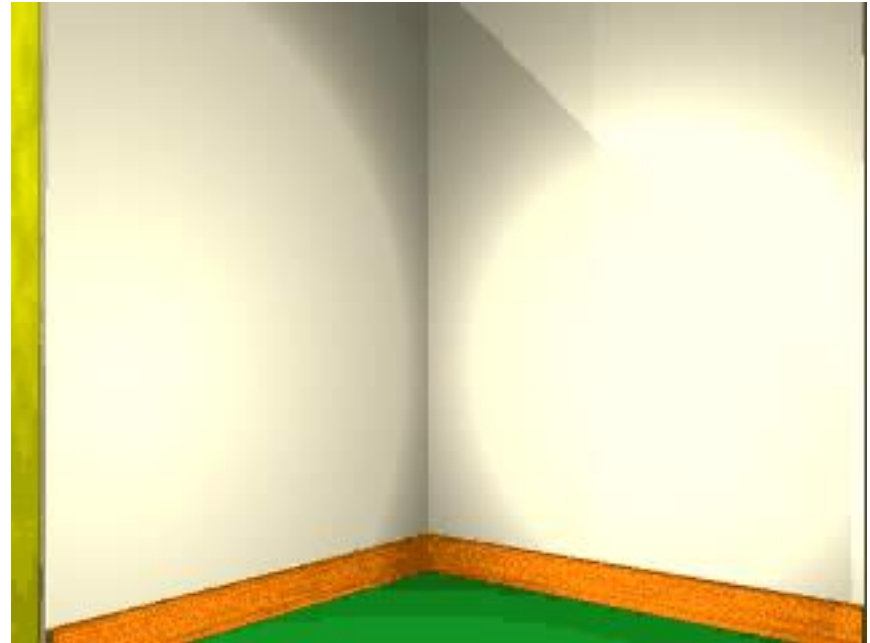
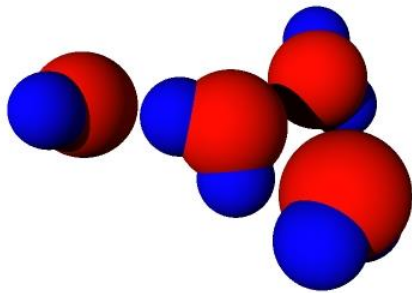


Condensation The Real Story

Dan Tempas
Sr. Scientist



Condensation The Real Story



1982



Chemical Engineering

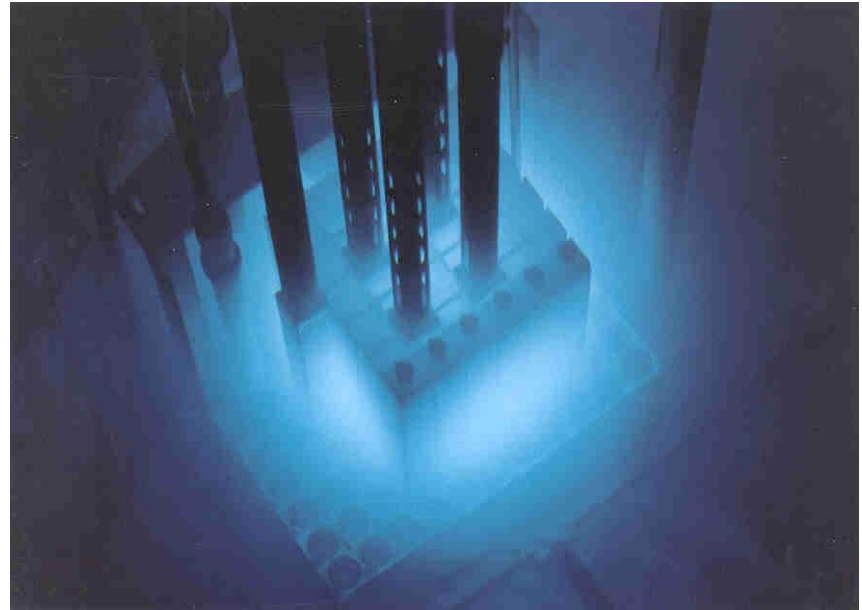
Dan Tempas
Sr. Scientist



Condensation The Real Story



1982



Nuclear Engineering

Dan Tempas
Sr. Scientist



Condensation

March 1, 2013

Condensation Scope

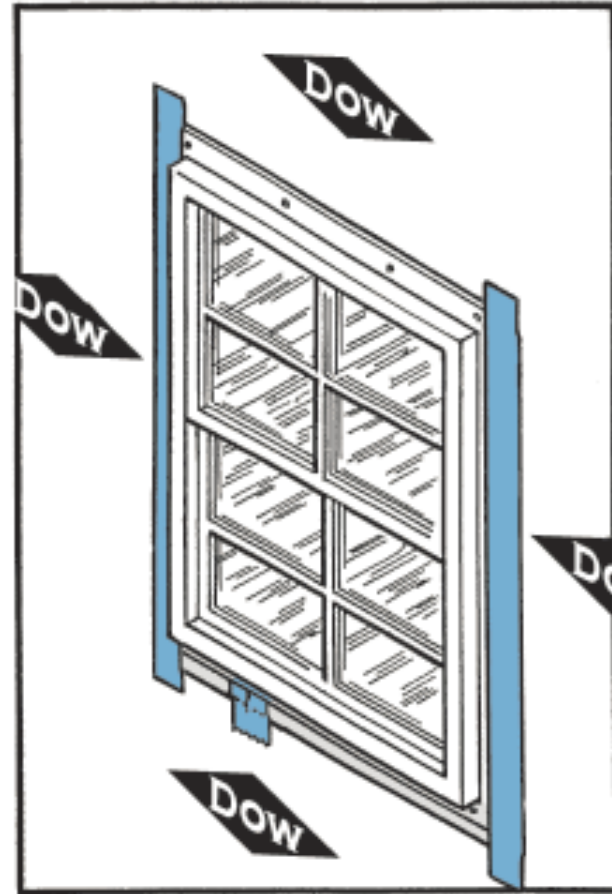
Why This Talk?

- **Misconceptions**
- **Errors**
- **Incompleteness**



Condensation Scope

Not About Bulk Water



Condensation Scope

**Bulk Water is
Important!**



Condensation: The Real Story

- Properties of Water
- Terms Relating to Condensation
- Wetting and Drying
- Analyzing Assemblies
- Wall Design

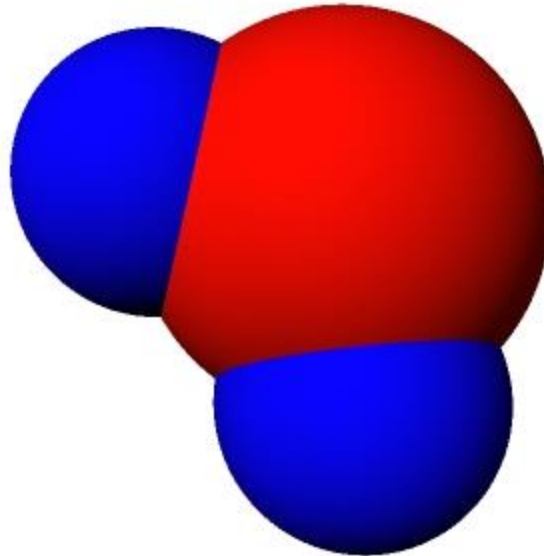
Condensation: The Real Story

- **Properties of Water**

- Terms Relating to Condensation
- Wetting and Drying
- Analyzing Assemblies
- Wall Design

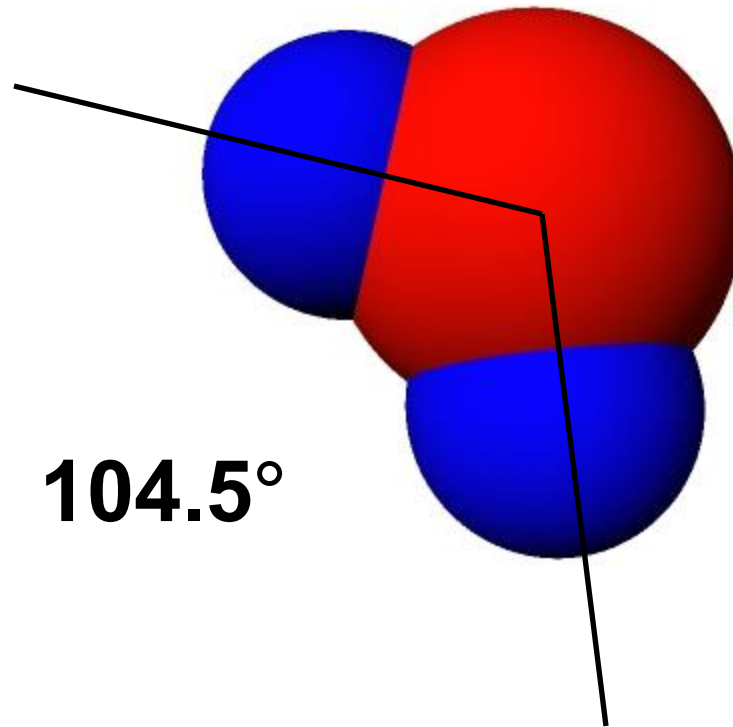
Condensation: Water Properties

Structure



Condensation: Water Properties

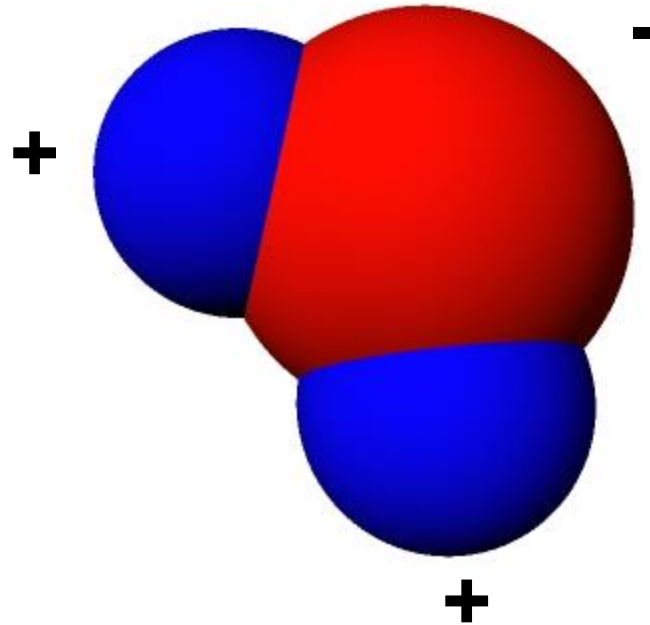
Structure



104.5°

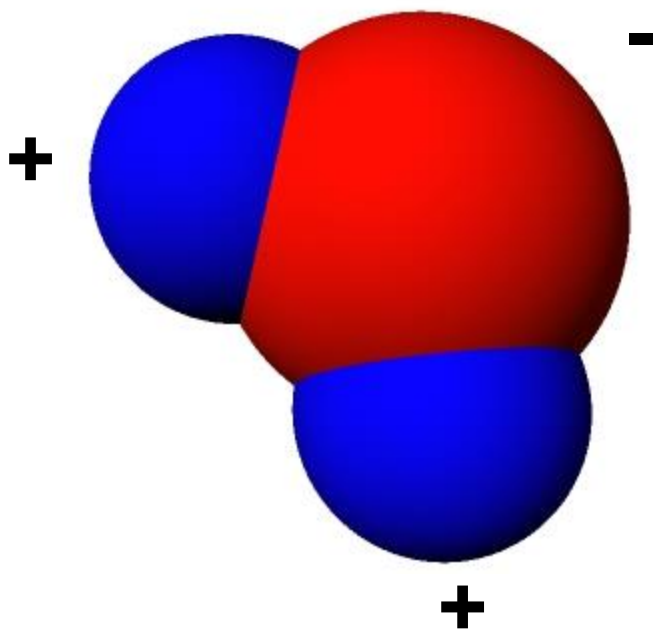
Condensation: Water Properties

Structure



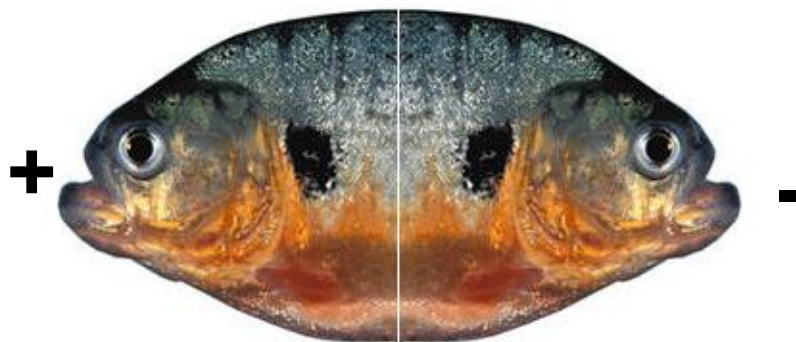
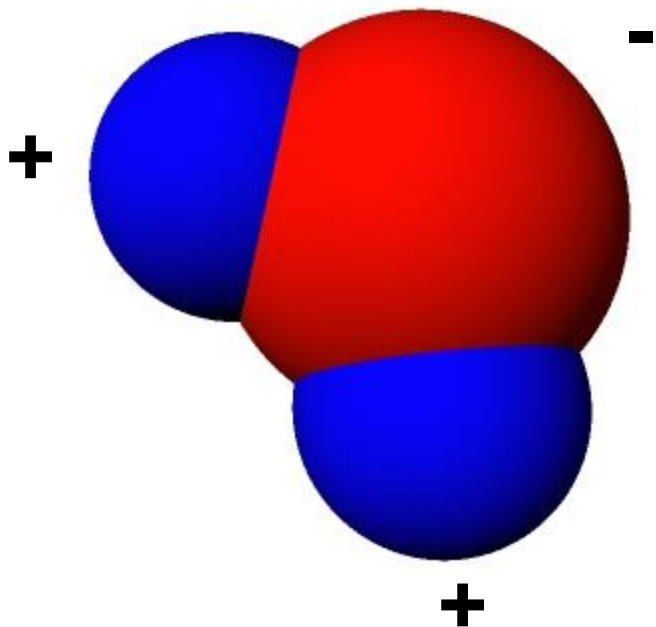
Condensation: Water Properties

