an Air Barrier

53.2°F

FLIR

47°F

60°F

- Spray foam doesn't air seal where it isn't there!
- Wood-to-wood connections

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### Spray Foam as an Air Barrier

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### Spray Foam as an Air Barrier

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### Swimming Pools and Spas

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### Swimming Pool Conditions

**Air in swimming pools → dangerous stuff that destroys buildings**

Condensation on any surface colder than ~69° F

Swimming pool

Museum 50% RH

Typical wintertime interior (30% RH)

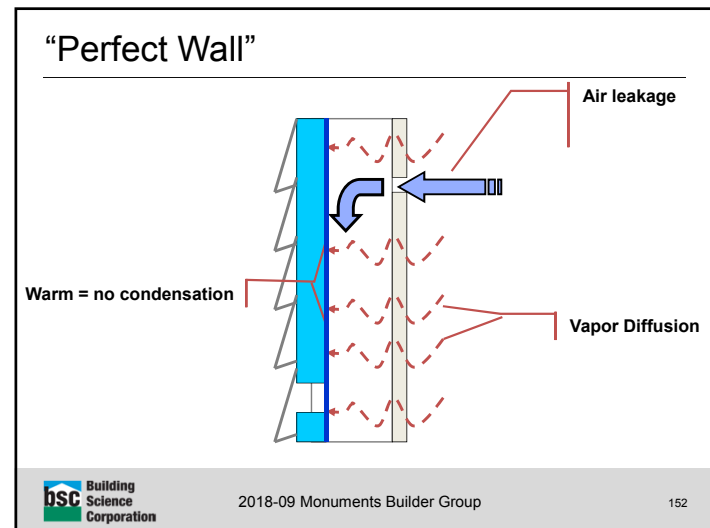
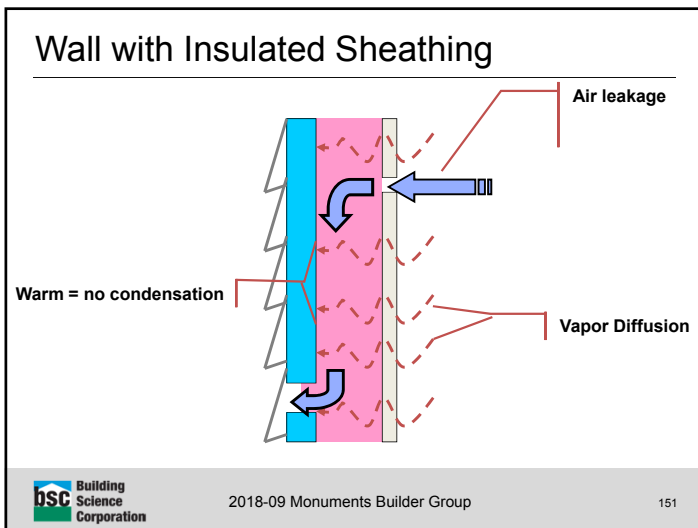
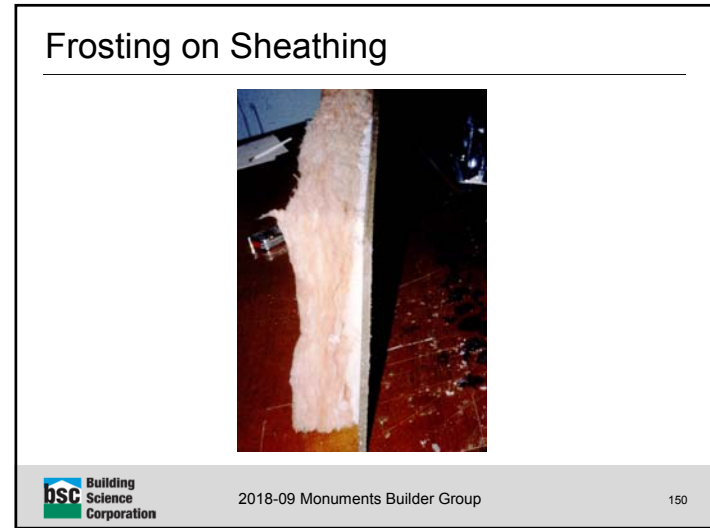
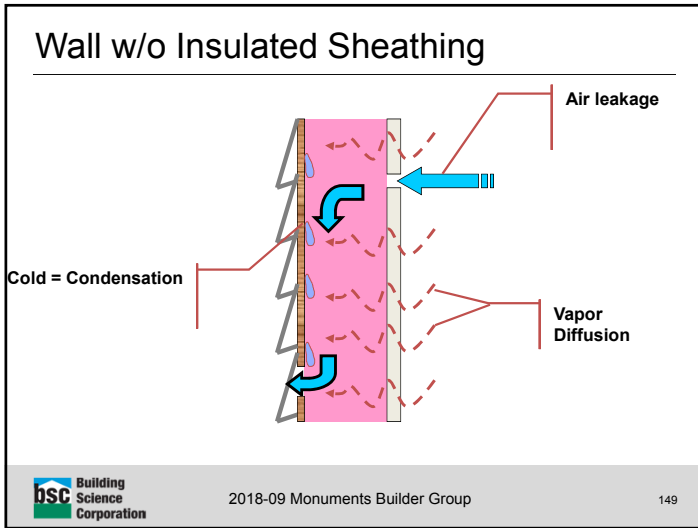
January-December monthly average temperatures

