Understanding Water

By Steve Peklenk

Many humans in modern society live their lives similarly each day; they work and die in buildings. Buildings are important ingredients in our lives! We want our buildings to give comfortable and healthy indoor environments, and to protected us from outdoor climate variations. We want our buildings to be efficient, durable, and of course economical with regard to investment, operation, and maintenance costs. Increasing focus on sustainability design and construction have given rise to new and improved materials, technology, and energy use in buildings.

Well-performing buildings is an important part of the world's infrastructure. The society continually adds stricter requirements onto the building industry to add pleasure, comfort and a benefit to each individuals desires of being served.

But there are some things are just beyond our control and understanding…

Some things are just beyond Understanding

Understanding Water

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Introduction:

It has been said that 85% of the construction related lawsuits are filed due to water intrusion problems. Although, there may not be a particular source for that percentage, experience tells us that water problems have been and are continuing to be an issue in construction.

The continuing problems are the result of ignorance of understanding water and how to manage it both in the construction trade and the design community. The lack of a skilled workforce and increasing pressures on designers for faster work for less money add to this problem.

THE PHYSICAL PROPERTIES:

When discussing physical properties of water, what needs to be understood in how and why water moves? Water of course being a molecular structure being made of two parts Hydrogen and one part Oxygen it has properties as a molecular structure.

Gravity – Kinetic Energy

Movement of rainwater down the face of the envelope or cladding and over sloped areas, into openings (such as cracks, holes, and flashing) encountered on the way.

Capillary Action (suction)

Capillary action is the property where water will draw itself into permeable materials through small openings (such as cracks, joints and small holes). For instance water get sucked into a small crack similar to sucking on a straw due to various forces of air movement.

Surface Tension

Surface Tension is the property that causes water to cling and run on to the underside of horizontal or nearly horizontal surfaces.

Differential Pressure Movement

Differential Pressure movement is when water or water vapor is driven in the direction of lower air pressure from high pressure. For instance, if a building has negative air (more air being exhausted than is being forced into it, it is considered to have negative pressure)

Vapor Movement – Through Diffusion & Air Transport

Vapor and air moves from warm toward cold driven by thermal differences (air currents) as well as the massing or concentration of absorbed liquid material.

Solar heating can take rain, heat it to vapor and drive it toward the interior space of a building.

–

<u>So, what is needed to protect a building from water?</u>

Management… Management of the forces that drive water to and through the building envelope.

Best practices would dictate a primary design and a secondary “back up” design, just as you have a UPS back up power supply for your computer server.

Joe Lstiburek, PhD., P.Eng. is well known for his understanding of water and is the author of a paper, "Investigating and Diagnosing Moisture Problems".

In his writings, he states that water comes in 4 forms, solid, liquid, vapor, and absorbed. Water investigation is difficult because the water can change forms and the investigator must hunt down all clues.

Lstiburek lists rules of water movement as:

1. *Water runs downhill due to gravity*
2. *Air carrying water vapor goes from areas of higher pressure to areas of lower pressure.*
3. *Water in the vapor form diffuses from warm to cold driven by thermal gradient*
4. *Water in the vapor form diffuses from more to less driven by the concentration gradient.*
5. *Water in a porous material diffuses on porous surfaces from more to less along concentration gradient in the form of absorbed water. When there is a lot of it and it fills the pores it is sometimes referred to as capillary water. In this way it can move upward against the force of gravity or sideways long distances. Just remember that porous materials "suck" and you'll be ok.*

General Practices for Water Management:

Gravity – Kinetic Energy

• Manage gravity-driven rain that flows over the cladding and over open horizontal joints with a minimum overlap of 3/8 inch. (IBC Residential code typically requires 1 inch lap for siding – 2 inches for weather barrier – NFPA 5000, 3" for weather barrier) Lapping and not reverse lapping is a basic protective practice. All construction efforts should avoid reverse laps (where lower element overlaps upper element), to direct water downward.

• Provide drainage holes (escape areas) for all horizontal surfaces that can act as troughs.

• Provide a minimum slope of 2% on 'horizontal' surfaces to prevent flow to the interior. The Brick Institute of America (BIA) calls for 10-14% slope on brick sills.

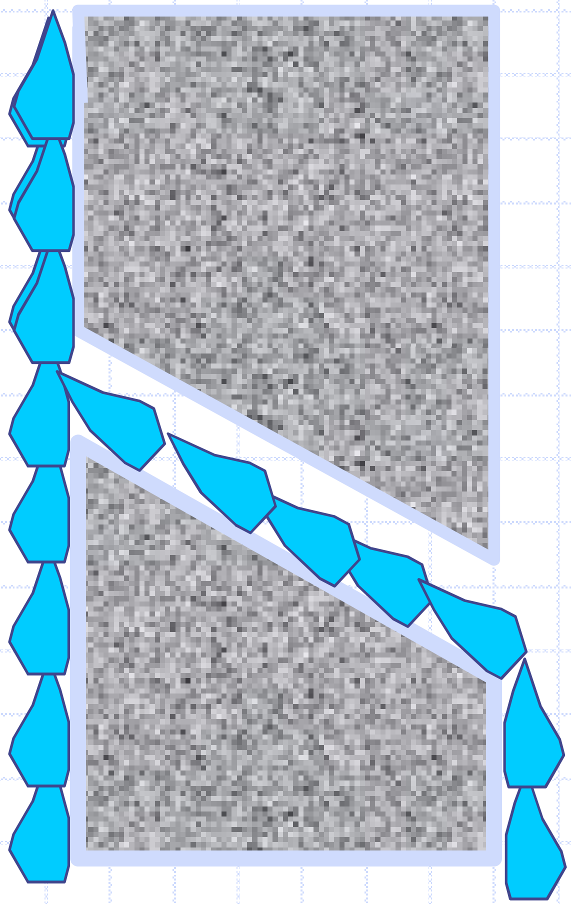
• Provide gaskets or sealants to close joints.

• Provide shielding for open joints.

• Shield openings from direct rain entry with overlapping materials, sealant, or preformed gaskets or deflectors.

• Provide practical designs to not create conditions ripe for water intrusion.

Gravity



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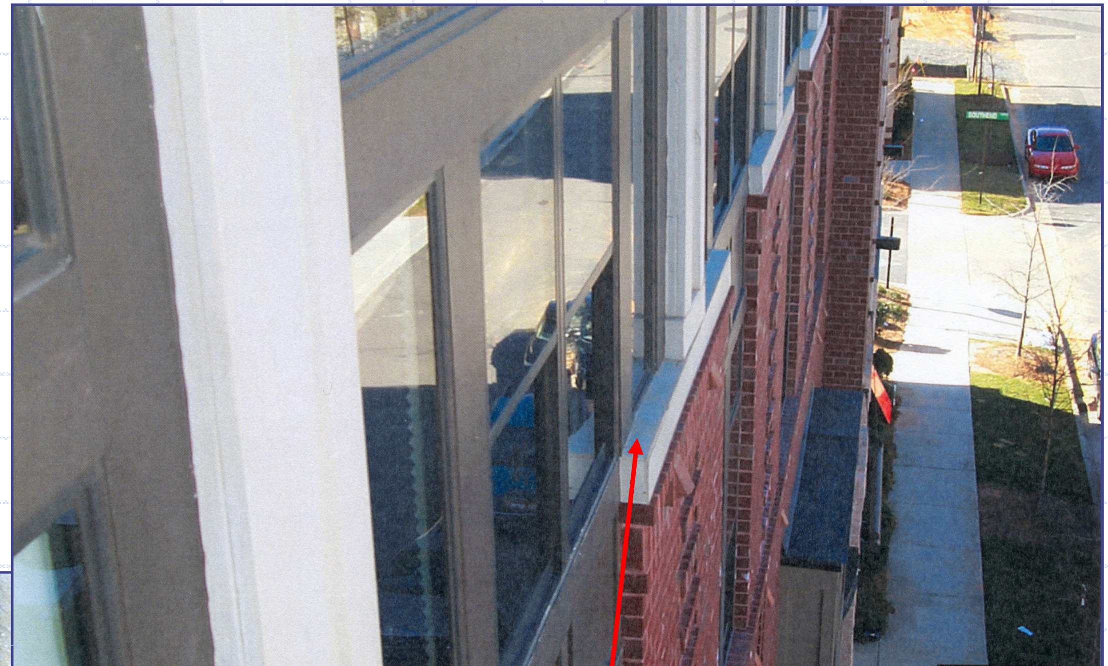
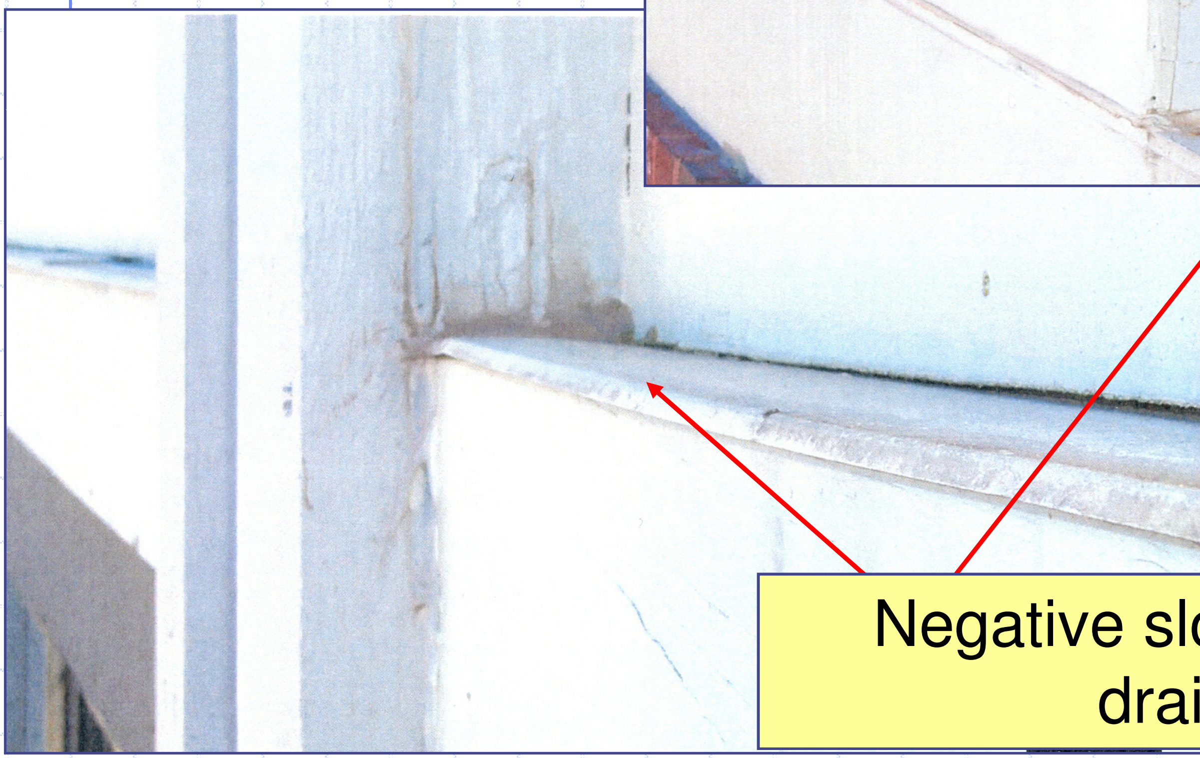
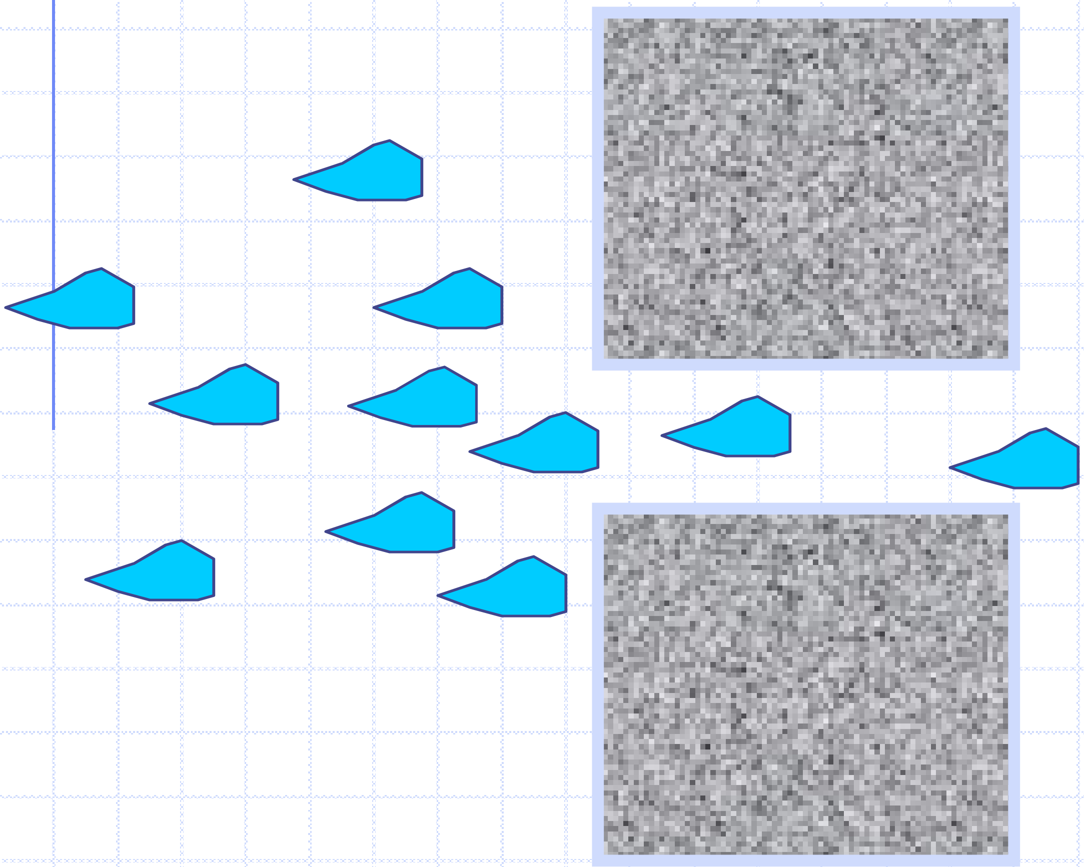


Negative slope – Gravity condition; Flat Brick Sill & failed sealant



Negative slope – Gravity drainage

Kinetic energy



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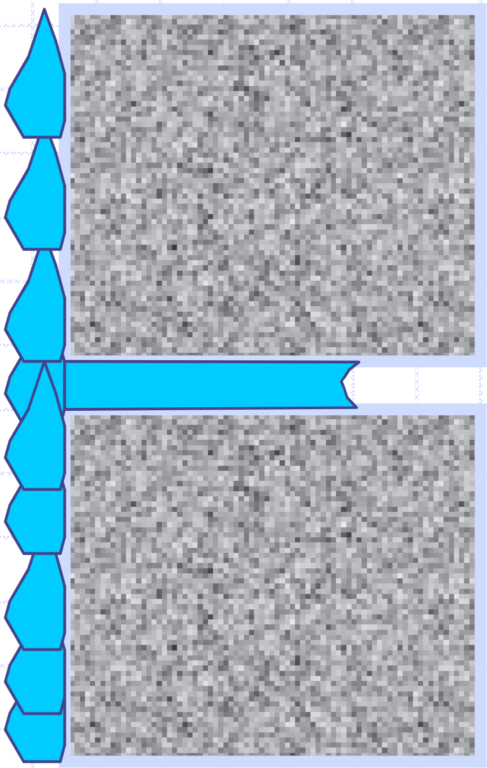
Capillary Action (suction)

- Shingle lap horizontal joints by at least 1 inch to eliminate water passage, since joints that are less than ~ **3/16** inch wide support capillary action.
- Ensure that drainage and venting holes are at least 3/8 inch wide to avoid bridging by water.
- Choose materials with properties that minimize water absorption or that have greater thickness in order to delay water transport. For example, ¾ inch thick stucco that is subject to continuous wetting will saturate in two days. Therefore, if the building location often experiences rain for this long, change the material or shield the wall with an overhang or other such device
- For a building location that often experiences rain for long periods of time , change the material or shield the wall with an overhang or other such device.

