A photograph of an ancient stone building, likely a temple or palace, with a massive tree growing through its structure. The tree's trunk is thick and gnarled, with many roots extending outwards and upwards, some reaching the top of the building. The stone walls are weathered and show signs of age. The scene is set outdoors with trees in the background.

Building Enclosures: Science & Pathology

An aerial photograph of a dry, eroded landscape. The foreground is a deep blue, showing intricate patterns of erosion and dry riverbeds. A bright white line, possibly a road or a ridge, runs diagonally across the middle of the image. The background is a vast, flat expanse under a bright yellow sky. The overall scene conveys a sense of environmental separation and aridity.

A Building Is An Environmental Separator

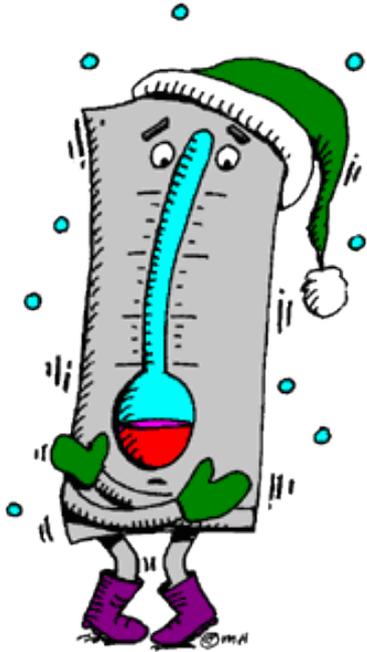
-Joe Lstiburek



Inside

Outside





Outside

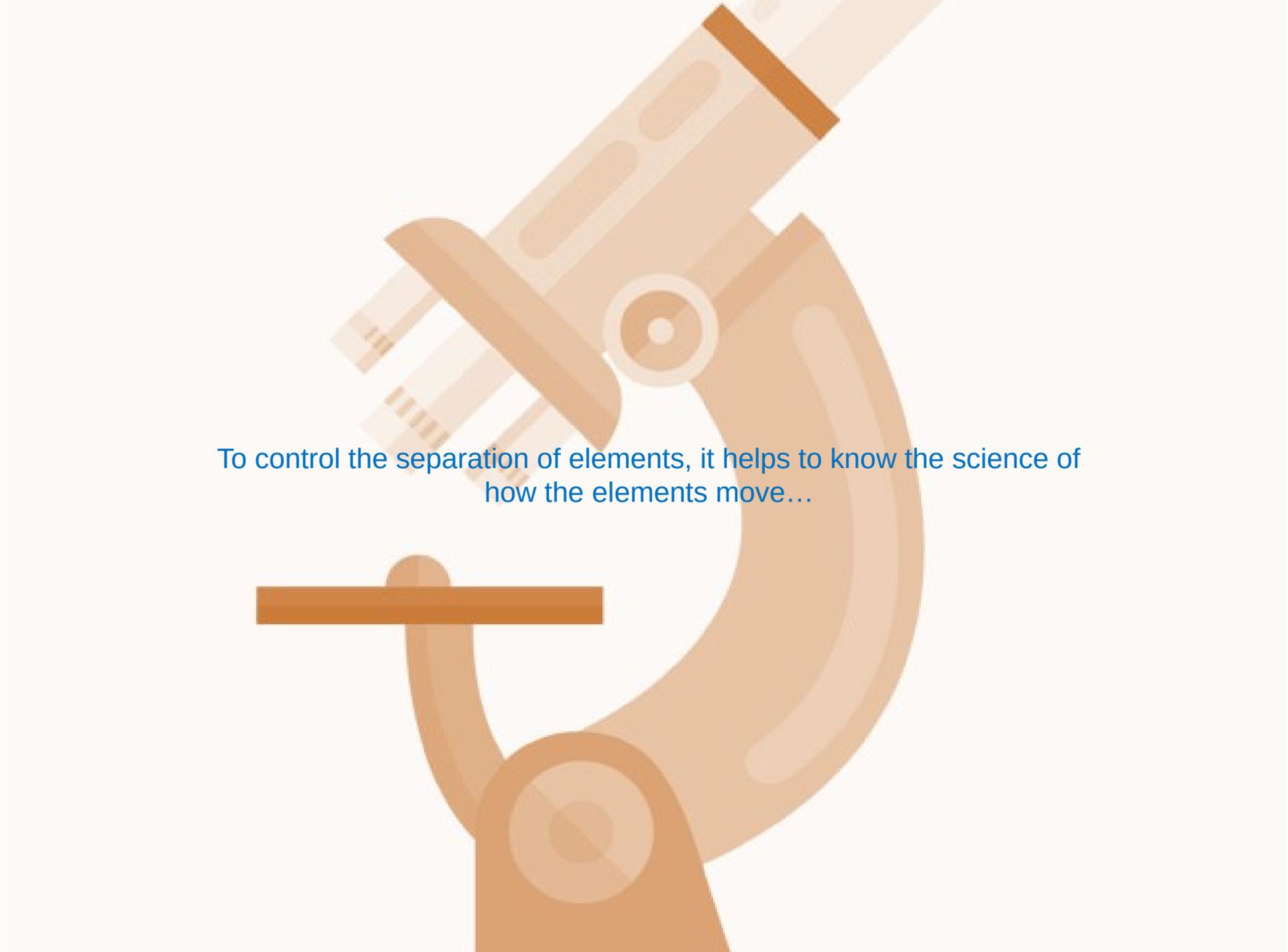
Inside





The Science of Separation

Science:
A systematically
organized body of
knowledge on a
particular subject



To control the separation of elements, it helps to know the science of how the elements move...

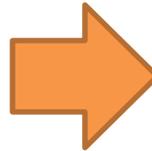
TEMPERATURE



AIR



VAPOR



TEMPERATURE

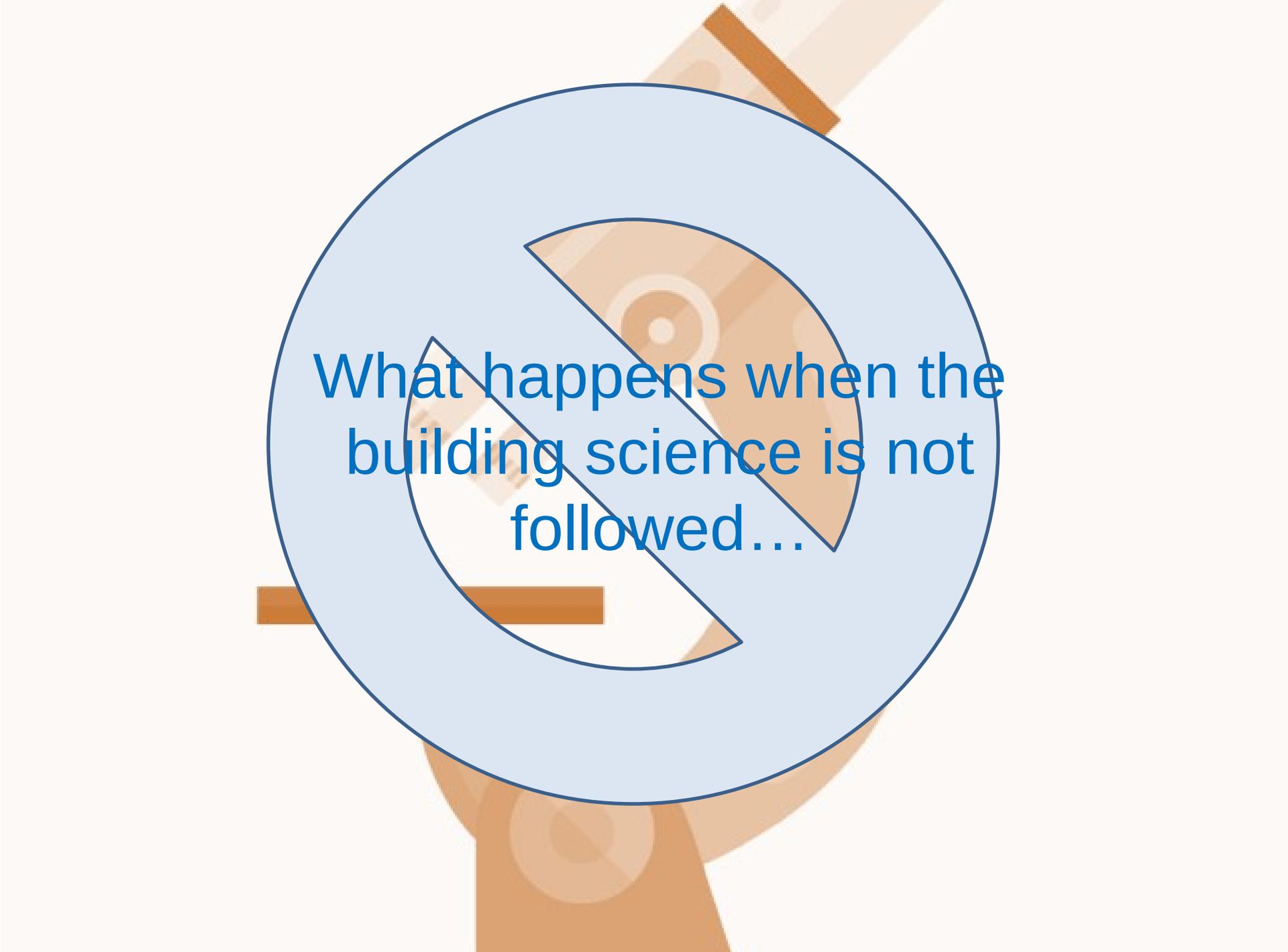
Mechanical Systems
Body heat
Equipment
Solar

AIR

Mechanical Systems
Wind
Stack Effect

VAPOR

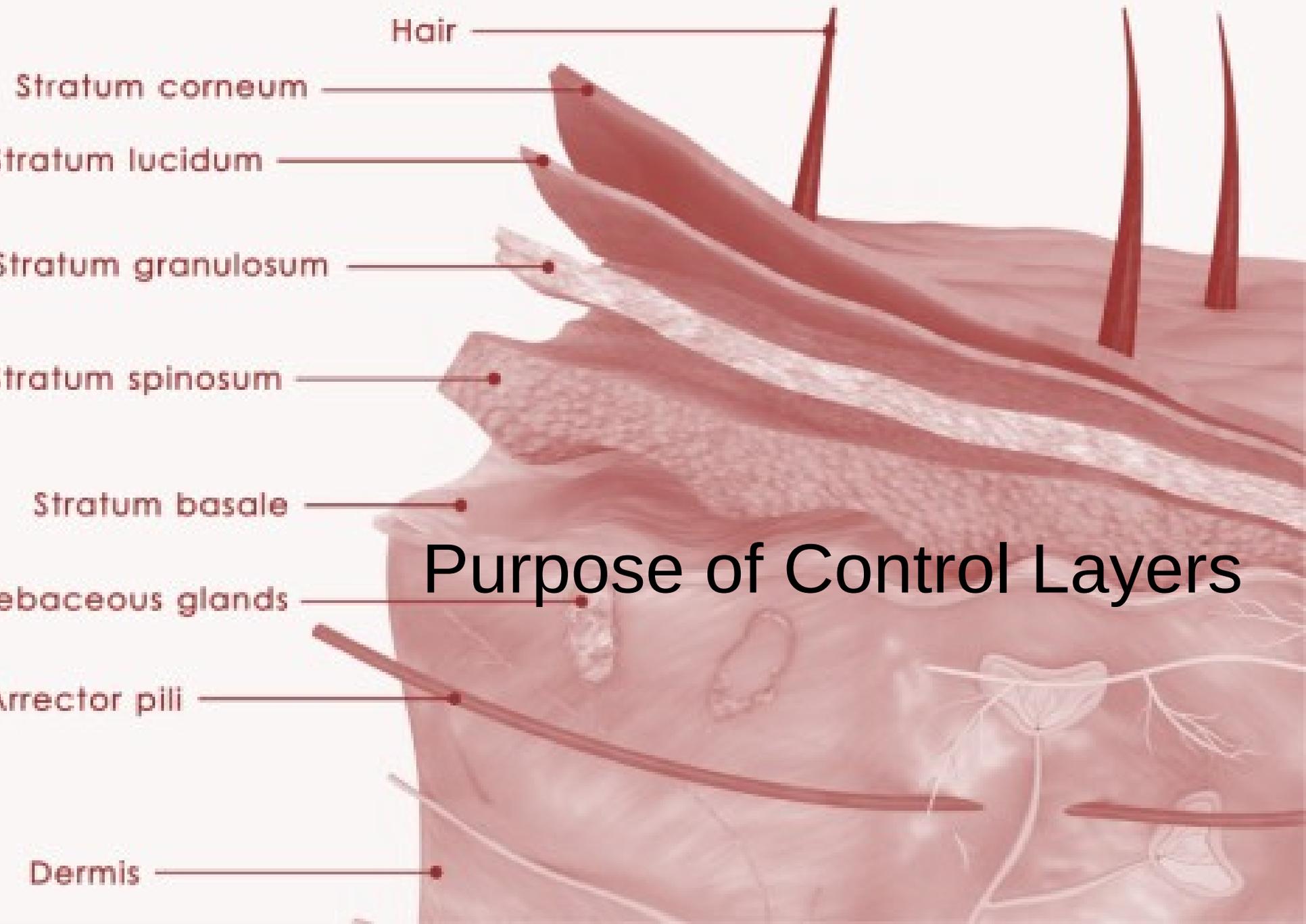
Rain
Humidity
Body Moisture
Equipment
Plumbing



What happens when the
building science is not
followed...



Another type of science comes into play - Pathology:
the science of the causes and effects of disease



Hair

Stratum corneum

Stratum lucidum

Stratum granulosum

Stratum spinosum

Stratum basale

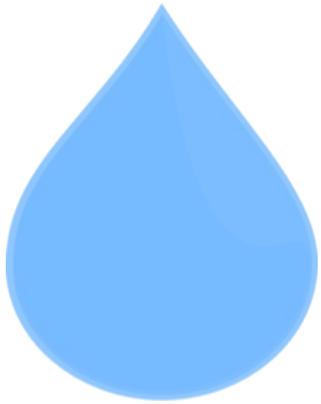
Sebaceous glands

Arrector pili

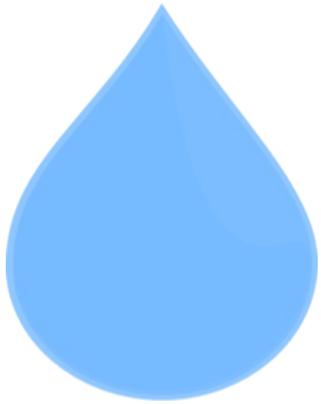
Dermis

Purpose of Control Layers

To Manage W.A.V.T



Shed Water
Retard Air
Control Vapor
Keep Heat on one side



water \propto air \propto vapor \propto thermal



water \propto air \propto vapor \propto thermal



water ◻ air ◻ vapor ◻ thermal



water \propto air \propto vapor \propto thermal



water \propto **air** \propto vapor \propto thermal



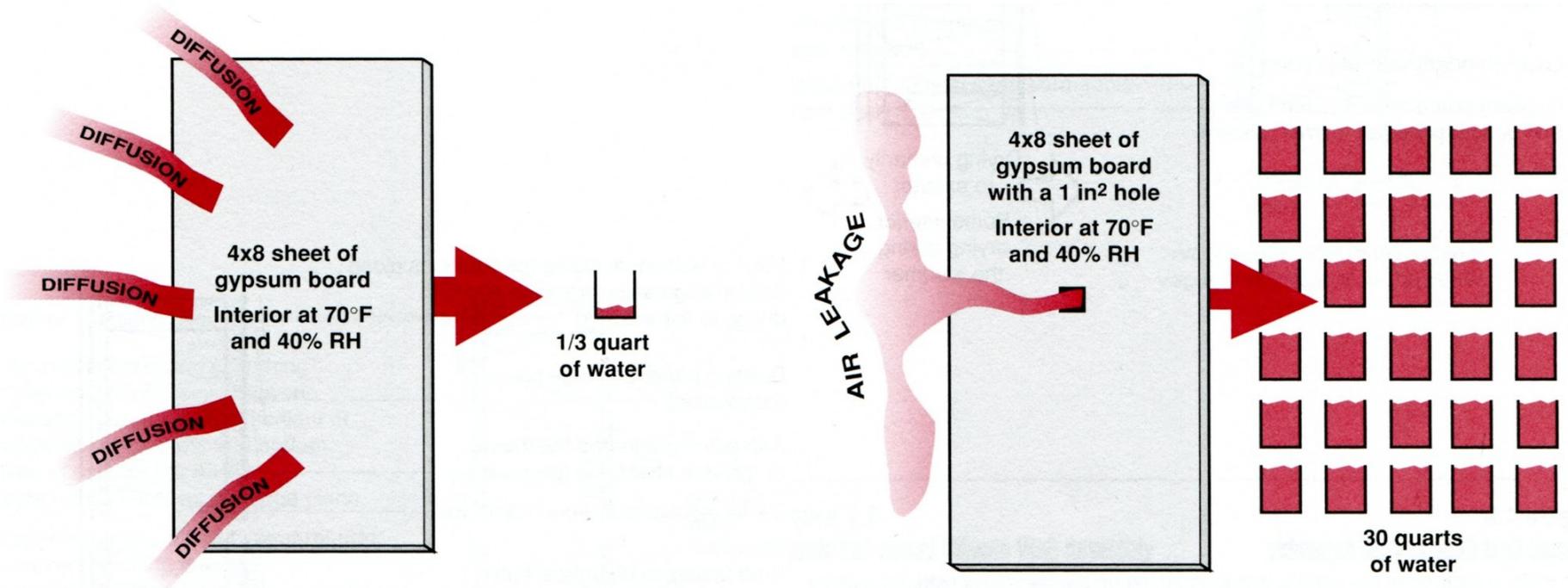
water \propto **air** \propto vapor \propto thermal



water \propto **air** \propto vapor \propto thermal



water \propto air \propto vapor \propto thermal



[images courtesy of Building Science Corporation]

