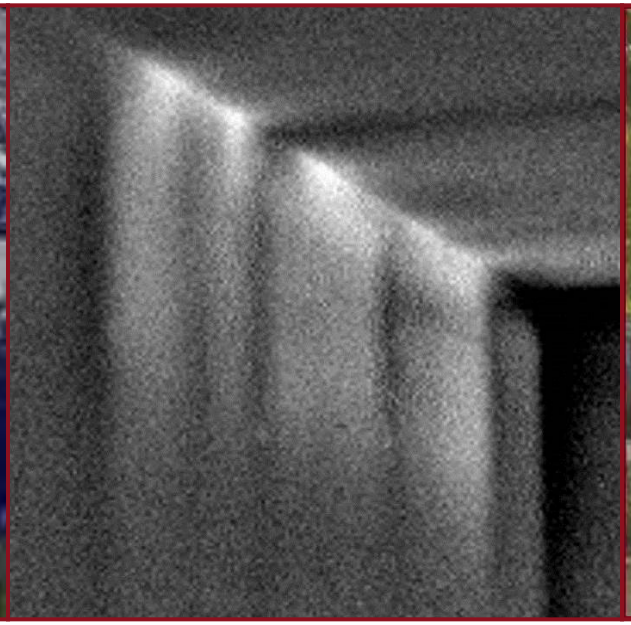
Air Pressures and Air Flows in Homes:

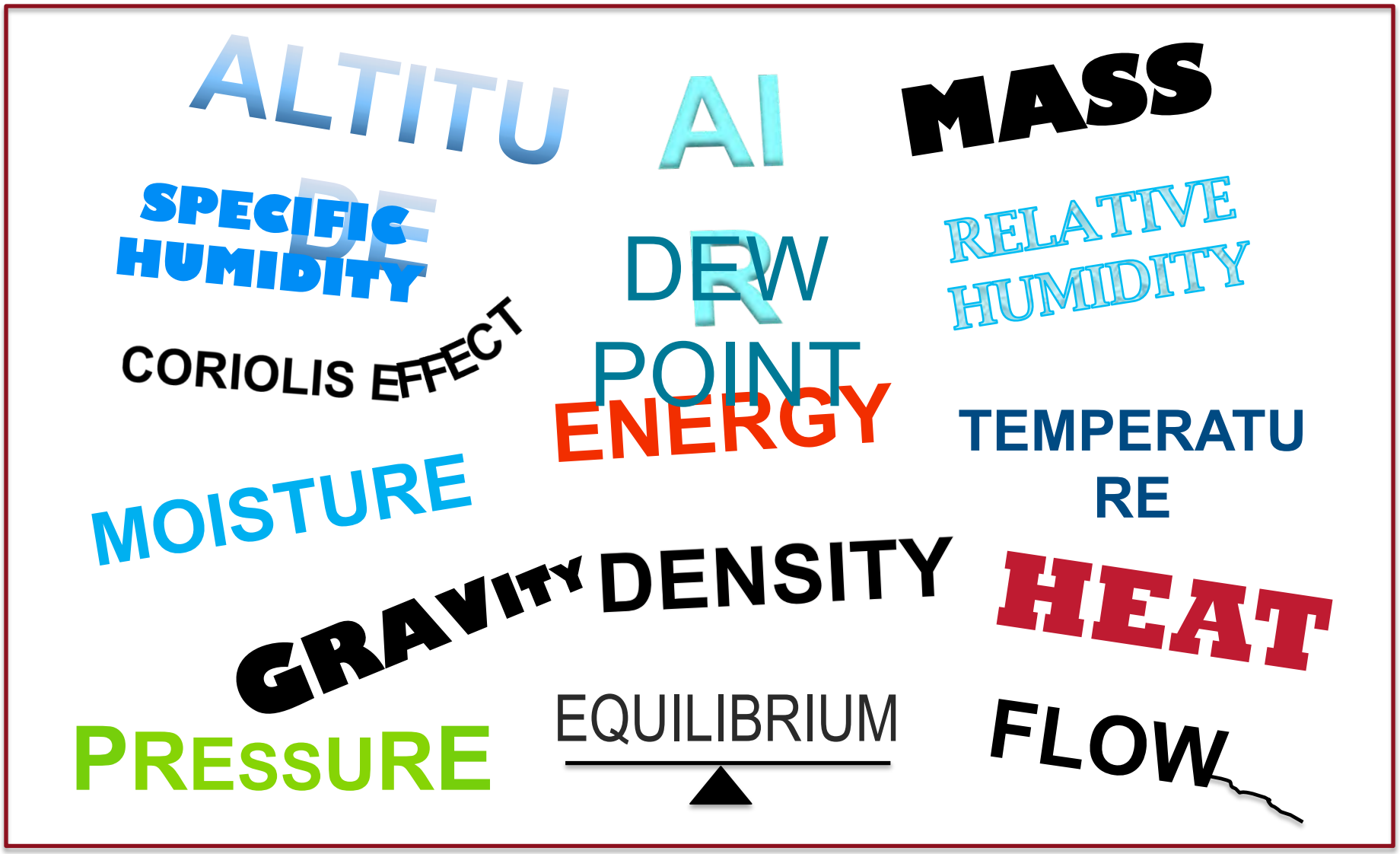


Causes and Effects

Richard Stone, Extension Educator in Housing Technology

The planet Earth is a System

Its performance is governed by rules we know as Physical Laws and Effects

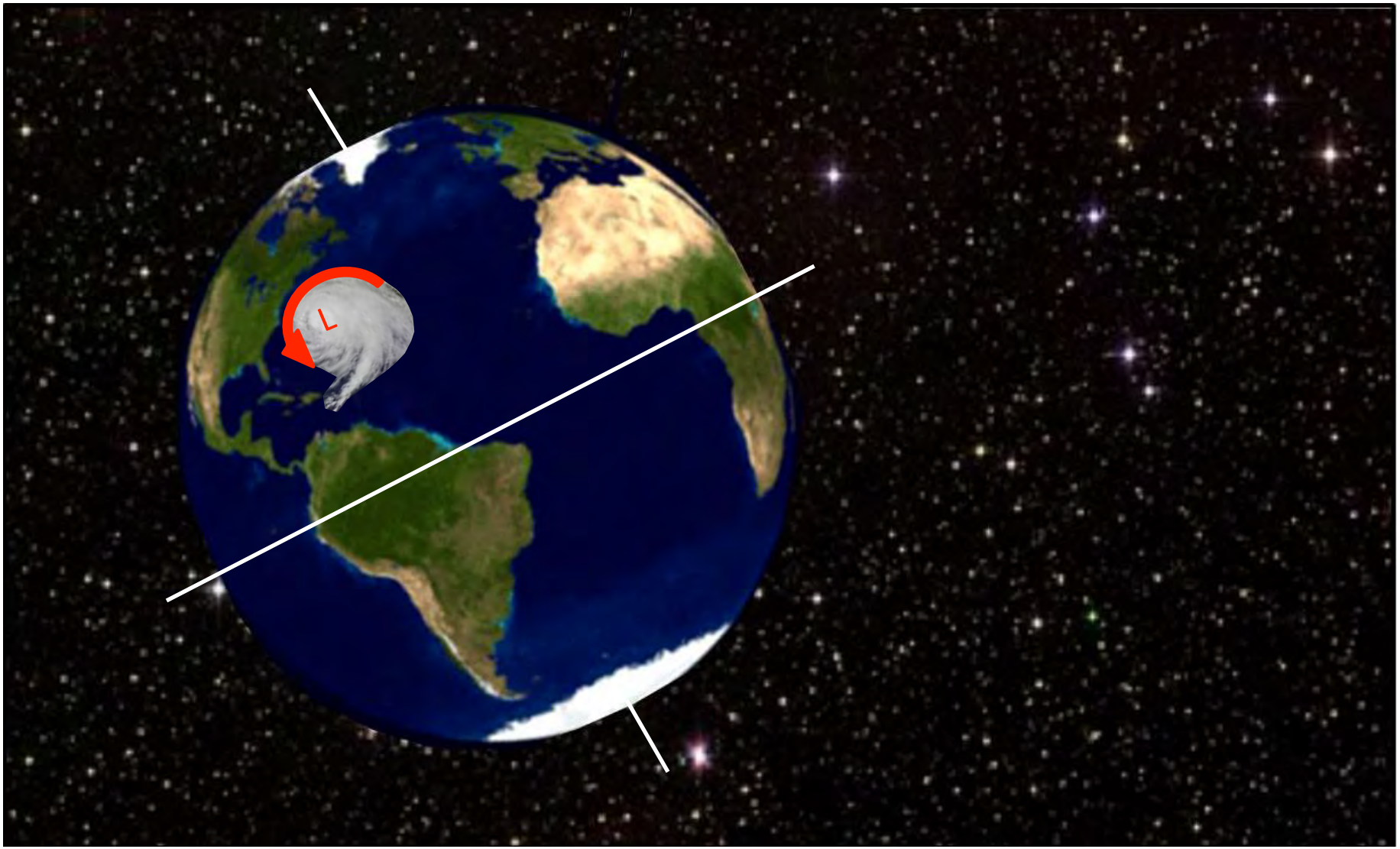


We should understand a few of these

Physical Laws define our understanding of how things work

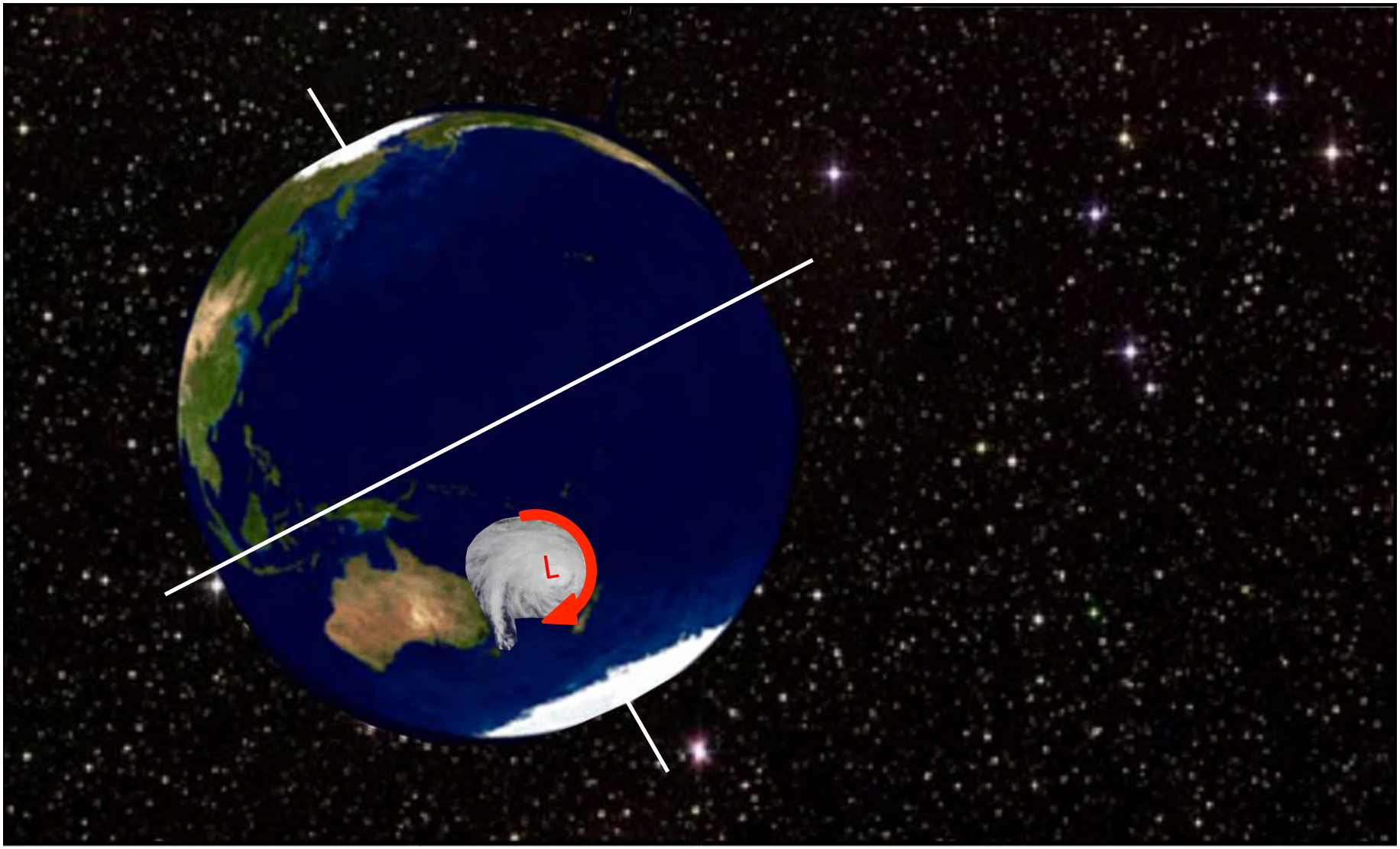
CORIOLIS EFFECT is a result of the earth's rotation

Equatorial regions move faster than polar regions as the earth turns



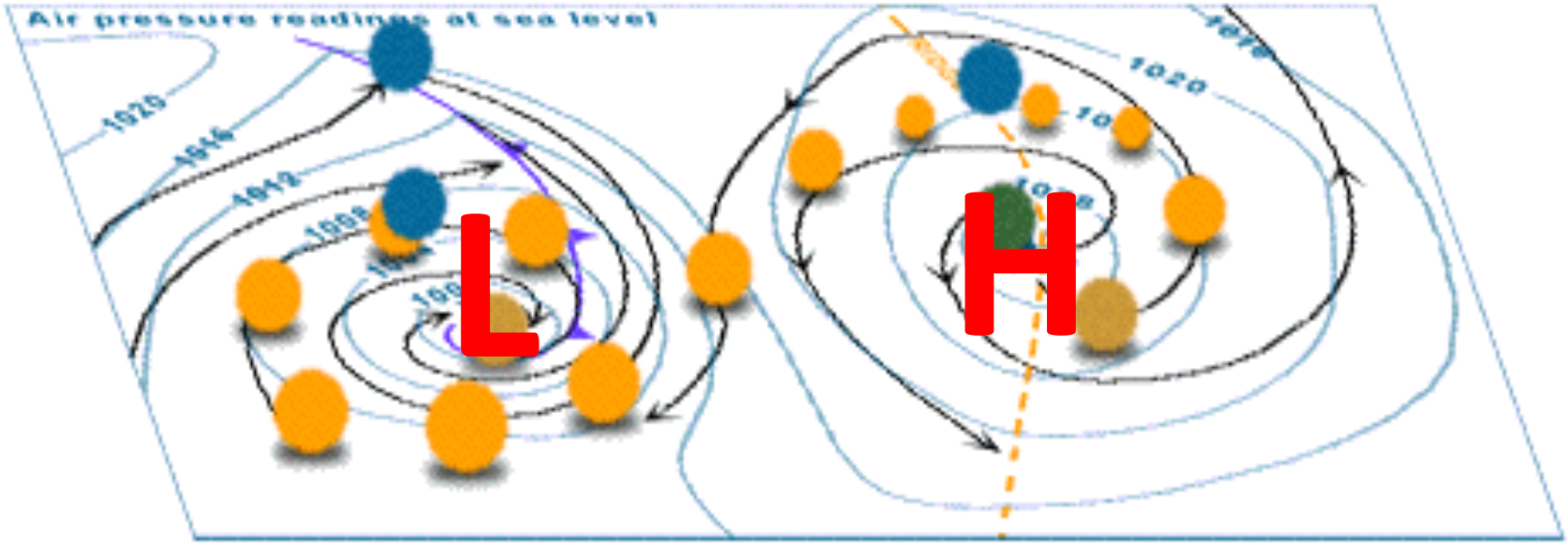
The resulting Coriolis force drives the rotation of air masses

It is why tropical storms rotate counter-clockwise in the Northern Hemisphere



It is why tropical storms rotate clockwise in the Southern Hemisphere

Tropical storms are LOW pressure systems.

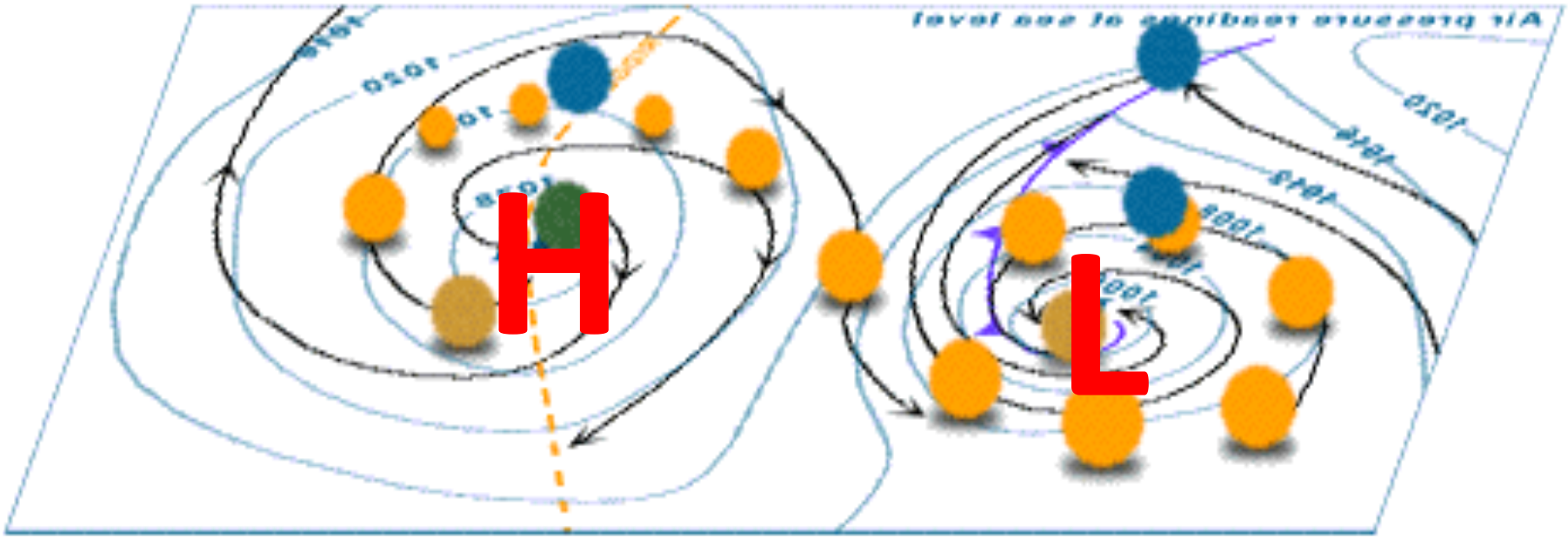


Rotation in Southern Hemisphere

Source: High and Low Pressure Systems *http://www.bom.gov.au/lam/Students_Teachers/pressure.shtml* © Commonwealth of Australia, Bureau of Meteorology

HIGH pressure systems rotate in the opposite direction.

Interactions between HIGHs and LOWs are one driver of Weather Systems on Earth



Rotation in Northern Hemisphere

Source: High and Low Pressure Systems *http://www.bom.gov.au/lam/Students_Teachers/pressure.shtml* © Commonwealth of Australia, Bureau of Meteorology

Wind is Air Flow around and between Pressure Systems

Wind velocity is determined by Pressure Differences

Homes are built on the planet Earth

They are subject to the same physical laws and effects

Our homes have become a Complex set of Systems

with many system actions and system interactions

Conditions inside the Home are managed by Mechanical Systems

Their performance is determined by many design, installation, and operational decisions

HOW DO WE MANAGE THE DECISIONS?

