U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable
Building Technologies Program

Building America
U.S. Department of Energy
Research Leading to Zero Energy Homes

Building High Performance Homes

Janet McIlvaine and David Beal

November 20, 2008

Mobile, Alabama

Building America
U.S. Department of Energy
Industrialized Housing Partnership
www.baihp.org
Florida Solar Energy Center®

Welcome and Introductions

Welcome and Introductions

- Janet McIlvaine and David Beal
  - Florida Solar Energy Center, Research Institute of UCF
  - Lead 1 of 6 Department of Energy Building America Teams
  - *Building America Industrialized Housing Partnership* (BAIHP)
  - Research Analysts
- Brenda C. Lawless and Brian Stanley
  - Mobile County Habitat for Humanity
  - Partners in Building America's Gulf Coast High Performance Demonstration Housing Project
- HBA of Metro Mobile
  - Promotional Partner

DOE Building America Program

- www.buildingamerica.gov
- Public-Private Research Initiative
- Public: DOE funded teams of researchers
- Private: Home builders across America
- Cost Shared Research:
  - Build high performance houses together
  - Document problems and solutions
  - Conduct training to spread lessons learned

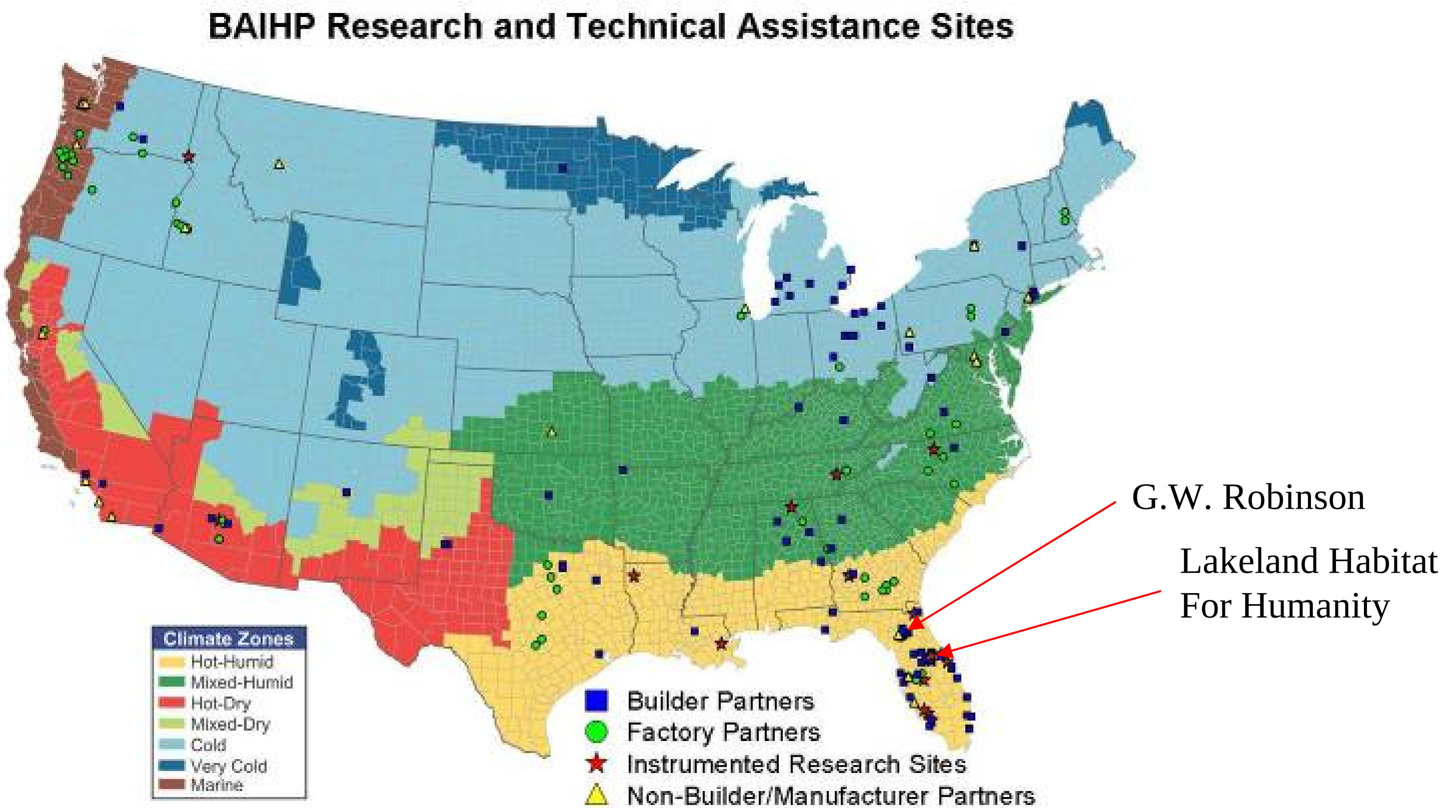
Building America Goals

- Move standard practice toward "High Performance"
- Climate specific solutions
- Work in key markets
- With production builders
- Produce whole communities
- Systems engineering approach
  - aka "house as a system" or "whole house" approach
- Transfer "Lessons Learned" to other builders
  - Workshops, documents, case studies

DOE Building America Program

- "High Performance" Goals
  - 30-70% energy savings (Mobile goal ~30% savings)
  - First year positive cash flow
  - While improving indoor air quality, durability, and comfort
  - How is this possible…

BAIHP is estimated to save over $14,000,000/yr in 168,000+ homes



G.W. Robinson Builders, Inc. – Gainesville, FL

- Progressively increased energy efficiency over time
- HERS Index <70 saving ~ 30% on a whole house basis
- 400+ Houses completed and sold
- Lead – Florida H.E.R.O. (Ken Fonorow)
- Detailed Case Study: www.fsec.ucf.edu/en/publications/pdf/FSEC-PF-430-07.pdf

G.W. Robinson Builders, Inc. – Gainesville, FL

- 1st year positive cash flow

	First Cost	Annual Cost (7%, 30 yr mortgage)
Total Incremental Cost (includes 10% mark up)	**$2,021**	**$161**
Estimated Annual Energy Savings (wrt typical)		**$863**
Net 1st Year Cash flow		**$702**

G.W. Robinson Builders, Inc. – Gainesville, FL

- Heating/Cooling Equipment features
  - SEER 15 Air conditioner, 93% AFUE Gas Furnace
  - ACCA Manual J system sizing
  - Ducts sealed with mastic and tested
  - Interior air handler closet
- Water Heating Equipment
  - EF=0.84 Tankless gas water heater
- Heating/Cooling Load Reduction Features
  - Energy Star Windows (0.28 SHGC, U=.39 Vinyl Low-e)
  - R-30 with Radiant barrier vented attic
  - 2 x 4 Advanced Framing w/R-13 cellulose
  - Wide Overhangs on Patio doors and windows
  - Passes Energy Star Thermal Bypass Inspection
- Indoor air quality, durability, and comfort features
  - Ducted kitchen and bath exhaust fans
  - Passive, positive pressure outside air ventilation
  - Drainage plane and flashing details
  - Passive return air pathways from bedorooms
  - Low VOC paints
- Verification
  - Blower door and duct leakage testing

Lakeland Habitat for Humanity – Lakeland, FL

- Goal: Cost Effectively Exceed Energy Star
- Builder Motivation – Reduce total cost of ownership
- Started with Energy Star ’99 in 2001, progressively improved
- HERS Index = ~70 saving about 30% in whole house energy use
- Understand Builder Needs:
  - Volunteer Friendly
  - Proven
  - Readily Available
  - No Maintenance Burdens
- Estimated First Cost Increase: $2000
- Detailed Case Study: www.baihp.org/habitat/pdf/Lakeland-Habitat-Case-Study.pdf

