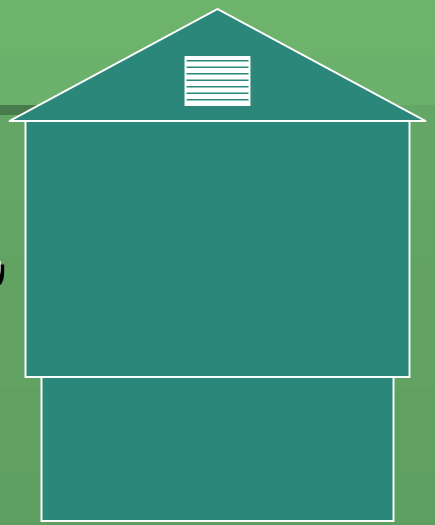
Auditor I

DAY Five

Tony Gill
MaineHousing

Homework House



- 20' x 30' (average 8") log cabin
- Two 6'- 8" x 3' x 2" wood doors
- Heated 7' 6" concrete basement,
- Sill 18" above grade,
- 6" fiberglass in attic
- Five 3' x 4' single pane windows with storms
- 1"styrofoam under cedar shakes on exterior
- exposed log interior
- H^2O = immersion coil
- CFM50 = 1800
- 7500HDD
- HO reports 4 fill-ups/yr ≈ 200-250 gal. each

Conductive Heat loss

- Ceiling: 20’ x 30’ x 7500HDD x 24hrs / 17
- Walls: 100’ x 8’ – (W&D) 7500HDD x 24 / ≈12 [(sid=1.styr=5.log=8) -10%+]
- Windows: 3’ x 4’ x 5 x 7500HDD x 24hrs / 2
- Doors: 6.66’ x 3’ x 2 x 7500HDD x 24hrs / 2
- Basement: 100’ x 1.5’ x 7500HDD x 24hrs / 1

Air transported heat loss

- Q = Vol x AC/H x 0.0182BTU/ft^3,°F x HDD x 24hrs

OR

- Q = CFH x 0.0182BTU/ft^3,°F x 7500HDD x 24hrs
- CFMnat = CFM50/LBLn = 1800/18.5 = 97CFMnat
- CF<u>H</u>nat = CF<u>M</u>nat x 60 minutes = 5820 ft^3/hr natural

Air transported heat: 5820 x 0.0182 x 7500 x 24

Domestic H^2O

- Immersion coil ≈ 15 gallons/#2 month
- 15 gal x 12 mo = 180 gal/yr

Do it in Therms ?

A therm = 100,000 BTU.

- Ceiling: 6,352,941 BTU/yr = 63.5 therm
- Walls: 10,500,000 BTU/yr = 105 therm
- Windows: 5,400,000 BTU/yr = 54 therm
- Doors: 3,600,000 BTU/yr = 36 therm
- Basement: 27,000,000 BTU/yr = 270 therm
- Air transport: 19,066,320 BTU/yr = 191 therm
- <u>$H^{2}O$: 18,000,000 BTU/yr = 180 therm</u>
- Total: = 899.5 therm

2 fuel oil burned @ 72% seasonal efficiency

≈ 100,000 BTU/gallon. A therm equals a gallon!

So whatcha' gonna' do?

- Ceiling: 63.5 therm/yr $286/yr
- Walls: 105 therm/yr $473/yr
- Windows: 54 therm/yr $243/yr
- Doors: 36 therm/yr $162/yr
- Basement: 270 therm/yr $1,215/yr
- Air transported: 191therm/yr $860/yr
- H^2O: 180 therm/yr $810/yr

$4,049/yr

($4.50/gal fuel)

Choose what's best !

- Basement walls: $2/sq' to install R-10
  - 4' x 100' x $2 = $800 to reduce by 148 therm/yr
- Domestic hot water: $2,000 to install cold start
  - $2,000 to reduce by ≈ 60 therm/yr
- Air moved heat loss (a bit more complicated!)
  - House vol = 20' x 30' x 8' = 4800 cu', so…
  - 4800 cu' x .35ACH = 1,680 cu'/hr required.
  - 5,820 nat – 1,680 req = 4,140 cu'/hr excess air
  - Opportunity to reduce by ≈136 therm/yr
  - Cost would include air sealing and mechanical ventilation (installation, maintenance & operation)

Review !

What's this ?

Attics revisited (One last time!)

The vast majority of air moving through houses is driven by stack effect.

Insulating the attic without airsealing it will not reduce the volume of air moved into the attic by stack effect.

Insulating the attic will lower the attic temperature causing condensation on surfaces which previously remained above the dew point.

Adding attic venting will most likely cause even more condensation in the attic as the “relief” at the top will pull harder on the house, moving more house air up.

The ONLY reliable “fix” is air sealing.

Quiz !

1. What is the latent heat of vaporization?
2. 24’ x 40’ two story house. 8’ ceilings. 7500 HDD. 900 gallons #2 fuel oil:
   - Calculate Home Heating Index (BTU/HDD/Sq’).
   - How many cubic feet of air must be moved through the house each hour to satisfy ASHRAE 62 (.35 ACH).?
3. What is the BTU content of:
   - One gallon of # 2 fuel oil? One gallon of propane?
   - 1 KWH of electricity?
4. What is a therm?
5. What is the function of a thermostat anticipator?

Quiz !

1. What is the latent heat of vaporization? 970 BTU/LB
2. 24' x 40' two story house. 8' ceilings. 7500 HDD. 900 gallons #2 fuel oil:
   - BTU/HDD/Sq'. 125,100,000BTU/7500DD/1920sq'= 8.7
   - cubic feet of air each hour to satisfy ASHRAE (.35 ACH).? 960sq' x 8' x 2 = 15,360 Cu' x .35ACH = 5376 Cu'
3. What is the BTU content of:
   - One gallon of # 2 fuel oil? 139,000
   - One gallon of propane? 92,000 1 KWH of electricity? 3412
4. What is a therm? 100,000 BTUs
5. The thermostat anticipator turns off the circulator just before the t'stat set temp is reached to prevent room overheating

DAY Five –Week One

- The blower door
- Pressure Diagnostics
- Unity Village
- Review

The blower door

- Blower doors measure air flow at a known pressure.
- Prior to the test the operator:

1. Puts the house in wintertime condition.
2. Opens all interior doors
3. Shuts off any atmospheric combustion appliances.

