Auditor I

DAY TWO

Tony Gill
MaineHousing

Day II Agenda:

- Review Homework
- Quiz
- Energy
  - What is it?
  - Where does it come from?
- Surface & air transported heat loss
- R & U values
- Insulation comparisons
- Building envelope definition
- Costing ACH (preview)
- Attic & crawl space venting

Homework Answers !

- How many square feet of heated space?
  - 20’ x 30’ = 600 sq’
- How many gallons for domestic hot water?
  - 15 gallons x 12 months = 180 gal/yr
- How many BTU for space heat?
  - 700 gal – 180 gal = 520 gal x 139,000BTU/gal = 72,280,000BTU/yr (Fuel off the truck)
- What is Home Heating Index rating ?
  - 72,280,000/600/7500 = 16 BTU/sq’/HDD

Day II Quiz !

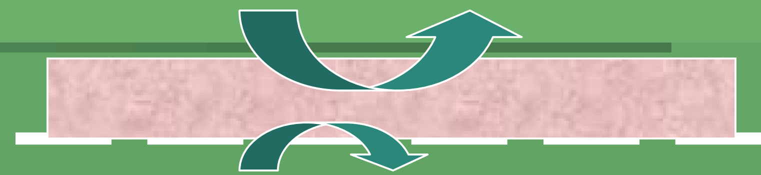
- What is a BTU ?
- What is a Therm ?
- What is a Quad ?
- How are Degree Days determined ?
- What is electrical baseload?
- How is baseload determined?

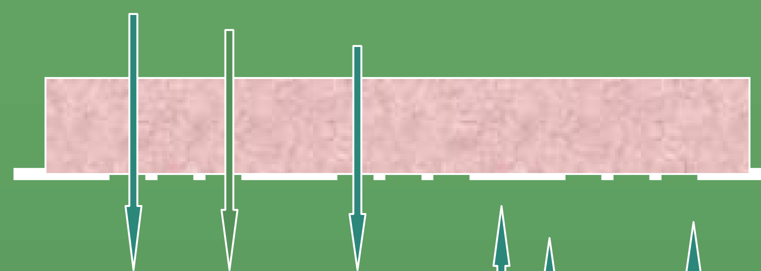
Quiz Answers

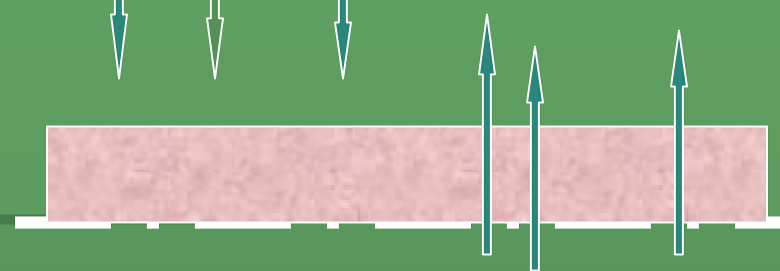
- A British Thermal Unit (BTU) is the amount of heat required to raise 1 lb of water 1º F.
- A Therm = 100,000 BTUs
- A Quad = a quadrillion BTUs – 10 BTUs to the 15^{th} power – 10 with 15 zeros beside it –

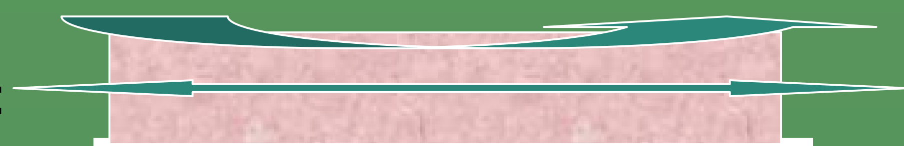
  10,000,000,000,000,000 BTUs !
- Degree Days are determined by adding the high & low reading for the day, dividing that number by two and subtracting the result from 65º
- Electrical baseload is the constant or background amount which accounts for everyday use: i.e. lights, H2O, clocks, chargers, etc.
- Average of three lowest use months x 12 x 1.1 (pp 269)

Today's terms* !

1. Air intrusion = 

2. Infiltration = 

3. Exfiltration = 

4. Wind-washing = 

* So we all speak the same language.

Quick Review:

- Specific heat = number of BTUs that a pound of <u>any</u> material absorbs or releases per °F of temperature change.
  - The specific heat of water is one. That is, one BTU will raise one lb of water one degree F *unless the water experiences a phase change.* The non-phase change relationship is called *Sensible Heat.* (It makes sense.)
- Latent heat = amount of heat absorbed or released by a phase change. (At first glance, it <u>doesn't</u> make sense)
  - For water, the latent heat of boiling is 970 BTUs/lb. i.e. 970 BTUs must be added to a pound of water to turn it to steam.
  - To freeze water, 144 BTUs/lb must be removed . i.e. The latent heat of fusion (fancy term for freezing) water is 144 BTUs/lb.

WHY DO WE CARE?

- Obviously if 970 BTUs are absorbed when water becomes steam, the same 970 BTUs will be released when the steam condenses back to water. – The principle behind steam heat!
- Refrigeration & air conditioning – really just another form of refrigeration – use the same principle. The medium is a manufactured refrigerant instead of water.

What is Energy? What controls it?

- A measurable quantity of:
  - Heat – Molecular movement
  - Work – Expended energy <u>with a result</u>
  - Light
- Laws of Thermodynamics:
  1. Energy is neither created nor destroyed.
  2. Energy always* goes from high to low.

* Absent an outside influence expending other energy.

ENERGY
Lots of terms.....

- Potential energy
  - Stored energy – gasoline
- Kinetic energy
  - Moving or transitional energy – an object moving at 60 MPH - a fire
- Temperature
  - Measure of heat present
- Heat
  - Molecular movement

Where does our Energy come from?

More than 99% of our energy comes from the sun!

What about wind?

Even coal & oil come from dinosaurs that ate what the sun grew!

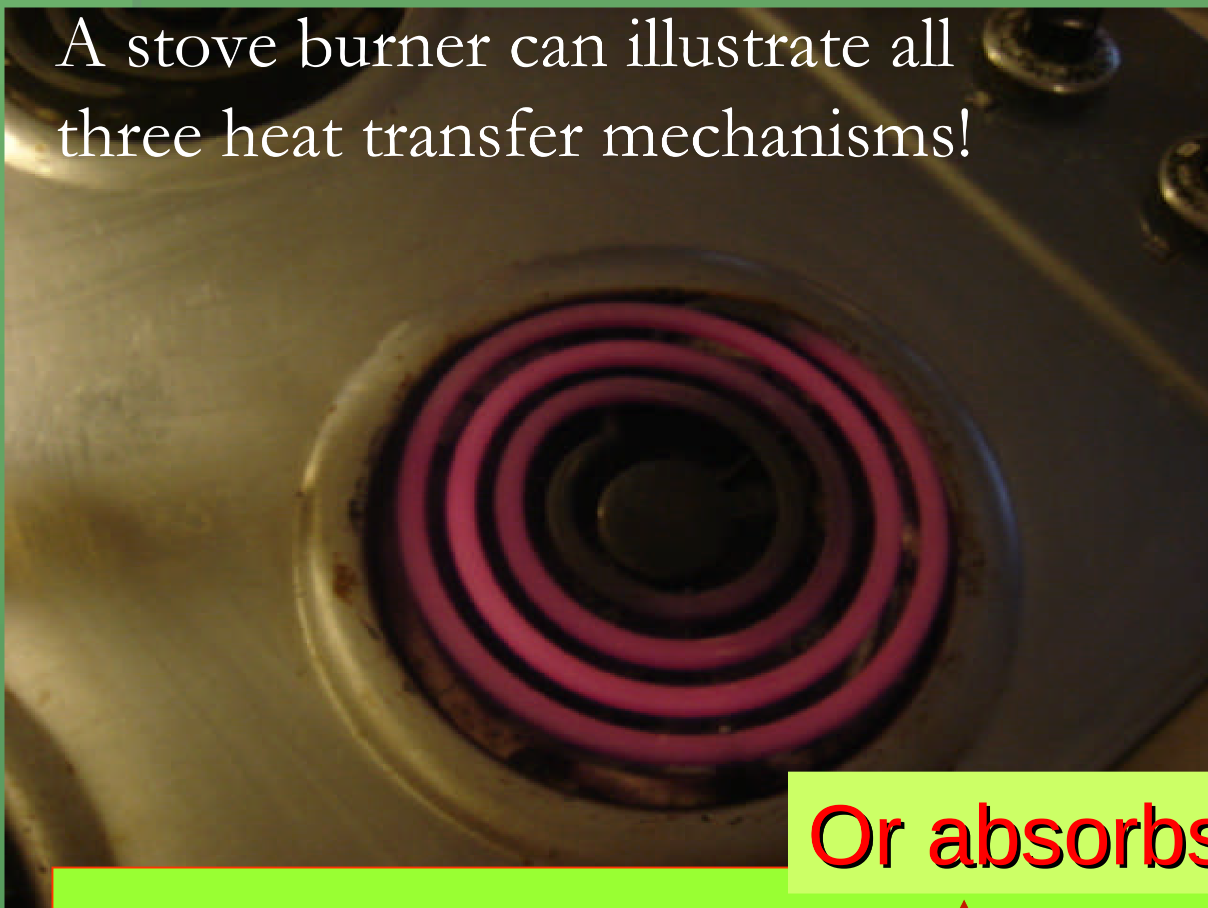
How does energy move?

- Energy reaches us from the sun by pure radiation.
- Once it’s here, other mechanisms get involved.
  - Conduction
  - Convection
  - (& more) Radiation

RADIATION

Radiation does not need physical contact or a medium!

A stove burner can illustrate all three heat transfer mechanisms!



Heat is radiating from this burner, warming any object in it’s vicinity: that’s

Radiation

Or absorbs

Everything radiates heat all the time!

Everything Radiates &/or Absorbs Energy

all the time!

Usually, both at once!

CONDUCTION

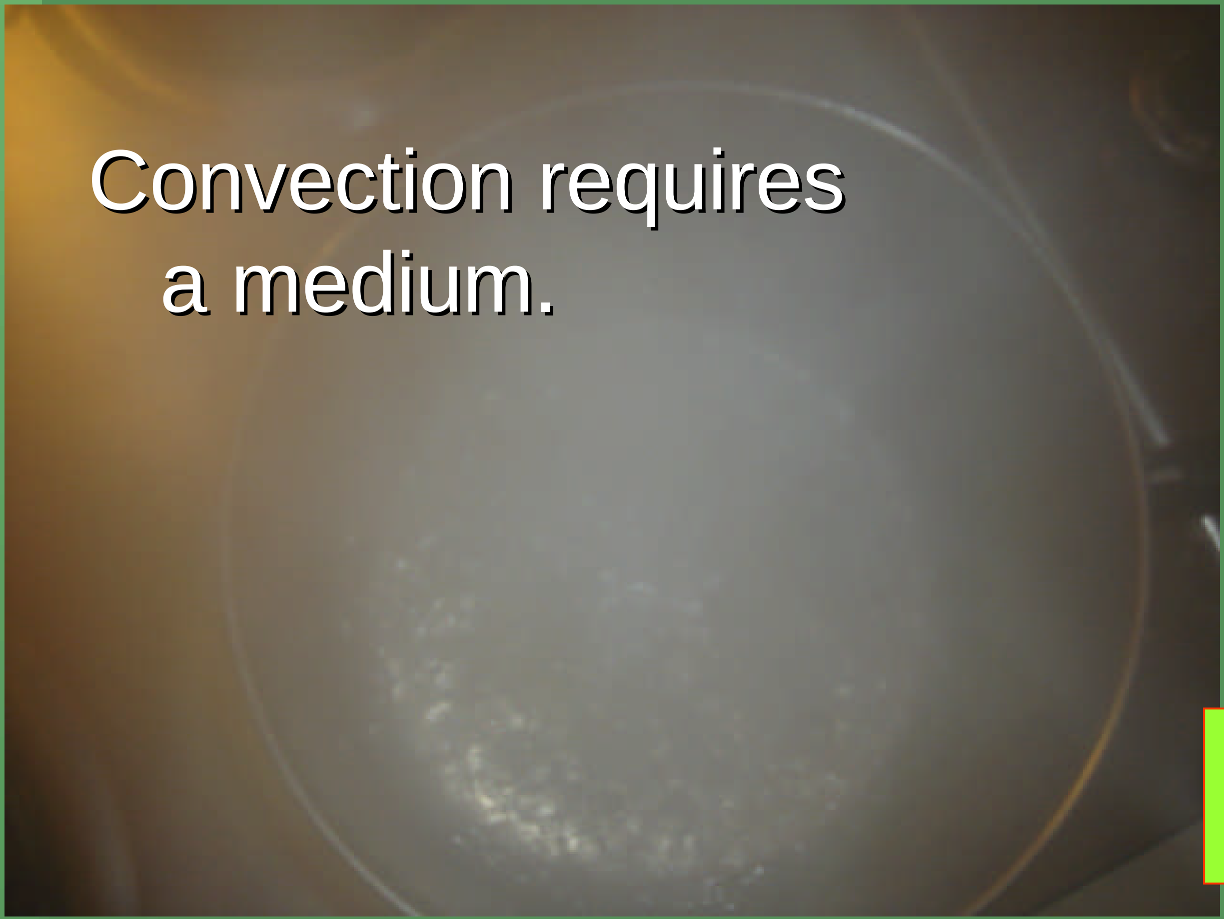
Conduction requires physical contact - touching

The pans are in contact with the burners. Heat is transferred from the burners to the bottom of the pans by:

Conduction

CONVECTION

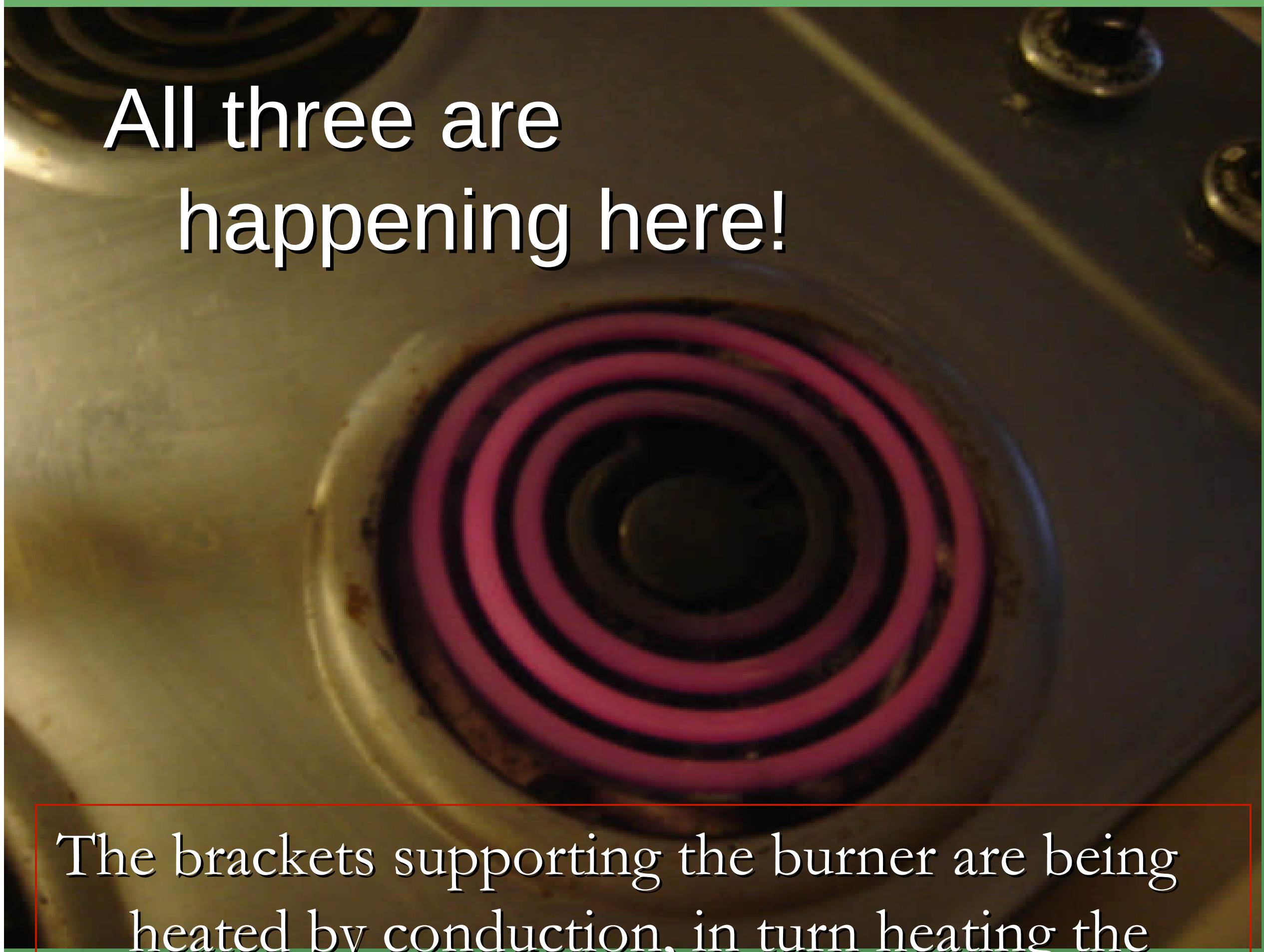
Convection is heat movement in a fluid.