Lakeland Habitat for Humanity – Lakeland, FL

- 1st year positive cash flow

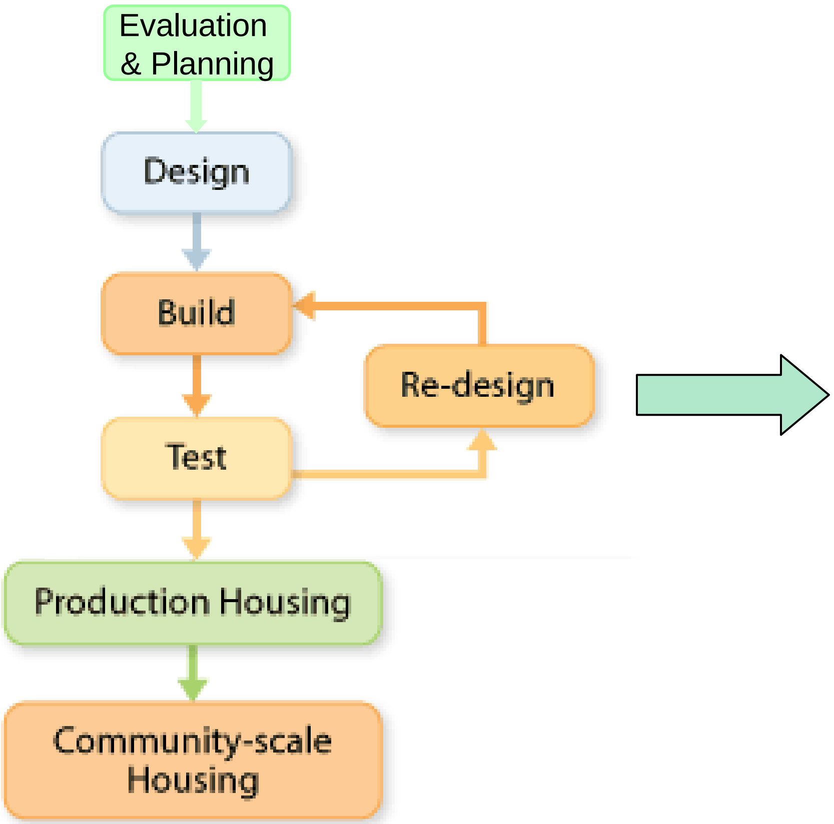
	First Cost	Annual Cost (0%, 20yr HFH mortgage)
Total Incremental Cost	**$2,000**	**$100**
Estimated Annual Savings		$250
Net 1st year cash flow to owner		$150

- $5000 grant from city for meeting energy standards

Lakeland Habitat for Humanity – Lakeland, FL

- Heating/Cooling Equipment
  - SEER 14, HSPF 8+ Heat Pump sized with ACCA Manual J
  - Duct system sealed with mastic and tested
  - Interior air handler closet, ducted central return
- Heating/Cooling Load Reduction
  - R-30 Ceiling and R-13 Wall Insulation
  - Passes Energy Star Thermal Bypass Inspection
  - Radiant Barrier below roof decking
  - Infiltration control (house wrap air barrier + extensive air sealing)
  - Energy Star Windows shaded by overhangs, Porches & shade trees
- Appliances & Lighting
  - Water heater timer
  - Energy Star Refrigerator
  - 20% CFL Lighting
- Indoor air quality, durability, and comfort features
  - Ducted kitchen and bath exhaust fans
  - Passive, positive pressure outside air ventilation
  - Drainage plane and flashing details
- Verification
  - Blower door and duct leakage testing

"Systems Engineering" Approach to Change



"Lessons learned" Translated into case studies, publications, & "Best Practices" documents

Systems Engineering Approach

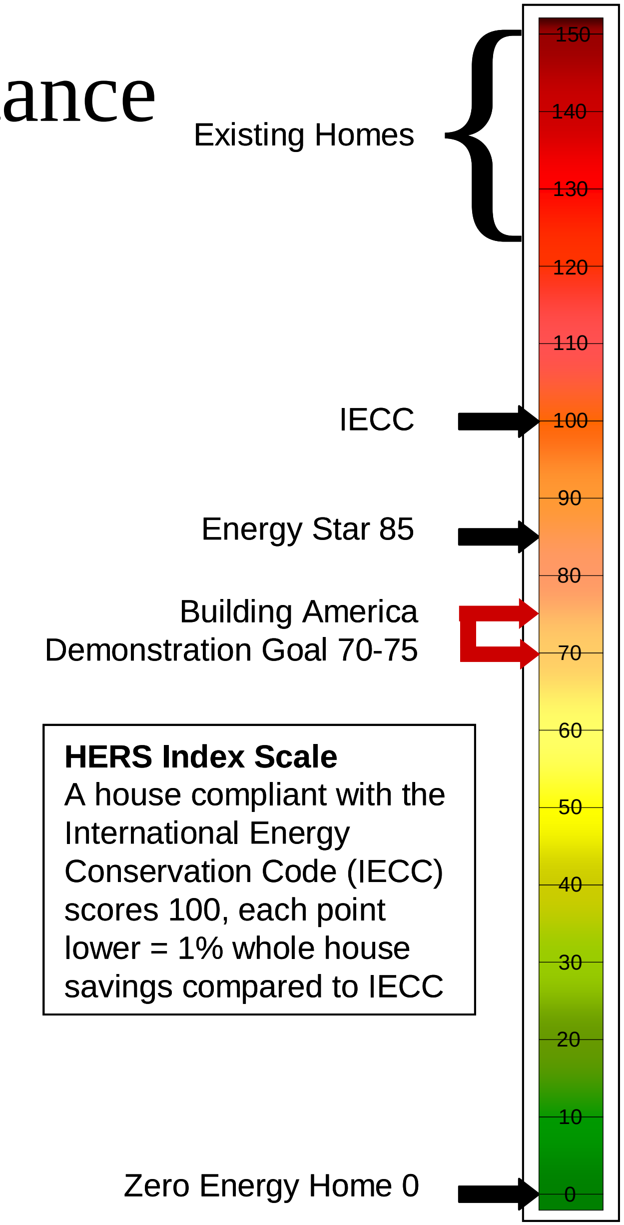
- More Case Studies & free BA resources online:
  - www.baihp.org
    - Case studies, publications, and presentations
  - www.baihp.org/habitat
    - Habitat specific information
  - www.baihp.org/gulfcoast
    - Demonstration project summary
  - www.buildingamerica.gov
    - Best practices, program overview, searchable database of publications

Systems Engineering Concepts

- "House as a System" thinking
  - As we make improvements, make sure we aren't creating new problems
- Involve whole construction team
- Anticipate and solve common problems on paper
- Reduce call backs by evaluating warranty claims
- Work with "off the shelf" products
- Seek first year positive cash flow
- Prototype, evaluate, and refine solutions

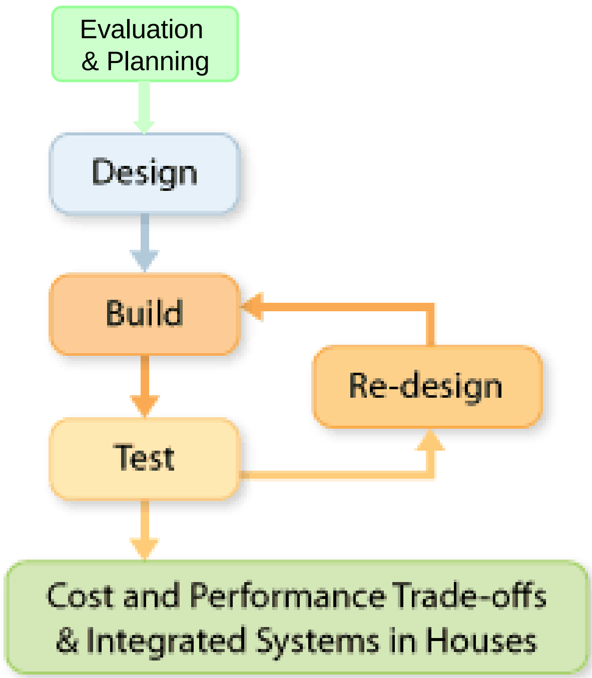
Building America Technical Assistance

- Partner steps toward reaching 30% whole house savings goal
  - First – Preliminary Evaluation
    - Combustion Safety
    - Warranty Issues
    - Energy Code Compliance
    - Begin "Systems Engineering" process
  - Next - Energy Star for Homes
    - HERS 85 + prescriptive req's
    - Ensure no IAQ, durability, comfort problems
  - Next – Exceed Energy Star
    - HERS 70-75
    - Ensure no IAQ, durability, comfort problems



Systems Engineering Process

- Preliminary Evaluation
- Set Energy Savings Goal - IECC? Energy Star? Beyond Energy Star?
- Develop a package of improvements
- Work with project team to anticipate and solve problems before implementation. Prototype and refine individual improvements, if necessary
- Build a TEST house
- Refine package as needed
- Integrate into production process



This is the process we used for GC Demonstration Houses…

Project Introduction:

Building America's Gulf Coast High Performance Affordable Housing Demonstration Project

Gulf Coast High Performance Affordable Housing Demonstration Project Goals

- 30% whole house energy savings
  - Proven results in Florida, but in a new market
  - Technical assistance alone did not attract much interest
- Demonstration houses show case…
  - NOT cutting edge technology
  - BUT an achievable, replicable high performance package that most builders can adapt to their houses
- Affordable housing focus to emphasize feasibility