- A blower door can:

1. Locate leaks.
2. Determine sq. in of hole in the tested surface.

- Comparing pre & post wx BD test results can:

1. Quantify air leakage reduction.
2. Indicate the need for further work.

The blower door

- The rings are to restrict air flow in small, tight houses.
- On the other end, if you can't reach 50Pa pressure, use the "can't reach 50" chart to project a CFM^{50} figure.
- CFM^{50} results range from 300 to 10,000+. The number is generally dependent on house size.
- The average #'s are steadily decreasing as air sealing installers improve technique and inherently tighter methods/products are employed.

The Blower Door !

Used to:

- Find holes
- Quantify holes
  - Relative size
- Determine “connectedness”
- Pressure diagnostics

With Infrared

UNITY VILLAGE

A Case Study

Tony Gill
Field Inspector, EHS Division
Maine State Housing Authority
April, 2005

Situation as Found

- 4 Apt. bldgs. Downtown Portland, Maine.
- ≈ Two Years Old.
- Thirty Three 2 & 3 Bedroom units.
- Some Section 8 vouchers.
- Heat included in rent.

Typical exterior elevations

The Problem:

Constant tenant complaints about cold.

Heating fuel use significantly higher than expected.

Water pipes freezing in floor/ceiling cavities.

The Buildings:

- Quality construction: Double studded walls between apartments for soundproofing & web floor trusses to eliminate interior bearing walls.
- Insulation is fiberglass – 6” batts in the walls and 6” batts with 8”-10” blown over in the attics.
- All drywall backed with 6 mil poly vapor retarder.

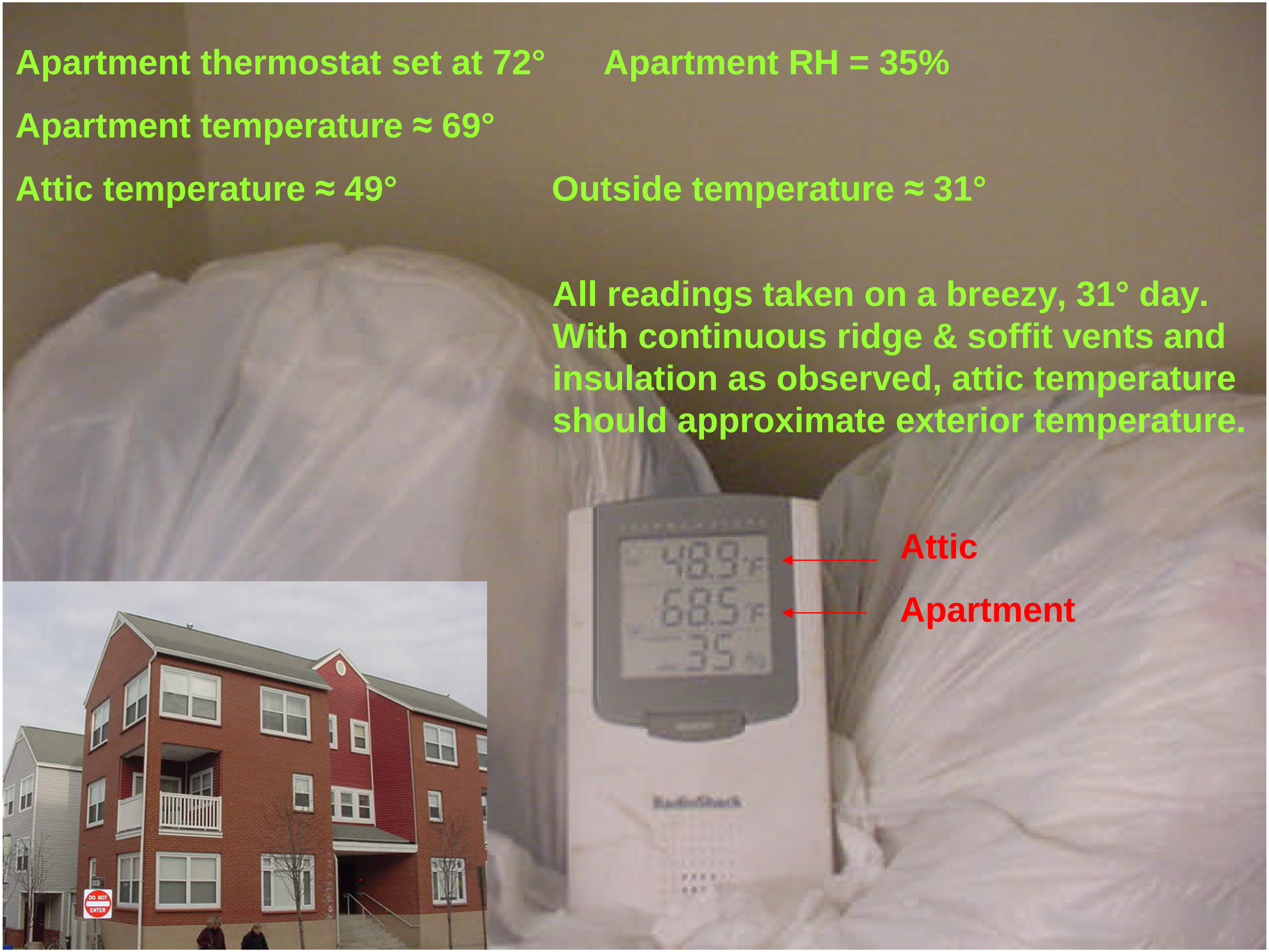
BLOWER DOOR

Individual Units Test
< 1000 CFM50

(Within acceptable limits)

INFRARED SCAN

- Generally acceptable insulation installation practices.
- Significant outside air leakage into interior wall & ceiling cavities!
- Observed pattern of air leakage into cavities does not change when the blower door is in operation!