Water \propto vapor \propto thermal



water • air • vapor • thermal

CONDENSATION

water ρ air ρ vapor ρ thermal



water \propto air \propto vapor \propto thermal



water ◊ air ◊ vapor ◊ **thermal**



water \propto air \propto vapor \propto **thermal**



water \propto air \propto vapor \propto **thermal**

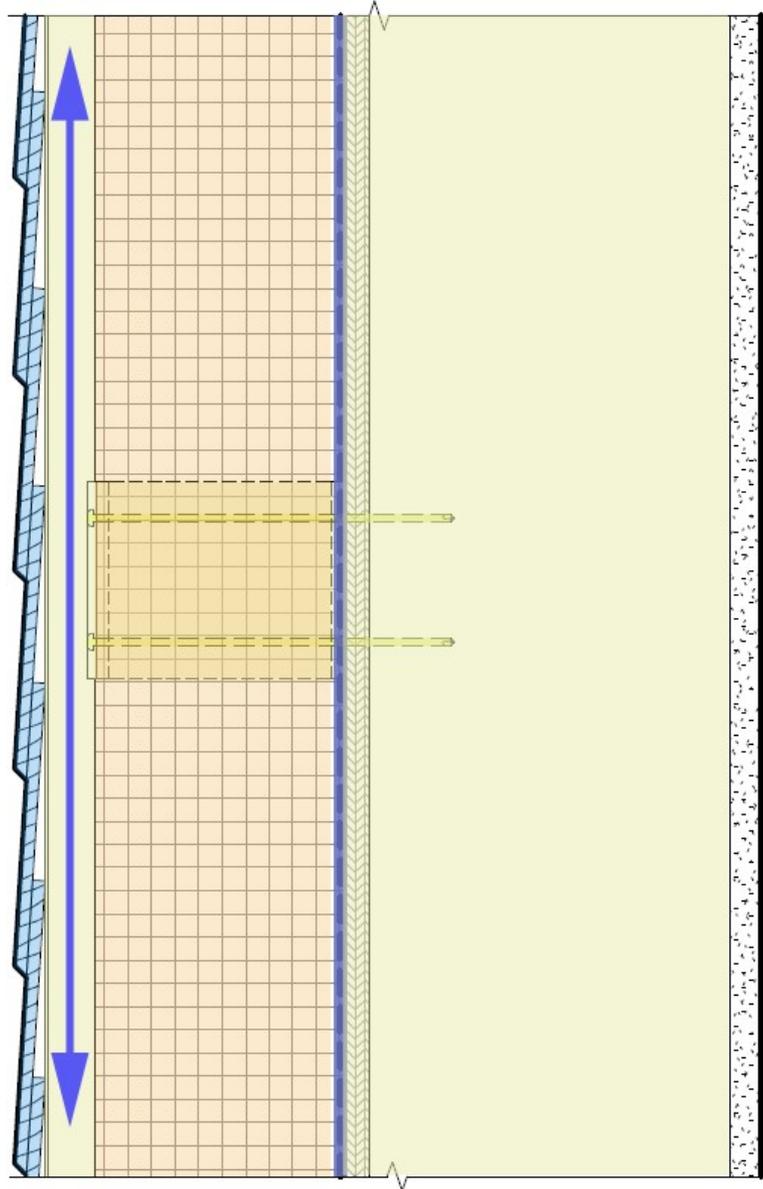


water \propto air \propto vapor \propto thermal

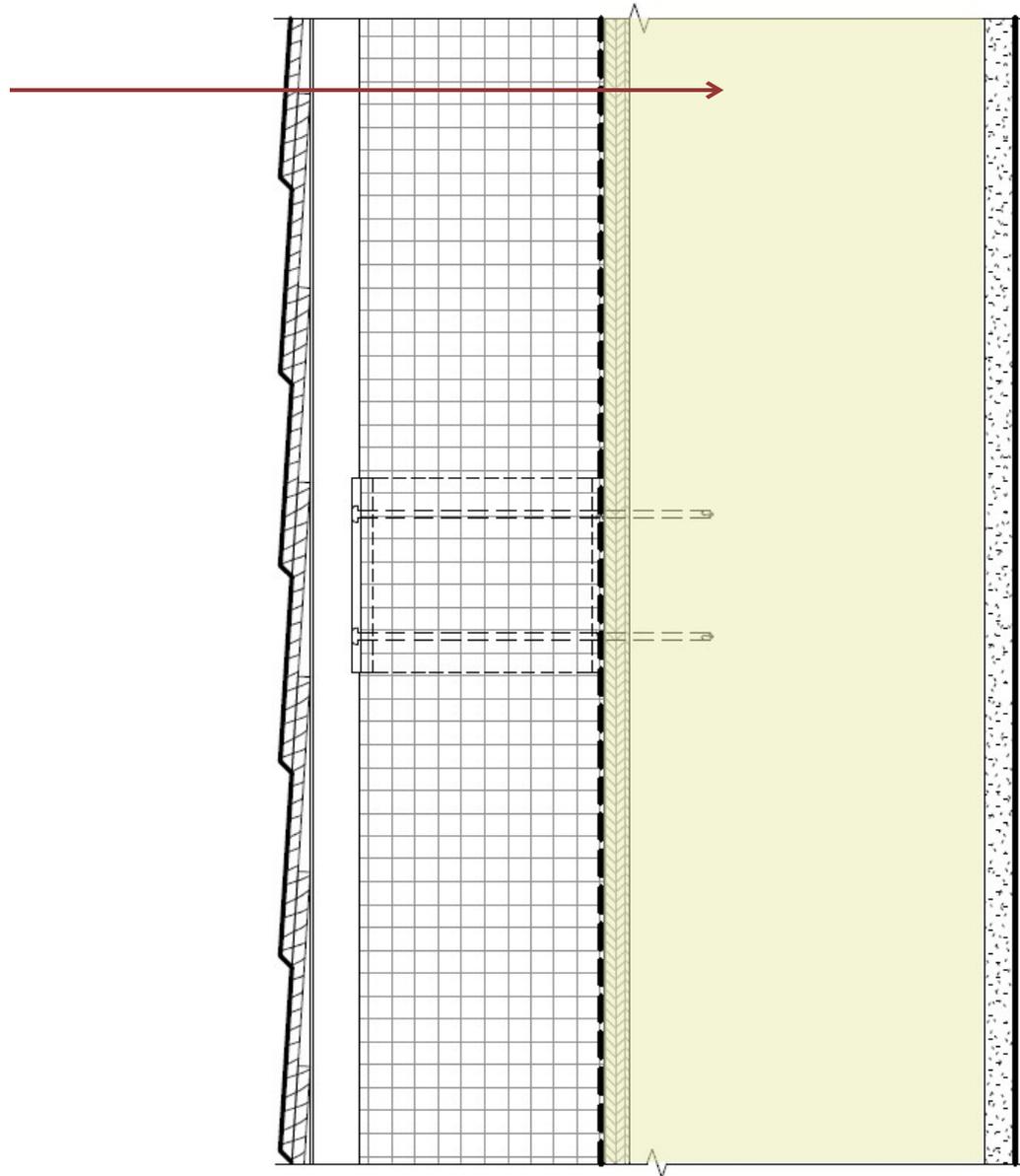


LOCATION OF INSULATION CAN IMPACT LOCATION OF DEW POINT

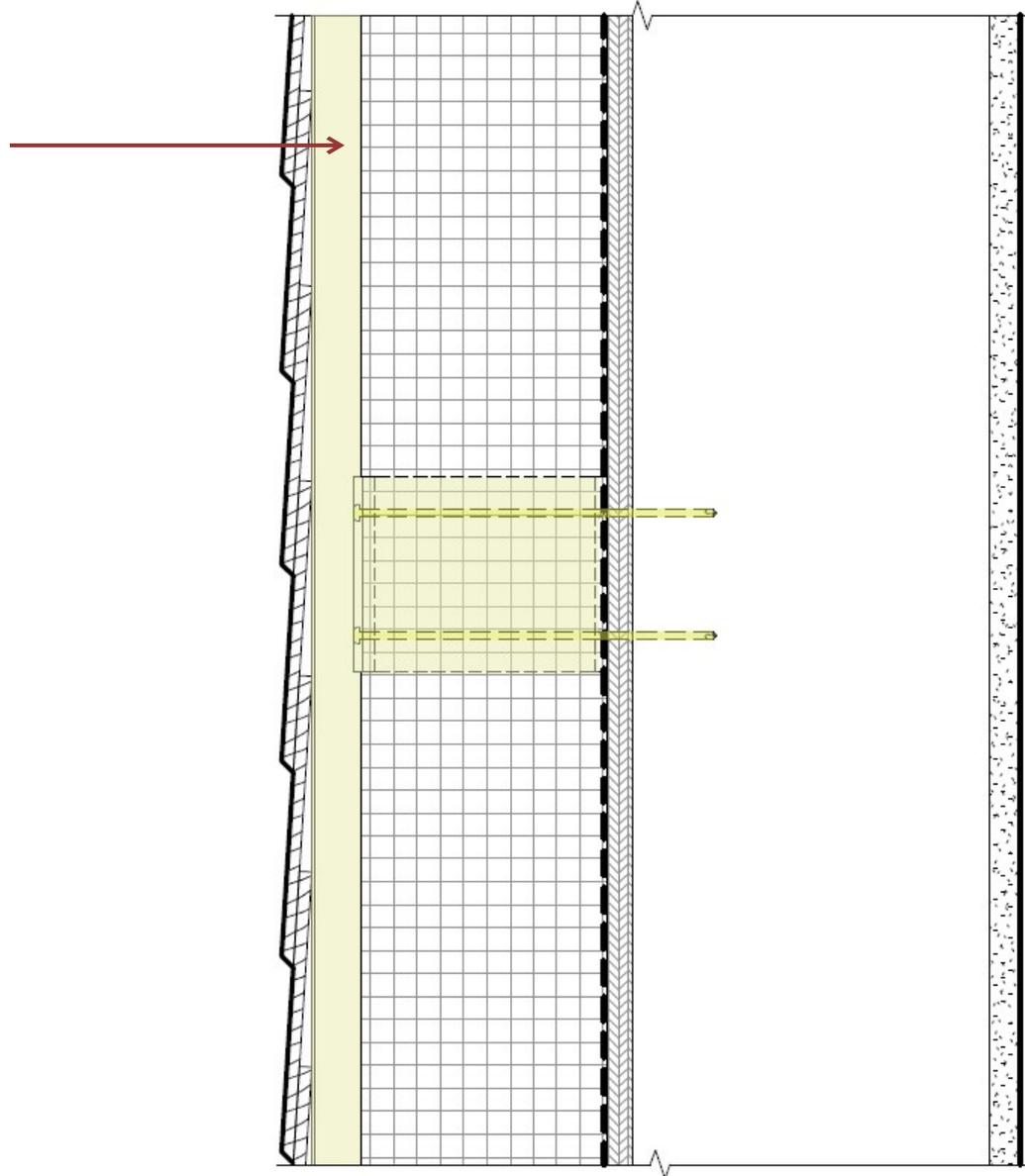
Perfect!



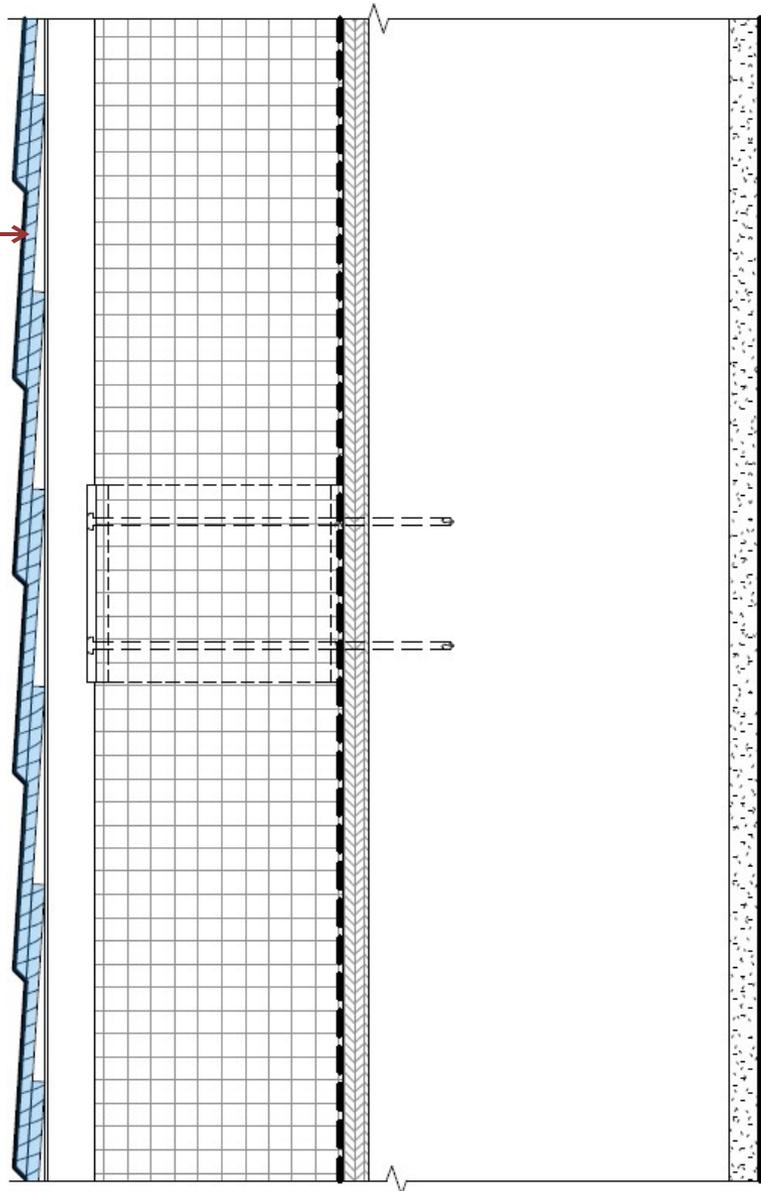
STRUCTURE
2ND STRUCTURE
RAINSCREEN
VENTILATION
WATER CONTROL
AIR CONTROL
VAPOR CONTROL
THERMAL LAYER



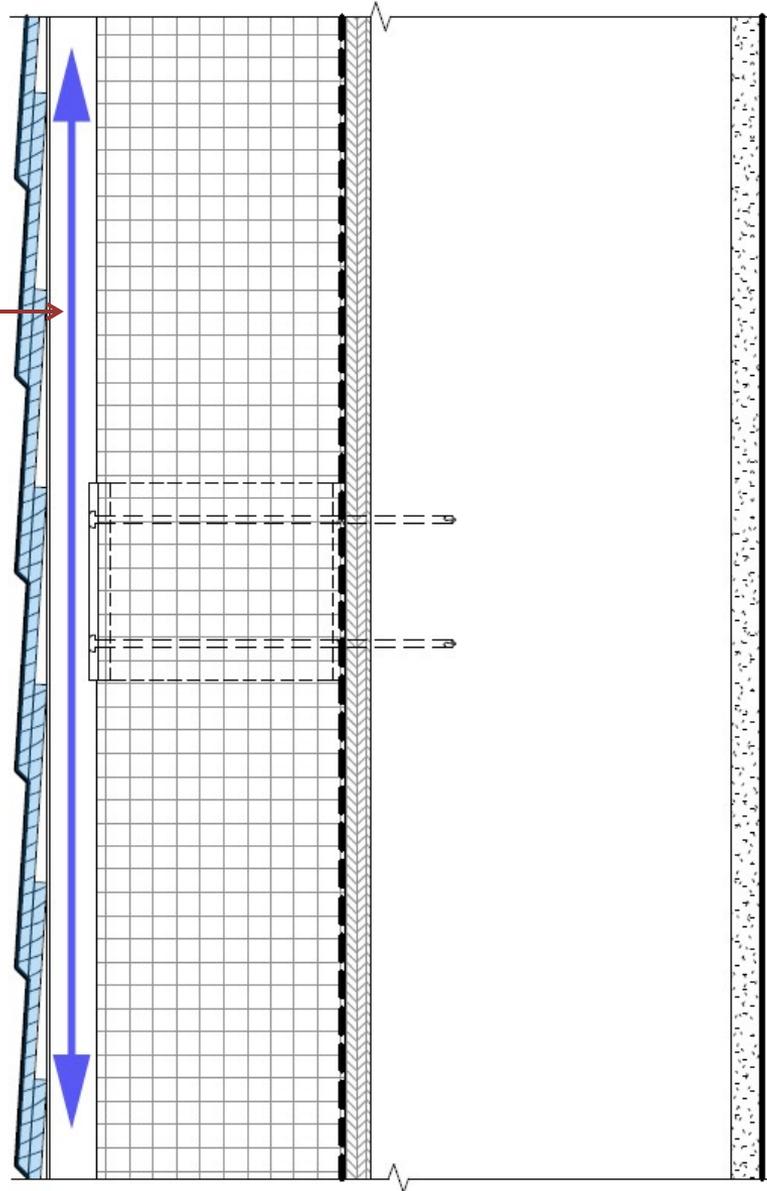
STRUCTURE
2ND STRUCTURE
RAINSCREEN
VENTILATION
WATER CONTROL
AIR CONTROL
VAPOR CONTROL
THERMAL LAYER



