Building Science
and
Thermal Imaging

Building Science for the Home Inspector

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What is Building Science?

Building science is the collection of scientific knowledge that focuses on the analysis and control of the physical phenomena affecting buildings. This includes the detailed analysis of building materials and building envelope systems.

This study includes materials science, thermodynamics, hydrodynamics, fluidics, architecture, engineering and construction sciences.

Building Science for the Home Inspector

Building Science is the study of structure construction, safety, maintenance and, most recently, energy efficiency.

It examines buildings by breaking down the house into systems, components and items.

- Chimneys
- Insulation
- Ventilation
- Roofing
- Drainage
- Windows
- Exterior
- Doors
- Structure
- Electrical
- Plumbing
- Interior
- Heating
- Air conditioning
- Foundation

Building Science

Building Science, specifically, studies the three major factors that affect the building:

- Heat
  - Resistance to heat effects on the building
  - Temperature control and management inside
- Air
  - Effects of air and wind on the exterior
  - Air flow and ventilation of the interior
- Moisture
  - Exterior resistance to water and moisture
  - Control of interior environment (humidity, organic growth

Building Science

Since ancient times, man has tried to make living easier and to protect himself from adverse environments.

- Wind
- Heat
- Cold
- Water
- Light
- Noise
- Animals
- Privacy
- Location
- Portability
- Durability

Building Science

Besides protecting its inhabitants from the outside environment, a building must also create and interior environment different from the outside.

Buildings are environmental separators, creating a building envelope to regulate the interior environment.

- Air Movement
- Humidity
- Temperature
- Air Quality
- Light
- Dust
- Insects
- Vermin
- Water
- Waste Management
- Food and material storage

Building Science

Besides providing shelter, buildings also provided space for community gatherings, religious and scientific study and for the preservation and commemoration of the dead.

Building Science

What factors effect the environment?

What must be controlled?

Exterior:

- Wind
- Rain
- Sun

Interior:

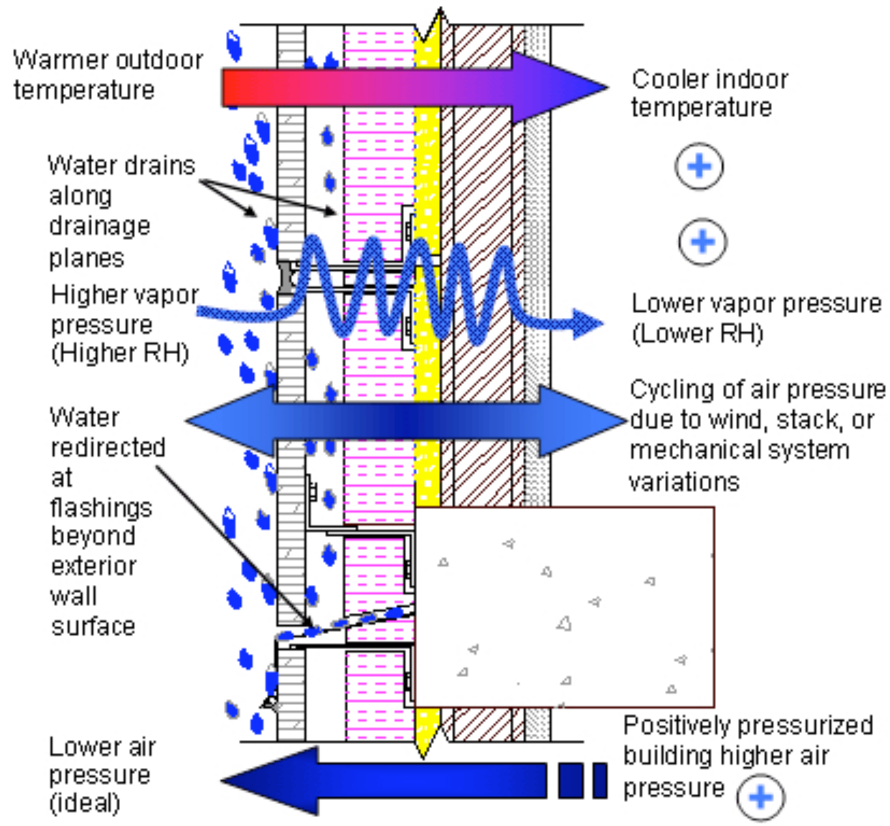
- Air Flow
- Heating / Cooling
- Humidity / Moisture
- Lighting

Building Science

The Building Envelope is the combination of systems that provide separation between the environment inside and outside the building.

It includes the roof, walls, exterior and interior wall coverings, insulation, foundation, windows and doors

These systems are barriers that work to maintain environmental stasis.



Building Science – Environmental Factors

Three main factors need to be controlled by the building. These factors are also most responsible for the degradation of the building.

- Heat
- Wind
- Moisture

All of these factors tend to add energy to the building. Energy is detrimental to the building and works against controlling the interior environment that is most needed by its inhabitants.

Building Science – Environmental Factors

These factors are exponential and synergistic in their effects.

This means that their effects grow fast and interact with each other.

Arrhenius Equation:

$$k = A \exp\left(-Ea/RT\right)$$ (Simple, eh?)

<u>For every 10 degree (centigrade) increase in temperature, the rate of any chemical reaction doubles.</u>

Building Science – Environmental Factors

Examples:

- As the temperature of asphalt shingles is increased, so is their degradation.
  - More brittle, more chance of breakage by hail or wind
  - Granule loss
  - Off-gassing of volatiles
- As the temperature increases, exterior wall coverings degrade faster.
  - Paint / Primer chalking, peeling
  - Increased differential movement of masonry
  - Degradation of vinyl siding
  - Split block sealer failure
- Together with elevated moisture levels
  - Increased moisture in materials speeds up degradation
  - Increased biological organism growth (mold, wood rot)

Building Science – Environmental Factors

Examples:

- For every 18% increase in relative humidity, the vapor pressure is doubled and the life of wooden building materials is decreased by 50%
- For every 20% increase in ultraviolet radiation (sunlight) there is a 50% decrease in the life of most building materials
- Water and moisture is the most harmful damage factor to buildings.
- Buildings will retain water and moisture, at differing rates, depending on the materials involved.
- The building envelope needs a drying period, which is usually done in the winter, not the summer.

Building Science - Heat

A building must work to provide a separation for the occupant (and the building's structure) from the 3 basic environmental factors:

- Heat
- Sunlight
- Moisture

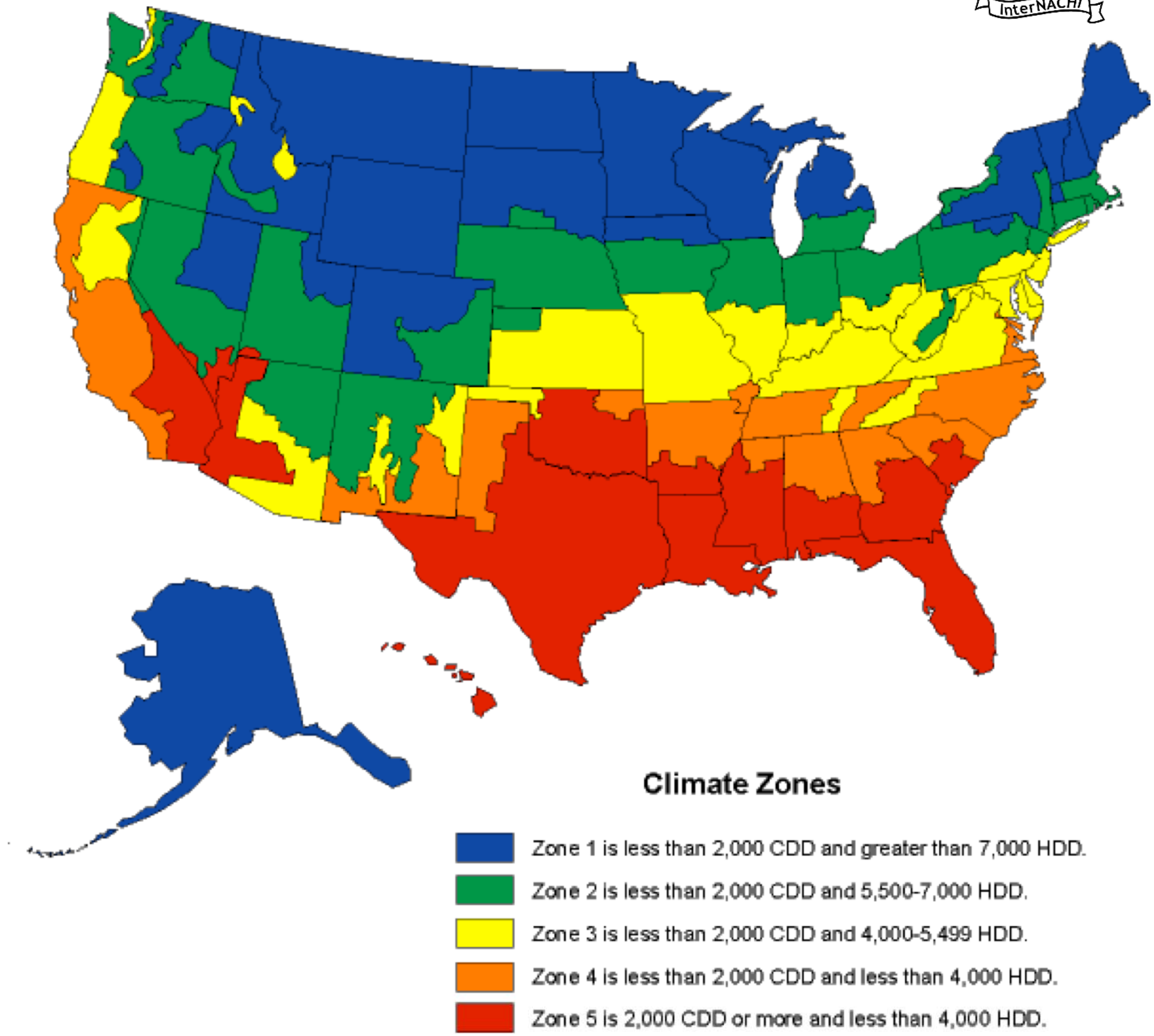
- Hot – Humid
- Hot – Dry
- Mixed Humid
- Marine
- Mixed Dry
- Cold
- Severe Cold
- Sub-Arctic / Arctic