Capillary suction



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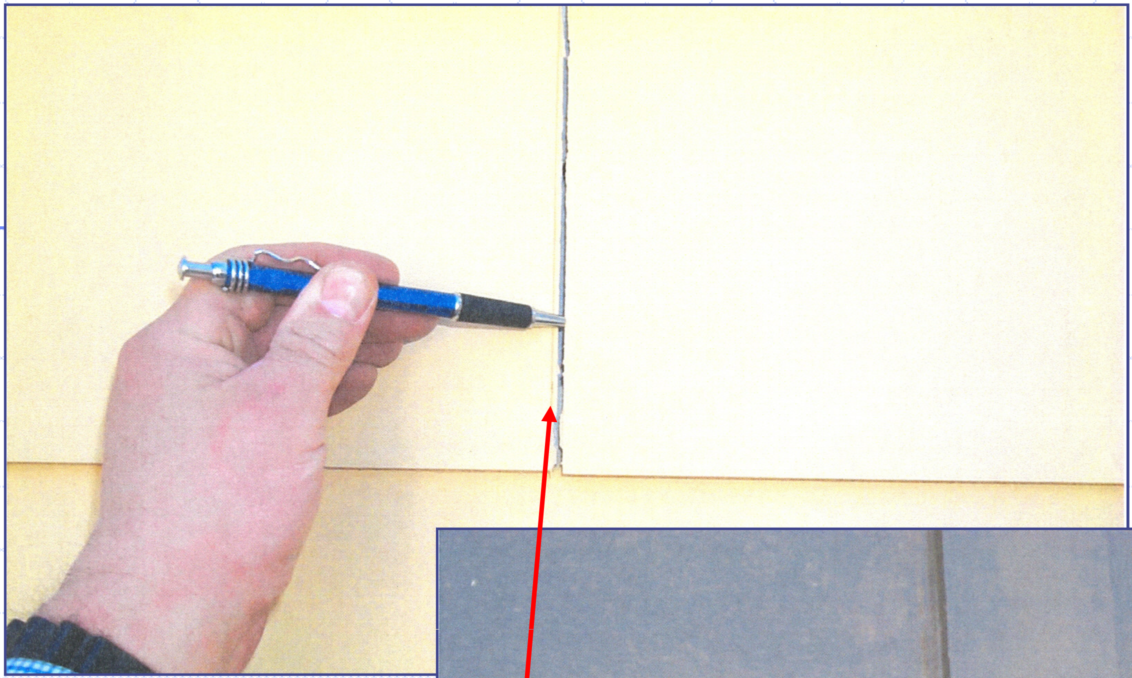
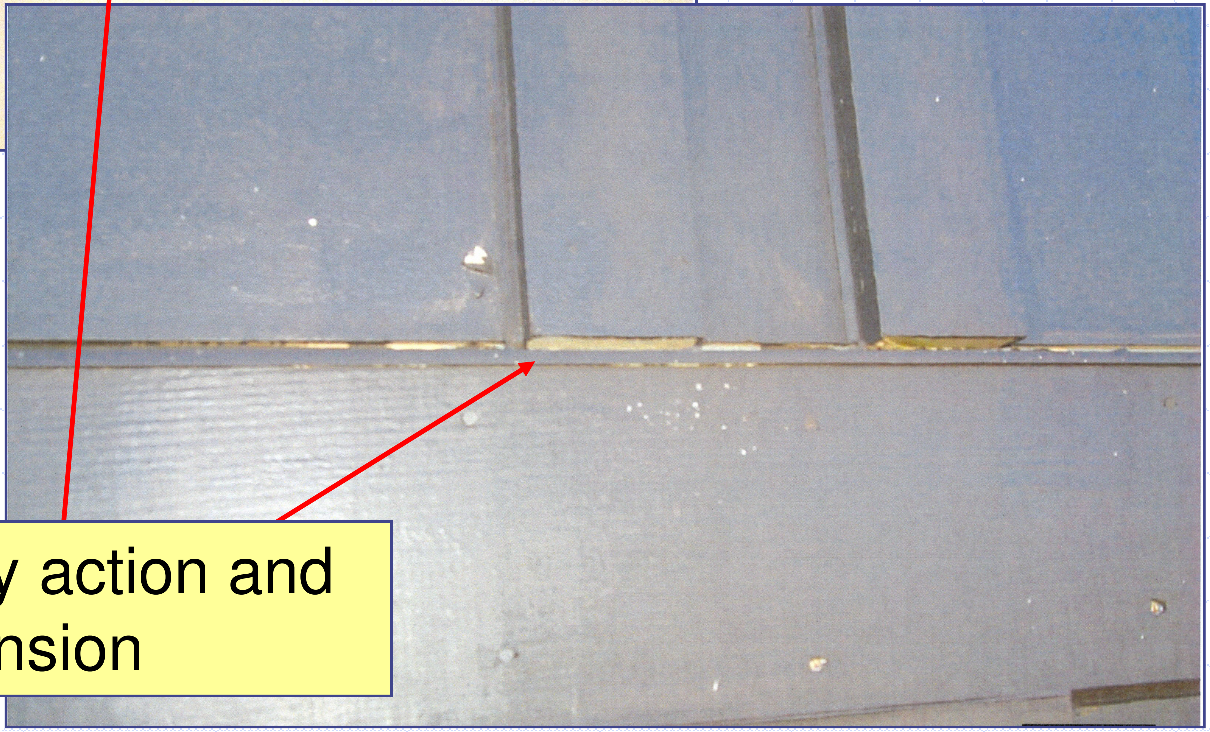
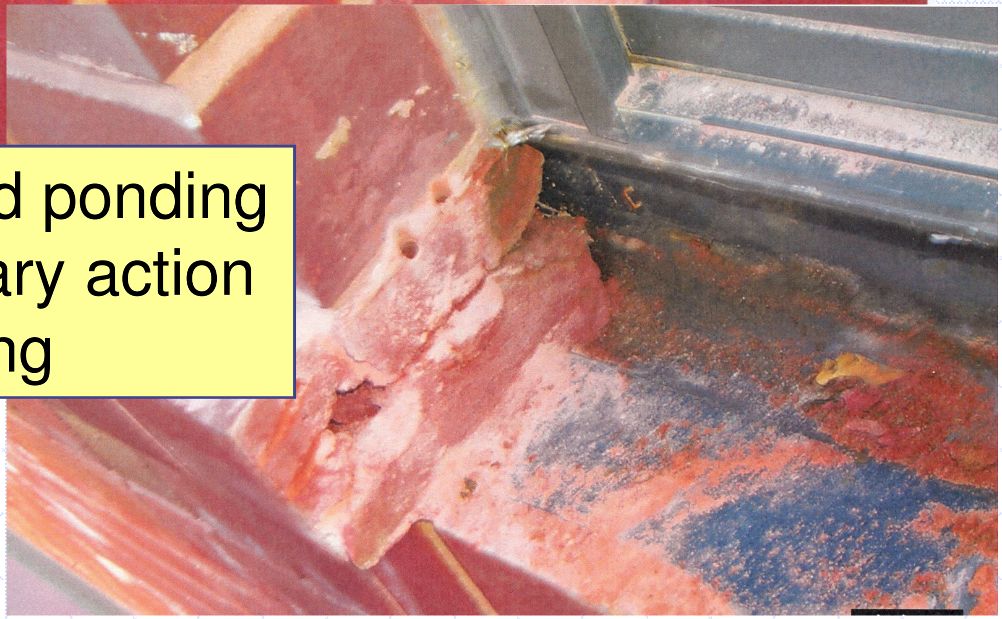




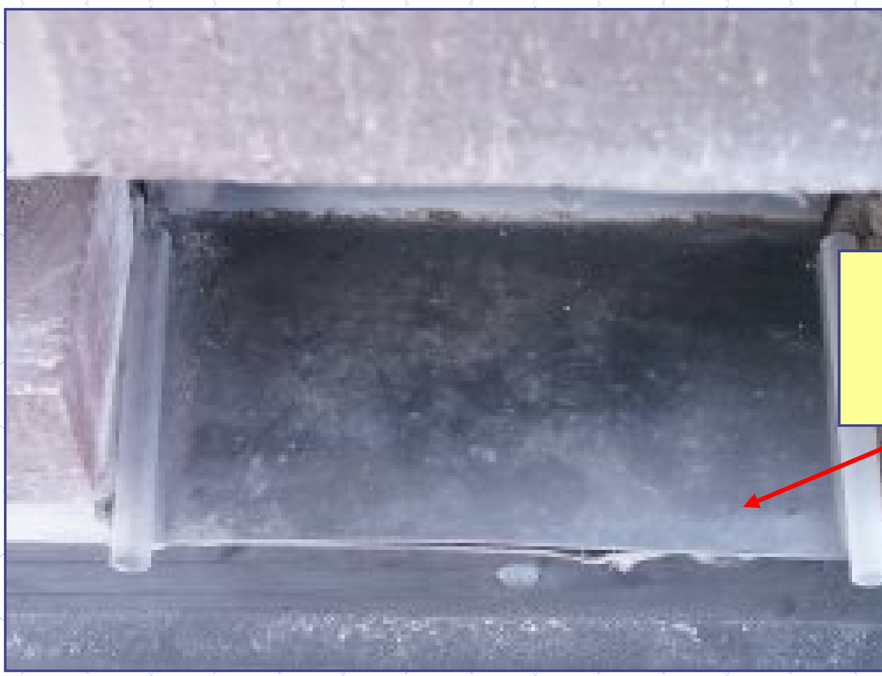
Open for capillary action and surface tension

Capillary Suction through CMU wall



Flashing too short and ponding water in back. Capillary action creating leaking

Improper Flashing & Clogged weep



Correctly installed flashing & weeps

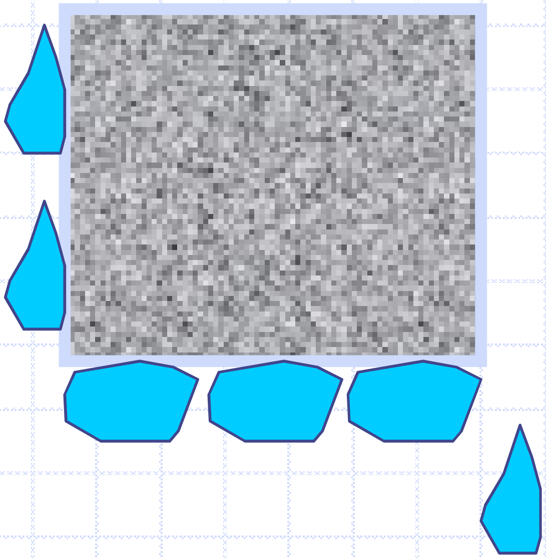
Flat sill and hole in sealant

Sealant Sill – No Weeps & through wall flashing above roof area

Surface Tension

- Incorporate a drip in the underside of projecting horizontal surfaces such as windowsills, balcony floors or soffits.
- Put a drip edge on flashing that changes the direction of the flow outward.
- Turn the sheet metal or copper flashing 180 degrees (or almost 180°) to stop and redirect water in the direction desired.

Surface tension



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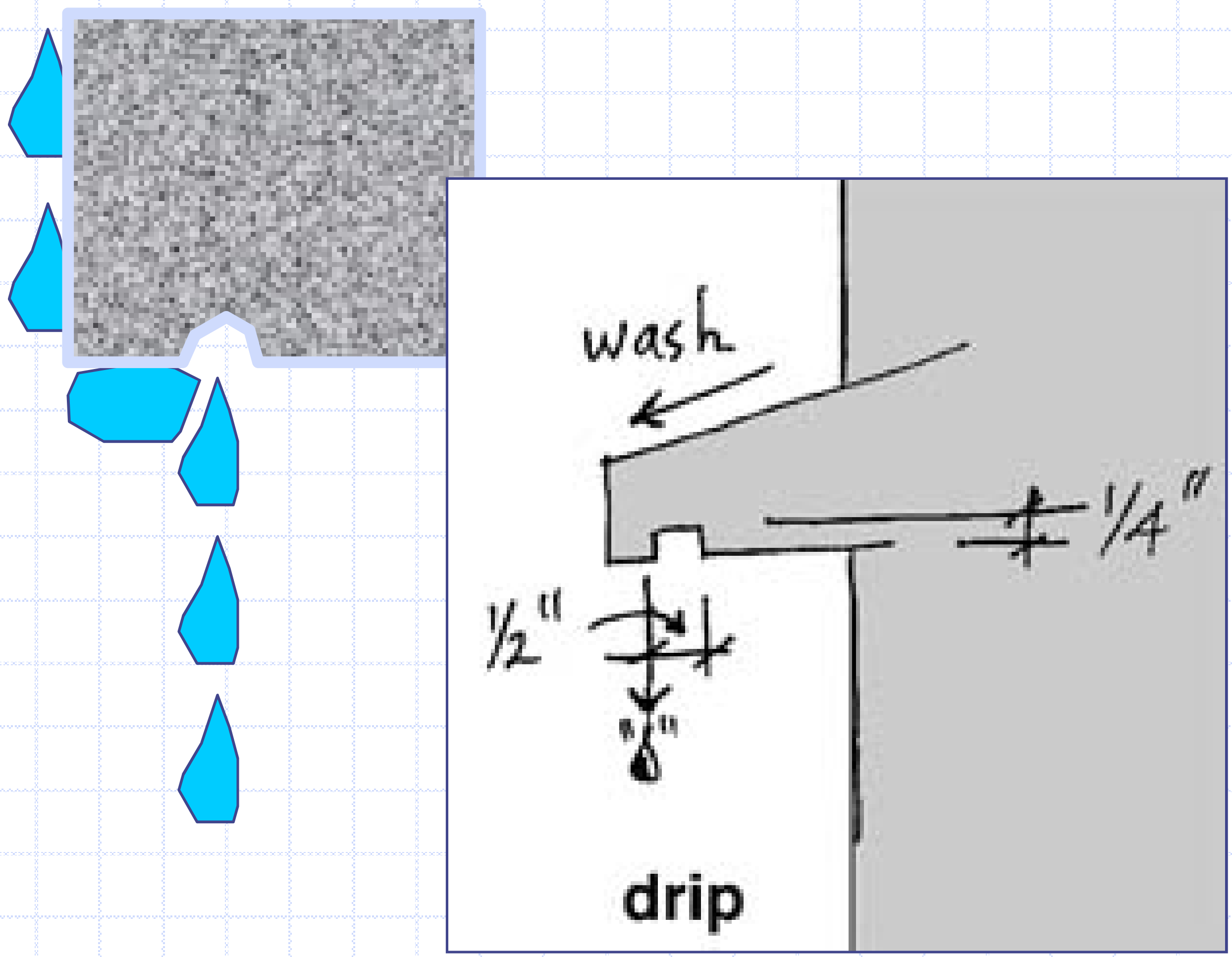
Surface tension



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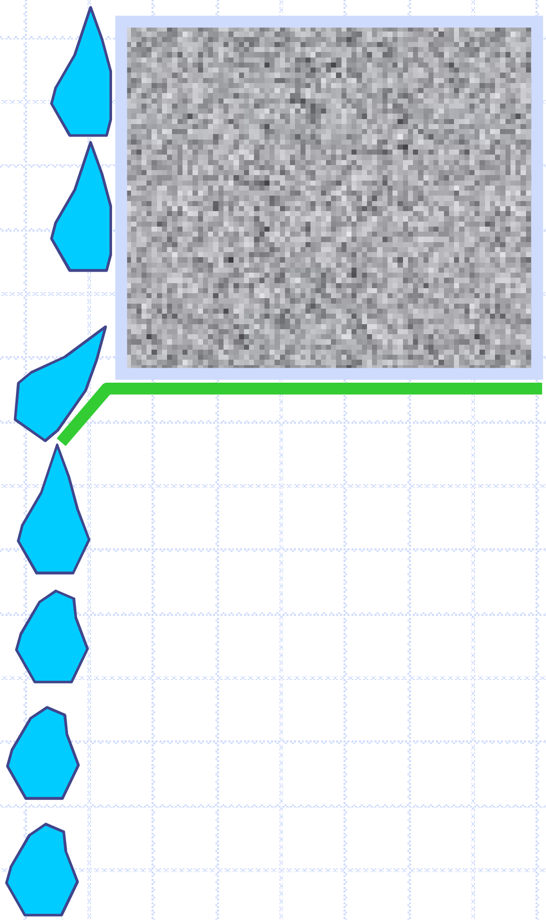
Surface tension