Apartment thermostat set at 72°
Apartment RH = 35%
Apartment temperature ≈ 69°
Attic temperature ≈ 49°
Outside temperature ≈ 31°
All readings taken on a breezy, 31° day. With continuous ridge & soffit vents and insulation as observed, attic temperature should approximate exterior temperature.
48.9°F
68.5°F
35%
Attic
Apartment
RadioShack
DO NOT ENTER

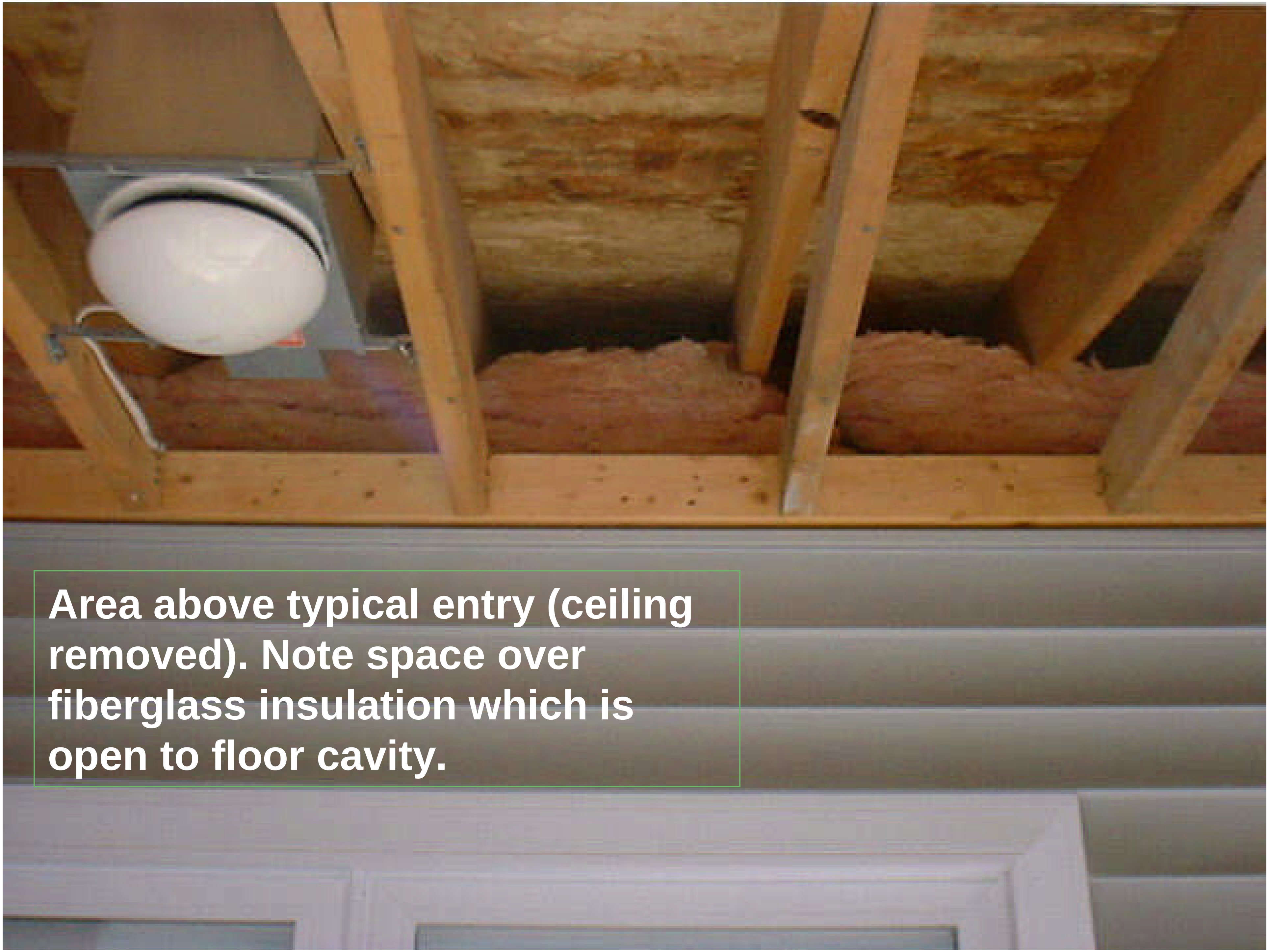
Top of double walls between apartments with vent stack as seen from the attic.

Top of an interior partition with vent stack as seen from the attic.

Top of an interior partition with vent stack as seen from the attic.

Top of interior partitions with vent stack, unused penetration & electrical wire hole as seen from the attic.