What are the Guiding Principles?

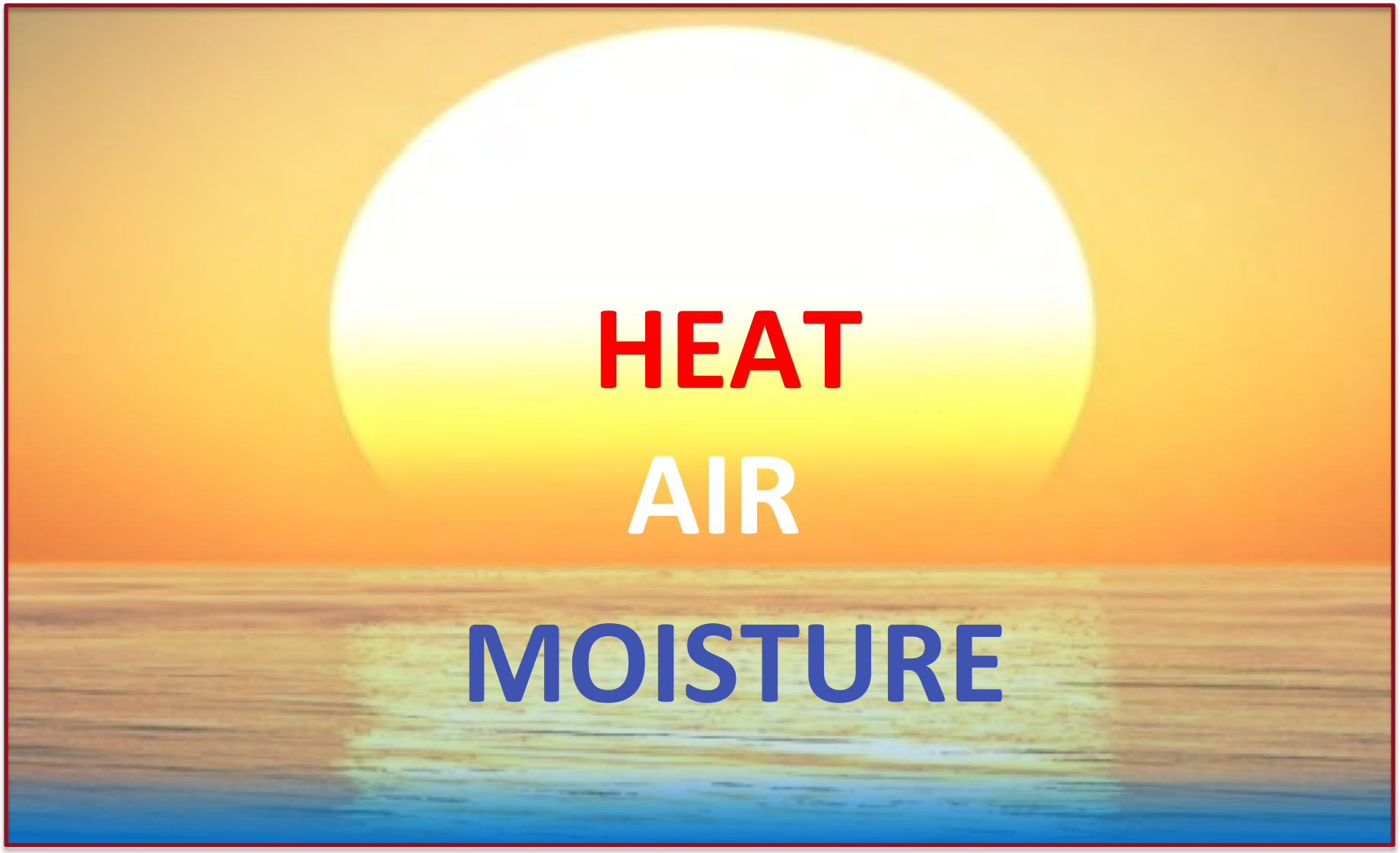
- Plan systems and changes to the home to ensure safety.
- Design, construct, and maintain homes for durability.
- Operate homes for health and comfort.

Here is the Priority List:

1. Combustion Safety - including attached garages **(safety and health)**
2. Ventilation and Indoor Environmental Quality **(health and durability)**
3. Water and Moisture Vapor Management **(health and durability)**
4. Building Enclosure Air-tightness **(durability and comfort)**
5. Insulation and Windows **(comfort and energy efficiency)**
6. Heating and Air Conditioning Design **(comfort and energy efficiency)**

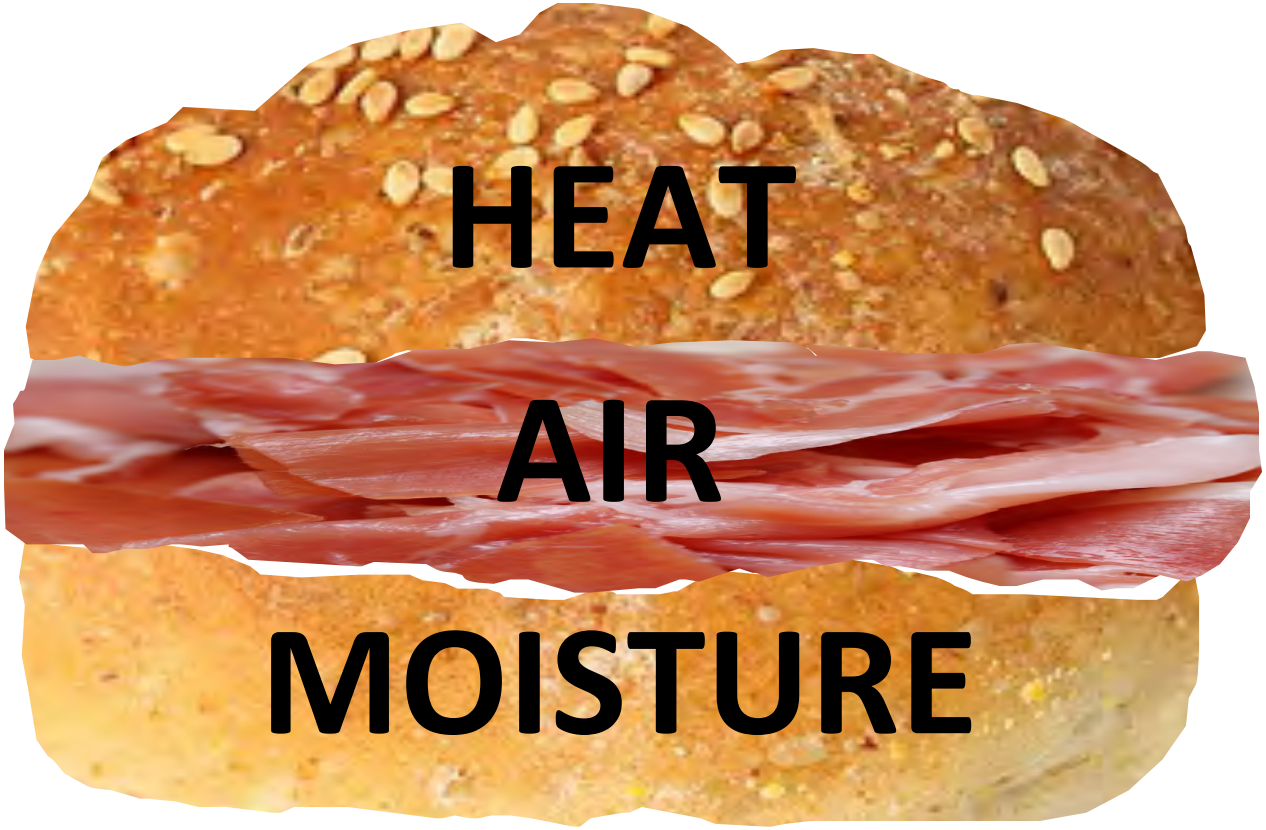
Priorities are Listed In Order of Importance! Apply the Priorities to Each Planned Change

SAFETY + HEALTH + DURABILITY + COMFORT + ENERGY EFFICIENCY

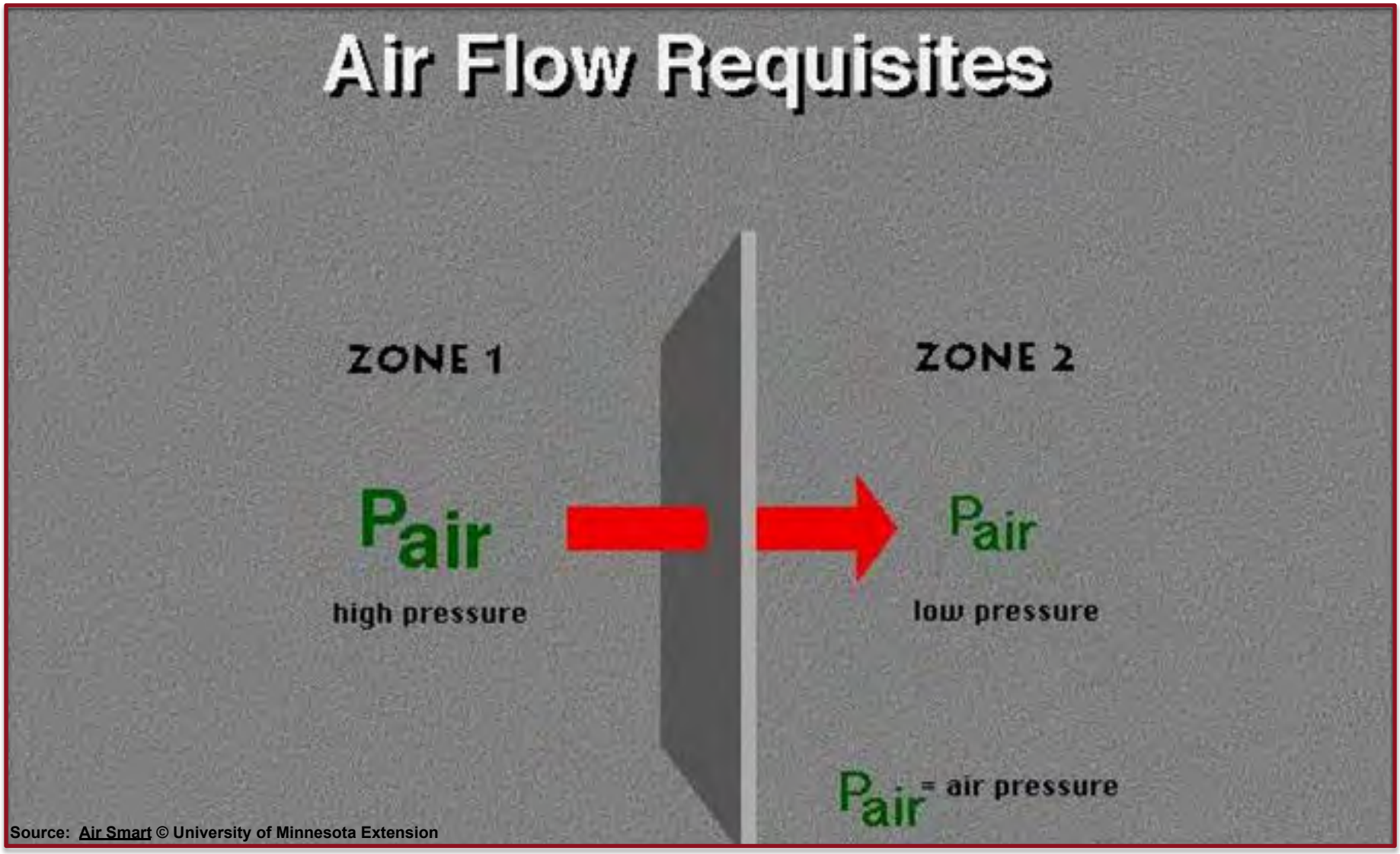


Building Science focuses on Relationships between These Three

They are at the center of our understanding of Building Performance



Easier to remember as the Building Science "HAM" Sandwich



Air is at the Center of the Sandwich

Because it is at the center of so many relationships with Heat and Moisture

Buildings can be Tested to Measure Performance

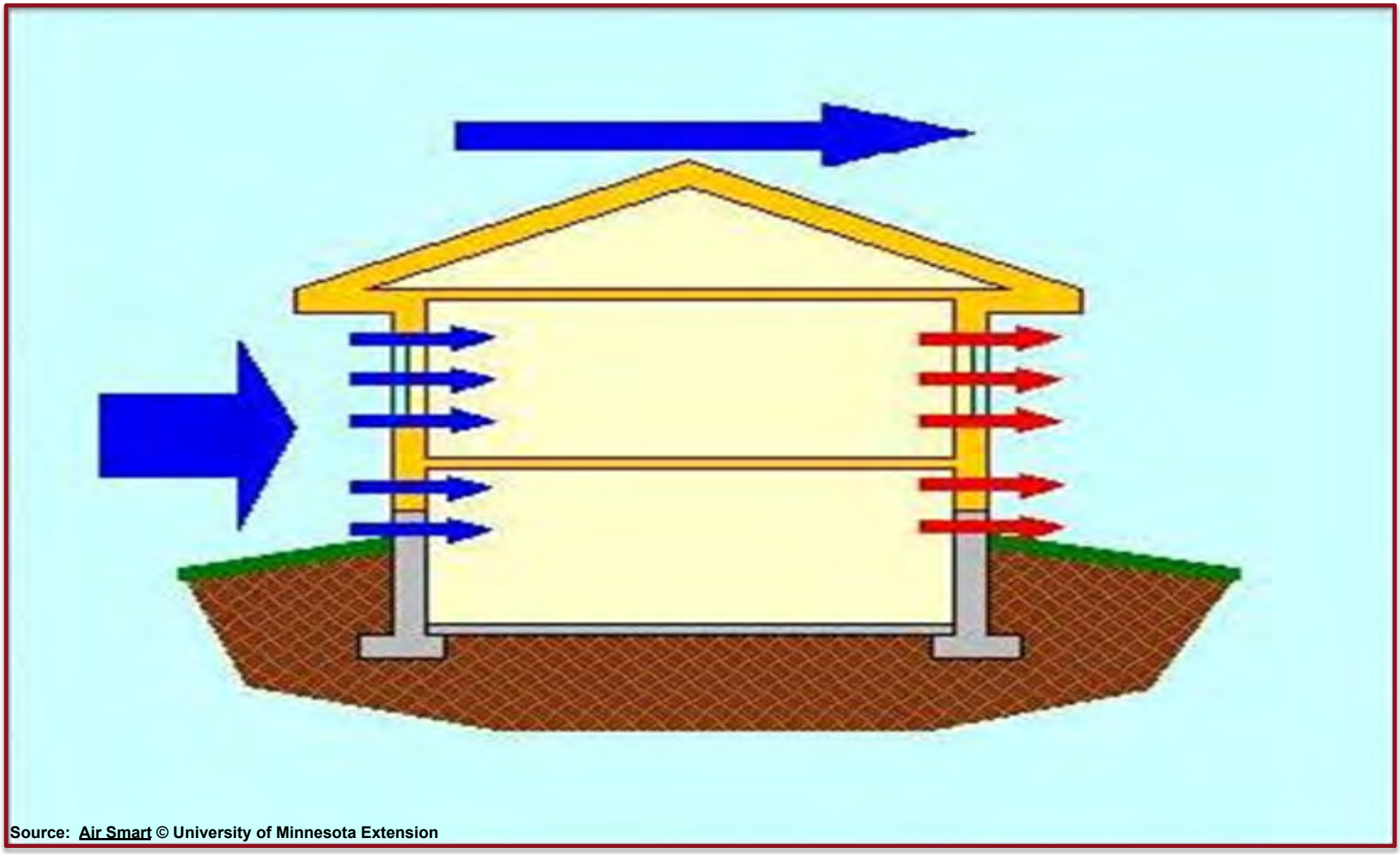
The digital manometer measures pressure differences

The Blower Door is used to measure air leakage

The combined size of leakage pathways can be determined

Thermal Imaging Cameras are often used with a Blower Door

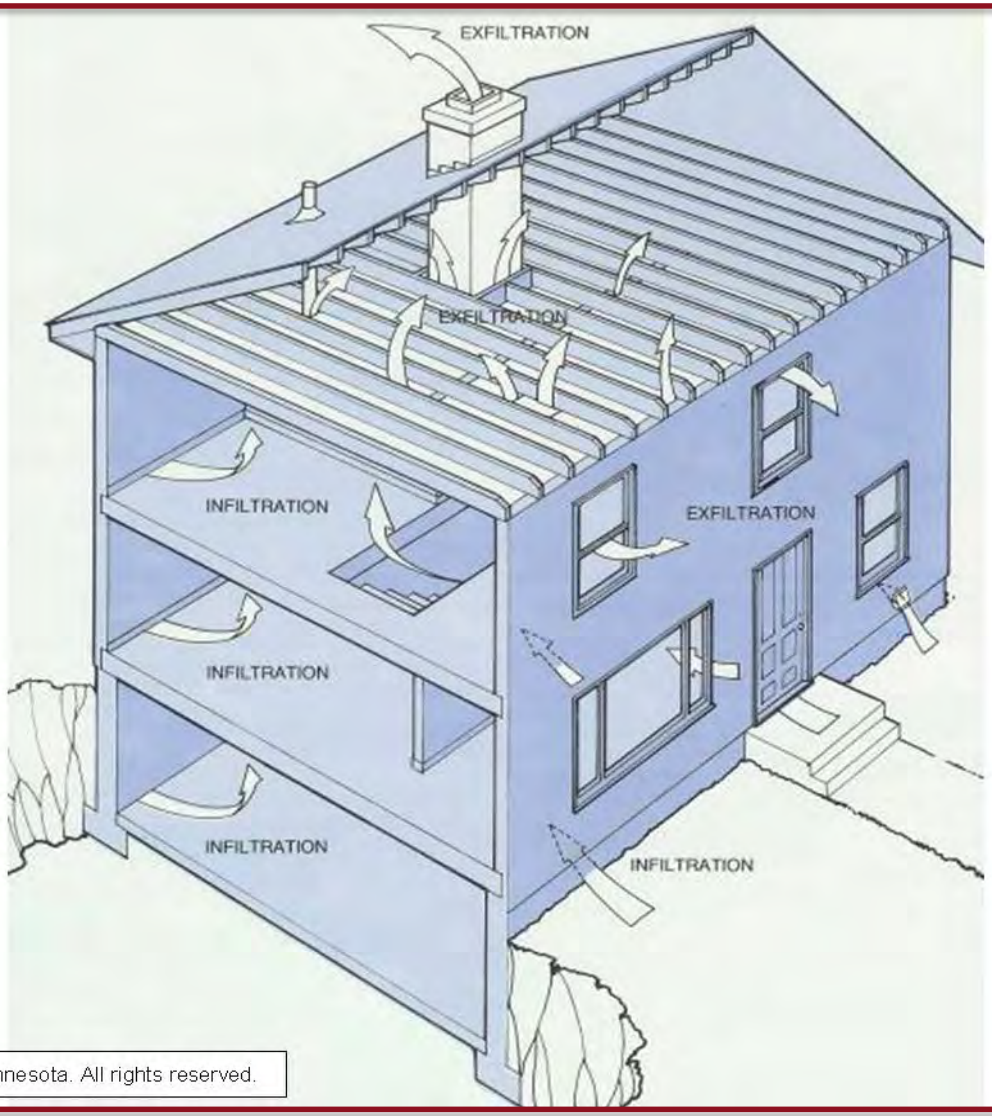
Leakage pathways can be identified by observing surface temperature changes