Heat conducted to the bottom of the pan warms the water. The water temperature will stabilize at 212° F – the boiling point of water – because of convection of heat in the water. Heat moving in a fluid (air, oil, or water) is:

Convection

Usually more than one mechanism is in play



All three are happening here!

The brackets supporting the burner are being heated by conduction, in turn heating the metal stovetop.

Heat is warming the air above the coil. The warmed air is rising & heating the room air by **Convection.**

Heat is also **Radiating** from the burner, heating objects above the stove.

Some of the heat reaching the ceiling by either mechanism will be absorbed & radiated back while some – depending on how shiny the ceiling is - will be reflected.

That's how it moves. Why does it move?

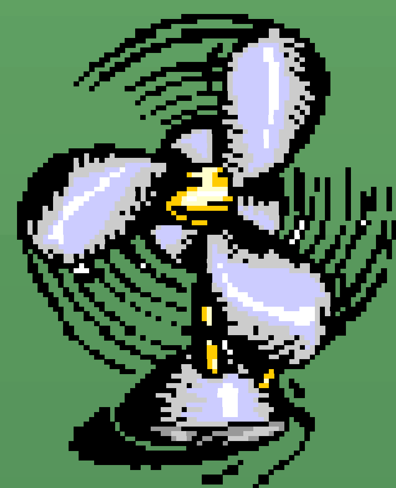
- Simply, nature is in a constant struggle to equalize everything.
- Scientists explain it with "The Second Law of Thermodynamics"
  - High goes to low
  - Wet goes to dry
  - Hot goes to cold

Don't forget air movement which carries heat with it as it goes.

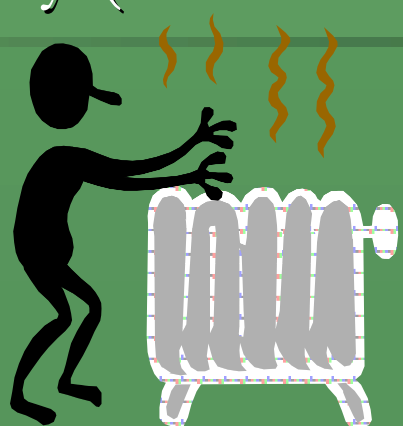
Three mechanisms move air:

- Wind

- Mechanical (fans)



- Buoyancy (warm air rising)



The “Practicality” of it !

- Heat inside a building warms the inside surfaces by convection & radiation.
- Heat is transferred through building surfaces mostly by conduction with help from convection & radiation.
- On the cold side of the assembly, heat leaves by convection - moving air carries it away – and radiation.
- Anything physically touching the building assembly will remove heat by conduction.
- Air transported heat is lost when conditioned air leaves the building & is replaced by outside air.
- In reality, heat moves constantly by whatever mechanism is available at any given moment.

Quantifying heat transfer

$$Q = \frac{A \times \Delta T \times t}{R}$$

Where:

Q = BTU/time period

A = Area in Square feet

ΔT = Temperature difference in °F

t = time

R = Total Resistance value of assembly

Quantifying heat transfer or…

$$Q = A \times \Delta T \times t \times U$$

Where:

Q = BTU/time period

A = Area in Square feet

ΔT = Temperature difference in °F

t = time

U = Total transmissive value of assembly

R Values & U Values

- U = Heat transmittance
- R = Resistance to heat transmittance
- U = 1/R & R = 1/U
- R values can be added
- U values can not.

Formula (Surface heat transfer)

- $Q = \dfrac{A \times \Delta T}{R} = \dfrac{BTU}{hr}$
- $Q = \dfrac{\text{Area in square feet} \times \text{temp diff in °F}}{\text{Total assembly R value}}$
- $Q = \dfrac{A \times HDD \times 24\ hrs}{R} = \dfrac{BTU}{\text{heating season}}$
- $Q = A \times \Delta T \times U = BTU/hr$
- $Q = A \times HDD \times 24\ hrs \times U = BTU/\text{heat ssn}$

Surface Heat Transfer

- 8’ x 12’ wall – no windows = 96 sq’
- 70°F inside - 30°F outside = 40°F ΔT
- 7200 HDD
- R-11 wall insulation
- How many BTU/hr?

Q = (96sq’ x 40°F x 1 hr)/11 = 349 BTU/hour

- How many BTU per heating season?

Q = (96 sq’ x 7200 HDD x 24 hrs)/11 =

1,508,072 BTU per heating season.

Quantifying Air Transported Heat Loss

- $Q = (A \times \Delta T \times t)/R$ (Look familiar?)
- $Q = \text{Volume} \times (AC/H) \times (0.0182\ BTU/ft^3, °F) \times \Delta T$
- $Q = \text{Volume} \times (AC/H) \times (0.0182BTU/ft^3, °F) \times HDD \times 24\ hr$

Where:

- Volume = cubic feet of air contained in the heated space.
- AC/H = the number of times the volume of air changes each hour.
- 0.0182 is the specific heat* of air.
- ΔT is the temperature difference between inside & outside air in °F.
- HDD = Heating Degree Days

*** The specific heat of air is the number of BTUs needed to raise one cubic foot of air one degree Fahrenheit.**

Quantifying Air Transported Heat Loss

Q = $V \times (AC/H) \times (0.0182\ BTU/ft^3,°F) \times \Delta T$

- 20'x 30' x 8' (ceiling height) - on slab
- 1.25 ACH
- 70°F inside □ 30°F outside
- 7200 HDD
- How many BTU/hr?
- How many BTU per heating season?

Quantifying AT heat loss

$$Q = V \times (AC/H) \times (0.0182\ BTU/ft^3,°F) \times \Delta T$$

- 20'x 30' x 8' = 4,800 cubic feet
- 1.25 ACH
- 70°F inside - 30°F outside = 40°F ΔT
- How many BTU/hr?

Q = 4,800 cu' x 1.25 ACH x (0.0182 BTU/cu',°F) x 40°F = 4,368 BTU/hour

- 7200 HDD
- How many BTU per heating season?

Q = 4,800 cu' x 1.25 ACH x (0.0182BTU/ft^3,°F) x 7200HDD x 24hrs = 18,869,760 BTU/heat season.

Controlling Surface Heat Loss

Insulation slows heat transfer (nothing stops it.)

- How does it work?
  - Trapped air pockets slow conductive heat loss.
  - Air barrier insulations reduce convective heat loss.
  - Reflective insulations reduce radiant heat loss.

How does insulation work?

- In its simplest form, insulation traps tiny air pockets which then act as conductive & convective breaks.
- To a point, the smaller & more isolated the air pockets are, the better the insulation works. (foam vs. others)
- Different insulations operate differently, making some better suited than others to a given application.

see Krigger PP 290

Radiant Insulation

- Radiant/reflective insulation works by reflecting heat back to where it came from – into or out of the building. It has several drawbacks:
  - It requires an air space to work – nothing can actually touch it.
  - The depth of the airspace is critical: too much or too little rapidly reduces the R value.
  - Its effectiveness drops rapidly when it gets dusty.
- Its major attraction is low cost, for both product & installation, although correct installation is critical to its performance.

Insulation characteristics

See Krigger pp292

- Fiberglass = R≈3-4/inch
  - Short fiber, (recycled product) batts & blown
  - Long fiber, (virgin) blown (Insulsafe II or III™)
- Mineral wool = R≈3-3.5/inch
- Cellulose = R≈3-3.5/inch
- Polyisocyanurate = Rigid board, R≈7/inch
  - (Dow Chemical - Cellotex™)
- Polyurethane = Spray foam, R≈6-7/inch
- Polystyrene
  - Expanded rigid board, R≈3-4/inch (white beadboard)
  - Extruded rigid board, R-5/inch (Styrofoam™)

Fiberglass vs. Cellulose

- Does not absorb water
- Can't be densepacked
- Quality control easy
- Batt configuration resists snug fit in cavity
- Won't seal holes/cracks
- Allows internal looping
- Allows wind-washing
- Remains where placed

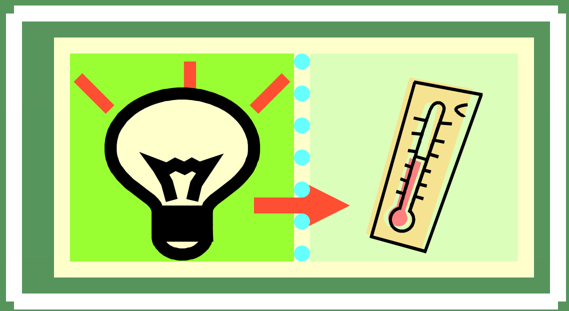
- Absorbs water
- Can be densepacked
- Quality control difficult
- Loose fill allows adapting to cavity shape
- Seals holes/cracks
- Prevents internal looping
- Prevents wind-washing
- Poor installation = settling

See Krigger pp 290-291 for others

"R" value

- R value is a number assigned to a material to quantify its resistance to heat transfer.
- The number is determined by Guarded Hot Box testing = A box inside a temp controlled box.
- The tested material is installed between a heat source & a thermometer in the inner box.
- The material's transmittance – its "U" value - is found by measuring how long it takes a known quantity of heat to equalize across the material .
- "U" is converted to "R"

  by dividing it into one.



Some typical R values

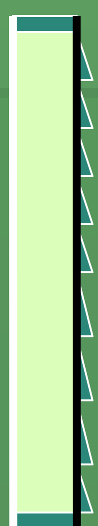
- **Fiberglass = 2.4 - 4.4 per inch ≈ 3.5/inch**
- **Cellulose = 3.0 - 3.6 per inch ≈ 3/inch**
- **Expanded polystyrene ≈ 3.6/inch (beadboard)**
- **Extruded polystyrene = 5/inch (Styrofoam™)**
- **Polyisocyanurate board ≈ 5.6 – 7.6 /inch**
- **Glass ≈ 1 per layer**
- **Wood ≈ 1 per inch**
- **Concrete ≈ 1 per <u>8 inches</u>**

See Krigger PP 103

Assembly R value

Building envelopes generally consist of layers of materials, each of which resists heat flow.

In addition, each layer – not in physical contact with another layer - has an air film which also resists heat flow.



The pictured assembly has ½"drywall, 3½" fiberglass, 2"x4" framing, ½" plywood, building wrap & clapboard siding. (see Krigger pp 67)

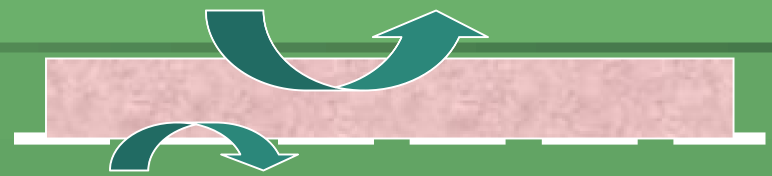
The assembly has a total theoretical R of ≈ 14. In reality it will test ≈ 20% lower; ≈ R-10 (K. pp 272)

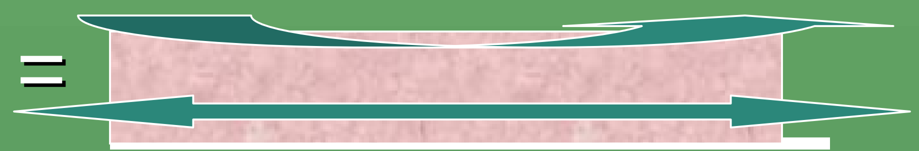
A really nice short-cut !

If you wish to look up the R value of almost any material, hundreds are listed in various texts & websites. It is possible to identify the components in any assembly, look up an R for each and calculate the total R-value. (Krigger pp 272-273)

- In reality, it is generally safe to rate an un-insulated wall assembly R-3, a ceiling with no attic floor, R-1 & with a floor , R-2.
- A properly insulated wall or ceiling assembly will approximate the insulation R value <u>minus</u> 10% (see Krigger pp 274)

When is an R not an R ?

1. Intrusion = 

2. Wind-washing = 

Both intrusion & wind-washing significantly lower R value. The more porous the insulation the more the R is reduced.

Exposed fiberglass in a well vented attic will test as much as 50% below its label rating.

Payback !

- The 1st layer of insulation has rapid payback.

IMPORTANT !

- AFTER THE FIRST INCH, each successive inch of insulation installed saves ≈ ½ of what is saved by the previous inch.
- To get accurate savings predictions you must determine the R value and calculate the loss through the existing assembly and then subtract that value from the loss through the planned assembly.

Example:

2" x 4" framed 8' x 12' drywall/board/clapboard wall.

Nominal assembly R value = R-3

70°F in; 30°F out

Install cellulose @ R-3.5/inch **hourly heat load**

- Empty wall (96sq' x 40°F x 1hr)/3 = 1,280 BTU/hr
- 1" cell = (96sq' x 40°F x 1hr)/6.5 = **591** BTU/hr
  savings = 689 BTU/hr (over empty wall)
- 2" cell = (96sq' x 40°F x 1hr)/10 = **384** BTU/hr
  savings = **207 BTU/hr** (over wall & 1" cell)
- 3" cell = (96sq' x 40°F x 1hr)/13.5 = **285** BTU/hr
  savings = **99 BTU/hr** (over wall & 2" cell)
- 4" cell = (96 sq' x 40°F x 1 hr)/17 = **226** BTU/hr
  savings = **59 BTU/hr** (over wall & 3" cell)

How about an attic?

- 30’ x 40’ duplex (each side 20’ x 30’)
- Attic “A” has R-11 fiberglass
- Attic “B” has R-19 fiberglass
- Heat set by LL @ 70°F

1. What is the annual heat load for each attic?
2. If cellulose costs $0.75/sq ft for the first inch & $0.10 for each subsequent inch and #2 fuel is $4.50/gal, what should the LL do?

1 (EASY!) Annual heat load:

"A" attic = (600 sq' x 7200 HDD x 24hrs)/R10* =
10,368,000 BTU/year

"B" attic = (600 sq' x 7200 HDD x 24hrs)/R17* =
6,098,824 BTU/year

How much money is that?

"A" attic =(10,368,000 BTU/yr)/ (139,000BTU/gal x ±70% eff) =
104 gallons/yr x $4.50/gal = $467.00/year

"B" attic = (6,098,824 BTU/yr)/ (139,000BTU/gal x ±70% eff) =
61 gallons/yr x $4.50/gal = $275.00/year

* Remember: A properly insulated wall or ceiling assembly will approximate the insulation R value <u>minus</u> 10%

#2.1 (Pretty easy!) Annual savings

"A" attic (base fuel use in $) = $467/year (R-10)

"B" attic (base fuel use in $) = $275/year (R-17)

	(A x HDD x hrs)/R	BTU/yr	gal/yr	$/yr	net sv/yr	incremental sv/yr
"A"+1"	= (600 x 7200 x 24)/13	= 7,975,385	= 80	= $360	= $107	$107
"B"+1"	= (600 x 7200 x 24)/20	= 5,184,000	= 52	= $234	= $ 41	$ 41
"A"+2"	= (600 x 7200 x 24)/16	= 6,480,000	= 65	= $293	= $174	$ 67
"B"+2"	= (600 x 7200 x 24)/23	= 4,507,826	= 45	= $203	= $ 72	$ 31
"A"+3"	= (600 x 7200 x 24)/19	= 5,456,842	= 55	= $248	= $219	$ 45
"B"+3"	= (600 x 7200 x 24)/26	= 3,987,692	= 40	= $180	= $ 95	$ 23
"A"+4"	= (600 x 7200 x 24)/22	= 4,712,727	= 47	= $212	= $255	$ 36
"B"+4"	= (600 x 7200 x 24)/29	= 3,575,172	= 36	= $163	= $112	$ 17

Insulate attics to R-38 – R-40

"A"+9"	= (600 x 7200 x 24)/37	= 2,802,162	= 28	= $126	= $341
"B"+7"	= (600 x 7200 x 24)/38	= 2,728,421	= 27	= $122	= $153

2.2 Payback eval options

- Simple payback (How long before I get my money back?)
  - Annual savings divided by cost.
- Lifetime savings (How much will I save before it wears out?)
  - Life expectancy times annual savings.
- Lifecycle costing (What is my net lifetime saving?)
  - Lifetime savings minus cost.
- Savings to Investment Ratio (Good use of my money ?)
  - Lifetime savings divided by cost.

#2.3 (NOT so easy!) Payback

"A" attic (base fuel use in $) = $467/year

"B" attic (base fuel use in $) = $275/year

	net sv/yr	cost - 600 sq ft	payback	lifetime sav.	life cycle sav.	SIR
"A"+1"	$107	@ $.75 $450	4.21 yrs	$3,210	$2,760	7.13
"B"+1	$ 41	@ .75 $450	10.98 yrs	$1,230	$ 780	2.73
"A"+2"	$174	@ .85 $510	2.93 yrs	$5,220	$5,046	10.24
"B"+2"	$ 72	@ .85 $510	7.08 yrs	$2,160	$1,650	4.24
"A"+3"	$219	@ .95 $570	2.60 yrs	$6,570	$6,000	11.53
"B"+3"	$ 95	@ .95 $570	6.00 yrs	$2,850	$2,280	5.00
"A"+4"	$255	@ 1.05 $630	2.47 yrs	$7,650	$7,020	12.14
"B"+4"	$112	@ 1.05 $630	5.63 yrs	$3,360	$2,730	5.33
"A"+9"	$341	@ 1.55 $930	2.73 yrs	$10,230	$9,300	11.00
"B"+7"	$153	@ 1.35 $810	5.29 yrs	$ 4,590	$3,780	5.67

Uninsulated Ceiling?