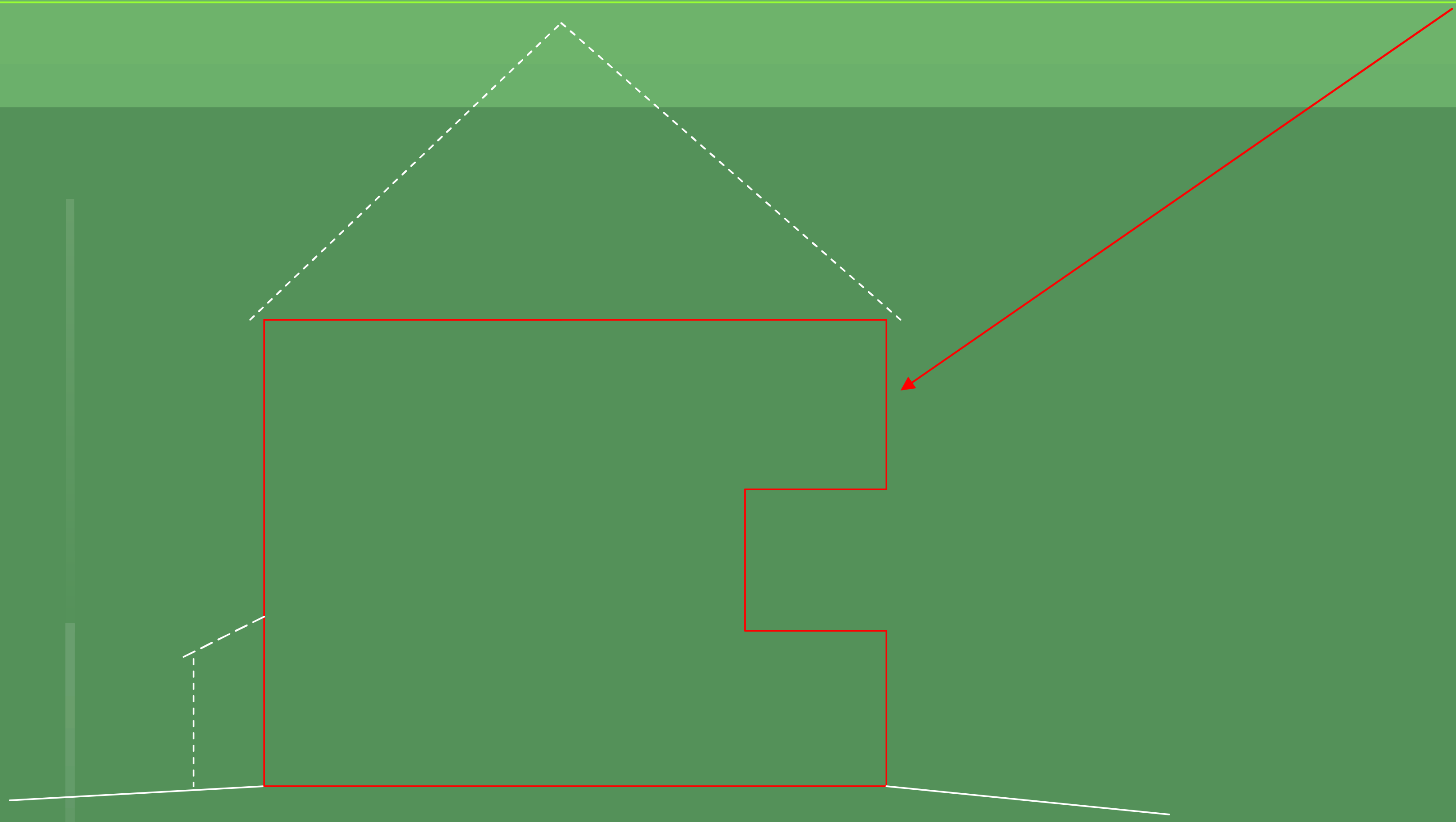
Typical entry overhang with vented soffit



Area above typical entry (ceiling removed). Note space over fiberglass insulation which is open to floor cavity.

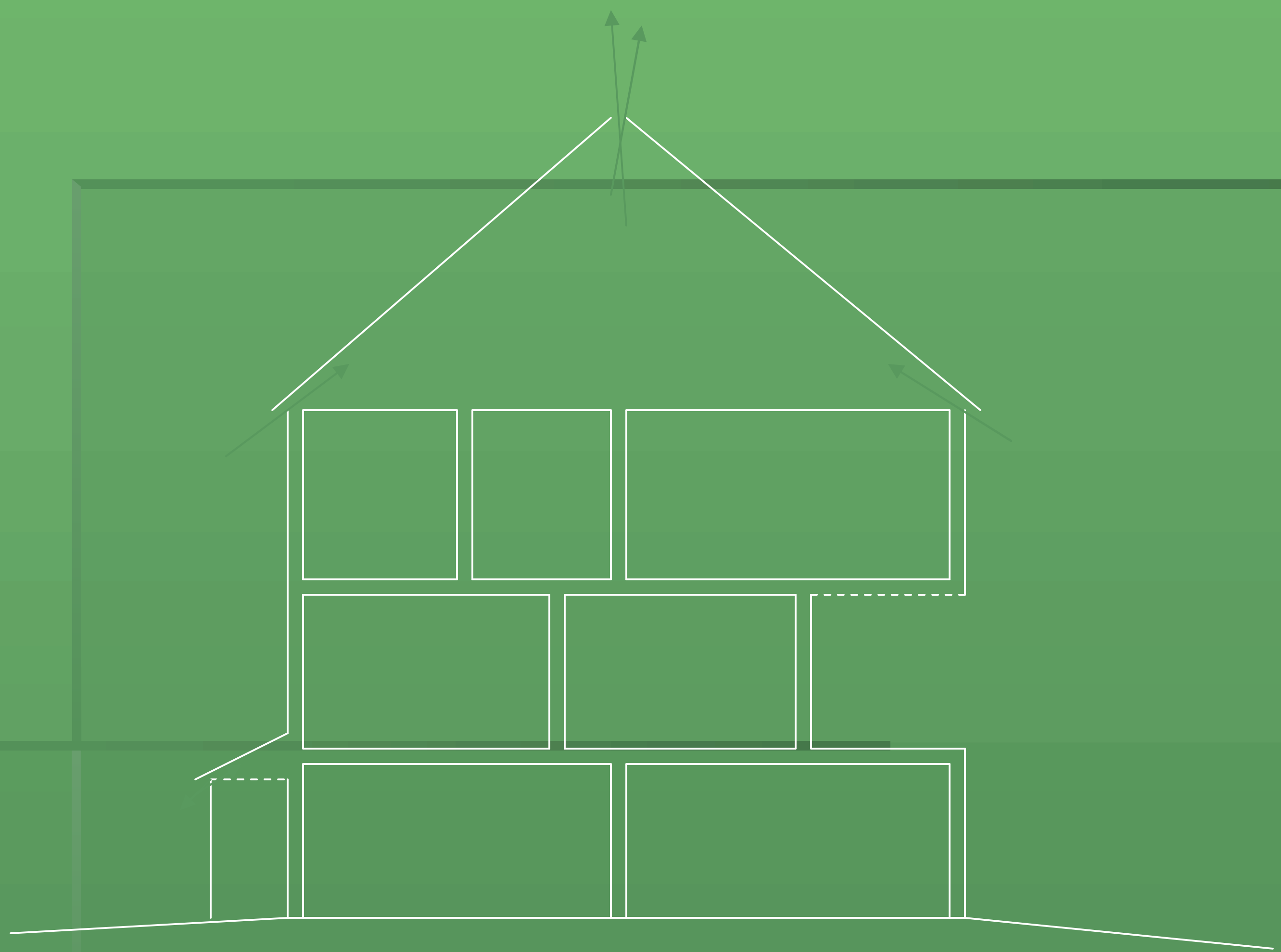
Area over typical entry (Ceiling removed) open to ceiling cavity over heated room.