DOE Gulf Coast High Performance Affordable Homes

- http://www.baihp.org/gulfcoast/
- Goals
  - HERS Index 70-75
  - $2,000 first cost
  - First year positive cash flow
  - Meets Indoor Air Quality, Durability, and Comfort Criteria
  - Conduct local builder training
- Four Builder Partners
  - Habitat for Humanity Affiliates
  - Baton Rouge, New Orleans, Slidell, and Mobile

New Orleans Area Habitat

East St. Tammany Habitat (Slidell)

Habitat of Greater Baton Rouge

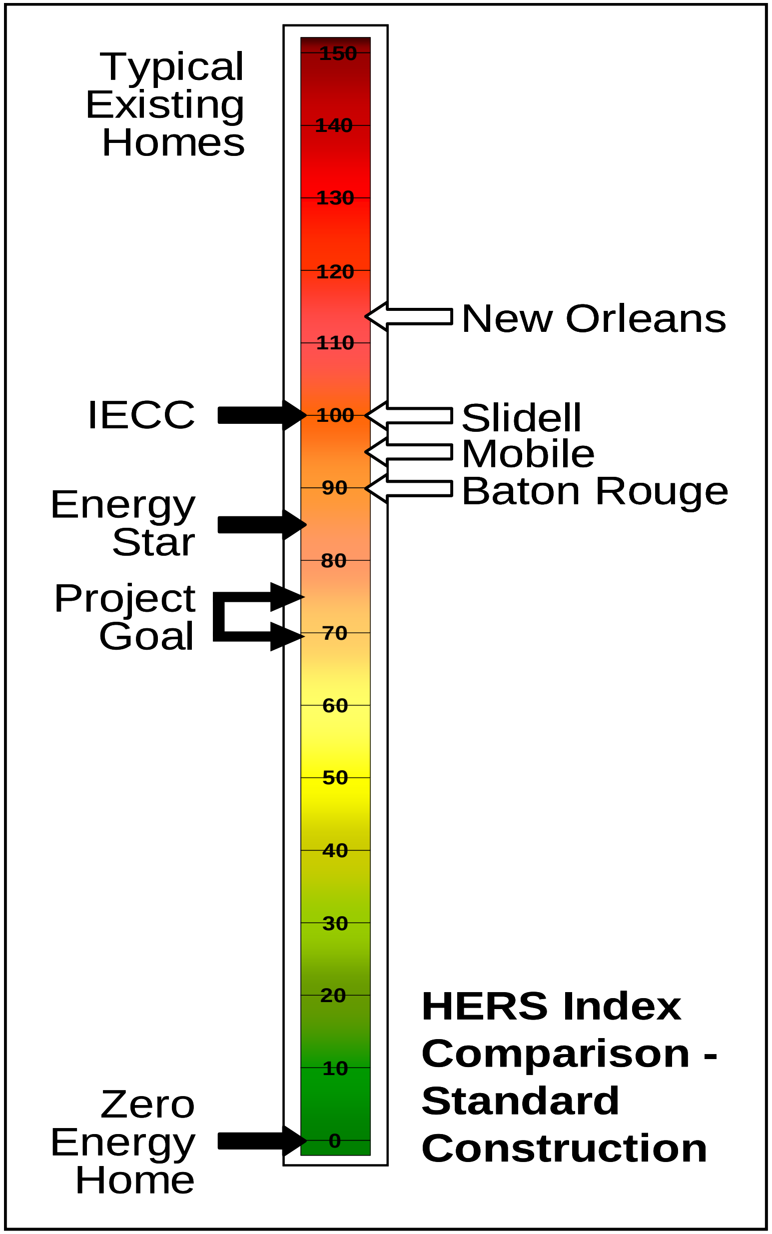
Mobile County Habitat

First Year Positive Cash Flow

	First Cost	Annual Cost (0%, 20yr HFH mortgage)	Annual Cost (7%, 30 yr Mortgage)
Total Incremental Cost	**$2,000**	**$100**	**$144**
Estimated Annual Savings		$250	$250
Net 1st year cash flow to owner		$150	$106

Gulf Coast High Performance Affordable Homes – Systems Engineering Process

- Preliminary Evaluation
  - IAQ, Durability, Comfort, and Energy (HERS Index)
- Identify "Package" & Develop Strategies
- Build a Trial House (Afternoon Tour)
- Refine Package
- Build Demonstration House
- Conduct Training with Home Building Industry



Systems Engineering Approach

- Avoidable IAQ, Durability, and Comfort Problems …
  - Combustion safety issues
    - Flame roll out and exhaust back drafting
  - Asthma/allergy triggers
    - Pollen, roach dander, dust mites
  - Bulk water and humidity issues
    - Biological growth, buckling, bulging, sagging, standing water, rusting, shorting electrical connections, water logged materials and fixtures, wet insulation, condensation
  - Comfort
    - "My bedroom/kitchen/family room never gets cool/warm"
- Many of these issues are driven by the same dynamics of air, heat, and moisture/water movement

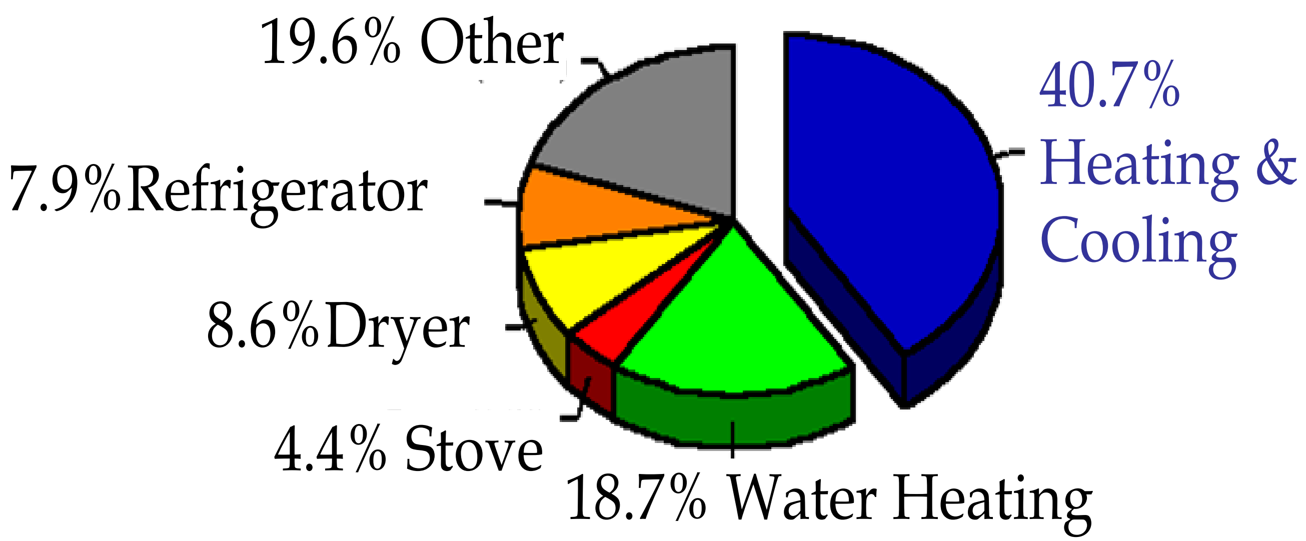
Building Science Fundamentals

Building Science Back Ground

- Our building science scope…
  - Energy use and efficiency, indoor air quality (IAQ), durability, and comfort
- Dynamics and management of air, heat, & moisture/water
- Outside our scope…
  - Structural integrity – engineering
  - Life safety (including disaster resistance) – codes

Typical Energy Use Profile

Average Annual Energy Use
Measured in 10 Florida Habitat Homes



Avg. for ten control houses
Total=43 kWh/day

Typical Energy Use (& Conservation) Profile

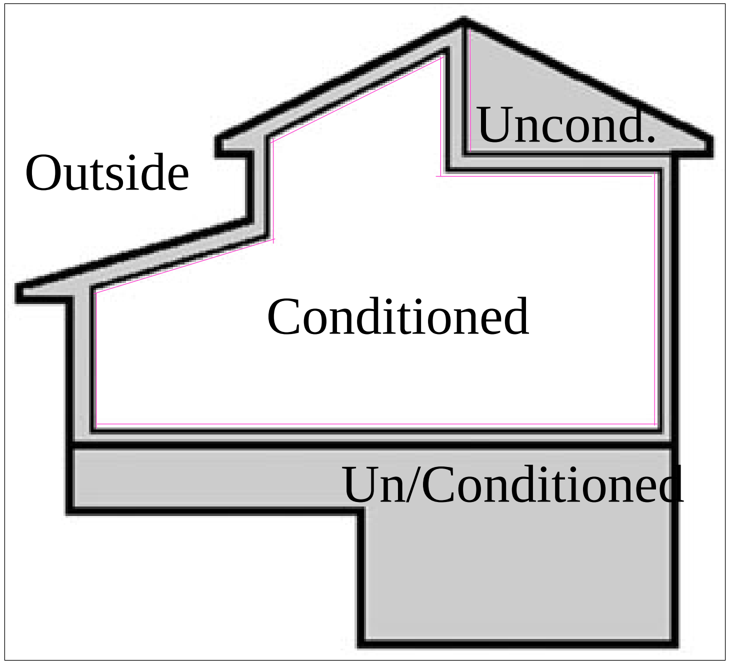
- 40% = Heat and Cooling
  - Efficient Equipment – Mechanical system
  - Load Reduction - Enclosure
- 20% = Water Heating
  - Efficient Equipment
- 20% = Appliances (stove, dryer, refrigerator)
  - Energy Star Appliances
- 20% = “Other” including lighting
  - Efficient Lighting