- (20’ x 30’ x 7200 HDD x 24 hrs)/ R-1 = 103,680,000 BTU/yr / 100,000 BTU/gal = 1,037 gallons x $4.50/gal = $4,666.

What’s our opportunity now ?

Air transported heat loss

(Convective heat transfer)

The drivers are:

1. Stack effect (warm air rising)
2. Wind
3. Mechanical (fans & pumps)

The most misunderstood and most frequently ignored heat transfer mechanism in today's homes is

air transported heat loss!

Air Transported Heat

- Technically, heat moving within any fluid - including air - is convection.
- Because “Heat goes to Cold”, given enough time, all fluids eventually stabilize at a uniform temperature equal to the mass weighted average temperature of whatever the fluid is in contact with.
- Translation: a fluid will absorb from or release heat to contacting solids until all reach a common temperature.

That accounts for heat movement <u>in</u> a fluid and to & from the fluid to solids it contacts:

- **What is it if the whole mass of conditioned air moves somewhere else?**

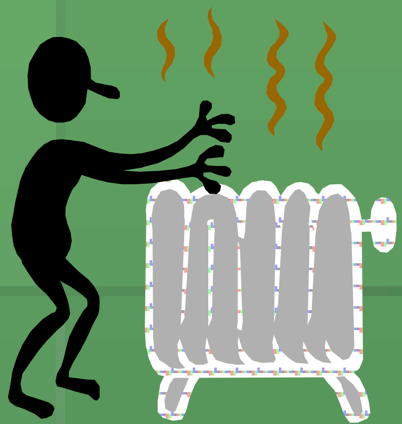
Air transported heat loss !

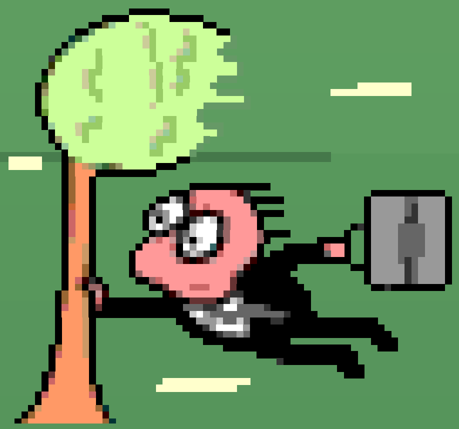
- Lets assume a volume of heated air. Because it is heated, it is less dense & therefore more buoyant than air around it; consequently it wants to rise.
- It's also at a higher pressure, making it want to move to a lower pressure areas (think weather maps).
- Wherever it goes, it will take whatever heat it contains "along for the ride."
- Cooler air will move in to replace it and in turn, be heated by whatever source heated the first batch repeating the cycle until equilibrium is reached

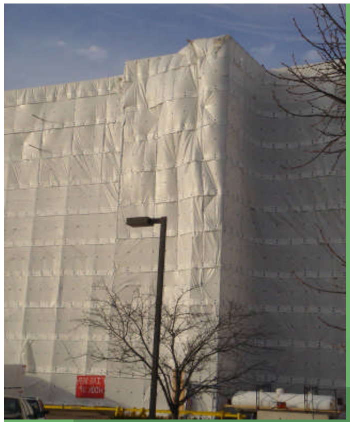
ATHL (continued)

- In the real world, equilibrium is impossible because heat is constantly being added somewhere (by the sun) and subtracted elsewhere (by radiant heat transfer to empty space), keeping the wind constantly blowing.
- Equilibrium is (nearly) possible in a dwelling, however.
- All we have to do is control air movement.

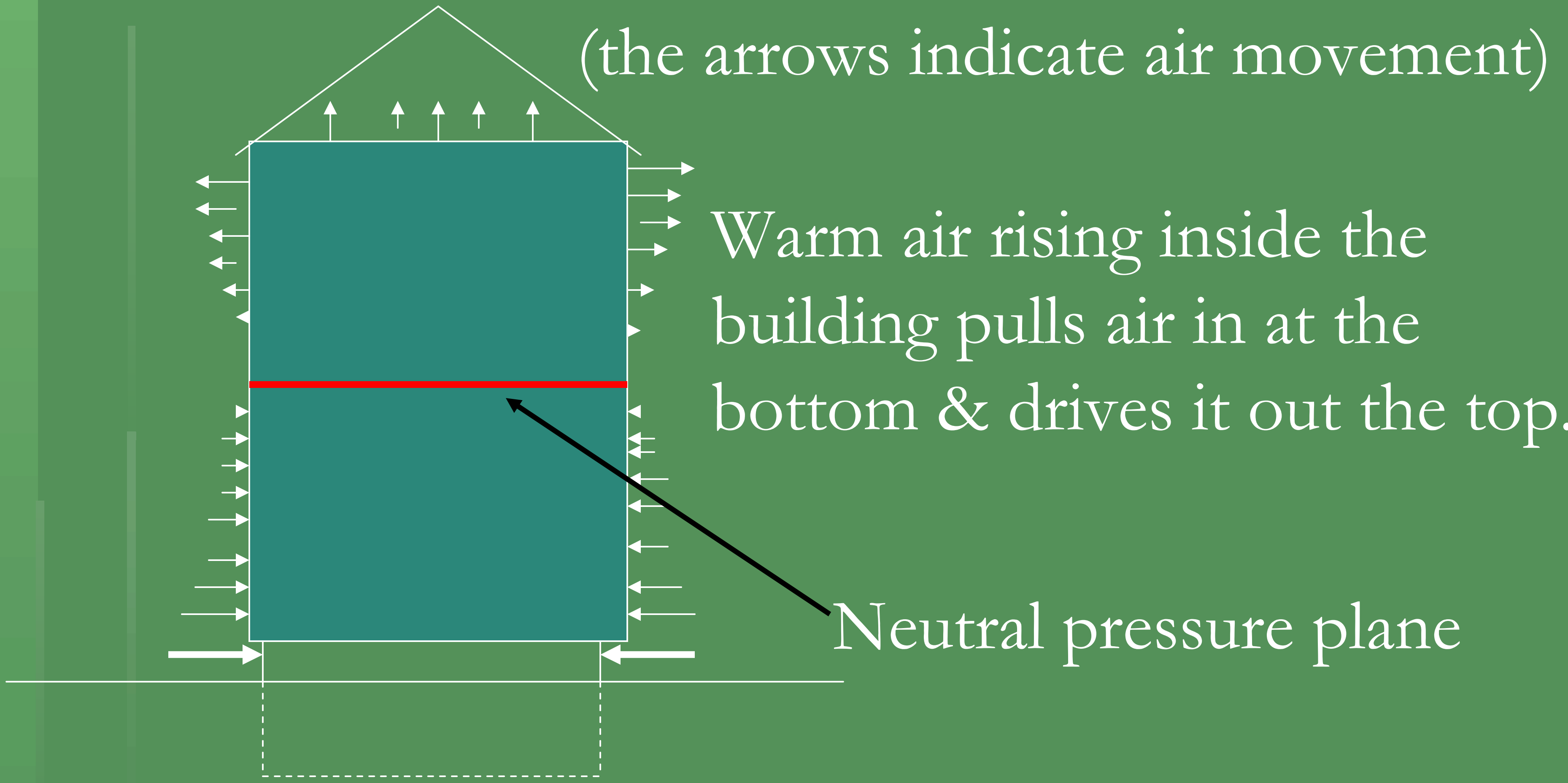
To control it we have to understand it!

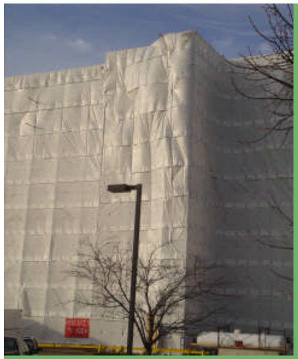






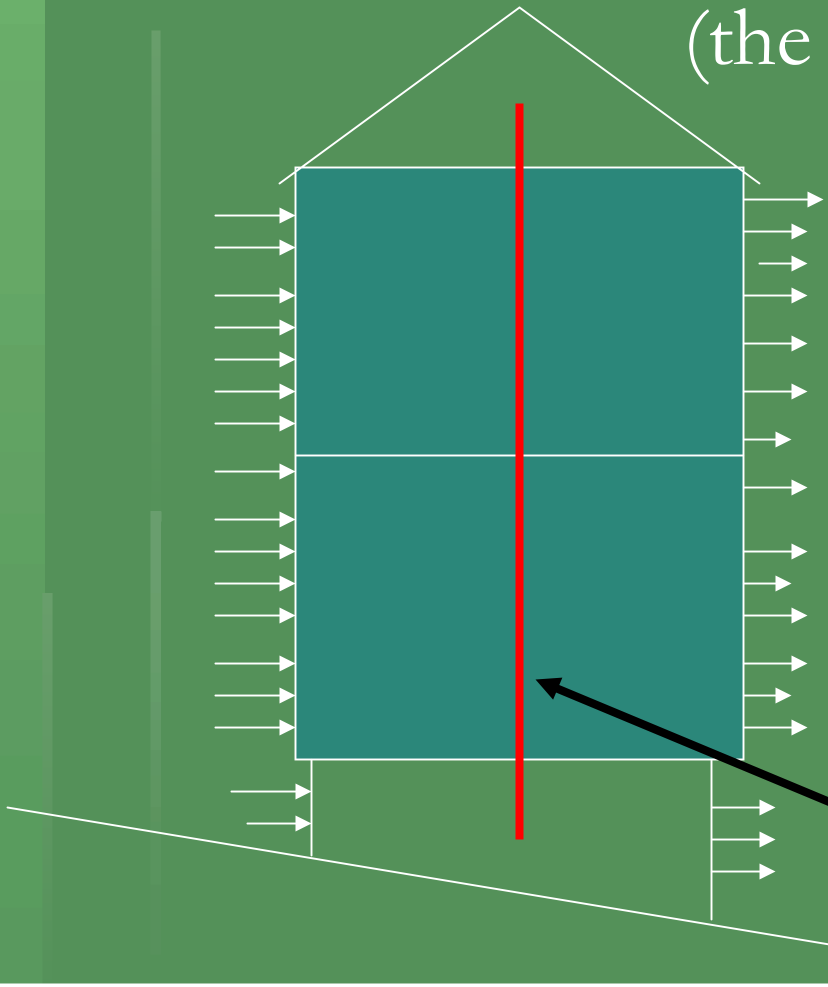
What drives air movement ?
1. Stack Effect





What drives air movement ? 2. Wind

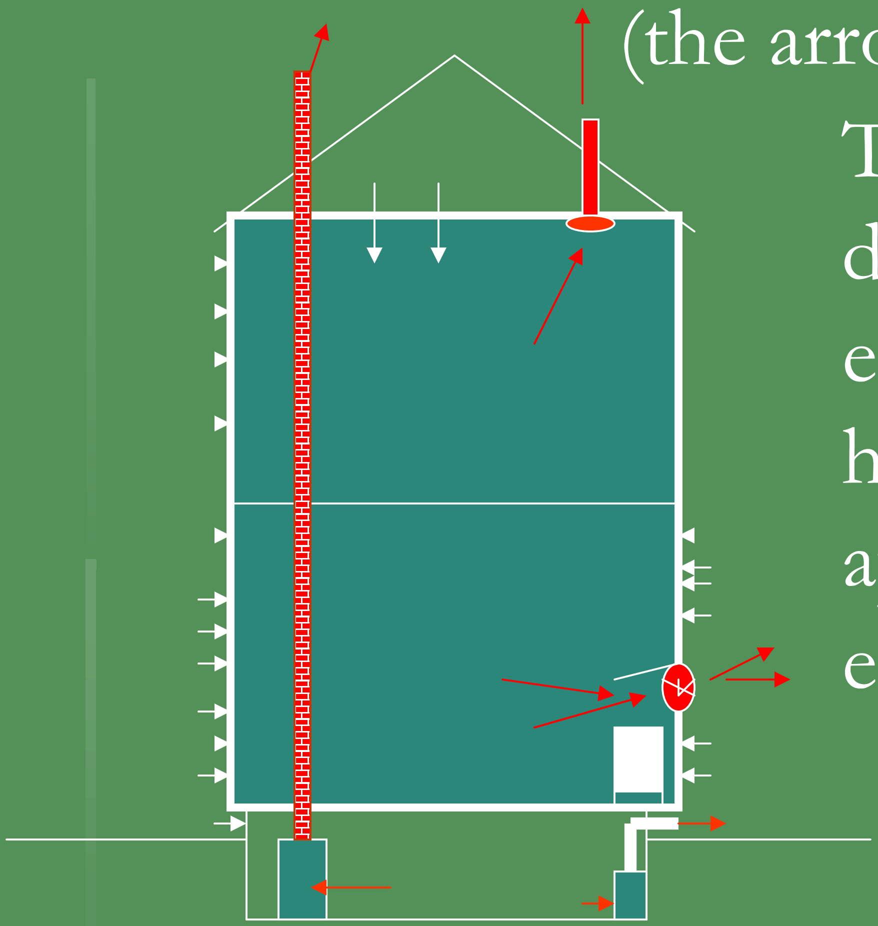
(the arrows indicate air movement)



Wind blowing against the building pushes air in the windward side and sucks it out the leeward side.

Neutral pressure plane

What drives air movement ?
3. Fans & pumps

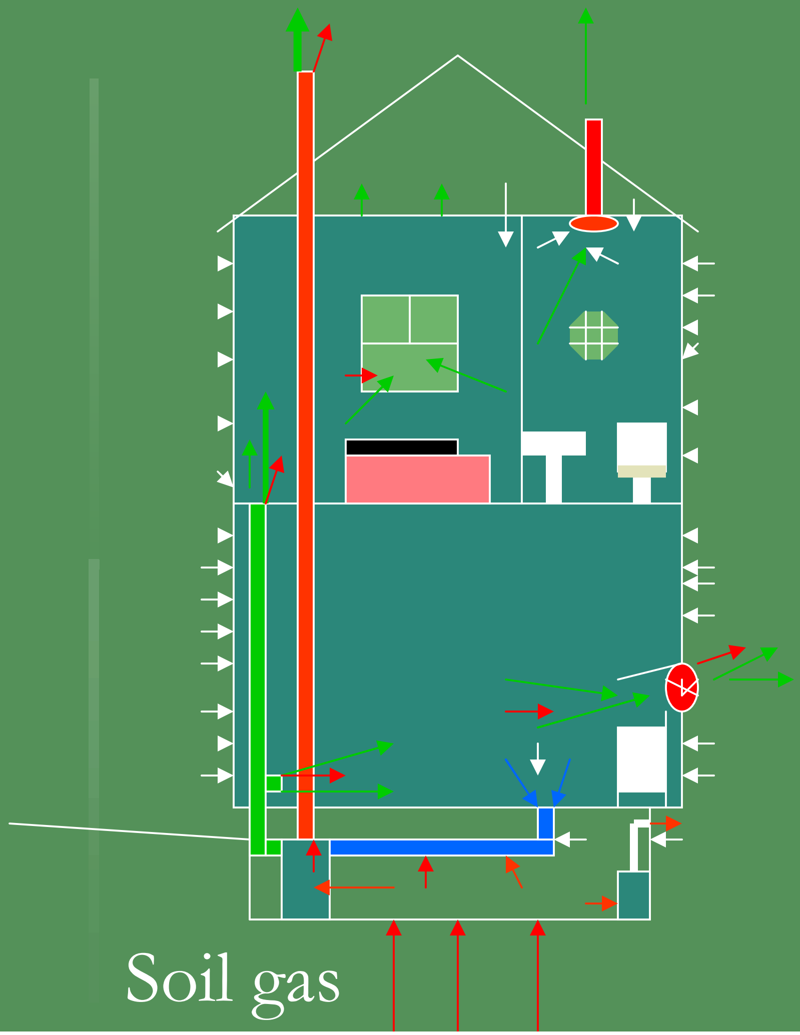


(the arrows indicate air movement)

The heating system, clothes drier, kitchen & bath vents, etc. all pump air out of the house. If enough exhaust appliances are turned on, all envelope holes will leak in.

There is **no** neutral pressure plane!