Hygrothermal Regions

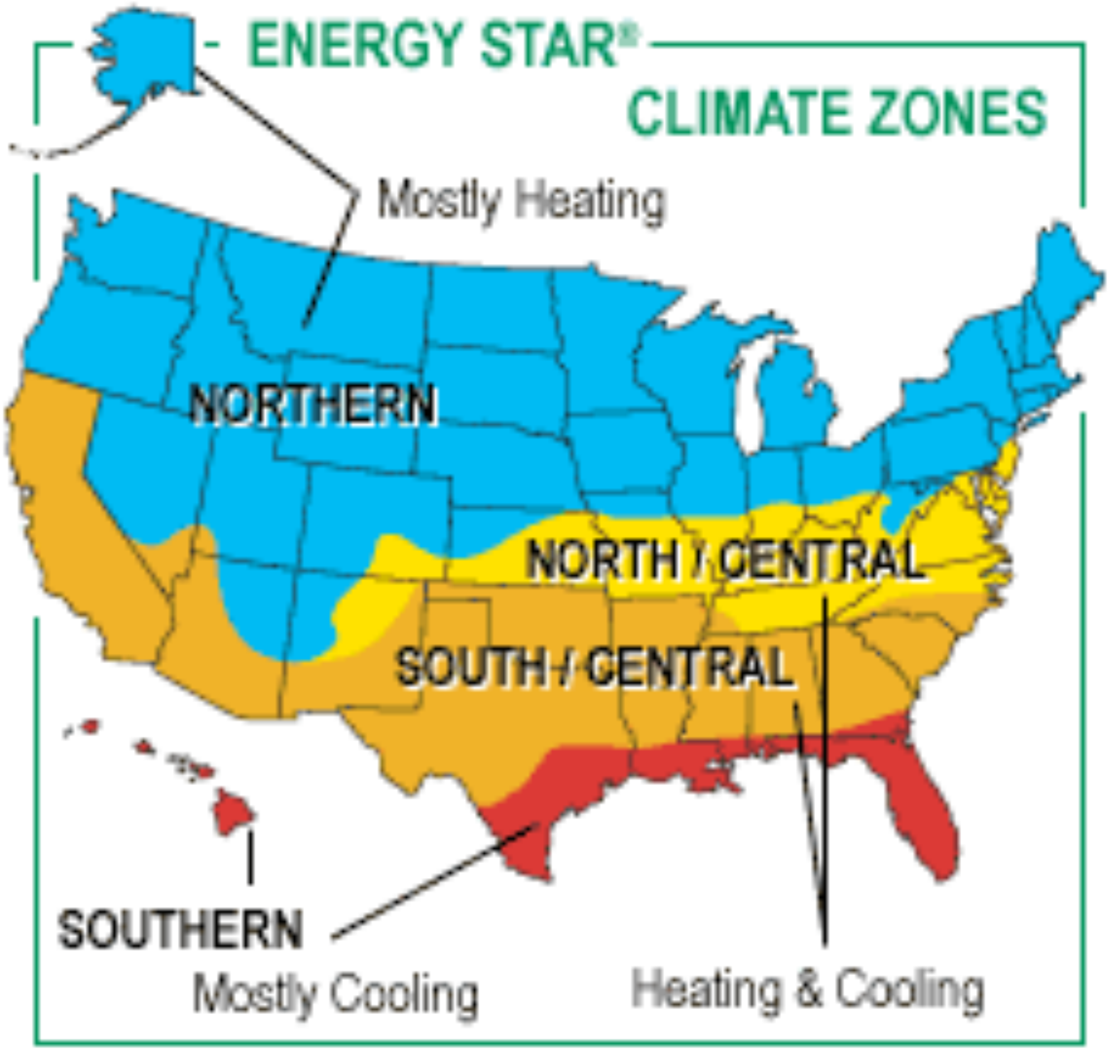
Building Science - Heat

U.S. Dept. of Energy

Climate Zone Map



Building Science - Heat



Energy Star

Climate Zone Map

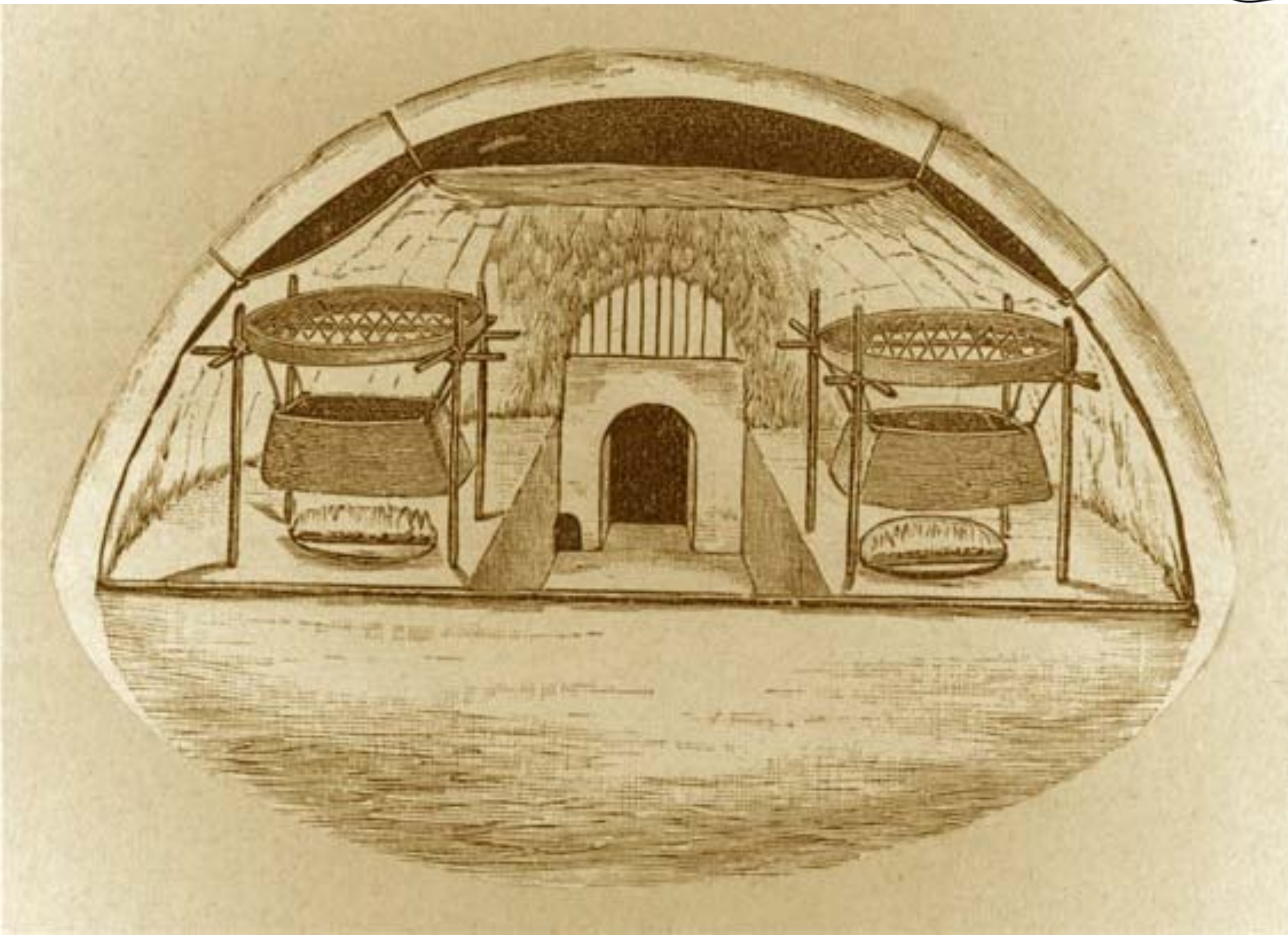
Building Science - Heat

Maintaining the temperature of a building relies on two factors:

- The heating (and cooling) system of the building.
- The retention of the building's interior temperature against the outside temperature.

These factors are synergistic with the other two controlling factors of the buildings environment. Both the air flow (both inside and outside) and the moisture levels of the building effect the heating of the house.

Building Science – Heat Loss



Building Science – Heat Loss

Building Science – Heat Loss

Houses lose heat by many different means.