Where the building designers intended for the heat barrier to be.



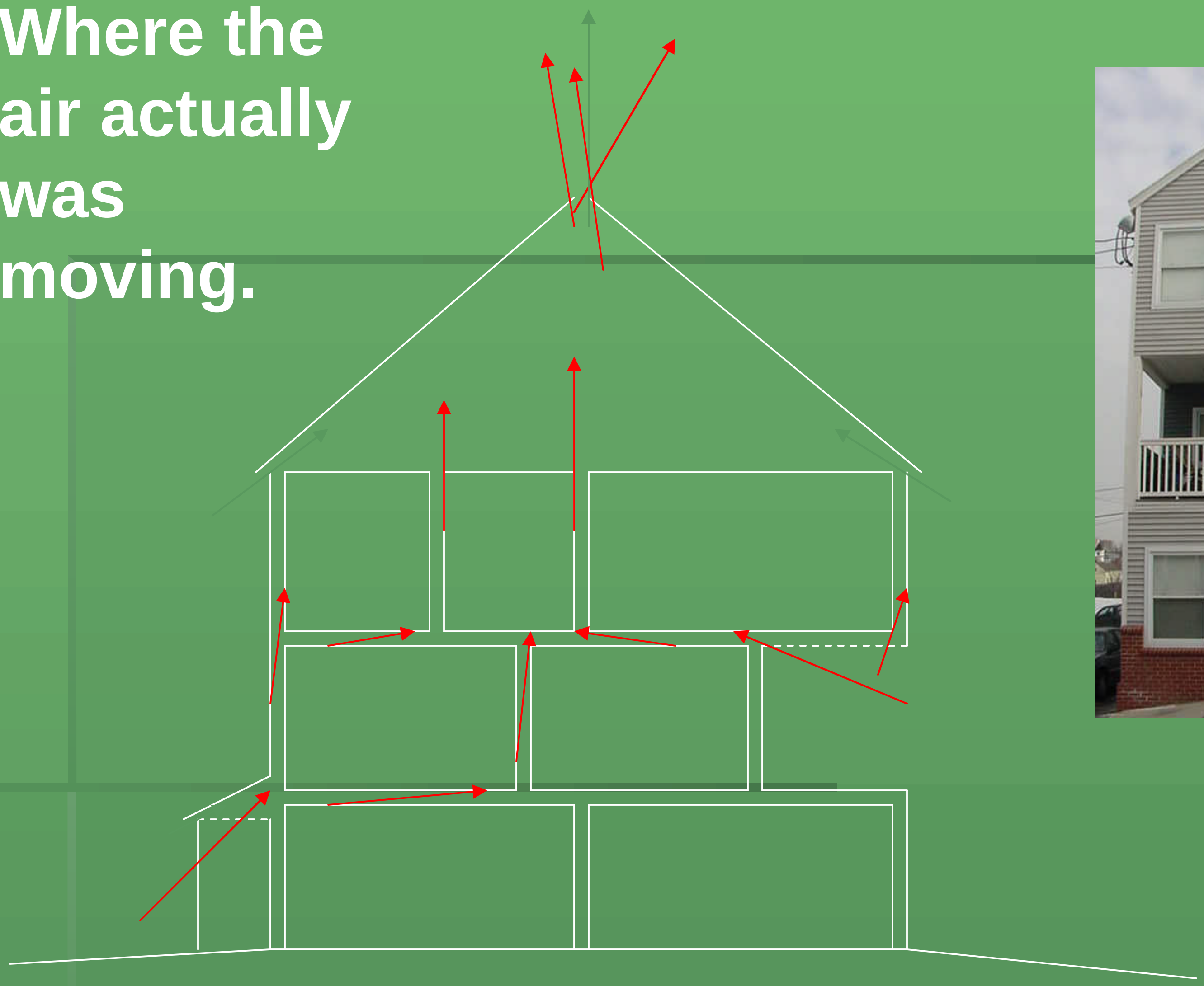
Solid red lines = Surface area intended to “see” cold.

How the building designers intended for attic ventilation air to move through the building.



Blue Arrows indicate ventilation air moving through soffit & ridge ventilation.

Where the air actually was moving.