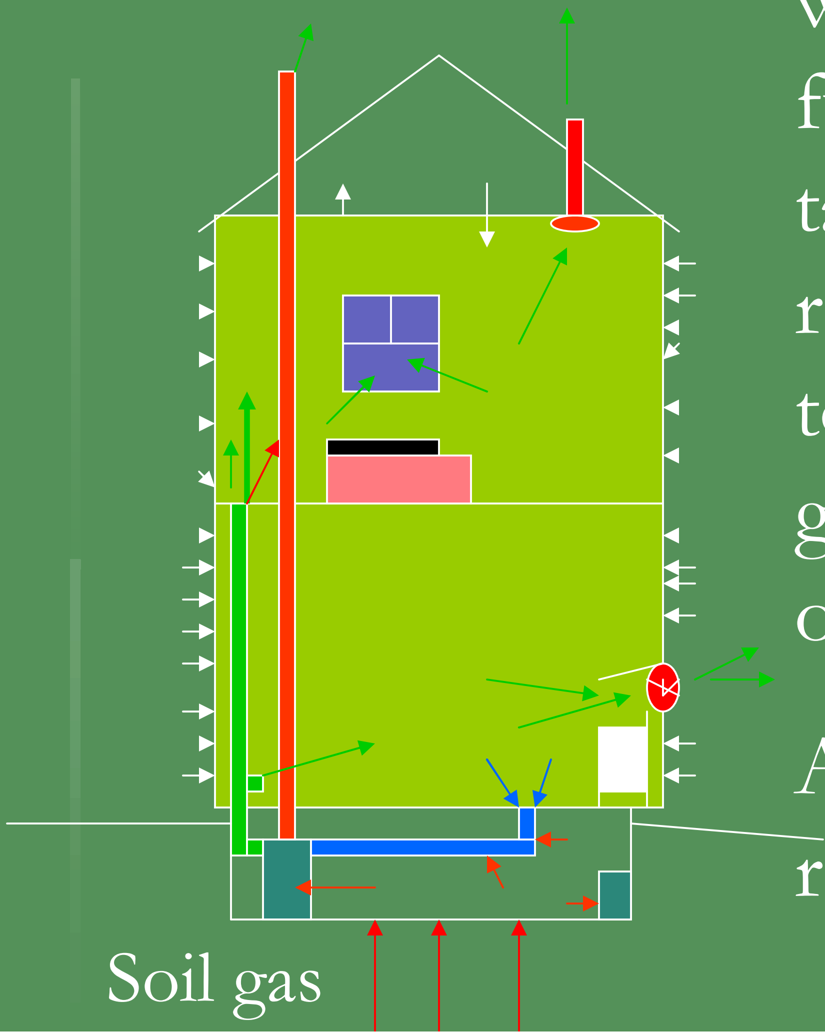
What drives air movement ? Duct leaks !



The ducts on a warm air heating system add another variable:

Returns are typically leaky. When so, the furnace can suck pollutants from the basement & deliver them through the home.

What drives air movement ?

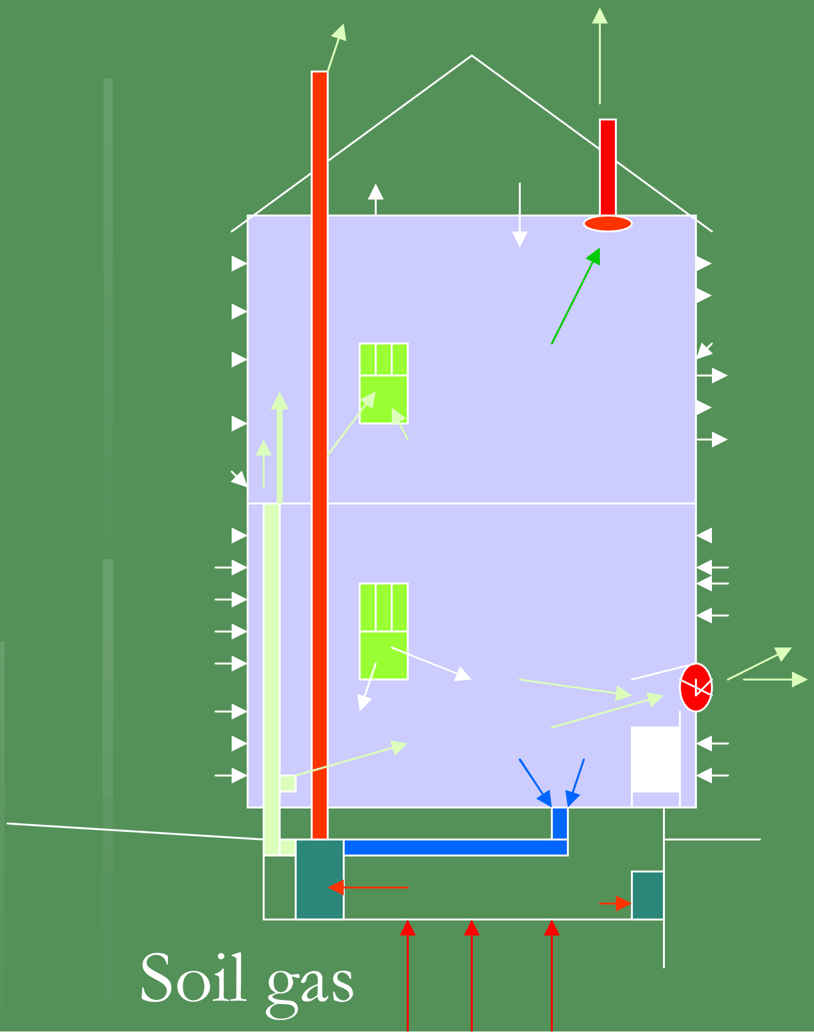


What happens when a window is opened with the furnace running? Air always takes the path of least resistance. If it's easier for it to go out the window than get back to the furnace it goes out the window.

Any air going out has to be replaced by air that comes in.

So what really happens ?

Everything at once!



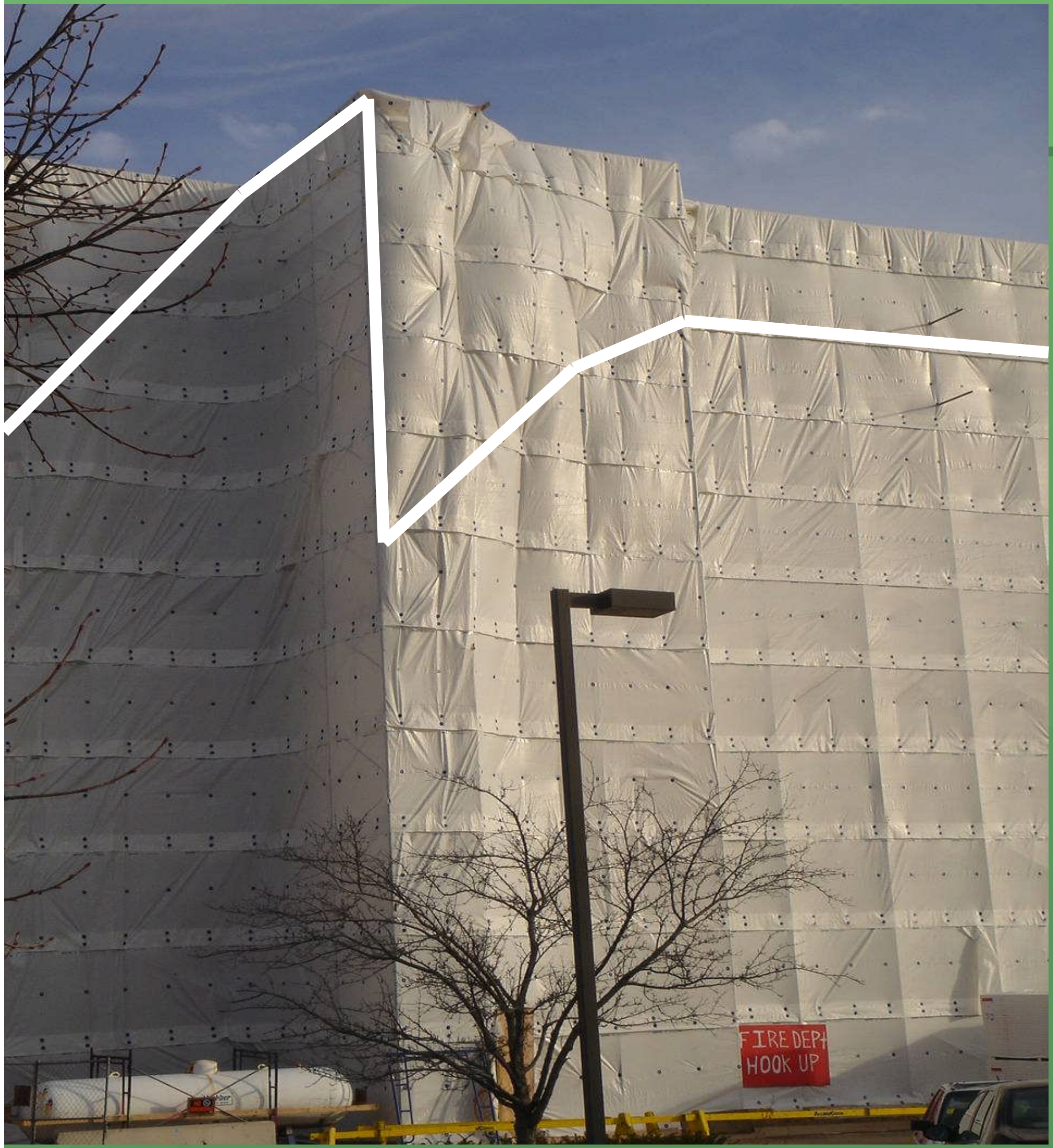
Stack effect, wind and fans all pump air into & out of a house. Some number of shell holes will leak in, while some number may continue to leak out, depending on driving force strengths.

Predicting air movement under natural conditions is virtually impossible !

OK, so we’ve got a Neutral Pressure Plane;
What do we call the building surface that keeps the pressure in ?

The Pressure Boundary !

Sometimes you can see it !



Here, the poly is the pressure boundary.

In a real building the neutral pressure plane is determined by all the "drivers" operating at once.

Visible or not, every building has a pressure boundary somewhere !

- If it didn’t, any conditioned air inside would simply leave.
- We have to:
  - Locate the boundary,
  - Evaluate it for integrity,
  - Decide if it’s where we want it &, if not,
  - Where it should be & how to put it there.
- Remember, sometimes there’s more than one pressure boundary*!

* More about that later !

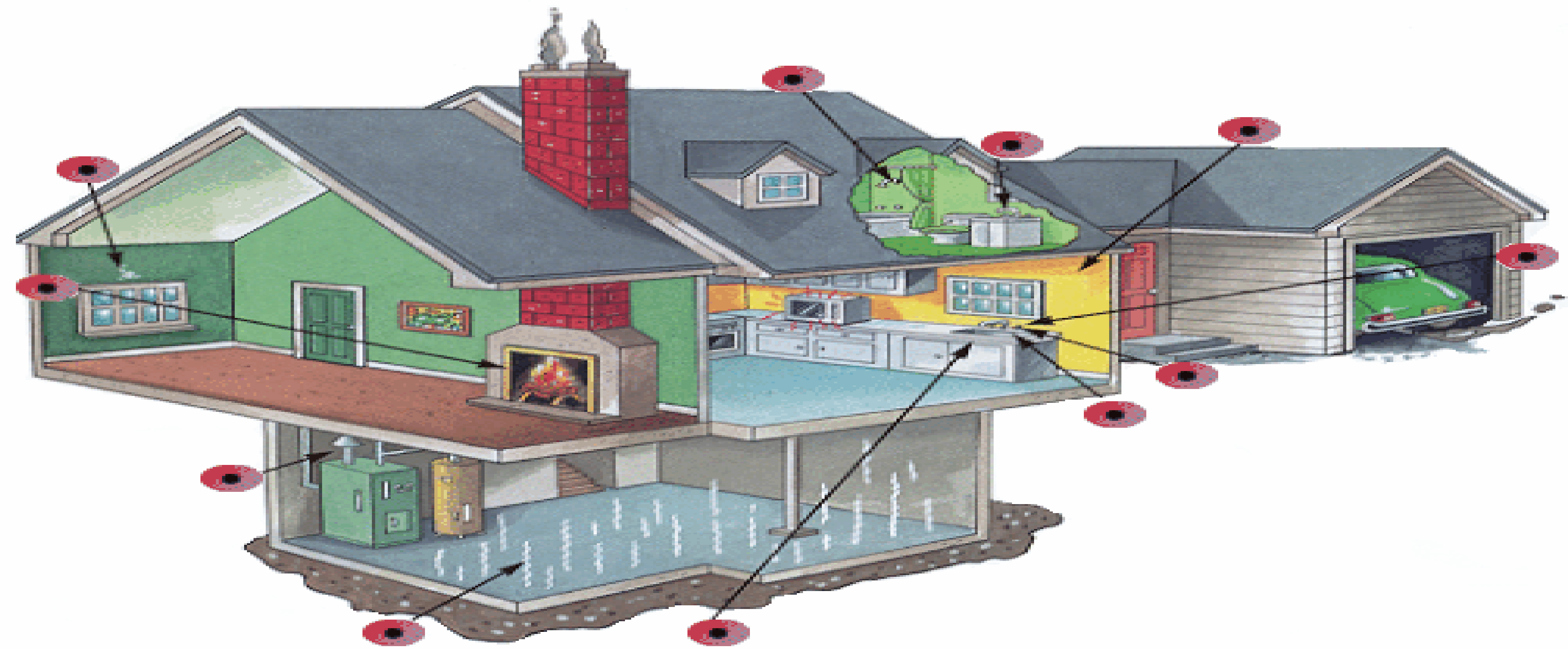
Pressure Boundary defined:

- **The pressure boundary is the surface – or surfaces – that contain pressure in a building – just like air in a balloon.**
- **Buildings may have layers of pressure boundaries or contain several interrelated or totally unrelated pressure boundaries, each affecting air movement inside and into & out of the building.**

REMEMBER:

Inside the pressure boundary of a house

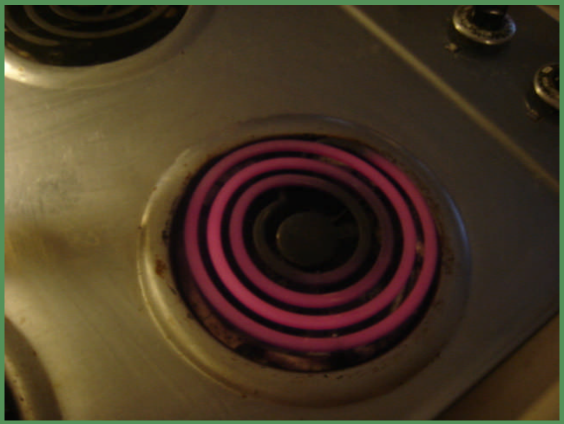
Everything can - & will - affect everything else!



Keeping Heat In:

Heat moves by three basic methods:

Conduction Convection Radiation



Insulation reduces conductive & convective movement by trapping small pockets of air. Reflective insulation slows radiation.

Keeping heat in requires:

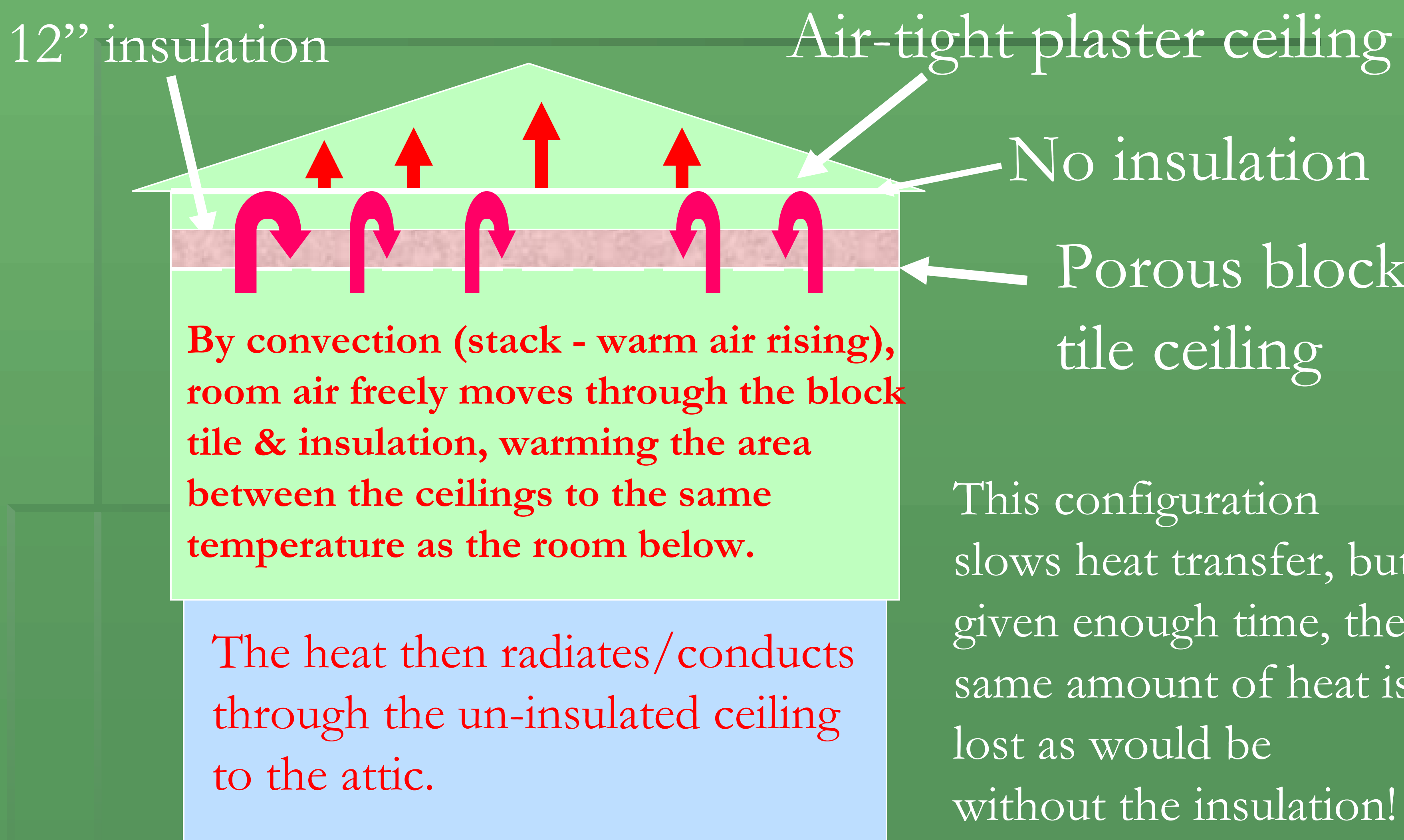
- Reducing conductive, convective & radiant heat transfer
- Controlling air leakage

<u>AT THE SAME SURFACE</u>

Why at the same surface ?...