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### Vapor Diffusion vs. Air Leakage

- Vapor Diffusion
  - more to less vapor
  - no air flow
  - flow through tiny pores
- Air Convection
  - more to less air pressure
  - flow through visible cracks and holes
  - vapor is just along for the ride

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### The Perfect Wall

- Structure (protected)
- Air-vapor barrier (“Control layers”)
- Insulation
- Ventilated gap (“Rainscreen”)
- Exterior cladding

Cladding  
Control layers  
Structure

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### The “Perfect” Wall: Higher Performance

Brick veneer/stone veneer  
Drained cavity  
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass  
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder  
Concrete block  
Metal channel or wood furring  
Gypsum board  
Latex paint or vapor semi-permeable textured wall finish

Vapor Profile

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### The Commercial Steel Frame Wall

Brick veneer/stone veneer  
Drained cavity  
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass  
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder  
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)  
Uninsulated steel stud cavity  
Gypsum board  
Latex paint or vapor semi-permeable textured wall finish

Vapor Profile

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### Conceptual Pool Enclosure

Vented roof  
All structure — steel, clay, not the trusses but you know what I mean  
Vented cladding  
Thermal control layer outside of air and vapor control layers  
Continuous air control and vapor control layer outside of structure  
Vented cladding  
All services inside, all, not some, all and I really mean it

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### Roof-to-Wall Connection

- Perfect wall
- Vented roof
- All mechanicals inside shell
- Thermal bridging at steel truss
- Roof-to-wall air/vapor barrier connection

Labels in diagram: Metal roof, Fully-adhered roofing membrane, Roof sheathing, Metal roof deck, Gypsum board air control layer, Liquid applied vapor control layer, 2x4 thermal bridge furring, Sheet metal closure strip, Surface-mounted fixtures, 2x6 continuous wood thermal break, Metal cladding, Hat channel, Thermal control layer, Water control/vapor control layer, Service space, Interior lining, Ducts, Dropped ceiling, Roof vents.

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### Roof-to-Wall Air Barrier Connection

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### Interior & Exterior Air-Vapor Barrier

- Interior view of a large room with a vaulted ceiling and exposed wooden trusses.
- Interior view of a swimming pool area with a vaulted ceiling and exposed wooden trusses.
- Exterior view of a green building with a gabled roof.
- Interior view of a swimming pool area with a vaulted ceiling and exposed wooden trusses.

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### Cathedral Vented Roof

- “Perfect wall” built on a slope

Labels in diagram: Roof sheathing, Shingles, Roofing paper, Plywood roof sheathing, Roofing membrane (vapor permeable liquid applied or roofing felt), Vented space, Air control layer/vapor control layer, Wood decking, Timber rafter or exposed joist.

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### Low-Slope (“Flat”) Roof

- Only works for Climate Zone 4 and warmer

Labels in diagram: Fully-adhered roofing membrane, Coverboard and hygric buffer, Rigid insulation (min. two layers; joints offset), Screw attachment, Gypsum sheathing (paperless), Fully-adhered air control layer/vapor control layer, Metal deck, Screw attachment.

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### Low-Slope (“Flat”) Roof

- For Climate Zone 5-ish

Labels in diagram: Fully-adhered roofing membrane, Coverboard and hygric buffer, Intermediate plywood layer; joints sealed, Screw attachment to intermediate plywood layer, Screw attachment to structural deck, Rigid insulation, Gypsum sheathing (paperless), Fully-adhered air control layer/vapor control layer, Metal deck, Screw attachment.

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### Inverted Membrane Roof

- Entirely safe: “perfect wall” as roof

Labels in diagram: Ballast, Filter fabric, Control layers, Roof structure.

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### Inverted Membrane Roof

- Entirely safe: “perfect wall” as roof
- Top side could be ballast, pavers, “green roof”

Labels in diagram: Ballast, Filter fabric, Control layers, Roof structure.