Source: Air Smart © University of Minnesota Extension

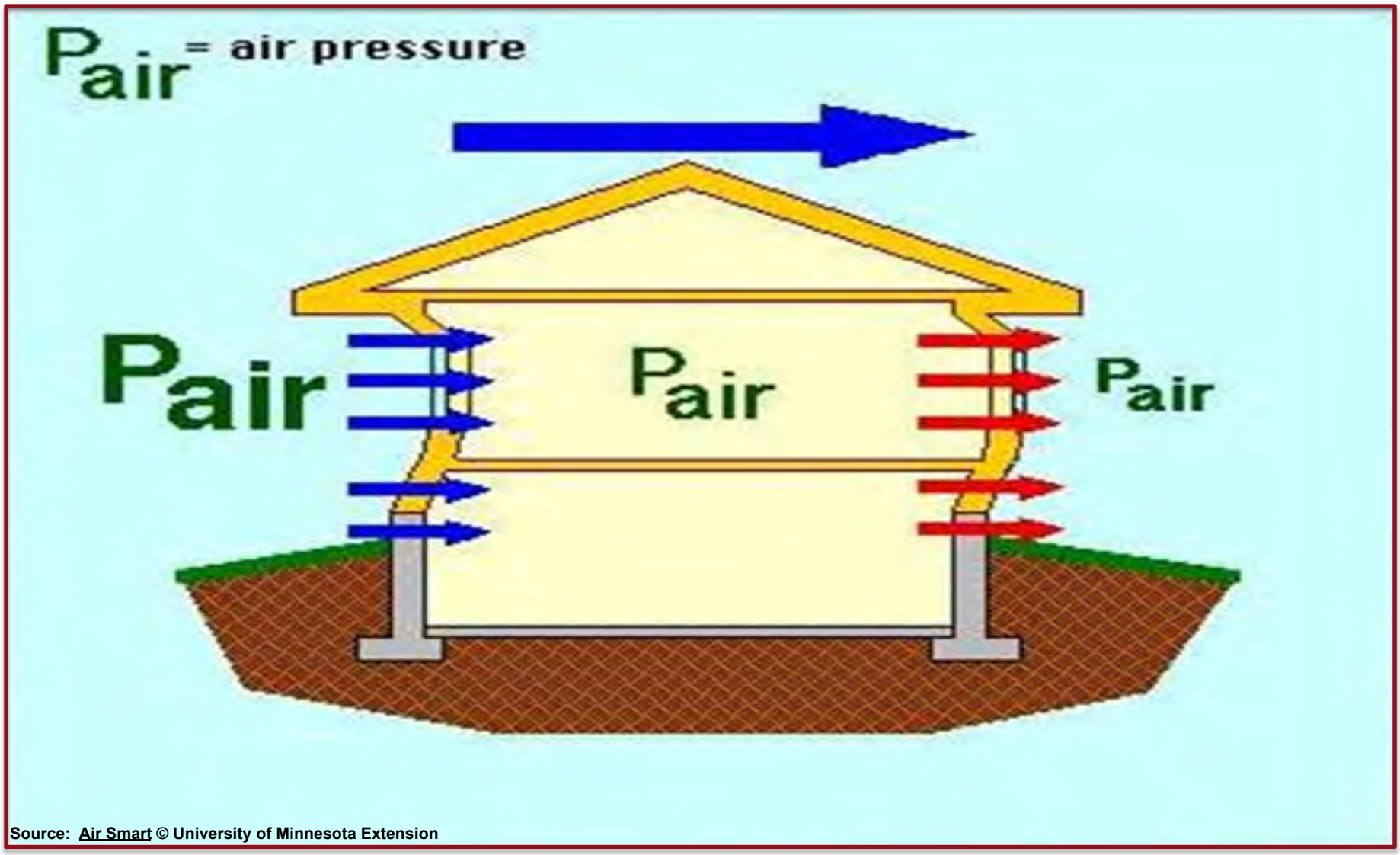
The Effect of Wind across a Home causes Pressure Differentials

Holes in the building enclosure allow air to move in and out of a home



Air In = Air Out

Air entering the home is called Infiltration. Air leaving the home is called Exfiltration



Source: Air Smart © University of Minnesota Extension

Not all Homes are Built to the Same Performance Standards

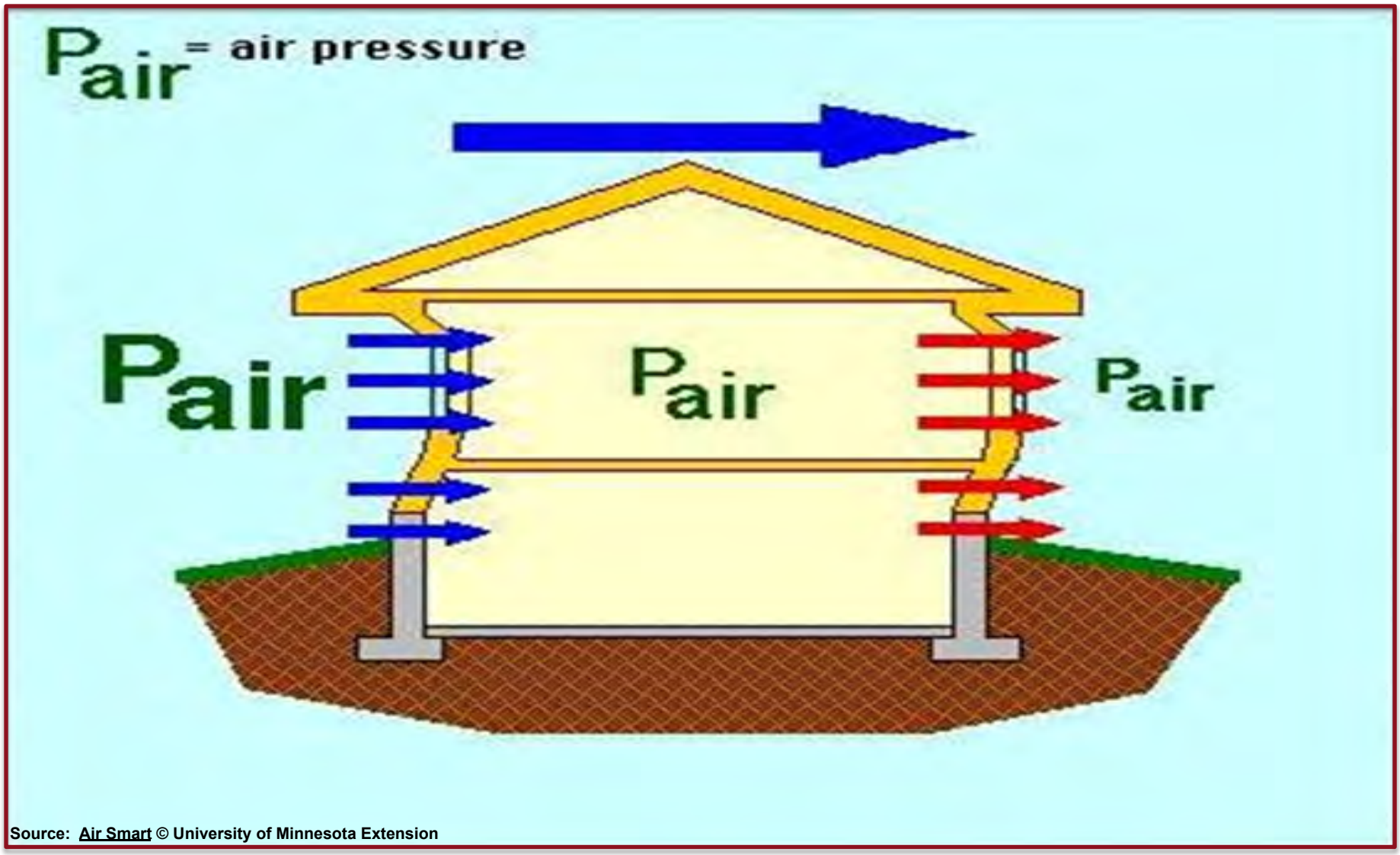
The amount of air leaking through a building varies between homes

Evidence of Infiltration from Outside

Dirt has been "filtered" out by the insulation as outside air leaked through the walls

Evidence of Infiltration from an Attached Garage

Combustion particulates have been "filtered" out by the insulation at leakage locations



Source: Air Smart © University of Minnesota Extension

Air Leakage carries Heat and Moisture into Building Cavities

The effects are most obvious along leakage pathways

This Damage was found in a 7 year old Home

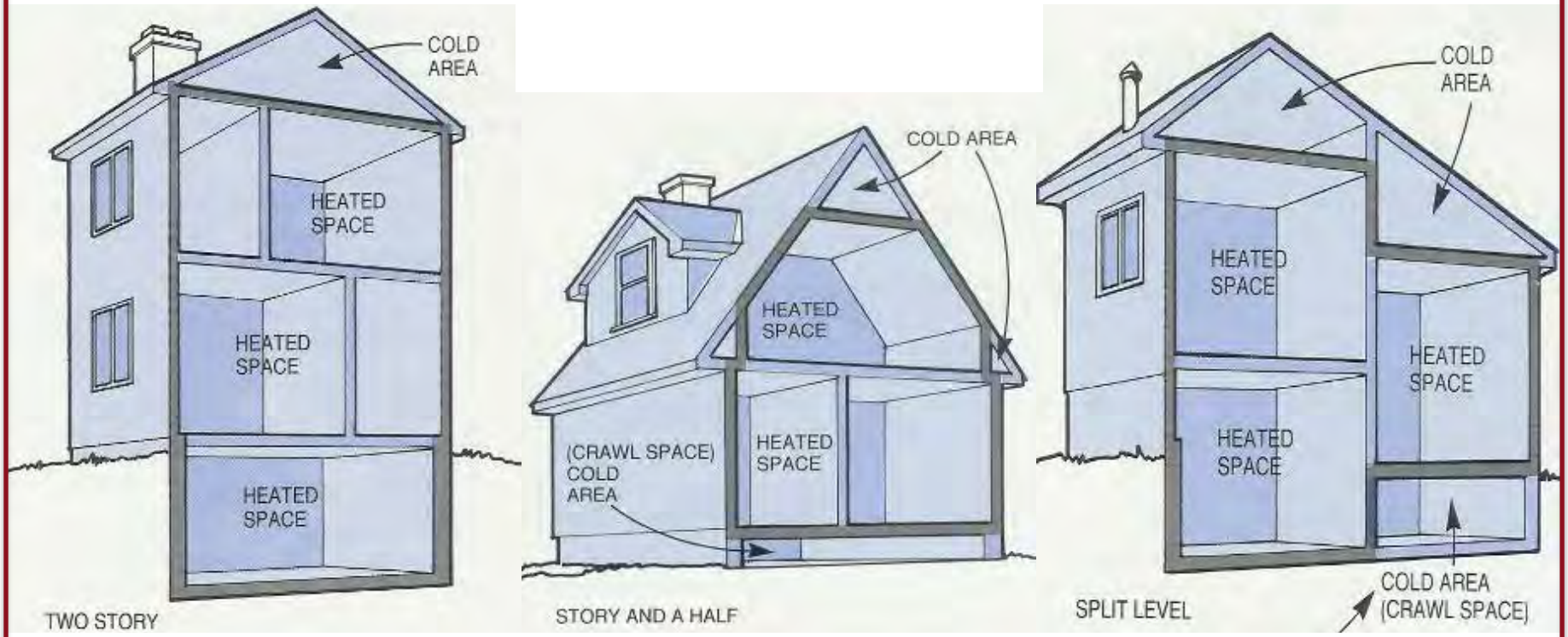
Warm, moist air entered the wall cavity at the gap around the electrical box

Air Leakage Pathways need an Opening at Each End

Moist air entered the wall cavity from inside and moved toward the opening that was just sealed

Massive Warm, Moist Air Leakage =Massive Moisture Damage

The frame and sheathing have been almost completely lost to decay in less than 10 years



Homes need a Continuous Pressure Boundary (The Air Barrier)

In Cold Climates, the Air Barrier is in contact with the Inside Surface of the Insulation

This Air Barrier and Insulation are not in proper alignment

This could compromise both Thermal and Pressure Boundary performance

Keep Insulation and Air Barrier behind the interior framed wall

The sealing details are easier if done before adding the interior framing

Or, Insulate All Framed Cavities and then add the Air Barrier

Blocking could be added to keep air from moving freely through the entire Wall Assembly

When boundaries are NOT aligned at the Ceiling/Attic Interface

a Leaky Ceiling may cause the Roof Deck to become the Pressure Boundary

Escaping Warm, Moist Air causes Damage to the Structure

Melting frost causes wood decay inside and Ice Dams cause roof damage outside

It's Not Just Older Homes that have this Problem

This 2 year old home appears to have Thermal/Pressure misalignment issues

This wall and band joist have been installed correctly

Polyethylene sheeting, foil faced rigid insulation, and acoustical sealant have been used

An alternative to using poly is the Airtight Drywall Approach

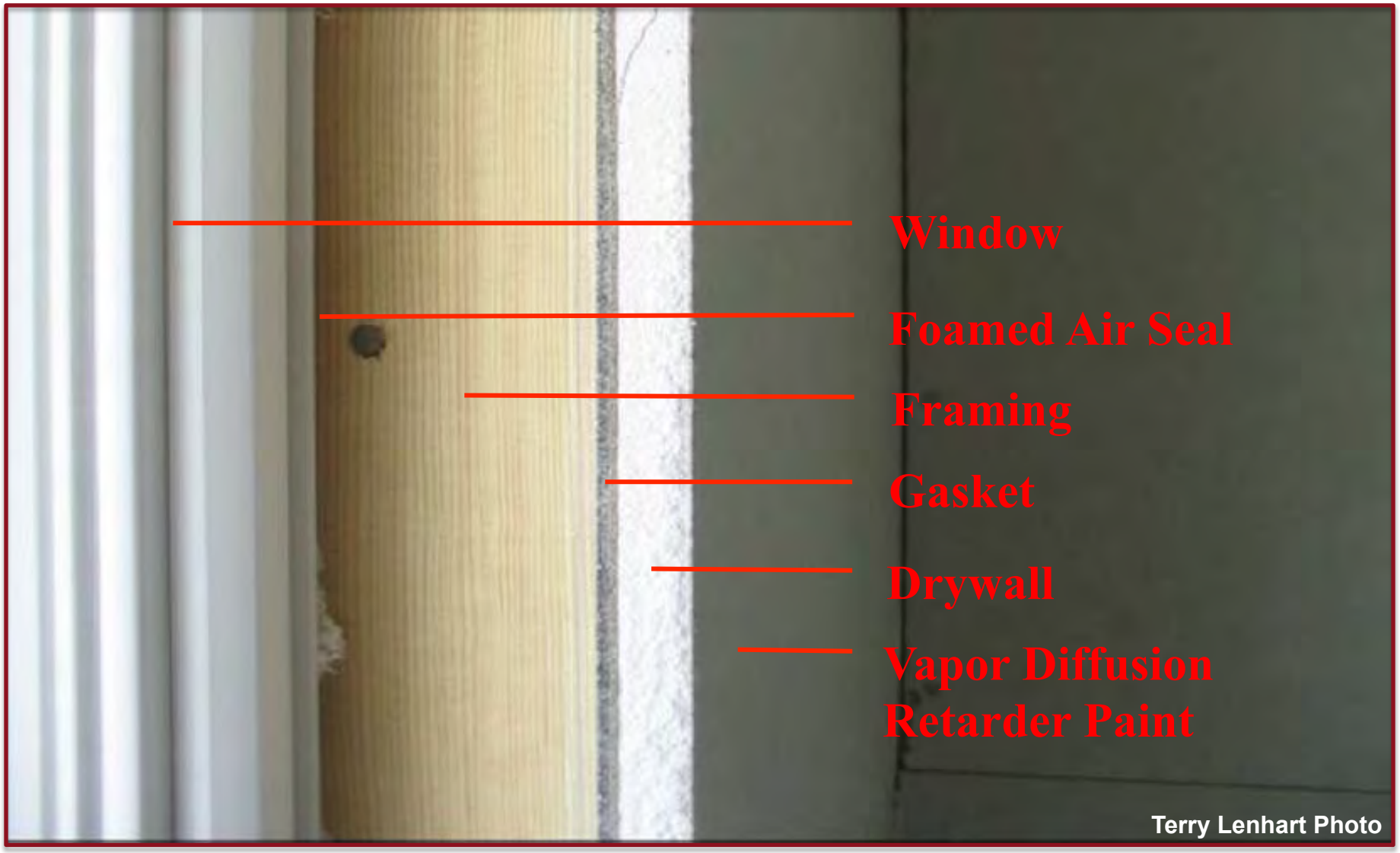
Closed cell foam gaskets are installed behind the drywall at the pressure boundaries

Closed cell sprayed foam has been used at the band joist areas

Gaskets have been used at floors, ceilings, windows, and penetrations

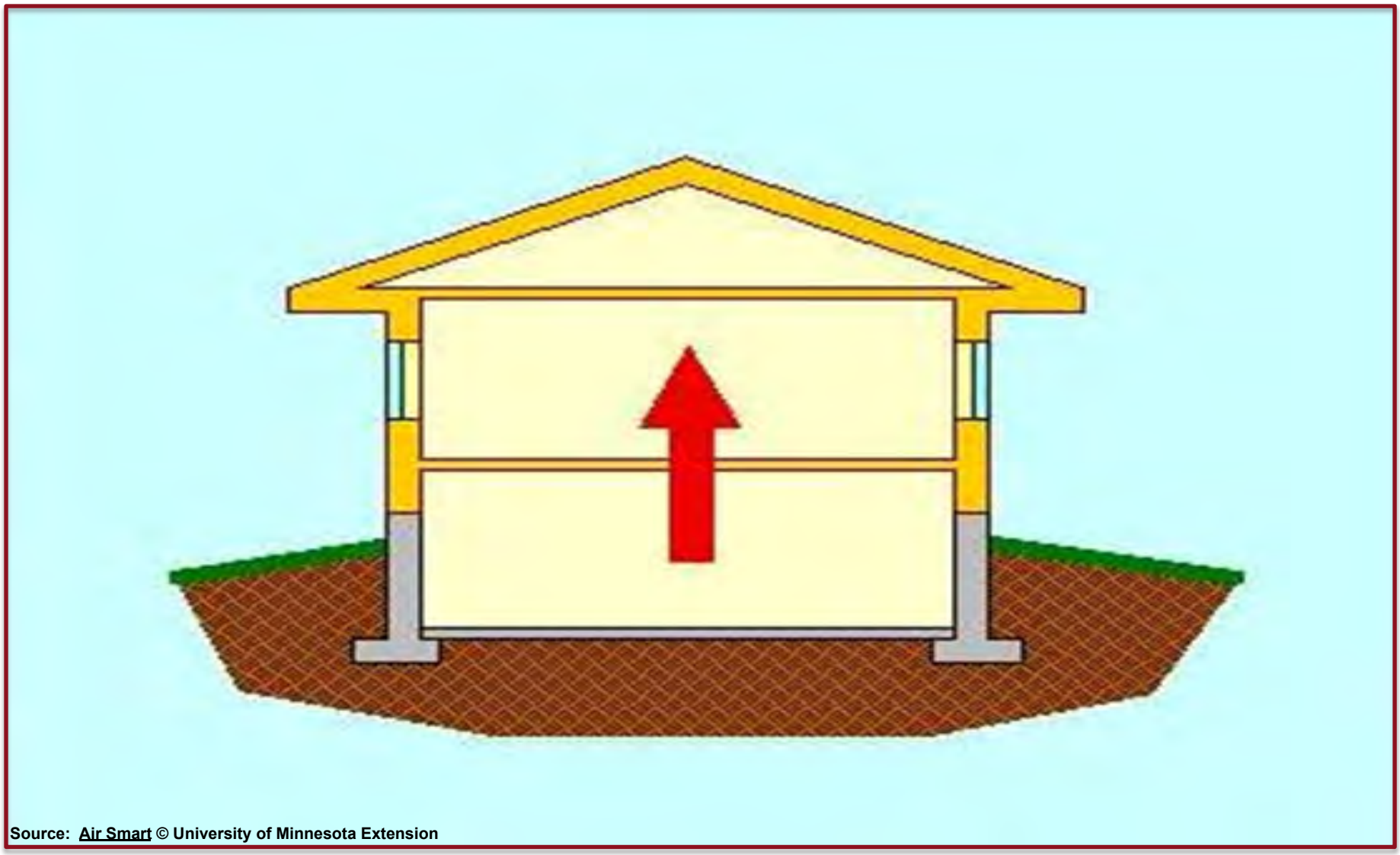
The Drywall, Gaskets, and Drywall Taping provide the Air Barrier