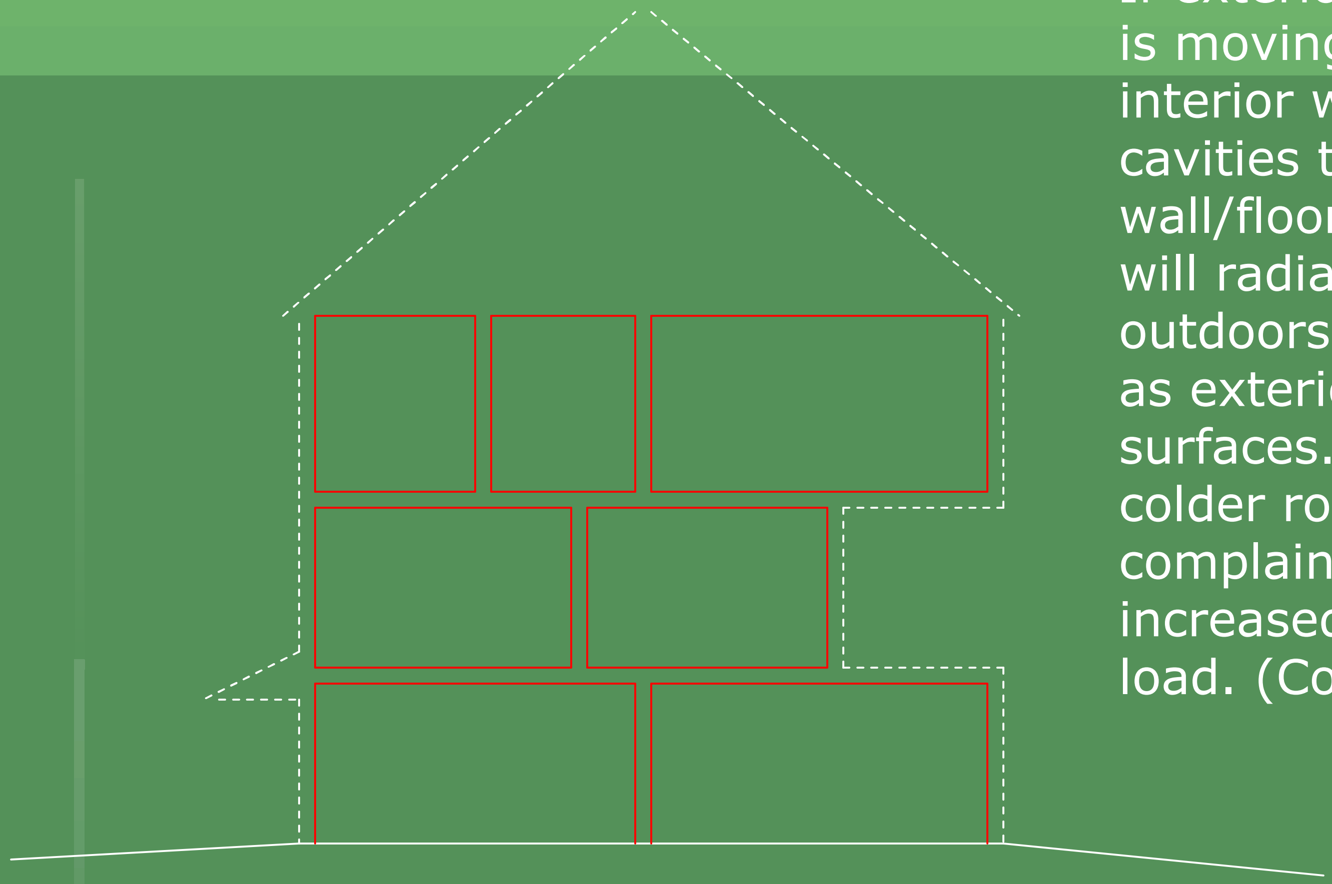
Blue Arrows indicate air moving through soffit & ridge ventilation.

Red arrows indicate exterior temperature air moving through wall & floor/ceiling cavities (driven by wind & stack effect).

Where the heat barrier actually was!

Heat loss is a function of time, Δt & surface area.

If exterior temperature air is moving freely through interior wall, ceiling & floor cavities the corresponding wall/floor/ceiling surfaces will radiate heat to the outdoors at the same rate as exterior wall & ceiling surfaces. The result is colder rooms, occupant complaints and dramatically increased the building heat load. (Cost to heat)



Solid red lines = Actual room surfaces "seeing" cold due to exterior air moving through wall and ceiling cavities.