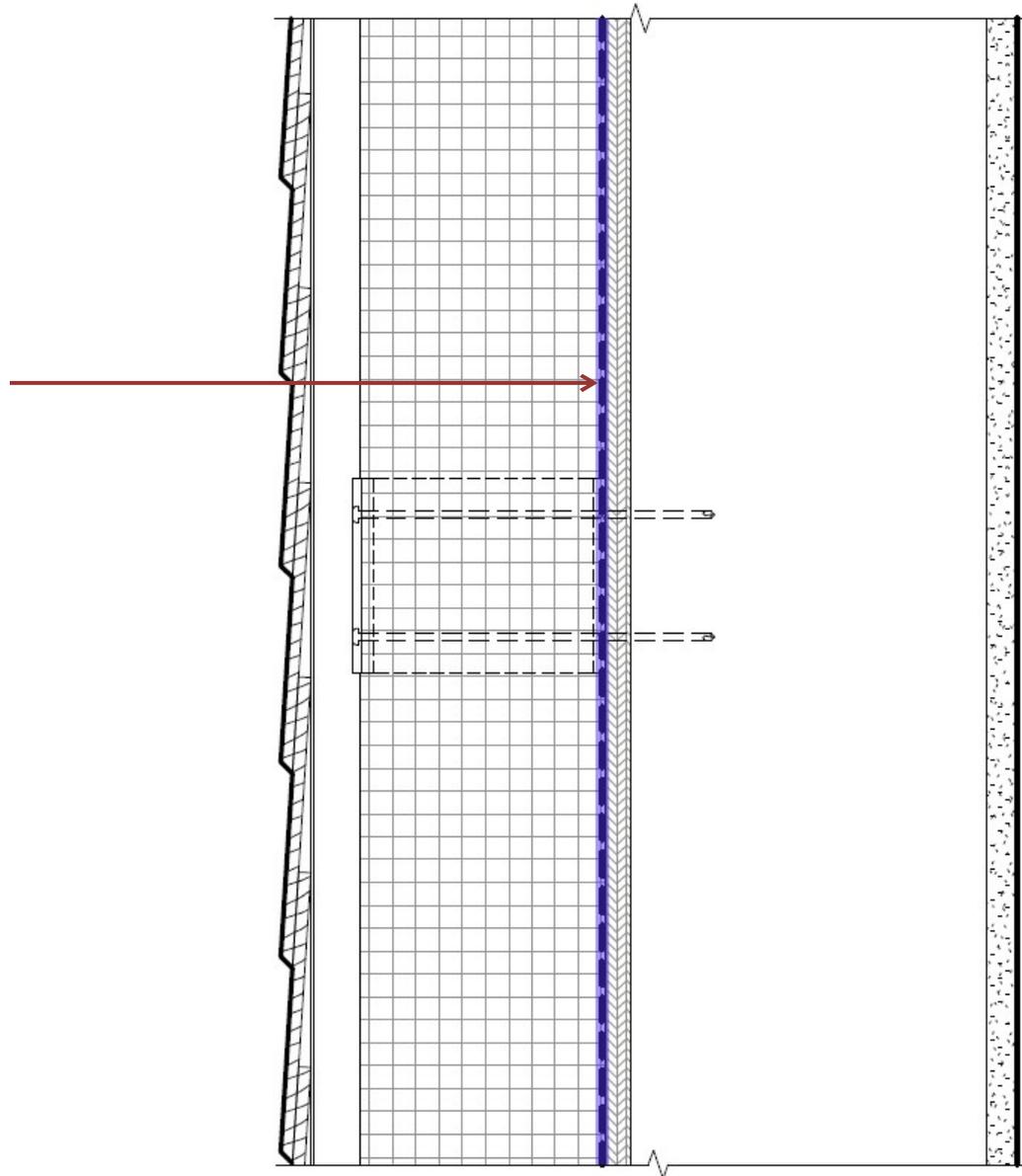
STRUCTURE
2ND STRUCTURE
RAINSCREEN
VENTILATION
WATER CONTROL
AIR CONTROL
VAPOR CONTROL
THERMAL LAYER



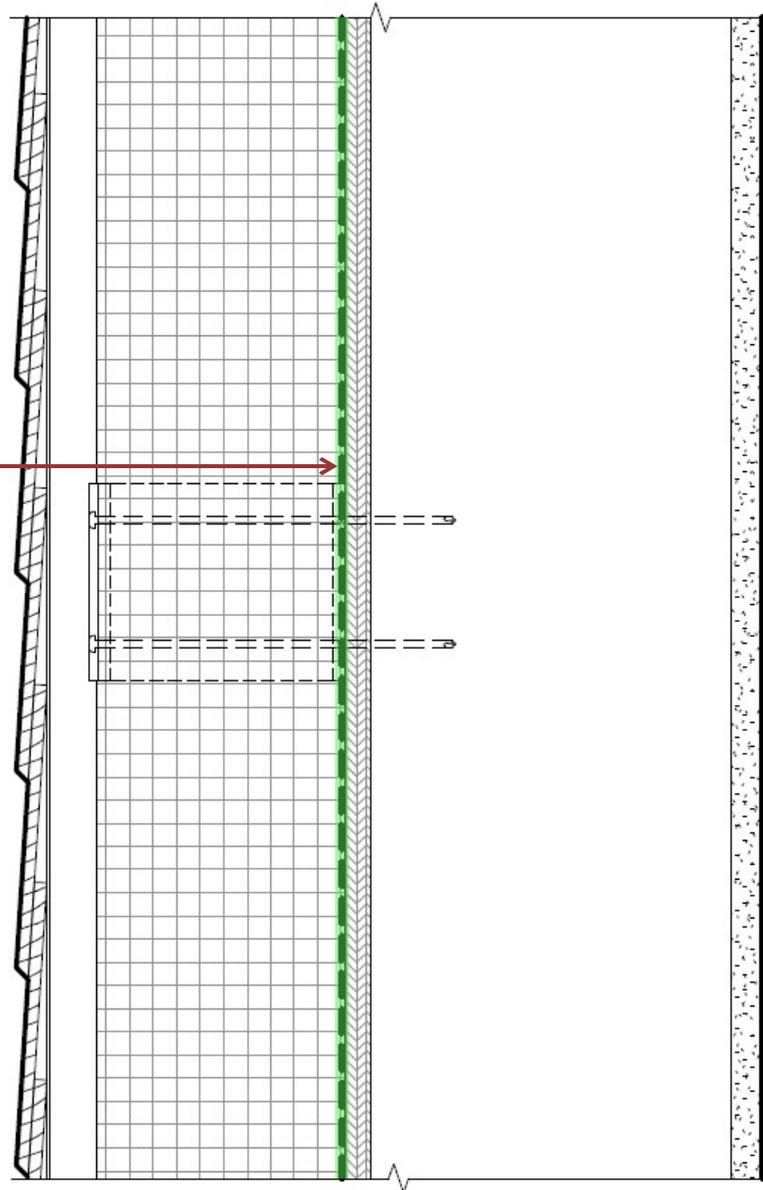
STRUCTURE
2ND STRUCTURE
RAINSCREEN
VENTILATION
WATER CONTROL
AIR CONTROL
VAPOR CONTROL
THERMAL LAYER



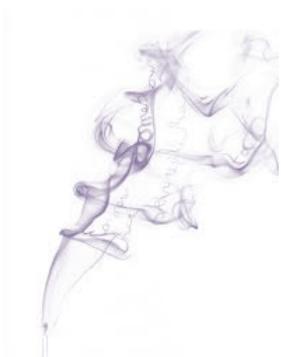
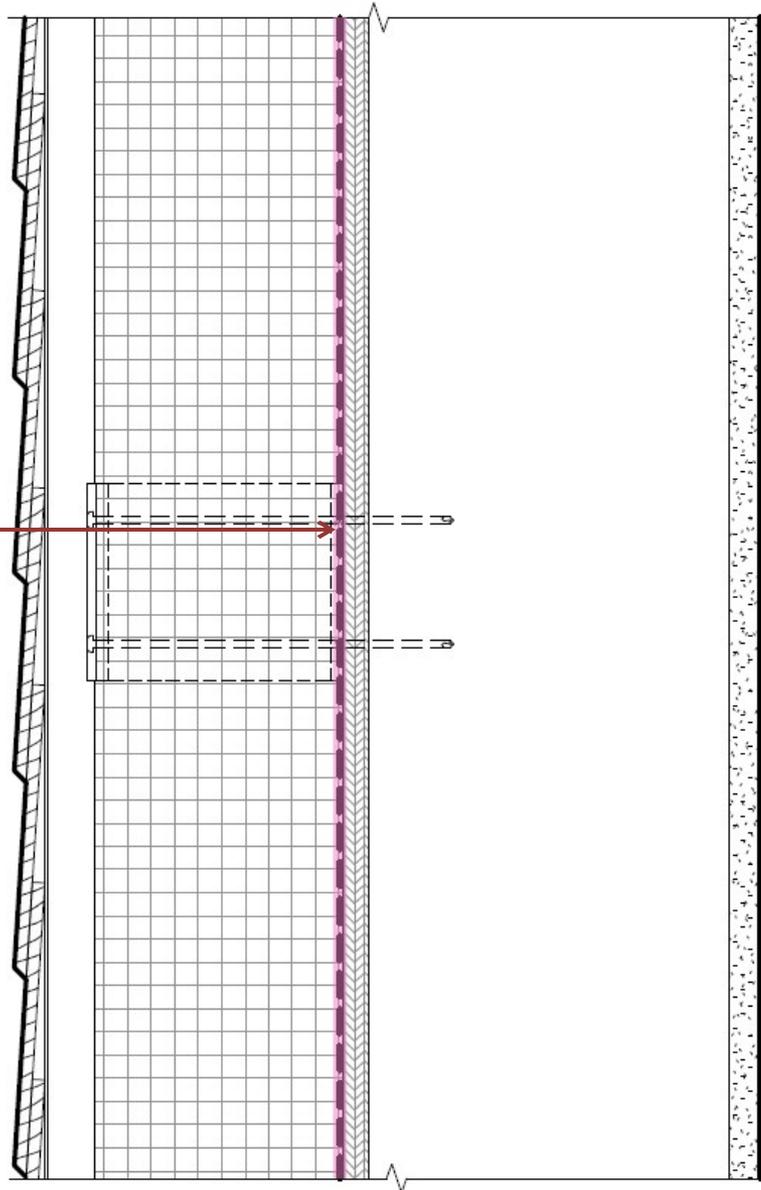
STRUCTURE
2ND STRUCTURE
RAINSCREEN
VENTILATION
WATER CONTROL
AIR CONTROL
VAPOR CONTROL
THERMAL LAYER



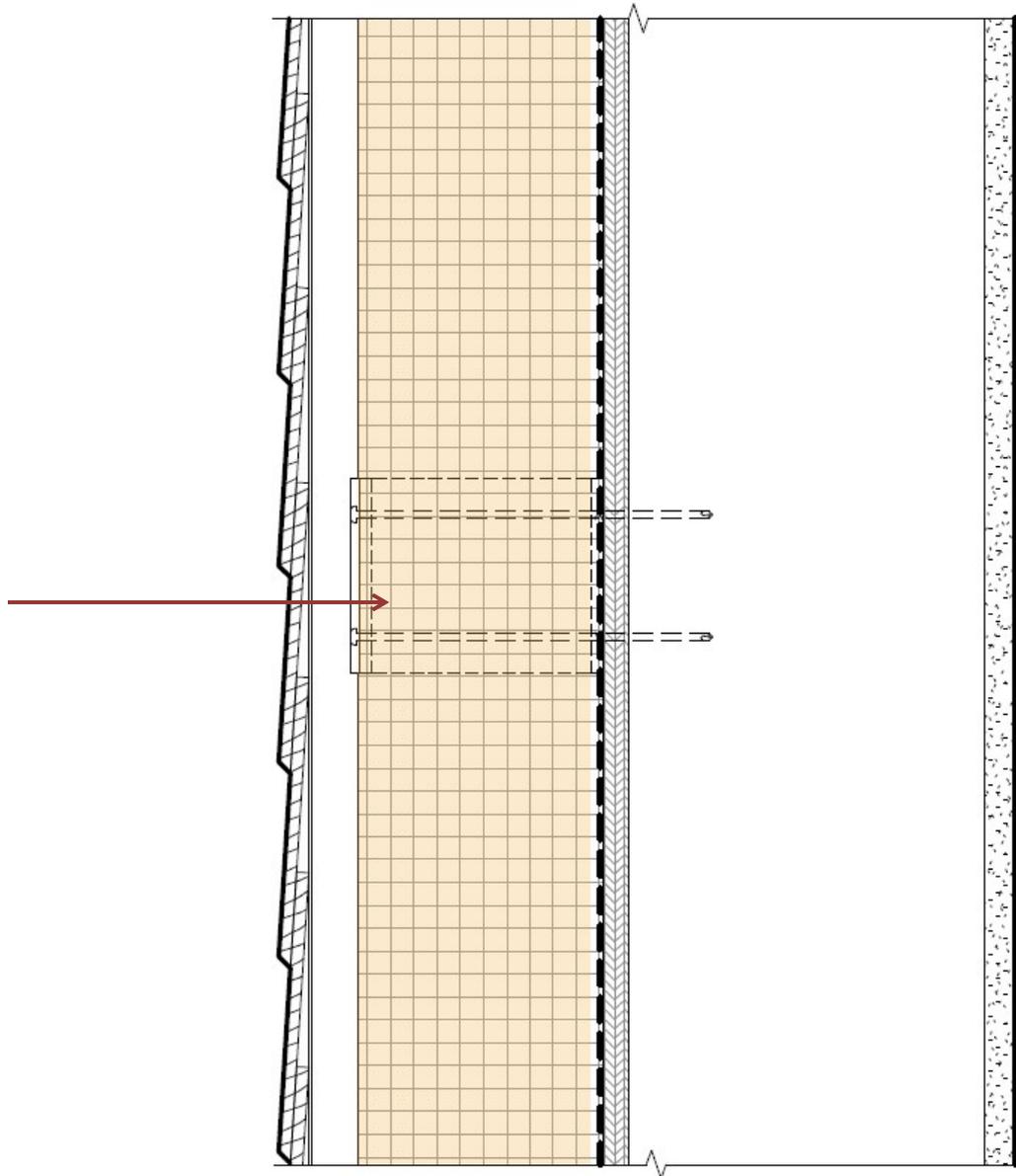
STRUCTURE
2ND STRUCTURE
RAINSCREEN
VENTILATION
WATER CONTROL
AIR CONTROL
VAPOR CONTROL
THERMAL LAYER