Building Science Back Ground

- Air, heat, moisture, and water often move together
- By controlling movement, we control
  - Indoor air quality
    - Example: entry of outside pollutants, soil gases
  - Durability
    - Example: path of rain over building materials, indoor humidity levels
  - Comfort and energy efficiency
    - Heat gain and loss, air flow in each room, humidity levels
  - Multiple benefits from individual improvements
    - Example: infiltration control
- Creating a "controlled" environment

Building Science Terms

- Conditioned space
  - Controlled environment – inside
- Unconditioned space
  - Less controlled environment – attic, crawl spaces
- Outside
  - Uncontrolled environment - outside
- Building enclosure ("envelope")
- Mechanical system



Movement of Air, Heat, Moisture and Water

- Building enclosure ("envelope")
  - Boundary
  - Materials and assemblies
    - Foundation, floor, walls, roof & ceiling
  - Air barrier + thermal barrier + drainage plane
  - Controls air, heat, and water flow – how…?
- Mechanical system
  - Moves air, removes heat and humidity
  - Heating/Cooling + ventilation + exhaust fans

Movement of Air, Heat, Moisture, & Water

- Air, heat, and moisture move in response to *differences*…temperature or pressure

- Direction of Movement…
  - "High" goes to "Low"
  - Air moves from high pressure or temp toward low
    - Air barrier stops it
  - Heat moves from high temp toward low temp
    - Thermal barrier stops it
  - Water moves from high ground toward lower
    - Drainage plane and flashing direct it

Movement of Air, Heat, Moisture, & Water

- House is full of air
  - 1 cfm “in” = 1 cfm “out”
  - Every 1 cfm exhausted is replaced by 1 cfm
- Example: Box fan in window

Movement of Air, Heat, Moisture, & Water

- To have movement, need three things…
  - Air/heat/moisture + hole + driving force
- Example: Drinking straw

Control Movement of Air, Heat, Moisture, & Water

- To control flow…
  - Minimize source
    - Nearly impossible
  - Minimize holes
    - Continuous boundaries between source & cond. Space
    - Air barrier + thermal barrier + drainage plane
    - At joints and penetrations…ship lap and/or seal
  - Minimize driving forces
    - Can't eliminate temperature difference
    - Maintain neutral air pressure

Controlling Water, Air, and Heat

Principal Strategies

Water:
- Dry Materials
- Continuous Ext. finishes
- Continuous Drainage Plane
- Flashing
- Assemblies that Dry
- Exhaust wet air

Air:
- Continuous Air Barrier
- Sealed Duct System
- Neutral Air Pressure

Heat:
- Continuous, Even Layer of Insulation

Controlling Water, Air, and Heat

Siding and Shingles are first line of defense against liquid water

Continuous drainage plane behind vented (vinyl, wood, fiber cement) siding.

Tar Paper/Felt (Ship lapped)

House Wrap (sealed at edges and seams)

Rigid Insulation (T&G or sealed at edges and seams)

Controlling Water, Air, and Heat

Principal Strategies

Water:
- Dry Materials
- Exterior finishes
- Continuous Drainage Plane
- Flashing
- Assemblies that Dry
- Exhaust wet air

Air:
- Continuous Air Barrier
- Sealed Duct System
- Neutral Air Pressure

Heat:
- Continuous, Even Layer of Insulation

All these materials are drainage planes.
Which are also air barriers?

Tar Paper/Felt
(Ship lapped)

House Wrap
(sealed at edges
and seams)

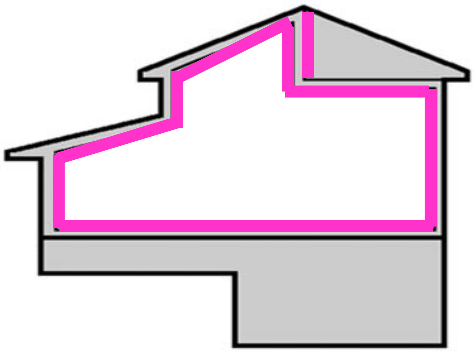
Rigid Insulation
(T&G or sealed at
edges and seams)

All these materials are drainage planes. Which are also air barriers?

Tar Paper/Felt (Ship lapped)	House Wrap (sealed at edges and seams)	Rigid Insulation (T&G or sealed at edges and seams)
		
Is NOT an Air Barrier	IS an Air Barrier	IS an Air Barrier

Continuous Air Barrier

- Controls Air Flow and Air Transported Moisture Flow
  - Separates conditioned space from unconditioned
  - Surrounds and contains "conditioned space"
  - Elements
    - Slab/floor decking
    - Sill seal or equivalent
    - House wrap or
    - Rigid insulation sealed at edges and seams
    - Top plates (exterior AND interior walls)
    - Ceiling drywall
    - Sealant in penetrations of above surfaces
    - Ducts and air handler, if in unconditioned space…



Sealed Duct System

- Duct system in unconditioned spaces is part of the house air barrier
- Each duct surrounds little piece of conditioned space
- Air handler is part of the air distribution system
- Special conditions in ducts
  - Very high pressure in supply
  - Very low pressure in return
  - Both in air handler
  - Very cold/hot air in supply
  - High potential for changing house air pressure

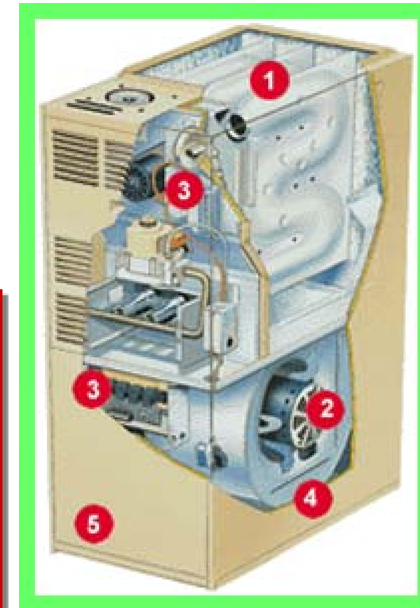
Unbalanced house air pressure

- Duct leakage can lead to uncontrolled air flow
  - From out to in, from in to out, and both at the same time
  - can heighten natural infiltration significantly
  - Can cause whole house depressurization or pressurization
  - Can lead to combustion safety issues, so can other causes of house depressurization such as…
    - Exhaust fans
    - Closed interior doors (without ducted returns)
    - (Demonstration of Air Flow Dynamics after break)

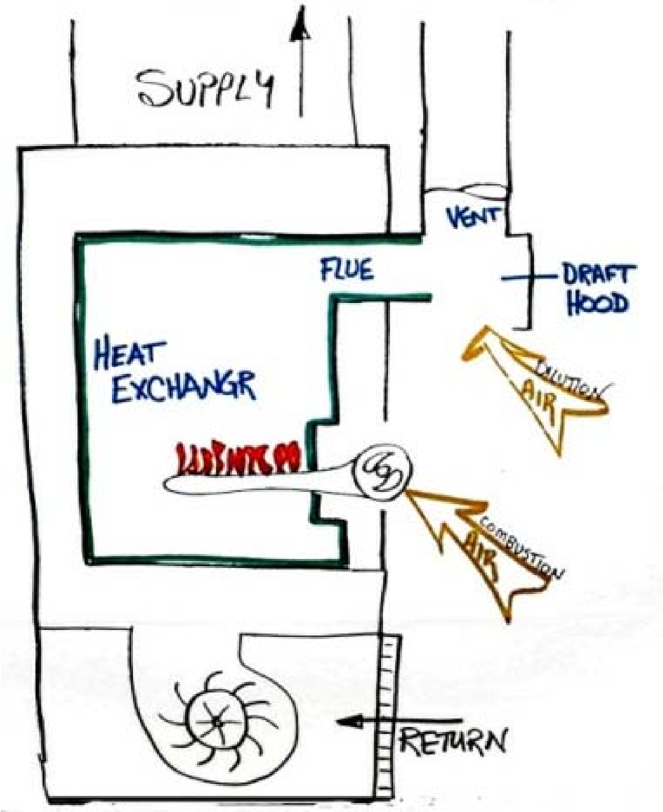
What combustion safety problem?