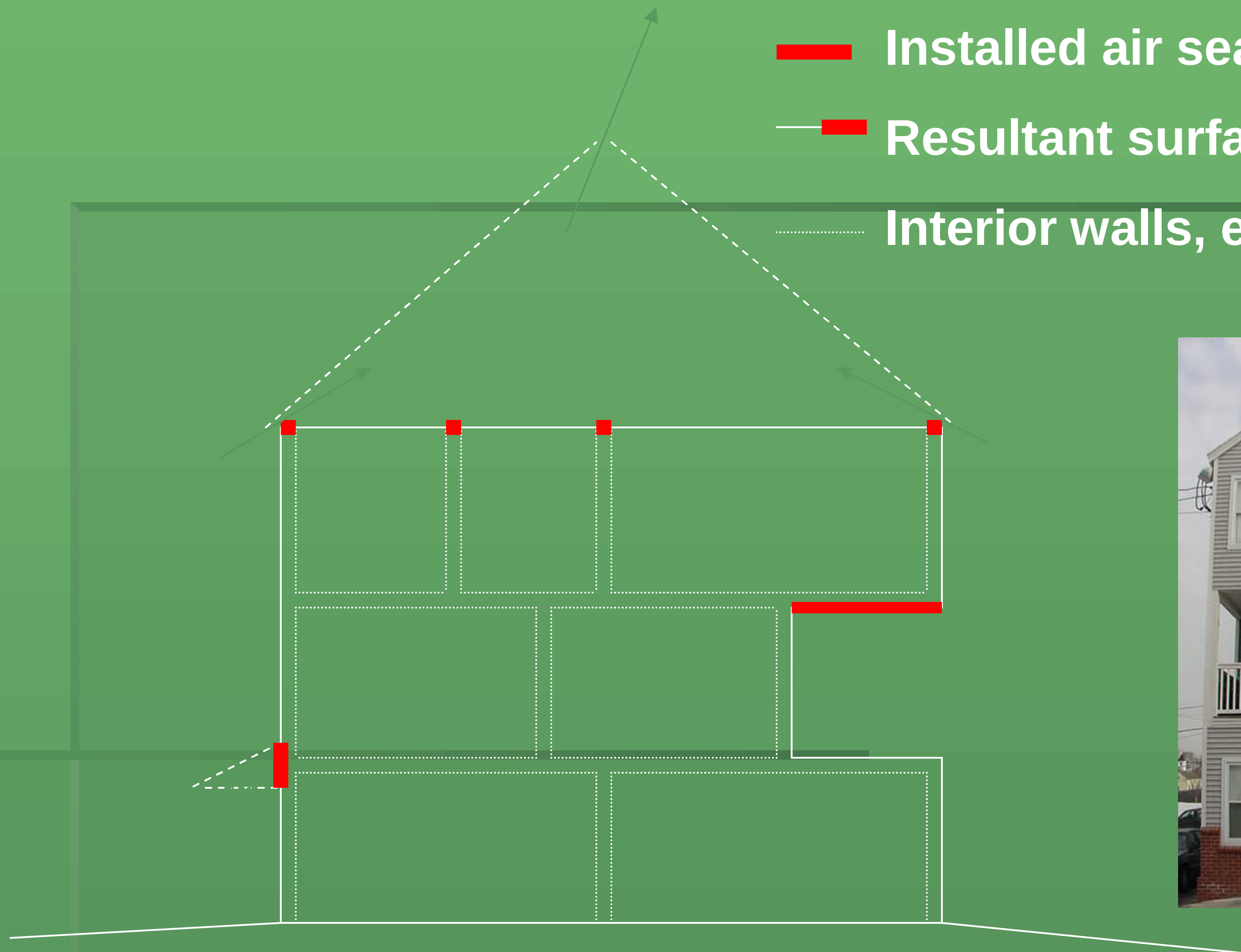
The Retrofit

Attic ventilation air.

Installed air sealing.

Resultant surface of heated area.

Interior walls, etc.



Blocking the unintentional air “feed” openings in the lower part of the building & the “relief” openings at the top of the building creates a continuous air & heat barrier surface where the building designers intended it to be.

Retrofit Measures

Air sealing installed by:

- **Removing & replacing attic insulation, locating and sealing all penetrations in the attic floor.**

- **Removing & replacing porch & bump out ceilings, caulking rigid board insulation in place over ceilings, thereby sealing off openings into floor/ceiling cavities.**

Using foam to air seal typical partition top in attic

Foam airsealing installed at top of typical step-down wall in attic.

Before

After

Foam air sealing installed at top of partition wall with vent stack in attic.

Before

After

Rigid insulation board & foam air sealing installed over entry ceiling.

Before

After

Rigid insulation board & foam airsealing installed over entry ceiling.

Summary:

Pre Air Sealing:

Several instances of frozen water pipes, at least one of which – a burst sprinkler line – caused severe property damage.

Cold apartments resulting in numerous tenant comfort complaints.

Excessive fuel consumption.

Post Air Sealing:

No frozen water pipes since work done.

No tenant heat related comfort complaints since work done.

Fuel consumption down about 20% since the work was done.

RESULTS

Net monthly savings*[1] extrapolated over one year approximates 4000*[2] ccf per year. At $1.42 per ccf – the current price – the $27,000 investment will be recovered in less than five years. As gas prices inevitably increase, the payback period will shorten correspondingly.

*[1] Post retrofit fuel use data is available from 12/04 to present. Pre retrofit fuel use data was obtained for 2003 & 2004.

Average of Jan, Feb, March ’03 & ‘04 gas heat use ≈ 9400 ccf.

Jan, Feb, March ‘05 gas heat use ≈ 7400 ccf.

This equals a savings of ≈ 667 ccf per month for the period where both pre & post retrofit fuel use data is available.

*[2] The actual heating season is at least 6 months longer than the period the available data set covers. We have arbitrarily doubled the three month usage to estimate the yearly use. Actual annual fuel savings are likely to be much greater than predicted.

Some Caveats:

This is simple payback only. No attempt was made to incorporate any discount rate or future fuel price increases.

Weather normalization was not done.

This is aggregate complex fuel consumption data. No attempt was made to differentiate between buildings.

Individual tenant behavior was not considered.

The fuel consumption data utilized was from records dated January, February & March, '03, '04, & '05. It is likely the periods when the fuel was actually used comprised consecutive 30 day periods not strictly aligned with the actual months stated. (i.e. say from the 10^{th} to the 10^{th}, as opposed to the 1^{st} to the 1^{st}.)

Because the actual heating season is much longer than the period the data set covers, realized annual space heat fuel savings are likely to be much greater than what is being predicted, resulting in a significantly shorter payback period.

State Certification Test Review

1. Definitions
2. Facts you should know
3. DTL – MVG - ASHRAE 62.2
4. Formulas & calculations
5. Heat transfer mechanisms
6. Air leakage
7. Moisture
8. Combustion appliances
9. Domestic water heaters
10. Construction styles
11. Blower Door
12. Other

1. Definitions

- Latent heat:
  - The amount of heat absorbed or released by a substance when it changes state.
  - LH of fusion = solid to/from liquid
  - LH of vaporization = liquid to/from gas
- Temperature:
  - The value assigned to molecular motion in any given substance

1a. Definitions

- ACH - Air Changes per Hour:
  - The number of times each hour the volume of air contained by a structure is completely replaced by outside air.
- Stack Effect:
  - The tendency of warm air to rise
- BTU – British Thermal Unit:
  - Amount of heat required to raise the temperature of one pound of water 1°F
- HDD – Heating Degree Days:
  - HDD = 65° - [(high temp + low temp)/2]
  - Based on average internal temperature being 70˚F.

1b. Definitions

- Internal Gain:
  - Heat given off by people & appliances
  - 5 to 7˚F
- R-Value:
  - Measure of resistance to heat flow
  - Expressed in BTU/hr, ft́, ˚F
  - Inverse of U-Value
- U-Value:
  - Measure of heat transmission
  - Inverse of R-Value

1c. Definitions

- Steady state efficiency:
  - The measured instantaneous efficiency of a combustion appliance at operating temperature expressed as a percentage of the energy available from the fuel consumed.

  i.e. the % of energy that doesn't go up the chimney.
- AFUE – Annual Fuel Use Efficiency (AKA):
- Seasonal efficiency:
  - The calculated annual efficiency of a combustion appliance, including warm-up, cool-down & standby losses over an entire heating season.

  i.e. the % of energy provided to the delivery system.
- Design Temperature:
  - The temperature low which is <u>not exceeded</u> > 2.5% of the heating season. i.e. 97.5% of the time, the temp is higher.

2. Facts you should just know !

- Q= Area x ΔT/R
- 1 BTU = energy to raise 1 lb water 1 °F
- 1 BTU = one wooden kitchen match
- 1 gallon #2 Fuel ≈ 139,000 BTUs
- 1 gallon propane ≈ 92,000 BTUs
- 1 kWh electricity = 3,412 BTUs
- 1 cubic foot natural gas ≈ 1,000 BTUs
- 1 Therm = 100,000 BTUs
- 1 Pascal = 1/250 inches of water
- R=1/U - U=1/R
- R-Values can be added: U-Values can not.