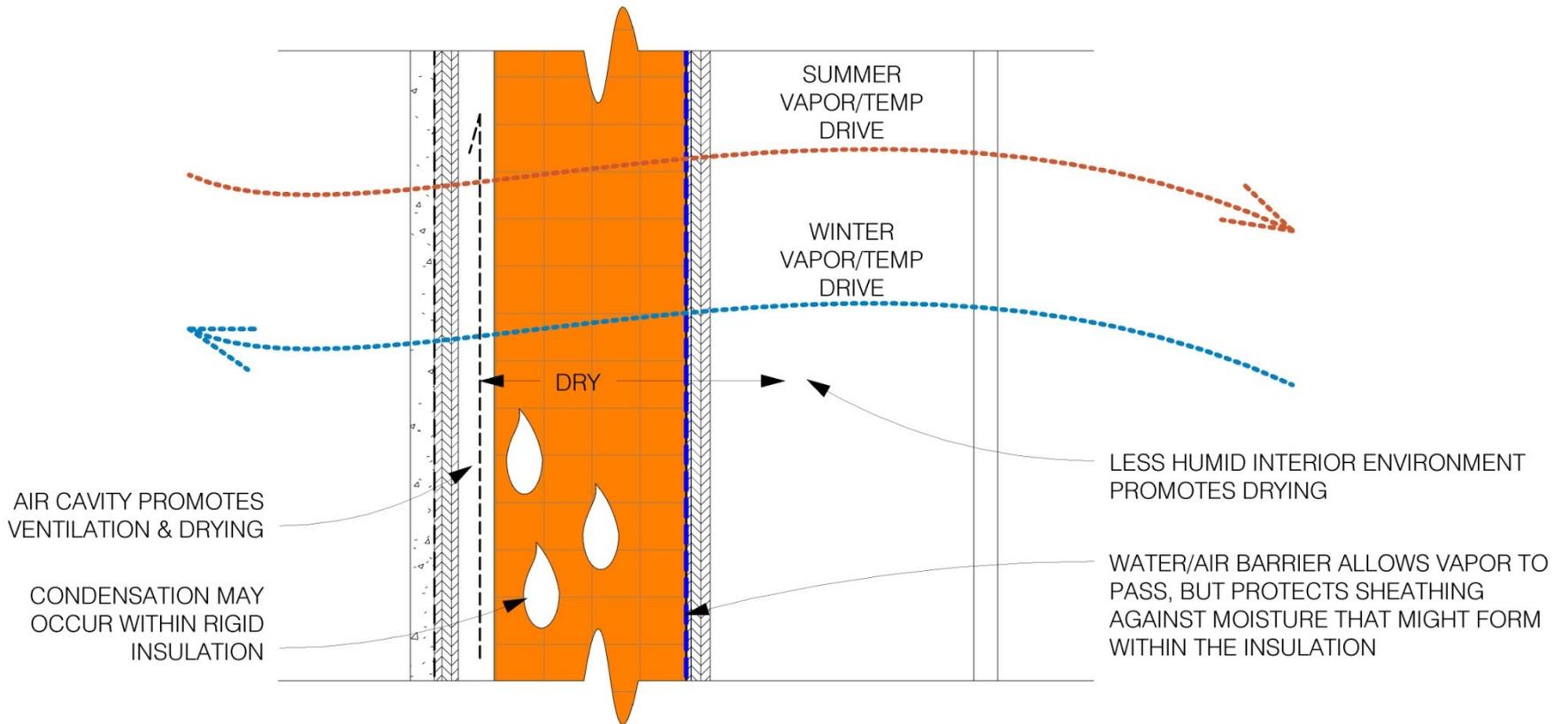


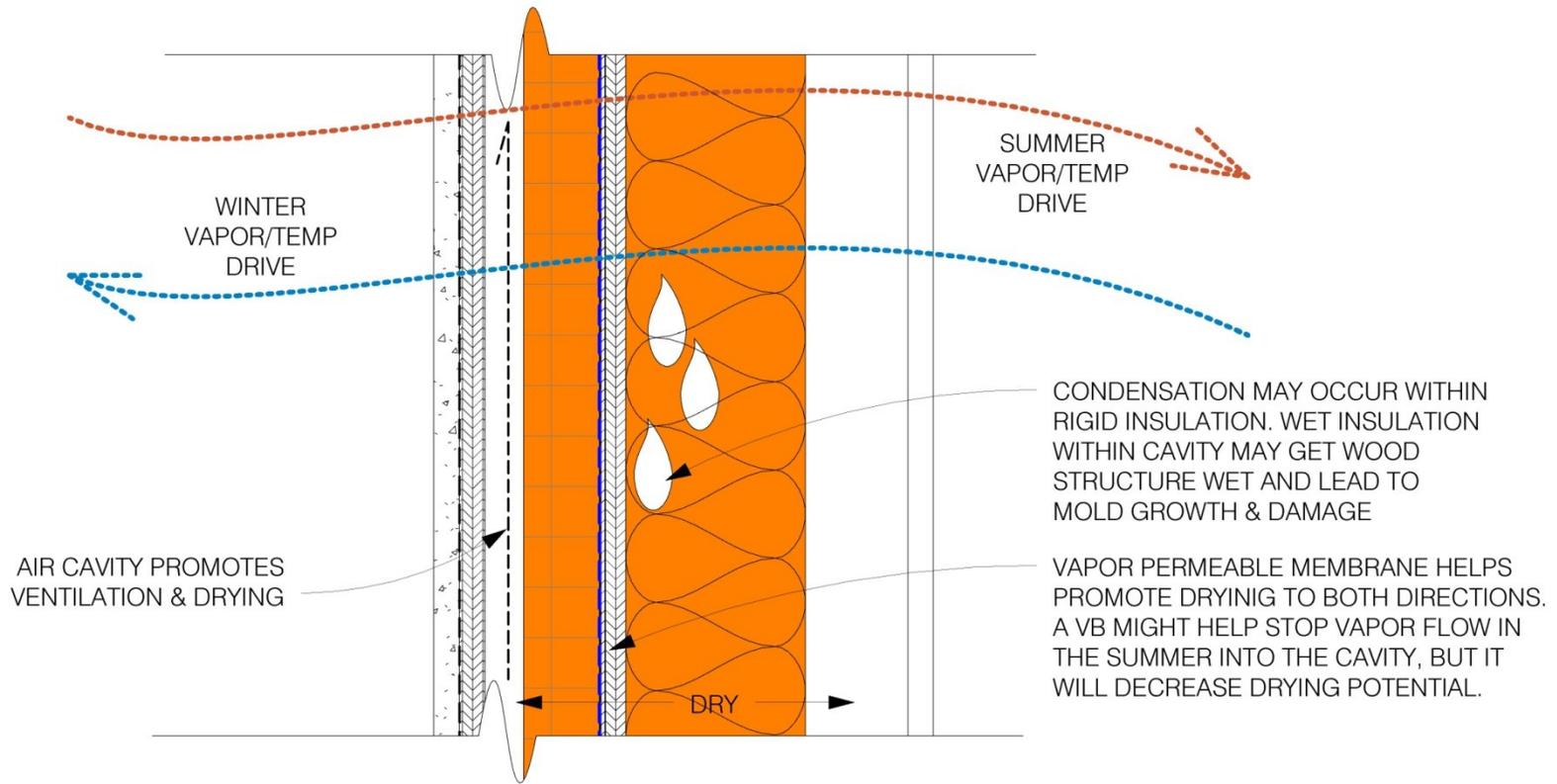
STRUCTURE
2ND STRUCTURE
RAINSCREEN
VENTILATION
WATER CONTROL
AIR CONTROL
VAPOR CONTROL
THERMAL LAYER

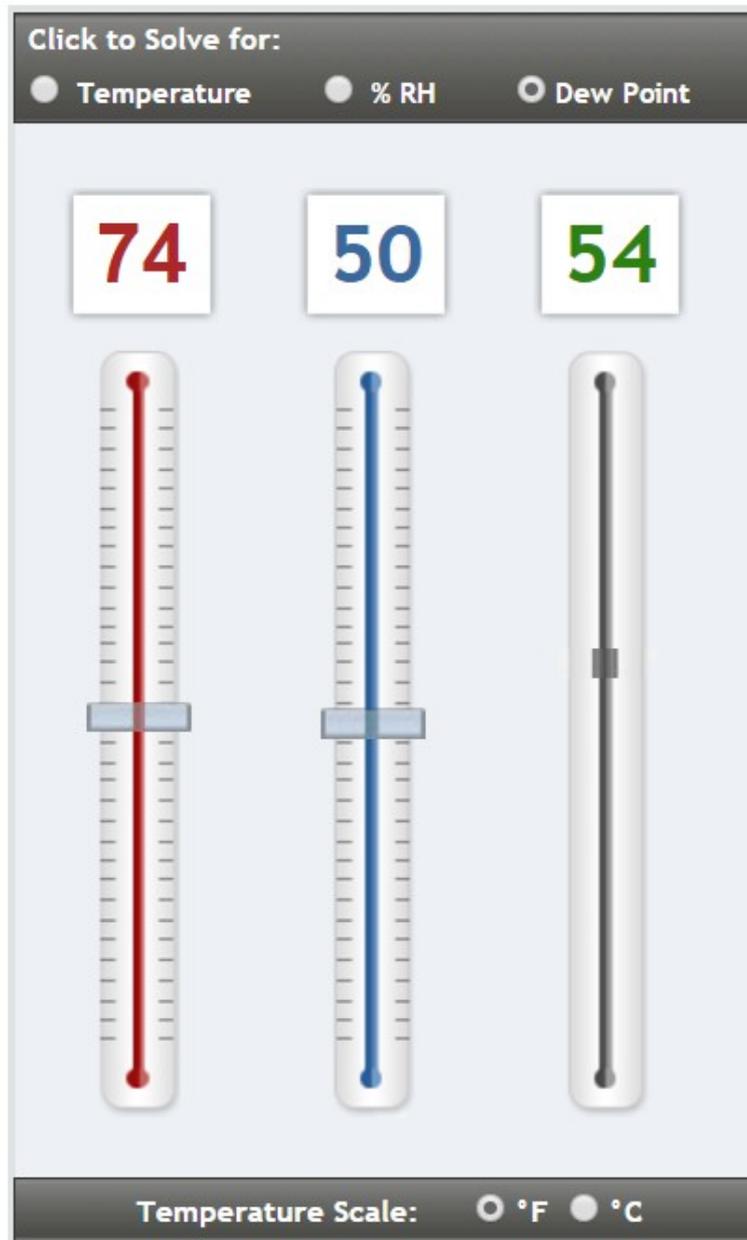


STRUCTURE
2ND STRUCTURE
RAINSCREEN
VENTILATION
WATER CONTROL
AIR CONTROL
VAPOR CONTROL
THERMAL LAYER



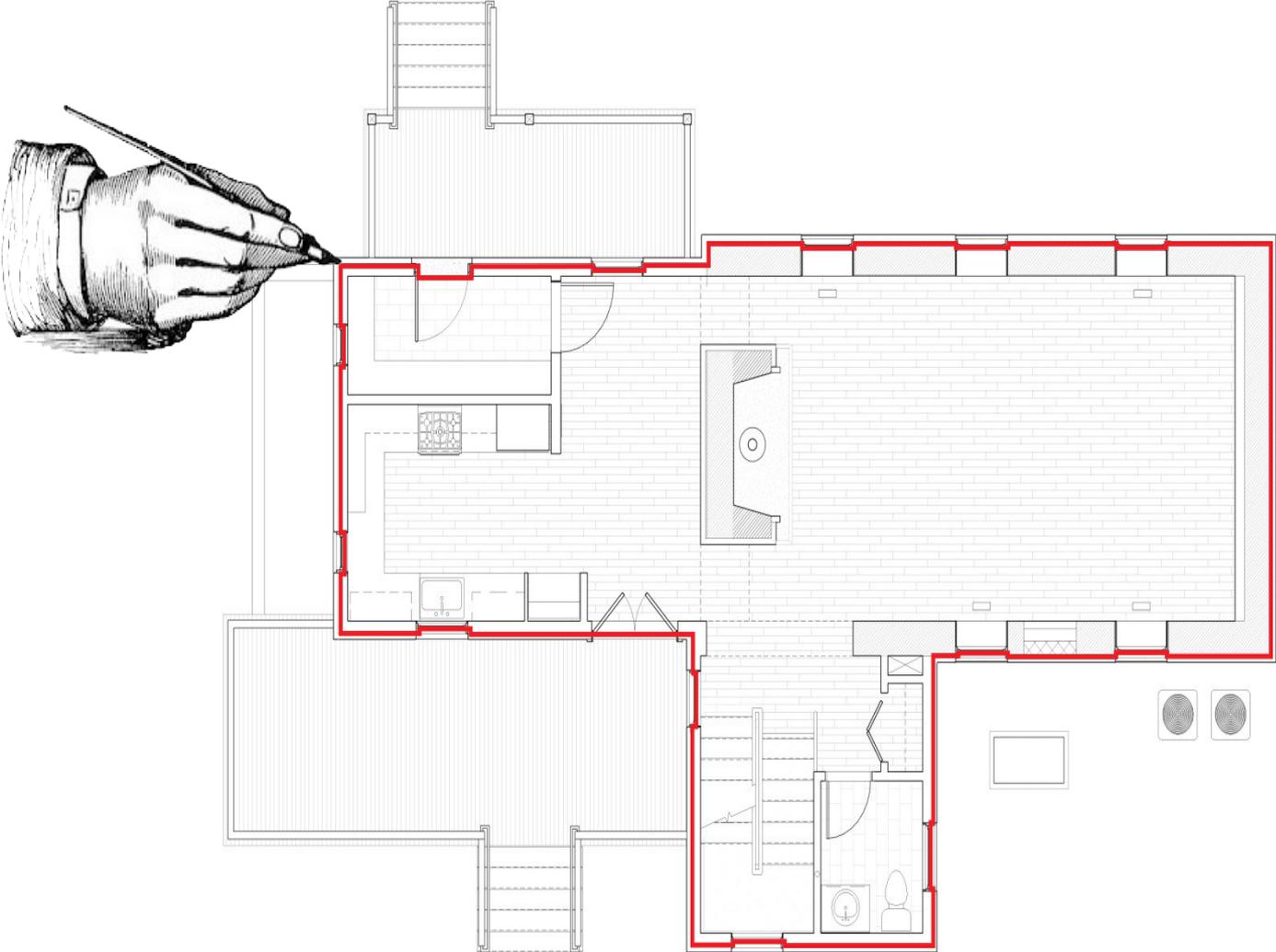




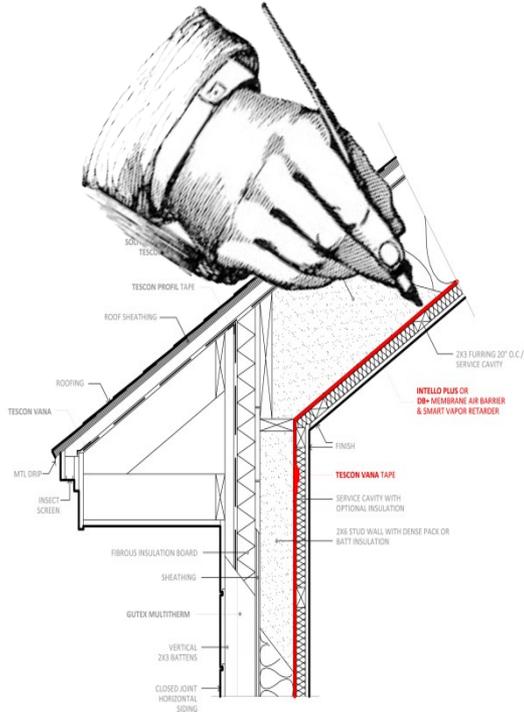


[images courtesy of www.dpcalc.org]

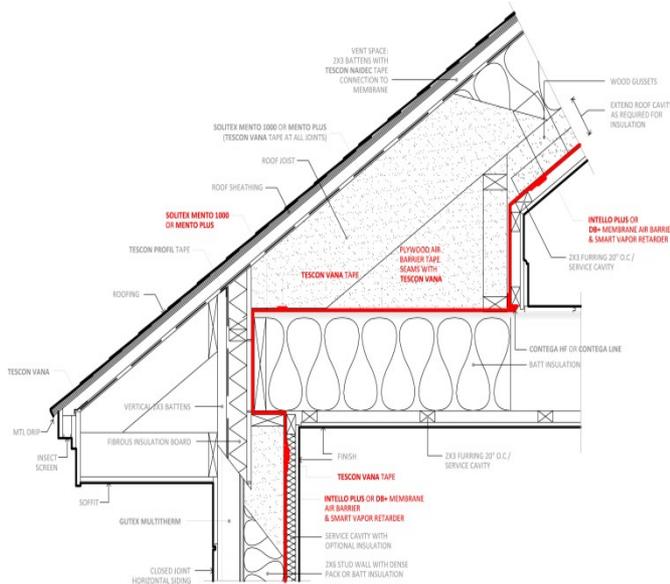
AIRTIGHT BOUNDARY



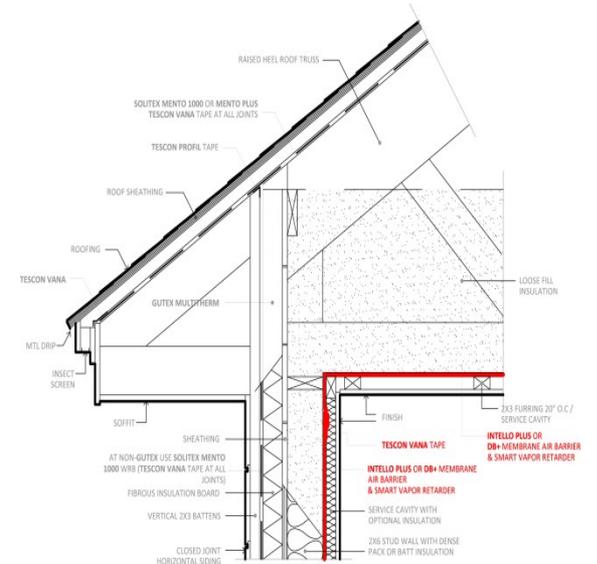
AIRTIGHT BOUNDARY: SECTION DETAIL



Cathedral Ceiling

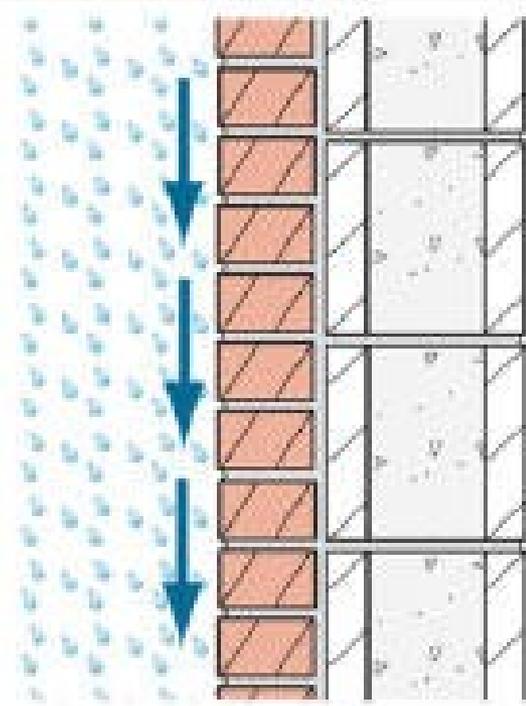
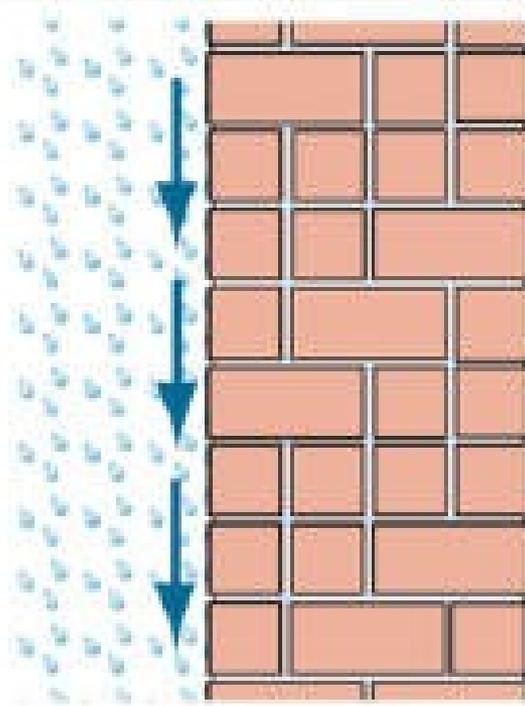
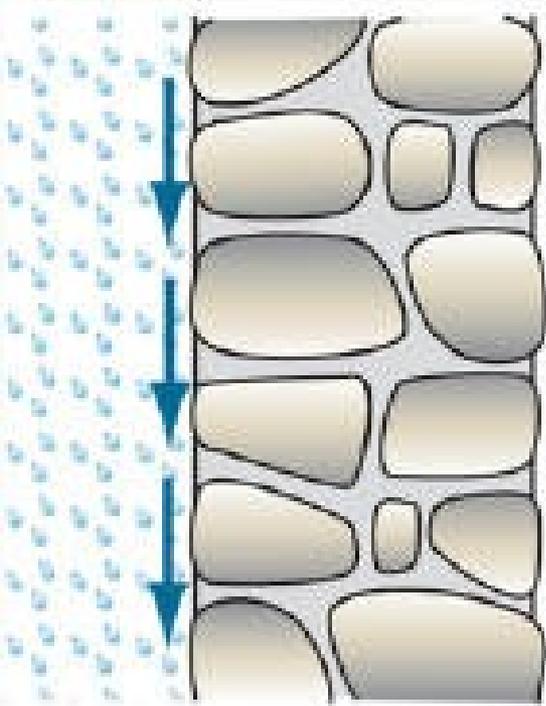