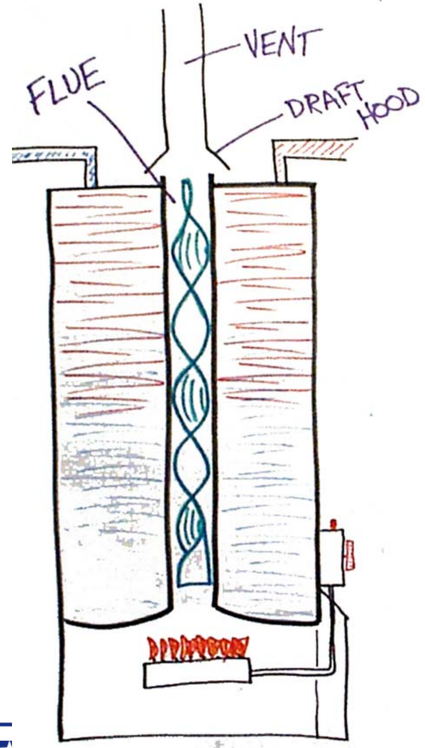
Water is a byproduct of combustion

- 1 cubic foot natural gas releases 1000 Btus
- 100K Btuh furnace burns about 100 cuft/hr
  - About 200 cuft water vapor per hour
  - Slightly more than 1 gallon water per hour
- Typical Btuhr Input (residential)
  - Furnace 50K-200K
  - Water Heater 30K-75K
  - Ranges 10K-15K



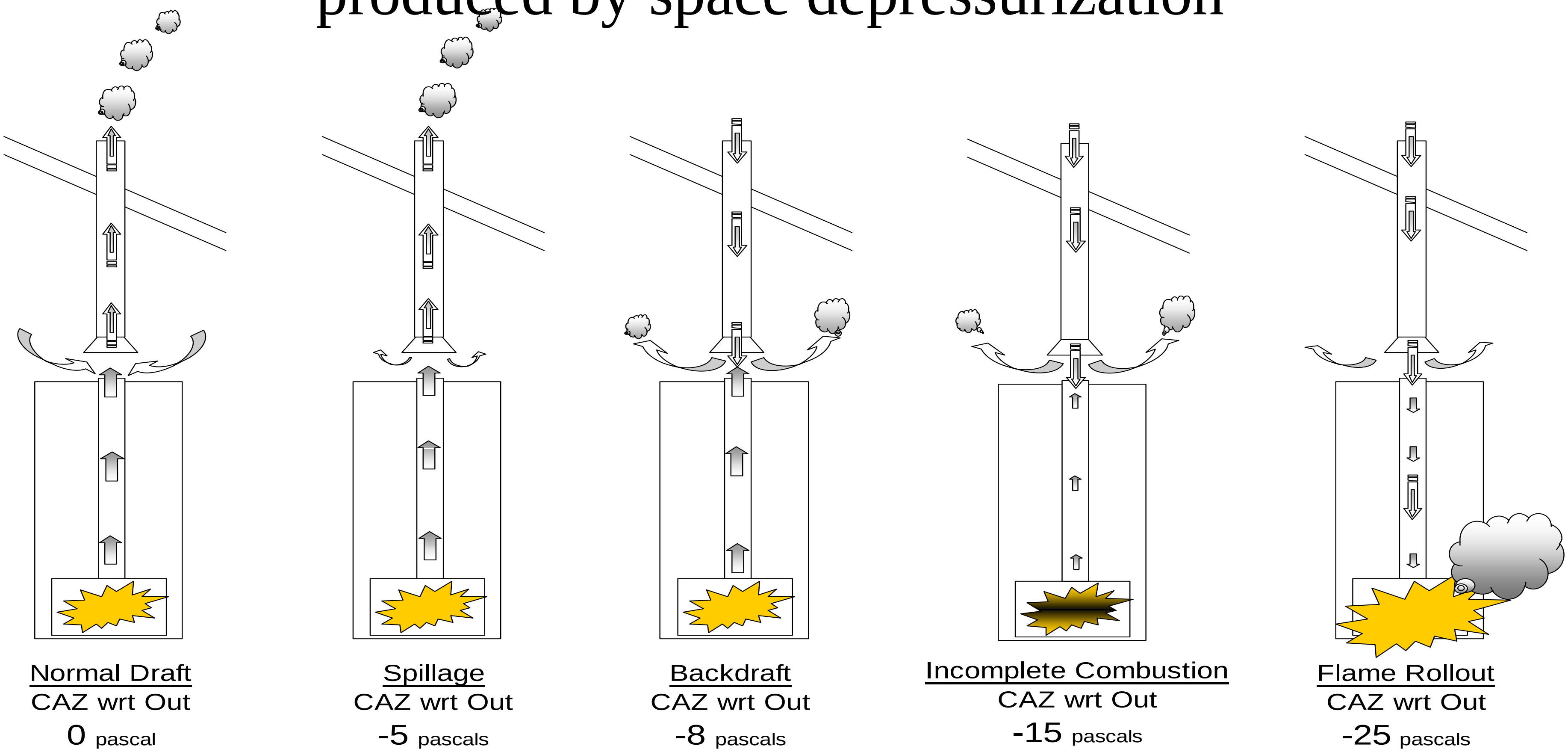
Naturally Aspirated Combustion Equipment





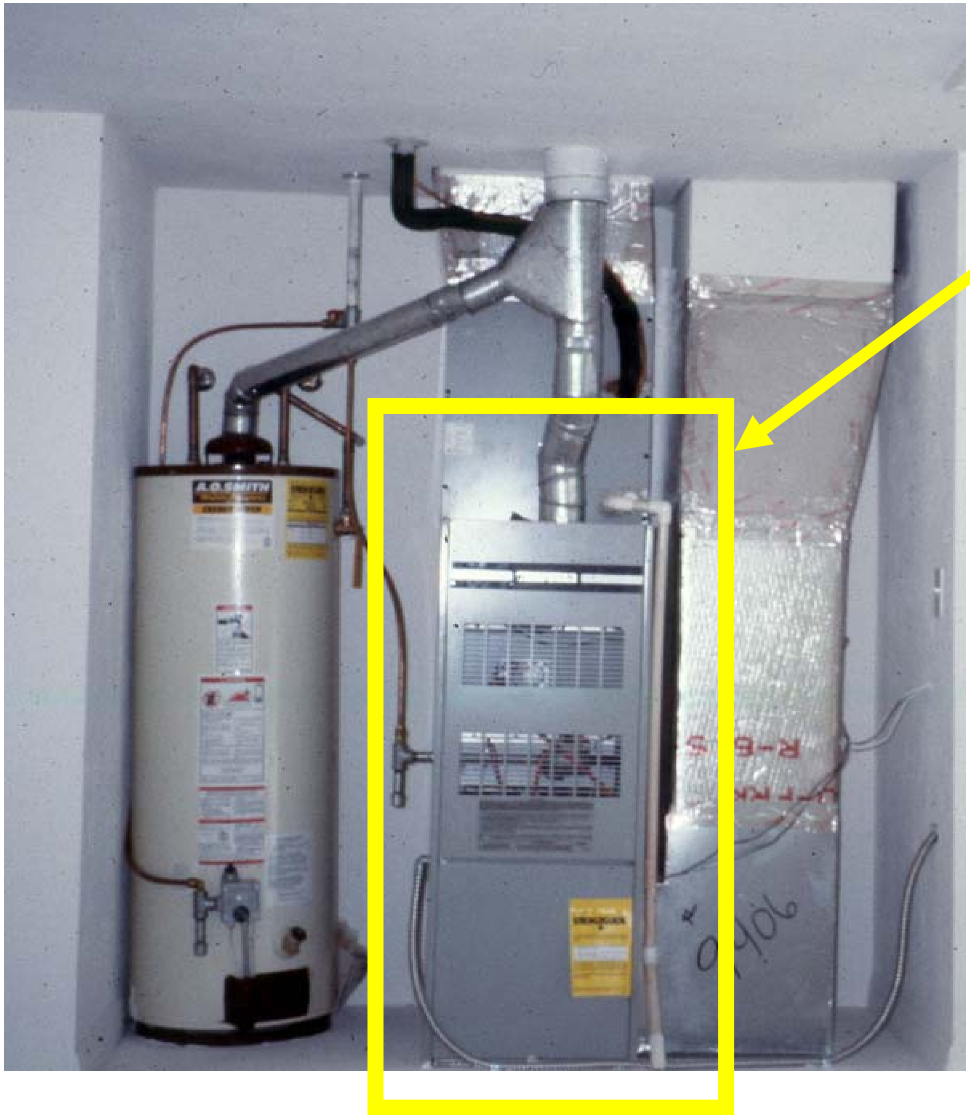
- And now we pause for a demonstration of air flow dynamics…and combustion safety discussion