- Attic / Roof: 10 – 15%. Easy to add insulation
- Exterior Walls: 25 – 50%. Harder to add insulation
- Basements: 10 – 15%. Crawlspaces lose more
- Windows and Doors: 15 – 30%. Easier to fix

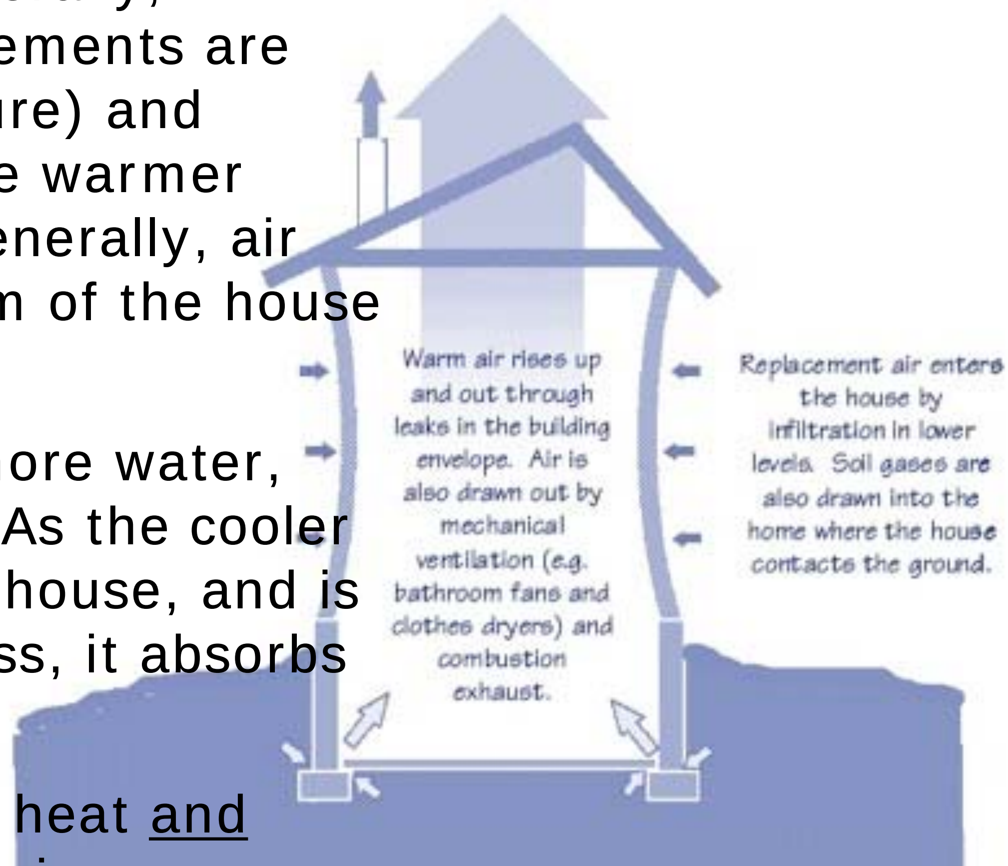
Air leakage is the most common, and least evident, source of heat loss.

The more airtight a house is, the more problems you have with proper air exchange and ventilation.

Building Science – Heat Loss

Stack Effect

- Air flows from high pressure to low pressure areas. Generally, crawlspaces and basements are colder (higher pressure) and ceilings and attics are warmer (lower pressure). Generally, air flows in at the bottom of the house and out the top.
- Warmer air carries more water, dissolved in the air. As the cooler air rises through the house, and is warmed in the process, it absorbs moisture.
- The air now contains heat <u>and</u> moisture (which contains even more heat from vaporization).



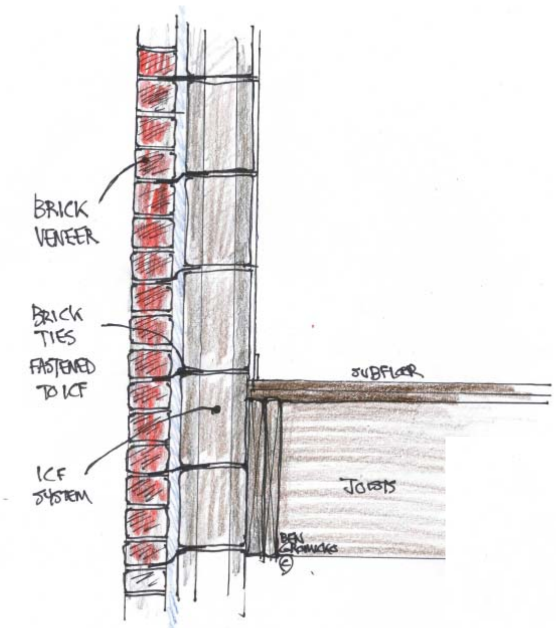
Building Science – Hygric Buffer

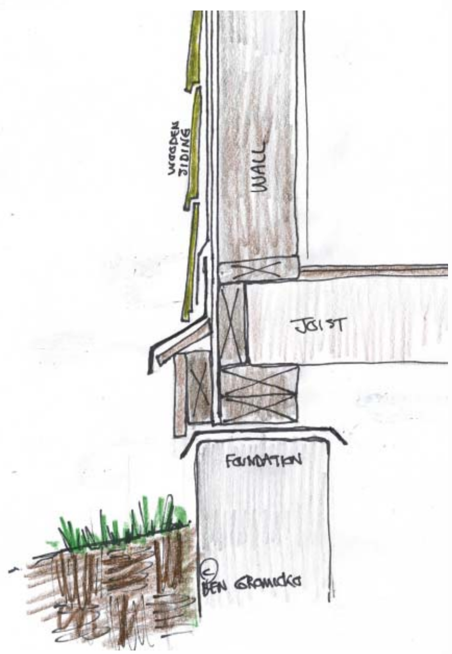
The Hygric Buffer Capacity is the storage water capacity of building materials.

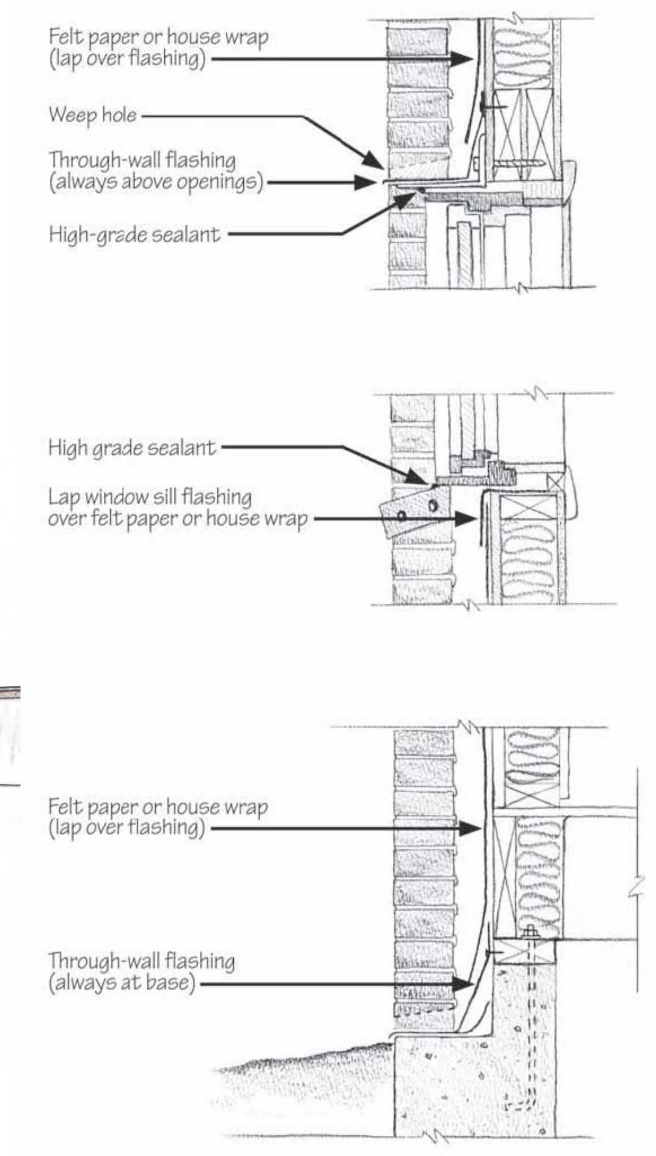
- All building materials will, to some extent, retain water.
- If the moisture levels do not exceed the hygric buffer capacity of the buildings materials, moisture damage will not occur
- When the building materials suspend (buffer) moisture, it cannot enter the building (condense) and cannot cause damage to the building.
- Different building materials have different hygric buffer capacities
- Most modern construction tries to utilize multiple layers of different materials to maximize the hygric buffer capacity.

Building Science – Hygric Buffer

Building Science – Hygric Buffer







Building Science – Hygric Buffer

Typical hygric buffer capacities of a typical 2,000 SF houses:

- Masonry – 500 gallons
- Wood siding, framing and sheathing – 50 gallons
- Metal siding and framing with gypsum sheathing – 5 gallons

The masonry house can absorb 100 times more moisture, compared to a metal siding house before allowing into the house

Moisture Control For Buildings, *Joseph Lstiburek, Ph.D., ASHRAE 2002, February 2002 ASHRAE Journal*

Building Science – Hygric Buffer

The exterior wall covering of the building will determine how it can much moisture absorb before the hygric buffer is saturated and deterioration begins.

The material must provide a hygric buffer capacity properly suited for the climate zone.

The material must also be able to dry, to gain more buffer capacity, which also depends on the climate area.

Vapor barriers add, somewhat, to the building’s capacity, but the proper vapor barrier should be used for the specific climate area of the house.