Conditioned Attic

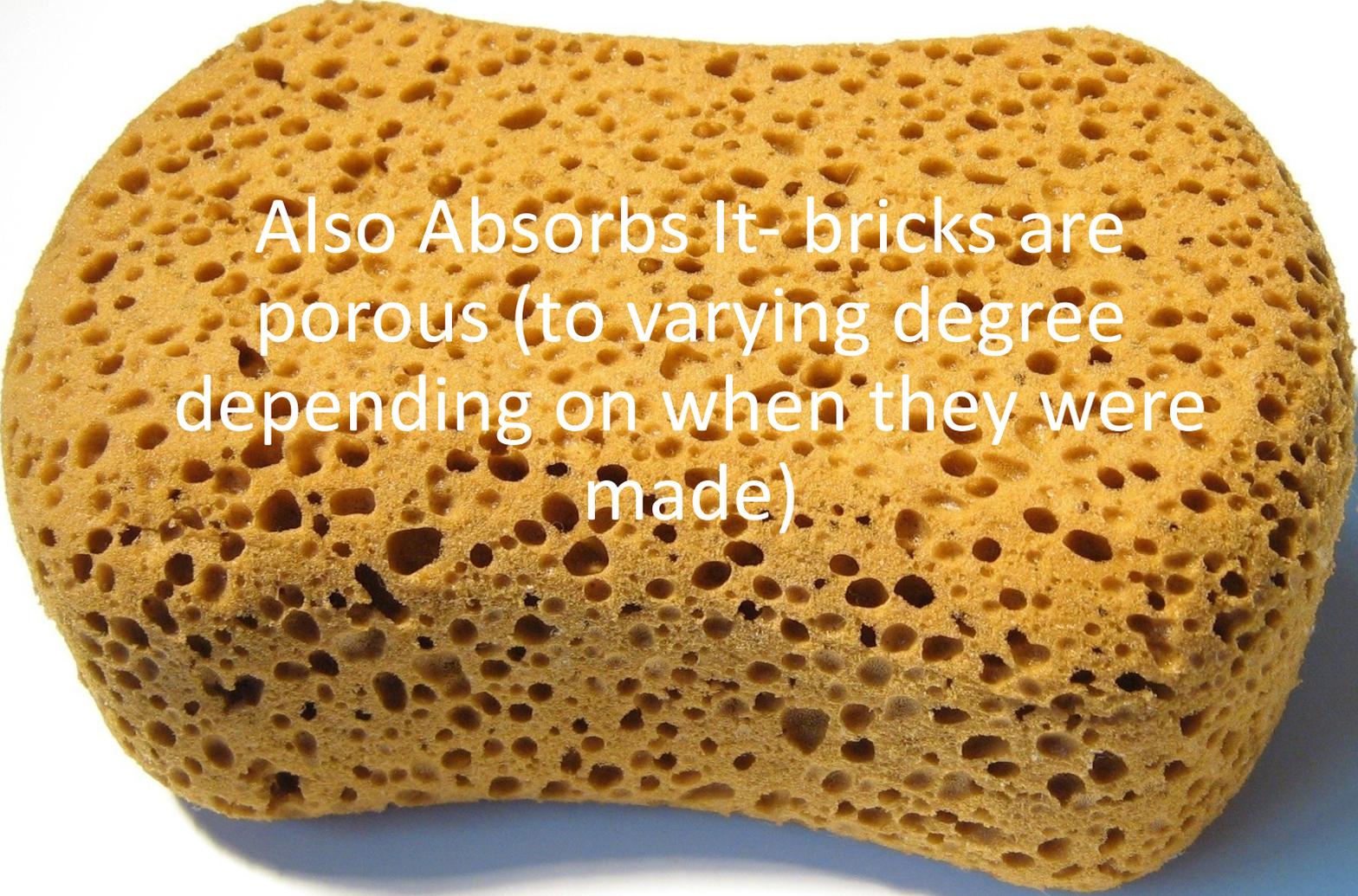


Vented Attic

Mass wall with no insulation
How does it manage WAVT



Inherently sheds water
but...



Also Absorbs It- bricks are porous (to varying degree depending on when they were made)

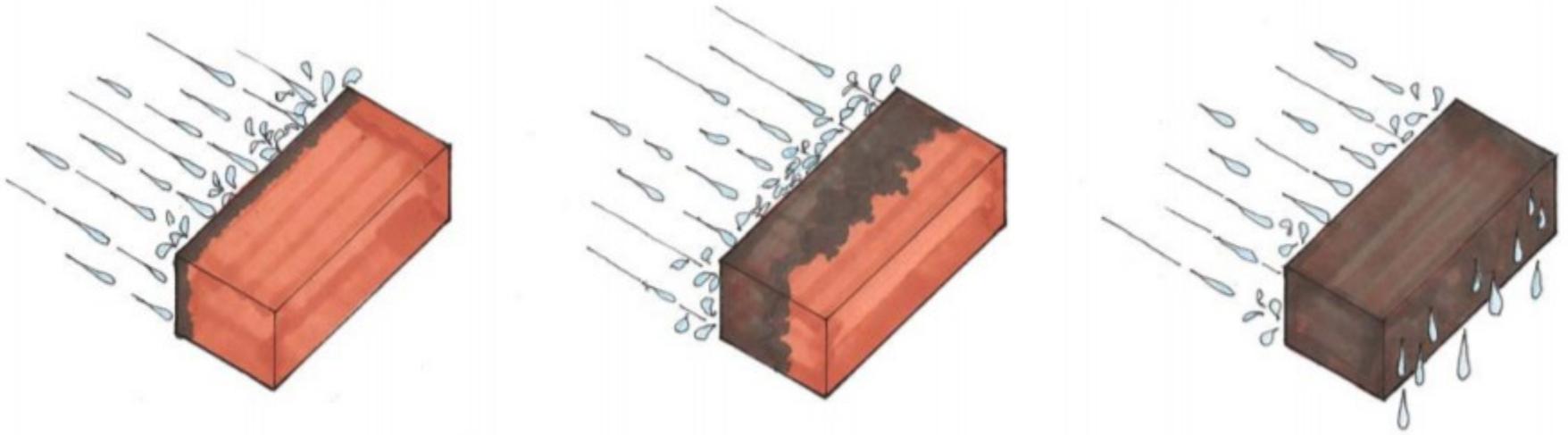


Figure 3 – Progression of moisture absorption.

[images courtesy of Chris Crissinger]



Hygroscopic salts within
brick also attract
moisture

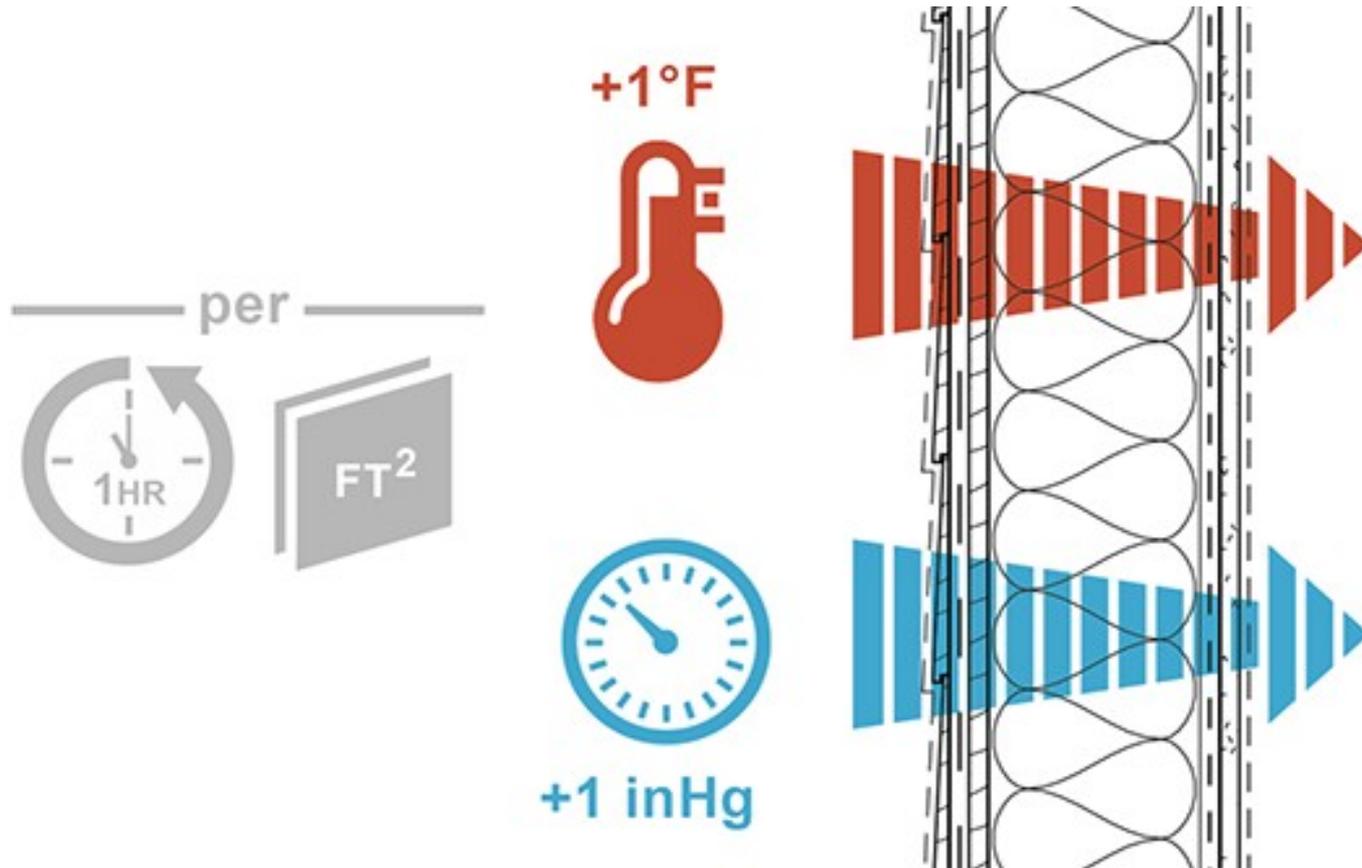


Fortunately solid masonry buildings have a high drying potential

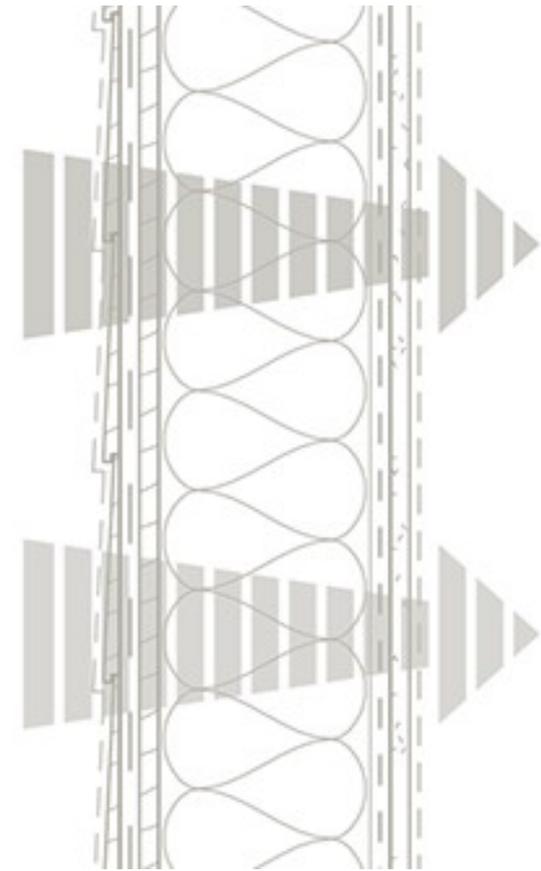
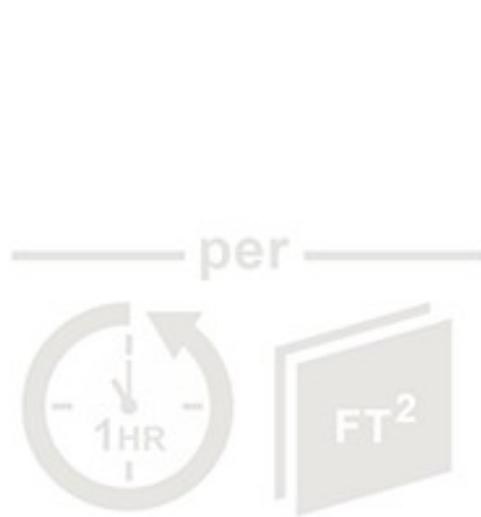


Masonry walls are permeable

Permeability vs. Permeance



[images courtesy of Daniel Overbey]



PERMEABILITY

*THICKNESS OF
MATERIAL*



*PERMEANCE
(PERMS)*

PERMEABILITY

A material property

[not dependent on thickness]

Measure of the ease with which
water vapor passes through 1" of
material

The unit is perm-inch

PERMEANCE

A layer value

[per specific thickness of material]

One perm equals the transmission of 1 grain of water vapor per hour per square foot of material under a vapor pressure difference of 1 inch of mercury

The unit is perm



ASTM E96

wet cup vs. dry cup

Method A

desiccant/dry cup

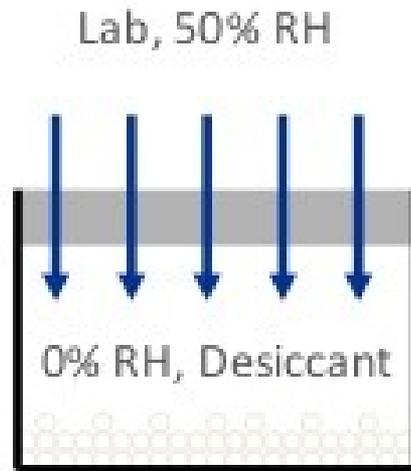


Method B

wet cup

Method A

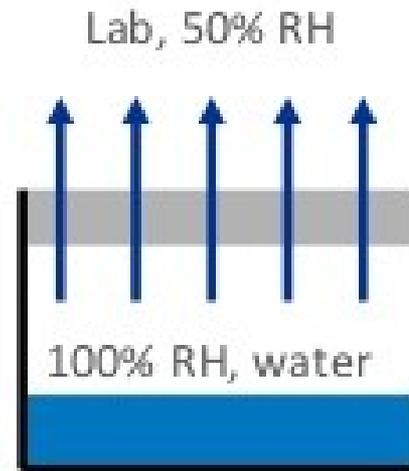
measures permeance of material when it is dry



DRY CUP –
Average RH = 25%

Method B

measures permeance of material when it is damp

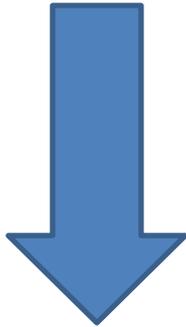


WET CUP –
Average RH = 75%

For many materials...

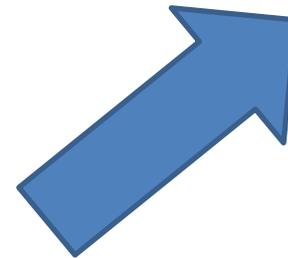
Dry

lower permeance



Damp

permeance rises



Some people refer to materials
with a variable permeance as
“smart retarders.”



Material	Typical Relevant Dimension	Water Vapor Permeability (perm-inch) ¹		Water Absorption ²	R-Value	Other Relevant Properties	Comments	Web Link for More Information
		Dry Cup	Wet Cup					
Exterior Sheathings								
Plywood (CDX)	3/8"	0.75	3.5	na	0.5	FS =76-200 SD =130	At saturation, factor of 10 increase in permeability -- 14 - 20.5 perms	More Information
OSB	3/8"	0.75	2	na	0.5	FS = 148 SD= 137	At saturation, marginal increase in permeability - 2.8 - 3.4 perms	More Information
Fiberboard - asphalt impregnated	7/16"	14.5	15	2.3 - 7%	1.2	FS > 75 AP=0.82	Among the most vapor permeable of exterior sheathings	More Information More Information
Thin profile structural sheathing	.078" - .137"	0.5 - 0.6	0.5 - 0.6	na	0.2 - 3.4		R-value dependent on air space; this sheathing is essentially an exterior vapor barrier	More Information
Foil-faced PIR insulation	1"	0.01	0.03	0%	7	FS = 5 SD = 165	Combined thermal, vapor transmission & combustion properties must be used appropriately	More Information
XPS rigid insulation	1"	1	1	0.10%	5	FS = 5 SD = 165	Compare/contrast moisture properties to	More Information

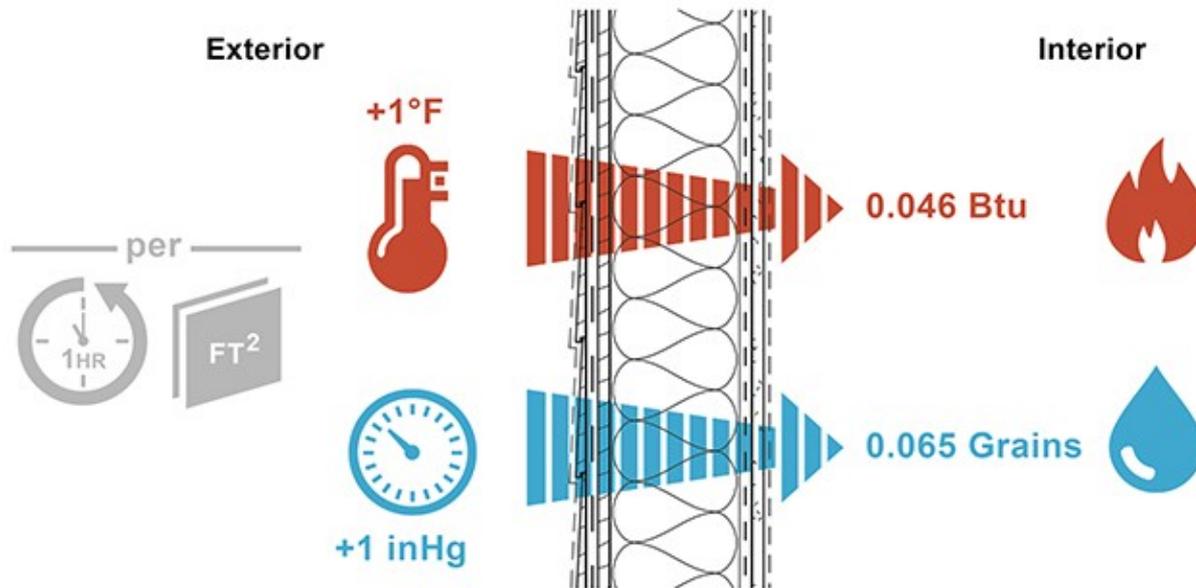
Vapor Retarder Classifications (IECC)

Class I
 $0.1 \text{ perm} > x$
impermeable

Class II
 $1 \text{ perm} > x > 0.1 \text{ perm}$
Semi-impermeable

Class III
 $10 \text{ perm} > x > 1 \text{ perm}$
Semi-permeable

$x > 10 \text{ perm}$
permeable



**Total Assembly R-Values
for Thermal and Water Vapor Transmission Resistance**

Component	R _t -Value* (h • °F • ft ² /Btu)	Permeance** (perms or gr/h • ft ² • in.Hg)	R _p -Value (1/perms)	Classification (based on perms)
Inside air film	0.68	---	---	---
Interior latex paint	---	7.00	0.14	Vapor semi-permeable
Gypsum board, 1/2 in.	0.45	50.00	0.02	Vapor permeable
Polyethylene film vapor retarder, 4 mil	---	0.08	12.50	Vapor impermeable
Fiberglass batt insulation, kraft-faced, nominal 6 in.	19.00	1.00	1.00	Vapor semi-impermeable
Plywood, Douglas Fir, exterior glue, 1/2 in.	0.62	0.70	1.43	Vapor semi-permeable
Weather-resistant barrier (air and water), 6.1 mil ***	---	48.00	0.02	Vapor permeable
Wood siding, 1/2 in. x 8 in., lapped	0.81	10.00	0.10	Vapor semi-permeable
Exterior acrylic paint, dry film thickness	---	5.47	0.18	Vapor semi-permeable
Outside air film	0.17	---	---	---
Total resistance (ΣR _t)	21.73	Total resistance (ΣR _p)	15.40	
U-factor (thermal transmission rate) = 1/ΣR_t	0.046	Permeance = 1/ΣR_p	0.065	

* Source: Grondzik, Walter T., Alison Kwok. *Mechanical and Electrical Equipment for Buildings*, 12th Edition. John Wiley & Sons (2014), unless noted otherwise.