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### Case Study: Roof-Wall Air Barrier

- Academic pool building stripped, re-insulated, reclad
- Efflorescence staining in first winter



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### Case Study: Roof-Wall Air Barrier

- "Perfect wall"



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### Case Study: Roof-Wall Air Barrier

- Excellent roof (air-vapor barrier below)



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### Case Study: Roof-Wall Air Barrier

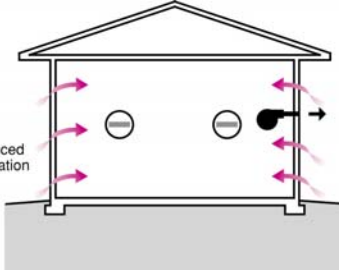


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### Run Pools at Negative Pressure

- Contains moisture (outside to inside air leakage)
- Contains odors (pool attached to rest of building)
- Tighter construction = smaller fan needed



Induced infiltration

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### Case Study: Pressurized Pool

- Recently rebuilt NH resort pool



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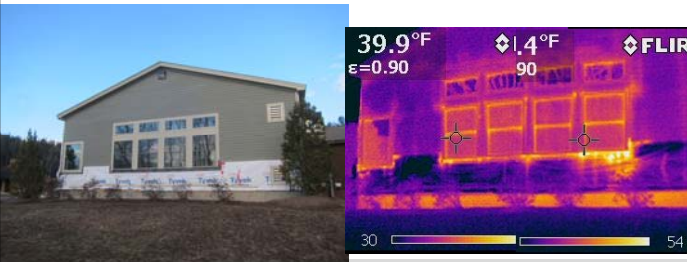
### Case Study: Pressurized Pool



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### Case Study: Pressurized Pool

- Pool conditioning system improperly configured
- Pressurized pool + greater airtightness → concentrated air leakage condensation




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# Wood Floors on Slabs

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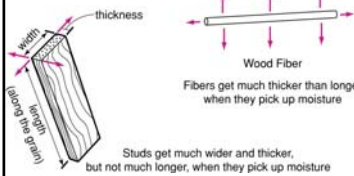
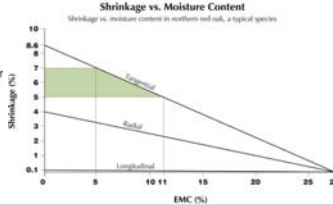



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## Wood Floors on Slabs

- Concrete + Water → No Problem
- Wood + Water → Problem
- Wood moisture movement
- Mold & decay

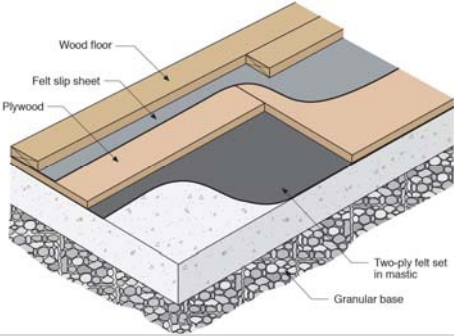



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## Wood Floors—Back in the Day...

- “Indoor Roof” on top of slab—no moisture





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## Wood Floors—Back in the Day...

- Bitumen, plywood, slip surface



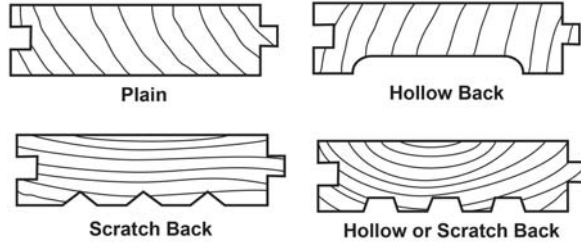


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## Wood Flooring Profiles

- Reduces curling due to differential seasonal moisture content at top and bottom