Structure



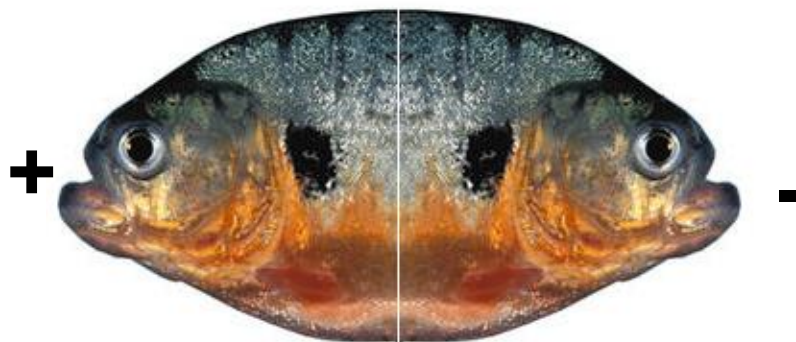
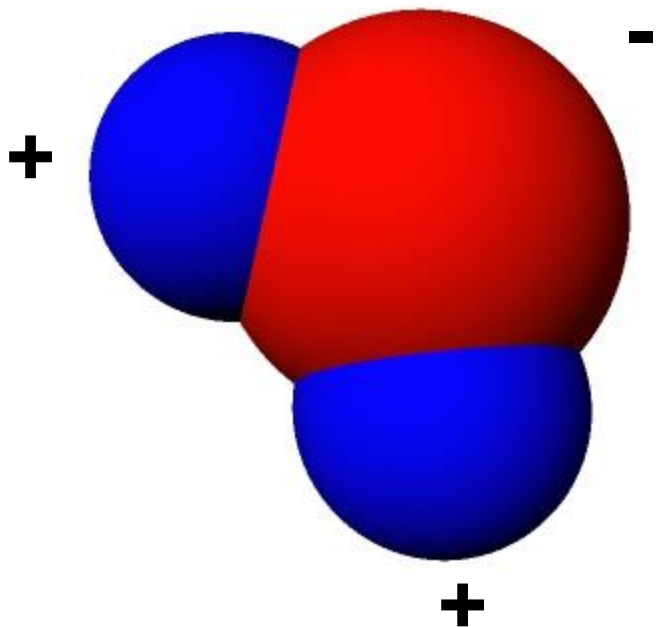
Condensation: Water Properties

Structure



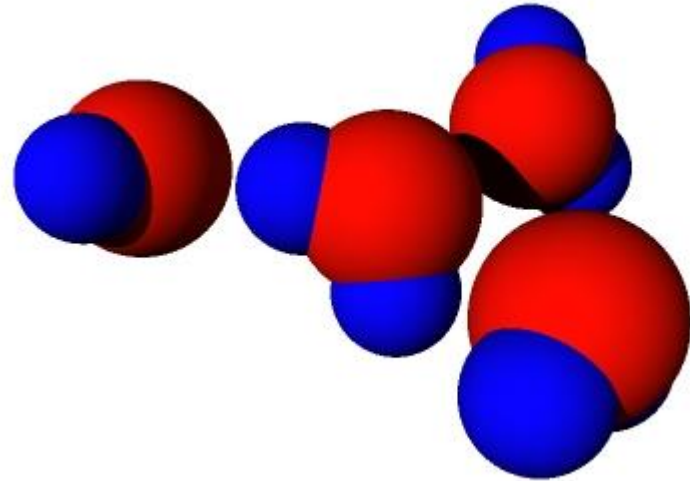
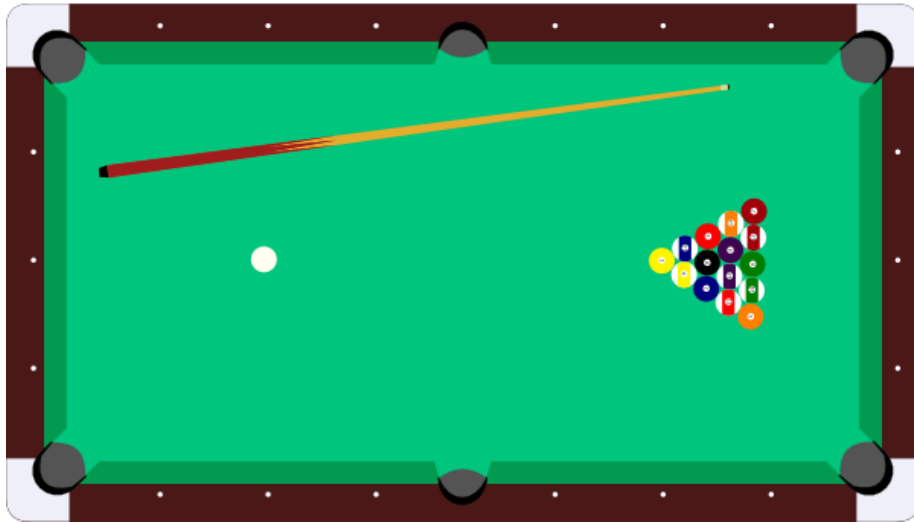
Condensation: Water Properties