** Source: Nash, Art., Richard Seifert. *Permeability of Common Building Material to Water Vapor*. Cooperative Extension Service. University of Alaska Fairbanks. 2013.

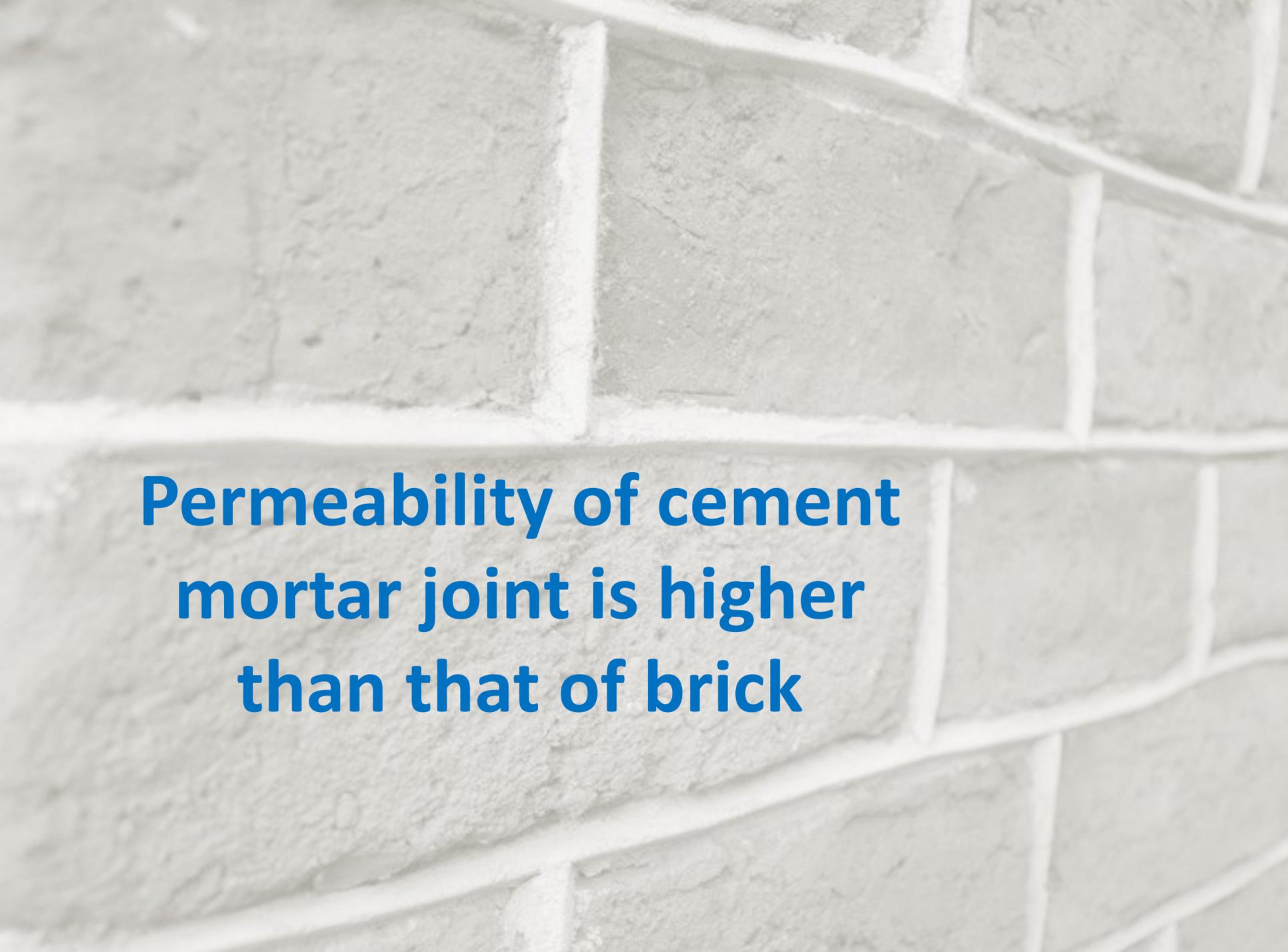
*** WRB in this example is single bonded polyethylene.

**4" of brick is about 0.8 perm.
Considered semi-impermeable.
Equivalent to Class II vapor retarder
(By comparison GWB is 50 perms)**



3 wythes of 4" of brick is about 0.27 perm
 $1/(1/0.8+1/0.8+1/0.8)$



A close-up photograph of a brick wall. The bricks are light-colored and arranged in a standard pattern. The mortar joints are visible between the bricks. The text is overlaid on the lower-left portion of the image.

**Permeability of cement
mortar joint is higher
than that of brick**



Masonry
property

MASS

Retains Heat



INSULATION

Impedes Heat



MASS WALL

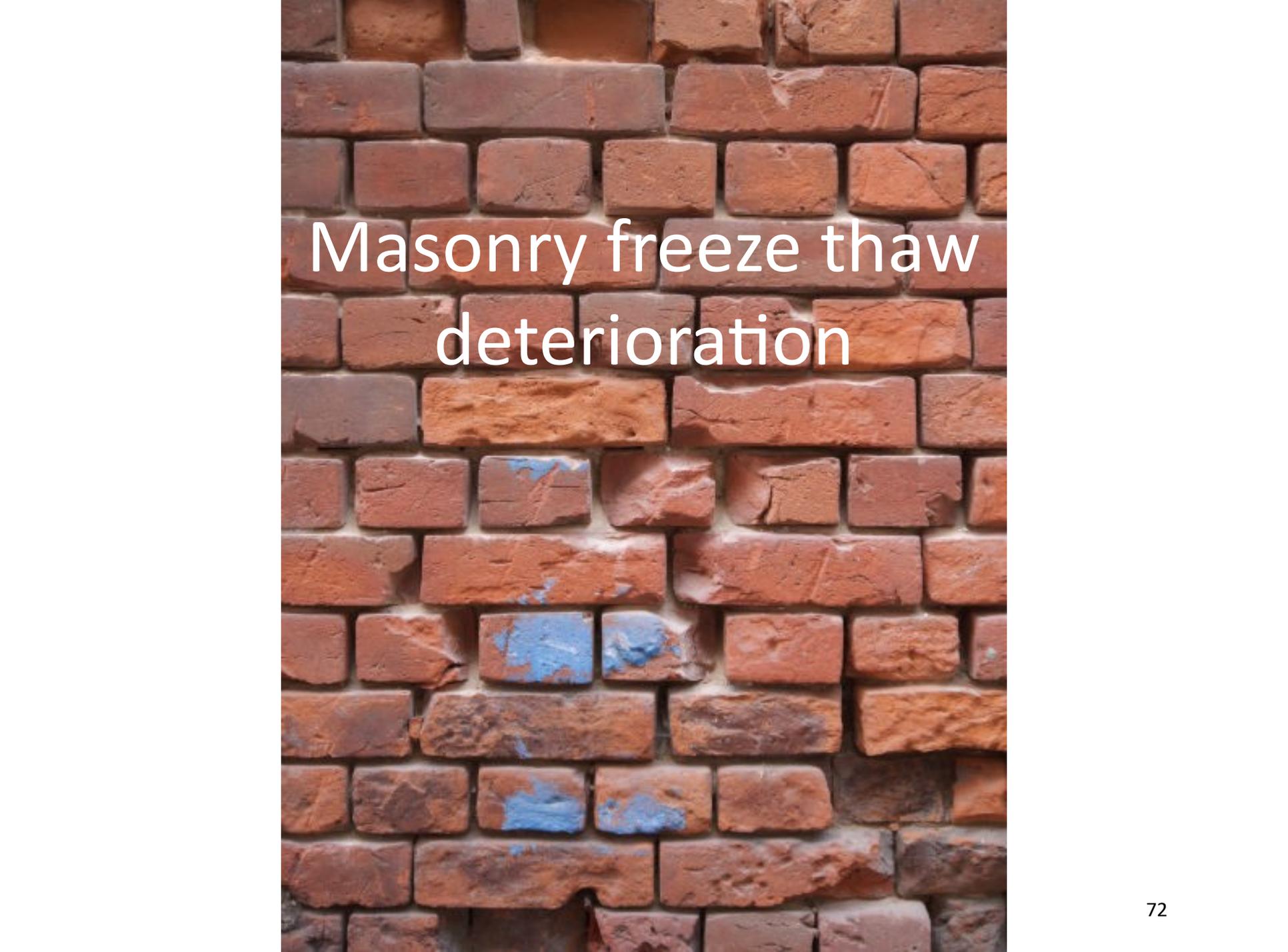
What happens when you insulate it?

How does the location of the insulation impact the wall's performance?