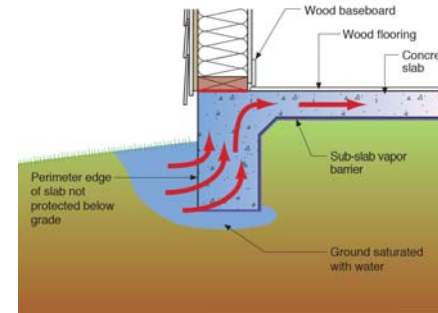


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## Slab Moisture Sources

- Exposed slab edge “wicks” from surrounding soil

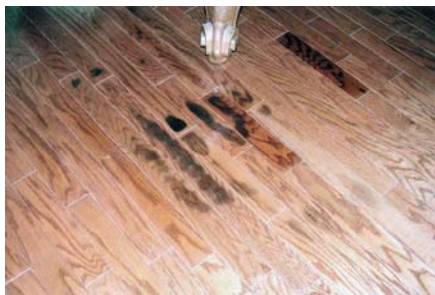


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## Slab Moisture Sources

- Can move moisture long distances inward

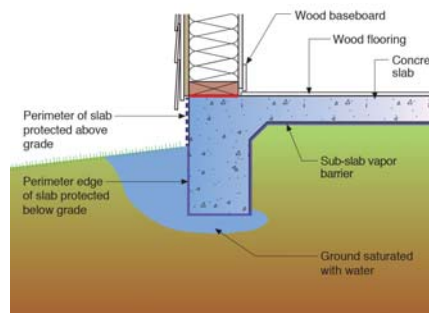


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## Slab Moisture Solution

- Protect with polyethylene at footing, slab coating



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### Slab Moisture Solution

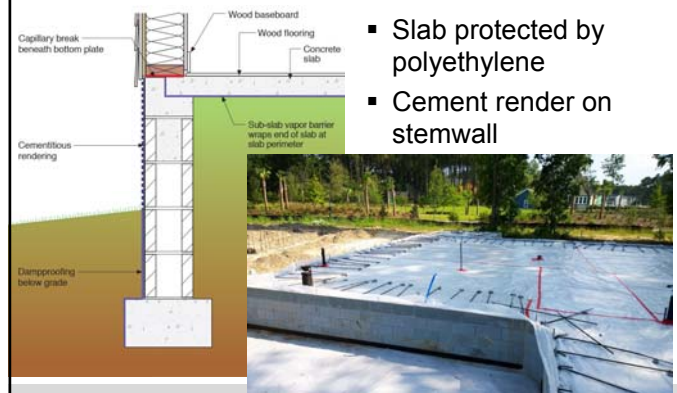
- Protect with polyethylene at footing, slab coating



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### Stemwall Detail



- Slab protected by polyethylene
- Cement render on stemwall

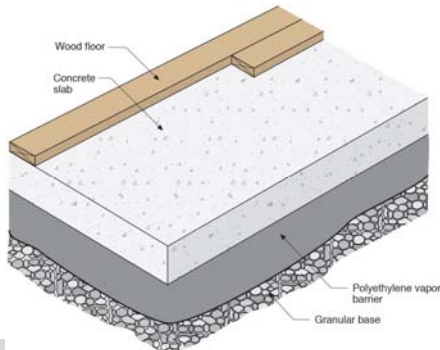


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### Installation on Dry Slab

- Low w/c ratio helps; fast schedules hurt



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### Built-In Slab Moisture

- Thickened slabs hurt (more concrete → more moisture)



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### Insulated Dry Slab

- Polyethylene over XPS (not reversed)

Labels in diagram: Wood floor, Concrete slab, Polyethylene vapor barrier, Extruded polystyrene (XPS) rigid insulation, Granular base.

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### Solution-Topside Vapor Barrier

- Fluid applied or self-adhered. Not polyethylene

Labels in diagram: Wood floor, Topside fluid-applied vapor barrier, Concrete slab, Polyethylene vapor barrier, Granular base.

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### Case Study: Cupping Floor Maine

- Polyethylene below XPS
- Slab exposed through winter

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### Case Study: Cupping Floor Maine

- Floors cupping during finishing (sleepers)
- Slab clearly wet during demolition

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### Case Study: Cupping Floor Maine

- High moisture levels on slab surface
- Previously wet cavity-corrosion



A photograph showing a person's hand holding a moisture meter against a concrete floor slab. The slab is partially covered with wooden planks, and there is a circular hole in the concrete nearby.

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### Case Study: Cupping Floor Maine

- Lower parts of slab 95%+ RH
- 4 months + of drying

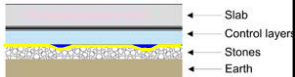
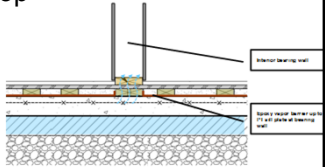


A photograph showing a hole drilled into a concrete slab. A moisture meter probe is inserted into the hole, and a pink bucket is placed nearby. The hole is filled with a blue liquid, likely a moisture indicator.

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### Case Study: Cupping Floor Maine

- Solution option: force drying of sleeper cavity, then observe through next year
- Potential for “trapped” water
- Solution option: demolish floor, epoxy vapor barrier top coat
- Client chose latter option
- Drying might have been sufficient to solve problem





A cross-section diagram of a floor assembly. The top layer is labeled 'Slab', followed by 'Control layers', 'Stones', and 'Earth'. A second diagram shows an 'Interior sleeper wall' and a 'Sand blotter layer' between the wall and the slab.

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### Slab Moisture and Low-Perm Floors

- Many floors are Class I (0.1 perm or less) vapor barriers: VCT, rubber-backed floor tile
- Concrete slabs are full of water when cast
- Sand “blotter layer” between polyethylene & slab makes things worse—permanent reservoir



A photograph showing a construction site where a sand blotter layer is being installed between a polyethylene vapor barrier and a concrete slab. The sand is piled up, and the polyethylene is visible in the foreground.