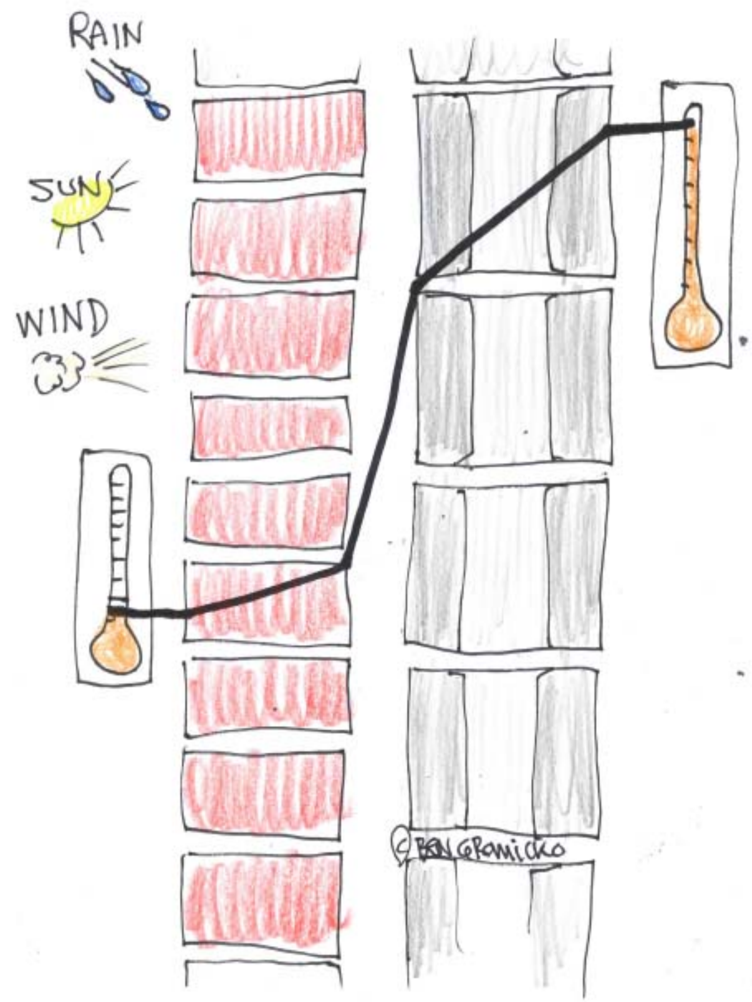
Building Science – Hygric Buffer

- Hot – Dry: Low moisture levels, low drying needs
- Hot – Humid: High moisture levels, high drying needs
- Marine: High moisture levels (water and humidity vary), high drying needs
- Cold: Medium moisture levels, varying temperatures
- Very Cold: Low moisture levels, cold temperatures

- Drying does not always require heat, in fact excessive heat and sun can actually slow drying
- Drying can occur more efficiently in cold and very code zones.
- Building materials must be suited to the zone, its conditions and the drying factors

Building Science – Hygric Buffer

- Sunlight dries, but also heats the brick which causes moisture to migrate inwards
- Rain, drawn by capillary action, also migrates inward
- Wind drives the rain, but also can create pressure differences
- Wind together with humidity, create a vapor pressure gradient which can further cause moisture migration
- Air gaps can slow this moisture movement



Building Science - Vapor Barrier

Vapor Barriers are used to control the flow of moisture into the building envelope. The moisture can be in liquid form or humidity.

New houses are generally wrapped in a “house wrap” material. House wrap allows some moisture vapor flow while stopping both liquid water and air. Different grades of house wrap have different properties.

Older houses sometimes used building paper (tar paper) which had many seam that would compromise the envelope.

Other houses just relied on asphalt impregnated fiberboard sheathing.

Building Science - Vapor Barrier

When discussing vapor barriers (also called "drainage planes") the measure of water vapor permeability is called the "perm".

A material with one perm would allow transmission of one grain (gram) of water vapor per square foot of area per hour per one inch of mercury pressure differential.

Depending on the climate zone, different levels of vapor barriers are used. Some areas require low perm vapor barriers and some require high perm vapor barriers.

Building Science - Vapor Barrier

Vapor Impermeable – Vapor Barriers

- Class I – 0.1 perms or less
- Class II – 1.0 perms or less
- Rubber membrane, polyethylene film, glass, sheet metal, aluminum foil, foil-faced sheathings.

Vapor Semi-Permeable – Vapor Retarders

- Class III – 10 perms or less
- Exterior grade plywood, asphalt impregnated building paper, many latex-based paints, paper or bitumen faced fiberglass batt insulation

Vapor Permeable – “Breathable”

- More than 10 perms
- Unpainted gypsum board, un-faced fiberglass insulation, most house wraps.

Building Science - Vapor Barrier

Moisture is transported through building materials by 3 different methods:

- Capillary Action: The surface must be wet.
- Air Transported Moisture: Small particles of water carried by the air. Usually occurs under high pressure. This method is usually more significant then vapor diffusion.
- Vapor Diffusion: Part of the 2nd law of thermodynamics. Moisture will flow across a concentration gradient as well as a heat gradient. More flows to less.

Proper moisture control usually requires both an air barrier as well as a vapor barrier.

Uncontrolled air infiltration into buildings because of inadequate air barriers can lead to significant damage.

Building Science - Vapor Barrier

Vapor Barrier Requirements in Different Climate Zones

- Cold Climate
  - Make it as difficult as possible for building materials to get wet from the <u>interior</u>
  - Install air and vapor barriers on the interior building walls
  - Let the building dry by installing vapor permeable materials on the exterior

- Hot and Humid Climate
  - Make it as difficult as possible for building materials to get wet from the <u>exterior</u>
  - Install air and vapor barriers on the exterior building walls
  - Let building materials dry to the interior
  - Interior spaces must be maintained at a slight positive pressure with dehumidification

Building Science - Vapor Barrier

Vapor Barrier Requirements in Different Climate Zones

- Mixed Climate - Complex
  - Flow through approach: Use permeable or semi-permeable material on interior and exterior. Requires both air pressure control and interior humidity control.
  - Install vapor barrier in the approximate "middle" of the wall with insulated sheathing on the exterior. Air barrier can be either towards the interior or the exterior. Air pressure and humidity control must be utilized.
  - Humidity flows inwards in the warm, summer months. Must be stopped at the exterior or at the sheathing.
  - Humidity flows outwards in the cold, dry months. Must be stopped at the interior walls.
  - Both air and vapor barriers should be employed.

Building Science - Vapor Barrier

Gypsum Board	50.00
Plaster (mud and skim coat)	15.00
Concrete Block	2.40
Semi-Gloss Acrylic Paint	6.61
Tyvek HouseWrap	58.00
Tyvek ThermWrap	36.00
Plywood (exterior grade)	1.90
Vapor retardant paint	0.45
Glazed Tile (grout sealed)	0.12
Polyethylene (6 mil)	0.06
Polyethylene (10 mil)	0.03
Mylar / Aluminum Foil	0.00

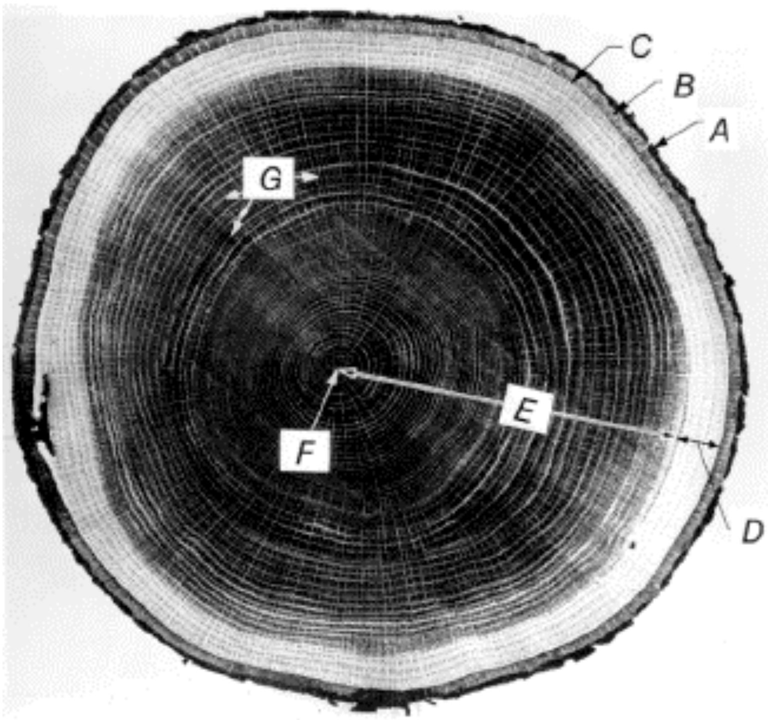
Building Science - Moisture

Wooden framed houses are common. Wood grows with increased moisture, thicker, not longer. It also shrinks along its width, not ins length.

Manufactured wood products try to compensate for this by using cross graining and fiber orientation, resins and water proofing materials. They tend to expand in all directions with rather than just one.

This expansion and contraction will cause separation and allow for water (and water vapor) to enter through the gaps.

Building Science - Moisture



Common moisture levels in wood:

- Green lumber – 45 to 50%
- Air dried lumber – 20 to 30%
- Kiln dried lumber – 5 to 6%
- Manufactured – 3 to 4 %

Remember, most builders do not take the time to cover their lumber, or their framed houses, to protect them from the elements. A wooden framed house can absorb a great deal of moisture during construction.