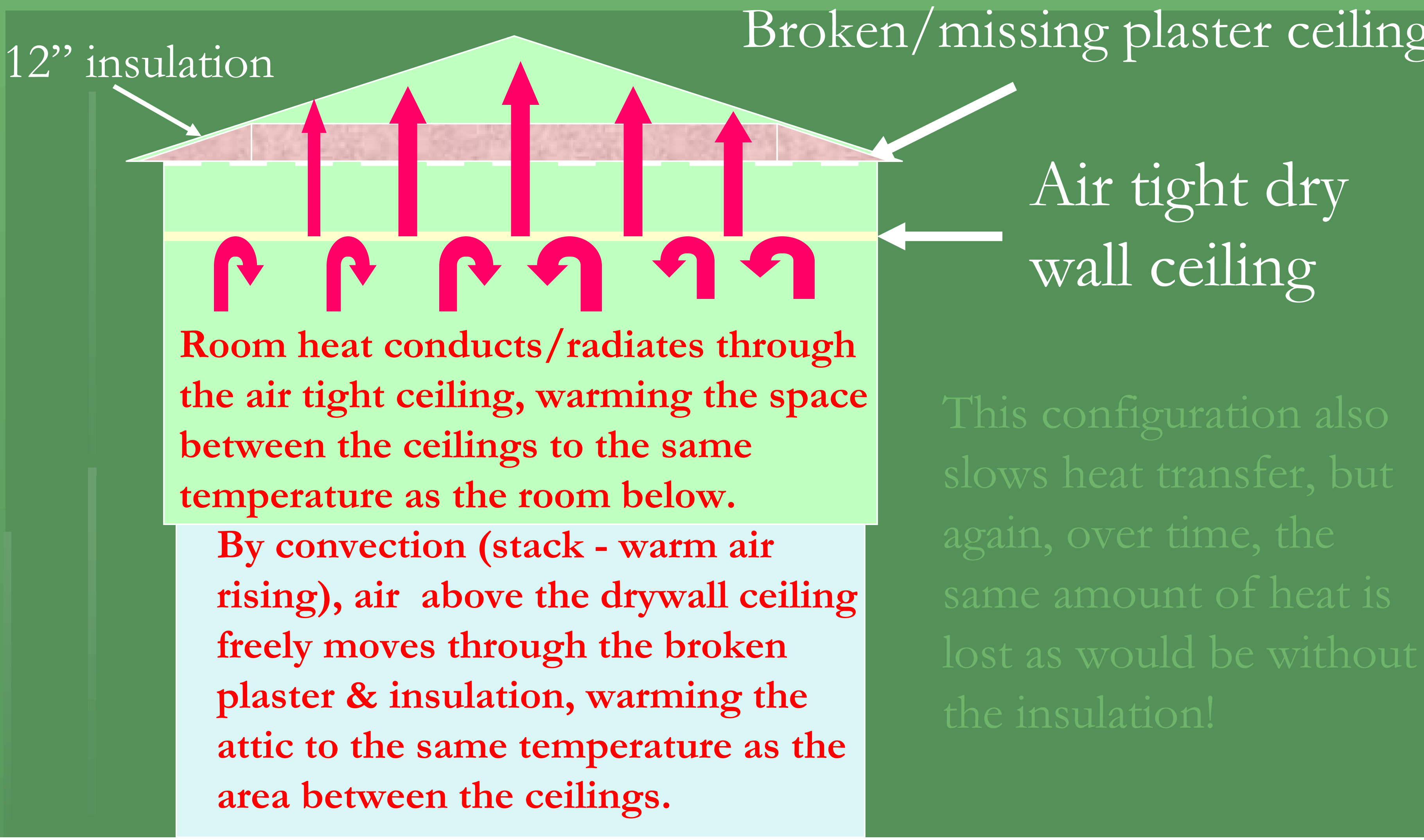
- Heat has the potential to move – escape – by any one of the three mechanisms at any given time. Stopping one without dealing with the others is pointless. (Fortunately, methods that work with one surface loss mechanism typically work with all.)
- Dealing with surface heat loss without considering air transported heat loss is foolish. Insulation does NOT equate to airsealing nor can it perform as designed without air sealing. Beyond that, it is **ABSOLUTELY NECESSARY** that insulation & air sealing occur at the same surface and be in contact with each other.

Why in contact?



This configuration slows heat transfer, but, given enough time, the same amount of heat is lost as would be without the insulation!

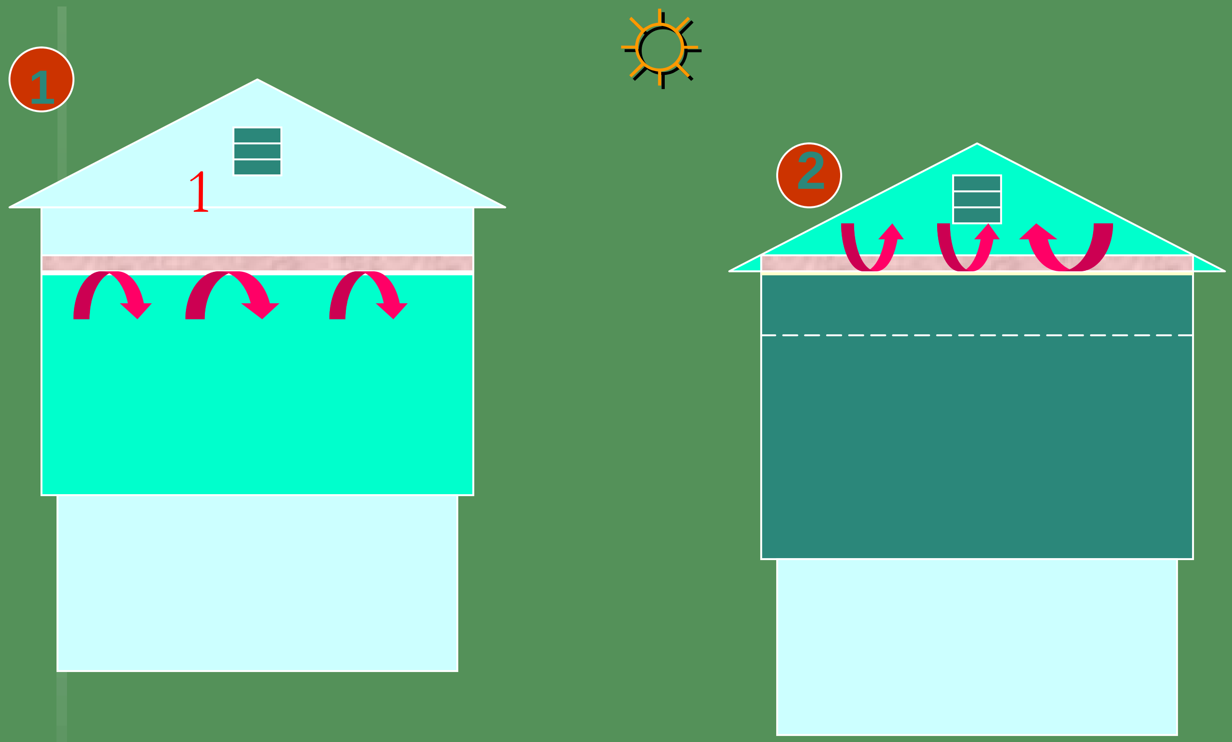
Let’s reverse the situation



This configuration also slows heat transfer, but again, over time, the same amount of heat is lost as would be without the insulation!

There are advantages to both!

Everything else being equal, in winter, #1 will use slightly less fuel as the surface area exposed to cold & the heated volume is smaller.



In summer, if exposed to the sun, #2 will heat less & cool more quickly as there will be lower volume of sun heated air created & stored in the attic.

Choose what's best for the individual house!

What about moisture?

- Vapor barriers (retarders) reduce moisture diffusion.
- Nothing completely stops moisture diffusion …not even polyethylene sheeting!

  (See Krigger pp 275)
- The good news:

  99% of moisture transport is by air movement!

If we control air movement, we control 99% of the moisture movement!

Why be concerned with moisture ?

- Excessive moisture historically has been the chief culprit in premature building failure.
- The old truism – buildings have to breathe – came from the most preferred method our ancestors used to deal with excess moisture – let natural conditions dry the building over the annual summer/winter wet/dry cycle.
- Acceptable method with cheap energy.
- Insulation – some types more than others – interferes with the natural drying cycle.

VERY IMPORTANT !

Energy conservation activities done without consideration for moisture management will destroy buildings !

Annother very important consideration!...

- The moisture boundary must not only align with the heat & air boundaries but must also be as close to the warm side of the assembly as possible.
- Ideally it will be on the surface.
- If it is below the surface it absolutely must be kept above the dew point temperature of any air contacting it!

All boundaries together

Conductive heat boundary

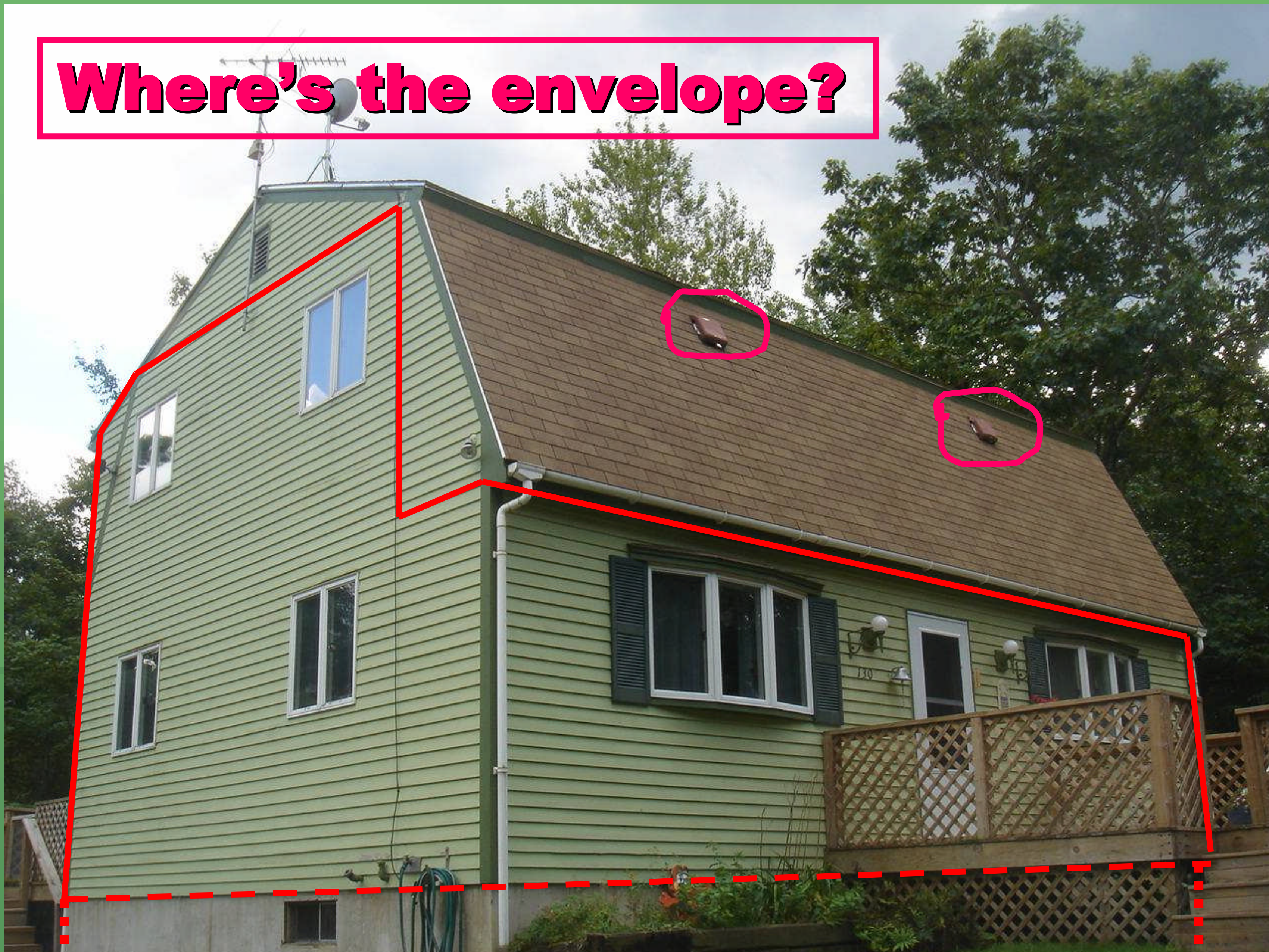
Air transported heat boundary

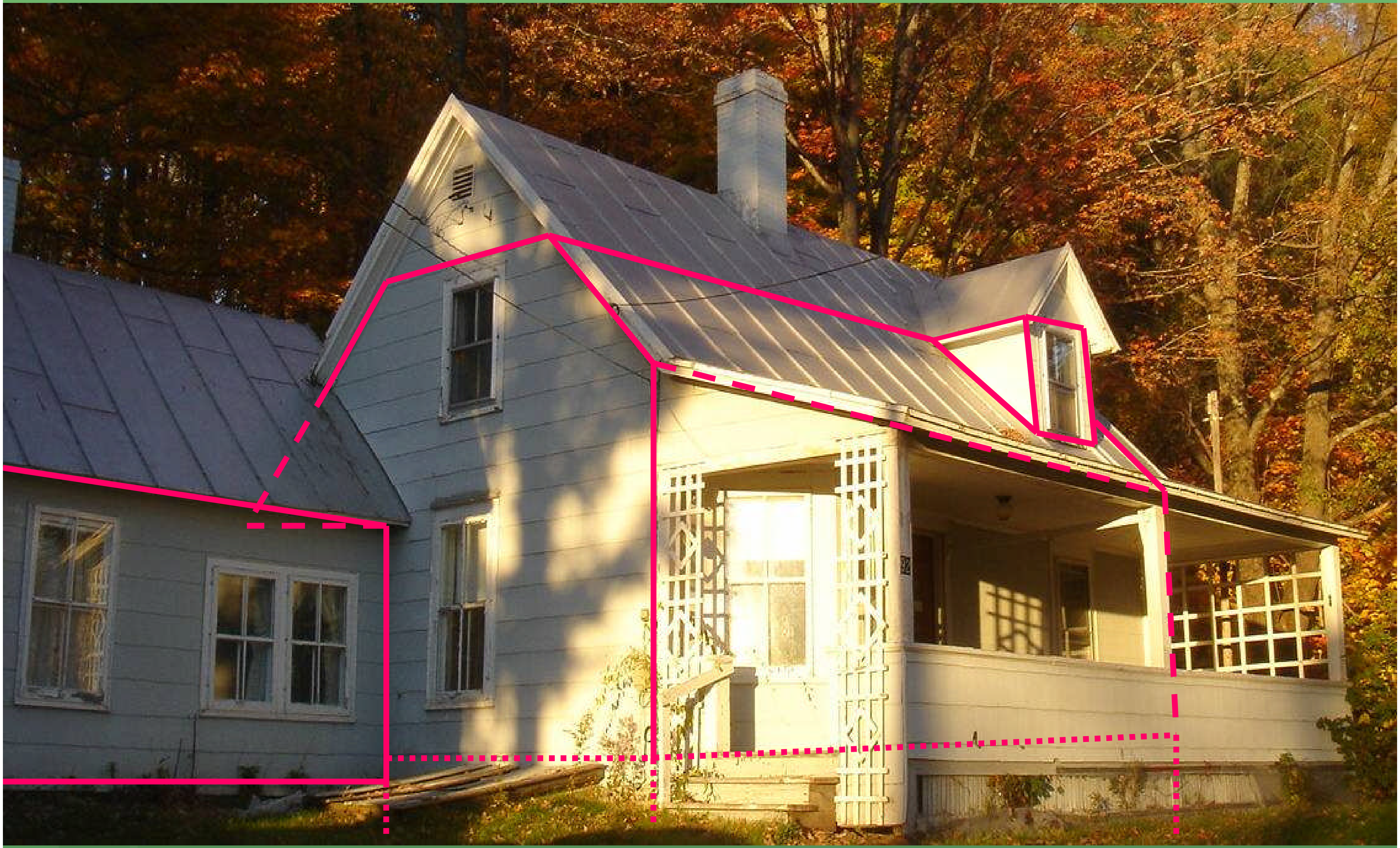
& Moisture boundary

make up:

THE BUILDING ENVELOPE !

Where's the envelope?





The blower door will:

1. Find the pressure boundary (or boundaries).
2. Quantify the total hole area.
3. Locate individual holes.

It is the auditor's responsibility to decide where the pressure boundary should be & how to put it there!

What size hole matters ?