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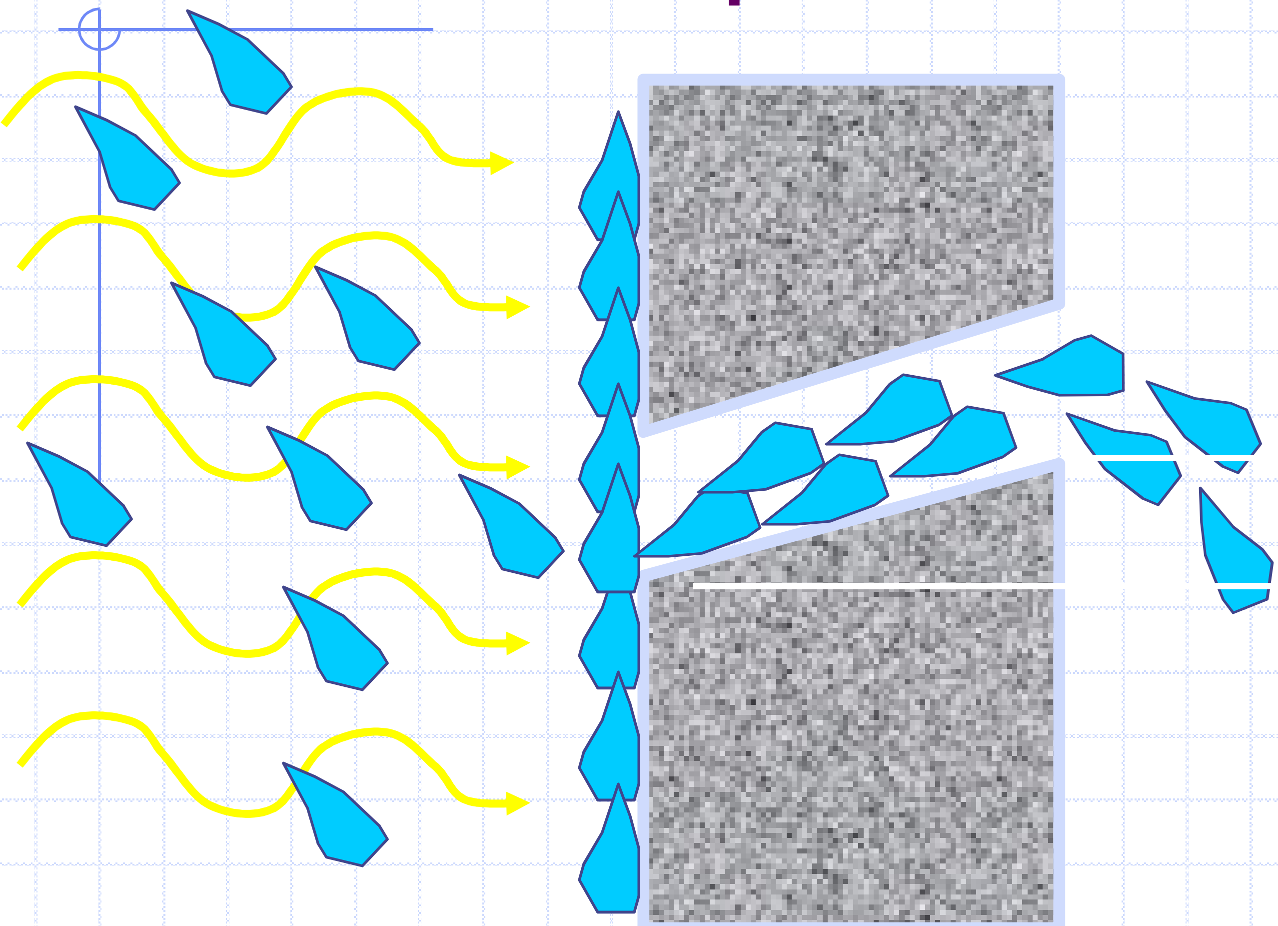
Differential Pressure Movement

- Achieve some degree of pressure equalization across the cladding, its joints and junctions. (Air pressure difference across the cladding is a function of the effectiveness of the air barrier system, the size of the venting in the cladding, the volume of the air chamber between the cladding and the air barrier, and the stiffness of the chamber.
- Maintain positive building pressure by design parameters.

Provide an adequate well constructed Water-Resistive Barrier (WRB) There are many 'house wraps' such as Tyvek, Building Paper, Typar, or No. 15 felt used to wrap the external sheathing of a building prior to the installation of the cladding.

Differential pressure



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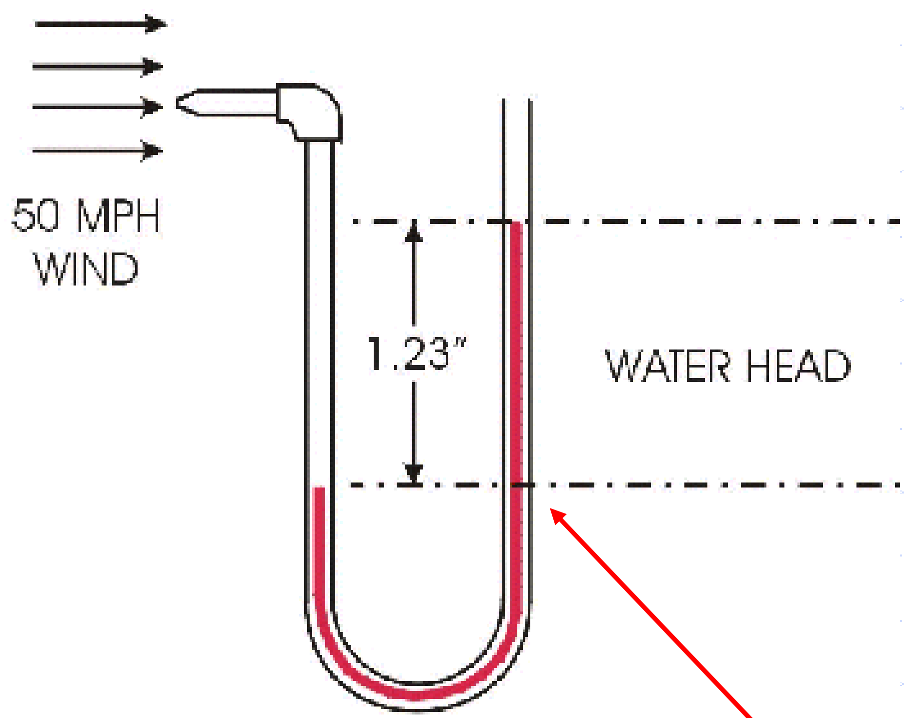
Differential pressure



Building Pressure measurements ought to be made by a Mechanical Engineer if needed

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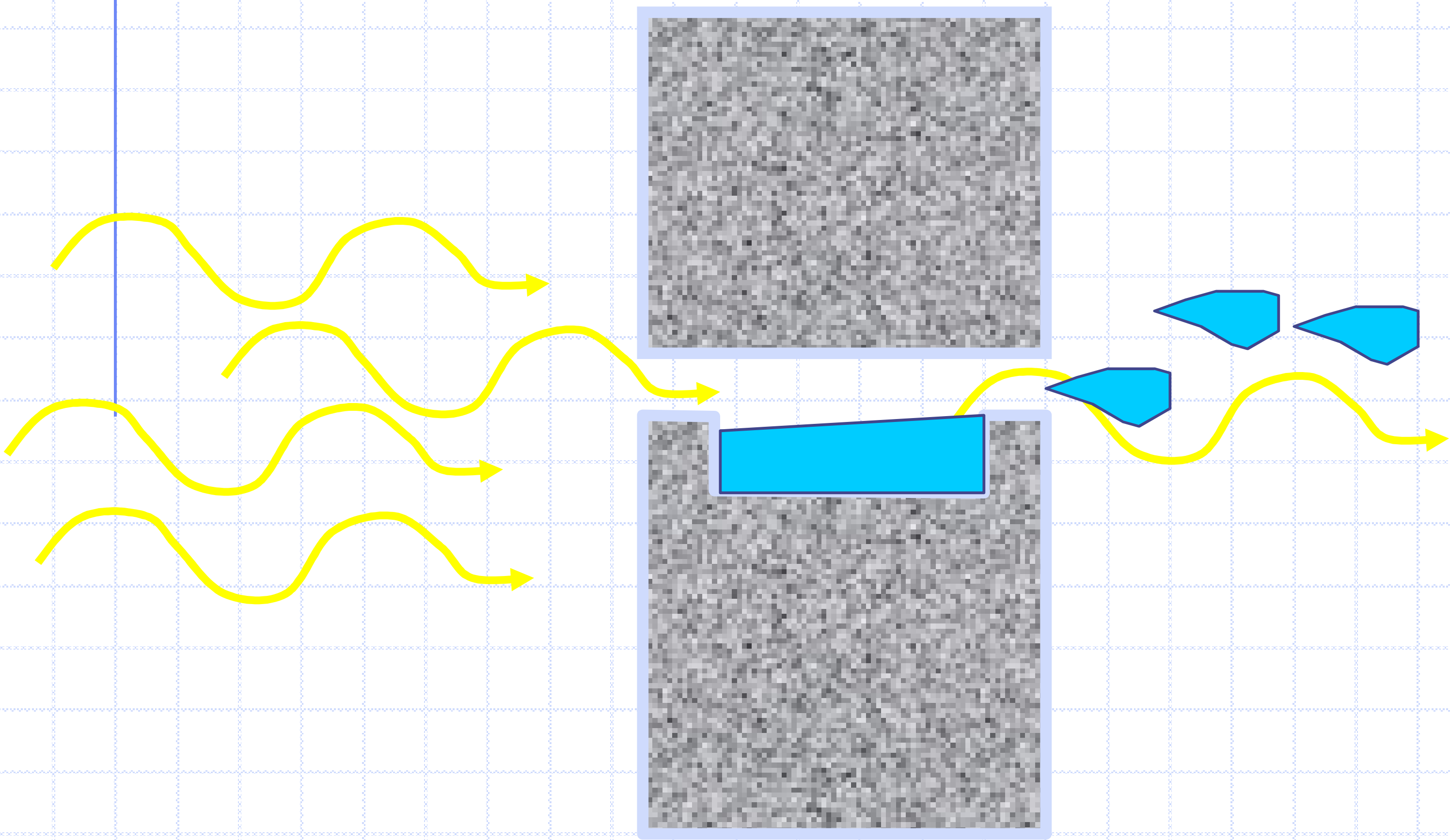
Air currents



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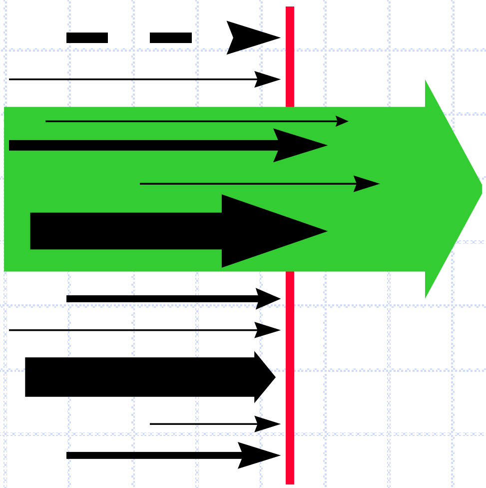
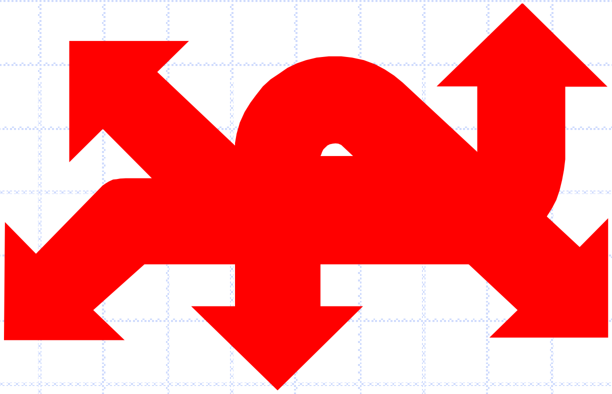
Transport Mechanisms

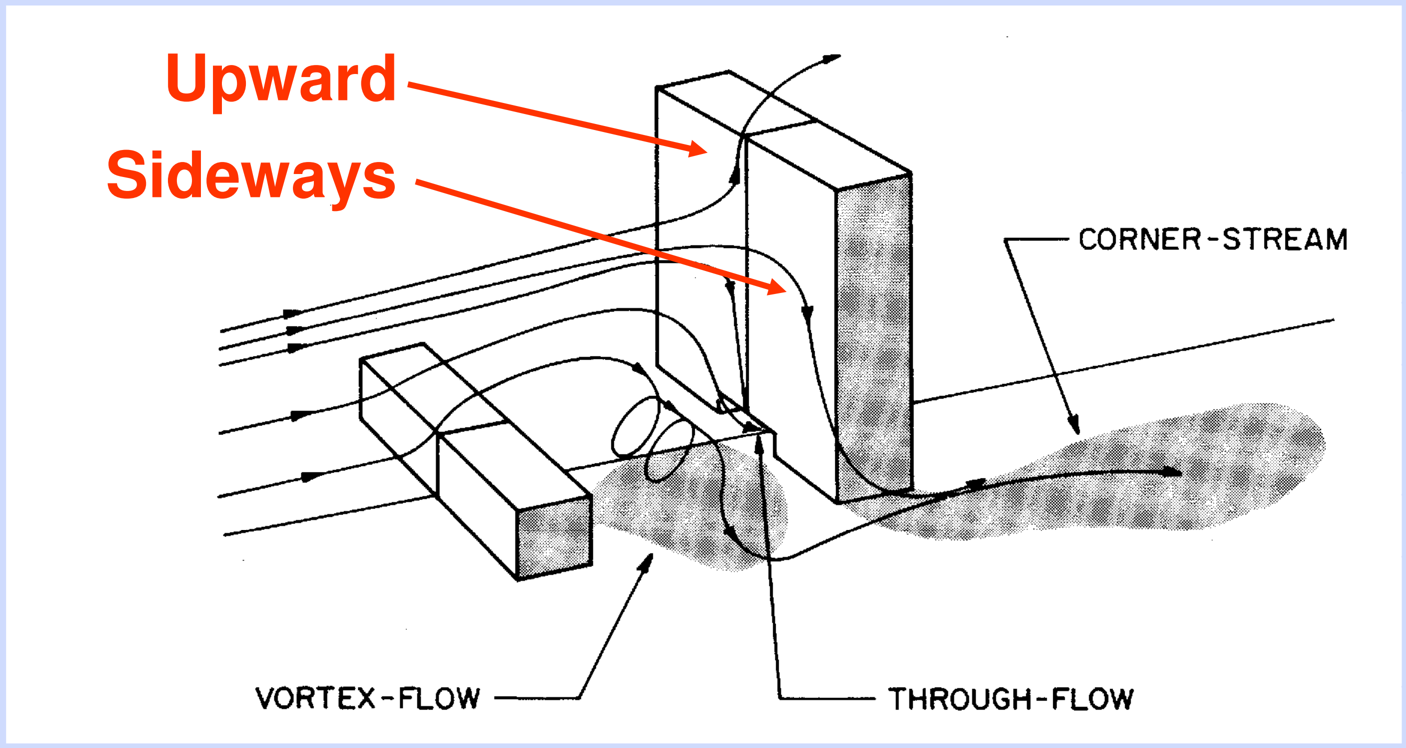
- Driving Forces



- Pathways



Wind patterns



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Vapor Movement – Through Diffusion & Air Transport

- Plan for evacuation of concentrated vapor inside of wall cavities.
- Design without vapor retarders (plastic or vinyl wall covering) on interior spaces of claddings, especially porous walls such as masonry walls that when heated allow lots of moisture through toward cooler space. The second option here is to vent cavity openings.
- Plan and calculate air and vapor movement to prevent condensation on interiors of walls and roof assemblies.
- Never create a condition where negative air pressure occurs in exterior walls from mechanical means.