Building Science - Moisture

- Wood fiber saturation is 25 to 30%, by weight.
- Naturally occurring wood rot (mold) spores in the wood will activate when the moisture content raises above 19 to 20%.
- To prevent mold amplification (accelerated deterioration of materials with mold growth) the moisture content must be kept below 16%.
- Even with low indoor humidity levels, cold weather caused condensation (window frames, exterior door hinges, inside walls without sufficient vapor barriers) which will increase moisture content in small areas.

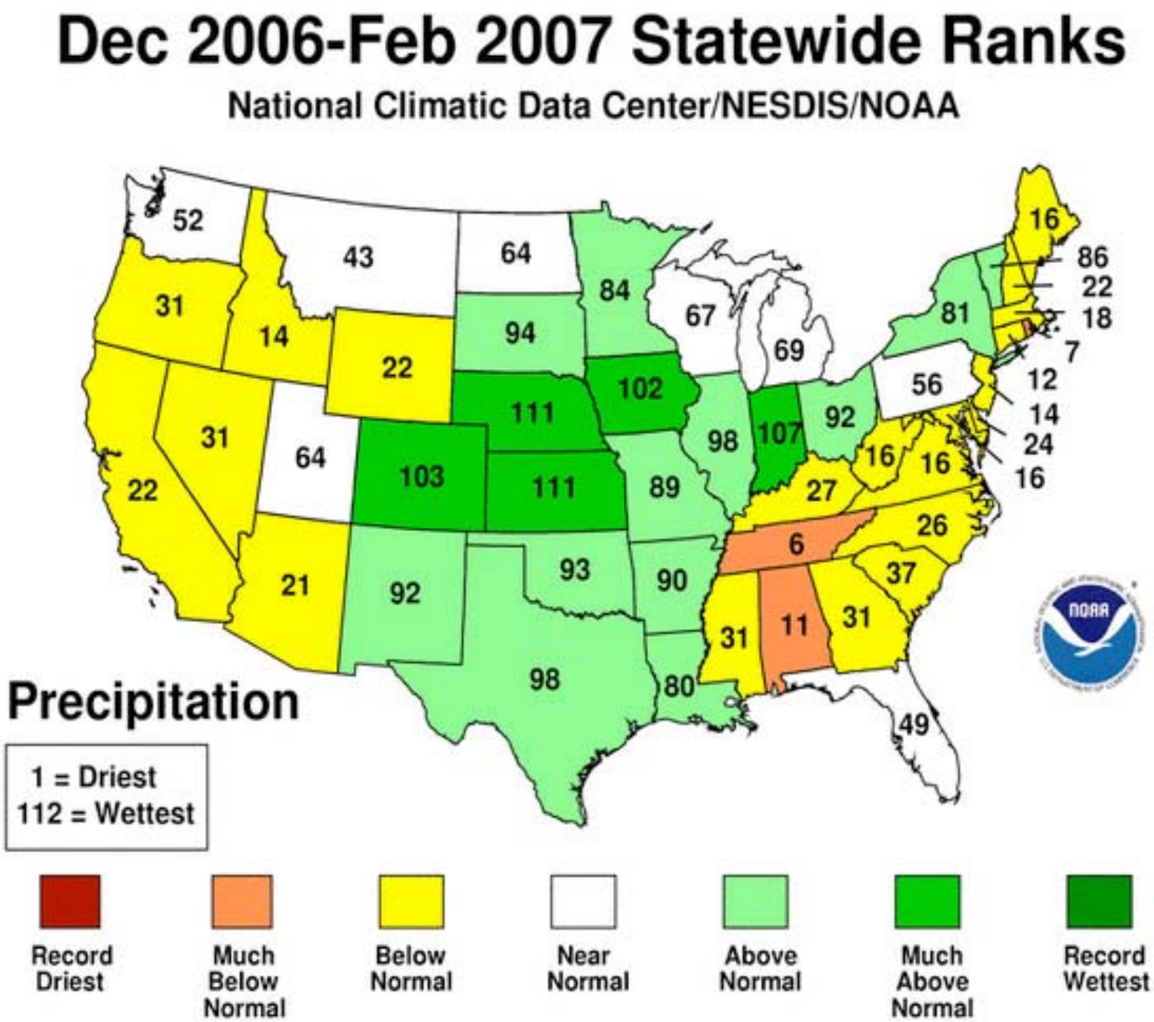
Building Science - Moisture

Exterior moisture can be from rain, but also from humidity.

While most people can understand that the house must be protected from rain, they can overlook the real mechanism of moisture penetration into the house.

Water, in the form of water vapor, has a much greater effect on the house than does liquid water.

Building Science - Moisture



Rain patterns differ each year and according to region.

Building Science - Moisture

Rain effects the house
even before it is built.

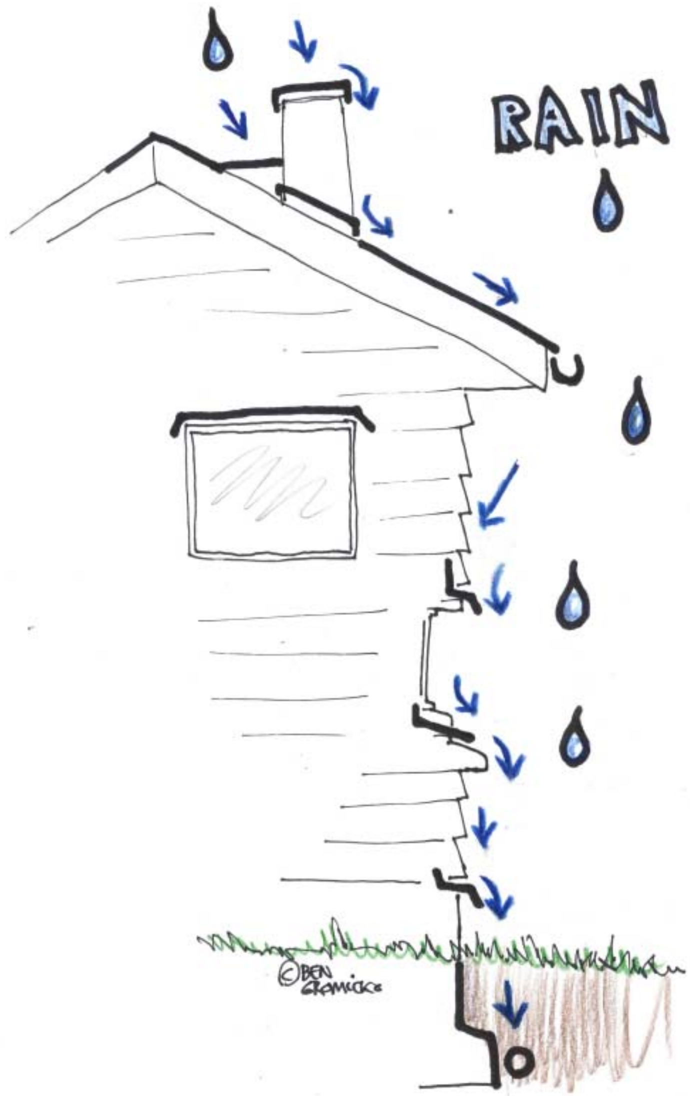
As well as after.

Building Science - Moisture

Rules for water movement:

- Water always runs downhill.
- Water vapor travels from areas of high pressure to areas of low pressure.
- Water vapor travels from warm areas to cold areas driven by heat.
- Water vapor travels from wetter areas to dryer areas driven by capillary action
- In short, water can move in many directions through the building's exterior envelope and inside the house as well.

Building Science - Moisture



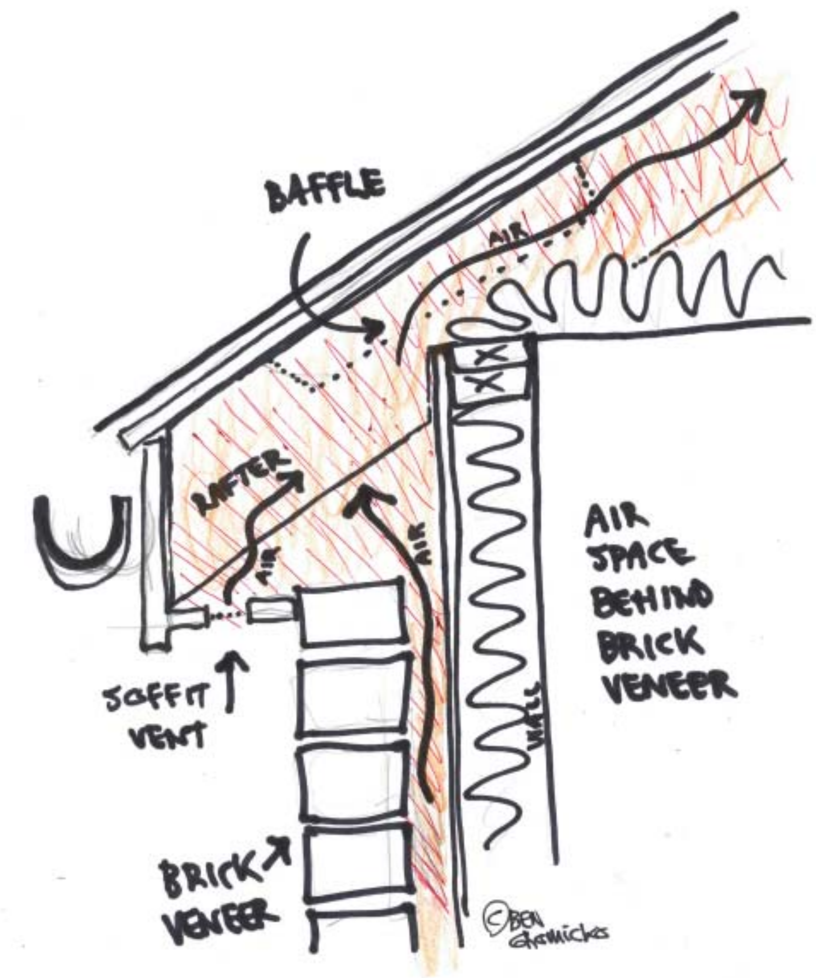
The house must be able to shed water, from the roof to the footing. The roof is not “water proof” but “water resistant”, designed to take the rainwater away from the house.