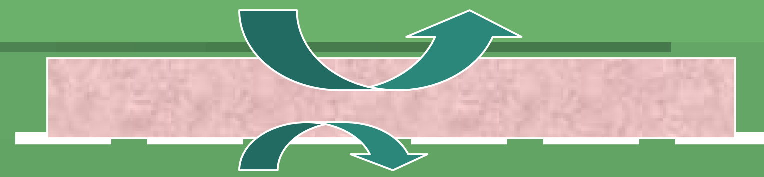
1. Turn the building over in your mind.
2. Mentally fill the upside down building with water.
3. If it would leak, the building envelope is faulty !

There's another problem !

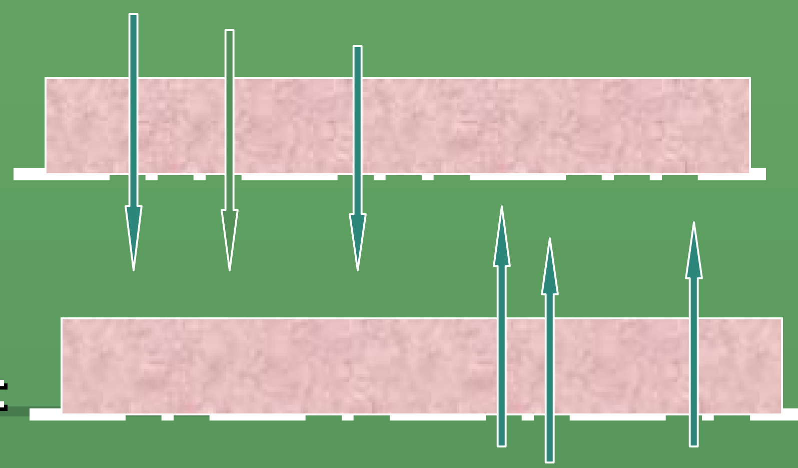
- Sometimes what we think is a boundary, actually isn't.
- The classic example is insulation.
- With a few exceptions, insulation reduces conductive and radiant heat transfer only.
- Contrary to popular belief, insulation alone does little to slow convective heat transfer.

Remember today's terms?

1. Air intrusion =

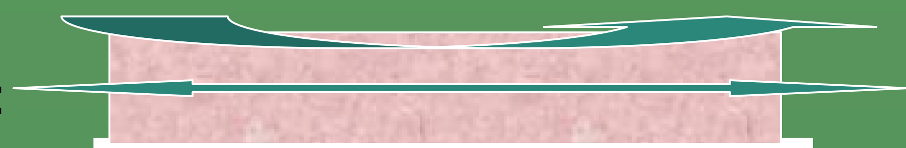


2. Infiltration =



3. Exfiltration =

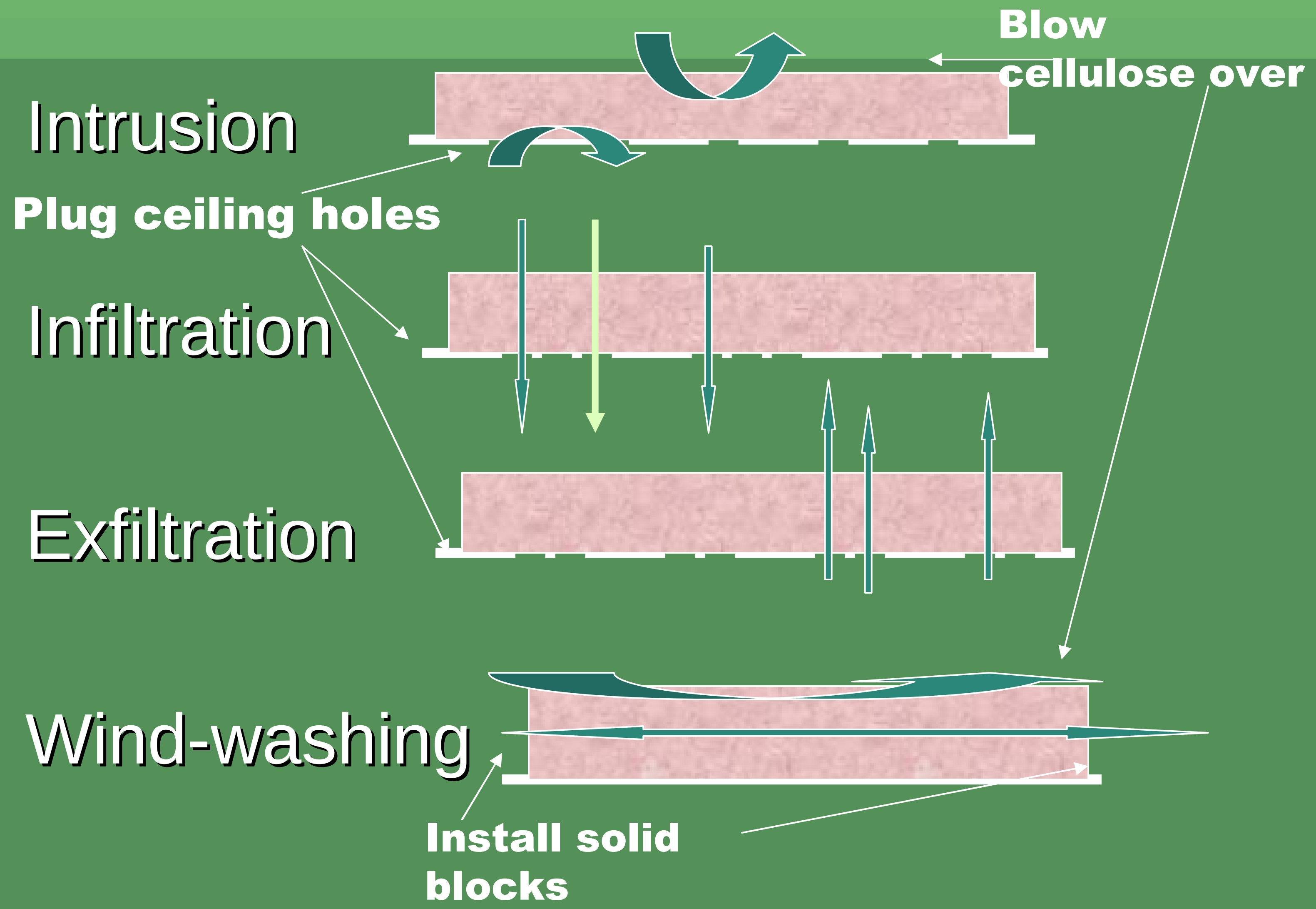
4. Wind-washing =



What can we do about them?

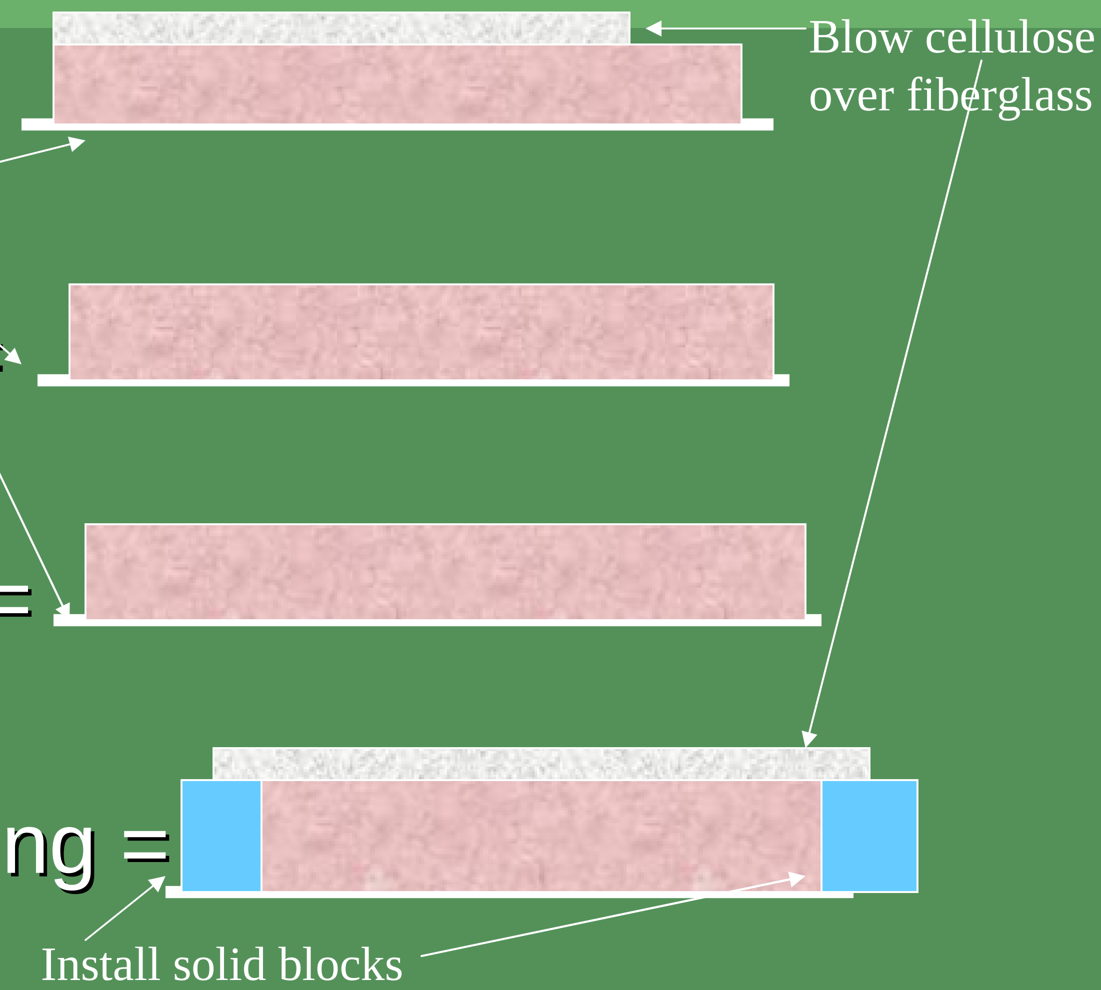
A bunch of solutions!

1. Intrusion
2. Infiltration
3. Exfiltration
4. Wind-washing

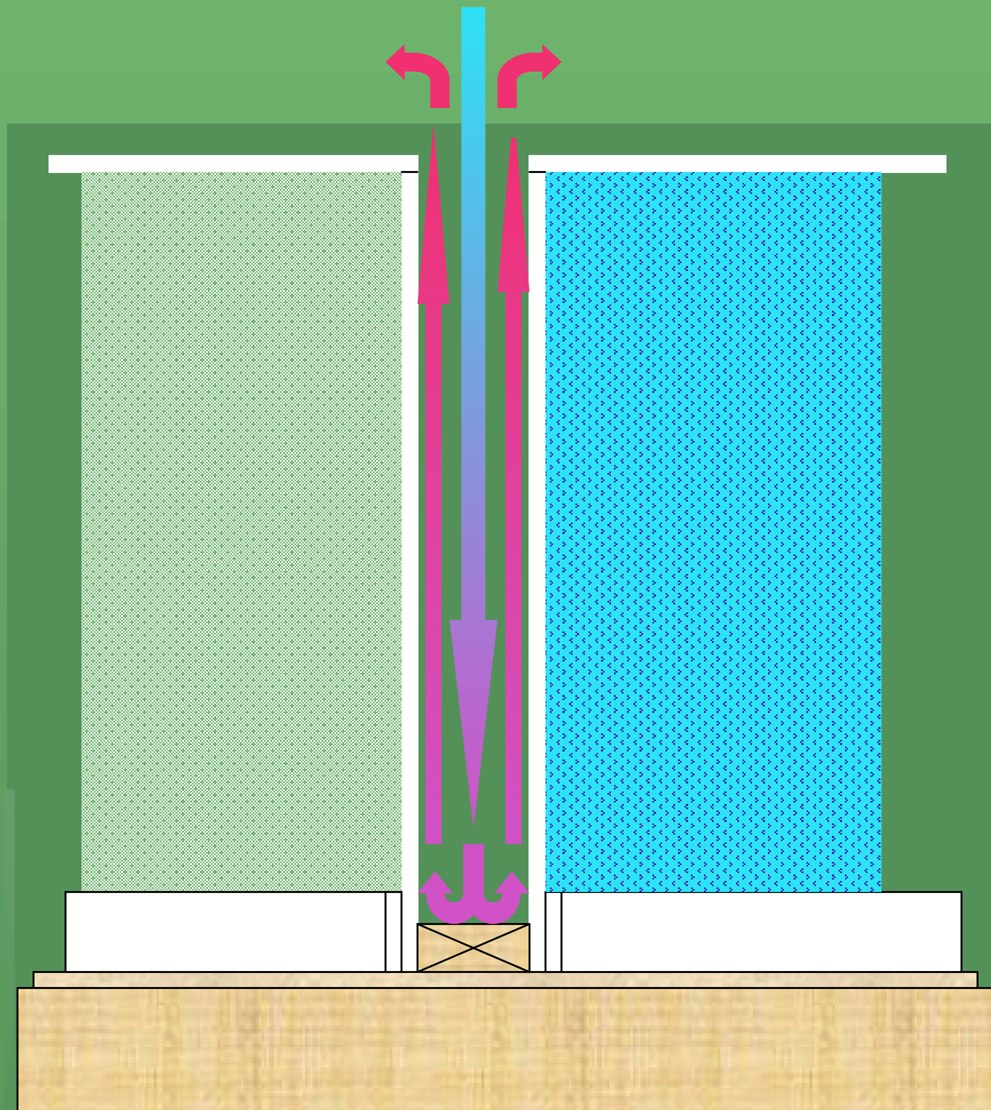


Done !

1. Intrusion =
2. Infiltration =
3. Exfiltration =
4. Wind-washing =



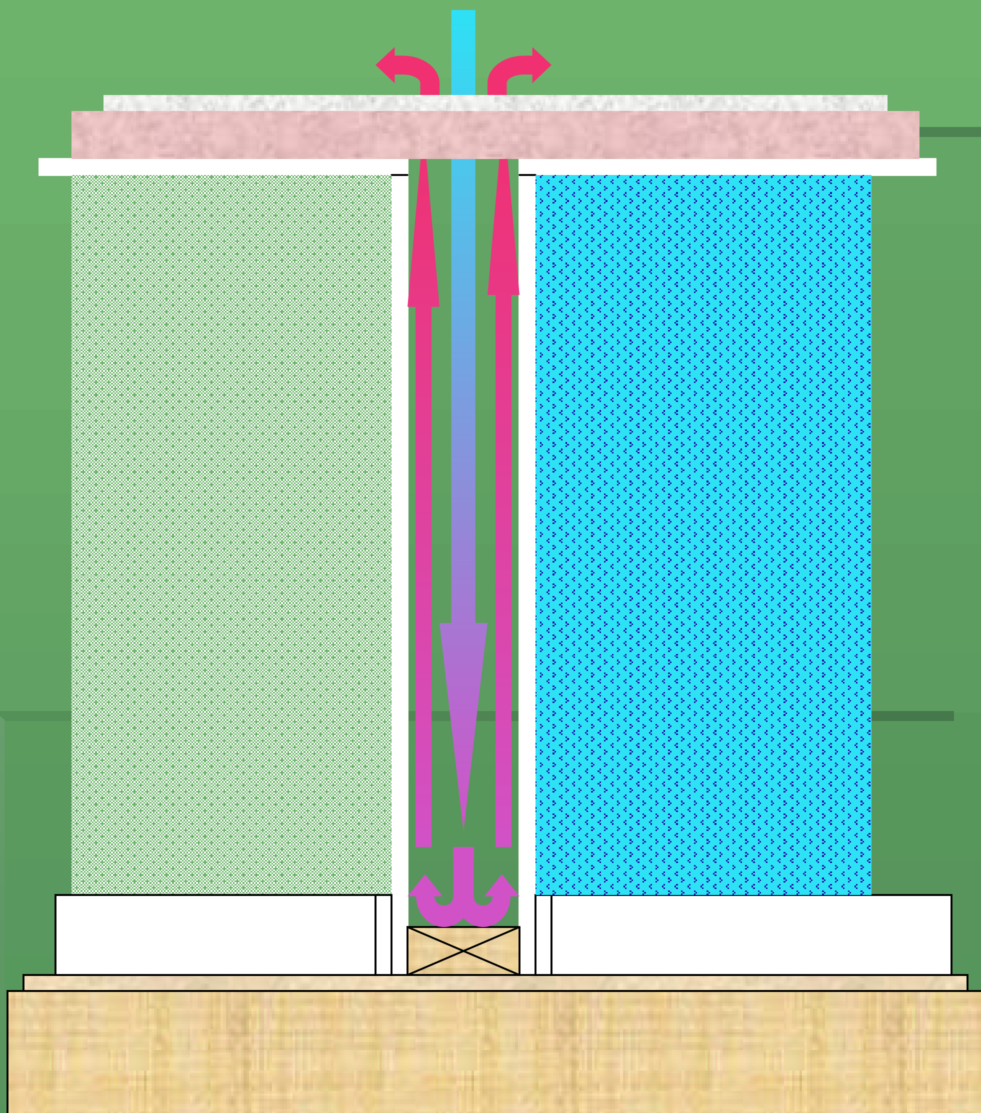
It happens in walls, too



Given an open topped wall (common in balloon construction or at the party wall in a split level), cold attic air will drop down the center of the wall cavity to the bottom & then rise up the sides being warmed as it goes back to the attic.