Combustion safety problems produced by space depressurization



Prevent combustion safety problems…

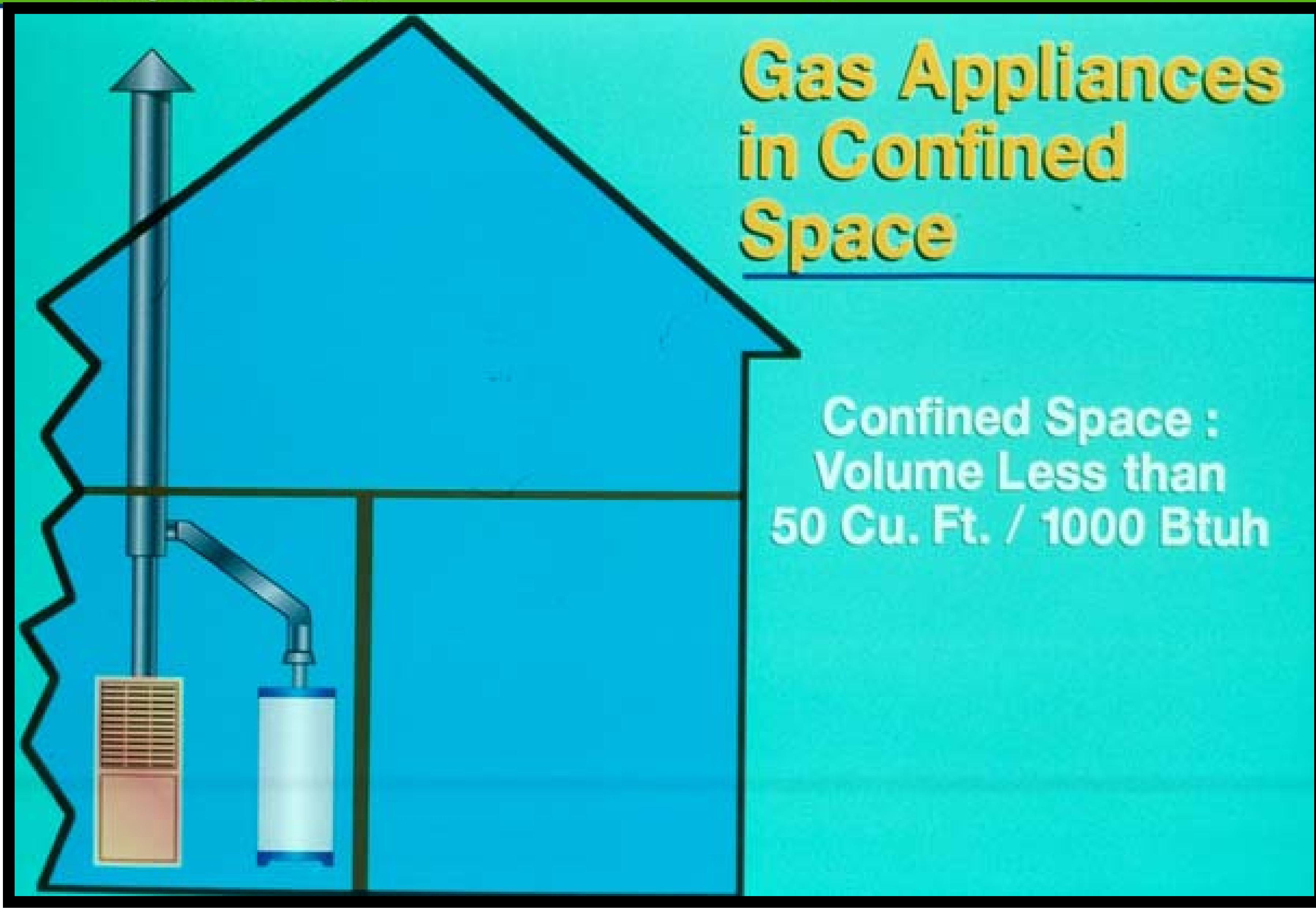
- Switch to non-atmospherically vented equipment
- Make combustion "zone" completely connected to unconditioned space or outside AND completely separated from conditioned space by a continuous air barrier and thermal barrier
- Always provide combustion "zone" with adequate (idiot proof) combustion air using the National Gas Code guidelines



80%, mid-efficiency or induced draft furnace

Direct Vent Water Heater

Sealed Combustion Condensing 90%+ AFUE Furnace


Gas Appliances in Confined Space
Confined Space : Volume Less than 50 Cu. Ft. / 1000 Btuh

All Air From Inside the Building

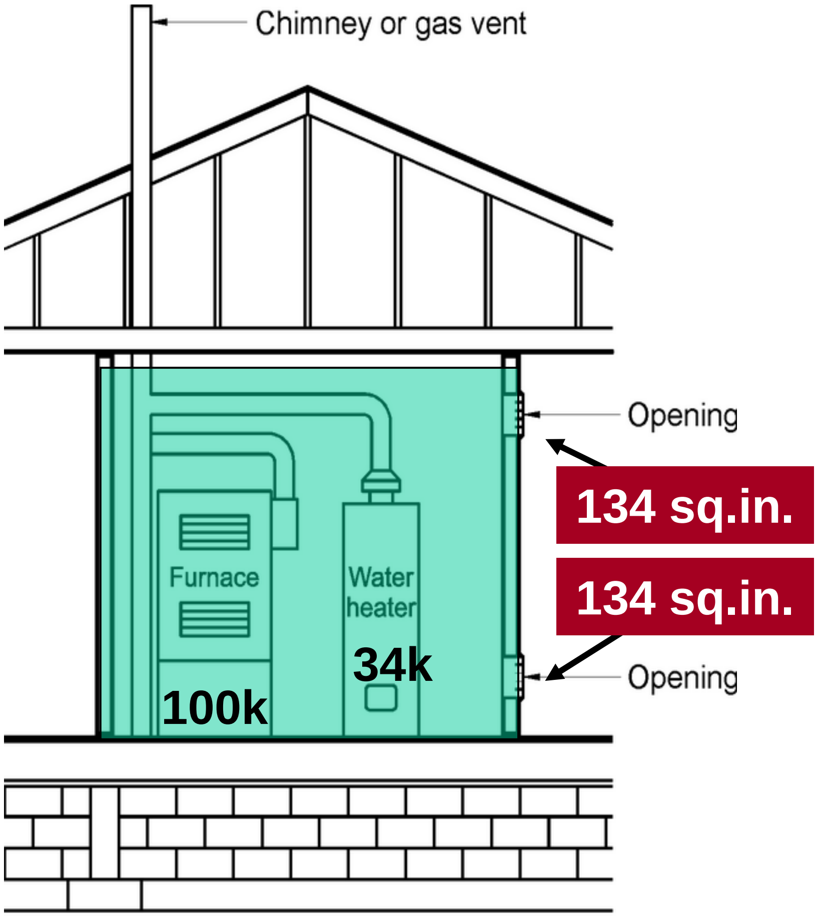


FIGURE 304.3.1

Example:

- Furnace = 100,000 btu/hr input
- Water heater = 34,000 btu/hr input
- Total btu/hr = 134,000 btu/hr input
- **1 square inch per 1,000 btu/hr input required.**
- 134,000 / 1,000 = 134 square inches for each opening.
- One within 12 inches of ceiling & one within 12 inches of the floor.