Structure



Condensation: Water Properties

Structure



Condensation: Water Properties

Structure



Condensation: Water Properties

Phases of Water

Gas



Condensation: Water Properties

Phases of Water

Liquid



Condensation: Water Properties

Phases of Water

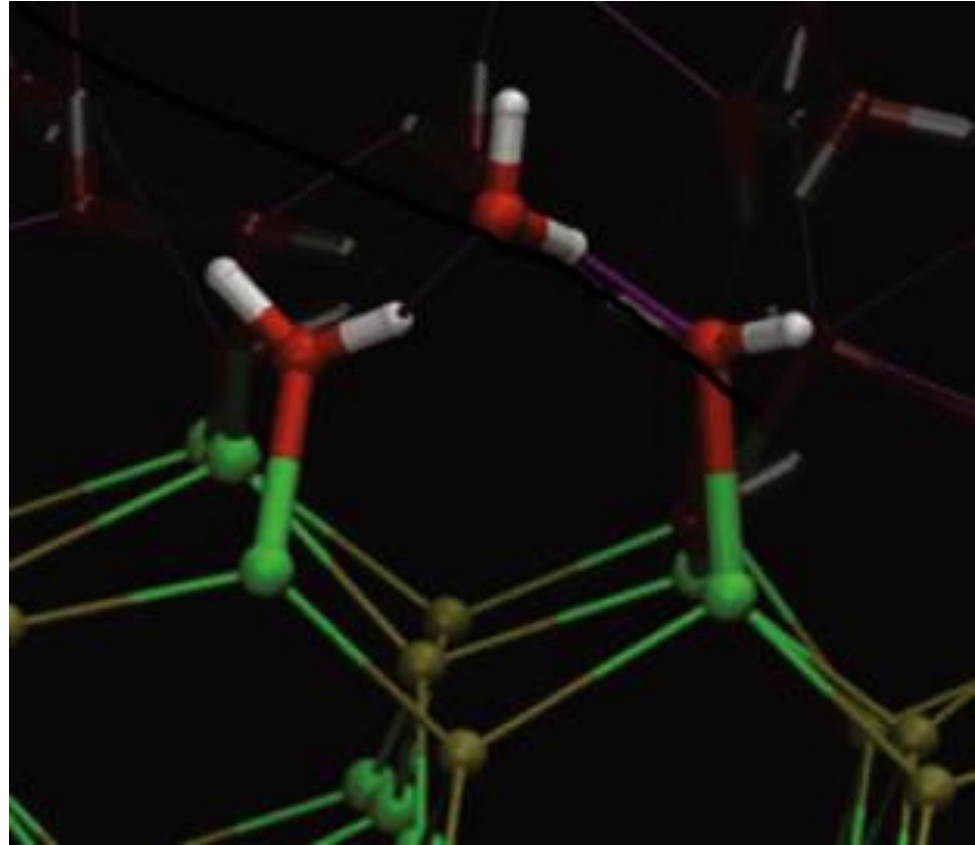
Solid



Condensation: Water Properties

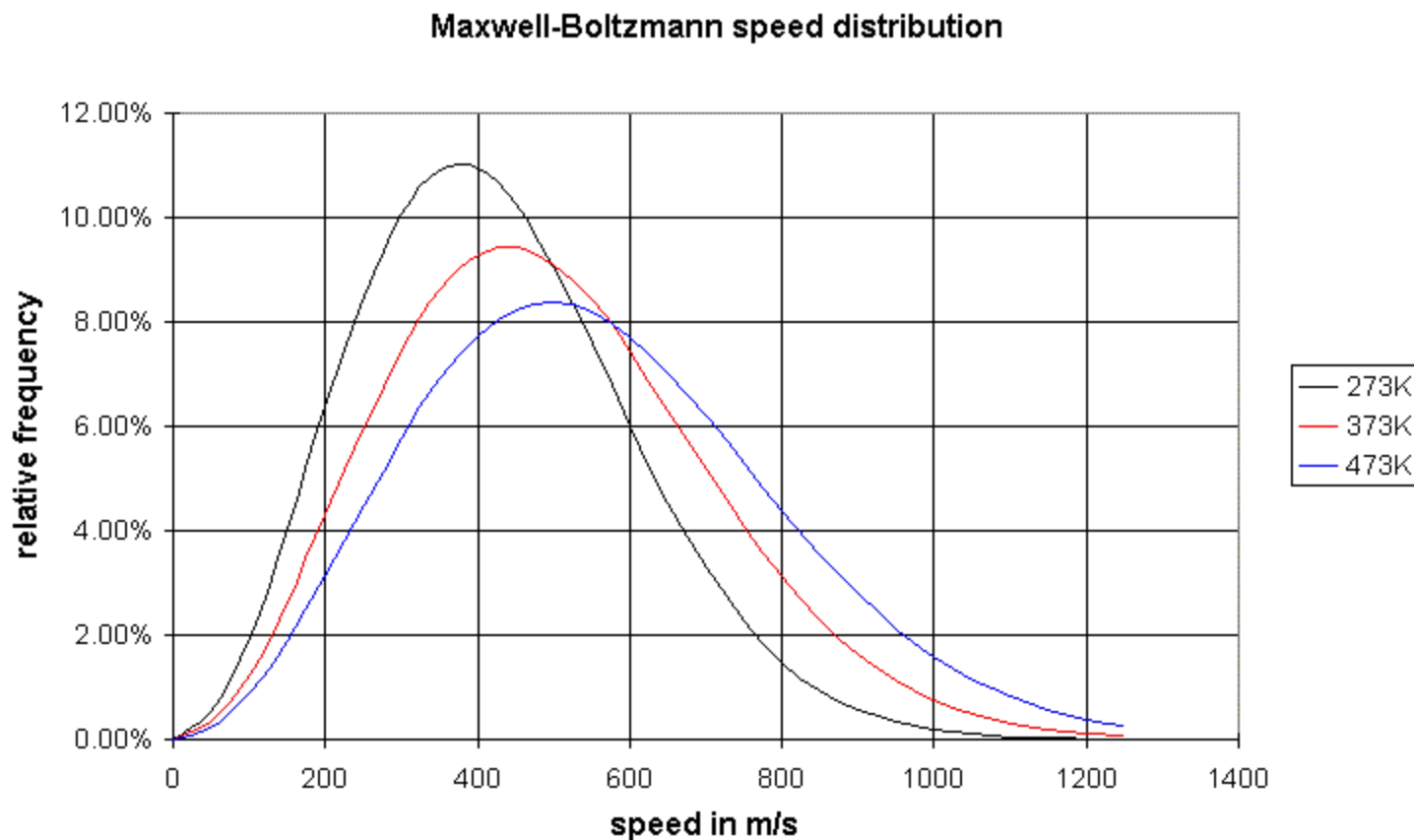
Phases of Water

Adsorbed



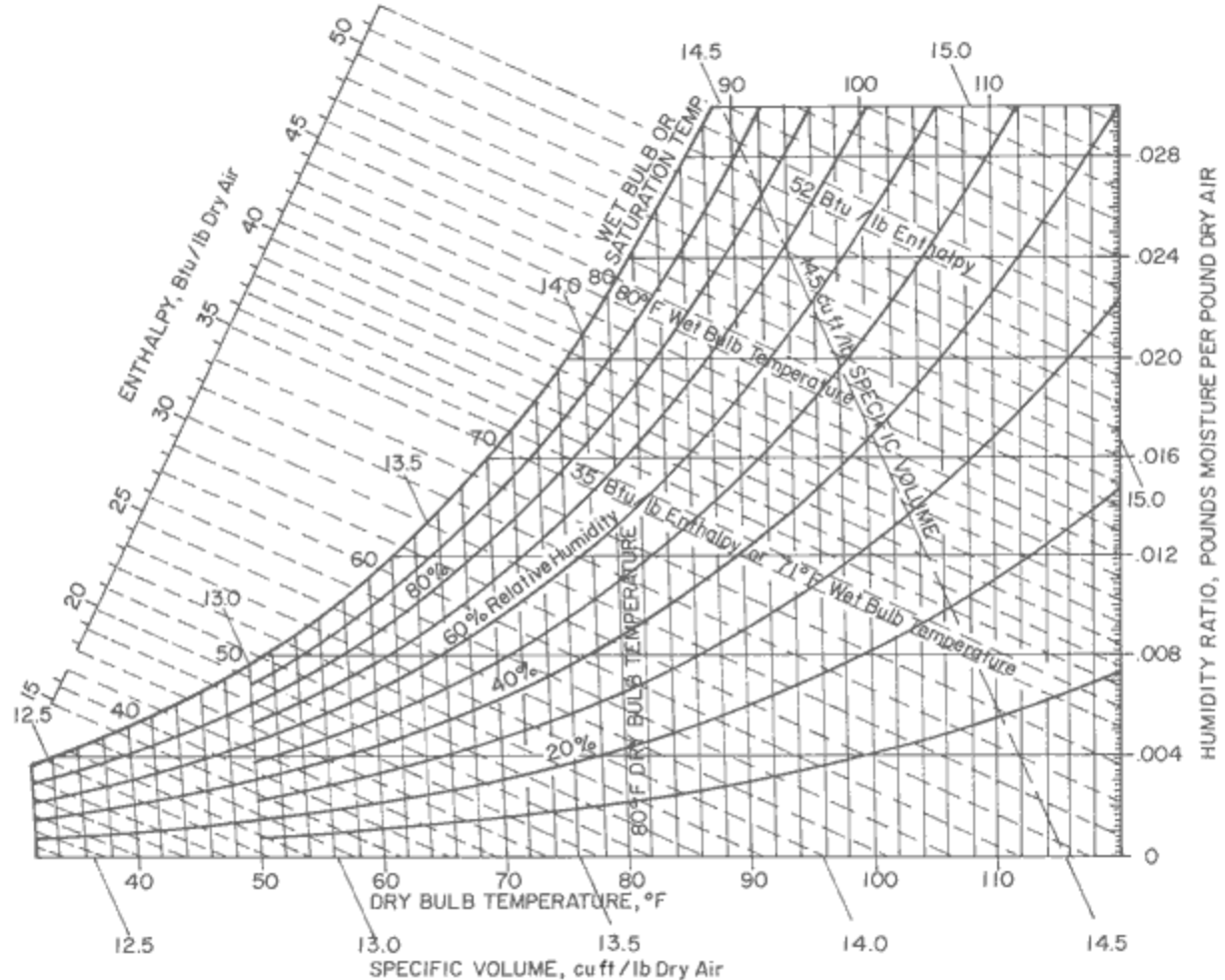
Condensation: Water Properties

Effect of Temperature

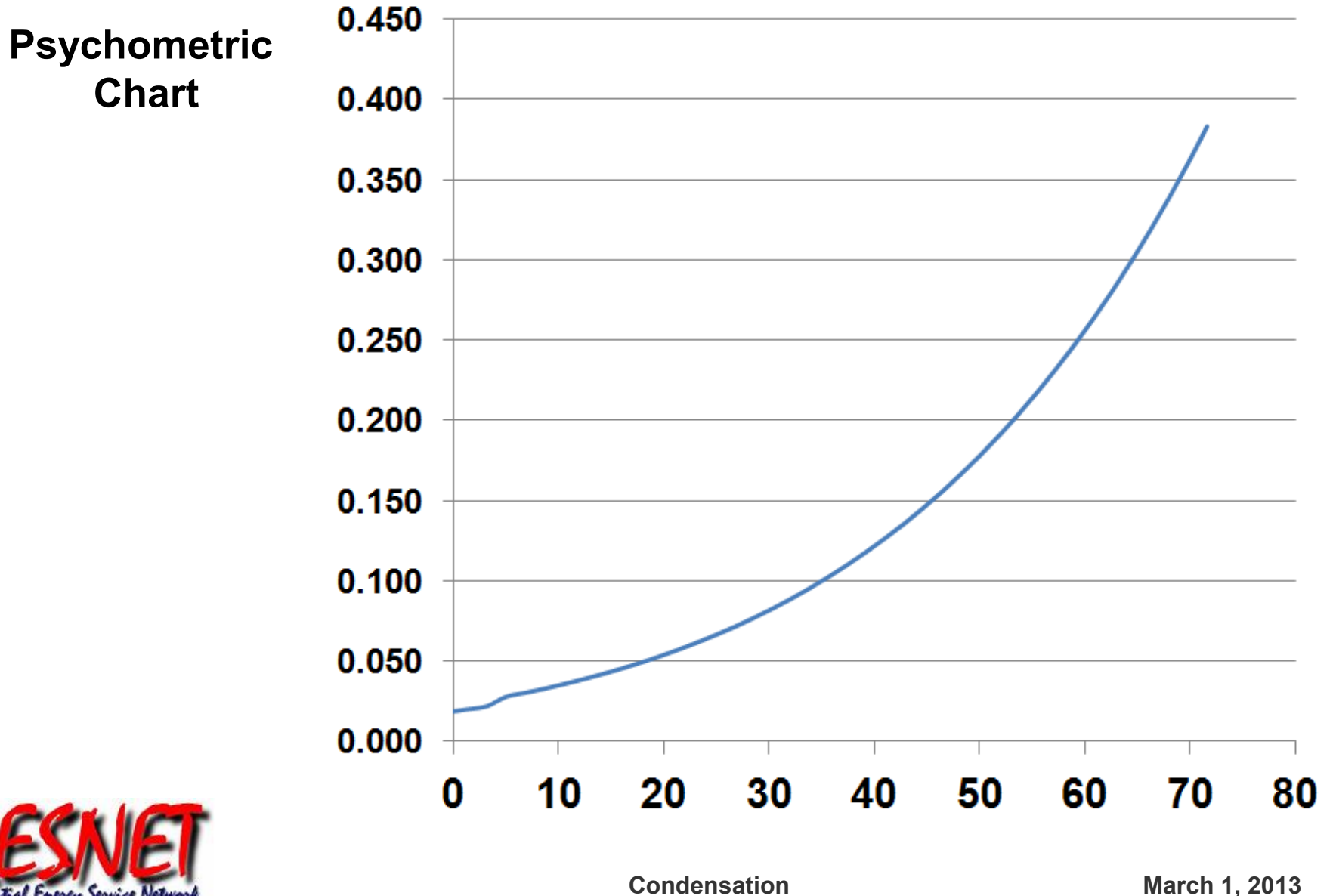


Condensation: Water Properties

Psychrometric Chart

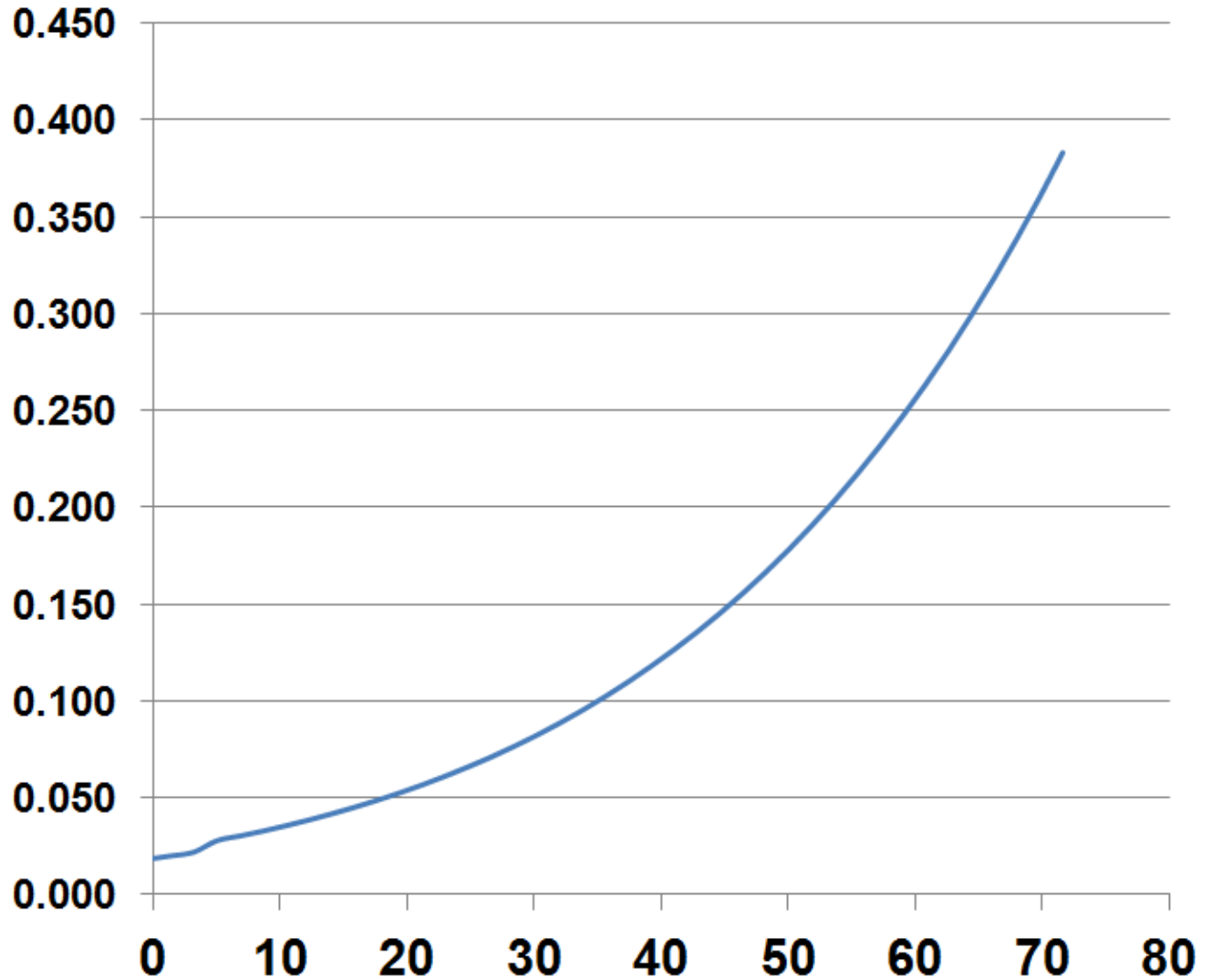


Condensation: Water Properties



Condensation: Water Properties

Psychrometric
Chart



Condensation: The Real Story

- Properties of Water
- **Terms Relating to Condensation**
- Wetting and Drying
- Analyzing Assemblies
- Wall Design

Condensation: Terms

Absolute Humidity

Measured in:

- Lbs Water/lb air
- Grains/cubic foot
- Psi
- Dewpoint Temperature

Condensation: Terms

Relative Humidity

Need 2 pieces of information:

- **Temperature (°F)**
- **Percent (%)**

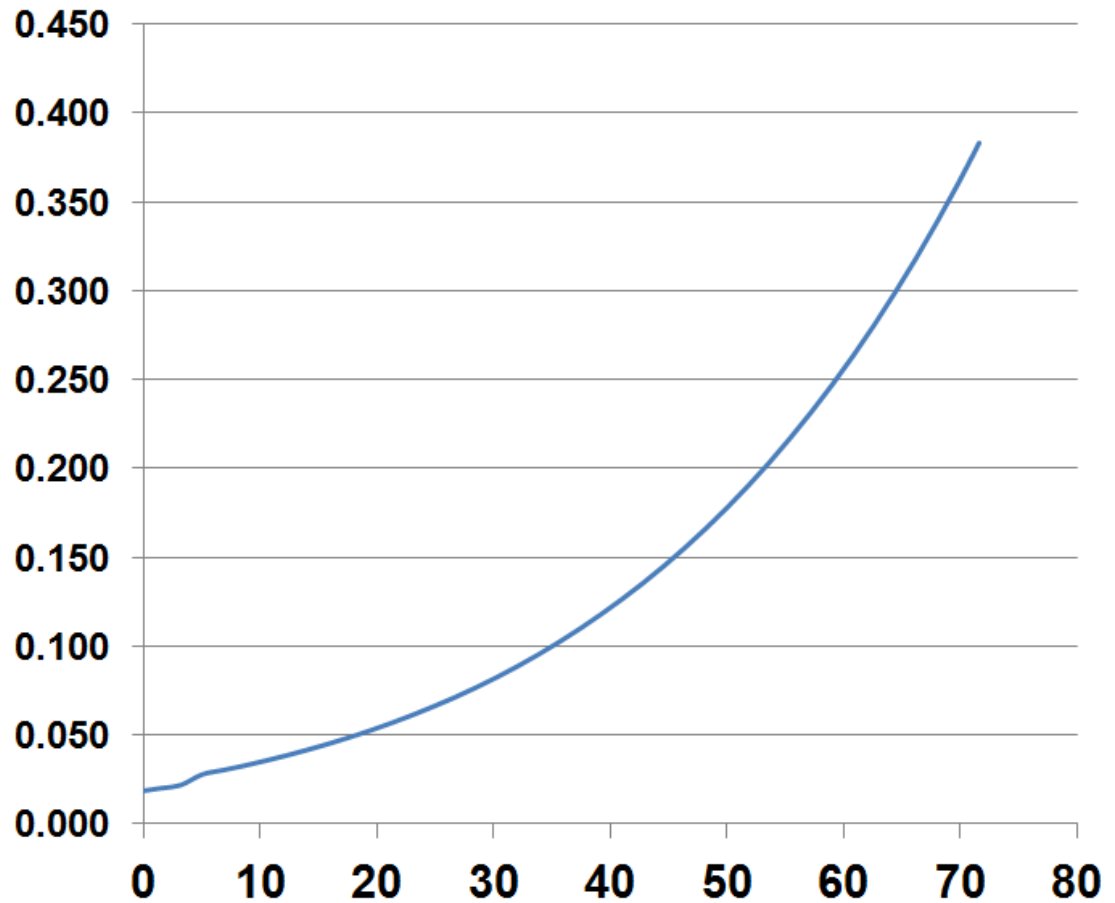
Condensation: Terms

Relative Humidity



Condensation: Terms

Relative Humidity

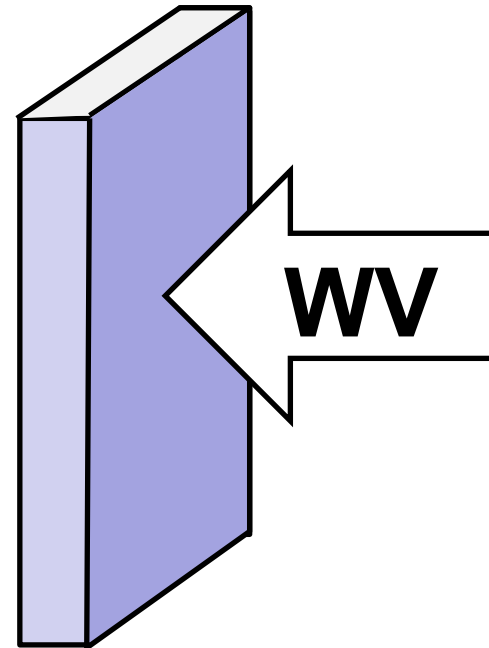


Condensation: Terms

Permeability: Diffusion

- Permeance
- Perms

gr/hr ft² in Hg



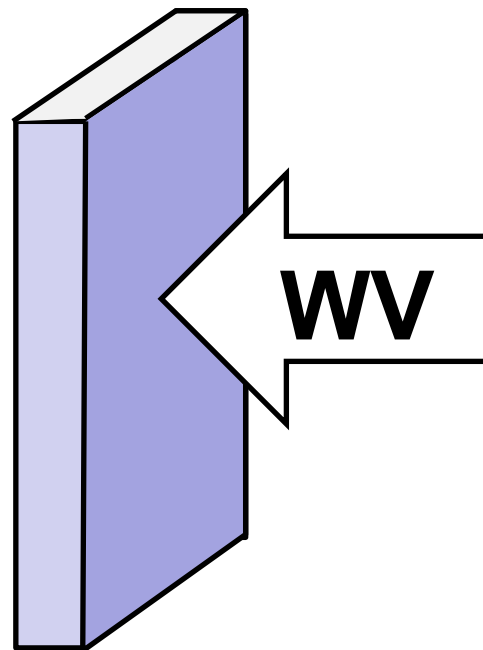
Condensation: Terms

Permeability: Diffusion

- Permeability
- Perm inch

gr in/hr ft² inHg

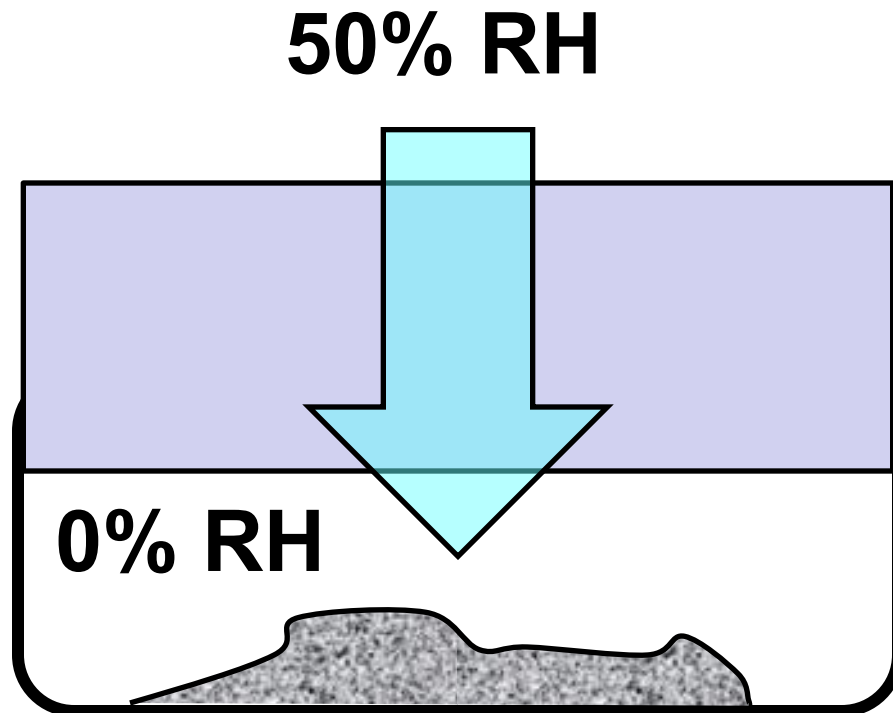
gr/hr ft inHg



Condensation: Terms

Permeability: Diffusion

ASTM E96

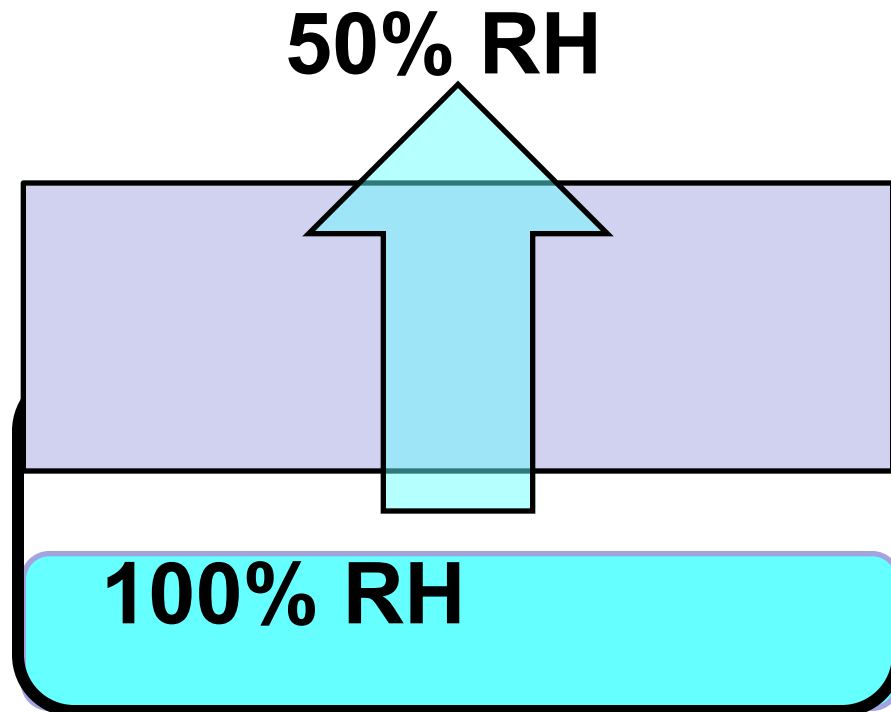


Dry Cup

Condensation: Terms

Permeability: Diffusion

ASTM E96

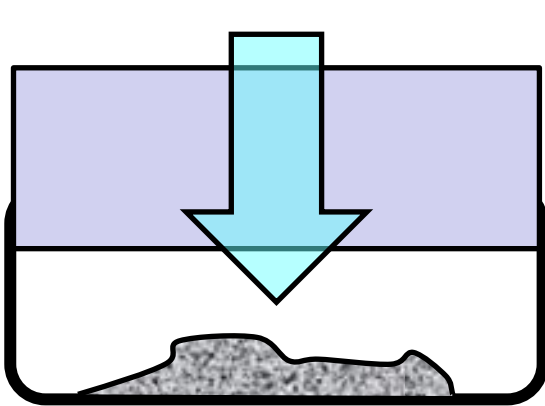


Wet Cup

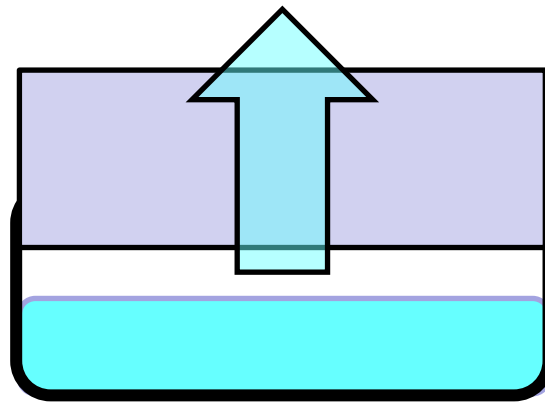
Condensation: Terms

Permeability: Diffusion

ASTM E96



Dry Cup



Wet Cup

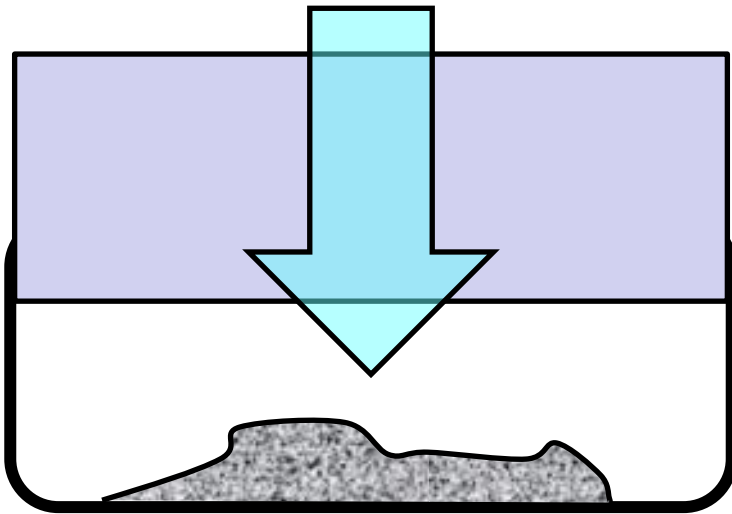


“Unfortunately, results from ASTM E96 are not particularly dependable.”