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### Impermeable Floors on Wet Slabs

- Latex-based adhesives re-emulsify
- Bubbling of sheet vinyl composition flooring



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### Case Study: Multi-Use Building RI


- Sleepers and Advantech on slab on grade
- Rubber-backed carpet tile, fine over basement



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### Case Study: Multi-Use Building RI

- Damage pattern matches seams of carpet tile
- High wood MCs: 18-25% typical



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### Case Study: Multi-Use Building RI

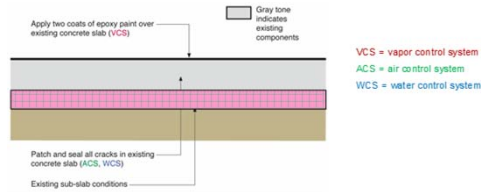
- Advantech damaged on top and bottom, wetter
- Slab RHs >98% at some spots



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## Case Study: Multi-Use Building RI

- “AdvanTech® Flooring over Concrete Slabs”:  
“Slab Preparation: Cover the slab with a minimum 6 mil polyethylene sheeting”
- Build back with epoxy coating on slab, or self-adhered membrane



## Ventilation and Over-Ventilation

## Ventilation Rates

- Ventilation rates are based on odor control
- Health science basis for ventilation rates is extremely limited
- Almost nothing cited applies to housing
- The applicable studies focus on dampness

## Ventilation Rates over Time

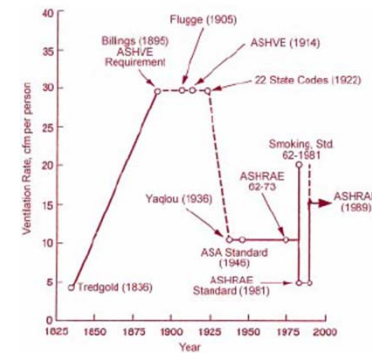


Figure 1: Minimum ventilating rate history.

## Ventilation Rates vs. Odor Acceptance

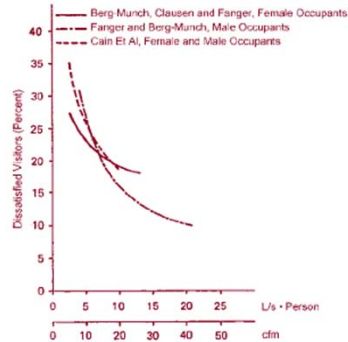


Figure 2: Odor acceptance.



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## Ventilation Rates and the Codes

### House

2,000 ft<sup>2</sup>  
3 bedrooms  
8 ft. ceiling  
Volume: 16,000 ft<sup>3</sup>

		Ventilation Rates	
.35 ach	93 cfm	62 - 73	5 cfm/person 20 cfm
			10 cfm/person 40 cfm
.30 ach	80 cfm	62 - 89	15 cfm/person 60 cfm
			0.35 ach 90 cfm
.25 ach	67 cfm	62.2 - 2010	7.5 cfm/person 50 cfm
			+ 0.01
.20 ach	53 cfm	62.2 - 2013	7.5 cfm/person 90 cfm
			+ 0.03
.15 ach	40 cfm		

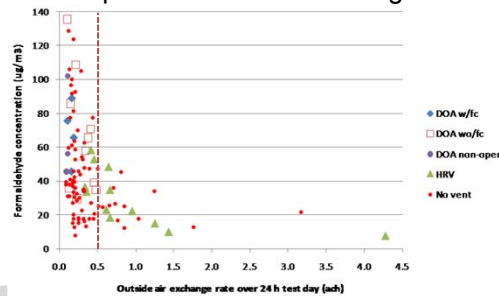


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## Interior Pollutants-Formaldehyde

- Under 0.5 ACH: no correlation w. levels
- Impractical to ventilate at much higher rates
- Need to keep the bad stuff out to begin with



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## HRVs vs ERVs and Dehumidifiers



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## Why Mechanical Ventilation?