All Air From Outdoors. Method 1a - Vertical

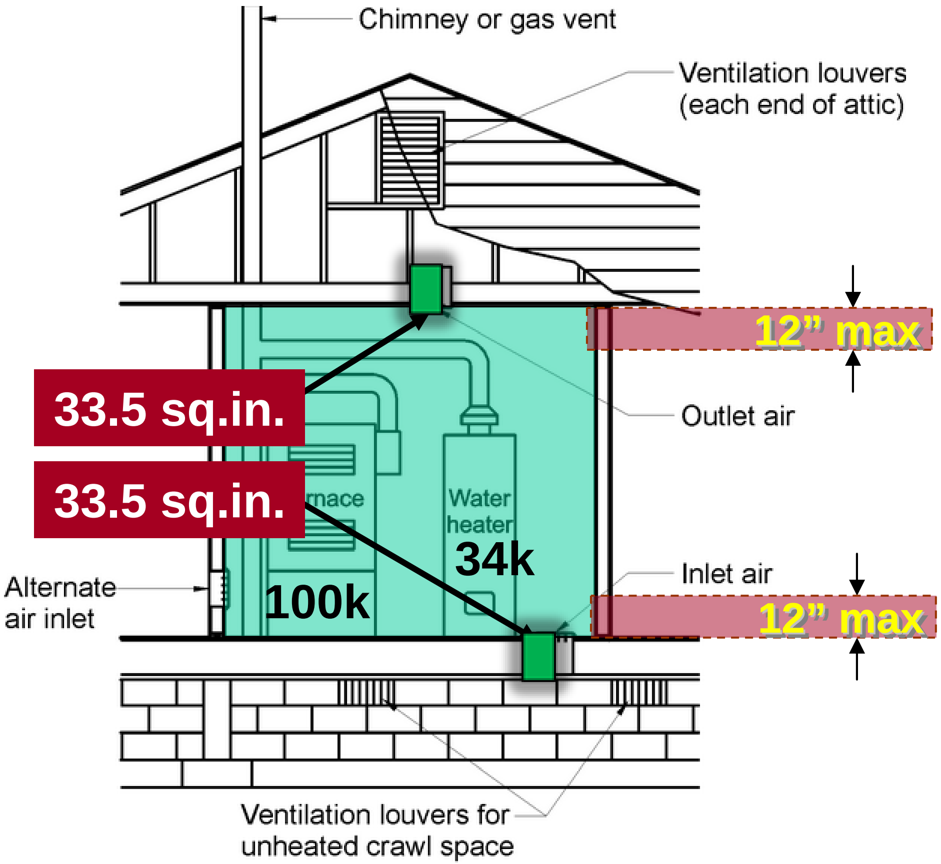


Figure M703.2(b)

- Example:
- Furnace = 100,000 btu/hr input
- Water heater = 34,000 btu/hr input
- Total btu/hr = 134,000 btu/hr input
- **1 square inch per 4,000 btu/hr input required.**
- 134,000 / 4,000 = **33.5** square inches for each opening.
- One within 12 inches of ceiling & one within 12 inches of the floor.

All Air From Outdoors. Method 1b - Horizontal

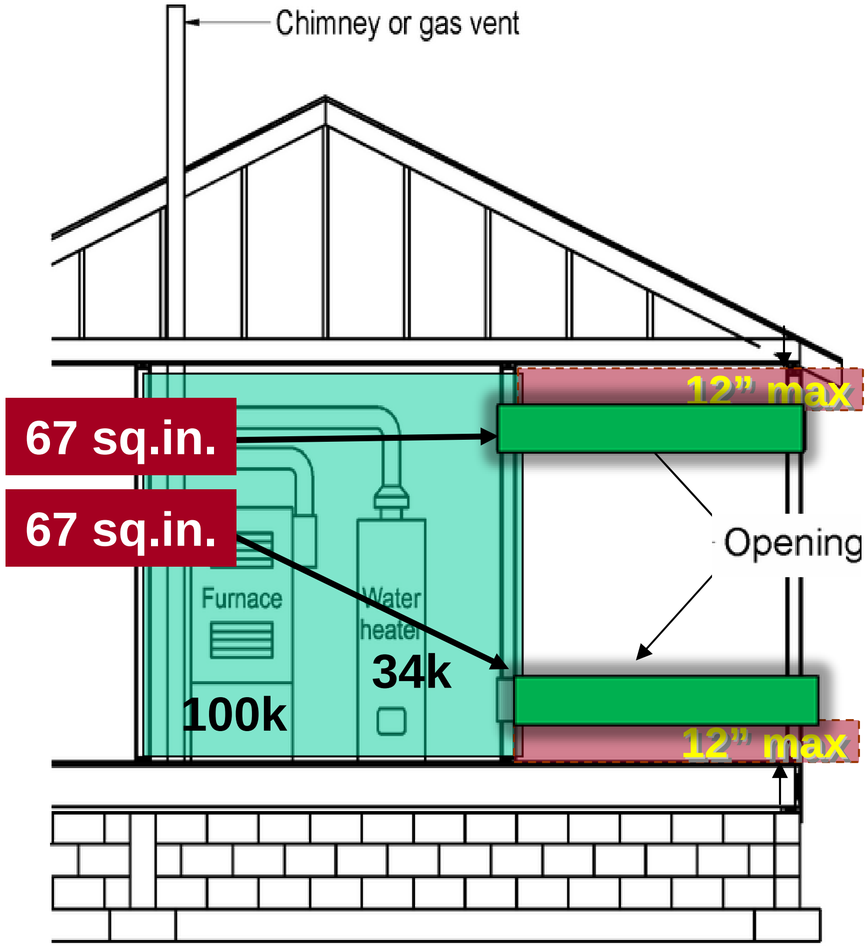


Figure M703.2(c)

Example:

- Furnace = 100,000 btu/hr input
- Water heater = 34,000 btu/hr input
- Total btu/hr = 134,000 btu/hr input
- **1 square inch per 2,000 btu/hr input required.**
- 134,000 / 4,000 = **67** square inches for each opening.
- One within 12 inches of ceiling & one within 12 inches of the floor.

All Air From Outdoors. Method 2

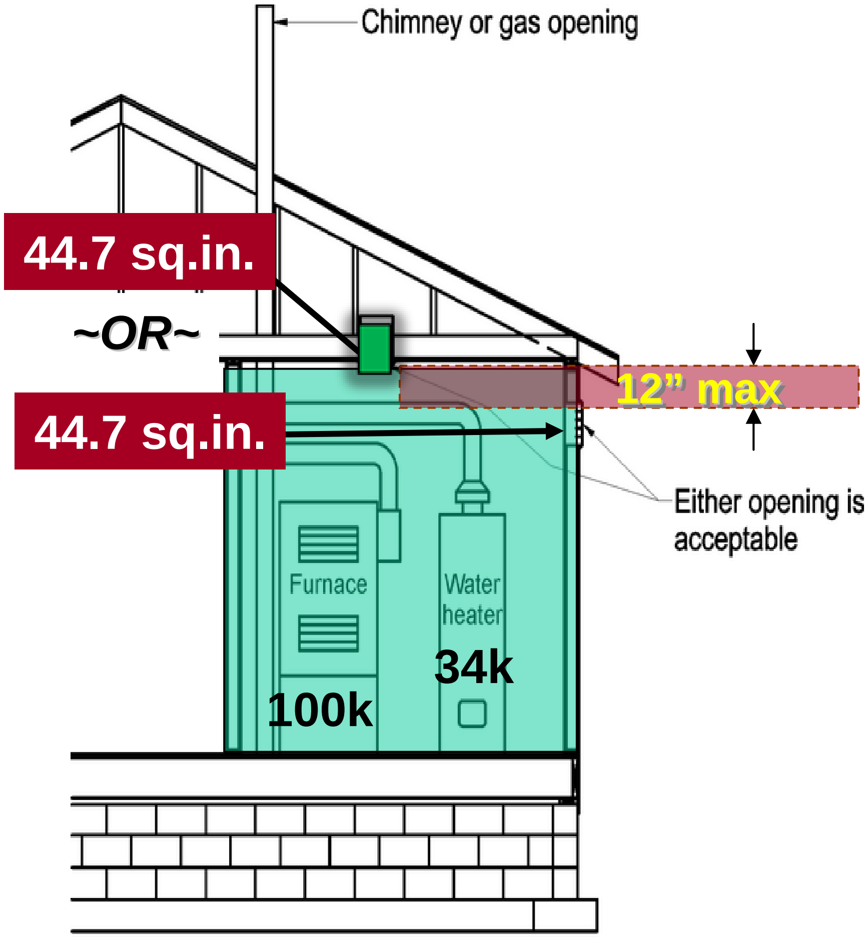


Figure M703.2(d)

- Example:
- Furnace = 100,000 btu/hr input
- Water heater = 34,000 btu/hr input
- Total btu/hr = 134,000 btu/hr input
- **1 square inch per 3,000 btu/hr input required.**
- 134,000 / 4,000 = **44.7** square inches for each opening.
- Within 12 inches of ceiling

Whole house air pressure

- For Hot Humid Climate
  - Negative House Pressure – Bad
  - Neutral House Pressure – Good
  - Positive House Pressure – Better
- Causes of negative house air pressure
  - Exhaust fans
  - Closed interior doors
  - Supply duct leakage
  - Supply duct leakage > return duct leakage
- To induce slight positive pressure…
  - Small amount of filtered, controlled outside air

- Air barrier and duct system holes are hard to see, but can be measured with a testing equipment.