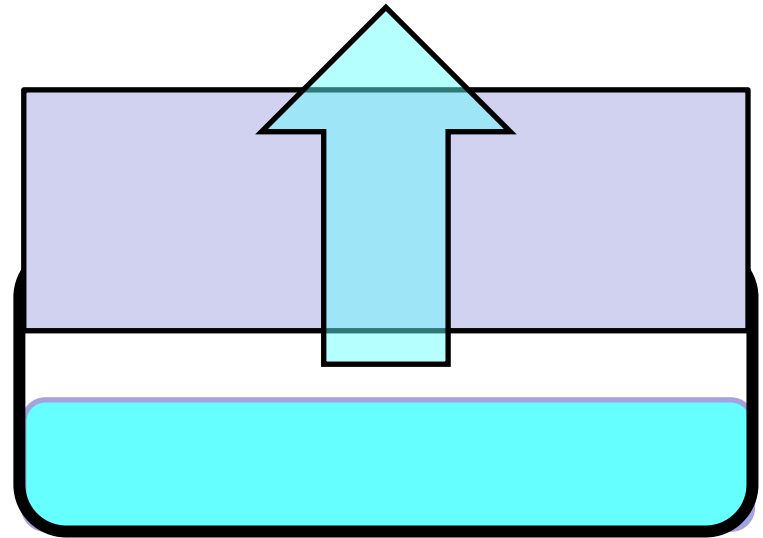
Condensation: Terms

Permeability: Diffusion

ASTM E96



Dry Cup



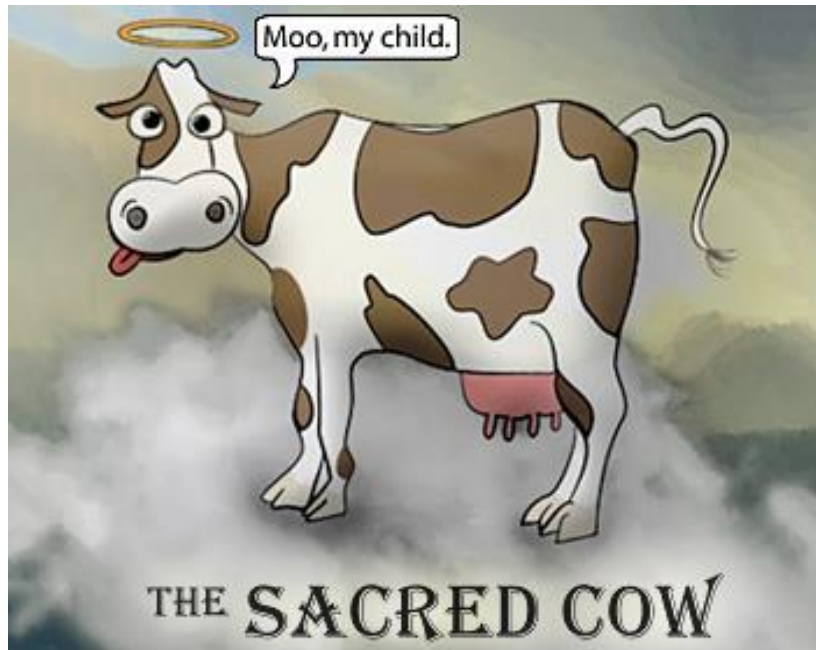
Wet Cup

Temperature?

Condensation: Terms

Permeability: Diffusion

Permeability = Breathability?



Condensation: Terms

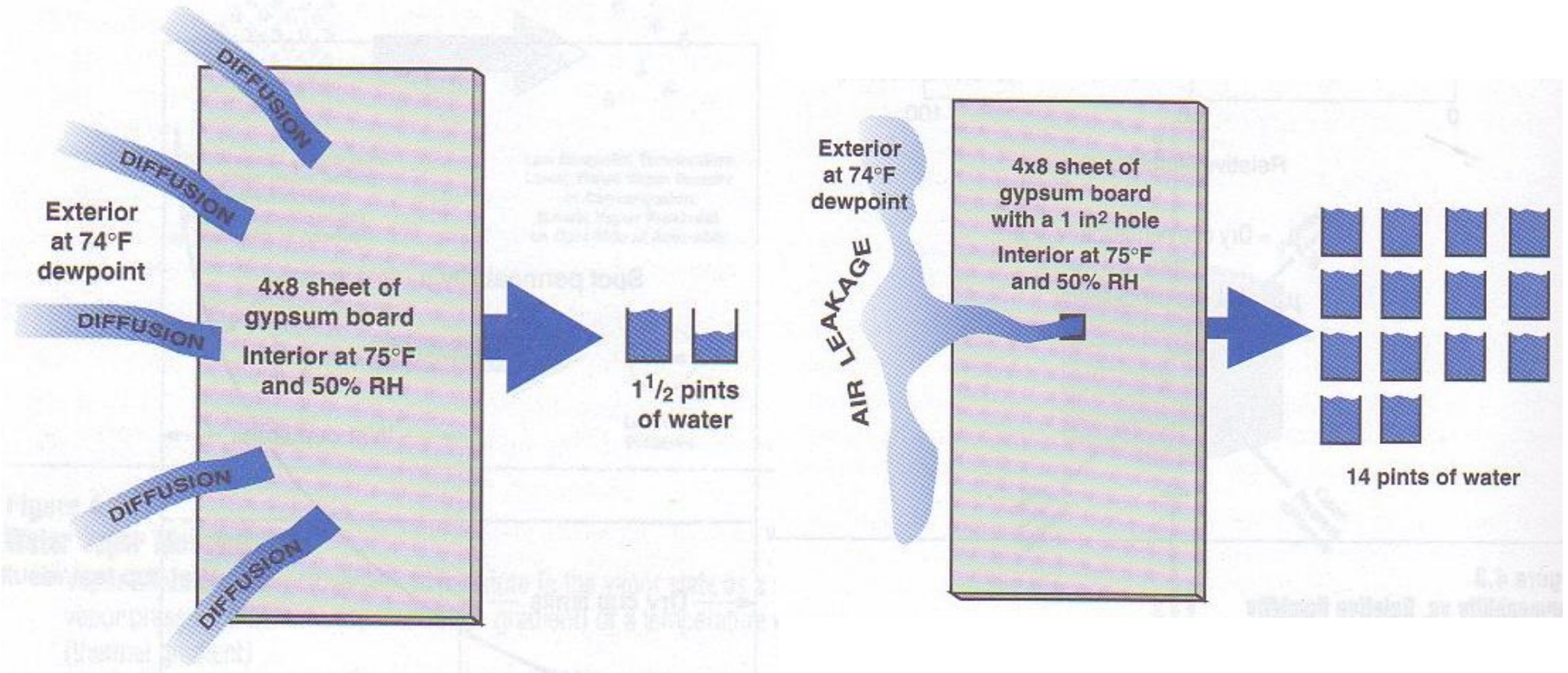
Permeability: Diffusion

Permeability = Breathability?



Condensation: Terms

Diffusion vs. Infiltration



Check on precise conditions and amounts shown here.

Condensation: Terms

Diffusion vs. Infiltration

Climate Zone	2009 IECC	2012 IECC
1 - 2	< 7 ACH	≤ 5 ACH @ 50 pascals
3 - 8	< 7 ACH @ 50 pascals	≤ 3 ACH @ 50 pascals

Still more than diffusion

Condensation: The Real Story

- Properties of Water
- Terms Relating to Condensation
- **Wetting and Drying**
- Analyzing Assemblies
- Wall Design

Condensation: Wetting and Drying

Two Sides of the same coin



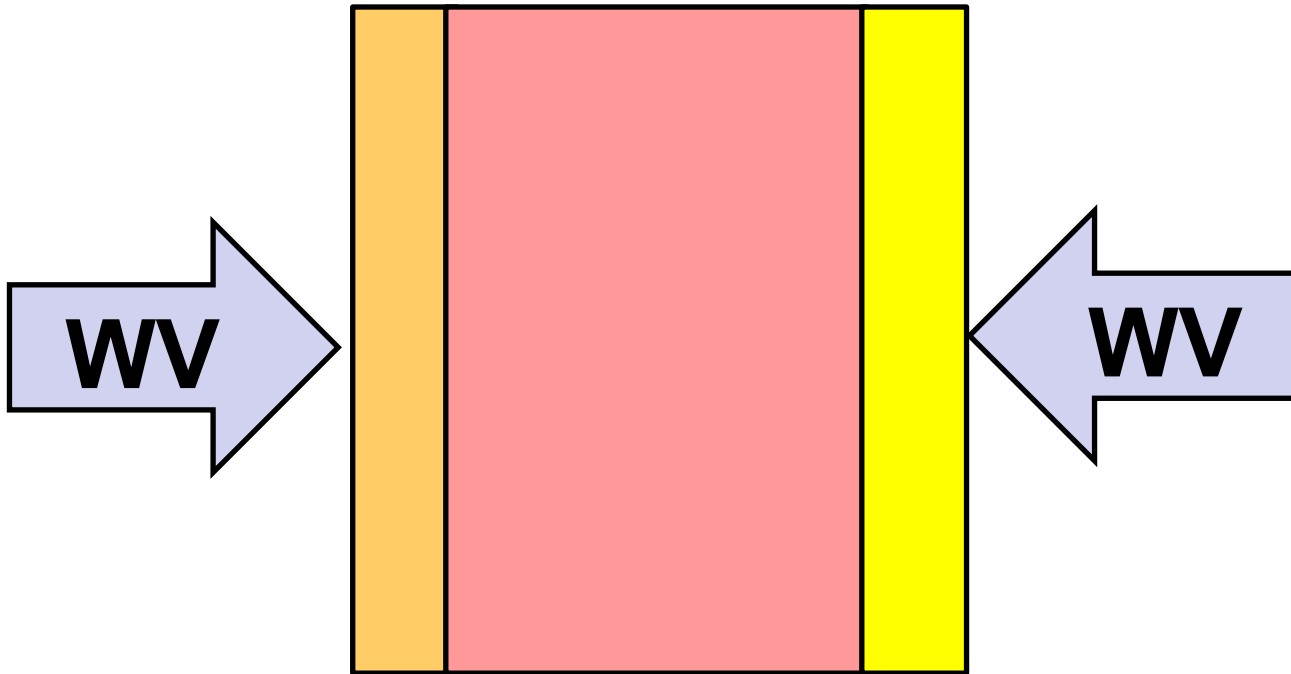
Condensation: Wetting and Drying

Two Sides of the same coin



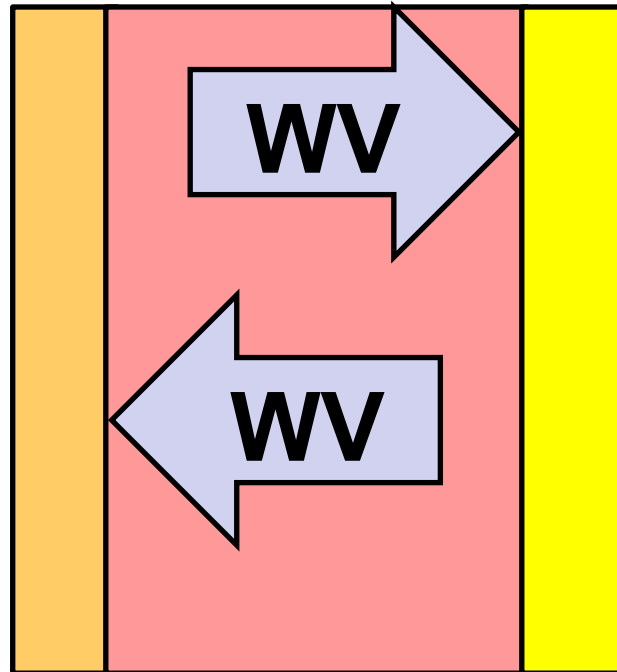
Condensation: Wetting and Drying

Two Sides of the same coin: Permeability



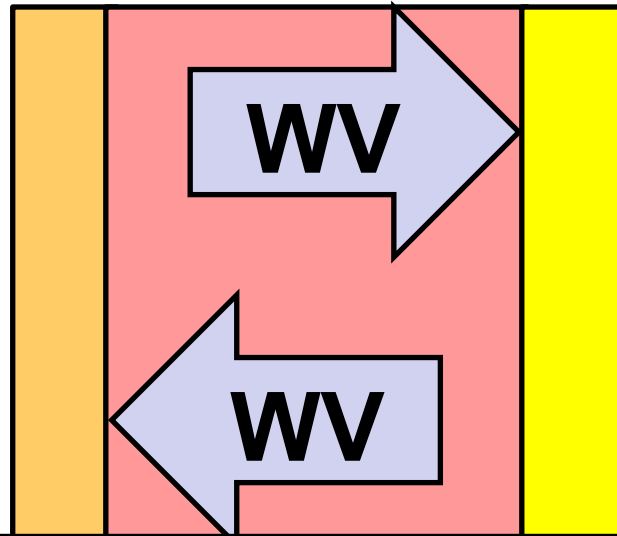
Condensation: Wetting and Drying

Two Sides of the same coin: Permeability



Condensation: Wetting and Drying

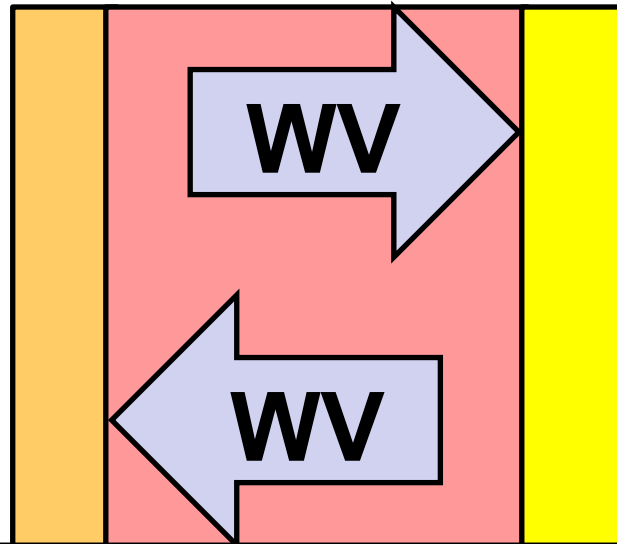
Two Sides of the same coin: Permeability



Permeability is just a rate of movement

Condensation: Wetting and Drying

Two Sides of the same coin: Permeability



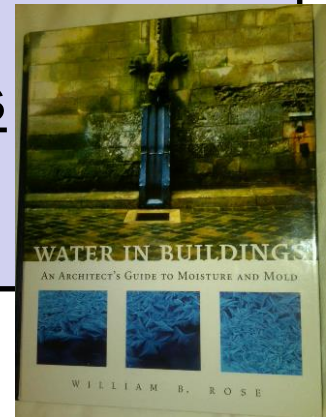
**Remember, air movement is
a lot more important**

Condensation: Wetting and Drying

Myth of Breathability

The vapor retarder also seems to have served yeoman's duty in keeping the thoughts of the public and the construction industry off the subject of thermal wetting.