3. DTL– MVG – 62.2

- DTL – Depressurization Tightness Limit:

  The measured number below which combustion appliances are likely to backdraft.

- MVG* – Minimum Ventilation Guideline:

  The calculated number below which mechanical IAQ ventilation is required based on climate zone, # occupants, building sq', height, volume & exposure and the LBL correction factor.

ASHRAE 62.2:

Ultimate version – calculates fan CFM & run time

* Sometimes referred to as the Building Tightness Limit or BTL

3. DTL– MVG – 62.2

- IAQ ventilation:
  - Maintains air quality
  - Decreases moisture build-up
- Attic Ventilation:
  - May reduce ice damming
  - Does little else

4. Formulas & Calculations

- Area:

  A = Length x Width

- Volume:

  V = Length x Width x Height

- Area of a Triangle:

  A(Δ) = Base x ½ Height

- Area of a Circle:

  A(O) = 3.1416 x radius squared [$A = pi\ r^2$]

- R = 1/U - R = BTU/ft^2,hr,°F
- U = 1/R

4a. Formulas & Calculations

- Surface heat loss

  Q= Area x Temperature Difference/Resistance

  [Q=A x ΔT/R]

  Q= A x Heating Degree Days x 24 hrs/R

  [Q=A x HDD x 24/R]

- Air driven heat loss

  Q=Volume x AirChange/Hour x 0.0182btu x ΔT

  [Q= V x AC/H x 0.0182 x ΔT]

  Q= V x AC/Hr x 0.0182btu X HDD x 24 hrs

  [Q= V x AC/H x 0.0182 x 24]

5. Heat Transfer Mechanisms

In auditing, heat loss is categorized as follows:

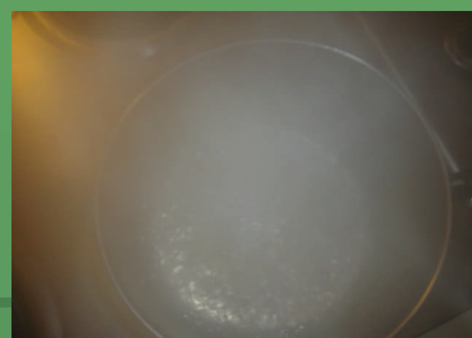
1. Transmission or Surface Heat Loss
   - Conductive, Convective & Radiant
   - Driven by ΔT (Temperature Difference)
   - Dependent on Area & time
   - Resisted by insulation (R-Value) $Q=(\Delta T \times A \times t)/R$
2. Air Leakage or Infiltrative Heat Loss
   - Requires driving force
     - Stack effect
     - Wind
     - Mechanical
   - Requires a hole

5a. Heat Transfer Mechanisms

- Conductive

The burner is conducting heat to the bottom of the pan

- Convective



The water in the pan is being evenly heated by convection.

- Radiant

The burner is radiating heat into the space above it.

Radiant heat transfer is the only transfer mechanism that does not require a medium.

6. Air Transported Heat Loss

- Subset of convective heat loss
- Requires a driving force
- Requires a hole
- Can be controlled by:
  - Sealing the holes
  - Eliminating the driver
- Major driver in NNE is stack
  - Goes away in summer

7. Moisture

- Generally speaking, moisture should be regarded as a pollutant
- 99% of moisture is transported by air movement
- Can move by diffusion also
- Moisture retarders must be at the winter warm surface
- Condensation releases heat

8. Combustion Appliances

Categorized by:

- Fuel type
- Medium being heated
- Heat delivery method
- What made of

Efficiency is determined by subtracting ambient from stack temps & measuring percentage of CO^2 or oxygen in flue gas

8a. Combustion Appliances

- Sealed vs. atmospheric combustion
- Boiler vs. furnace
- Wet base vs. dry base
- Hi mass vs. low mass
- Cold start vs. temp maintaining

8a. Combustion Appliances

- CO is major concern:
- Leaking return ductwork can pull combustion byproducts into home.

9. Domestic Water Heaters

Categorized by:

- Fuel type
  - Electric
  - Gas (propane or natural gas)
  - Oil (#2 or kerosene)
- Sealed vs. atmospheric combustion
- Stand alone vs. appended to other appliance

9a. Domestic Water Heaters

- Should normally be set at 120°
- Are equipped with:
  - Temp/pressure relief valve
  - Sacrificial anodes
- Insulation payback and/or the amount of energy used depends on:
  1. Ambient temperature around the heater
  2. Temp of entering water
  3. Surface area of the tank
  4. Tank insulation
  5. Water temp set point
  6. Number of gallons used

10. Construction Styles

- Post & Beam *or* Post & Girt:

  Large timber frame with horizontal girts

- Balloon:

  Dimension lumber frame - headers & footers rare - irregularly spaced studs – floor stringers tied to sides of wall studs connecting floor & wall cavities.

- Platform:

  Dimension lumber frame - walls headed & footed @ each story – regularly spaced studs – floors typically extend through exterior walls to cladding & over interior walls, isolating all cavities.

- Pier & Post:

  Building supported by posts resting on poured piers in ground.

10a. Construction Terminology

- Header – Horizontal framing above a window or door or at the top of a wall
- Footer – Horizontal concrete shoe which poured wall rests on.
- Jack or cripple stud – Less than full height stud over or under a window or door – in knee wall, dormer, etc.
- Girt – Horizontal framing member in post & girt (post & beam) construction.

11. Blower Door

- Testing done in “Wintertime Condition”.
- Rings are to concentrate air by venturi openings.
- Remove rings when BD can’t reach 50PA.
- Add rings when fan reaches 50PA at low RPM.
- Primary value is locating leaks
- Readout in “Pascals” = 250^{th} of 1” water

12. Other

- Windows:
  - Tightness varies with condition & style
    - Double hung “losest”
    - Casement tightest