Even if there is a header, air will enter & exit through any cracks or around pipes & wires.

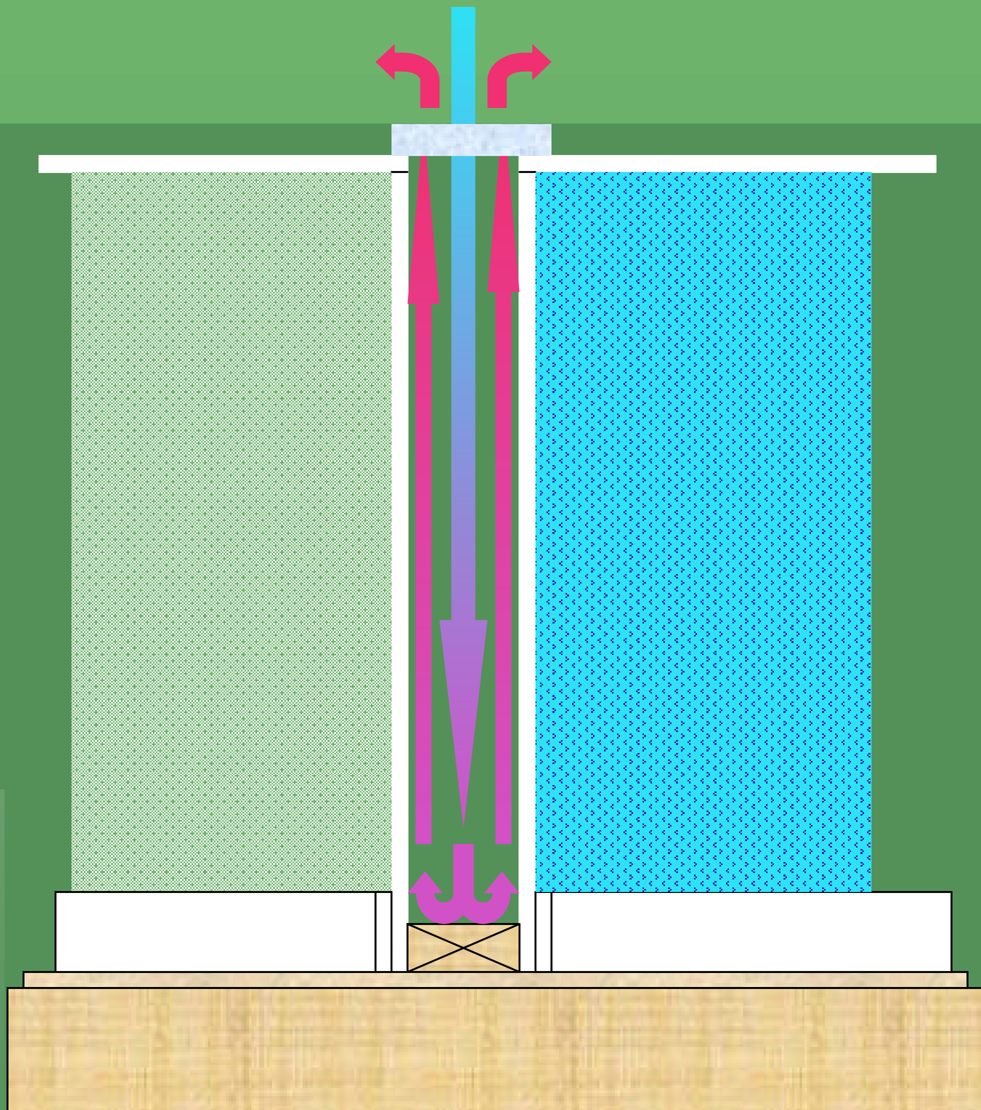
It happens in walls, too



A fiberglass batt – even if faced – does nothing !

Cellulose blown over it all slows air movement somewhat but not enough to matter !

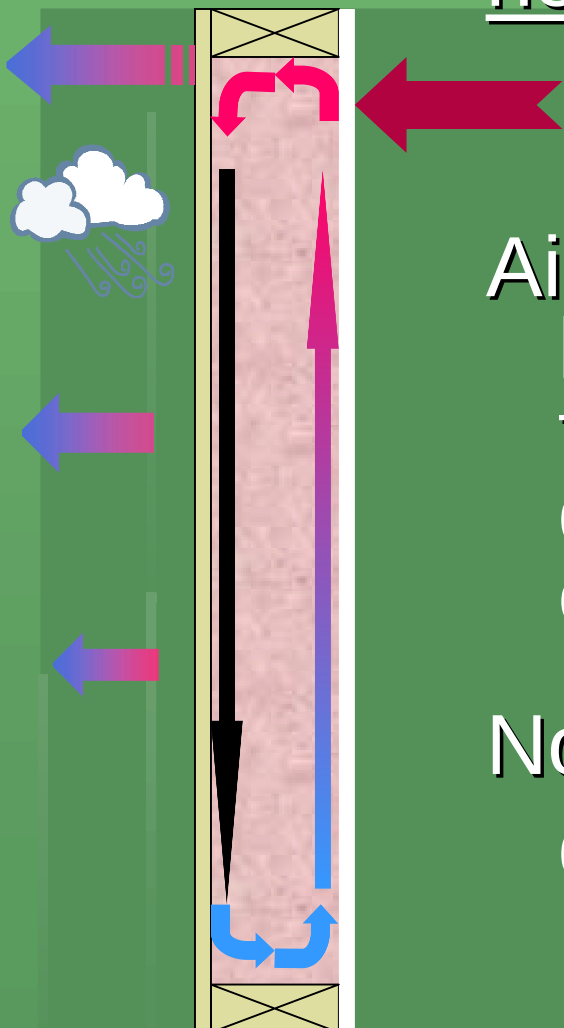
What's the fix?



- Rigid blocking at the top !
- The blocking should be a hard material – drywall, scrap plywood, foam board, etc. - cut to fit & caulked in place.
- Fiberglass jammed in the wall cavity and sealed over with two-part foam also works well.

Then there's Looping !

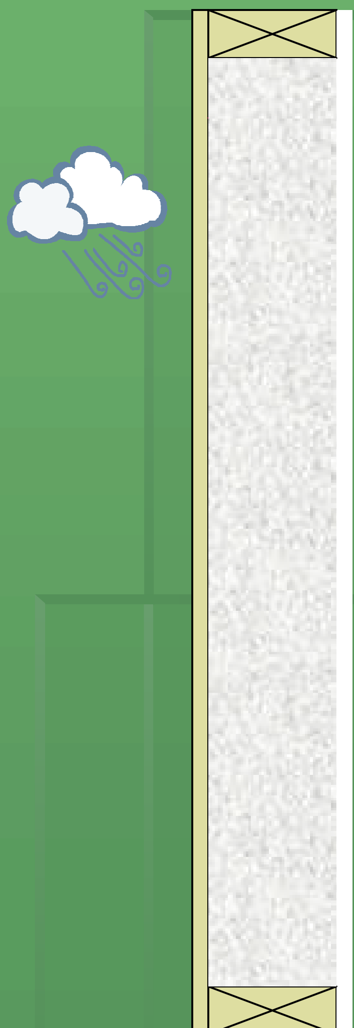
- Warm air always rises & cold air always falls no matter what size the cavity is !



Air inside a wall cavity moves up the heated side picking up heat. It then drops down the cold side, depositing heat which is in turn conducted to the exterior.

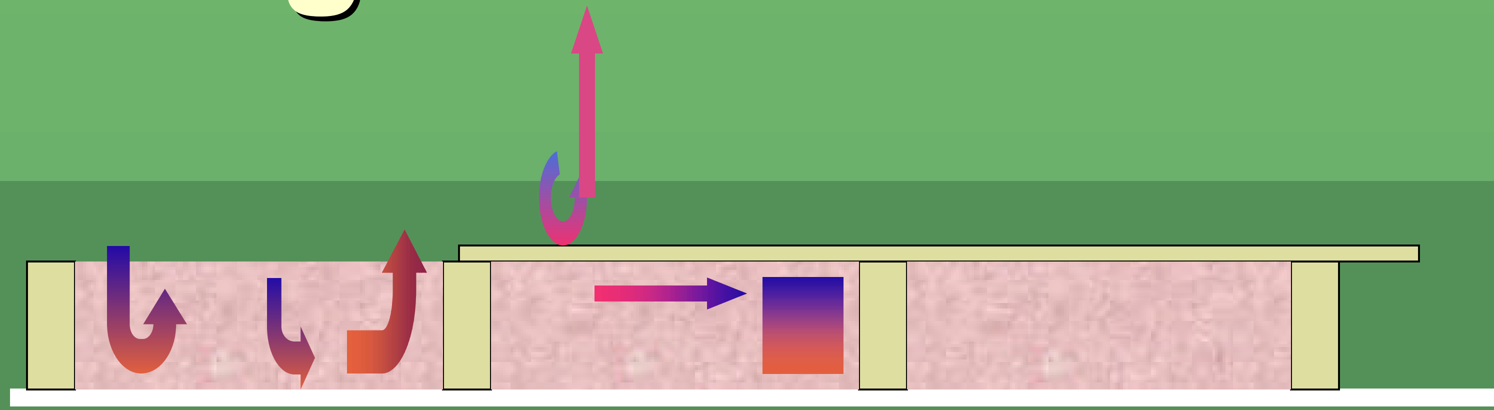
Note: The cavity can be air-tight. Air does not need to enter or leave it.

Looping minimized



The only “fix” is to pack the insulation so tightly air movement is restricted. This is nearly impossible with fiberglass, relatively difficult with cellulose and quite easy with two-part foam.

Ceilings are no different !



If the attic is floored over, air circulates inside the closed cavity, carrying heat from the bottom to the top where it conducts/radiates to the attic.

If it isn't, the heated air will rise out of the insulation & into the attic where it escapes through the attic venting.

Again, cellulose slows, but doesn't stop, the air movement.

Building Envelope Wrap-up

Consists of:

1. **Heat barrier**
2. **Moisture barrier**
3. **Vapor barrier**

ALL THREE MUST BE:

1. at the same plane
2. continuous
3. durable
4. accessible & repairable
5. doable!

One last comment!

- As with the wind/stack/fan driven air movement, it's nearly impossible to isolate one category from another.
- Air intrusion, infiltration, exfiltration, wind-washing and looping all go on continuously – depending upon the cavity configuration & contents, the strength of the drivers and the size of the holes – in every cavity of every building.
- Reducing the drivers is impractical.
- Your task is to locate & plug the holes !

Costing Energy: Air Transported Heat Loss:

0.0182 BTU is required to raise 1 cubic foot of air 1 degree Fahrenheit so…

- $Q = V \times 0.0182 \text{ BTU} \times \Delta T$ where
  - V = volume of heated air
  - ΔT = Difference in temperature
- $Q = V \times ACH \times \dfrac{0.0182 \text{ BTU}}{\text{Cu ft / °F}} \times HDD \times 24 \text{ hrs}$

ACH = Air Change per Hour

So what does it cost?

- $Q = V \times \frac{AC}{H} \times \frac{0.0182\ BTU}{Cu\ ft\ ,\ °F} \times HDD \times 24\ hrs$

28’ x 40’ ranch on slab – 8’ ceiling

0.5 ACH

7500 HDD

Electric heat (3412 BTU/kWh)

Annual cost for heating escaping air @ $0.15 kWh?

Calculations:

- $Q = V \times AC/H \times \dfrac{0.0182\ BTU}{Cu\ ft\ /\ °F} \times HDD \times 24\ hrs$

28’ x 40’ x 8’ = 8,960 Cu’ times

0.5 ACH = 4,480 Cu’/hr times

0.0182BTU/cu’/°F = 81.54 BTU/°F/hr times

24 hours = 1956.96 BTU/°F/day times

7500 HDD = 14,677,200 BTU/yr divided by

(Electric heat) 3412 BTU/kWh = 4301 kWh/yr

(Annual cost) times $0.15 kWh = $645/yr

Costing energy: 100 CFM fan running 20 minutes per hour:

$$Q = CFM \times \frac{(n\ \text{minute})}{\text{hour}} \times \frac{0.0182\ BTU}{\text{Cu ft} / °F} \times HDD \times 24\ \text{hrs}$$

100 CFM x 20 min/hr = 2,000Cu'/hr times

0.0182BTU/cu'/°F = 36.40 BTU/°F/hr times

(7500 HDD x 24 hours) = 6,552,000 BTU/yr

Using electric heat:

6,552,000BTU/yr divided by 3412BTU/kWh = 1920kWh/yr times $0.15kWh = $288* per year

* **Plus electricity for the fan (≈ $0.50 per month)**

Attics & Crawlspaces Ventilation

- Why airseal & vent?
- What's the physics?
- When do we airseal? Vent?
- How?
- Where?

Improve IAQ

- Uncontrolled air movement inside a building moves odors & other contaminants throughout the building.
- Soil gasses, particularly Radon, can be deadly.
- Persons with breathing difficulty, particularly asthmatics, are often negatively affected by crawlspace generated pollutants.

Building Durability

- Ground moisture can migrate throughout the structure, causing mold and rot in remote locations.
- Improperly vented attics can cause ice damming and water intrusion.
- Shingle degradation is rarely an issue!

What’s the physics?.

To evaluate airsealing & venting needs we must understand the relationship each has to what is occurring in the home.

Let’s think about it in terms of moisture.

Keep in mind that there are many pollutants confined in the average home. Most of them are air transported. Understanding air transported moisture will provide a key to understanding the behavior and control of all of them.

Over the year, warm air rising is by far the most influential of the three drivers

- Away from the ocean or a hilltop, the wind blows only 15% of the time; while over the three coldest months the ΔT will be between 40°F & 60°F 24/7.
- A 40°F ΔT creates ≈ 3 to 4 Pascal stack pressure per story. A two story house with a basement can easily create a 10 PA stack pressure on a cold day.
- All the holes below the neutral pressure plane will leak in. All those above it will leak out.
- Given a random distribution of the ≈200 in² of holes in a 2000 CFM_{50} envelope, (200/5 or) 40 in² will be in the ceiling.
- In winter, from stack, a 2000 CFM_{50} house will leak about 70 ft³ of air/minute through the ceiling.

What does that cost per year? (An interesting little exercise!)

- Formula:

  Q=ft/hr x 0.0182BTU/ft x HDD x 24hrs
- 70 ft/minute = 4,200 ft/hr
- Our fictional house is @ 7500 HDD

Q= 4,200 ft/hr x 0.0182BTU/ft/hr x 24hrs x 7500HDD = 13,759,200 BTU/heating season

- How much #2 fuel is that?

At 100,000BTU/gal (accounts for seasonal losses, etc.) we need 13,759,200BTU/100,000BTU/Gallon or 138 gal

- 138 gallons @ \$2.40/gal = \$331.20 per year

A closer look…

- During the heating season cold, dry exterior air is pulled into the home through “low” holes and heated.
- As it warms, it’s capacity to hold water increases. It absorbs moisture from any higher moisture content source it contacts.
- At the same time, as it warms and becomes more buoyant, it rises up through the building.
- Eventually it exits holes at the top…

- …where it contacts solid, cold surfaces such as the underside of the roof deck.
- There the moisture condenses out,…
- …forming frost on the deck.
- Eventually, when the attic warms,…
- …the frost melts and, as liquid water,…
- …runs back down to the living space…
- …(where it may be seen as a roof leak.)

Remember that moisture is only one pollutant carried by moving air. While CO won't condense on the roof deck & cause rot, it will pass through the home, sickening the occupants as it goes.

(Attics & Crawlspaces)

Venting ↑ rarely works!

- Doesn’t reduce short term moisture buildup
- Doesn’t extend shingle life.
- Doesn’t prevent mold growth
- May dry building components
  - From an annual perspective only
  - Requires excessive heat loss to “net dry”
- Done right, can reduce ice dams

Globally:

What to do….
(In order of importance)

- Isolate the attic from the heated space
- If impossible, consider a “hot” roof.
- Keep moisture out of the crawlspace
- If moisture gets in – get it out!
- If ice dams happen, cool the attic.
- If faced with code enforcement, document the existing venting with ZPD before adding ventilation.

Isolate the attic

- Number One!
  - Isolate the attic from the living space!
  - Always!
  - No matter what!

Ridge vent air source ?

1” x 4” matched board

Hot Roof

- “Hot Roof” simply means the insulation is directly in contact with underside of the roof deck. There is no venting.
- The technique is used when:
  - The roof cavity is too small to allow venting & sufficient insulation
  - The roof design (i.e. Mansard, cathedral, cross perlin post & beam, intersecting dormers) doesn’t allow adequate venting.
  - The attic can not be airsealed from the living space
- Guess what? Done right, it’s code approved!

Attic

Note heavy mold & water

Attic "super" connected to living & very wet crawl space below. No practical way to air seal.

Attic – before & after

Ditto

Crawl Space Moisture

- To vent or not to vent…?
  - Wet-dry cycle
  - When humidity is high, moisture *enters*!
- Ground cover?
  - Standing water?
- Gutters & swales

As with any pollutant, preventing entry is far preferable to removal which is, in turn, far preferable to dilution.