William Rose, Moisture in Buildings



Condensation: Wetting and Drying

Two Sides of the same coin: Temperature

Condensation: Wetting and Drying

Two Sides of the same coin: Temperature

- Collin Murphy, 2002, Moisture Within Walls, Interface
- Brad Carpenter, 2010, Modern Performance Expectations and Historic Masonry Walls, RCI
- ABCB, 2009, The Condensation Handbook, Australian institute of Architects
- Nusser and Teibinger, 2012, Coupled Heat and Moisture Transfer - Implementing WUFI, COMSOL Conference
- DOE, 2011, Air Leakage Guide, DOE
- Joseph Lstiburek, 2006, Understanding Vapor Barriers, BSC
- Joseph Lstiburek, 2010, Mind the Gap, BSC/Insight
- Maria Spinu, 2012, Design Without Compromise, Construction Specifier
- Smegal and Straube, 2011, Hygrothermal Analysis of Exterior Rockwool Insulation, BSC
- Smegal, Lstiburek, Straube, Grin, 2012, Vancouver Field Exposure Facility: Phase III Exterior Insulation Analysis, BSC
- Straube, 2002, The Influence of Low Permeance Vapor Barriers on Roof and Wall Performance, Buildings VIII
- DOE, 2004, 5.C.2.1 Vapor Barrier Journal Paper, DOE

Condensation: Wetting and Drying

Two Sides of the same coin: Temperature



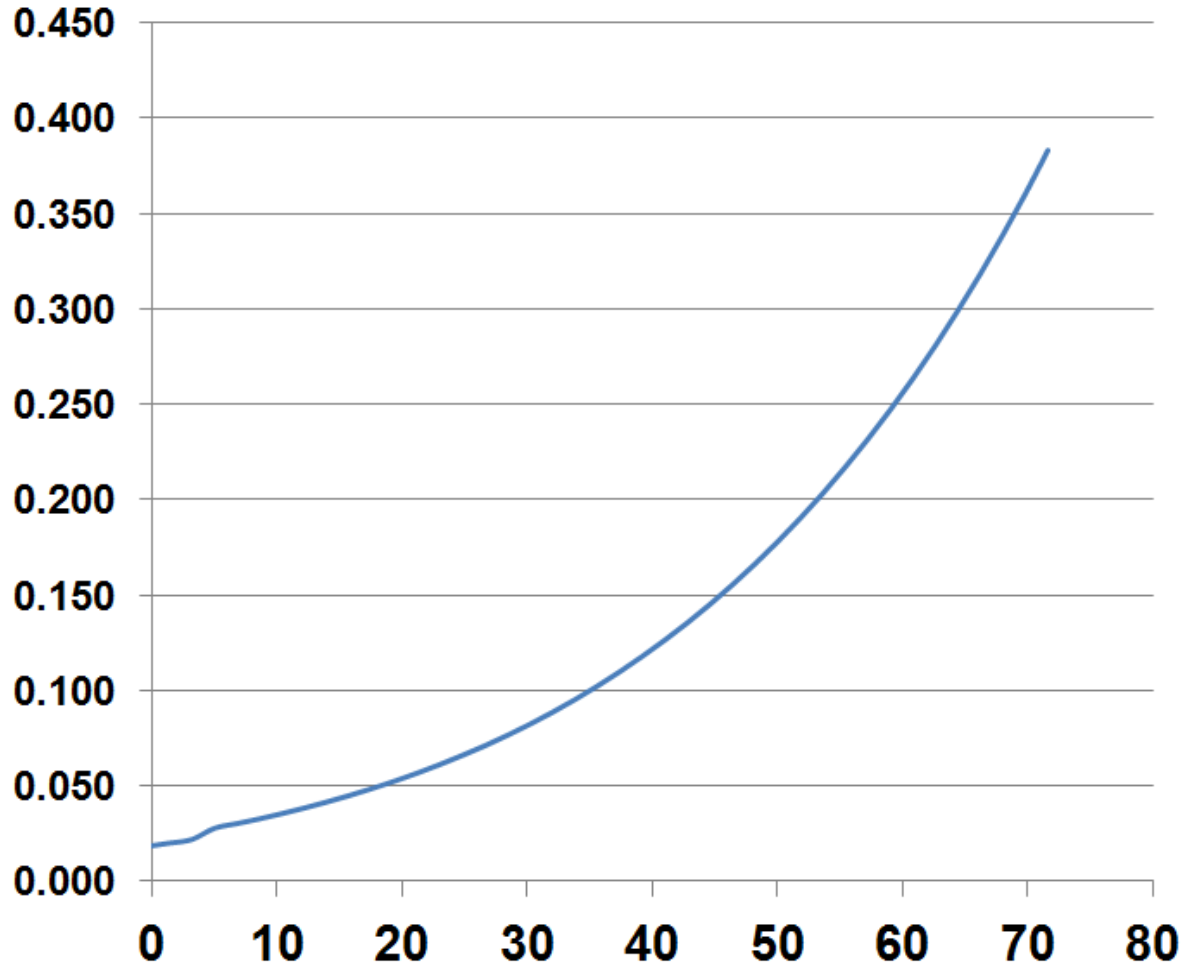
Condensation: Wetting and Drying

Two Sides of the same coin: Temperature



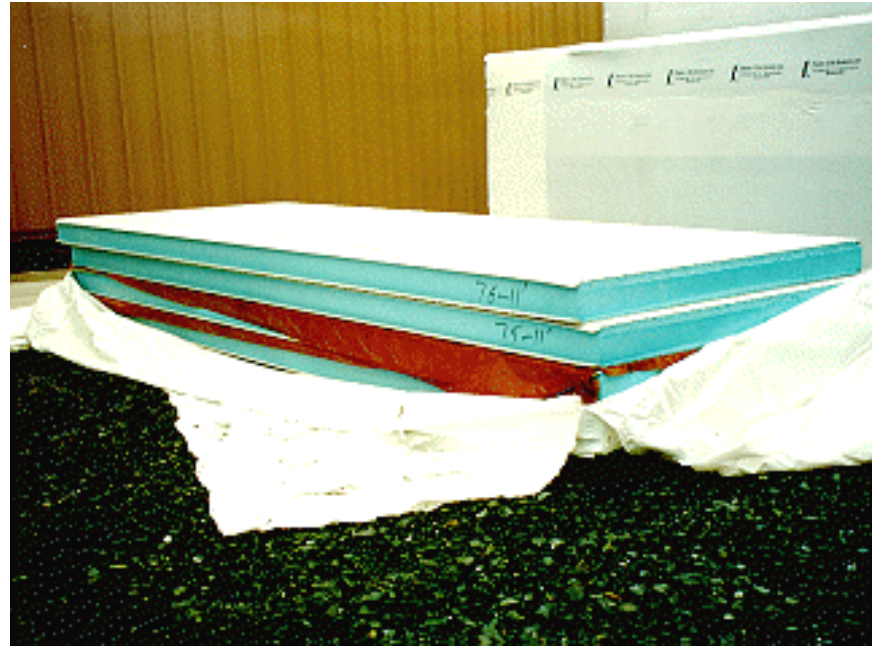
Condensation: Wetting and Drying

Temperature



Condensation: Wetting and Drying

Myth of Breathability

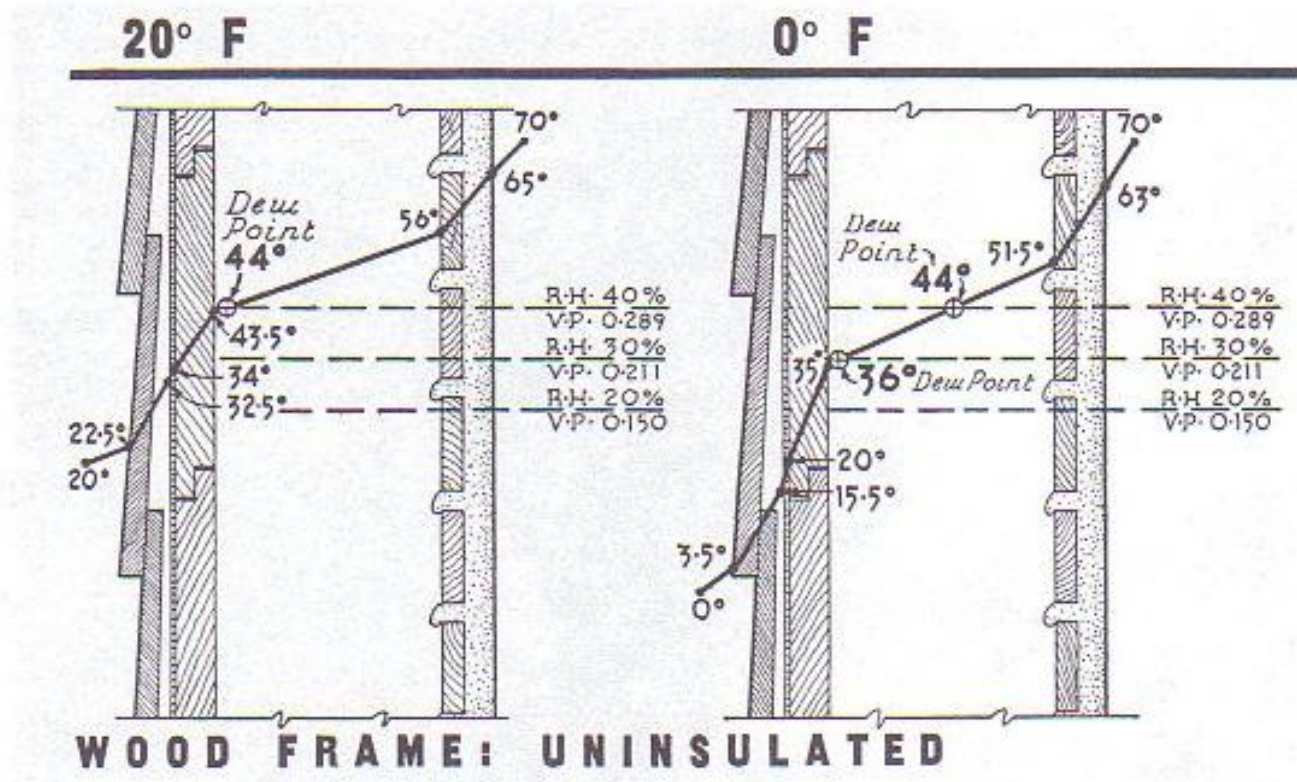


Condensation: The Real Story

- Properties of Water
- Terms Relating to Condensation
- Wetting and Drying
- **Analyzing Assemblies**
- Wall Design

Condensation: Analyzing Assemblies

Profile Method



Teesdale, 1938 (Water in Buildings, Rose)