The roof must work with the gutters, downspouts and the exterior wall covering. These different components must be matched on order to work together properly.

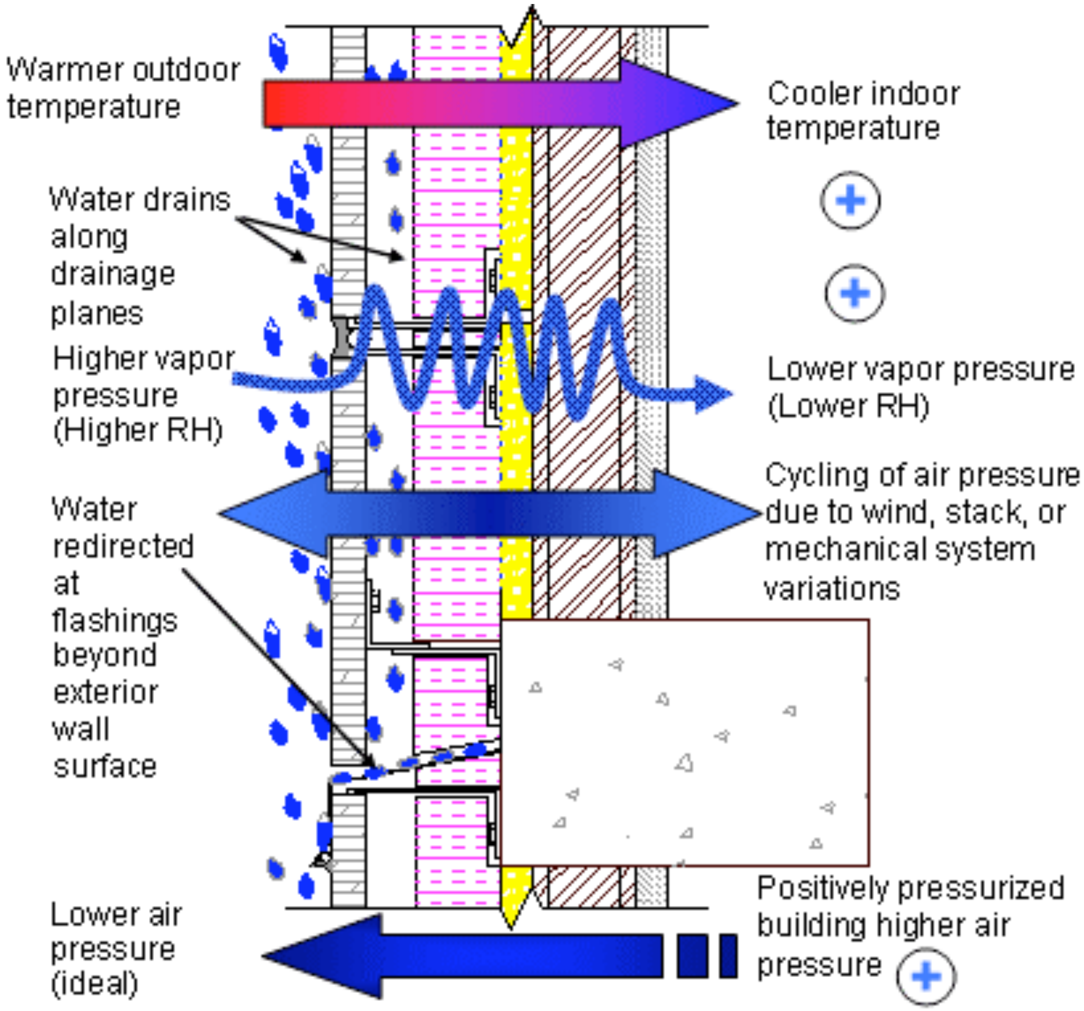
Building Science - Moisture

The interface of the roof to the exterior wall must also allow water to properly shed as well as allowing for proper ventilation of the attic area and provide a proper seal against water intrusion into the exterior wall covering.

These details are often lost between the work of the framers, roofers and masons. If not properly coordinated a latent defect is created.



Building Science - Moisture



Warmer to cooler

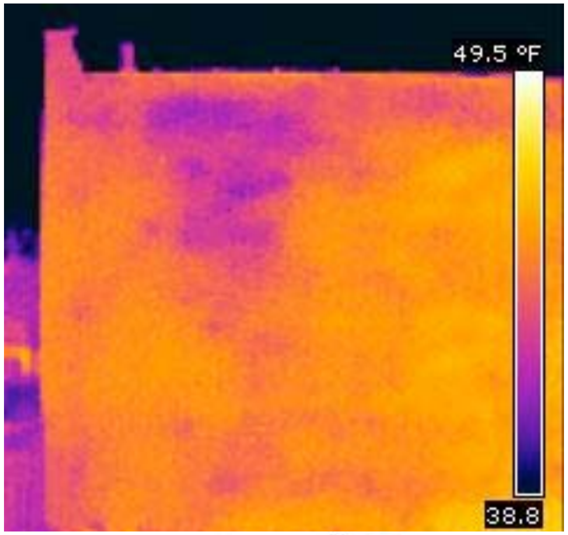
Wetter to dryer

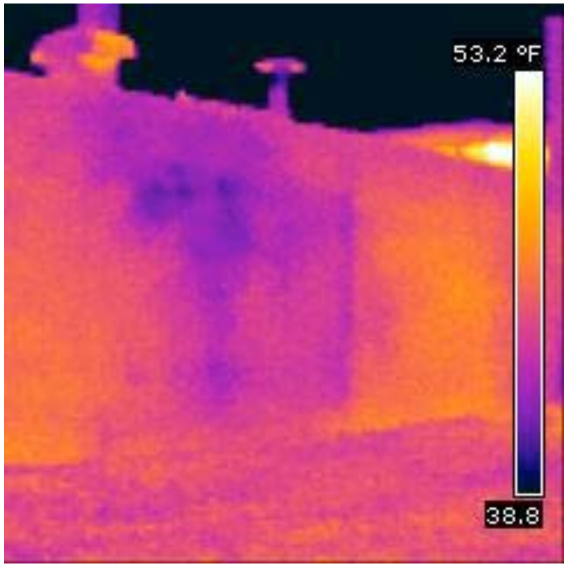
Higher pressure to lower pressure

Downhill, watch the flashings.