Vapor Diffusion Retarder paint provides the Vapor Retarder part of the system



All these details create an effective, continuous Air Barrier

VDR paint allows more vapor diffusion than well sealed polyethylene sheeting



Source: Air Smart © University of Minnesota Extension

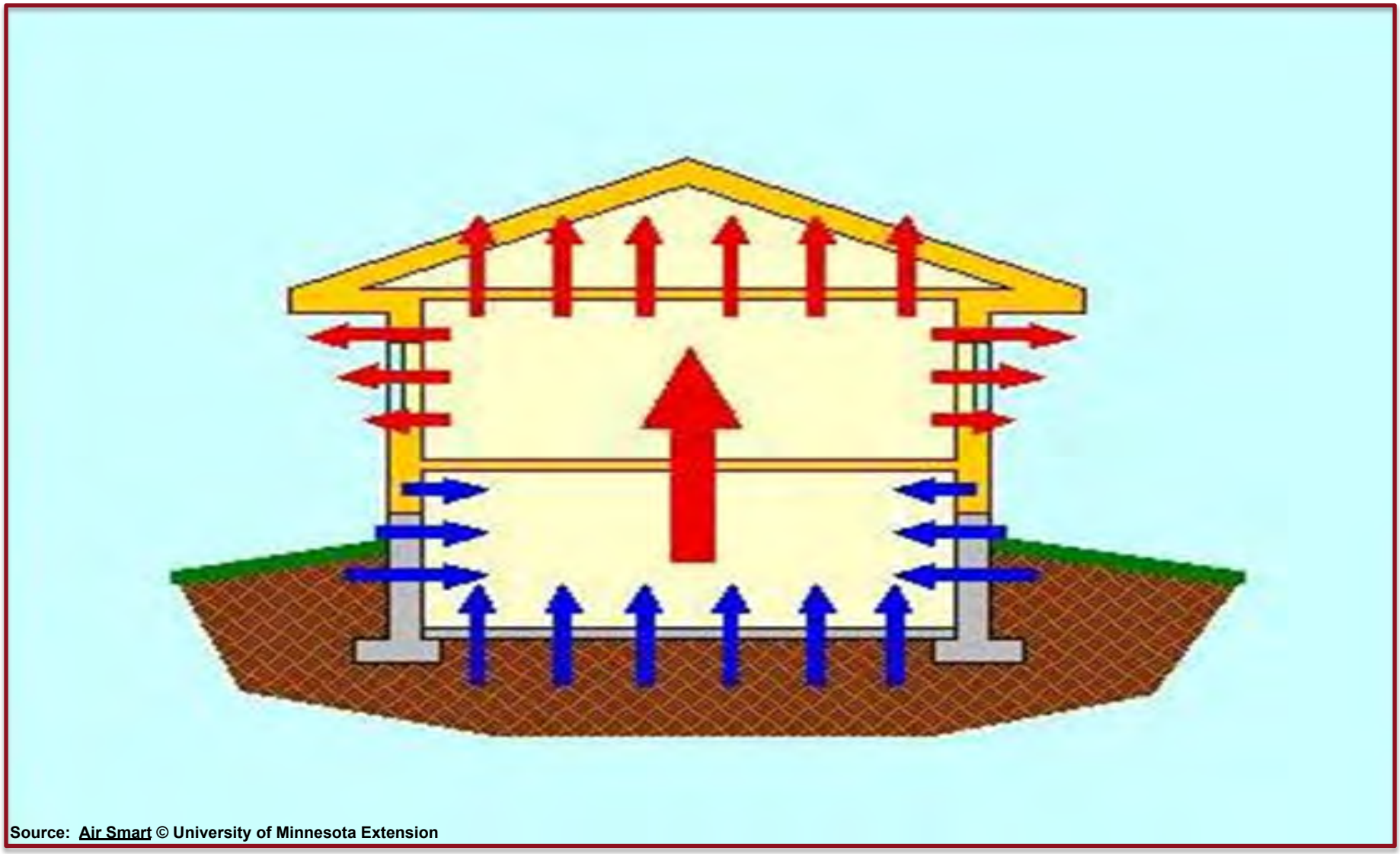
Warmed Air Rising causes Stack Effect in Buildings

Temperature Differential and Building Height are factors in the strength of the force

Source: Air Smart © University of Minnesota Extension

Warmed Air is Less Dense than the Surrounding Cooler Air

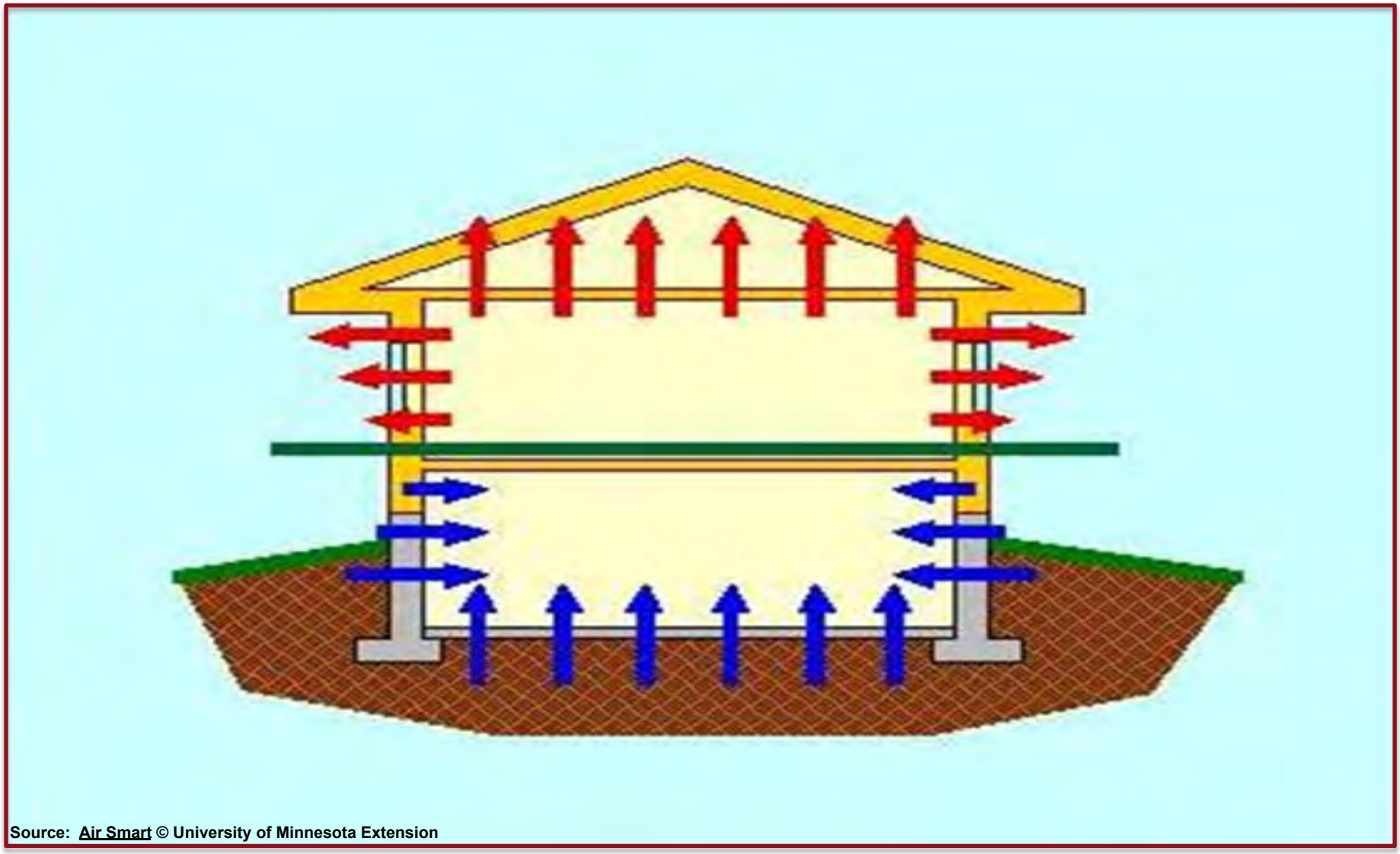
The increased buoyancy of the warm air causes the balloon to rise into the sky



Source: Air Smart © University of Minnesota Extension

Buildings are too heavy to rise like balloons

Warmed air rises to the pressure boundary at the ceiling or roof of a home



Source: Air Smart © University of Minnesota Extension

Pressure is Most Positive at the Top – Most Negative at the Bottom

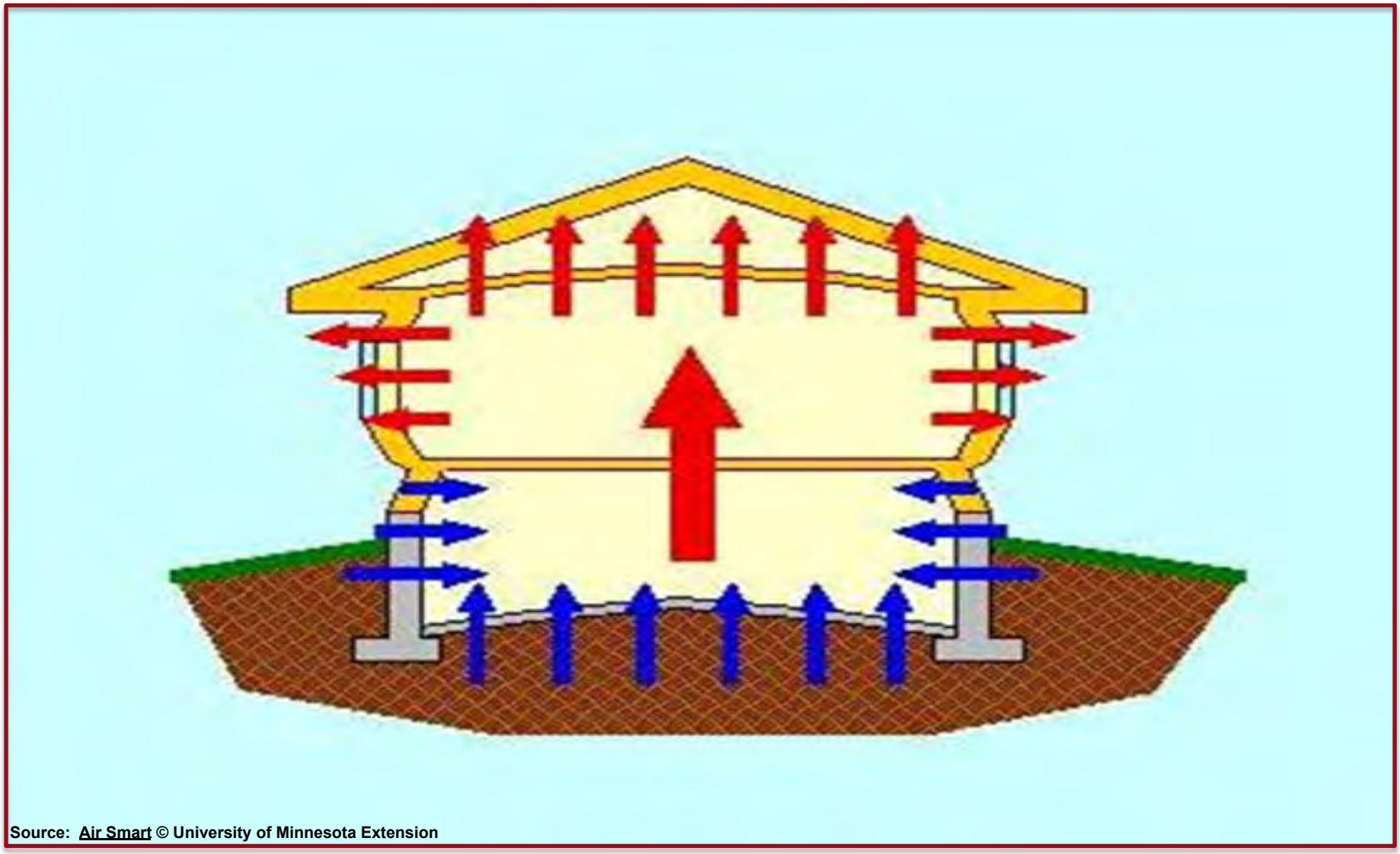
Where Negative Pressure meets Positive Pressure is called the Neutral Pressure Plane.

The Neutral Pressure Plane can be seen on this Paneled Ceiling

Infiltration (cold) is below the window head. Exfiltration (warm) is seen above that level

An Air Barrier was Obviously NOT Present in that Paneled Ceiling

If an Air Barrier had been installed, the Infiltration and Exfiltration Flows could not occur



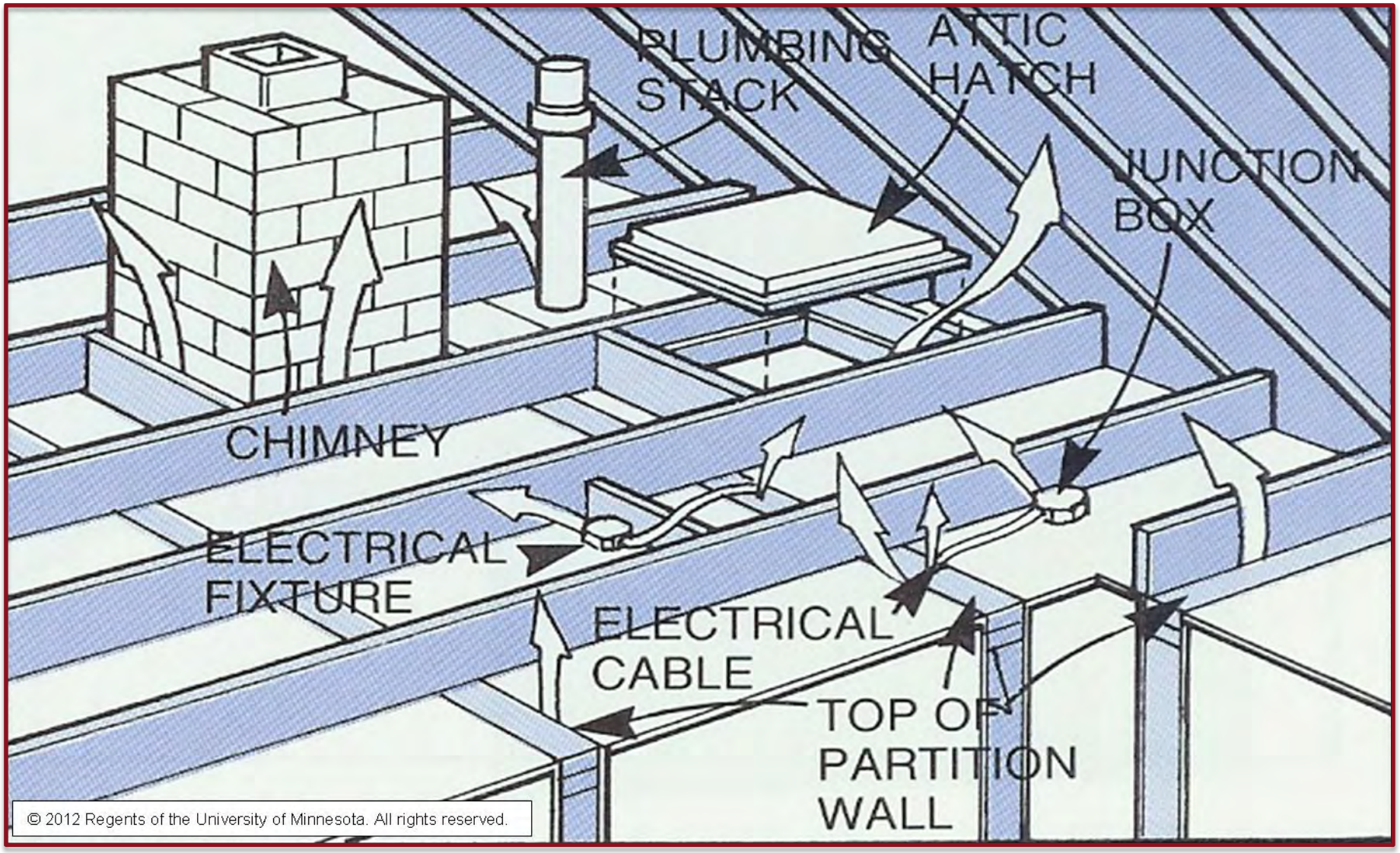
Source: Air Smart © University of Minnesota Extension

Air Barrier Details at the Ceiling are Critically Important

Air Leakage at the top of the house creates a significant durability risk for the building

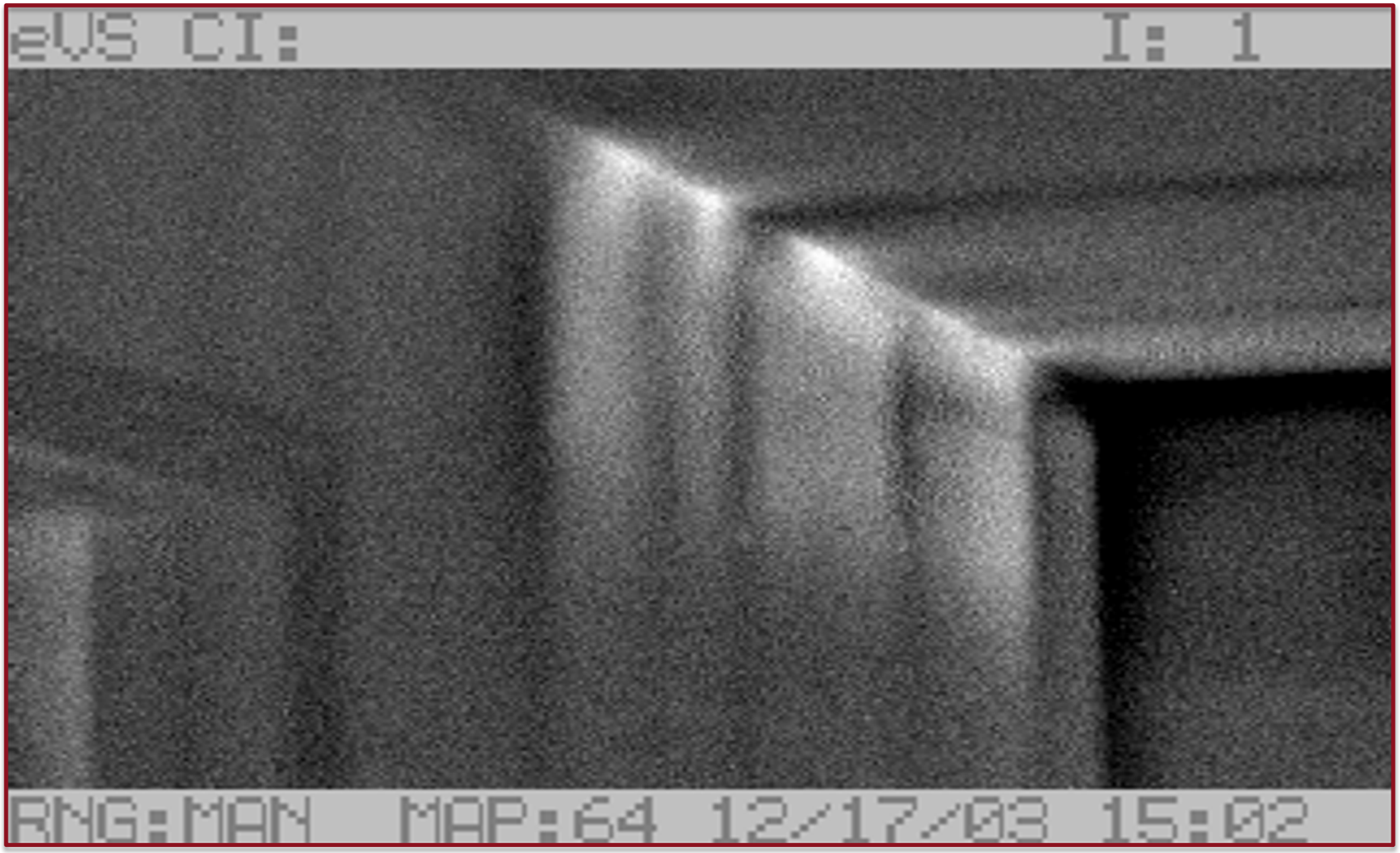
The Poly in this Two-Story Home has Torn Loose at the Top Plate