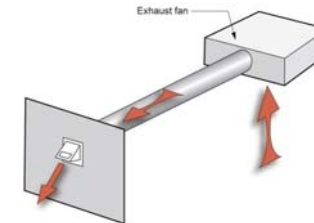
- Overventilation → energy, possible humidity problems
- Tighter construction → less air change
- Controlled mechanical ventilation to match occupancy



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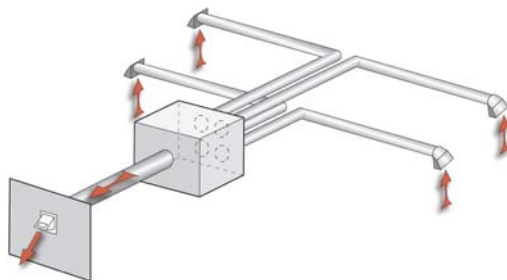
## Single-Port Exhaust



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## Multi-Port Exhaust

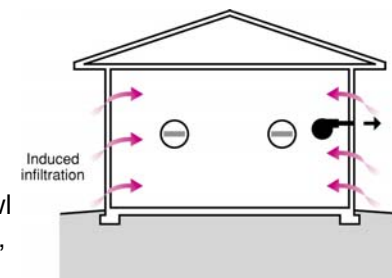


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## Exhaust-Only Ventilation

- Lowest cost
- Depressurizes building
- Draws air from wherever leaks are (unknown sources)
- Draws air from crawl spaces, basements, attics, garages...



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### Central-Fan Integrated Supply Ventilation

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### Central-Fan Integrated Supply Ventilation

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### Supply-Only Ventilation

- Pressurizes building
- Draws air from known source
- Problems with tighter construction, multifamily

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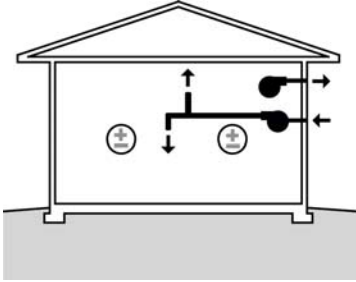
### Balanced Ventilation (HRVs & ERVs)

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### Balanced Ventilation (HRVs & ERVs)

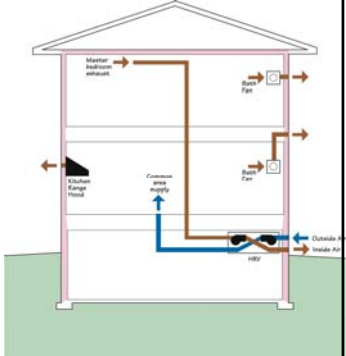
- Building pressure neutral
- Draws air from known source
- Works with tighter construction, multifamily
- Heat recovery → energy performance



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### Single-Point HRV/ERV

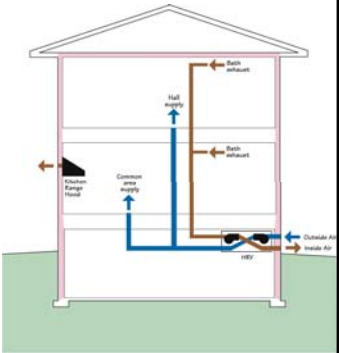
- Draw from bedroom, supply to common area
- Bathrooms and kitchens on separate exhaust systems



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### Multi-Point HRV/ERV

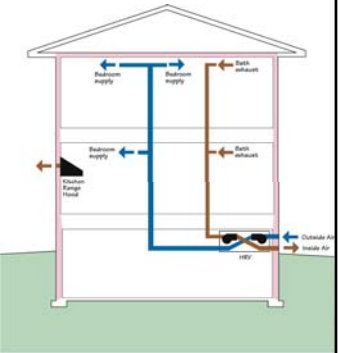
- Draw from bathrooms, supply to common area
- Kitchen on separate exhaust systems
- Or...



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### Multi-Point HRV/ERV

- Draw from bathrooms, supply to bedrooms
- Kitchen on separate exhaust systems
- Bedrooms are where pollutants are generated and concentrate!
- But don't "dump" on occupants



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### Multi-Point HRV/ERV

- Draw from common spaces, supply to bedrooms
- Kitchen and baths on separate exhaust systems

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### HVAC-Integrated HRV/ERV

- HVAC integration
  - Lower cost (less ductwork)
  - Good distribution of supply air
  - More complicated-interlocks
- Draw from common areas, supply to HVAC plenum
- Damper to avoid backdrafting

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### HVAC-Integrated HRV/ERV

- Draw from bathrooms, supply to HVAC supply plenum
- Damper to avoid backdrafting

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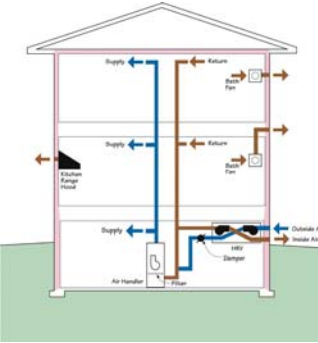
### HVAC-Integrated HRV/ERV

- Draw from return plenum, supply to HVAC supply plenum
- Damper to avoid backdrafting
- Risks of pressure relationship problems

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### HVAC-Integrated HRV/ERV

- Draw from return plenum, supply to return plenum
- Damper to avoid backdrafting
- Risks of pressure relationship problems