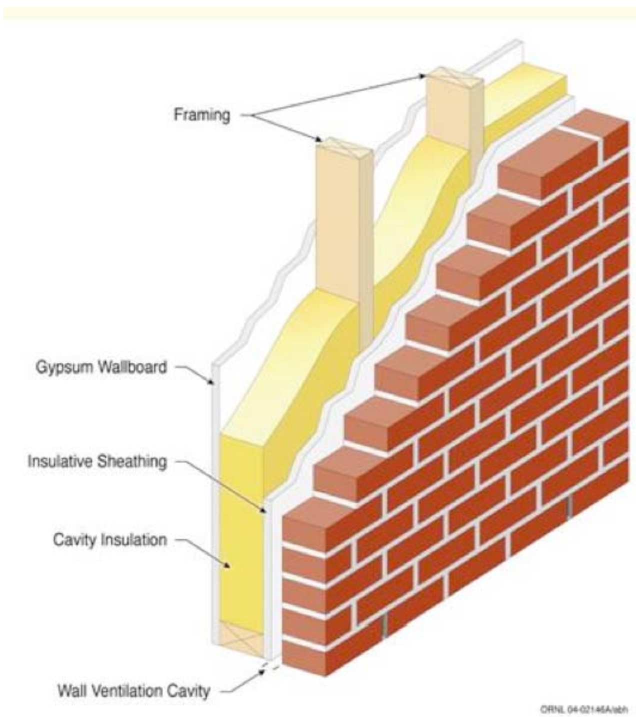
Building Science - Moisture

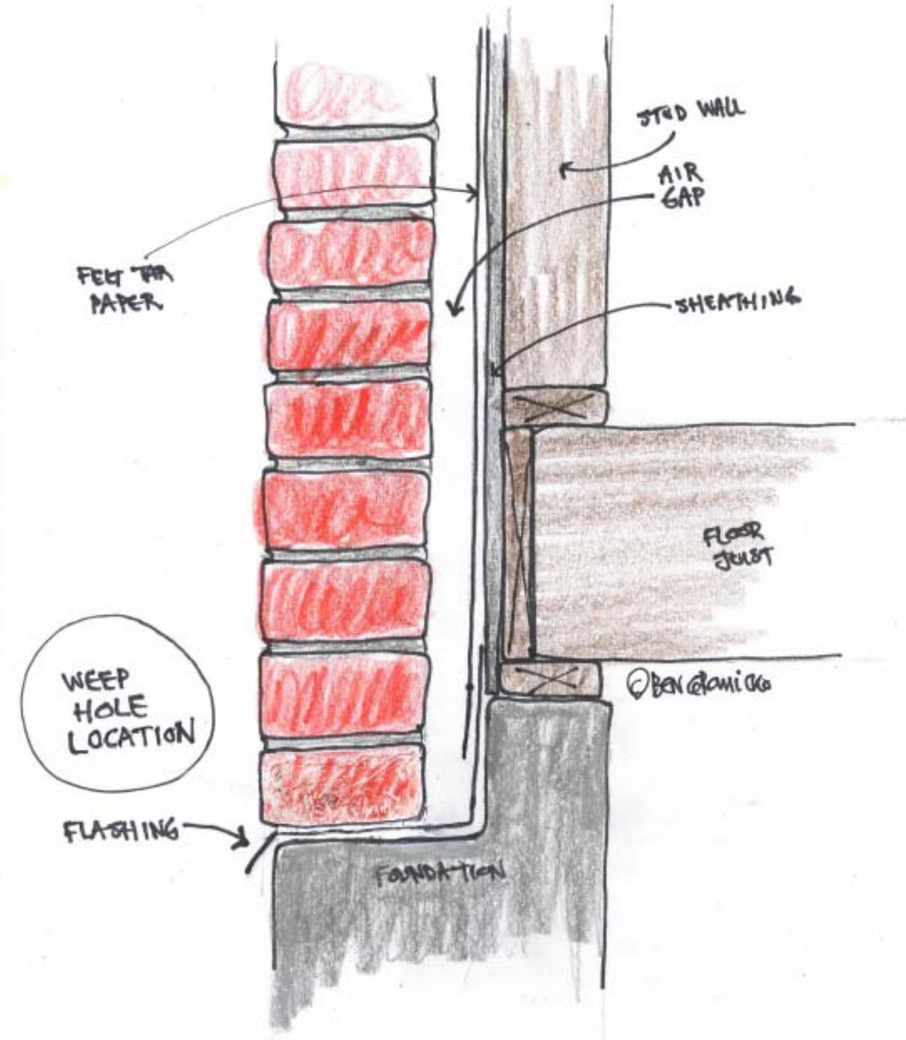
Building Science - Moisture





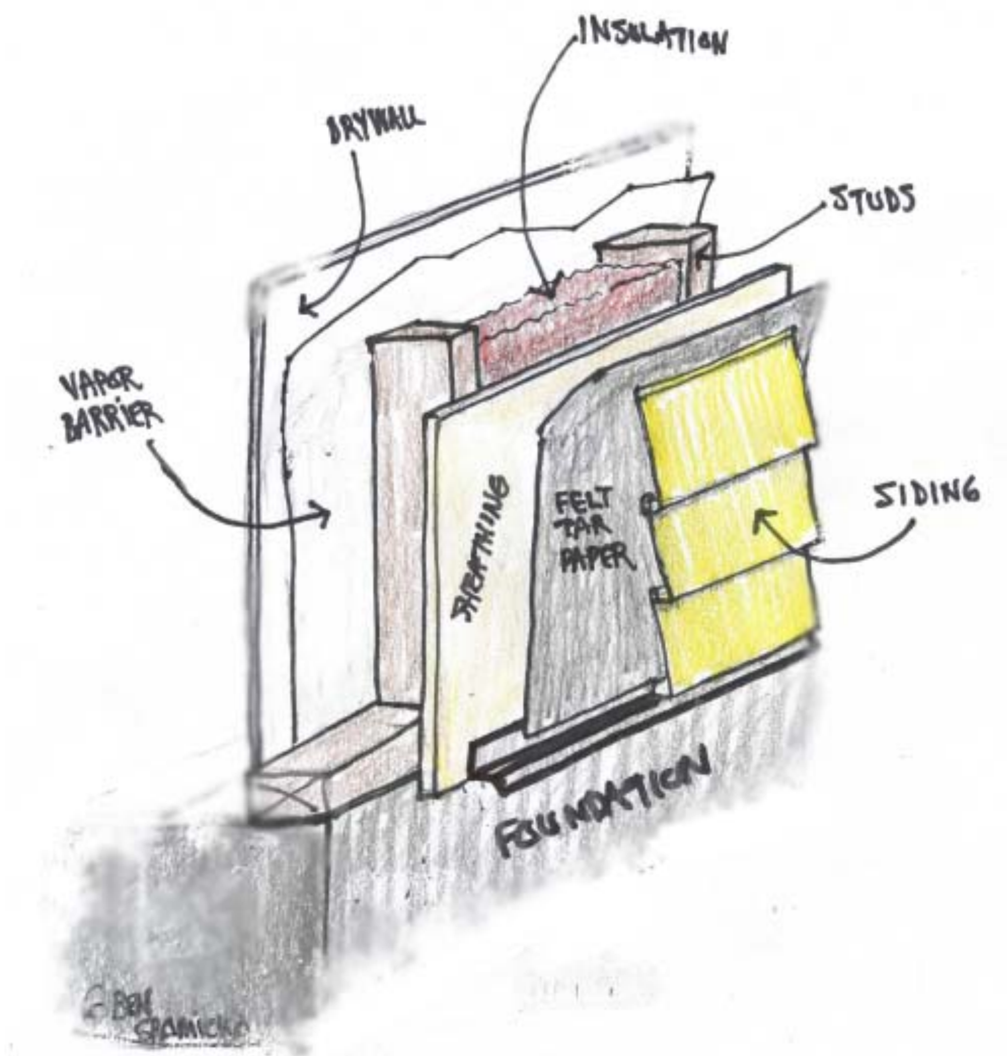
Building Science - Moisture



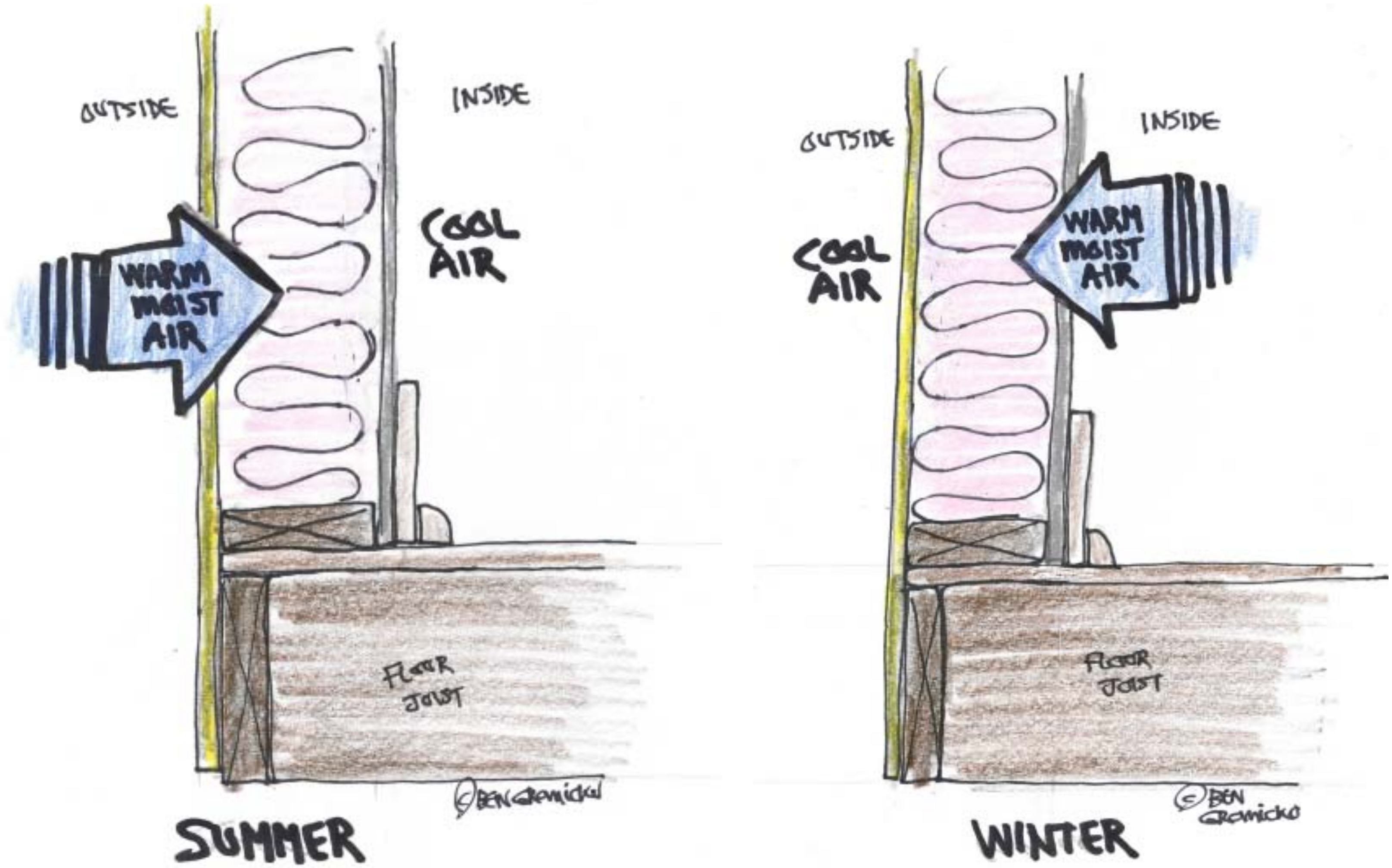


Building Science - Moisture

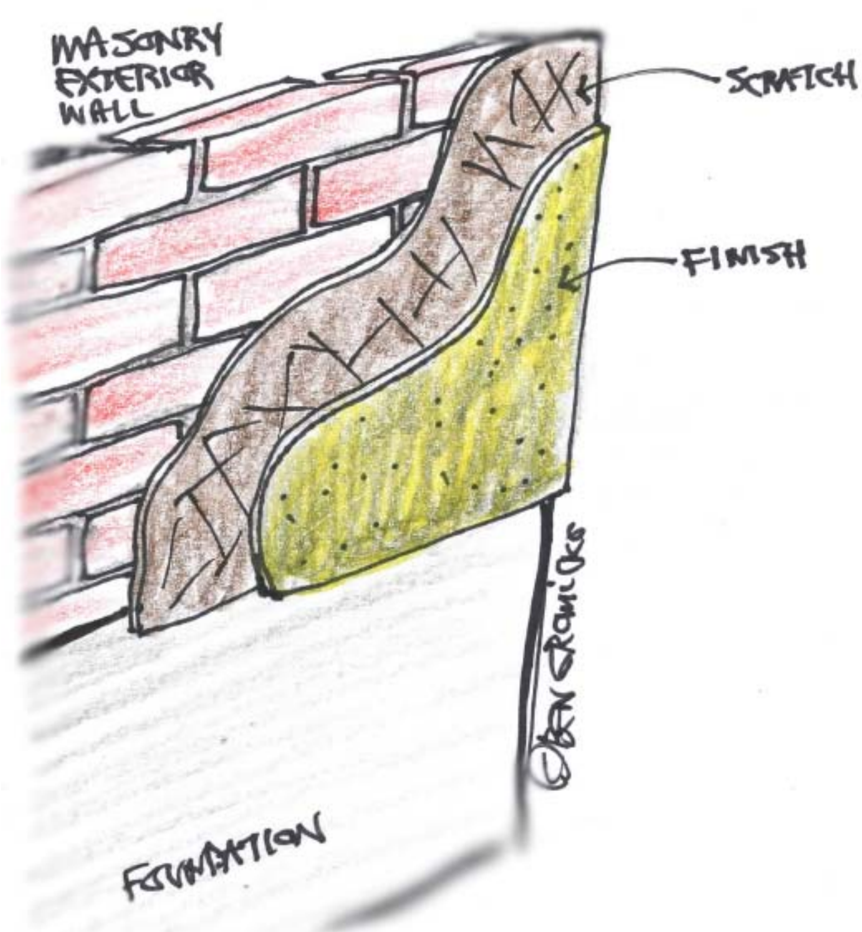
- Siding (wood, metal or vinyl) does not provide this additional air barrier.
- How does this differ with regards to the hygric capacity of this wall system?



Building Science - Moisture



Building Science - Moisture

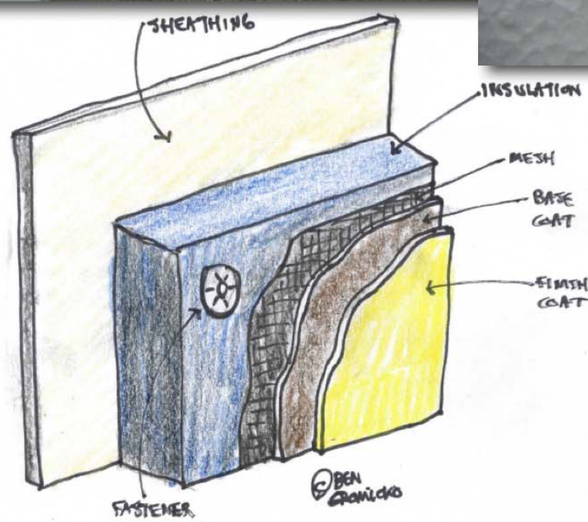


Two coat stucco, usually applied over a brick wall, allows for a greater hygric buffer, but unless sufficient drying is allowed, moisture is retained in the brick.

Building Science - Moisture

- Three coat stucco adds a waterproof layer of sheathing paper.
- This system has a lower hygric buffer capacity, but makes up for it in the added waterproof layer.
- The type of waterproofing is important.
- Regular tar paper or rubber membrane?

Building Science - Moisture

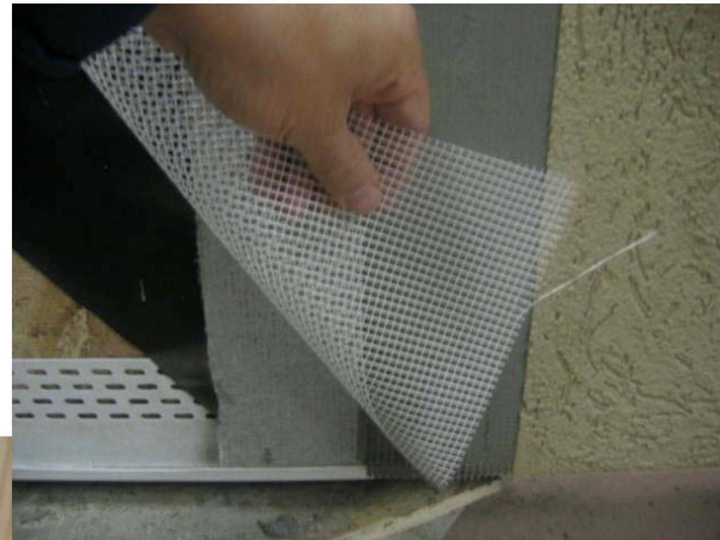


EIFS systems add an insulation layer but are very susceptible to damage if not flashed or sealed properly.