Temperature differential and height created the force that caused this to happen

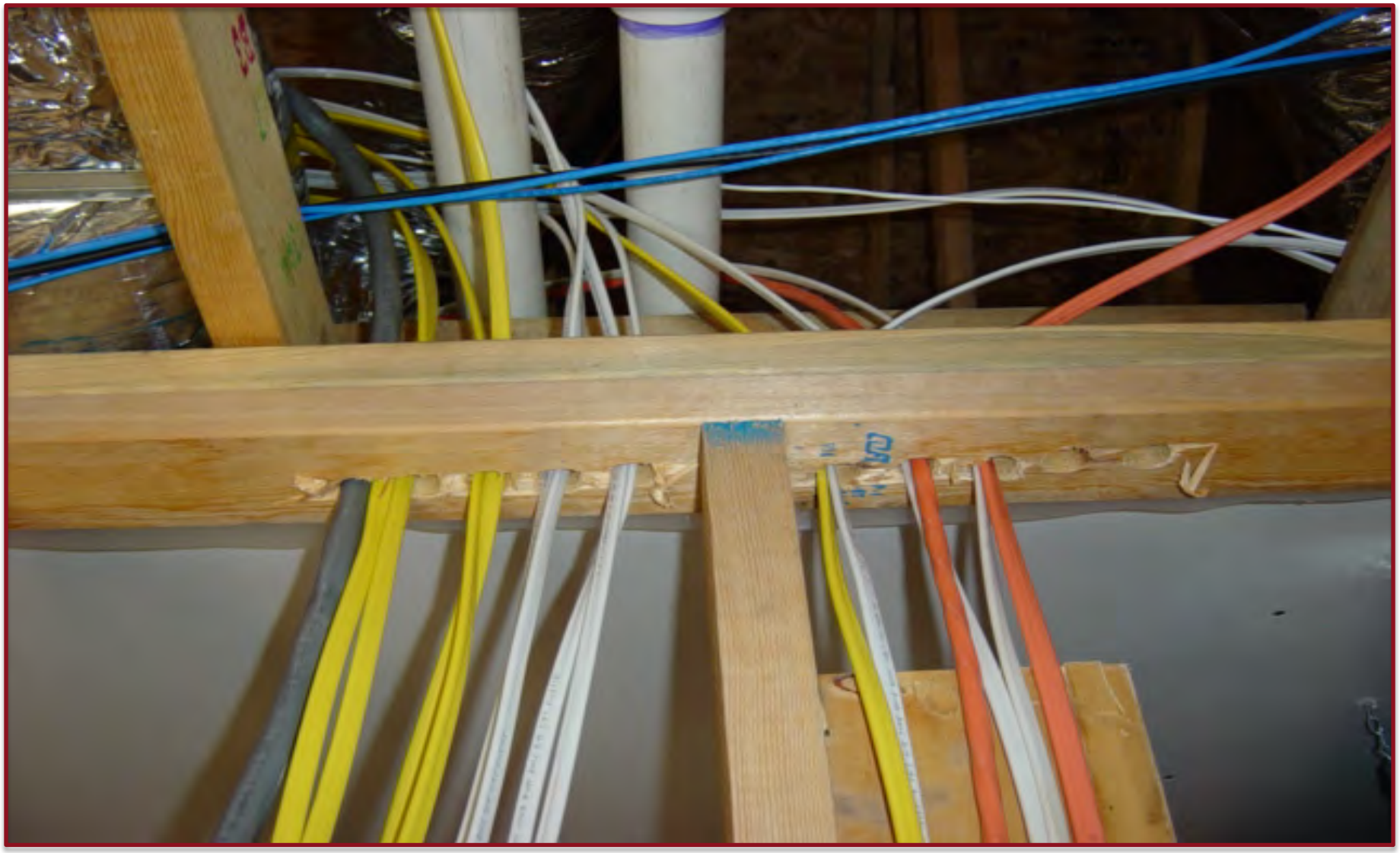


Common Air Leakage Pathways into the Attic

Most trades are represented by some type of bypass shown here



As Found condition noticed in the first walk-through of new home appears to be caused by rising warmed air. No lights are heating the opposite side of the wall.

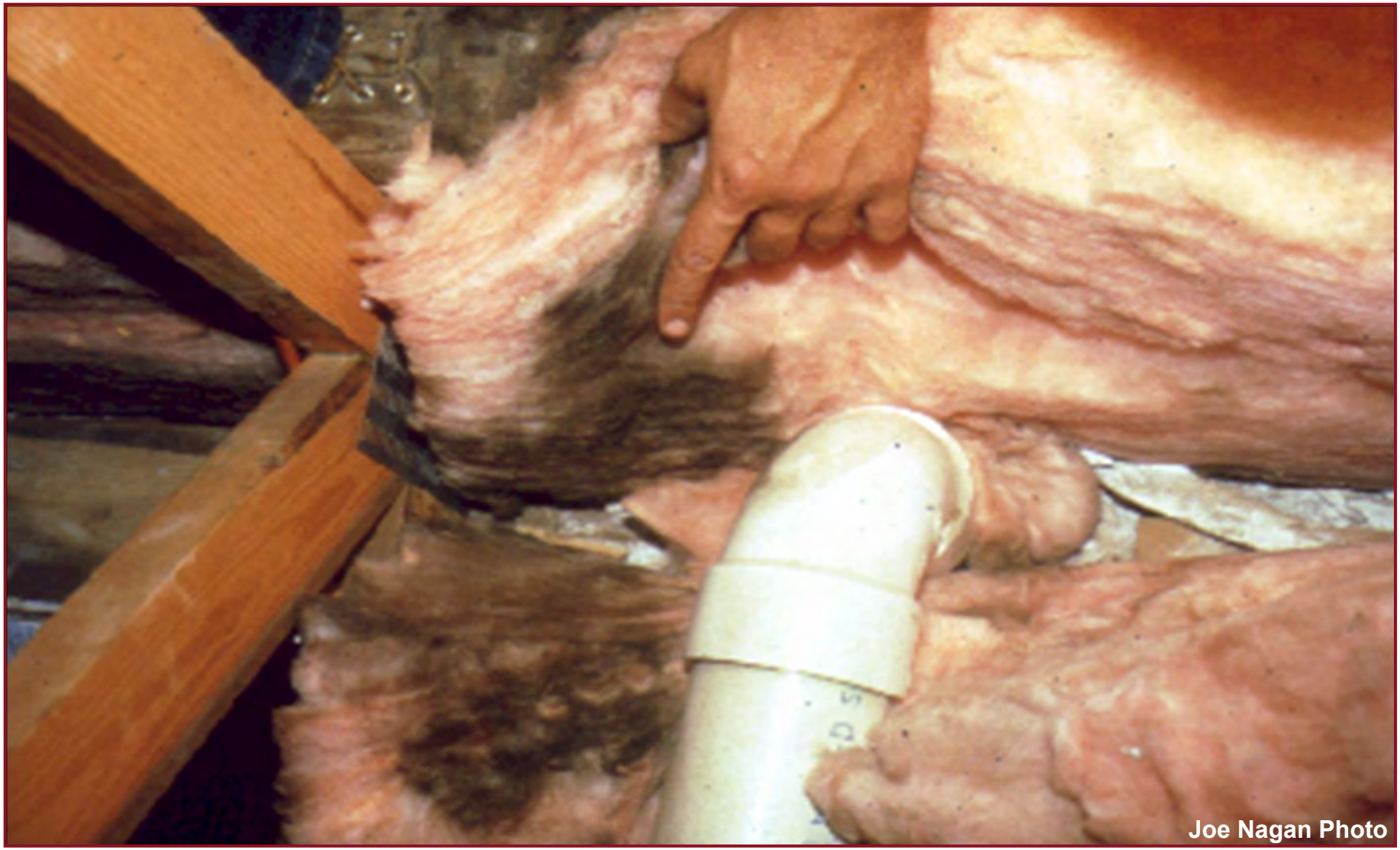


In the Attic, the Top Plate looked Similar to this

Multiple holes for AV cable had been drilled by the owner after the builder air-sealed the attic

Oversize Openings are often cut for Plumbing and Ductwork

Holes closer to the actual duct or pipe size are easier to air-seal



Evidence of Exfiltration

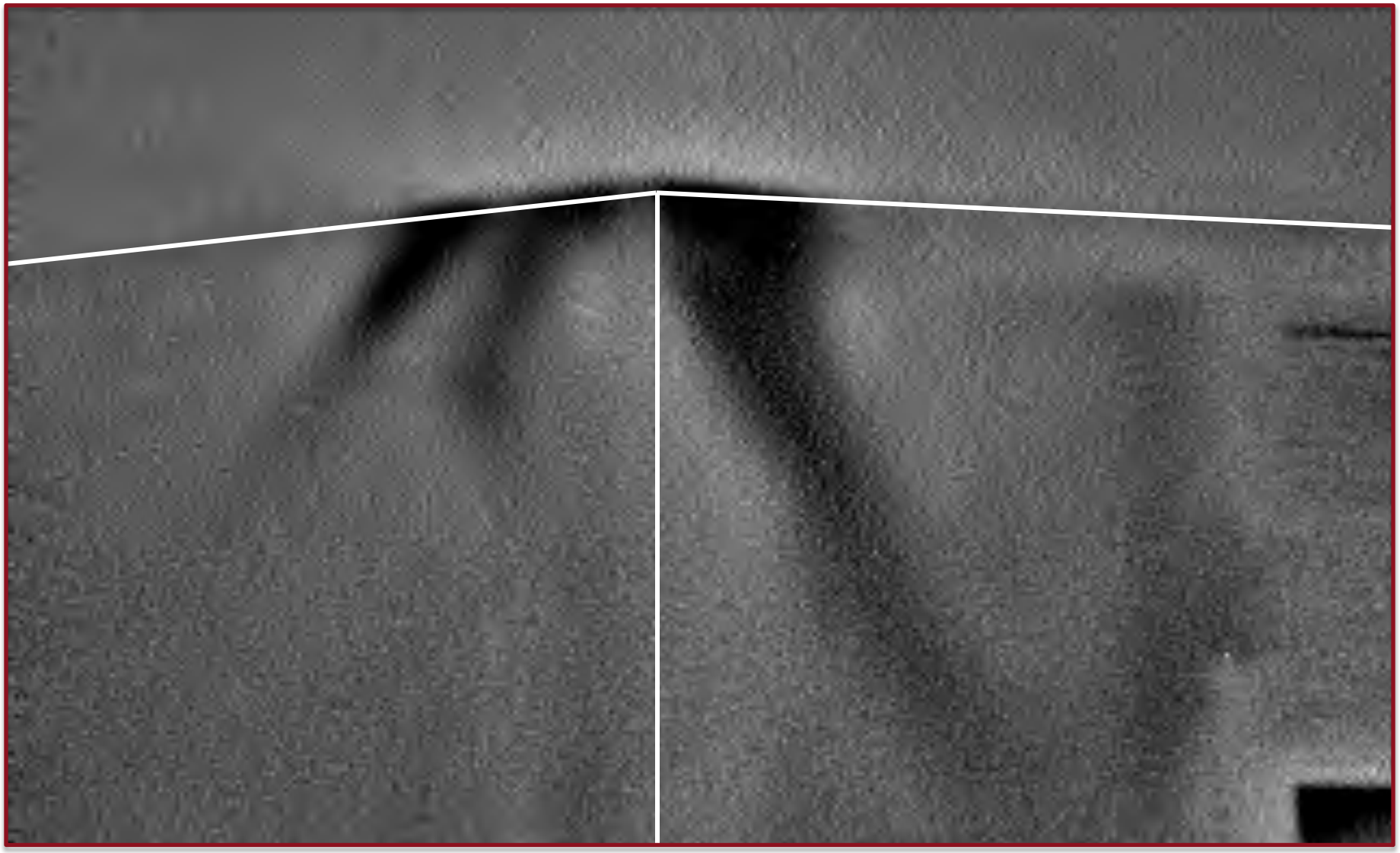
Insulation batt has filtered dirt from warmed air escaping into the attic

Air escaping into the Attic from below is Warm and Moist

Frost is formed as the moisture condenses on the roof deck and keeps lumber wet

The Air-Sealing at this Corner was Almost Finished Right

Sealant was stopped short of the corner and the tape was not well fitted



When Viewed using a Thermal Imaging Camera

Blower Door depressurization shows leakage between walls and attic at that corner

Polyethylene, Acoustical Sealant, Tape, and Foam

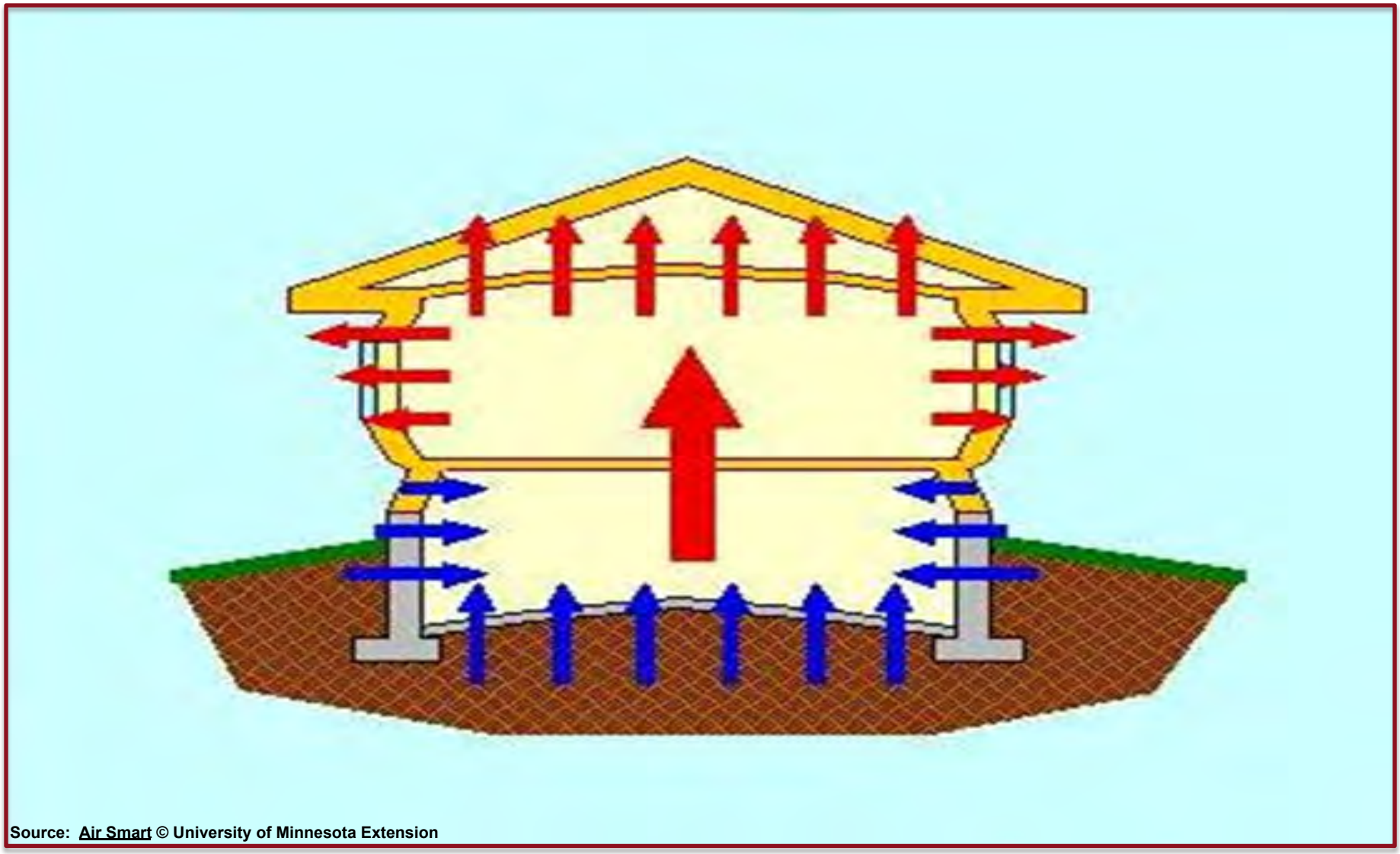
This corner is completely detailed to prevent air leakage into the attic

A Big Bypass that is Difficult. . .and Frequently made More Difficult

Plywood blocking had been removed instead of cutting a round hole to fit

By Using a Lot of Foam and Extra Time

This big opening to the attic was effectively sealed after adding insulation below the plenum.