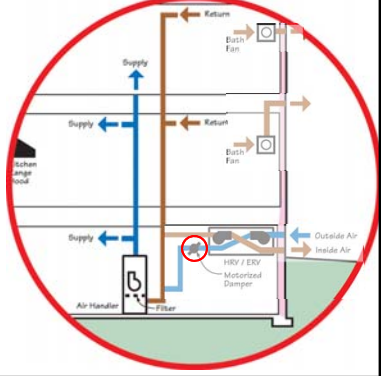


The diagram shows a cross-section of a house with an HVAC system. Blue arrows indicate supply air flow from the air handler through ducts to various rooms. Brown arrows indicate return air flow from rooms back to the return plenum. A damper is shown at the air handler's intake, and an HRV/ERV unit is connected to the return plenum. Labels include 'Supply Air', 'Return', 'Return Dampers', 'Air Handler', 'Filter', 'HRV / ERV Damper', 'Outside Air', and 'Inside Air'.

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### HRV Induced Flow

- AHU running, HRV not running → unintended airflow
- Overall air leakage + duct leakage issues
- Need motorized damper in addition to backdraft dampers



The diagram shows a similar house cross-section as slide 221, but with a red circle highlighting the HRV/ERV unit and its damper. It illustrates unintended airflow paths when the HRV is not running, showing air being drawn from the return plenum through the HRV/ERV unit and into the rooms. Labels include 'Supply', 'Return', 'Return Dampers', 'Air Handler', 'Filter', 'HRV / ERV Motorized Damper', 'Outside Air', and 'Inside Air'.

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### HRV/ERV Takeaways

- Supplying to bedrooms → outside air where pollutants are generated/concentrated
- Ductwork independent of HVAC system: simpler, fewer things to go wrong, but more expensive
- Multi-point ducted system better than single-point ducted system (and more expensive)
- HRV/ERV can do double duty as bath fan, but avoid long dumb runs
  - Bathroom exhaust via ERV recovers moisture—typically not a good thing

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### HRVs vs. ERVs

- Hot-humid and mixed-humid climates: ERV
- ERVs do not dehumidify
  - They only partly reduce the moisture load due to outdoor air humidity
- Cold climates: HRVs vs. ERVs
  - Recover or reject moisture?
  - Building size and occupancy
  - Large houses, low occupancy → ERV typical
- Do not over ventilate: HRV + overventilation = “too dry” complaints

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## Part-Load Humidity and Dehumidification

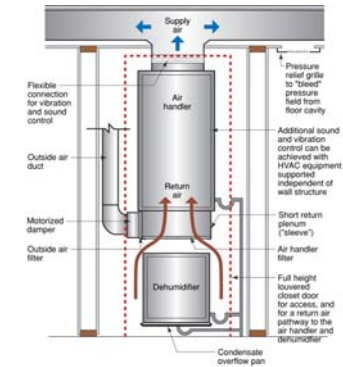
- Better enclosures/shells: less cooling load
  - Windows, shading, insulation levels, airtightness
- Less runtime → less dehumidification
  - “Shoulder” seasons often worst
- Oversized cooling equipment → poor dehumidification
  - Two stage/multi speed helps, but...
- High-efficiency HVAC → worse dehumidification
- Adding supplemental dehumidification



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## Adding Dehumidification (Closet AHU)



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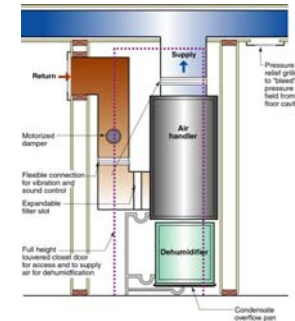
## Adding Dehumidification (Closet AHU)



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## Adding Dehumidification (Closet AHU)



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## Adding Dehumidification (Closet AHU)

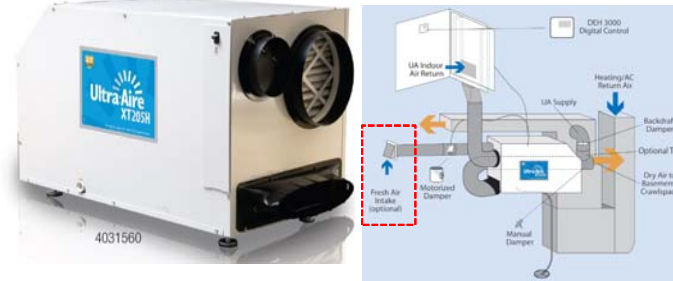


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## Dehumidifier Integrated with HVAC

- Ducted high efficiency units
- Dehumidify outside supply air option

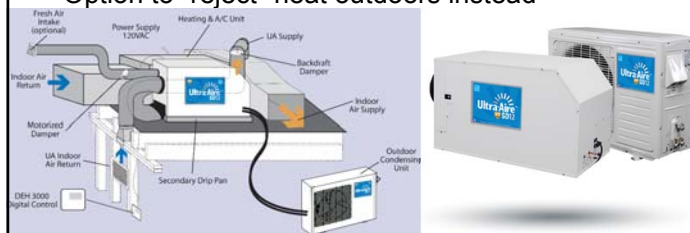


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## Dehumidifier Integrated with HVAC

- Dehumidifiers add heat to indoors
  - Pros and cons
- Option to “reject” heat outdoors instead



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# Questions?