With EIFS, the quality of the installation is always the key.

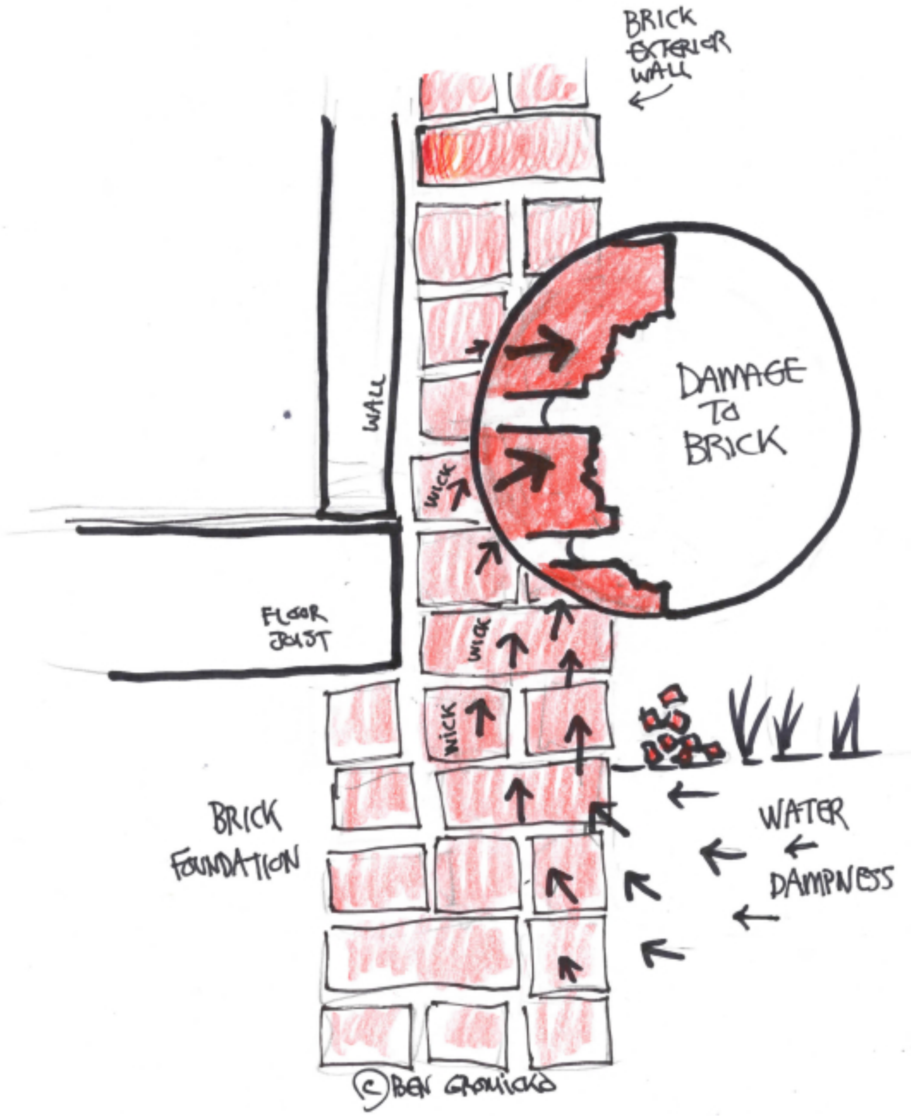
If not properly installed, the foam becomes a huge sponge.

Building Science - Moisture



Building Science - Moisture

Because of the foundation's porous nature, moisture can also wick up from the ground.



Building Science - Moisture

Downspout near the foundation.

Water wicking up the foundation wall.

Colder temperatures on the exterior.

Water concentration

Knowing what we now know, how many ways is this causing water to enter the house? Where will this water show up inside the house?

Building Science - Moisture

Building Science - Moisture

Since moisture is also dissolved in air (water vapor), moisture also moves with air movement.

The effects of wind on the exterior of the house are synergistic with the effects of moisture intrusion, they work in tandem with each other.

Wind can drive water intrusion, but it can also have a drying effect if the relative humidity (RH) is different.

Moist air can wet a house and dry air can dry the house.

All these effects interact and effect the hygric buffer capacity of the house.