Source: Air Smart © University of Minnesota Extension

Bypasses at the Top Should be Handled First, but

large openings at the bottom could be allowing soil gases including moisture to enter the home

Openings in the Slab for Bathtub plumbing are Oversized

Closed cell foam is water resistant and provides effective air-sealing

Measure Twice and Seal Once to Keep Soil Gas Out

This large opening to moist soil is almost never properly blocked and sealed

The Sump Crock often contains Standing Water

The drain tile under the basement slab is not a good "make-up air" source for the home

Install a Sealed Sump Lid with Gaskets at the Pipes

This sump crock and drain tile are vented by the active radon mitigation system

Open Gaps around the Basement Slab Perimeter

add up to a lot of square inches of opening for soil gas and moisture to enter the home

Spray installed Closed Cell Foam seals gaps and Insulates

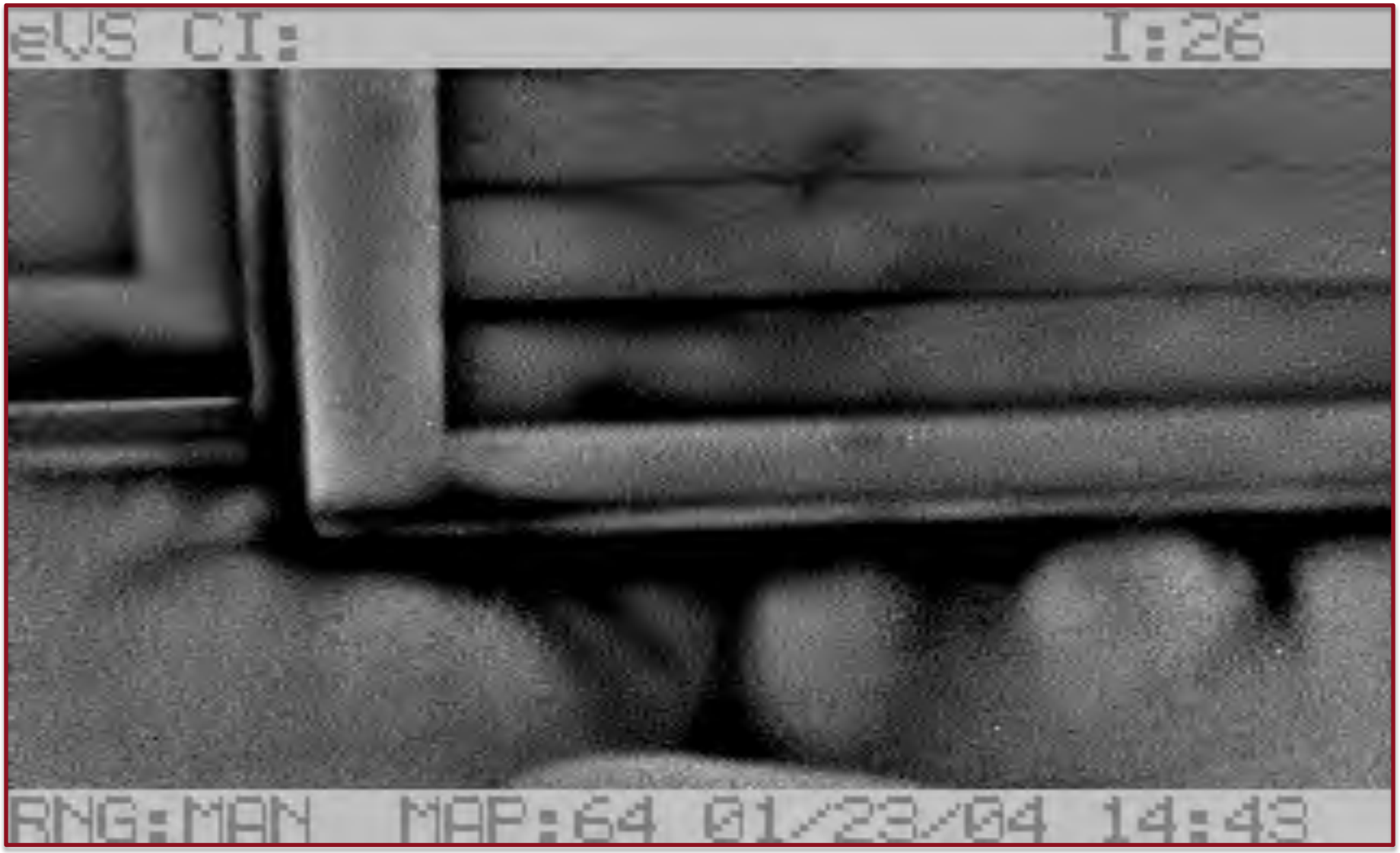
Framing is held back at least one inch from foundation walls

Rim Joist Insulation and Air-Sealing Can be a Challenge

Air Leakage and Condensation are common issues

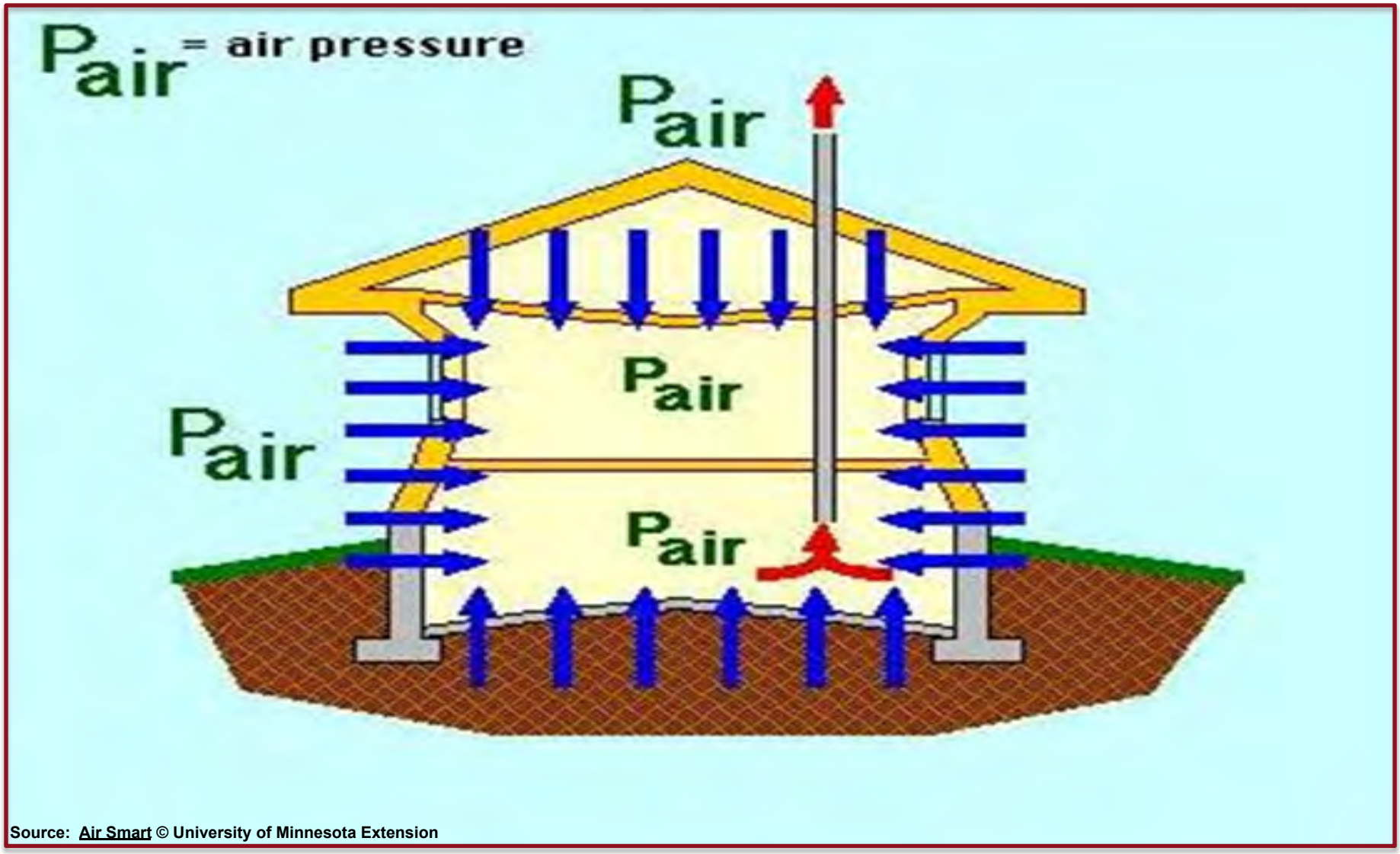
Spray installed Closed Cell Foam in Rim Joist Locations

Air-sealing and insulation are completed in one application



Infiltration between Bottom Plate and Floor

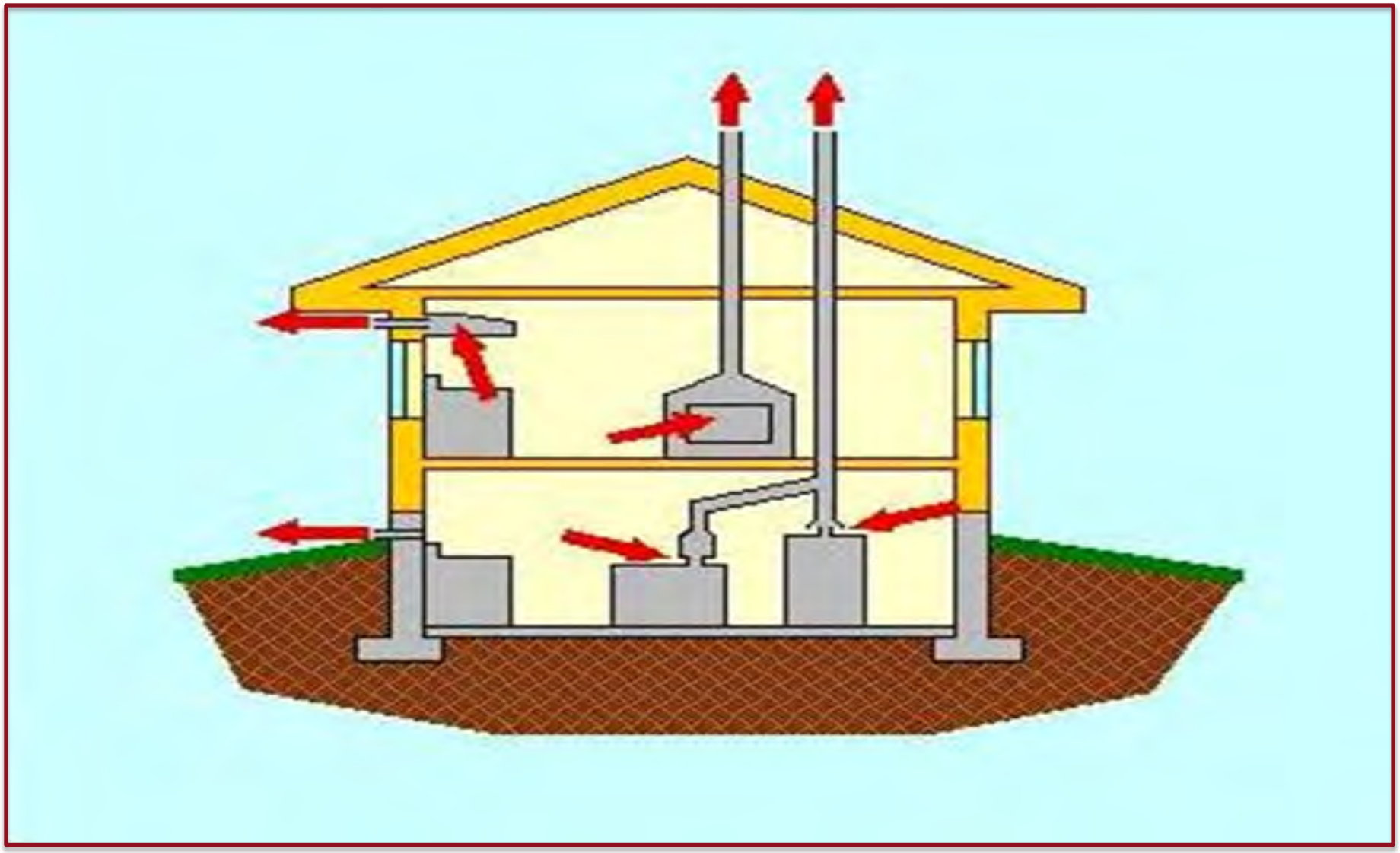
Sealant at this location could have eliminated the leakage



Source: Air Smart © University of Minnesota Extension

Chimneys Act as Large Exhaust Fans

Combined with mechanical exhaust appliances, the total air volume adds up quickly



Most Homes have Several Mechanical Exhaust Systems

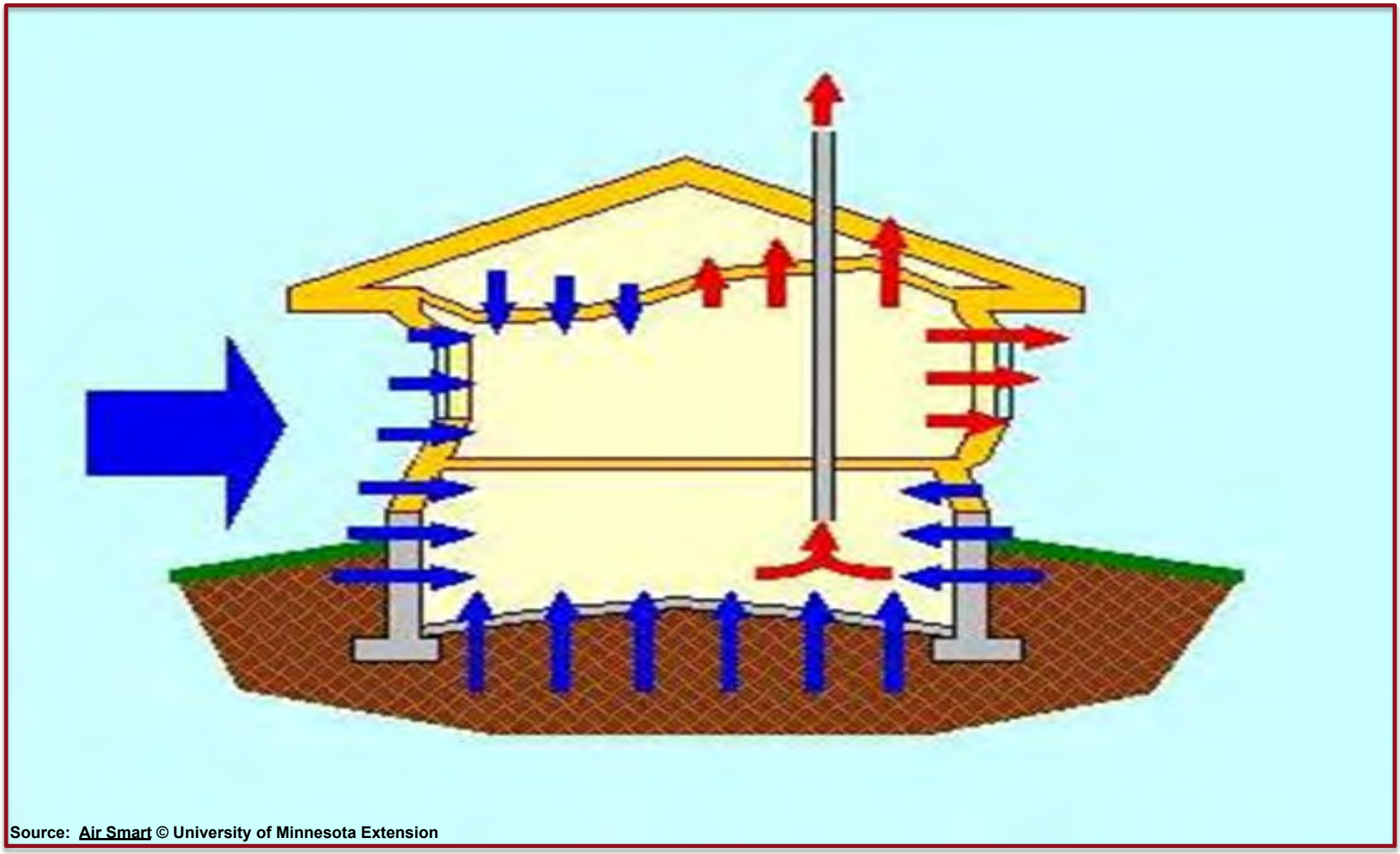
In addition to those shown, most homes have bath fans and some have central vacuum systems

Combustion Appliance Drafts can be Measured

Test Natural Draft Equipment at Worst Case Depressurization for Occupant Safety

Exhaust Fan Flow can be Measured

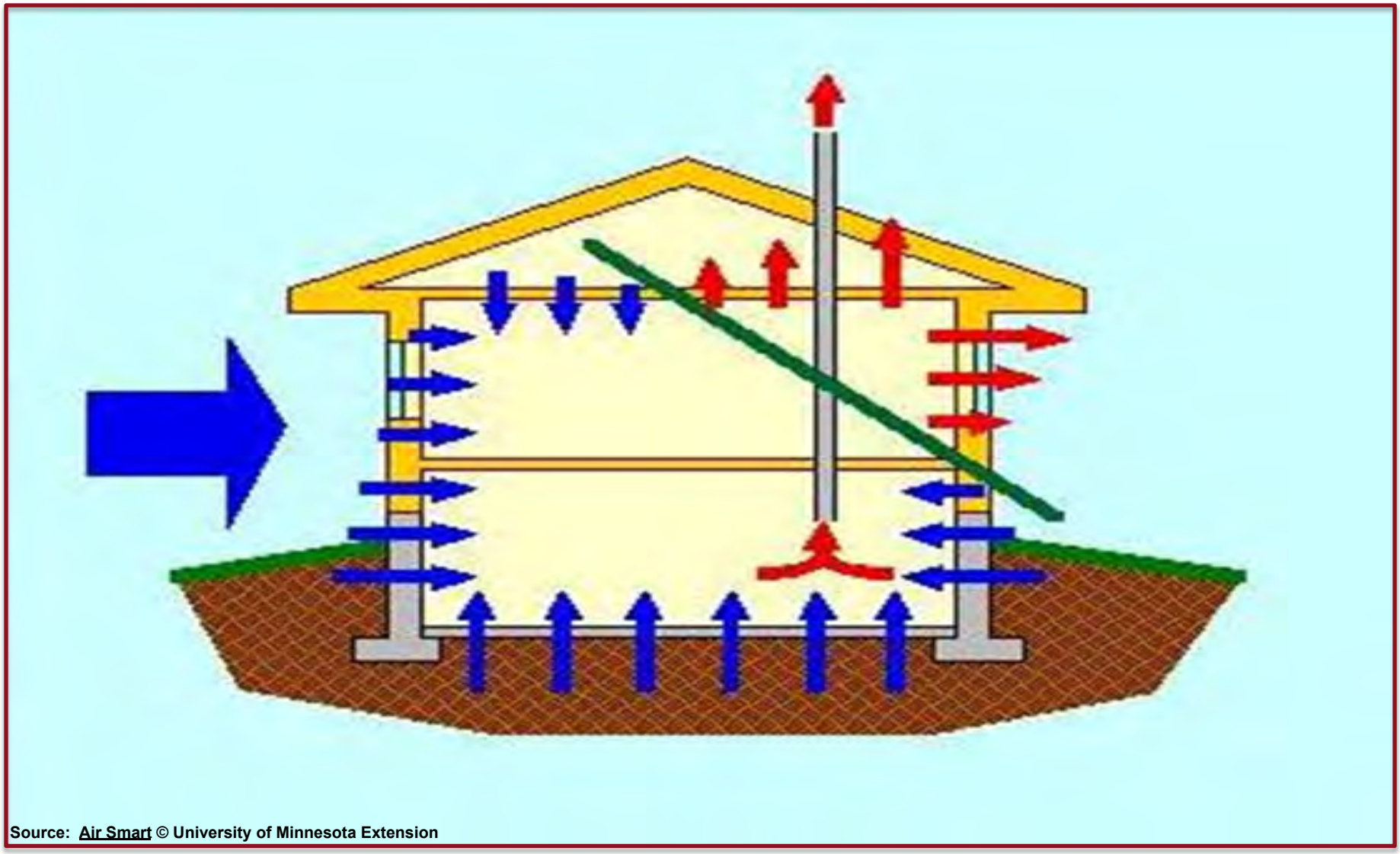
Test equipment to assure that it is performing as designed