Infiltration

Infiltration (leaking) of air and water into and out of buildings can cause serious building envelope problems including such things as:

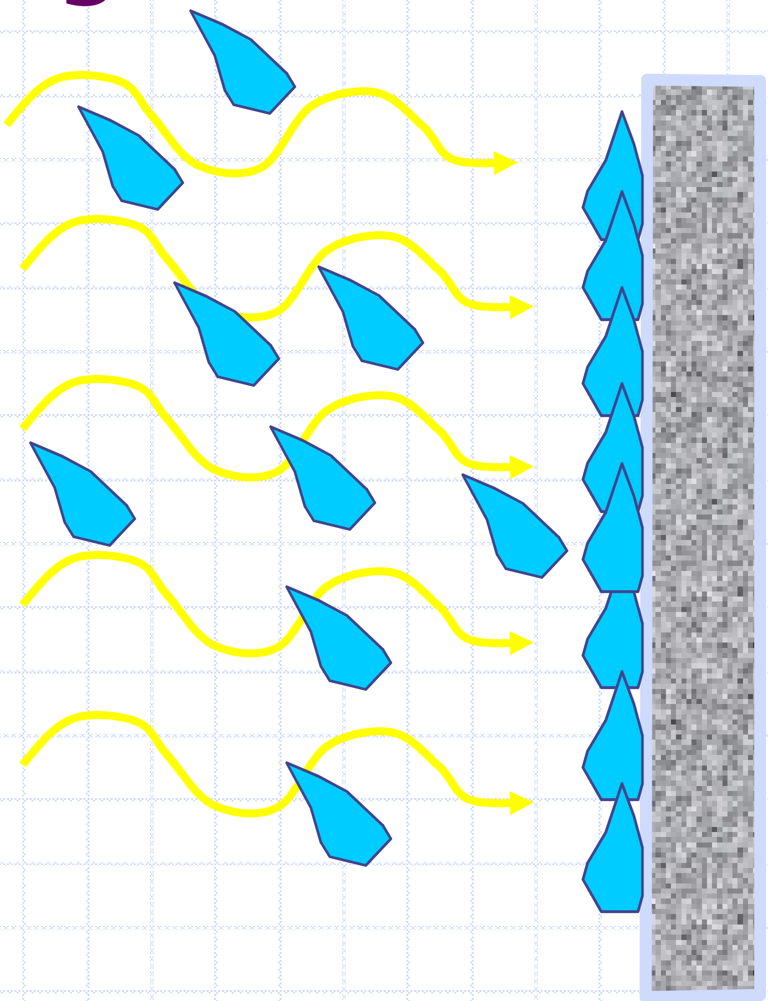
1. **Energy loss**
2. **Contamination of indoor air (where the outside air quality is poor) Mold and fungal growth; Bacteria; Disease**
3. **Drafts of air through the envelope creating heating and cooling issues**
4. **HVAC malfunction or under-functioning**
5. **Freezing pipes**
6. **Damage to building components such as framing, plaster, gypsum board, paint or wall covering; etc.**
7. **Staining, rot, frost damage; reduction of insulating capacity.**

Air Infiltration is caused by mechanisms that create differential pressure between inside and outside. It does require "holes" or openings in building, but such holes are common (gaps, tolerances, cracks, expansion, contraction, and so on, all can lead to holes). The differential pressures result from:

- wind (these are changing, unpredictable, and turbulent)
- stack effect (e.g., shafts, smoke stacks)
- convection within a space (e.g., within an exterior wall cavity)
- mechanical pressure (fans, etc.)

Water intrusion is caused by holes or openings often un-intended by contractors or as the result of design without proper consideration as to water infiltration protection.

Resisting intrusion - face seal



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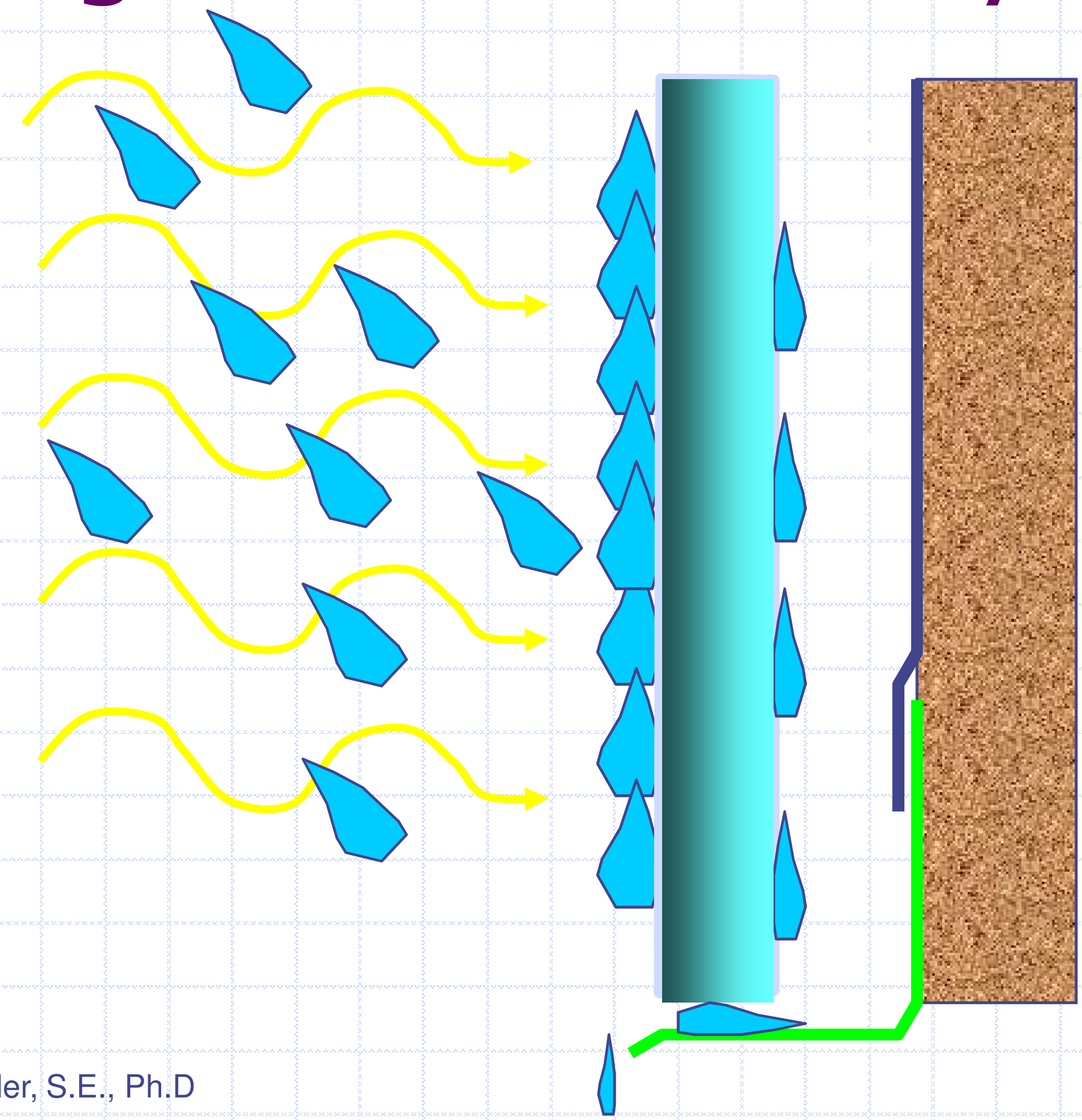
Resisting intrusion - cavity



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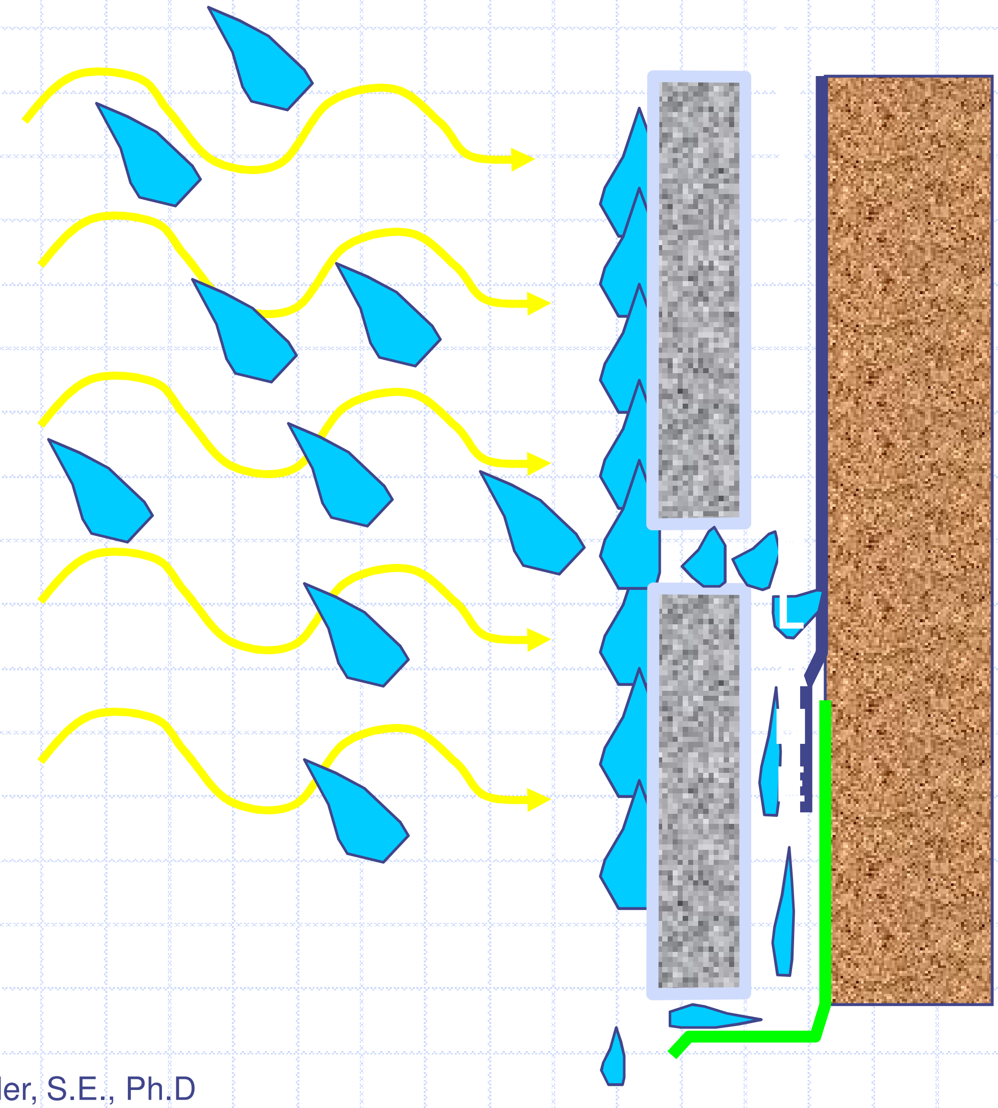
Resisting intrusion - rain screen



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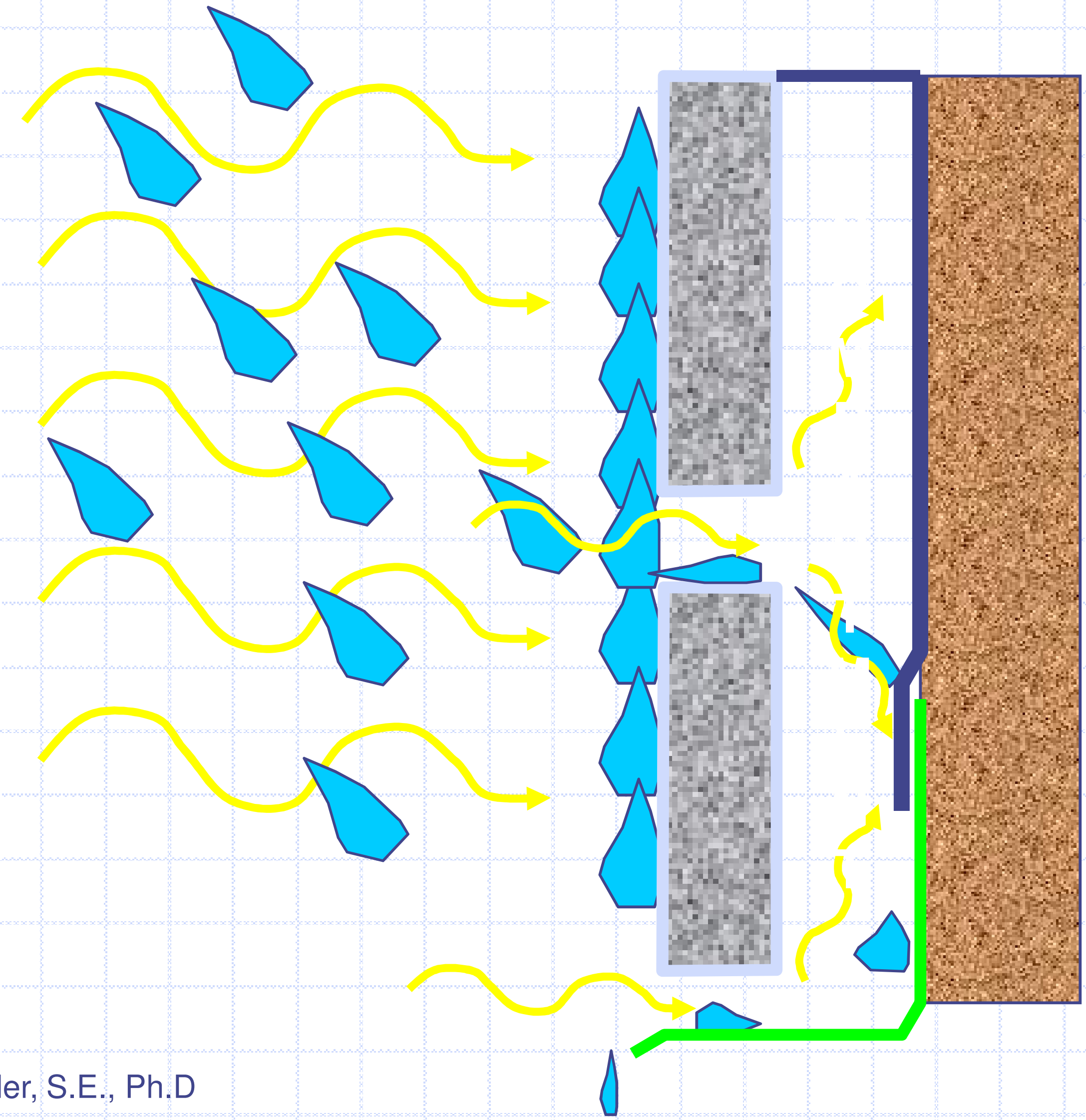
Resist intrusion – pressure equal'