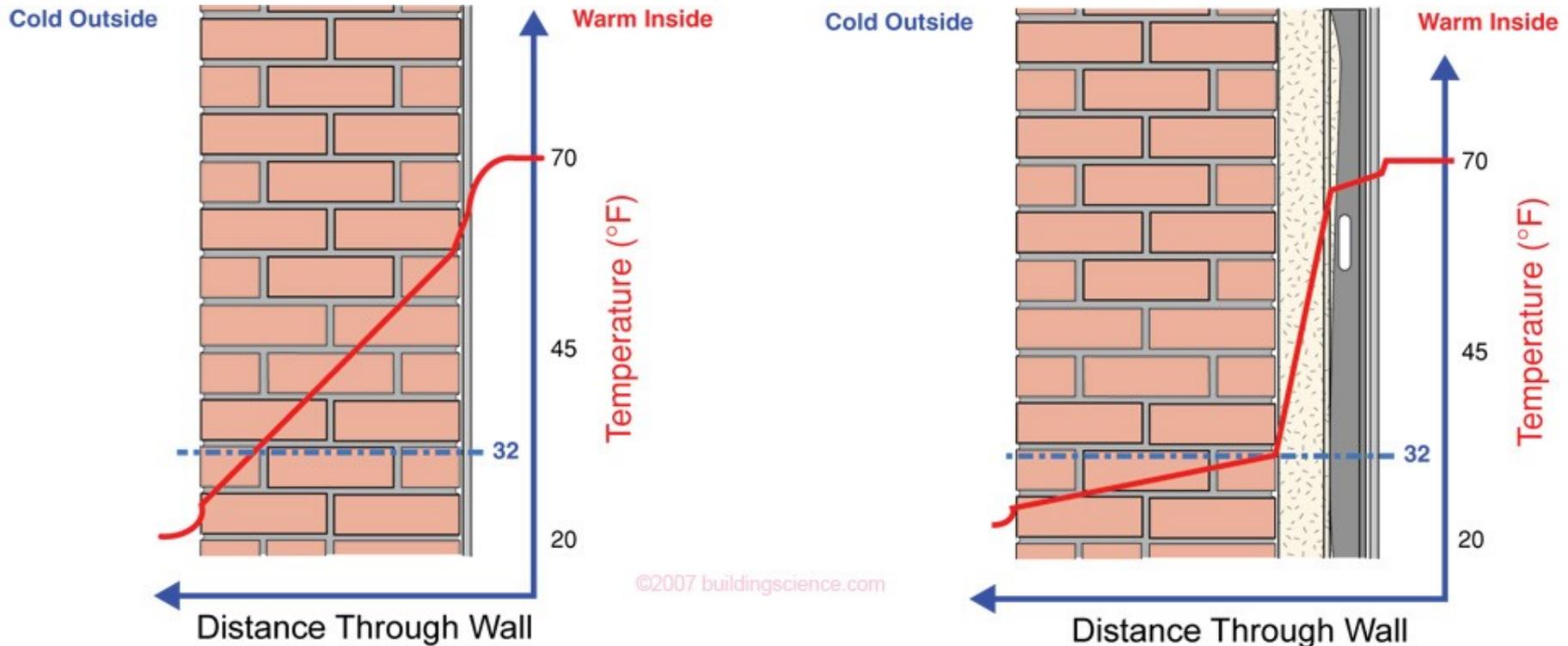
Interior insulation



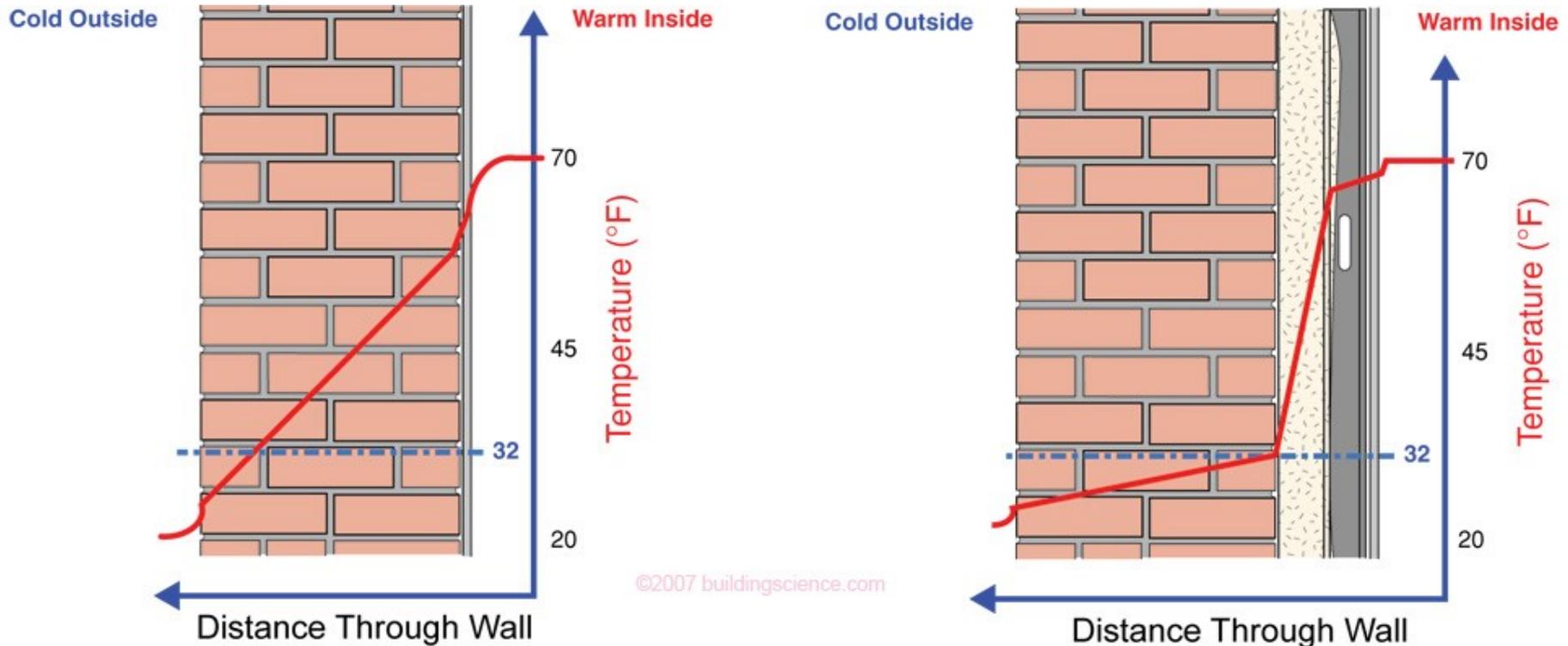


Masonry freeze thaw deterioration

More of the brick gets cold, and has less drying potential



Thickness of insulation is critical. Thicker is not necessarily better



Embedded steel corrosion



Interior plaster finish deterioration



Wood joist rot



Mold growth

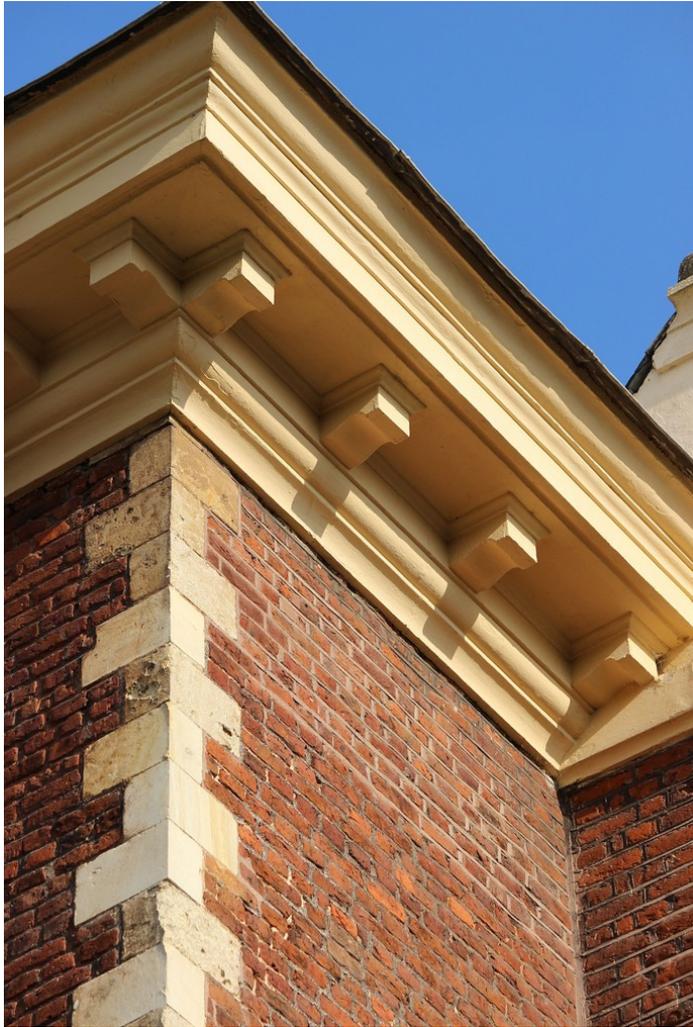




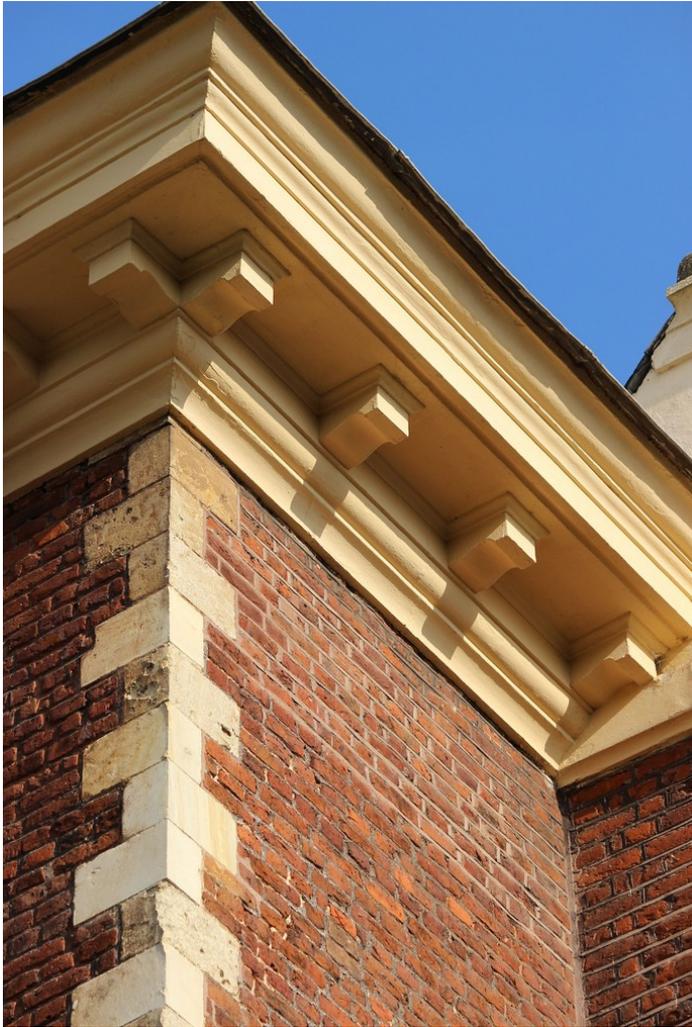
Is it better to just concentrate on W.A.V. and not worry about T with interior insulation strategies?



“Sometimes you just don’t insulate the walls. Even if the walls are left uninsulated, you can often reduce heating demand by 50% by addressing air sealing, the basement, the roof, and the windows”
- J. Straube



Remember... W is most important. If the brick is pretty dry, then freeze-thaw is less damaging



“You can insulate walls to a great extent if water isn’t concentrated on the surfaces,”
- J Lstiburek



Mechanical
systems can help
promote drying

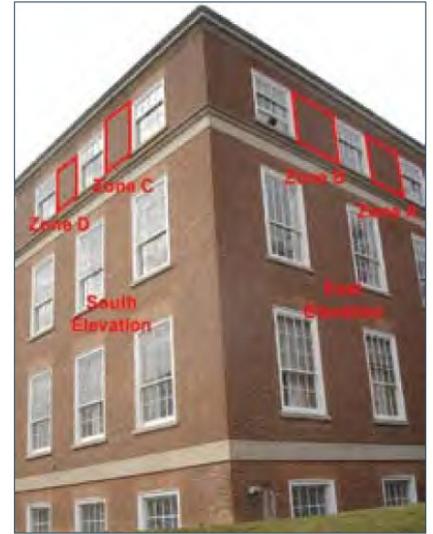


A 3D rendered illustration of a magnifying glass with a dark handle and a silver rim, positioned over a stack of several light-colored folders. The magnifying glass is focused on the text 'PRIVATE SCHOOL [TORONTO]' which is overlaid on the folders. The text is in a bold, orange, sans-serif font.

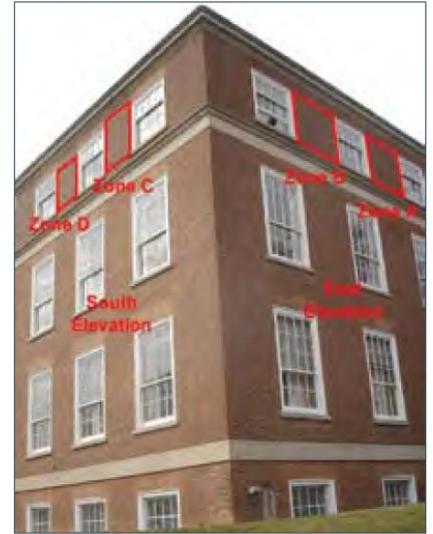
PRIVATE
SCHOOL
[TORONTO]

STRAUBE *ET AL*, 2009

- 1950's
- Exterior: 3 wythes load bearing brick
- Interior: hollow clay tiles & painted plaster finish



4 test conditions
(2 on each façade):



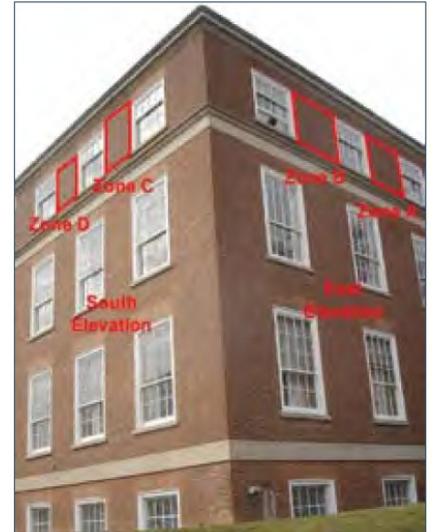
A – Masonry wall, hollow clay tile, plaster, paint [uninsulated]

B – Masonry wall, SPF (1.9”), air space (1”), drywall (1/2”), paint

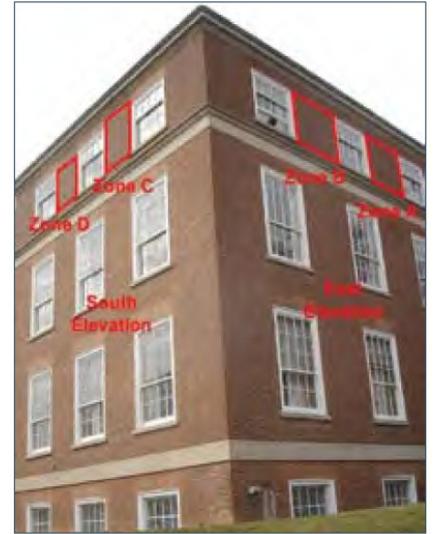
Straube et al, 2009

Below average winter climatic conditions during the monitoring period.

- About half the expected rain wetting
- below average number of 32 degree crossings.



Low freeze-thaw risk,
and minor increase in
steel corrosion.



Straube et al, 2009

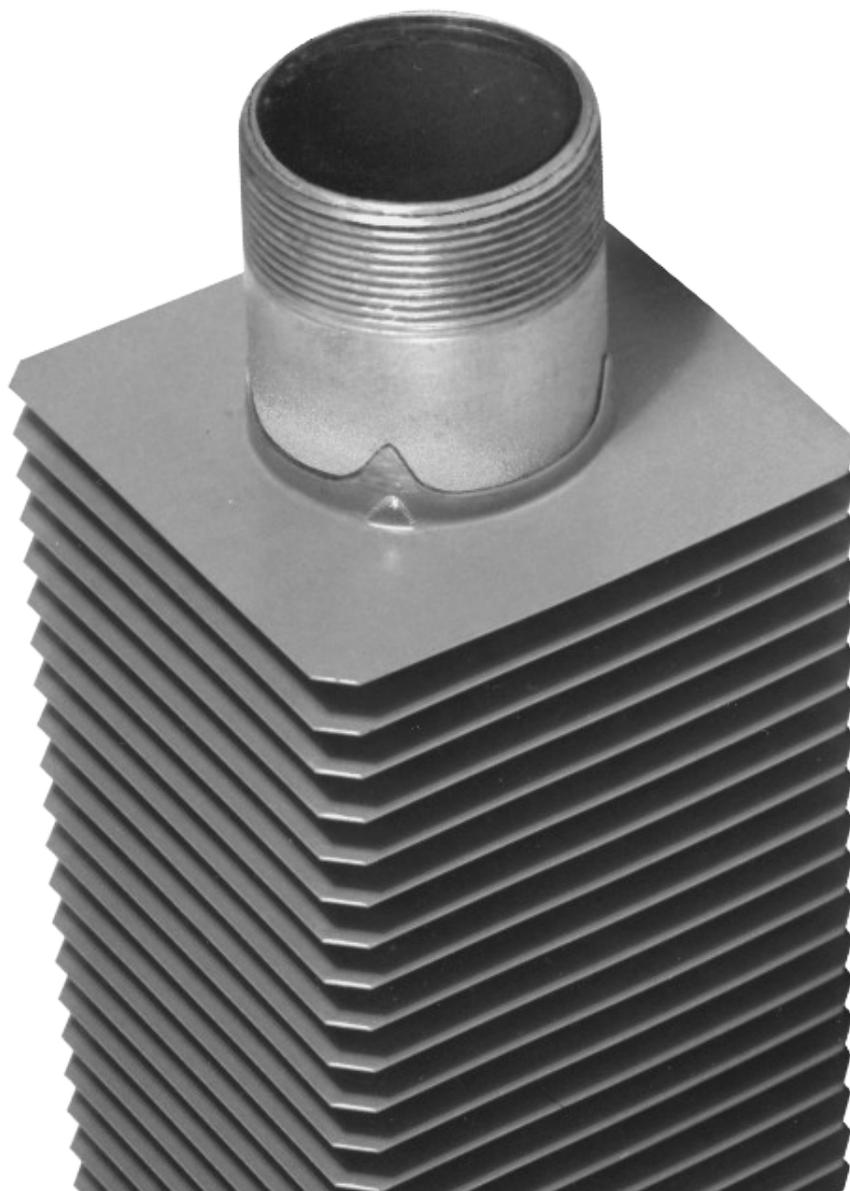
Exterior insulation

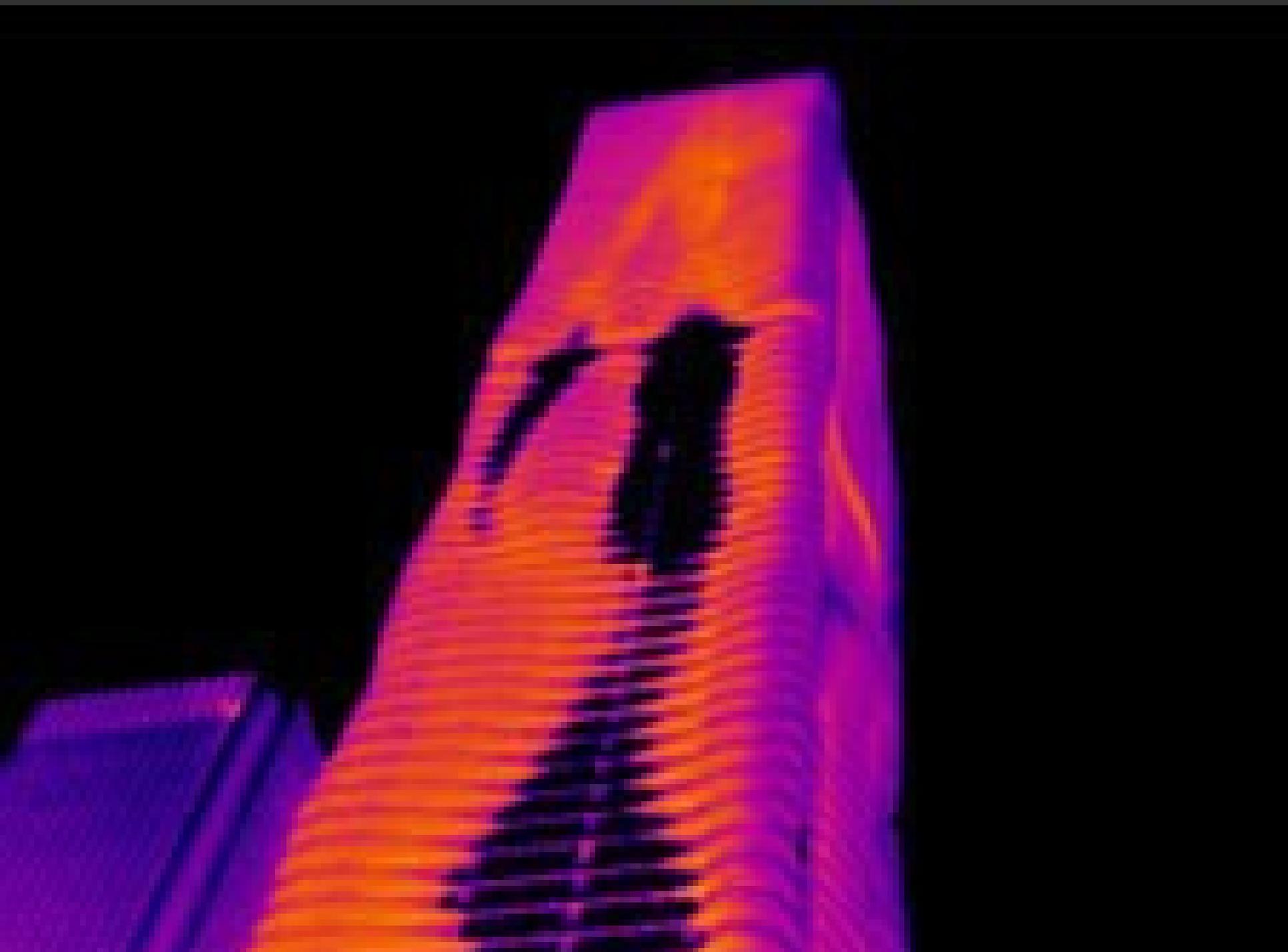


A wooden sign with the text "PEACE OF MIND" is mounted on a post. The sign is made of light-colored wood and has a double-headed arrow shape. The text is in a bold, blue, sans-serif font. The background is a bright blue sky with white clouds and a blurred ocean horizon.