Source: Air Smart © University of Minnesota Extension

Combined Wind, Stack, and Mechanical Forces are Dynamic

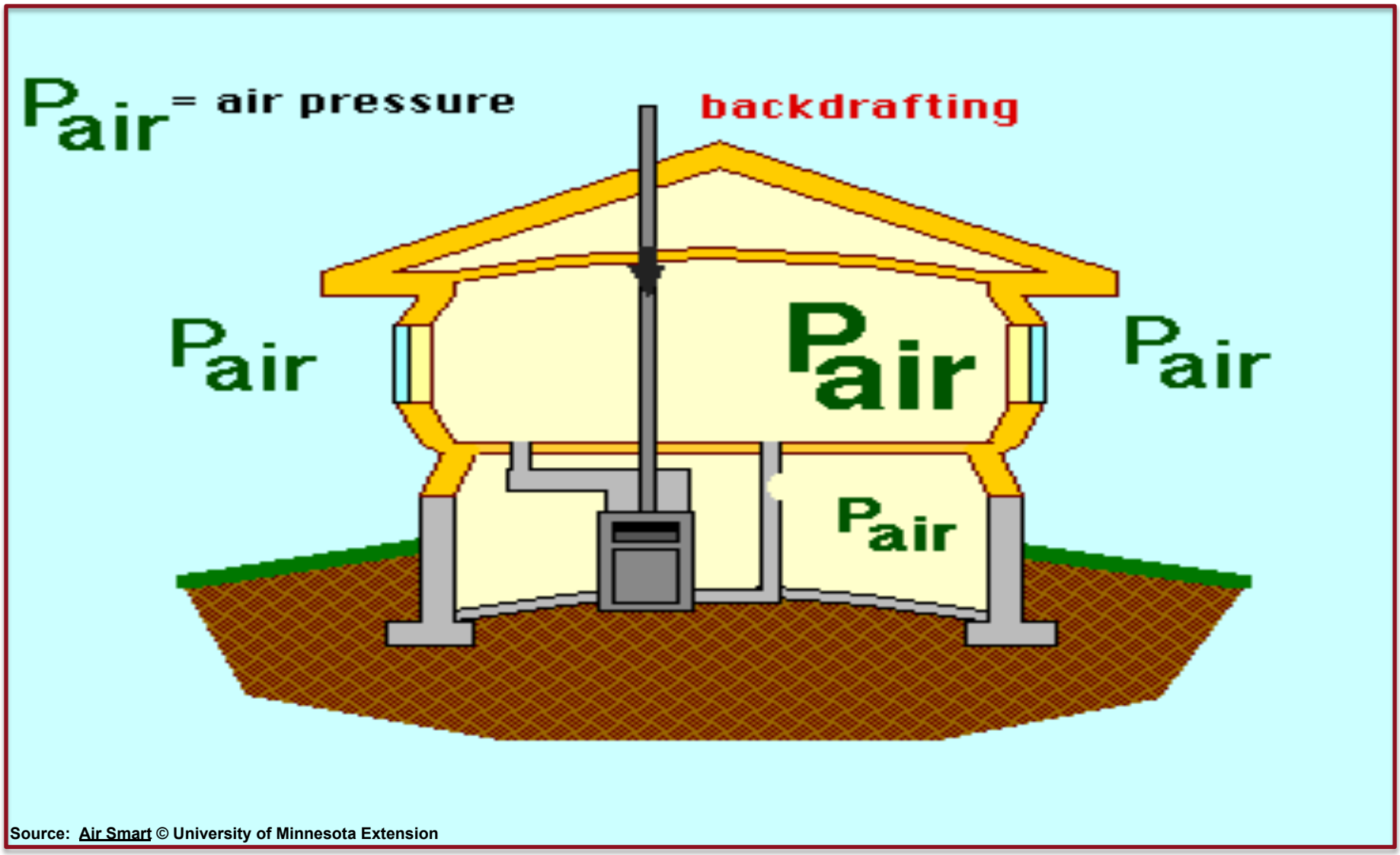
Wind shifts, temperatures change, and equipment is cycled on or off



Source: Air Smart © University of Minnesota Extension

The Neutral Pressure Plane moves as the Forces Change

The greatest forces are still seen at the top and bottom in most conditions



Source: Air Smart © University of Minnesota Extension

Leaks in Return Side Ductwork in Basements

A pressure imbalance between floors can cause backdrafting of combustion equipment

Evidence of Backdrafting

Combustion particulates collecting around the vent

Evidence of Extreme Sudden Depressurization

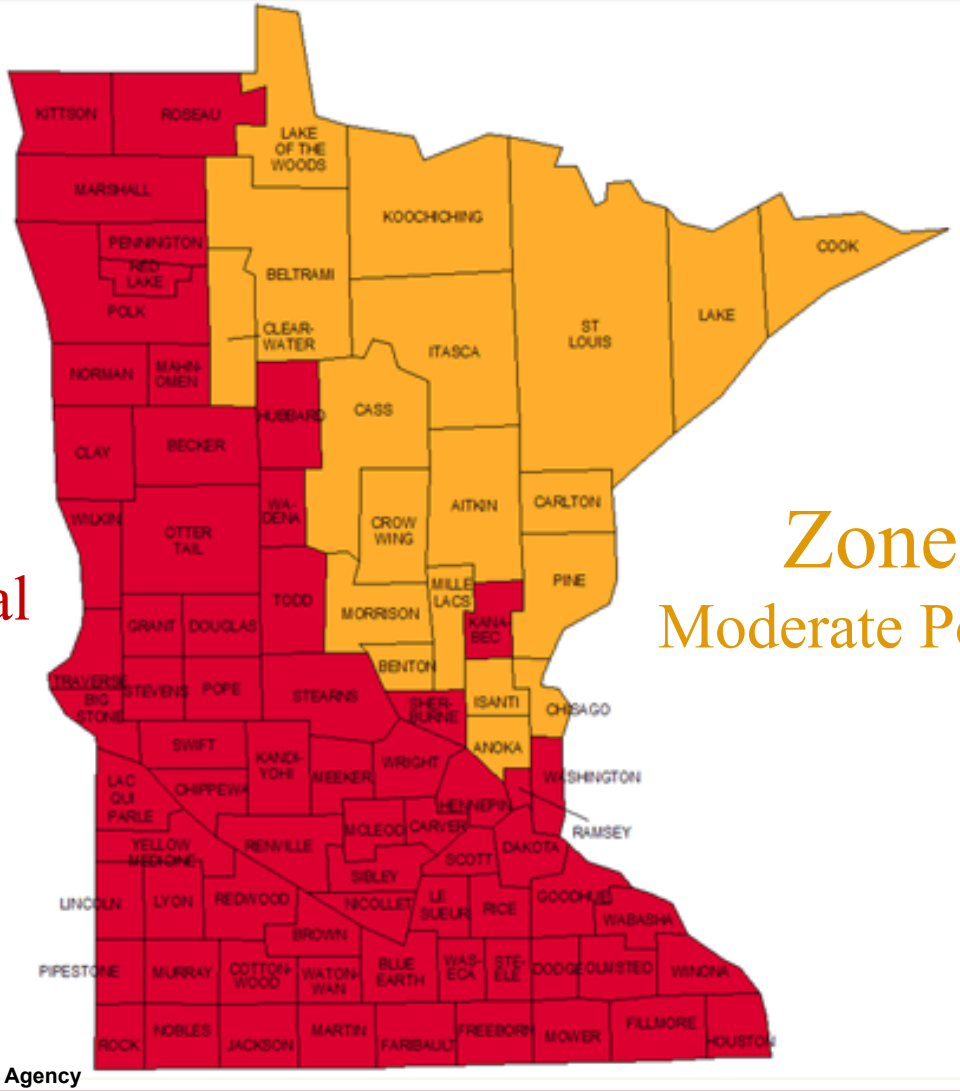
Flame Roll-Out of a combustion appliance is extremely dangerous

Source: Air Smart © University of Minnesota Extension

Leaks in Return Side Ductwork in Basements

Adding to the negative pressure can increase the amount of soil gas infiltration

Zone 1
Highest Potential



Zone 2
Moderate Potential

Source: United States Environmental Protection Agency

Minnesota Radon Zones

Testing can only be accomplished after the home is completed and in final operating condition

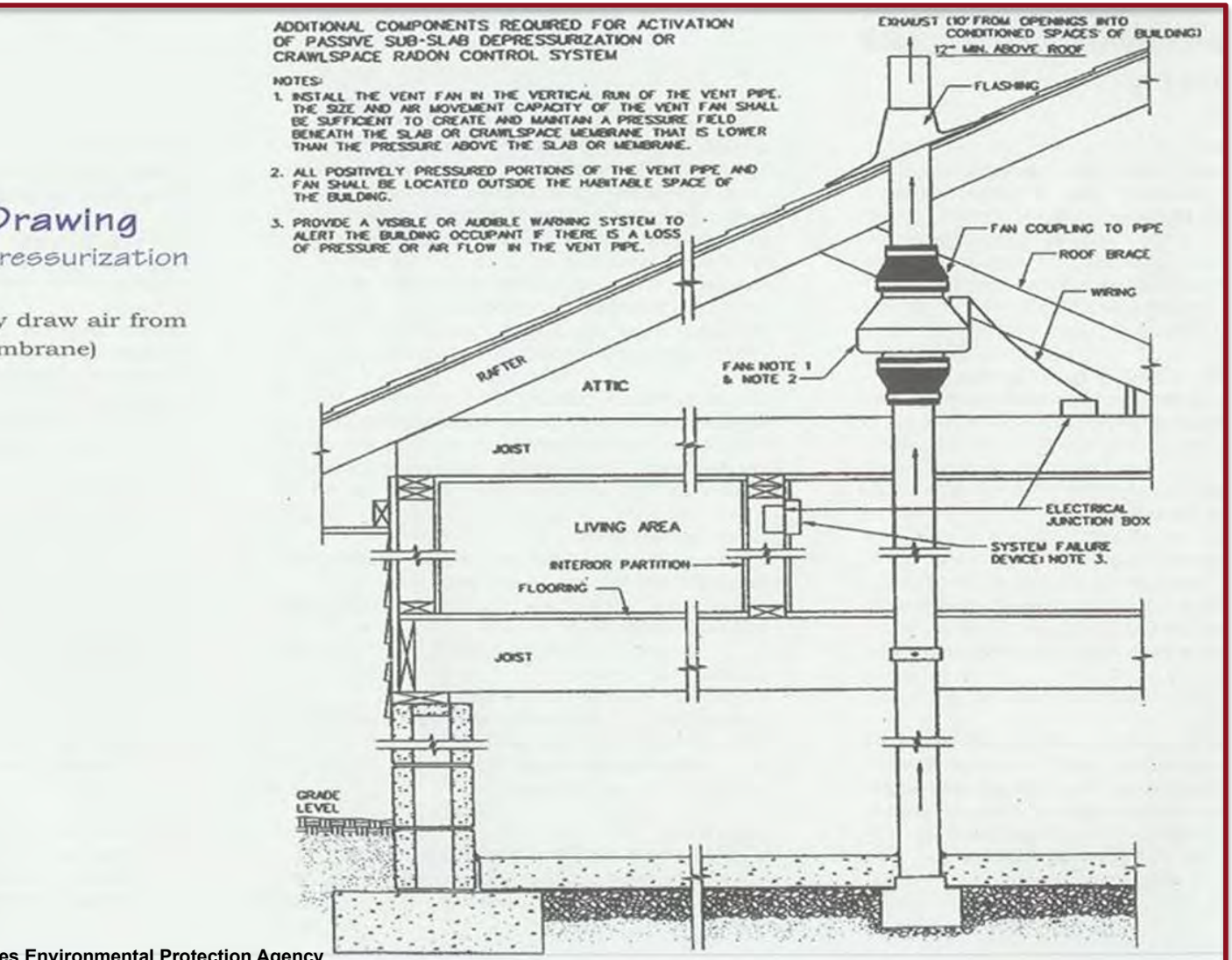
One in Three Minnesota Homes has High Radon Levels

Source: Radon: keeping your home safe from radon *www.health.state.mn.us/divs/eh/indoorair/radon/radonconbrochure.pdf*

Architectural Drawing

Active Sub-Slab Depressurization System

Uses fan to mechanically draw air from beneath the slab (or membrane) through the vent pipe.



Source: Building Radon Out -United States Environmental Protection Agency

Radon System Diagram

Pipes inside the home should be under a negative pressure

Leaky Ductwork Creates a Pressure Imbalance

Leaks concealed in floor systems can force conditioned air through unsealed gaps to the outside

Plenum Leaks Pressurize or Depressurize Basements or Attics

Building durability and occupant safety are put at risk

Which Gap was Sealed? Which Gap was Missed?

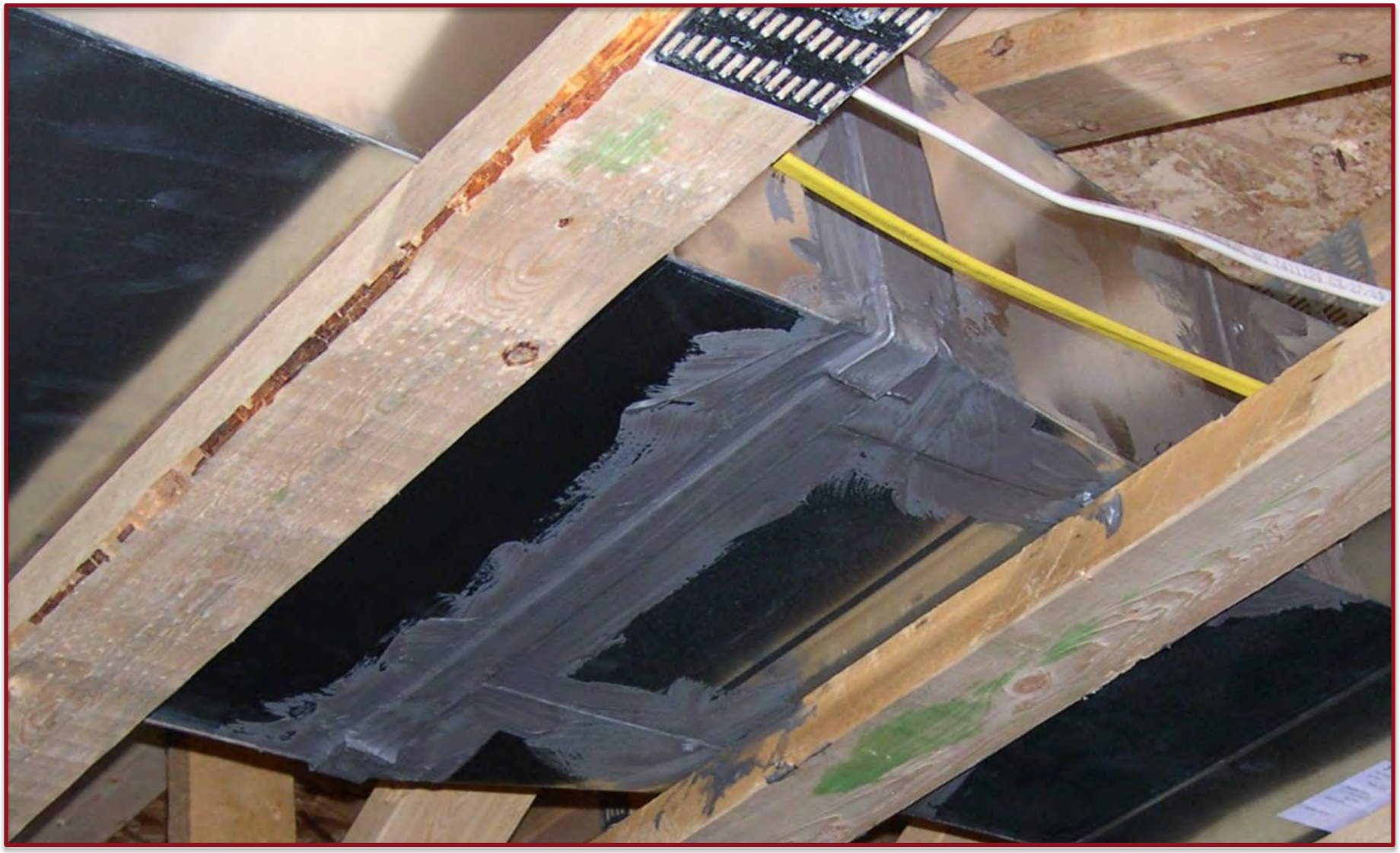
Not my Job?

Transite Duct Systems are installed Under Slabs

Leaks allow air to escape or draw in pollutants and water from the soil

Flexible Mastic is the Most Effective way to Seal Ductwork

Proper sizing for rooms also assures improved pressure balance through the home



Sealing Seams Protects the Home and its Occupants

Leakage in ductwork prevents the system from performing as designed

Balanced Whole House Ventilation Systems

Provide heat or energy recovery and filtration when properly installed and maintained

Exhaust Fan Efficiency

More planning can deliver improved efficiency at a lower operating cost

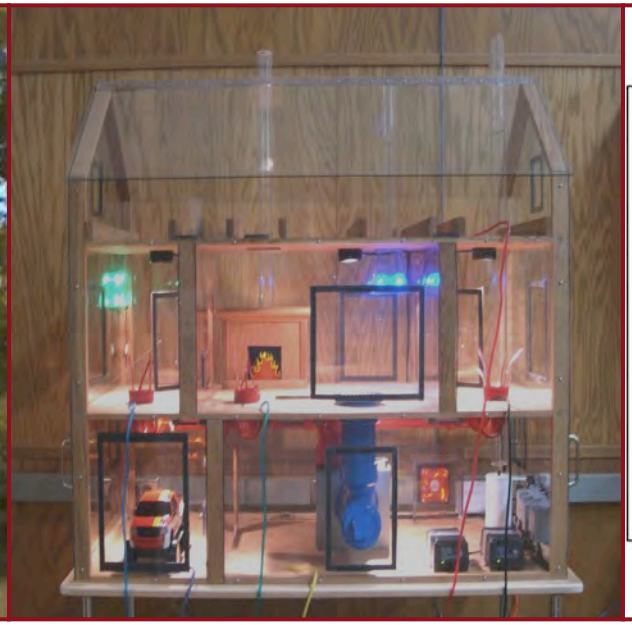
Moisture and Pollutants should be Exhausted to the Outdoors

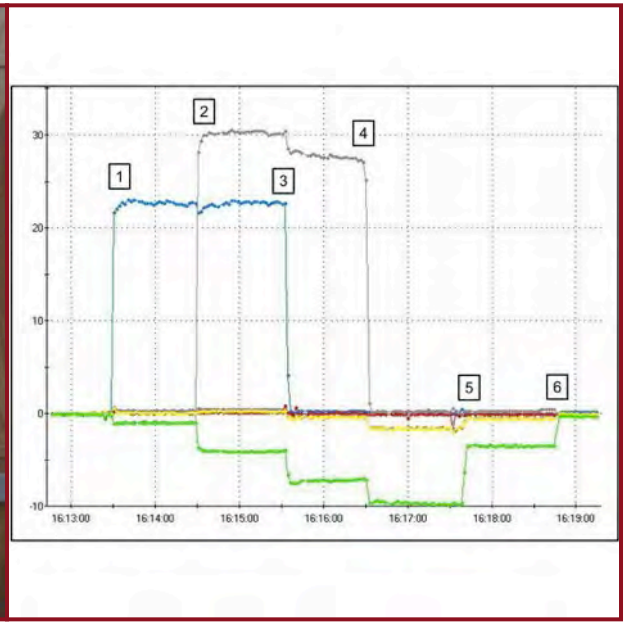
This is creating a pressure imbalance and adding moisture and pollutants to the attic

Efficient Ductwork is Short, Straight, and Smooth

Properly designed and installed ductwork helps keep things in balance

Demonstrating Pressure Differences in Homes:





Can Closing a Bedroom Door Push a Fragile House "Over the Cliff" ?