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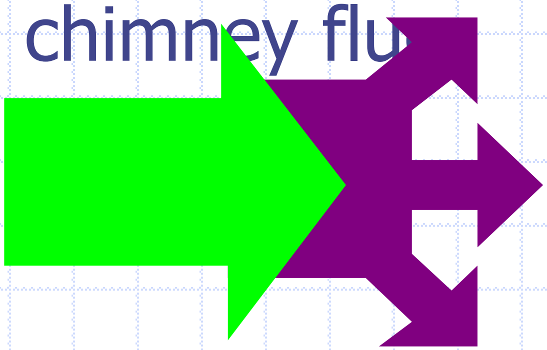
Building Leakage

- Estimated air infiltration rates for residential buildings
  - 0.1 to 1.6 air changes per hour (ach), NAHB
  - 0.2 to 2.0 ach, ASHRAE
- Wall assemblies account for 5% to 50% of building leakage, ASHRAE

NAHB – National Association of Homebuilders
ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers

Air Transport of Moisture

- Problems are caused by unplanned airflow
  - Mechanical system design
  - Utility chases and chimney flu
  - Stack effect
  - Wind effects



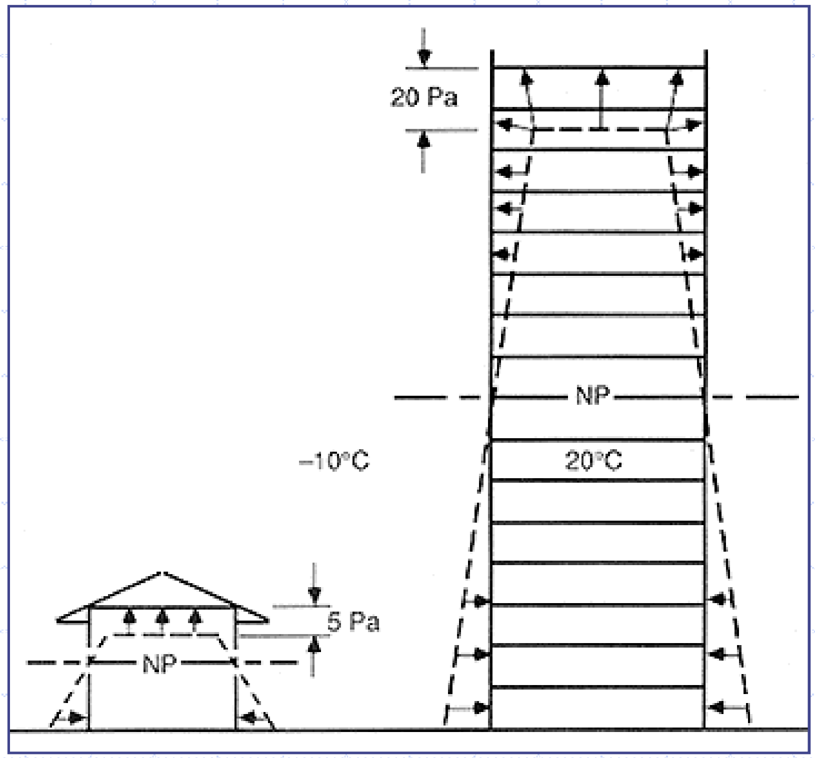
The Mechanism of Air Leakage

For air to flow in and out of a building, two conditions must be fulfilled.

1. **A hole in the envelope**
2. **An air pressure difference across the wall at that location.**

(The hole need not be directly through the wall but can follow a tortuous path inside the wall. The pressure difference, on the other hand, can result from one or more of three possible causes: stack effect, wind, and fan pressurization.)

Stack effect results from the difference in air temperature between indoor and outdoor air during the heating season. Warm air, being lighter than cold air, rises in a building, creating a suction at the base and exerting an outward pressure at the top. The higher the building, the greater the pressure difference across the walls and roof. The suction is greatest at the base, decreasing as the building rises to a neutral pressure plane somewhere between the ground floor and the roof. Above the neutral pressure plane the pressure becomes positive (active outwards) and increases with height, reaching its highest value at the roof. The quantity of air entering the building below the neutral pressure plane is equal to the quantity of air leaving the building above that level

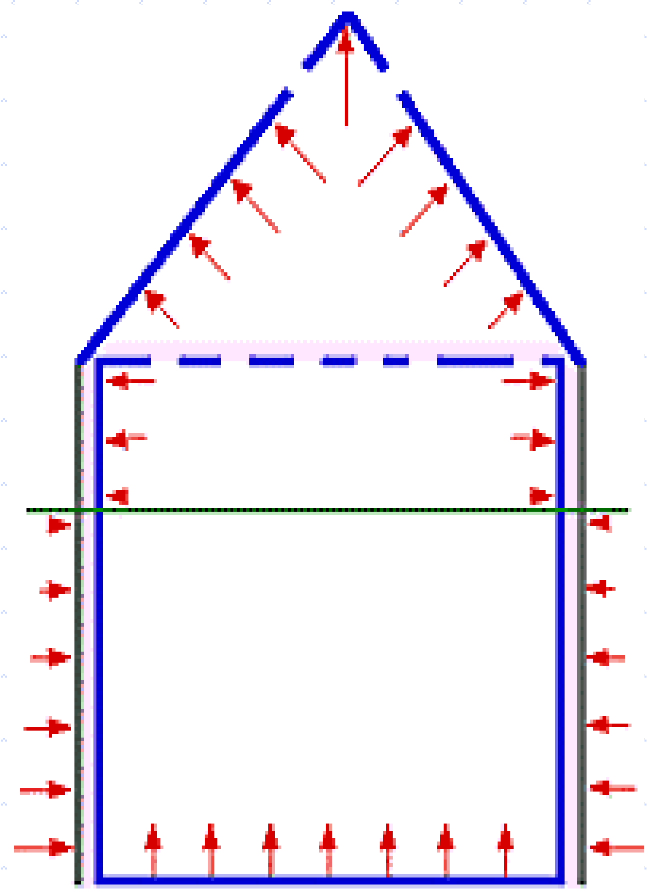


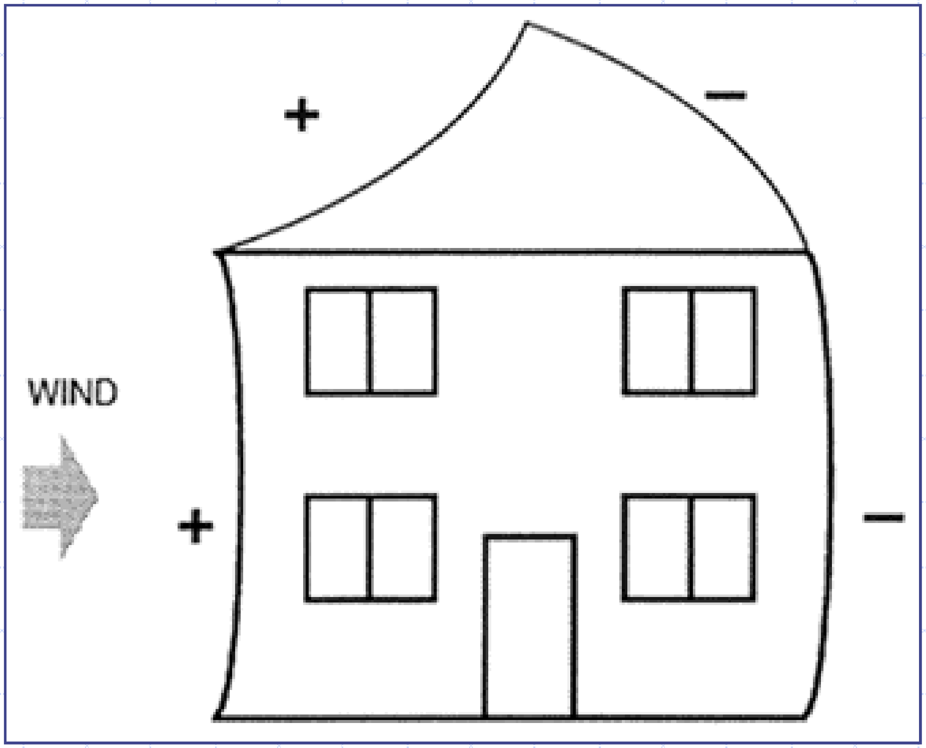
Building Pressure Differential

Stack Effect (caused by ΔT)

- In a heated building, the indoor air is buoyant and applies pressure to the envelope.

- The pressure increases with the height of the envelope.

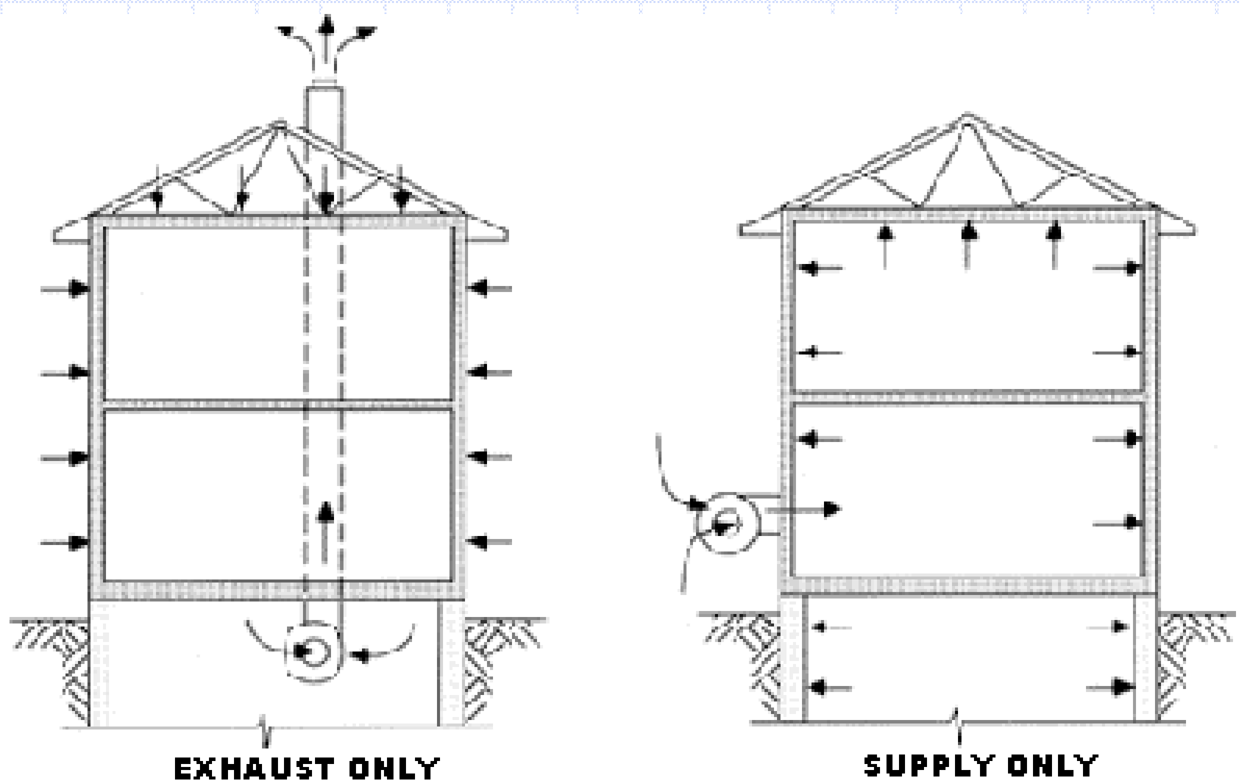




Wind, like stack effect, is a natural phenomenon. Wind increases the positive air pressure acting against a building on the windward side, and produces a negative pressure on the leeward side and on the walls parallel to the wind direction. The wind also exerts a suction on flat or low-sloped roofs and a positive pressure on the windward side of steeper sloped roofs

Since the wind in most regions of the country does not blow strongly all that often, its importance does not reside in the increased air leakage that it causes, but rather in the large pressures it can exert on those components in a building envelope that otherwise offer a high resistance to air leakage. If the difference in air pressure across a component exceeds its strength, that component may cease to be useful as an air barrier.

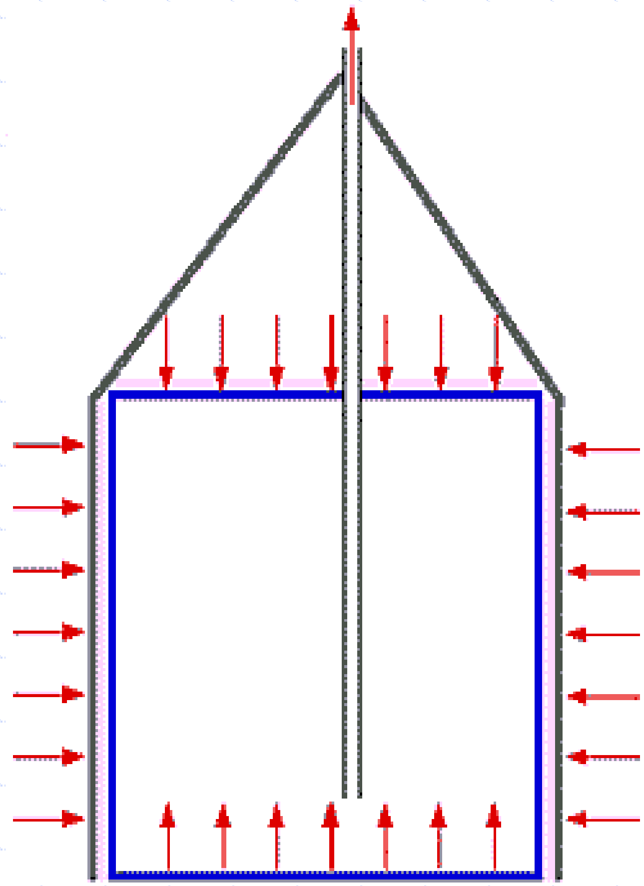
Fan pressurization. Most buildings rely on some form of ventilation system to exhaust contaminated air. This system may run continuously, or may be operated automatically or manually. Ventilation systems can be of three types: a) exhaust only, resulting in a lower air pressure inside a building relative to the outside and increased infiltration; b) supply only, raising the pressure inside a building and increasing exfiltration, and c) balanced, with both supply and exhaust being operated by fans (Figure 3). Even in a balanced system, the amount of air supplied may be increased or decreased relative to the amount being exhausted, increasing or decreasing the inside pressure accordingly.