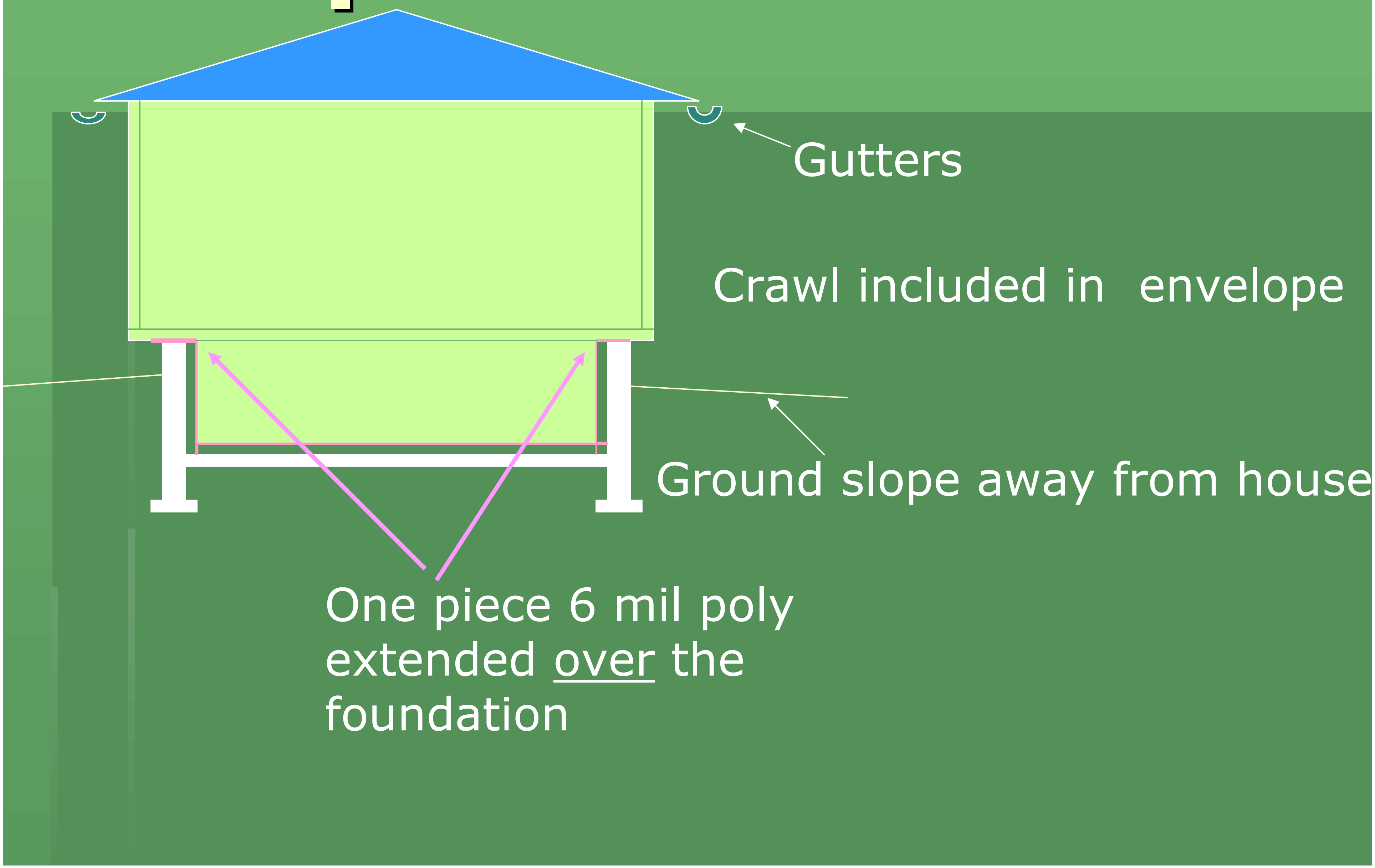
Condensation on a crawl wall.

The solution?

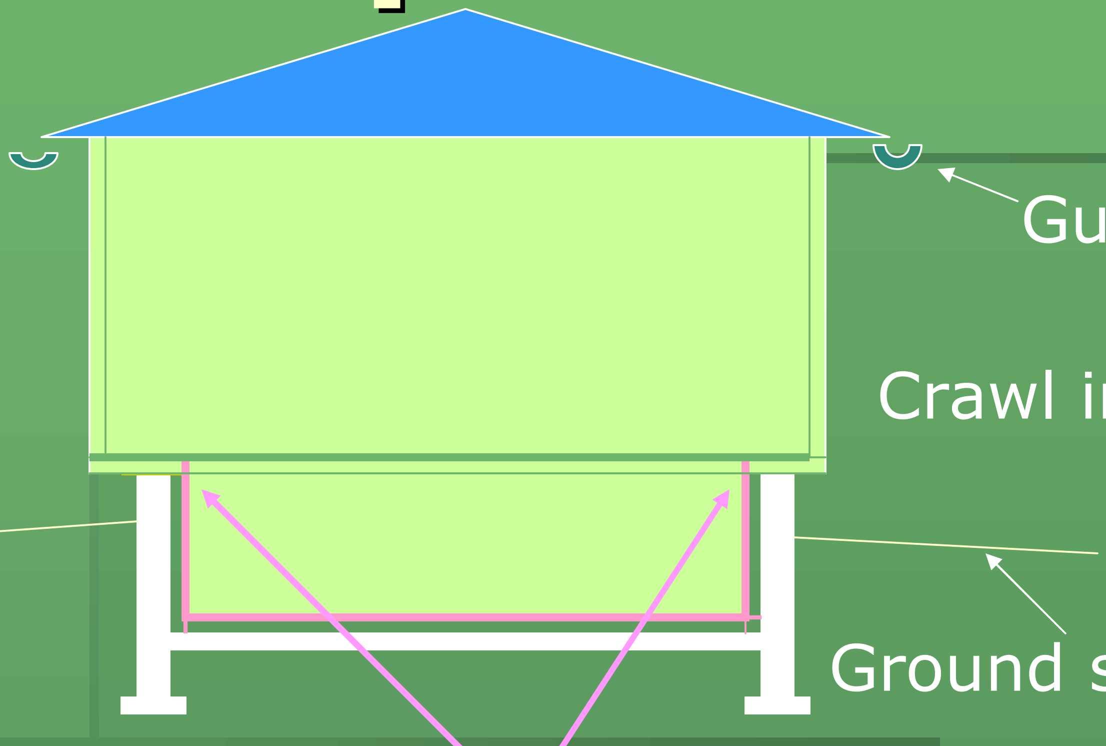
Ground cover

(New construction)

The "perfect" crawl



The “perfect” crawl (Retrofit)



Gutters

Crawl included in envelope

Ground slope away from house

One piece 6 mil poly sealed to underside of floor decking

Poly on the ground with foam blown up to the deck works extremely well.

The ultimate crawl retrofit !


Very low ceiling crawl:
Before & after
Note
poly

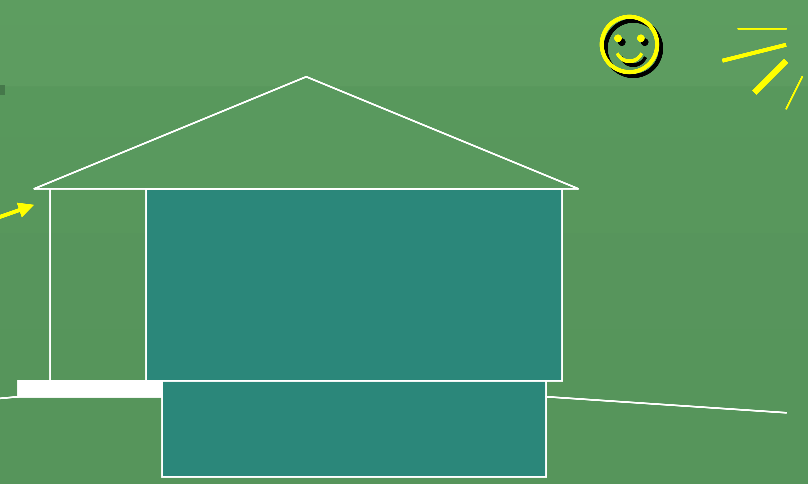
Ice Dams

- Ice dams typically occur because snow cover near the top of a roof melts before that near the eves. The melt runs down the roof and refreezes in the snow remaining over the colder eves, a layer at a time, until a natural dam builds up.
- Conventional wisdom says if a roof is sufficiently vented it will warm & melt uniformly, preventing the ice buildup.
- In the real world, things have a way of being a little more complicated!

It’s always snow melt refreezing.

Two Questions:

- Why is it melting?
  - (Or, Why is it not melting uniformly?)
- Why is it refreezing?



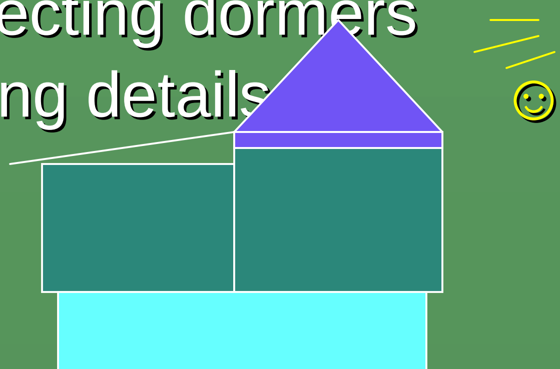
Refreezing is always caused by the lower edge of the roof being cold.

The easy fix is a heat tape.

It’s an energy hog!

Why is it Melting?

- Insufficient attic insulation
- Poor air sealing
- Heat source in attic
  - Bath/kitchen vent “dump”
  - Sun hitting roof
- Architectural anomalies
  - Intersecting dormers
  - Framing details



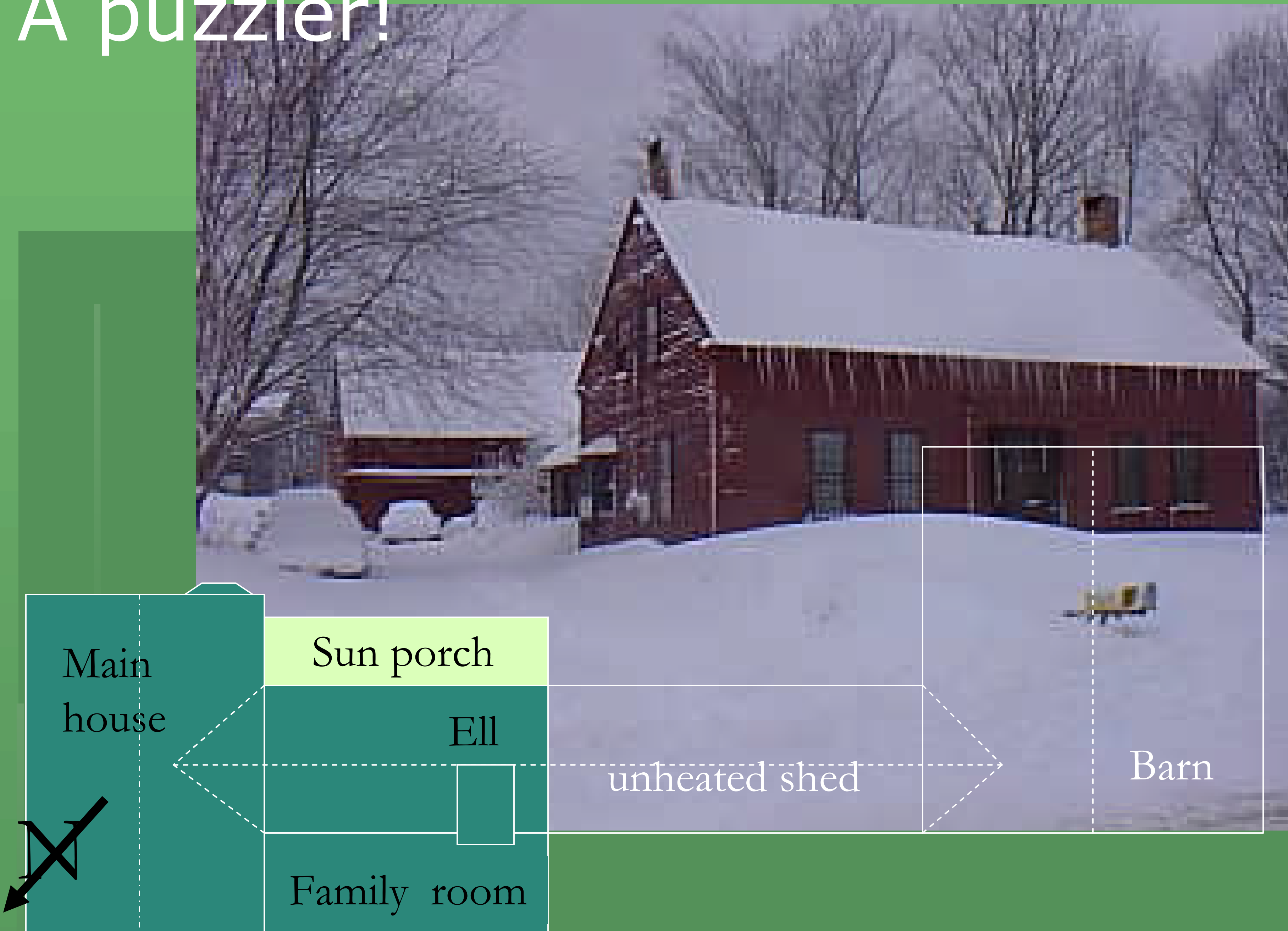
Solution?

- Raise attic R
- Airseal
- Duct out
- Add venting!
- If you can’t solve it, a heat tape may be the only way!

Lower (shed) pitch uninsulated

Upper pitch underinsulated & undervented

A puzzler!



Why do we insulate?

Does it work?

Save energy	Yes
Remove moisture	No
Prevent condensation	No
Dry up mold	No
Prevent rot	No
Extend shingle life	Probably
Satisfy code officers	Usually

Why do we vent attics?

Does it work?

Remove moisture	Rarely
Prevent condensation	No
Extend shingle life	No
Save energy	No
Prevent Ice Dams	Sometimes
Satisfy code officers	Usually

Why do we vent crawls?

Does it work?

Remove moisture	Rarely
Prevent condensation	No
Dry up mold	No
Prevent rot	No
Save energy	No
Satisfy code officers	Usually

Why do we air seal?

Does it work?

Save energy	Yes
Prevent condensation	Yes
Dry up mold	Yes
Prevent rot	Yes
Prevent ice dams	Yes
Extend shingle life	Probably
Satisfy code officers	N/A

Always Remember…

- Insulation and airsealing are two distinct activities.
- With a few exceptions – foams, sealed-in-place isocyanurate boards & true dense-pack cellulose – insulation <u>does</u> <u>not</u> create an airseal.
- Airsealing <u>does not</u> insulate.
- Airsealing without insulating ignores conservation opportunity big time
- Insulating without airsealing can cause <u>**serious**</u> problems!

For instance…

INSULATING AN ATTIC – WITHOUT AIRSEALING IT - WILL NOT AFFECT THE VOLUME OF AIR MOVED INTO THE ATTIC BY STACK EFFECT!

The driver is the ΔT, (living space to outdoors). It's the same. The path – the holes – hasn't changed either. The same pressure over the same holes will move the same amount of air.

THE SAME AMOUNT OF WARM, MOIST AIR WILL CONTINUE TO ENTER THE ATTIC FROM THE LIVING SPACE IN SPITE OF THE ADDED INSULATION.

INSULATING THE ATTIC <u>WILL</u> LOWER THE ATTIC TEMPERATURE BECAUSE THERE IS LESS CONDUCTIVE HEAT LOSS FROM THE HOUSE TO WARM IT.

<u>ATTIC SURFACES – PARTICULARLY THE UNDERSIDE OF THE ROOF DECK - WHICH MIGHT NOT HAVE BEEN COLD ENOUGH TO ALLOW CONDENSATION & SUPPORT MOLD GROWTH PRIOR TO INSULATING NOW WILL BECAUSE THEY HAVE BEEN COOLED TO BELOW THE DEW POINT!</u>

THE CONVENTIONAL SOLUTION

-ADDING ATTIC VENTILATION –

WILL MOST LIKELY CAUSE EVEN MORE CONDENSATION IN THE ATTIC BECAUSE THE ATTIC WILL NOW SUCK HARDER ON THE HOUSE, INCREASING THE PRESSURE ON THE EXISTING HOLES & BRINGING EVEN MORE WARM, MOIST AIR UP FROM BELOW.

AIRSEAL THE ATTIC !

Sample House #2

- 20’x30’ ranch on full concrete basement
- Average 2’ exposed concrete basement wall
- 7500 HDD - Open, rural area
- Garage, boiler, washer & drier in basement
- 8’ Ceilings - main floor & basement
- 1000 gallons #2 fuel oil – $4.50/gallon
- 3.5” Fiberglass walls
- 6” Fiberglass attic
- Continuous ridge & soffit venting
- DHW by immersion coil in boiler

Homework:

For Sample House # 2 :

- Assume 10% wall area = R-2 windows & doors.
- What is the home's annual surface heat loss in BTU?
- What is the annual surface heat loss cost?
- What is the volume of heated space?
  - Main floor ?
  - Basement ?
- Assume 1 ACH.
- What is the annual cost to heat the air moving through the house?
- If the house were airsealed to .35 ACH what would the annual savings be?
- Weds reading: Krigger Chap 5, 6, 10