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kohta (at sign) buildingscience dot com

This presentation will be available at <http://buildingscience.com/past-events>



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## Document Resources

- Building Science Digest 014: Air Flow Control in Buildings  
<http://www.buildingscience.com/documents/digests/bsd-014-air-flow-control-in-buildings>
- Building Science Digest 104: Understanding Air Barriers  
<http://www.buildingscience.com/documents/digests/bsd-104-understanding-air-barriers/>
- Building Science Digest 105: Understanding Drainage Planes  
<http://www.buildingscience.com/documents/digests/bsd-105-understanding-drainage-planes>
- Building Science Digest 163: Controlling Cold-Weather Condensation Using Insulation  
<https://buildingscience.com/documents/digests/bsd-controlling-cold-weather-condensation-using-insulation>
- Building Science Insight 001: The Perfect Wall  
<http://www.buildingscience.com/documents/insights/bsi-001-the-perfect-wall/>
- Building Science Insight 003: Concrete Floor Problems  
<https://buildingscience.com/documents/insights/bsi-003-concrete-floor-problems>
- Building Science Insight 006: No Good Deed Shall Go Unpunished  
<http://buildingscience.com/documents/building-science-insights/bsi-006-no-good-deed-shall-go-unpunished>



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## Document Resources

- Building Science Insight 012: Balancing Act - Exhaust-Only Ventilation Does Not Work  
<http://buildingscience.com/documents/building-science-insights/bsi-012-balancing-act-exhaust-only-ventilation-does-not-work>
- Building Science Insight 029: Stucco Woes—The Perfect Storm  
<http://buildingscience.com/documents/insights/bsi-029-stucco-woes-the-perfect-storm>
- Building Science Insight 037: Mold in Alligator Alley  
<http://buildingscience.com/documents/insights/bsi-037-mold-in-alligator-alley>
- Building Science Insight 038: Mind the Gap, Eh!  
<http://www.buildingscience.com/documents/insights/bsi-038-mind-the-gap-eh/>
- Building Science Insight 055: In the Deep End  
<http://www.buildingscience.com/documents/insights/bsi-055-in-the-deep-end/>
- Building Science Insight 057: Hockey Pucks and Hydrostatic Pressure  
<http://buildingscience.com/documents/insights/bsi-057-hockey-pucks-and-hydrostatic-pressure>
- Building Science Insight 070: First Deal with the Manure and Then Don't Suck  
<https://buildingscience.com/documents/insights/bsi-070-first-deal-with-the-manure>
- Building Science Insight 082: Walking the Plank  
<https://buildingscience.com/documents/insights/bsi082-walking-the-plank>



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## Document Resources

- Building Science Insight 084: Forty Years of Air Barriers\*—The Evolution of the Residential Air Barrier  
<http://buildingscience.com/documents/insights/bsi-084-forty-years-of-air-barriers>
- Building Science Insight 102: The Coming Stucco-Pocalypse  
<https://buildingscience.com/documents/building-science-insights/bsi-102-coming-stucco-pocalypse>
- Information Sheet 611: Balanced Ventilation Systems (HRVs and ERVs)  
<http://buildingscience.com/documents/information-sheets/info-611-balanced-ventilation-systems>
- Information Sheet 620: Supplemental Humidity Control  
<http://buildingscience.com/documents/information-sheets/information-sheet-supplemental-humidity-control>
- Research Report 0203: Relative Humidity  
<http://www.buildingscience.com/documents/reports/rr-0203-relative-humidity/view>
- Design Guide: Improving Commercial Kitchen Ventilation System Performance  
[http://www.energy.ca.gov/reports/2003-06-13\\_500-03-034F.PDF](http://www.energy.ca.gov/reports/2003-06-13_500-03-034F.PDF)



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## Document Resources

- Indoor Pool Building  
<https://buildingscience.com/project/indoor-pool-building>
- Mixed-Use Building  
<https://buildingscience.com/project/mixed-use-building>
- Pool and Recreation Facility  
<https://buildingscience.com/project/pool-and-recreation-facility>



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