Building Pressure Differential

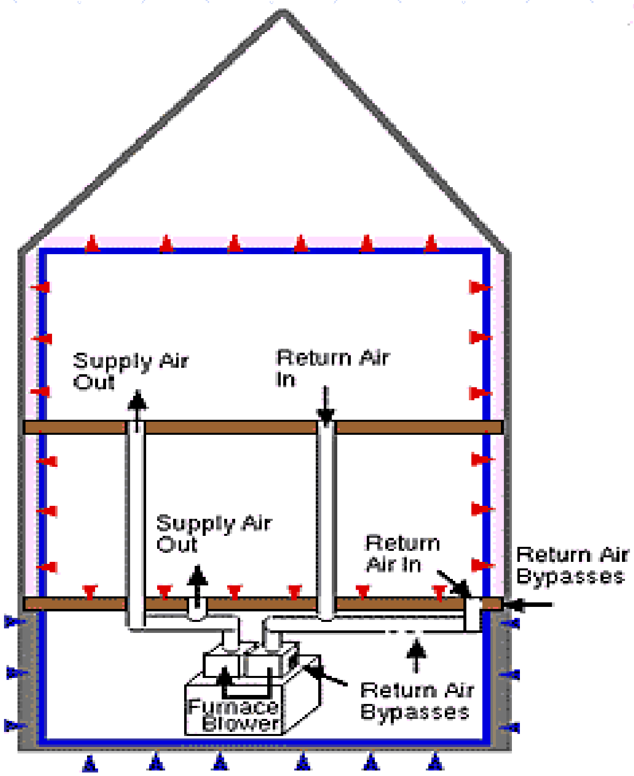
Mechanical Systems

- Exhaust Effect
  - Mechanical blower
  - Combustion flue
  - Pressurized hole

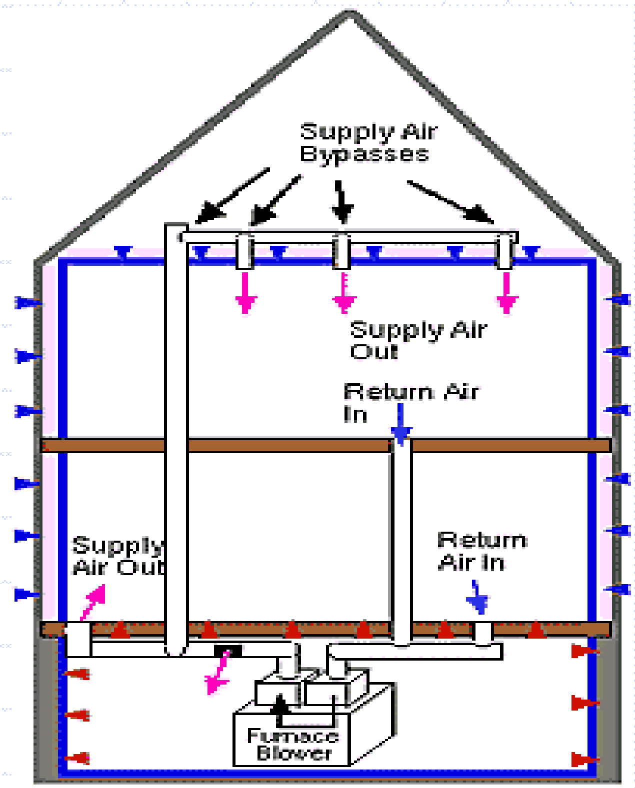


Building Pressure Differential

Mechanical Systems



Leaky Supply System



Vapor Diffusion

Moisture moves from an area of higher vapor pressure to and area of lower vapor pressure

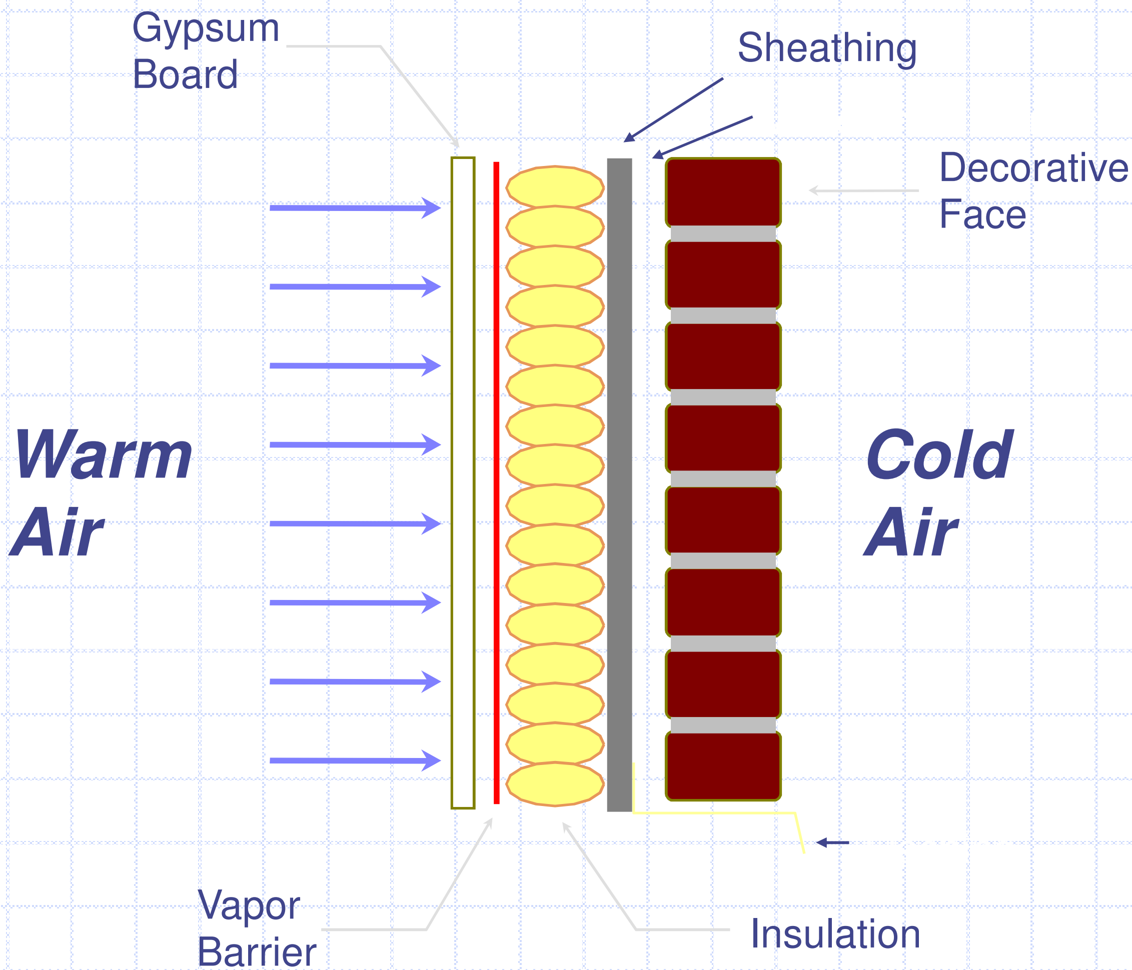
Moisture

moves from warm to cold

Lstiburek Climate Zones

Vapor Diffusion Control

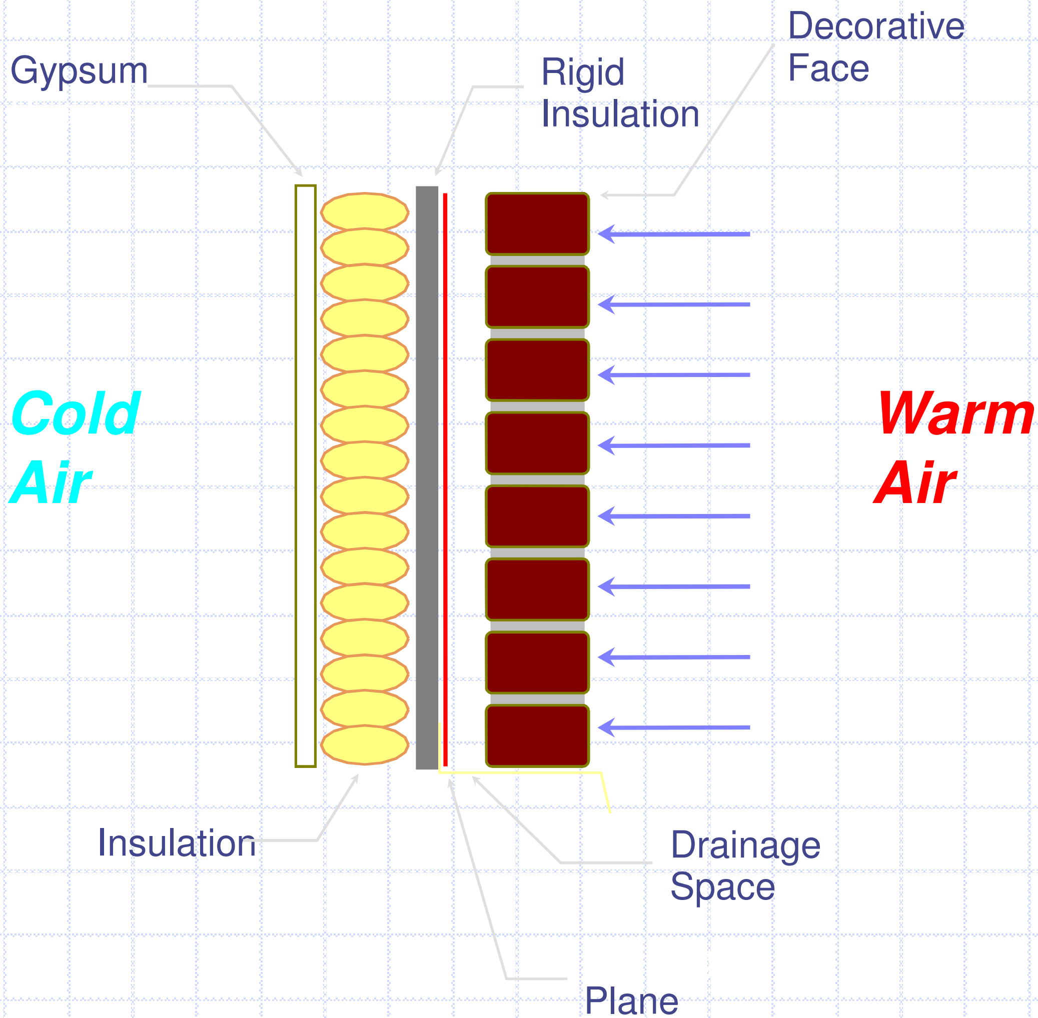
Building Envelope, Cold Climates



Lstiburek, 1997

Vapor Diffusion Control

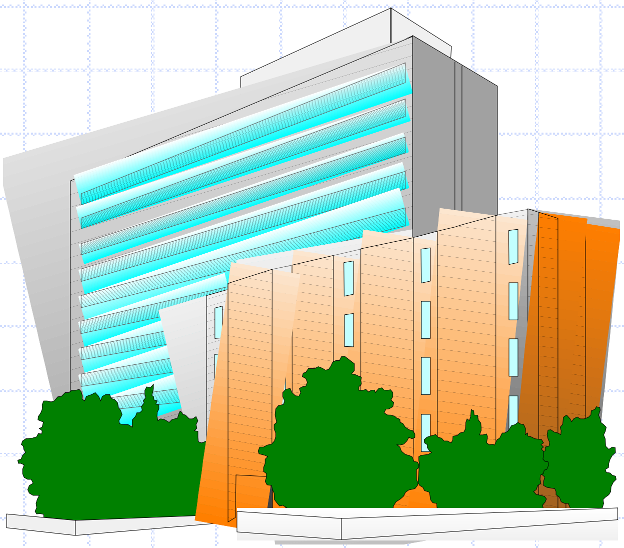
Building Envelope, Hot Climates



Lstiburek, 1997

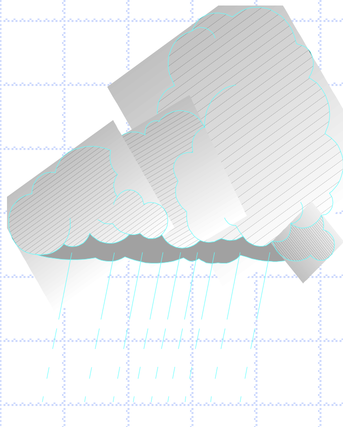
Moisture Entry by Air Leakage and Vapor Diffusion

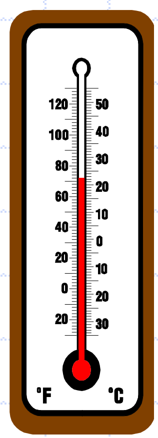
- These processes move moisture through the building envelope as a vapor



Psychrometric Properties of Air

- Air
- Water
- Temperature





- Absolute humidity
- Relative humidity
- Vapor pressure
- Dew point

Psychrometric Properties of Air

- Moisture content

$$MC = \frac{\#\ \text{water vapor}}{\#\ \text{dry air}}$$

- Relative humidity

$$RH = \frac{\text{Amount of moisture in air}}{\text{Max amount of moisture in air at } T_s}$$

- Vapor pressure

P_v= Partial pressure of water vapor at T_s

- Dew point

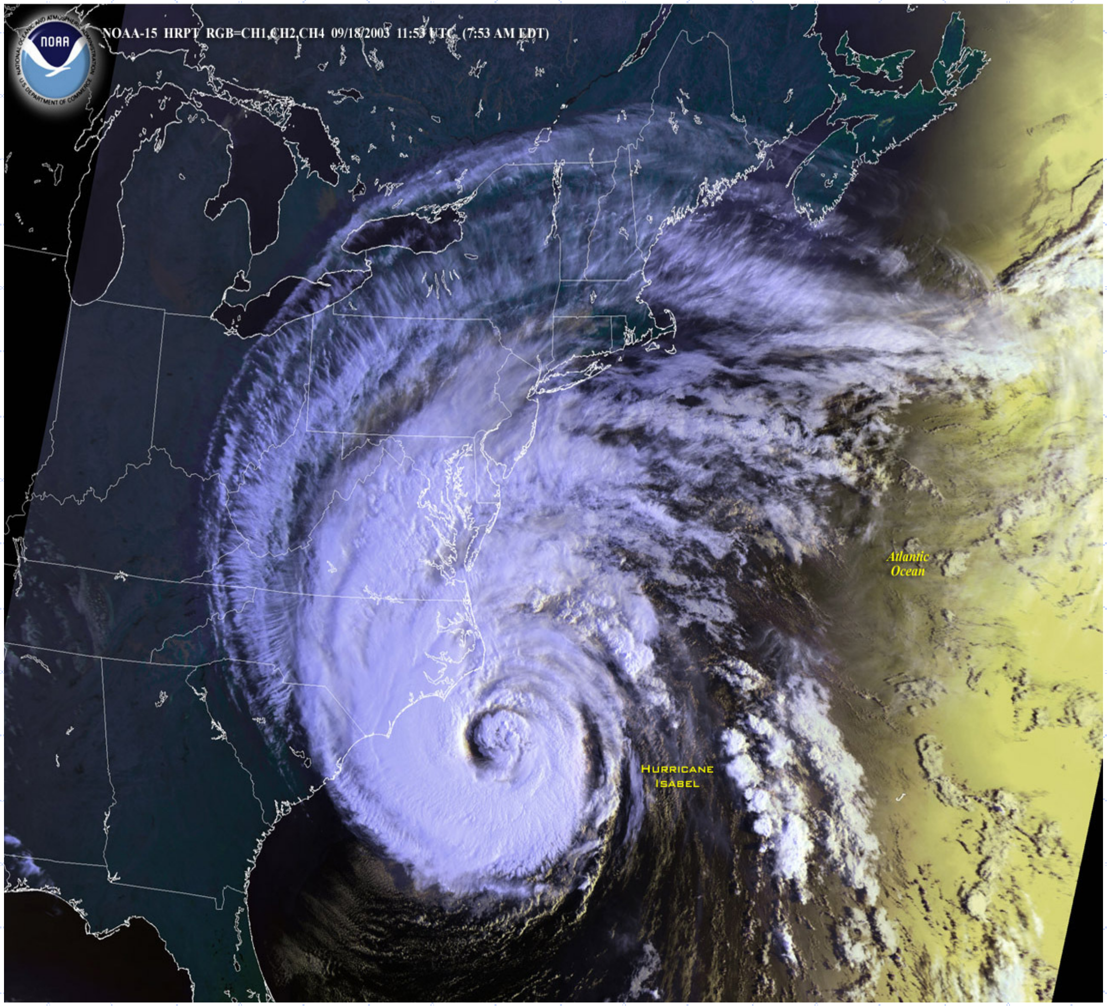
T_D=Temperature at which the RH is 100%

Relative Humidity

- CONCEPT #1

  If you add or remove moisture to air that is kept at a constant temperature, you will increase or decrease the relative humidity of the air.