Controlling Water, Air, and Heat

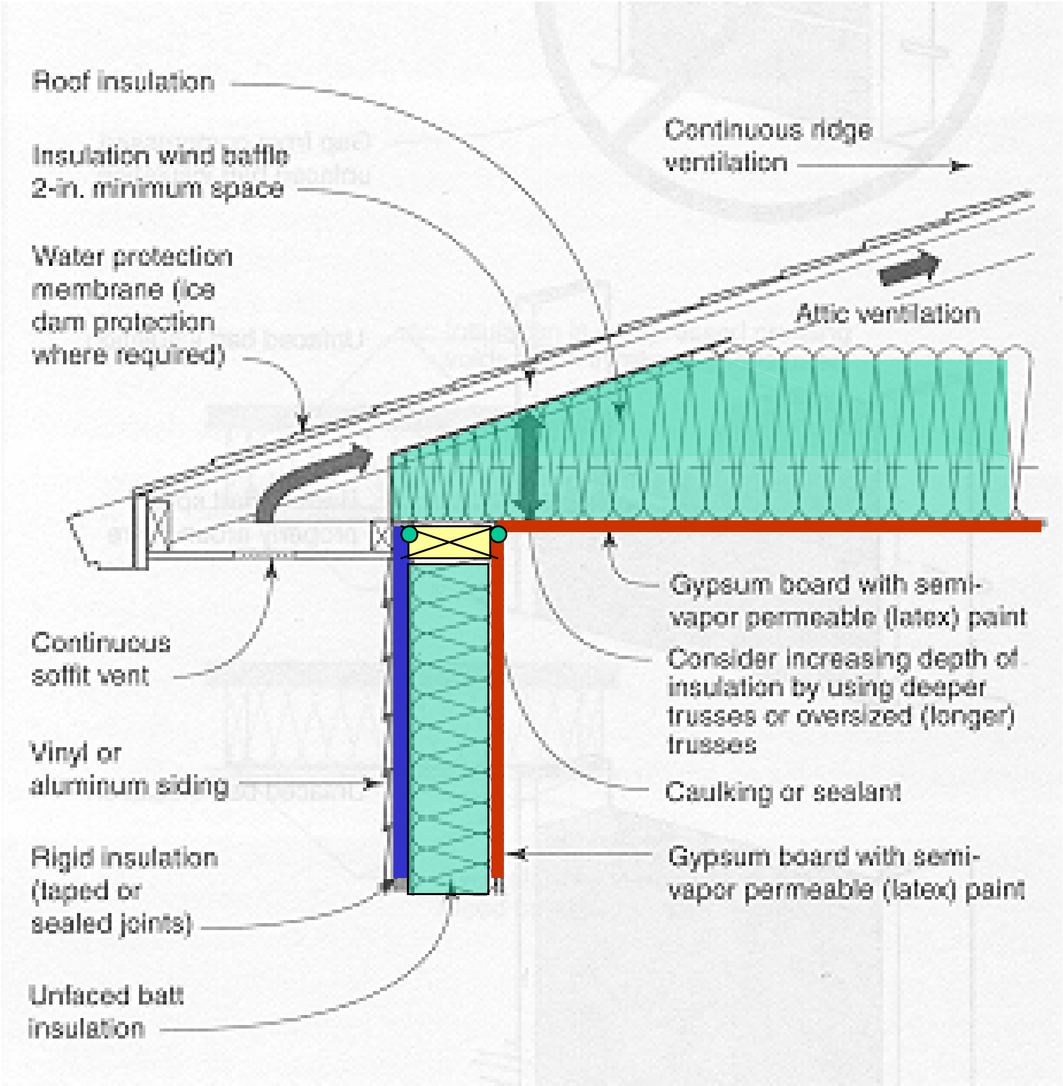
Principal Strategies

Water:
- Dry Materials
- Exterior finishes
- Continuous Drainage Plane
- Flashing
- Assemblies that Dry
- Exhaust wet air

Air:
- Continuous Air Barrier
- Sealed Duct System
- Neutral Air Pressure

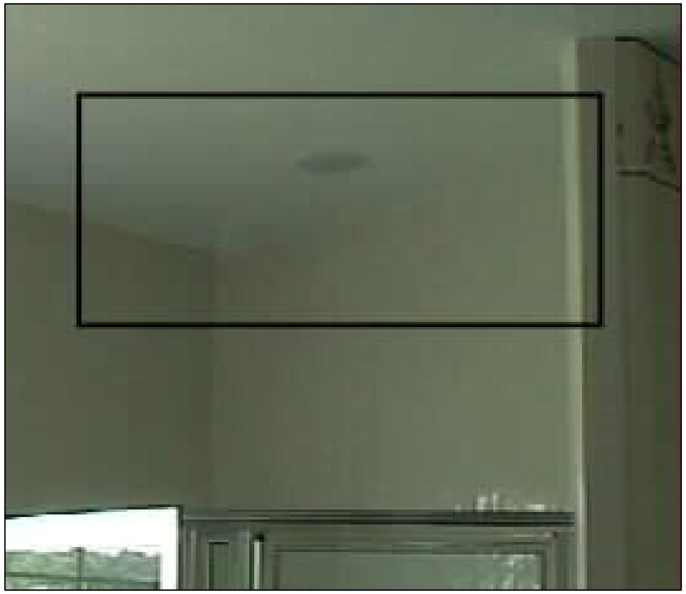
Heat:
- Continuous, Even Layer of Insulation

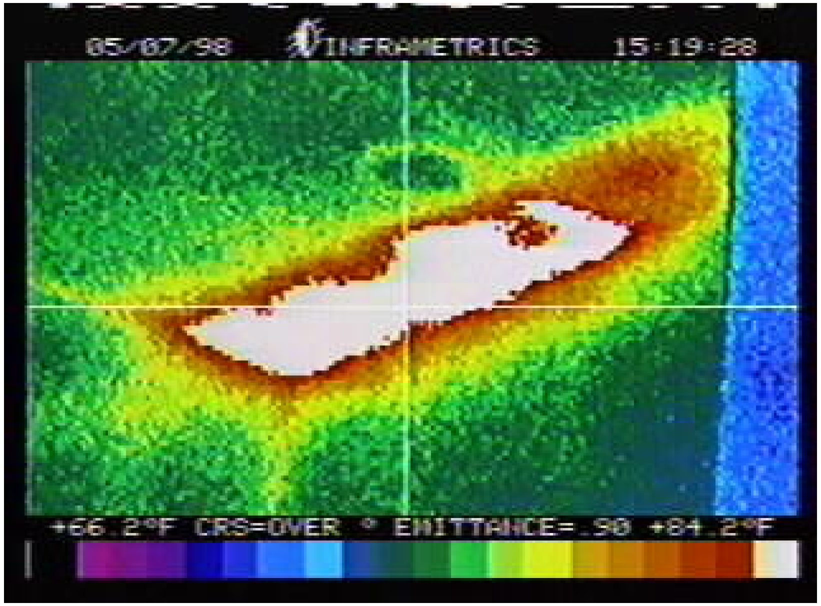
Controlling Water, Air, and Heat



Thermal Barrier

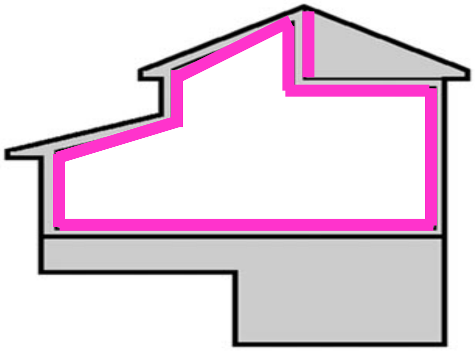
- Install in a continuous, even layer
- Missing insulation isn't seen, it's felt.





- Like a hole in your coat.

Building Science Summary



- Driving Forces
  - Temperature difference
  - Pressure difference
- Control Boundaries
  - Air barrier, sealed duct system, thermal barrier, drainage plane
- Energy Star for New Homes
  - Thermal Bypass Inspection covers air and heat flow!
  - www.energystar.gov

Step 1 – Achieve Energy Star

- Home energy rating system index
- Energy star program overview and technical requirements
- Thermal bypass inspection
- Overview of Afternoon Field Activities

Preliminary Evaluation

- The HERS Index
- HERS=Home Energy Rating System
- Compares a "designed" or "as built" home
- To the HERS "Reference Home"
  - same size, wall areas, structural system, fuel
  - Minimum efficiency equipment
  - Insulation etc to comply with 2004 International Energy Conservation Code (IECC)

Preliminary HERS Index Evaluation for Demonstration House Partners