Condensation: Analyzing Assemblies

Profile Method

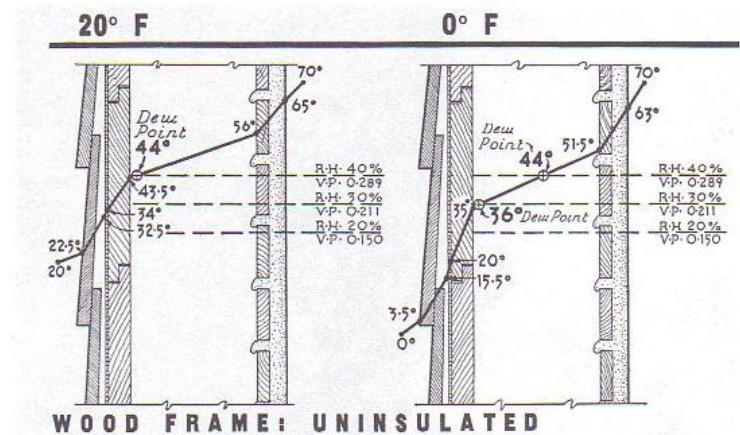
No infiltration

Not dynamic

Water movement

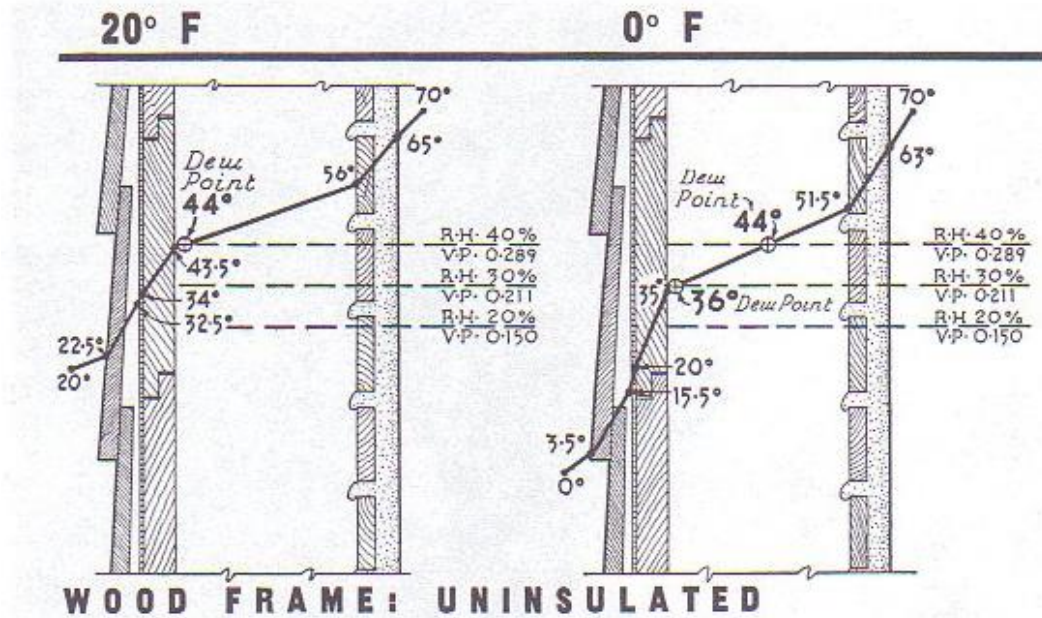
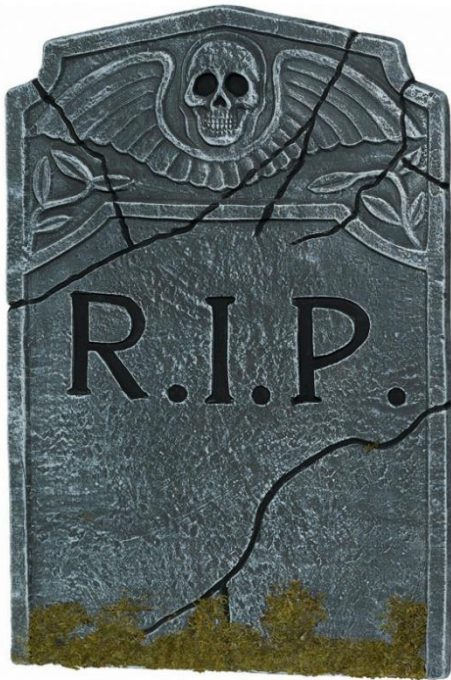
RH or Temperature Dependencies

Adsorption



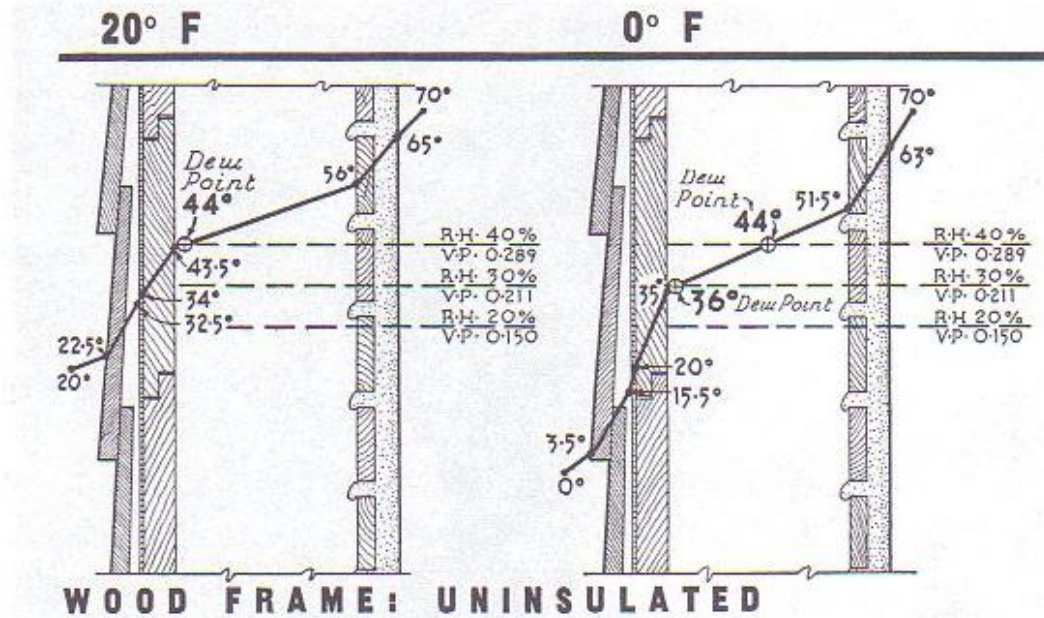
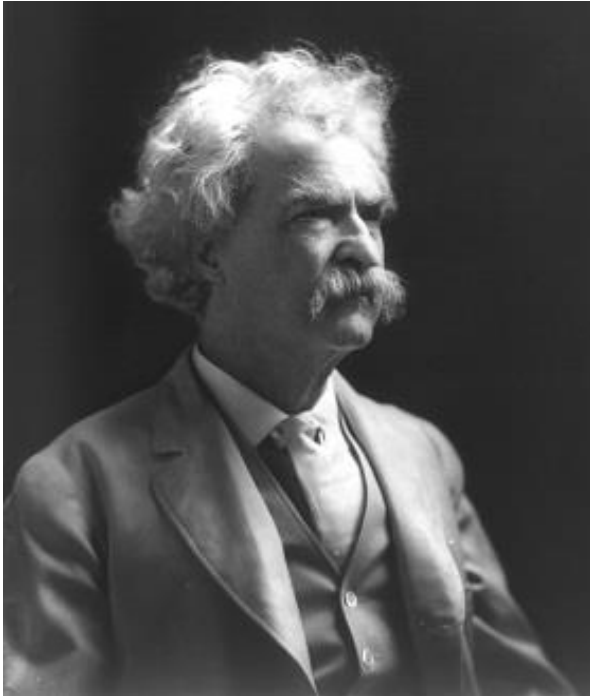
Condensation: Analyzing Assemblies

Profile Method



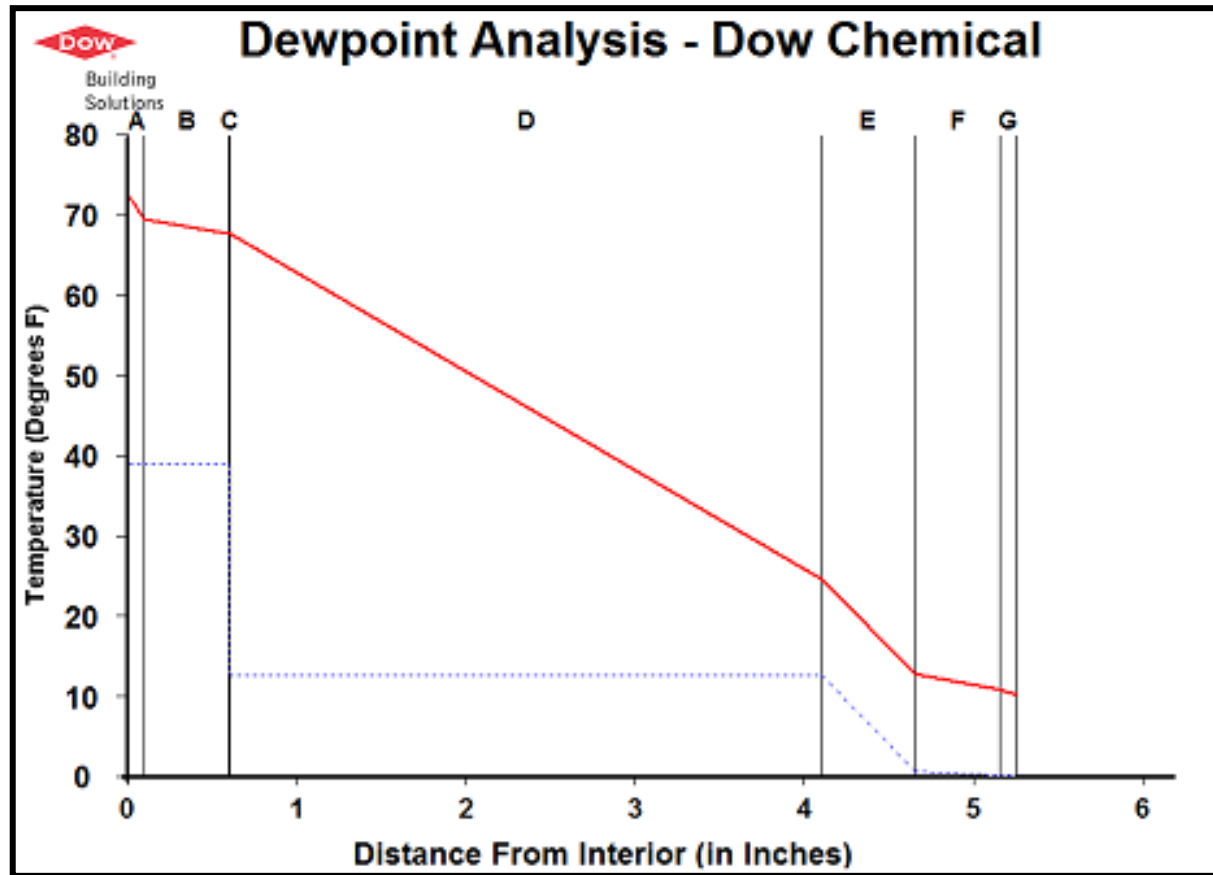
Condensation: Analyzing Assemblies

Profile Method



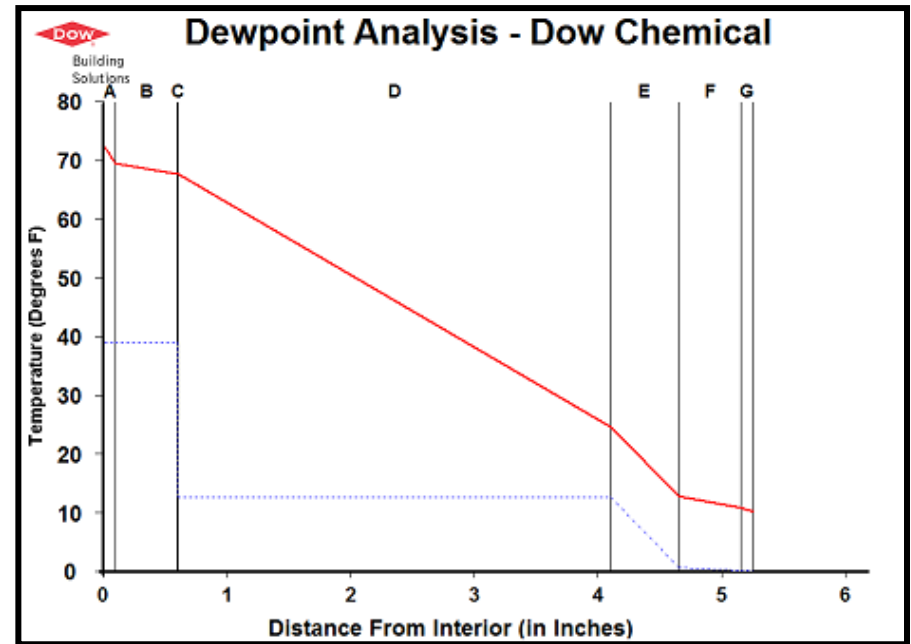
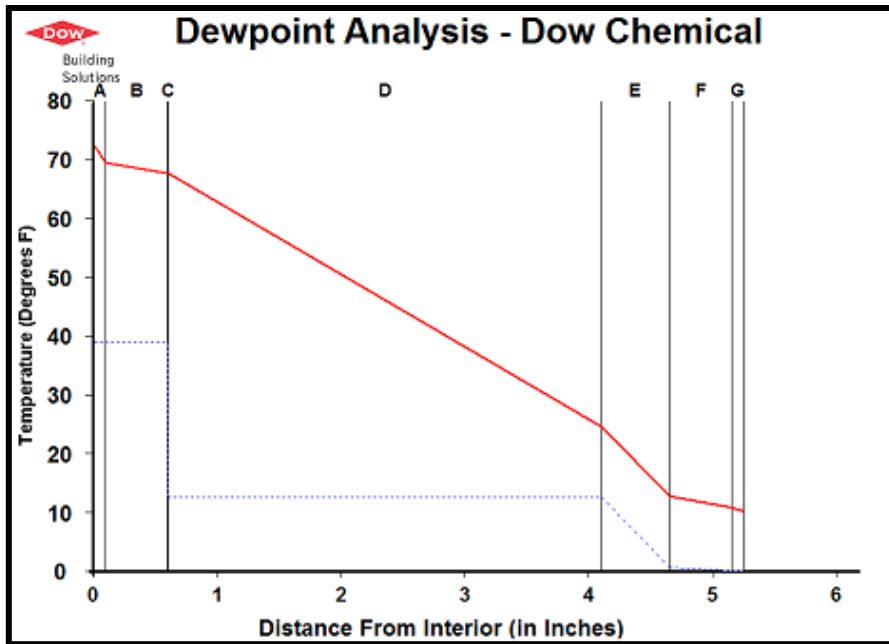
Condensation: Analyzing Assemblies