Outdoor Sources of Moisture



Indoor Sources of Moisture

- Bathing/Showering
  - 0.5 liters per day per person
- Plants
- Cooking
  - 0.9 to 3 liters per day (dinner for four)
- Un-vented clothes dryer
- Humidifier
  - 2 to >20 liters per day

Controlling Indoor Sources of Moisture

- Source control
  - Kitchen range exhaust to the outside
  - Bathroom exhaust to the outside
  - Clothes dryer exhaust to the outside
  - Control humidifiers
- Basement dehumidification

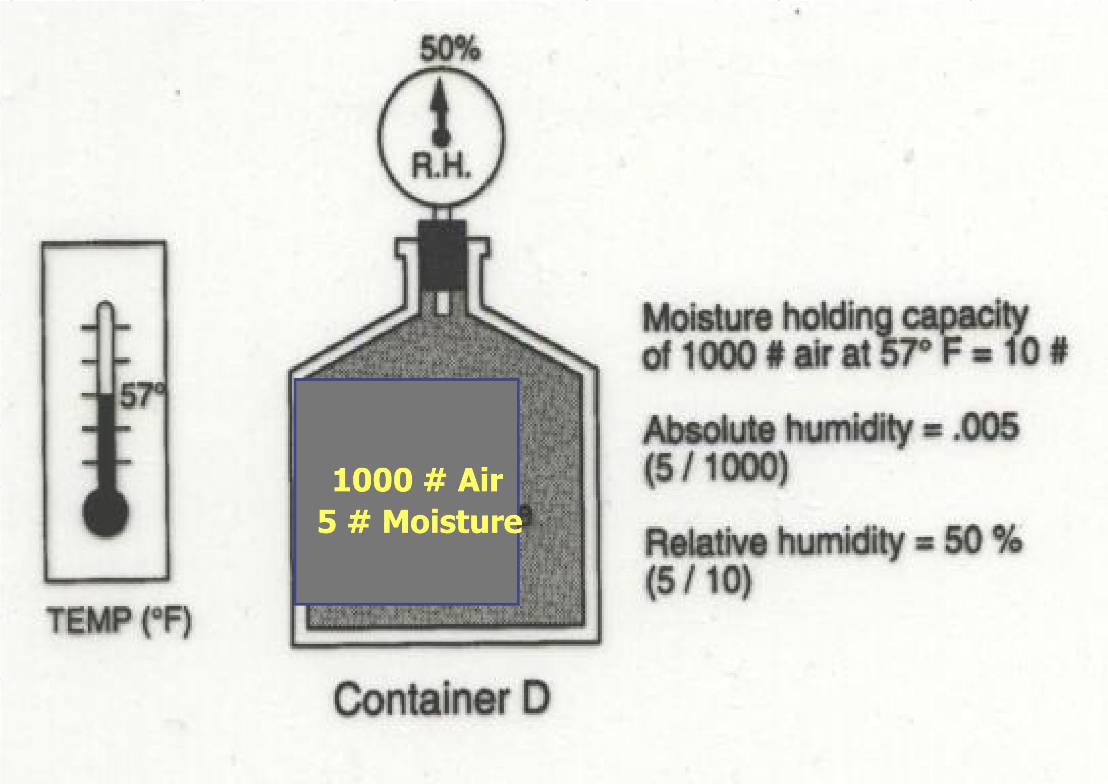
Relative Humidity

- CONCEPT #2

  If you raise or lower the temperature of air and keep the amount of moisture constant, you will increase or decrease the relative humidity of the air.

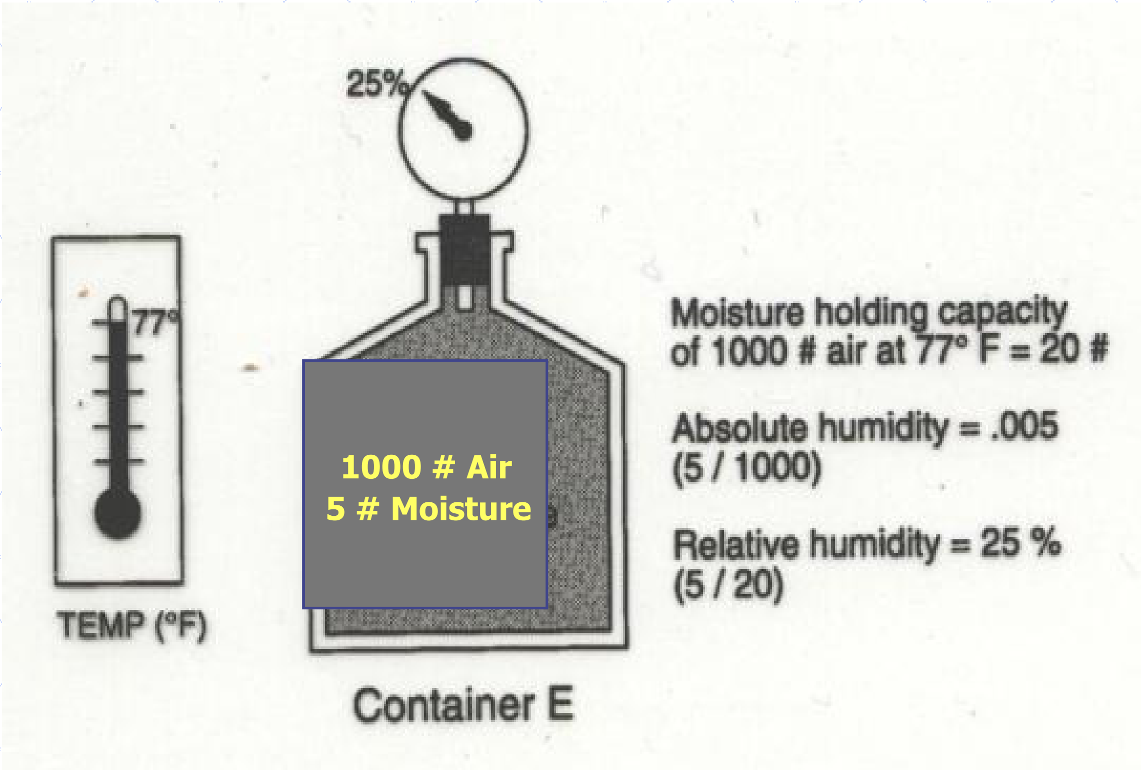
Relative Humidity

Constant moisture



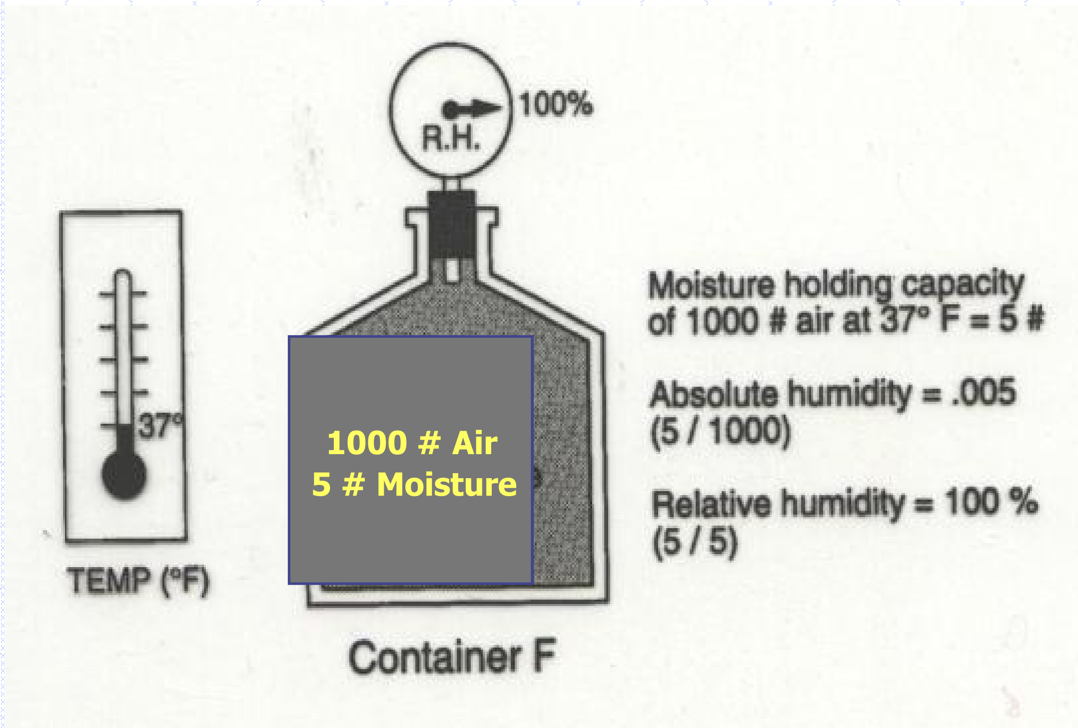
Relative Humidity

Constant moisture



Relative Humidity

Constant moisture



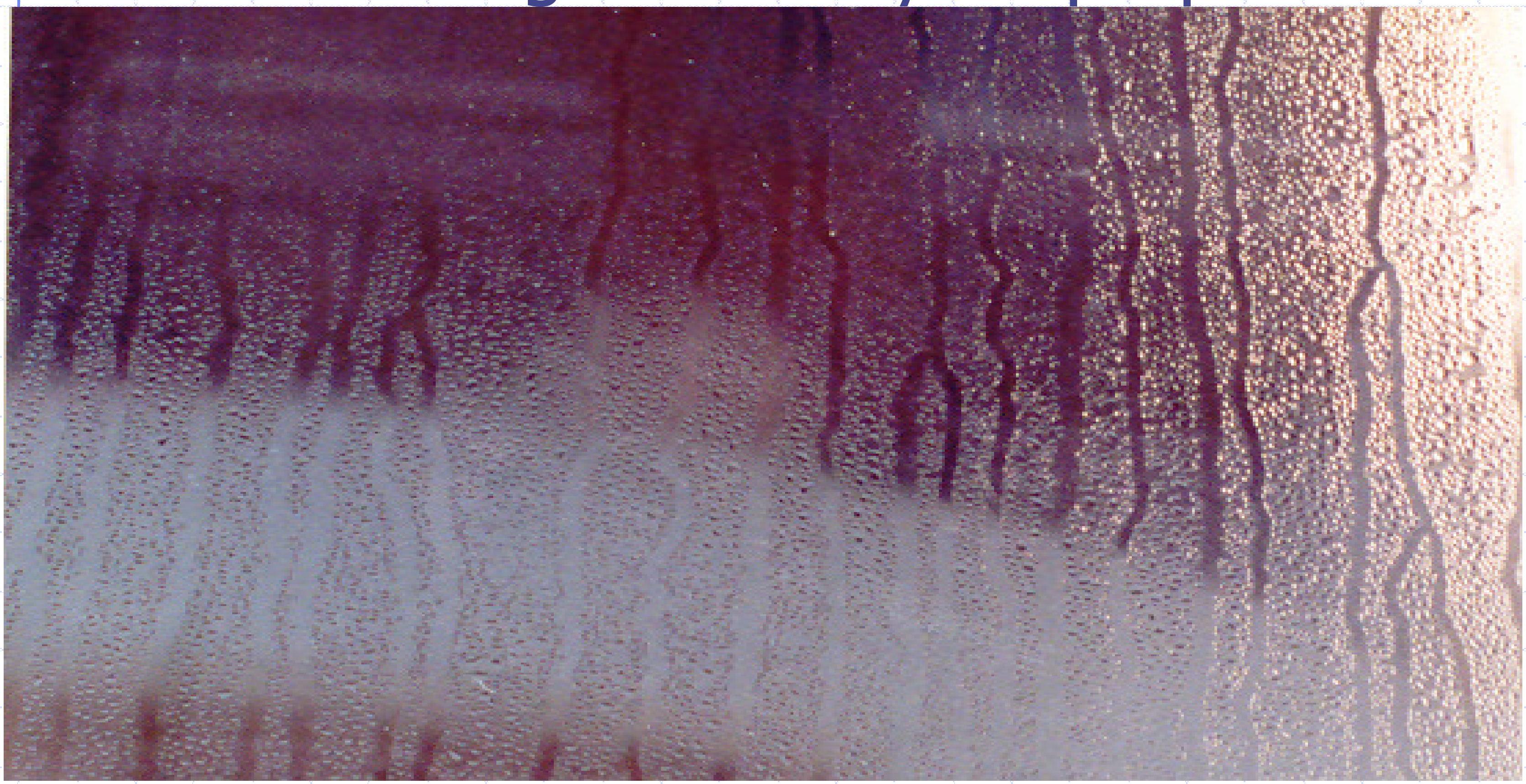
Why are Psychrometrics Important?

Moisture behavior in a room or the building envelope is controlled by surface temperatures

First Condensing Surface

Hot vs. Cold = Condensation

Insulated glass a 12 year proposition



Water Vapor Transmission

Water vapor transmission is the amount of water vapor passing through a given area such as a wall in a given time, when the area is maintained at a constant temperature and when its faces are exposed to certain different relative humilities. The result is usually expressed as grams per 24 hours per square meter ($g/24\ hr \cdot m^2$).

The amount of moisture entering a building through the Building Envelope System due to vapor migration depends on the vapor pressure differential (ΔP) and the perm rating of the materials it must pass through.

This value is known as the Water Vapor Transmission Rate (WVTR). The calculation is simple:

$$WVTR = A \times T \times \Delta P \times perms$$

A = Area in sq. ft.

T = Time in hours

ΔP = difference in vapor pressure between inside and outside measured in inches of mercury (in Hg)

1 perm = 1 grain of water/1 sf of material / hr at a ΔP of 1 in. Hg

1 psi = 2.0434 in Hg (68° F)

[Permeance is a measurement of the ability of a material to retard the diffusion of water vapor at 73.4°F (23°C) in response to an applied vapor pressure gradient. A perm (a permeance measurement unit) is the number of grains of water vapor that pass through a square foot of material per hour at a differential vapor pressure equal to one inch of mercury.]

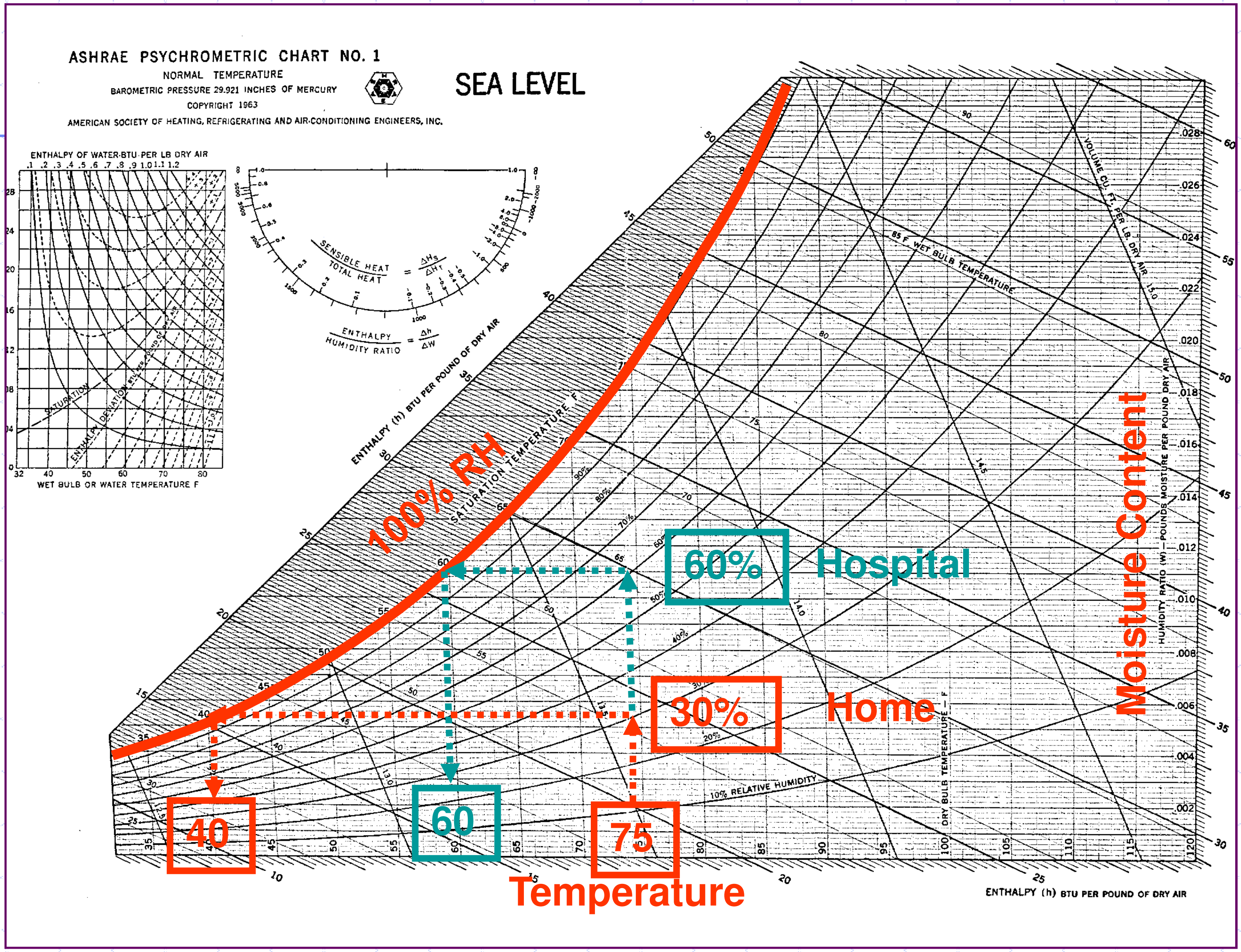
Hygrothermics

Besides the thermal properties of a building component and their impact on heating losses, a buildings hygric or moisture behavior should also be considered as part of building investigation problems if other sources are not found.