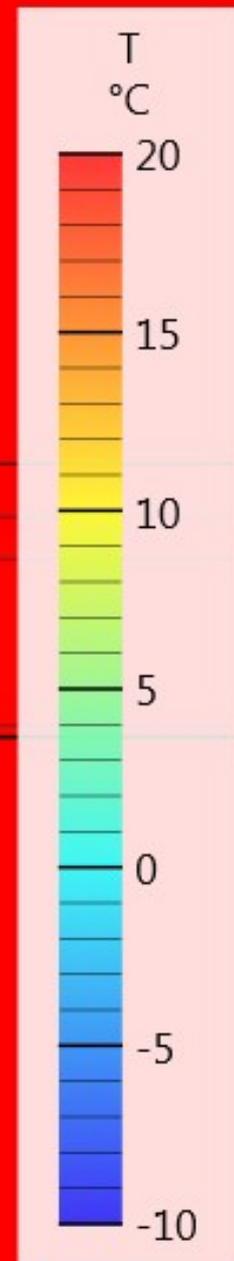
PEACE OF MIND

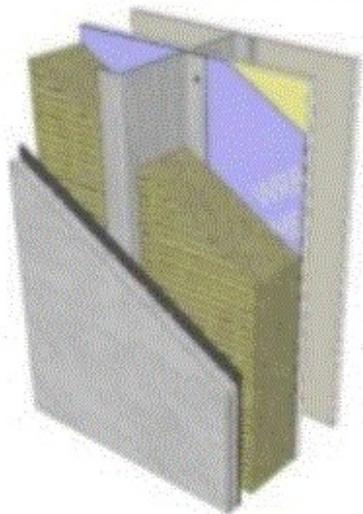




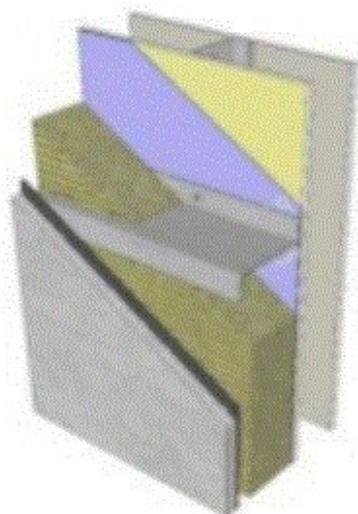


$\Psi = 0,107 \text{ W}/(\text{mK})$

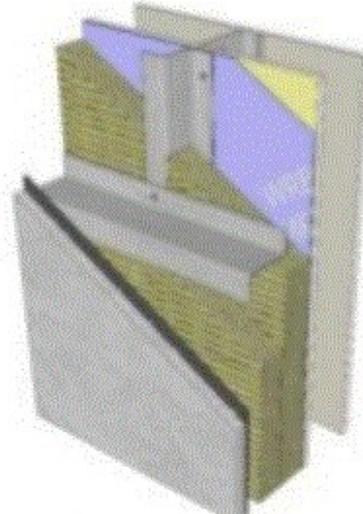




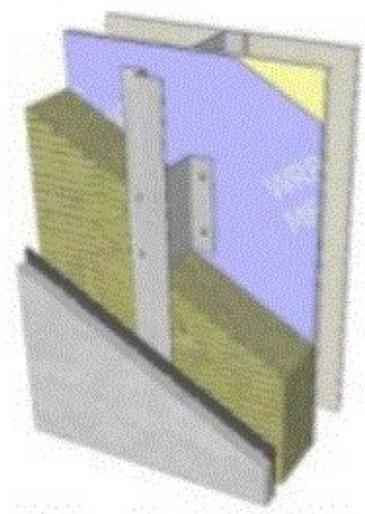
Vertical Z-girts



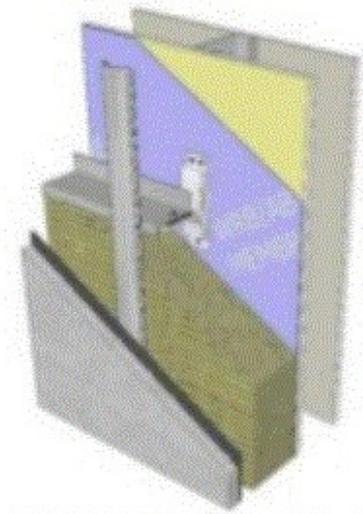
Horizontal Z-girts



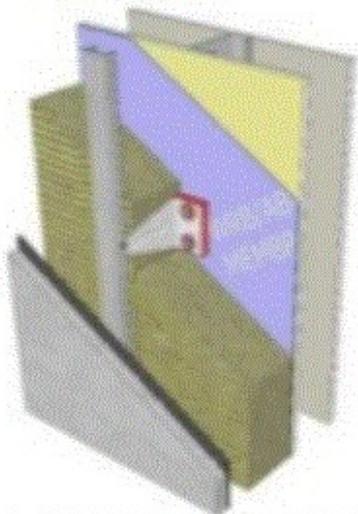
Crossing Z-girts



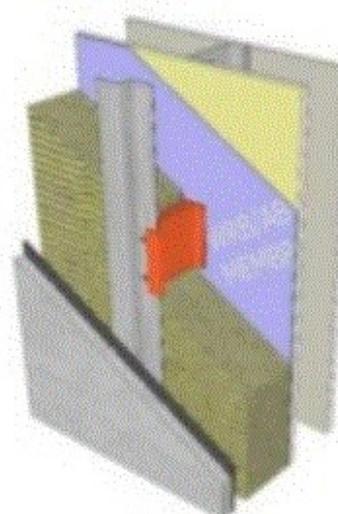
*Galvanized/Stainless
Clip & Rail*



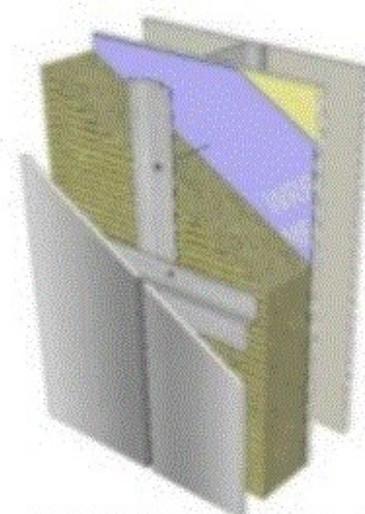
Aluminum Clip & Rail



*Thermally Improved
Clip & Rail*



*Non-
Conductive Clip*



*Long Screws through
Insulation*

Climate Zones



It gets cold and wet... but not as bad as New England, or Canada.

Zone 4, IRC	IECC 2009	IECC 2012	IECC 2015	IECC 2018
Ceiling	R-38	R-49	R-49	R-49
Wood frame wall	R-13	R-20 or 13+5 [^]	R-20 or 13+5 [^]	R-20 or 13+5 [^]
Mass wall *	R-5/10	R-8/13	R-8/13	R-8/13
Floor	R-19	R-19	R-19	R-19
Basement wall **	R-10/13	R-10/13	R-10/13	R-10/13
Slab ***	R-10, 2 ft	R-10, 2 ft	R-20, 2 ft	R-20, 2 ft
Crawl space wall **	R-10/13	R-10/13	R-10/13	R-10/13

Abbreviations: ci = continuous insulation | NR = no requirement | LS = liner system

* Second R-value applies when more than half the insulation is on the interior of the mass wall

** R-10/13 means R-10 ci on interior or exterior or R-13 cavity insulation at the interior of the basement wall

*** R-5 shall be added to the required slab edge R-value for heated slabs.

[^] First value is cavity insulation, second is ci or insulated siding.

Effective Insulation/Framing Layer R-Values

Steel-framed wall information adapted from ANSI/ASHRAE/IESNA Standard 90.1-2007 Table A9.2B.

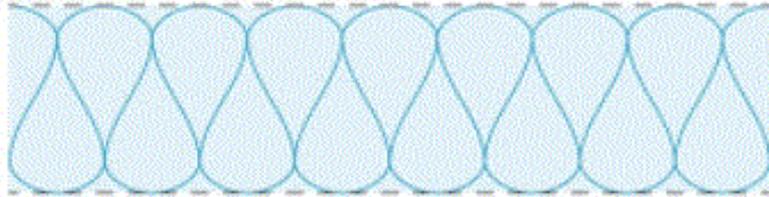
Stud Wall Framing Type	Nominal Cavity Depth (inches)	Actual Cavity Depth (inches)	Rated R-Value	Effective R-Value at 16 in. on Center ¹	% Change (Rated vs Effective)	Effective R-Value at 24 in. on Center ²	% Change (Rated vs Effective)
Batt Insulated Cavity							
Steel	4	3.50	R-11	R-5.5	-50%	R-6.6	-40%
Steel	4	3.50	R-13	R-6.0	-54%	R-7.2	-45%
Steel	4	3.50	R-15	R-6.4	-57%	R-7.8	-48%
Steel	6	6.00	R-19	R-7.1	-63%	R-8.6	-55%
Steel	6	6.00	R-21	R-7.4	-65%	R-9.0	-57%
Steel	8	8.00	R-25	R-7.8	-69%	R-9.6	-62%
Wood	4	3.50	R-11	R-9.3	-15%	R-9.5	-14%
Wood	4	3.50	R-13	R-10.8	-17%	R-11.1	-15%
Wood	4	3.50	R-15	R-12.3	-18%	R-12.7	-15%
Wood	6	5.50	R-19	R-16.0	-16%	R-16.3	-14%
Wood	6	5.50	R-21	R-17.5	-17%	R-17.9	-15%
Wood	8	7.50	R-25	R-21.1	-16%	R-21.5	-14%

* Rating for airspace per ANSI/ASHRAE/IESNA Standard 90.1-2007.

¹ Per the ASHRAE Handbook of Fundamentals, a residential wall framing factor of 25 percent is assumed for conventional framing at 16 in. on center.

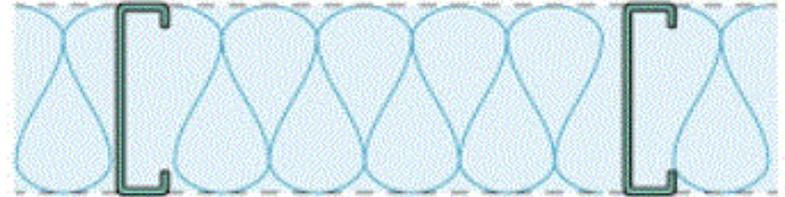
² Per the ASHRAE Handbook of Fundamentals, a residential wall framing factor of 22 percent is assumed for conventional framing at 24 in. on center.

BATT INSULATION



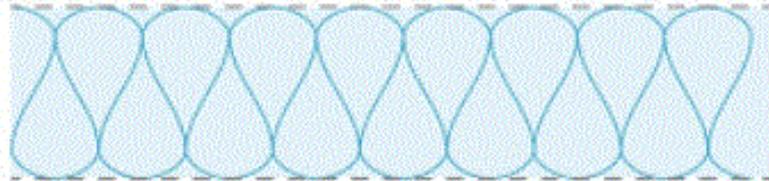
**RATED
R-19**

w/ 2x6 METAL STUDS @ 16" O.C.



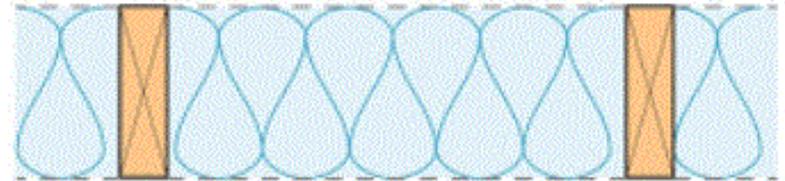
**EFFECTIVE
R-7.1**

BATT INSULATION



**RATED
R-19**

w/ 2x6 WOOD STUDS @ 16" O.C.



**EFFECTIVE
R-16**

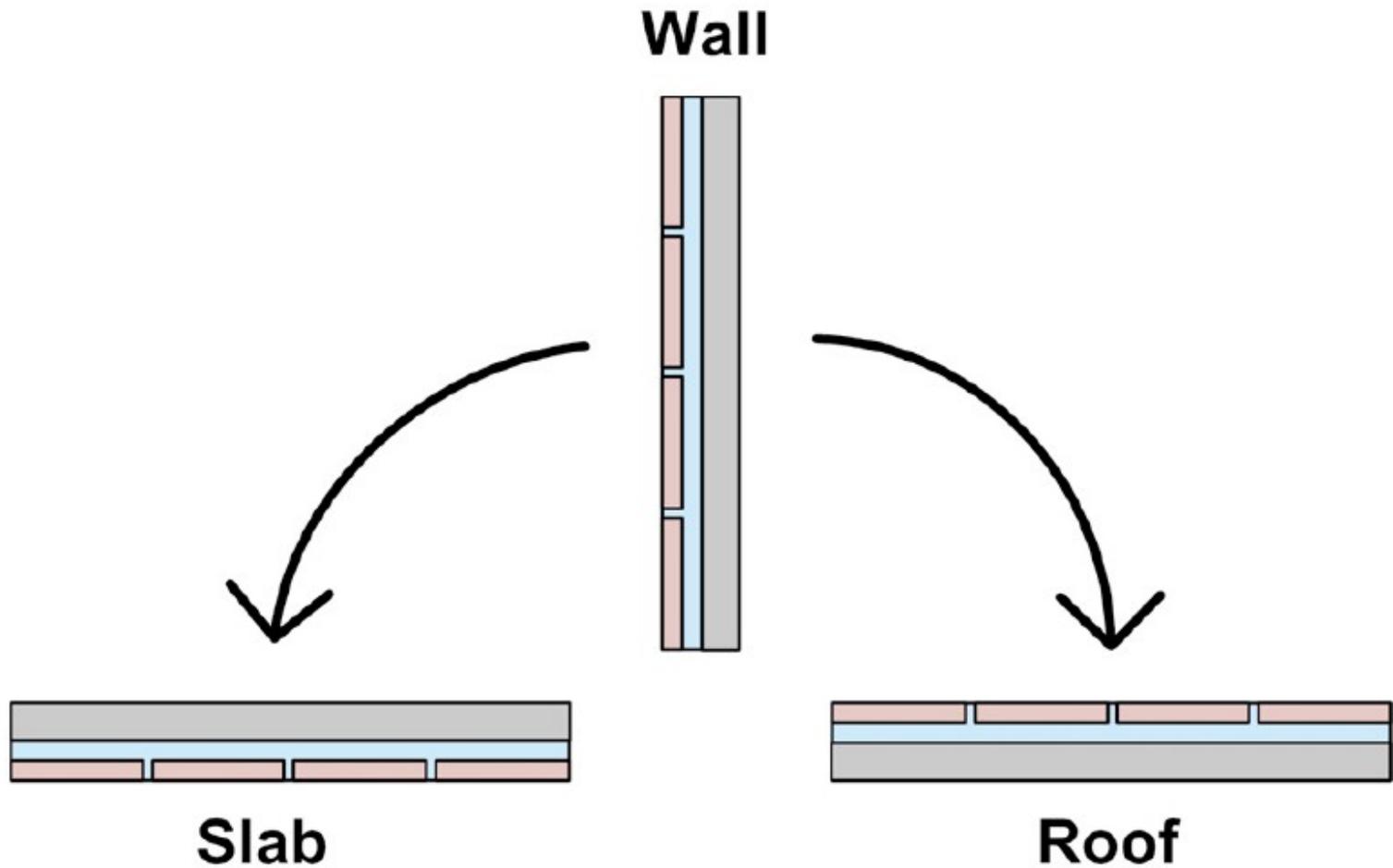
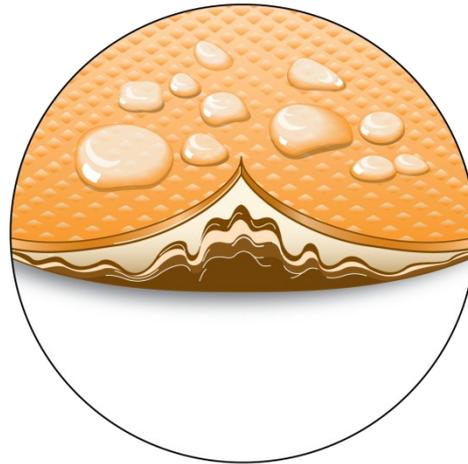
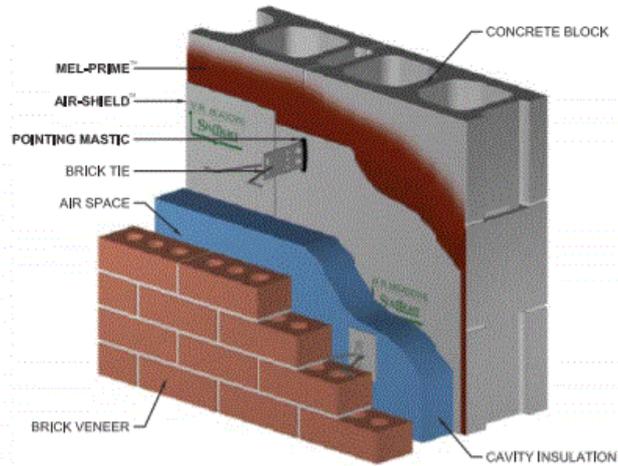


Figure 4: A Wall Is A Roof Is A Slab

The physics of walls, roofs and slabs are conceptually the same.

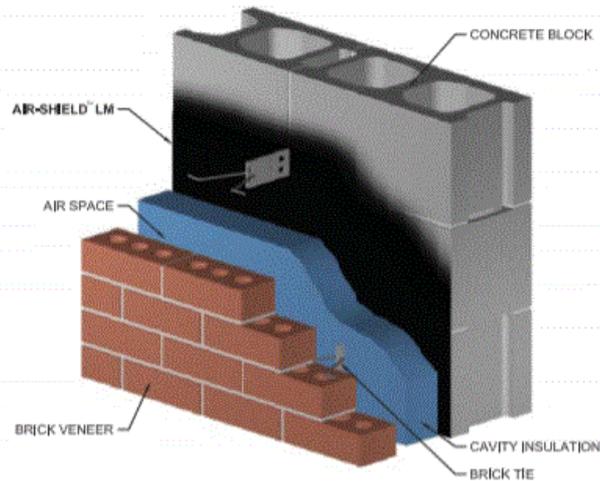


WRAPSHIELD SA[®]
SELF-ADHERED



AIR-SHIELD™

self-adhering air/vapor and liquid moisture barrier is a part of a total system to complete the building envelope. It is a roll-type product that is nominally 40 mils thick. This unique, self-adhesive membrane, protected by a special release paper, is strong and durable. It remains flexible when surface mounted and will adhere to most primed surfaces at minimum temperatures of 40° F (4° C). [A low temperature version for applications between 20° F (-7° C) and 60° F (16° C) is also available.]



AIR-SHIELD™ LM

is a liquid applied, water-based, polymer-modified air/vapor and liquid moisture barrier. AIR-SHIELD LM cures to form a tough, seamless, elastomeric membrane, which exhibits excellent resistance to air and moisture transmission. An all-season version is available for use in lower temps.

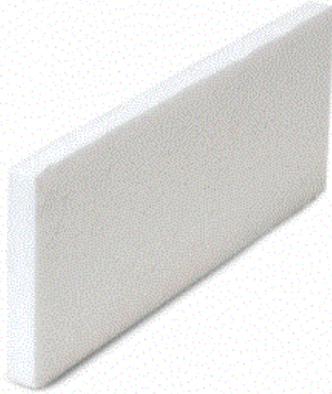
W. R. MEADOWS®

SEALIGHT®

A Family Company Since 1926

QUALITY...SERVICE...INTEGRITY

Expanded Polystyrene



EPS is cheap and effective

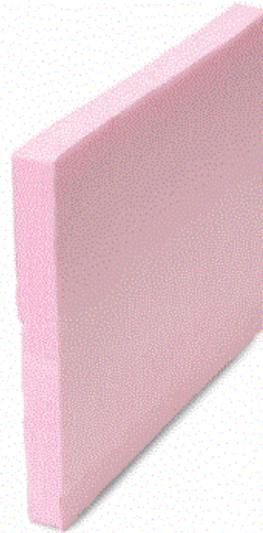
EPS is the least expensive and most vapor-permeable of the three types of rigid foam.

One inch of EPS has a permeance of 2.0 to 5.8 perms, making it a semi-permeable material.

R-value: 3.6 to 4.2 per in., depending on density

EXPANDED POLYSTYRENE

Extruded Polystyrene



XPS is versatile, tough, and waterproof

Because of its high compressive strength and water resistance, XPS is often used below grade to insulate slabs and foundation walls.

One inch of XPS has a permeance of 1.1, while 2 inches have a permeance of 0.55, making XPS a semi-impermeable material.

R-value: R-5 per in.

EXTRUDED POLYSTYRENE

Polyisocyanurate



Polyiso has a higher R-value

Polyiso doesn't use ozone-depleting blowing agents; it uses pentane.

Because it can absorb water, polyiso is not recommended for use under slabs or on the exterior of foundation walls. The foil facing, however, makes it an excellent exterior drainage plane for above-grade walls, as long as seams are taped.

R-value: R-6 to R-6.5 per in. (lower in cold temperatures)

POLYISOCYANURATE