Uncontrolled Air Pressures and Air Flows

Contribute to Familiar Problems in Homes



Photo Credit: Joe Nagan

- Ice dams and water damage
- Mold and decay caused by trapped moisture
- Frost and moisture damage in attics

Think of the House as a System

Actually, a set of complex systems and system interactions

- Central heating and cooling equipment
- Distribution systems for air, water, and electricity
- Insulation for comfort and energy savings
- Air sealing and vapor management for durability and comfort

The Story of the Little Bungalow where . . .

. . . a family unknowingly changed the pressure balance and created a dangerous condition

Understanding System Interactions is Critical

Features of this Compact Bungalow include:

- A simplified heating distribution system
- Warm air supply ducts to the bedrooms
- Central cold air return in the living room
- Wood-burning fireplace in the living room

After Using the Fireplace in the Evening

Some family members experienced mild headaches with flu-like symptoms the next morning

Set up for the Incident

How Many Air Pressure and Air Flow System Inputs ?

- Central heating system running
- Fire in the fireplace allowed to burn out at bedtime
- Bedroom doors closed
- Bedroom windows opened slightly for fresh air

What Happened Next

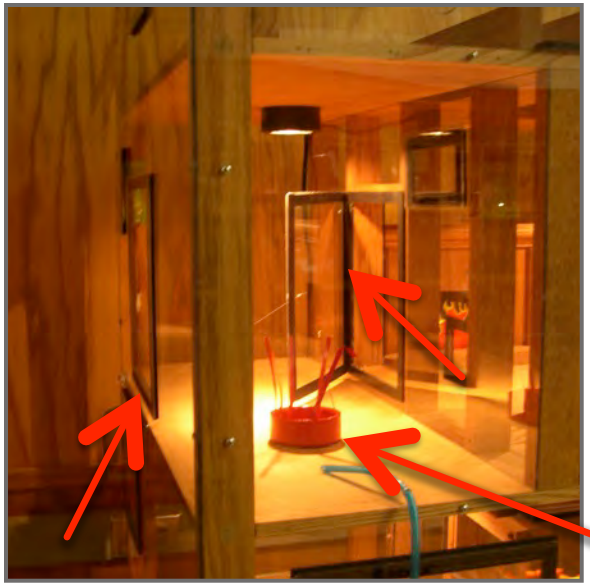
Family was hospitalized for carbon monoxide poisoning

How Could That All Happen ?

Using the NRCERT House of Pressure to recreate the incident

Setting Up the Simulation

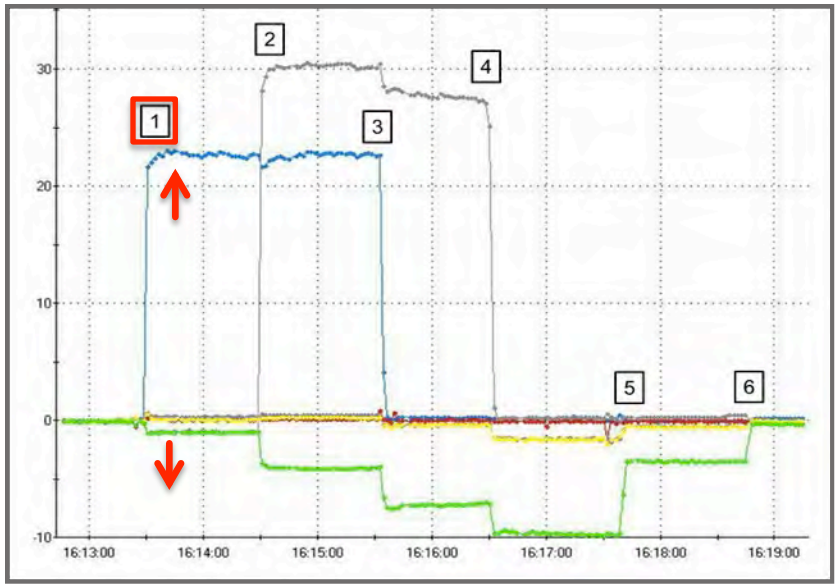
Starting conditions and changes made are the Same as in the Real House



- Heating distribution system is running
- Bedroom doors are open and bedroom windows are closed
- Fireplace is in use
- Pressures are graphed while recreating the steps taken by the family

1. Close Bedroom 1 Door

Taking the First Step "Over the Cliff"



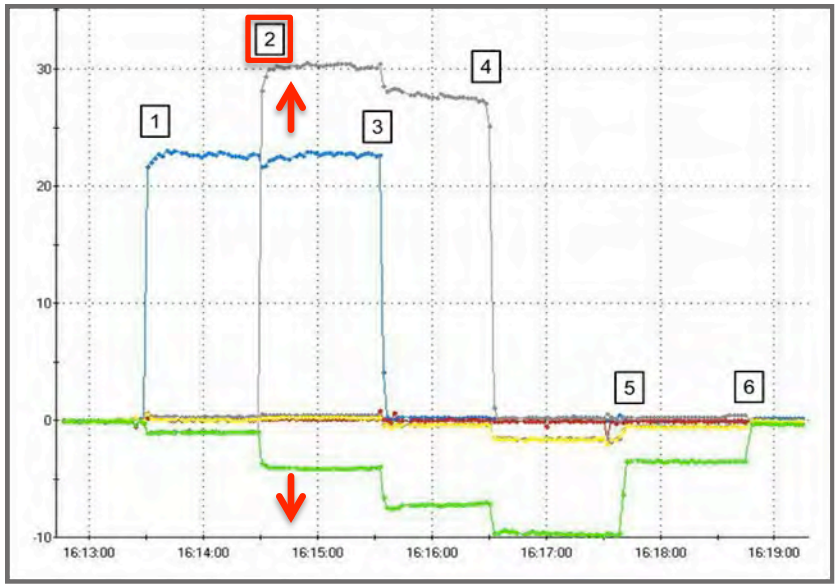
- Pressurizes bedroom 1
- Depressurizes living room
- Fireplace backdrafts
- Combustion gases drawn into cold air return

Fireplace is now Backdrafting

Combustion gases are drawn into the living room instead of exhausting up the chimney

2. Close Bedroom 2 Door

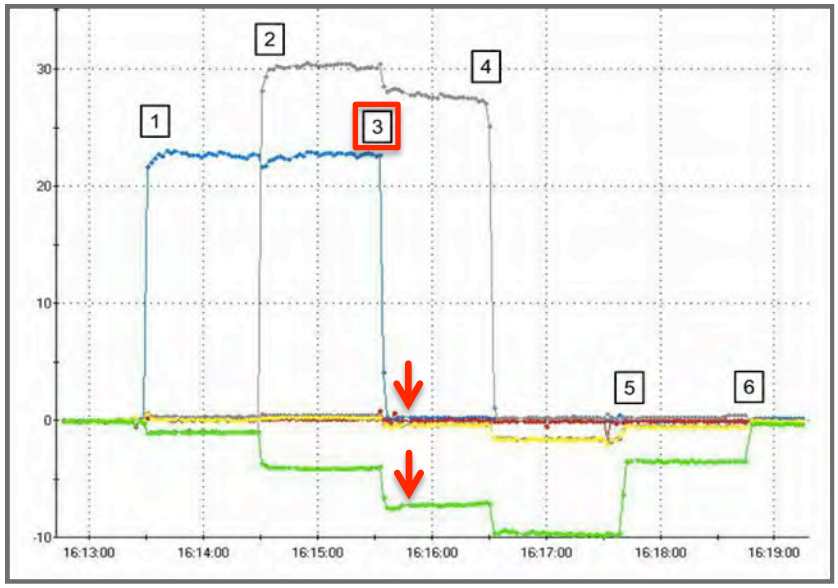
Stepping Further "Over the Cliff"



- Pressurizes bedroom 2
- Living room depressurizes further
- Fireplace continues backdrafting
- Combustion gases continue entering the cold air return

3. Open Bedroom 1 Window

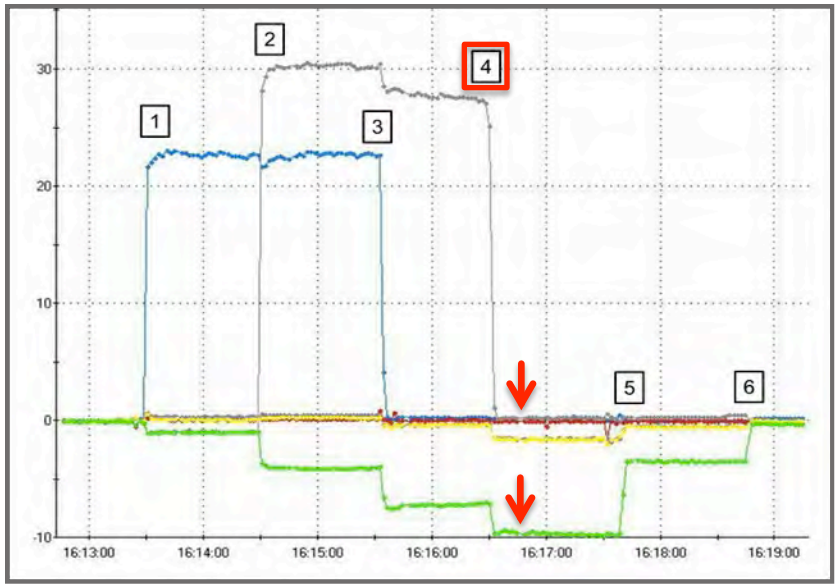
A Little Fresh Air is Always Good, Right ?



- Bedroom 1 returns to zero relative to outdoor air pressure
- Living room depressurizes even further
- Fireplace continues backdrafting
- Combustion gases continue entering the cold air return

4. Open Bedroom 2 Window

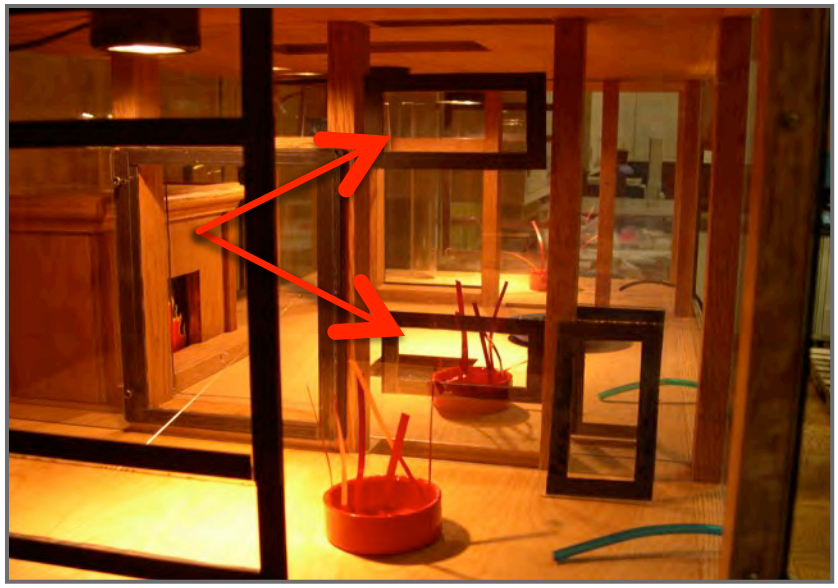
More Fresh Air Should be Better, shouldn't it?

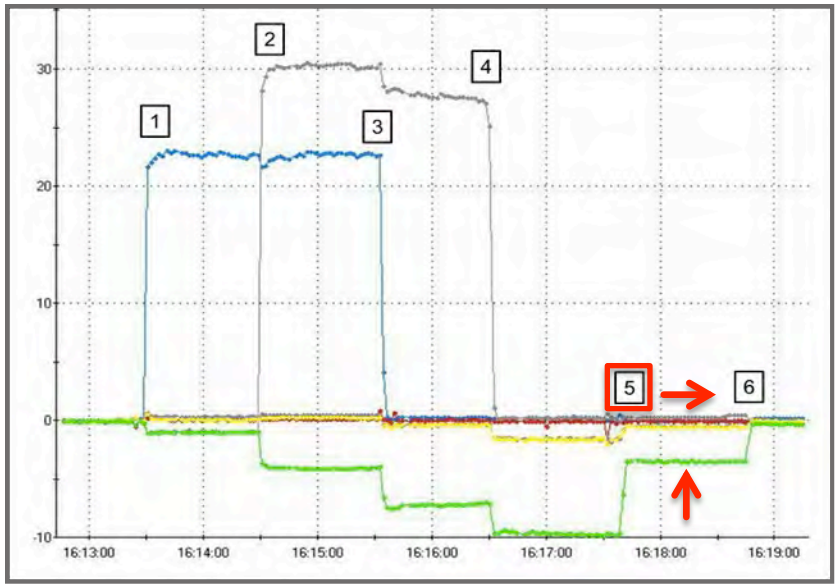


- Bedroom 2 returns to zero relative to outdoor air pressure
- Living room depressurizes even further
- Fireplace continues backdrafting
- Combustion gases continue entering the cold air return

5. Open Passive Return

Connects Bedroom 1 and Living Room

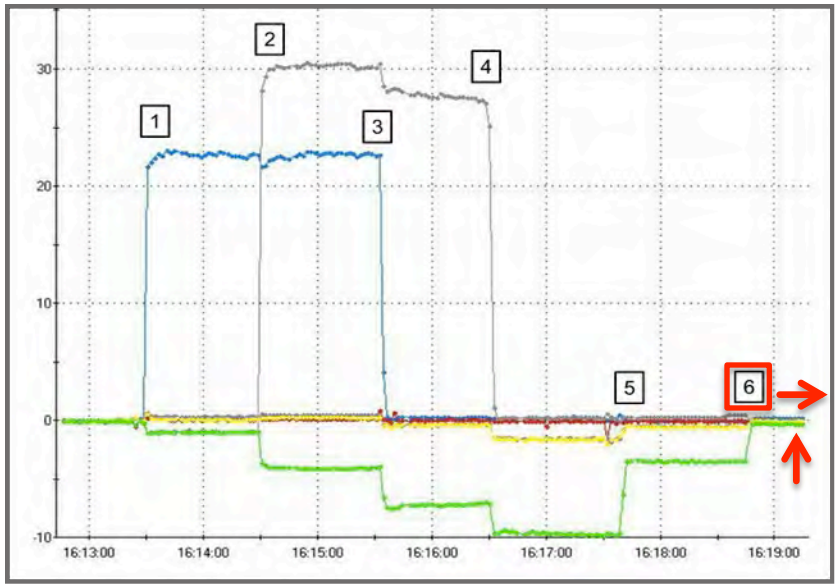




- Bedroom 1 remains at zero relative to outdoor air pressure
- Reduces level of living room depressurization
- Fireplace continues backdrafting
- House is moving back toward proper pressure balance

6. Open Bedroom 2 Door

Has the Same Result as a Passive Return Between Bedroom 2 and the Living Room



- Bedroom 2 remains at zero relative to outdoor air pressure
- Living room returns to zero relative to outdoor air pressure
- Fireplace draft is restored to safe operation
- House is restored to proper pressure balance

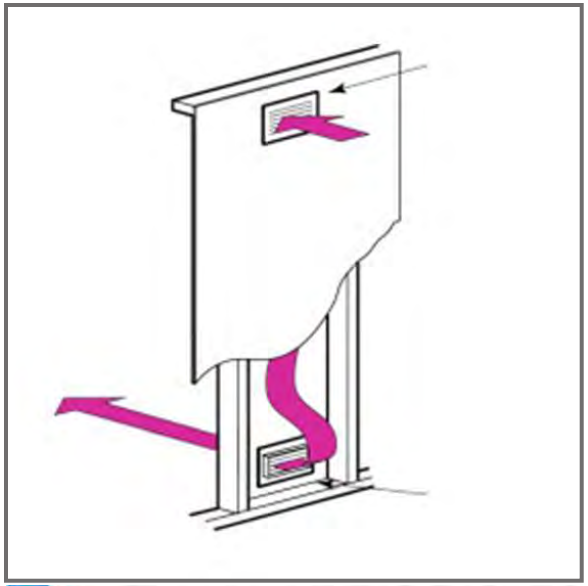
The Lesson

Existing Conditions in a House can make it Fragile and Easy to Push "Over the Cliff"

- This little house was fragile and ready for a performance failure
- Closing doors was enough to take the house "over the cliff"
- Opening the bedroom windows for fresh air made things worse
- A solution for problem is already known and used in homes

More About the Solution

Installing Passive Returns is Simple and Inexpensive



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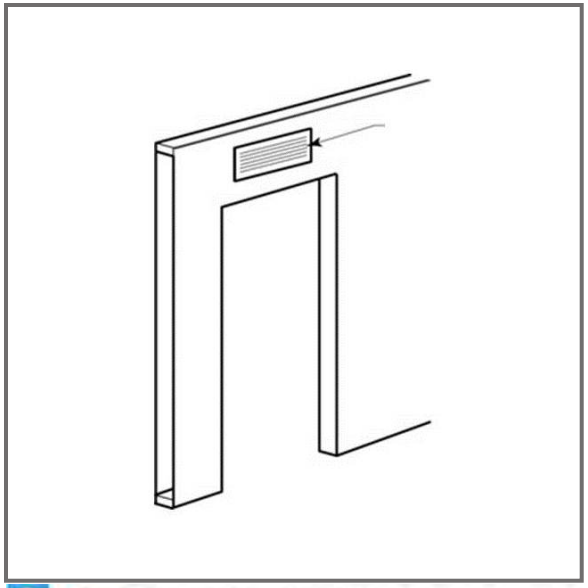

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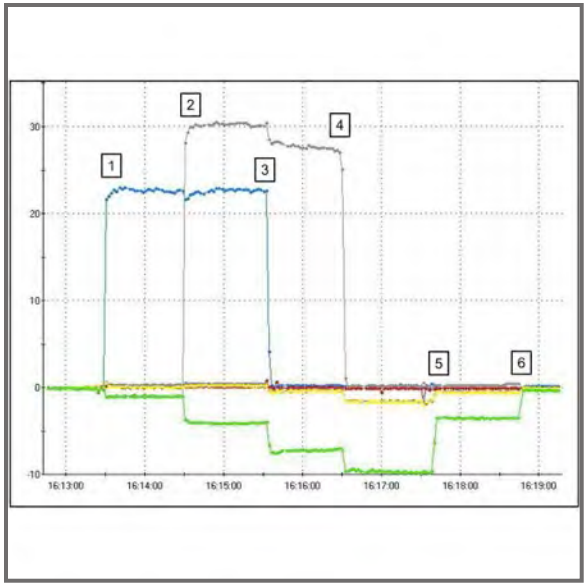
- Pressure differences between rooms can be measured by testing
- Pressure differences that are identified can be managed
- Passive returns are already used in homes
- Performance testing of homes is relatively inexpensive

Teaching the Value of Testing Homes

Classroom Simulation Tools Demonstrate Real Conditions



- The House of Pressure was developed by Anthony Cox
- Versatile tool can simulate many conditions
- Visual demonstration of pressure differences and air flows
- Understanding gained can be applied in real homes

Thank You

Photo and Graphics Sources

Slides 1,2 Photos by NASA
Slides 7,8 Graphics from High and Low Pressure Systems **http://www.bom.gov.au/lam/Students_Teachers/pressure.shtml**
Slides 15,19,21,24,40,41,42,43,46,59,69,70,73,74,75,78 Graphics from Air Smart, University of MN Extension
Slides 20,28,48 Graphics from Cold Climate Information Center, University of MN Extension
Slide 25 Photo by William Angell
Slides 32,33,51,52,53,62,76,77,88,91 Photos by Joe Nagan
Slides 36,37,38,39 Photos by Terry Lenhart
Slide 79 Graphic from U.S. Environmental Protection Agency
Slide 80 Graphics from MN Department of Health Radon Pamphlet
Slide 81 Graphic from Building Radon Out / EPA
Slide 90 Photo by Todd Owens