In addition, thermal and hygric behavior of a building component are often closely interrelated. With increased moisture there is often heat losses. The thermal situation affects moisture transport. Therefore, both have to be investigated together in their mutual interdependence; the research field of hygrothermics is dealing with these problems. Infrared Thermography only shows differences in temperature, but these may be signs of water problems.

In previous decades the Dew-Point method (Glaser method) as detailed in ASHRAE has been a common method to assess the moisture balance of a building component by considering vapor diffusion transport in its interior. [*ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers. Recognized authority that publishes a handbook that contains basic principles and essential fluid flow and heat transfer engineering data.*]

This method does not allow for the capillary moisture transport in the component parts of the area, nor for its sorption capacity, both of which reduce the risk of damage in case of condensation. Furthermore, since the method only considers conditions that do not change (or steady-state transport of water vapor) with heavily simplified fixed conditions, it cannot replicate individual short-term events or allow for driven rain and solar radiation effects. It is meant to provide only a general picture of the hygrothermal movement and possible suitability of a envelope system. It does not to produce realistic heat and moisture conditions in a system exposed to the weather prevailing at a particular location and building design factors.



Air at 75º F and 30% RH = 40º F   Air at 75º F and 60% RH

The newest method of calculating vapor transmission is WUFI®. The menu-driven PC program WUFI-ORNL/IBP developed by the Fraunhofer-Institute fÜr Bauphysik (IBP) and Oak Ridge National Laboratory (ORNL). It has been validated using data derived from outdoor and laboratory tests. It allows realistic calculation of the transient hygrothermal behavior of multi-layer building components exposed to natural climate conditions.

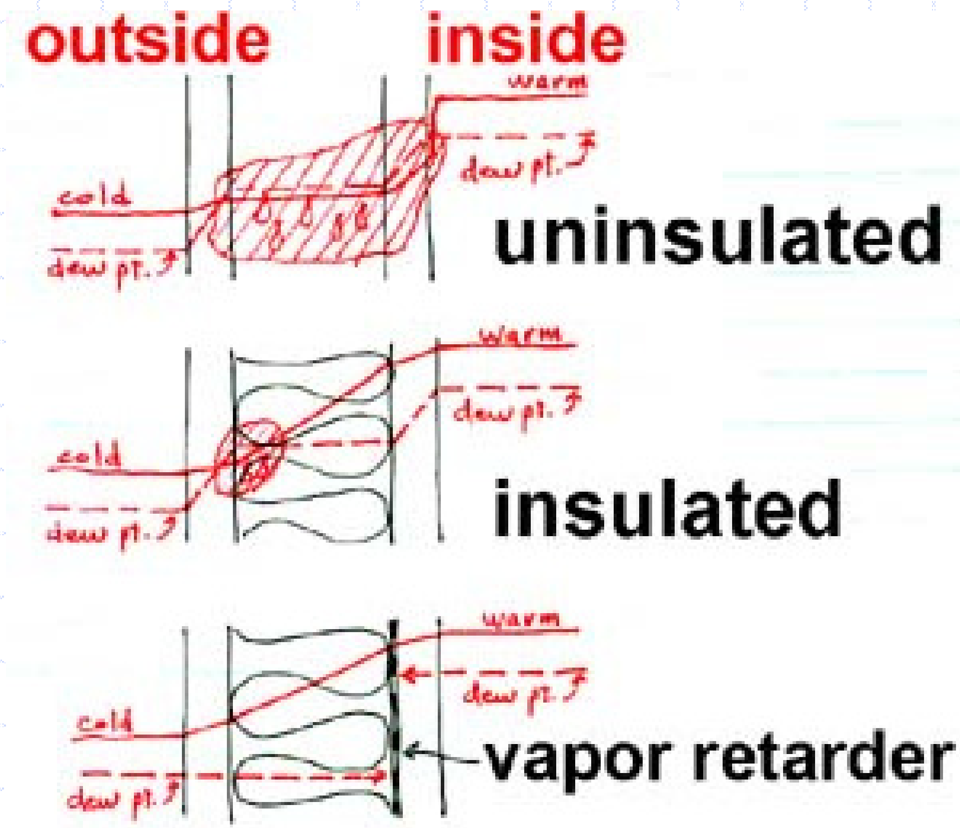
Modeling workshops are held around the county and often hosted by the U.S. Department of Energy. For information go to www.section08.com.

Although, hygrothermal modeling may be beyond the scope of your services as inspector, if there are signs of moisture problems within a building envelope recommending these studies may be an important consideration.

A hygrothermal study can be used for:

- the drying time of masonry with trapped construction moisture
- the danger of interstitial condensation
- the influence of driving rain on exterior building components
- the effect of repair and retrofit measures
- the hygrothermal performance of roof and wall assemblies under unanticipated use or in different climate zones.

If you don't check, it rains. Most EIFS manufacturer's literature now states that the designer of record must calculate the vapor transmission of a wall system for the EIFS warranty to be valid.



Air barriers and infiltration

A. **Basic air barrier theory:** Moisture moves through material either by diffusion (based on permeability of material) or leakage. Leakage can be the more serious mechanism, with up to 400x more water conveyed.

B. **Why vapor barriers are different:** Vapor retarders work to prevent diffusion of moisture, but not necessarily leakage or infiltration of air.

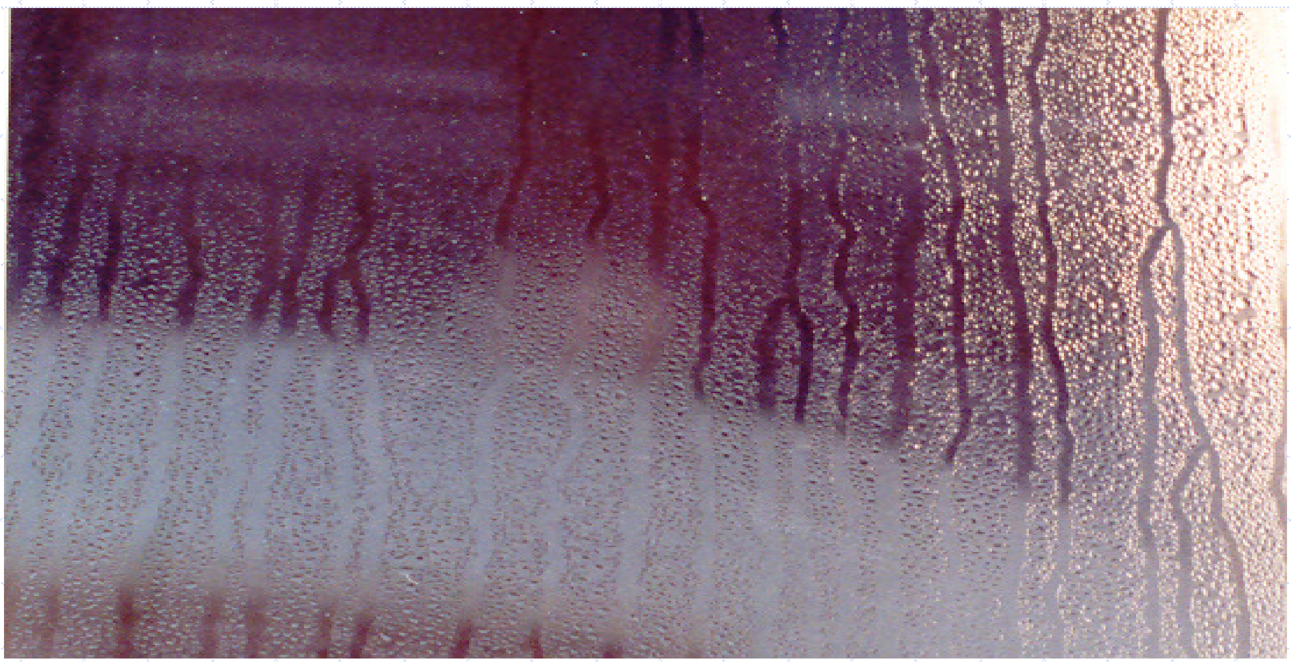
C. **Air barrier composition:** Air barriers are designed to prevent infiltration, and consist of different materials within the building envelope with the following characteristics:

1. low permeability to air
2. continuity
3. durability under dynamic pressure

need not be on "warm side," but must account for build-up of moisture is placed on cold side (by using permeable air barriers such as "Tyvek").

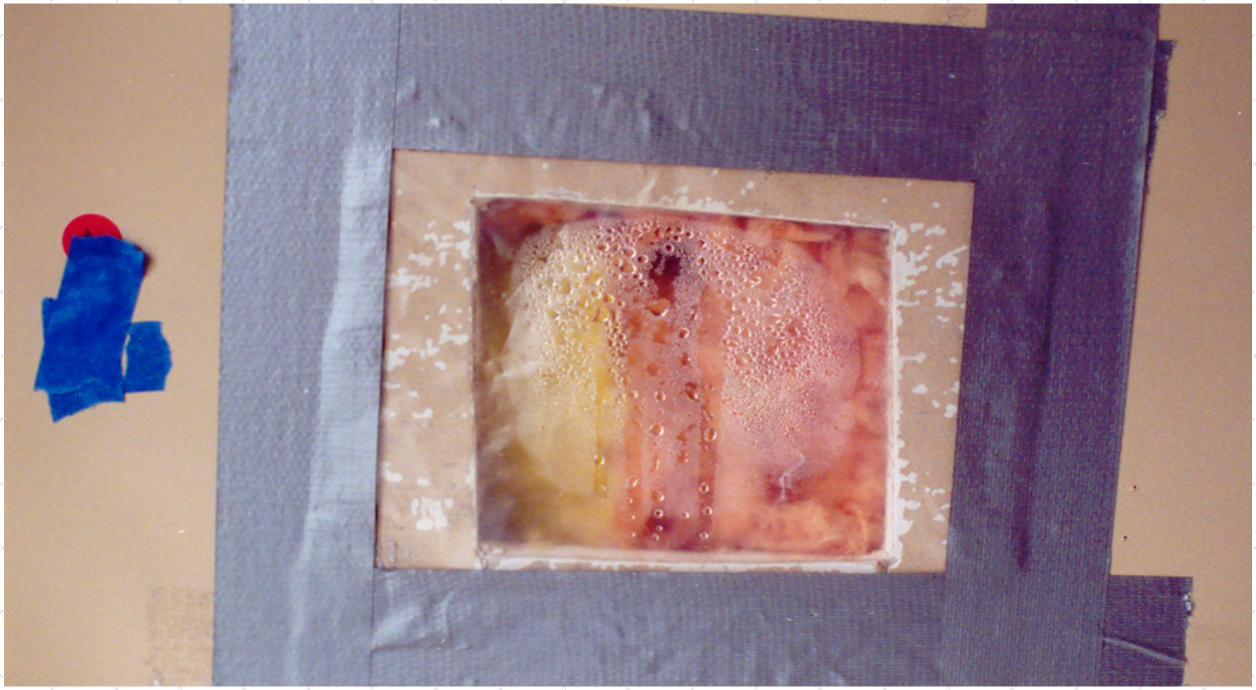
Vapor Barrier vs. Vapor Retarder A Debate of Terminology

A true Vapor Barrier by definition *excludes* 100% of moisture vapor migration – Aluminum foil, Glass



Vapor Barrier vs. Vapor Retarder A Debate of Terminology

- Vapor Retarder – *Retards* the passage of vapor based upon Permeance – most materials retard vapor migration to some degree.



Vapor Barrier vs. Vapor Retarder A Debate of Terminology

Building Code Definition of Vapor Retarder - a material with a permeance of 1 Perm or less.

- Most areas of the US - required on the warm side of the insulation in the winter
- Required to prevent condensation by retarding the flow of moisture vapor from high to low vapor pressure, typically, Warm to Cold.

Vapor Barrier vs. Vapor Retarder A Debate of Terminology

Building Code Definition of Vapor Retarder - a material with a permeance of 1 Perm or less.

- Does **not** limit us to the use of Polyethylene!
- Ventilation of the interior wall cavity is an option.

  A vented attic is a sloped wall with a vented cavity and a VB is not required by code.

Vapor Barrier vs. Vapor Retarder Classes

An Attempt to define and sort through the confusion

- Vapor Barrier - Class I - 0 to .1 perm
- Vapor Barrier – Class II - .1 to 1 perm
- Vapor Retarder > 1 perm to 10 perms
- Permeable material > 10 perms

Building Code Definition of Vapor Retarder - a material with a permeance of 1 Perm or less.

- Revise code verbiage to Vapor Barrier

Vapor Barrier vs. Vapor Retarder Classes

Vapor Barrier - Class I - 0 to .1 perm

- Aluminum Foil – 0 Perm
- Glass – 0 Perm
- Polyethylene - .02-.06 Perms
- Shellac and lacquers – VB Paints
- Rubber Roofing
- Vinyl wall covering

Vapor Barrier – Class II - .1 to 1 perm

- Kraft facing of insulation
- Plywood and OSB – Exterior Glue
- 4" Brick Veneer

Vapor Barrier vs. Vapor Retarder Classes

Vapor Retarder 1 perm to 10 perms

- Semi Permeable
- ½ " Dow Styrofoam
- Building felt Not including open laps
- ½" Fiberglass faced Isocyanyrate foam insulation
- ½"Fiber board sheathing
- ¾" Fir Sheathing with out joints
- 8" Concrete block - CMU

Vapor Barrier vs. Vapor Retarder Classes

Permeable material > 10 perms

- Gypsum Drywall
- Fiberglass insulation
- Mineral wool insulation
- Tyvek
- Other House Wraps

Permeance Based upon material design

Air Barrier

A strategy for controlling **air movement** and the moisture carrier with it, through the building envelope.

A very detail specific **System** of the building envelope.

- All and penetrations joints sealed
- Perimeter profile continuous including all seals

"Build Tight - Ventilate Right"

- Building tight refers to Air Flow NOT Vapor Flow

Air Barrier vs. Vapor Barrier

A material may be both an air barrier and a vapor barrier

- Polyethylene
- The detailing will determine success.

Air Barrier vs. Vapor Barrier

A material may be a component of an air barrier system while being **very** vapor permeable

- Gypsum Wall board
- Tyvek

Air Barrier /Bulk Moisture Barrier

A material may be very permeable to moisture Vapor but essentially impermeable to Air and Bulk Water

- House Wrap
  - Material design based upon th
    water molecule
  - Surfactants
  - Surface Tension
- Detailing of the System joints

Air Barrier /Bulk Moisture Barrier

House Wrap

- Non Woven Non Perforated
    - Tyvek
    - R-Wrap
- Non Woven Perforated
- Woven Perforated

Air Barrier /Vapor Barrier /Moisture Barrier

A material/system may be very permeable to moisture but essentially impermeable to Moisture vapor

- Brick Veneer

  We must be very careful with the use and installation of these "One Way" Materials

  Drying Via Ventilation