Profile Method



Condensation: Analyzing Assemblies

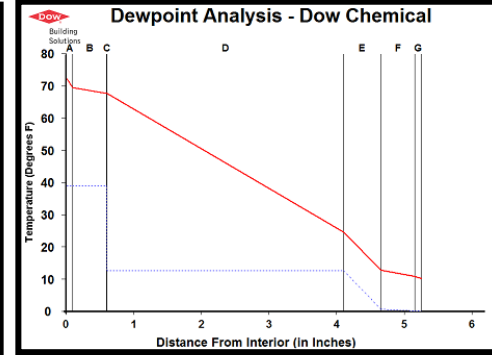
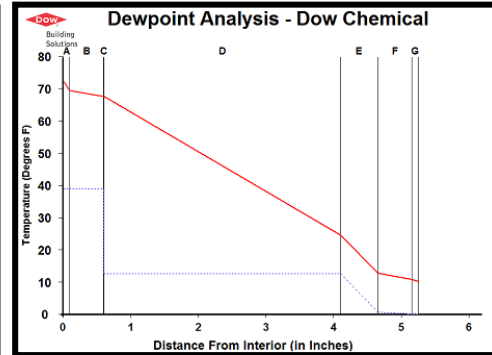
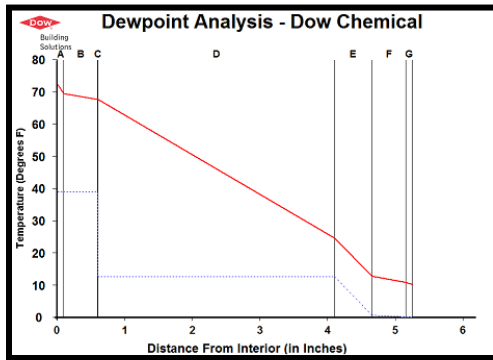
Profile Method



Compare Assemblies

Condensation: Analyzing Assemblies

Profile Method



“The results from transient modeling do a much better job of replicating physical processes. They have entirely supplanted the profile method as a design tool. This comes at the expense, however, of tinkering.”

Condensation: Analyzing Assemblies

WUFI Method



Condensation: Analyzing Assemblies

WUFI Method

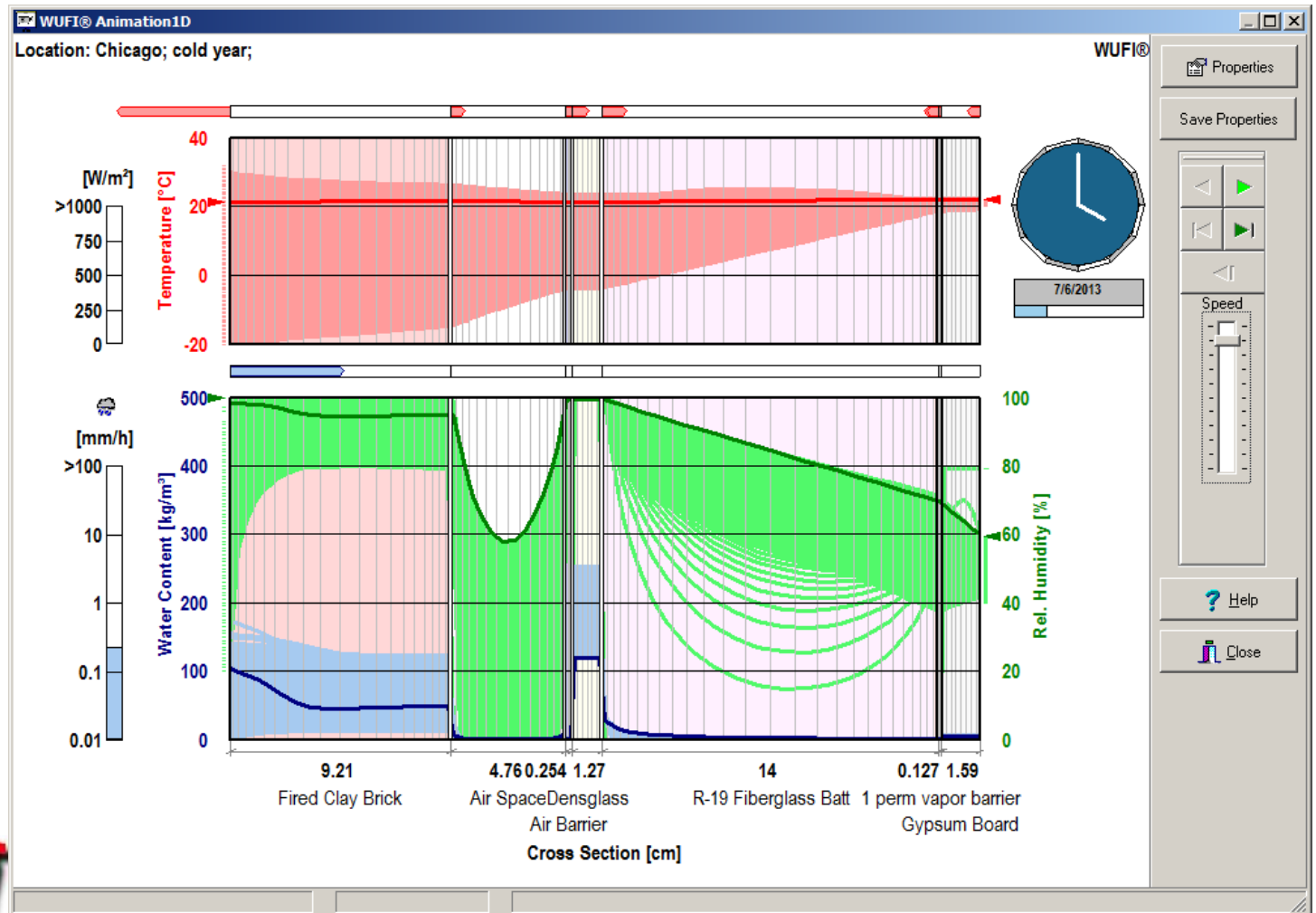
The screenshot displays the WUFI Pro 4.2 software interface. The main window is titled 'WUFI Pro 4.2 IBP' and shows a project named 'RESNET'. The left sidebar contains a tree view with 'Case: 1 (Act. Case)' expanded, showing sub-items like 'Component', 'Assembly/Monitor Positions', 'Orientation', 'Surface Transfer Coeff.', 'Initial Conditions', 'Control', 'Climate', and 'Quick Graph'. The main workspace is divided into several sections:

- Assembly/Monitor Positions:** Shows a cross-section of a wall assembly. The top layer is 'Fired Clay Brick' with a thickness of 3.625 inches. Below it are three layers: a white layer (1.875 inches), a yellow layer (10.5 inches), and a pink layer (5.5 inches). The exterior (left side) has a thickness of 3.625 inches, and the interior (right side) has a thickness of 0.0,625 inches.
- Assembly Properties:** Includes buttons for 'Material Data', 'Sources, Sinks', 'New Layer', 'Duplicate', and 'Delete'. There is also an 'Edit Assembly by:' section with radio buttons for 'Graph' (selected) and 'Table'.
- Grid Settings:** A 'Grid' section with a checked 'Automatic Grid' option and radio buttons for 'Coarse', 'Medium', and 'Fine'.
- Summary:** At the bottom, it shows 'Total Thickness: Thickness: 12,28 in' and 'Total Thermal Performance: R-Value: 29.1 h ft² °F/Btu' and 'U-Value: 0,033 Btu/h ft² °F'.

The status bar at the bottom indicates 'Units: IP' and 'Last Calculation: 2/26/2013'.

Condensation: Analyzing Assemblies

WUFI Method



Condensation: Analyzing Assemblies

WUFI Method

- No infiltration
- Subtle data does not exist
- Temperature Dependencies
- Hard to learn
- Time consuming



Condensation: Analyzing Assemblies

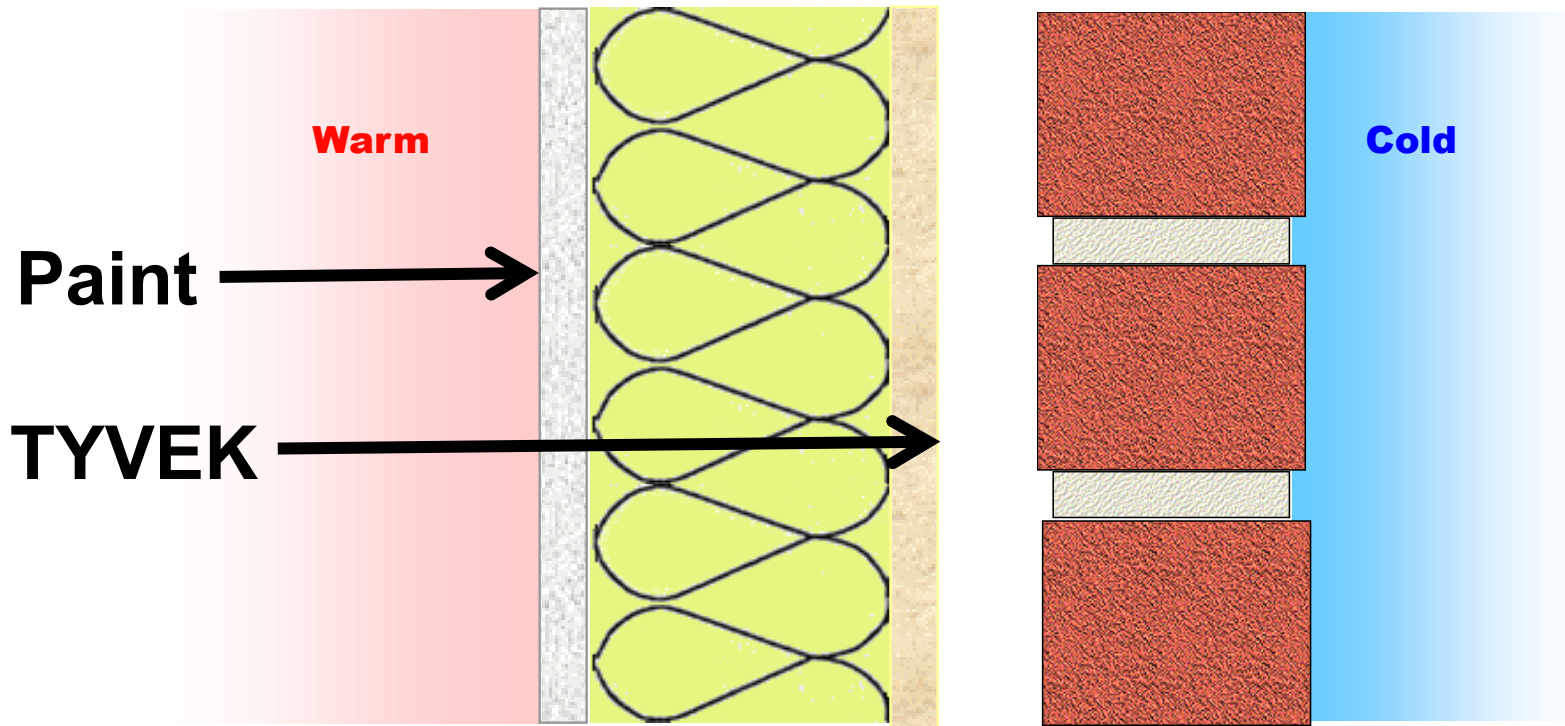
WUFI vs. Profile: Predictions



Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions

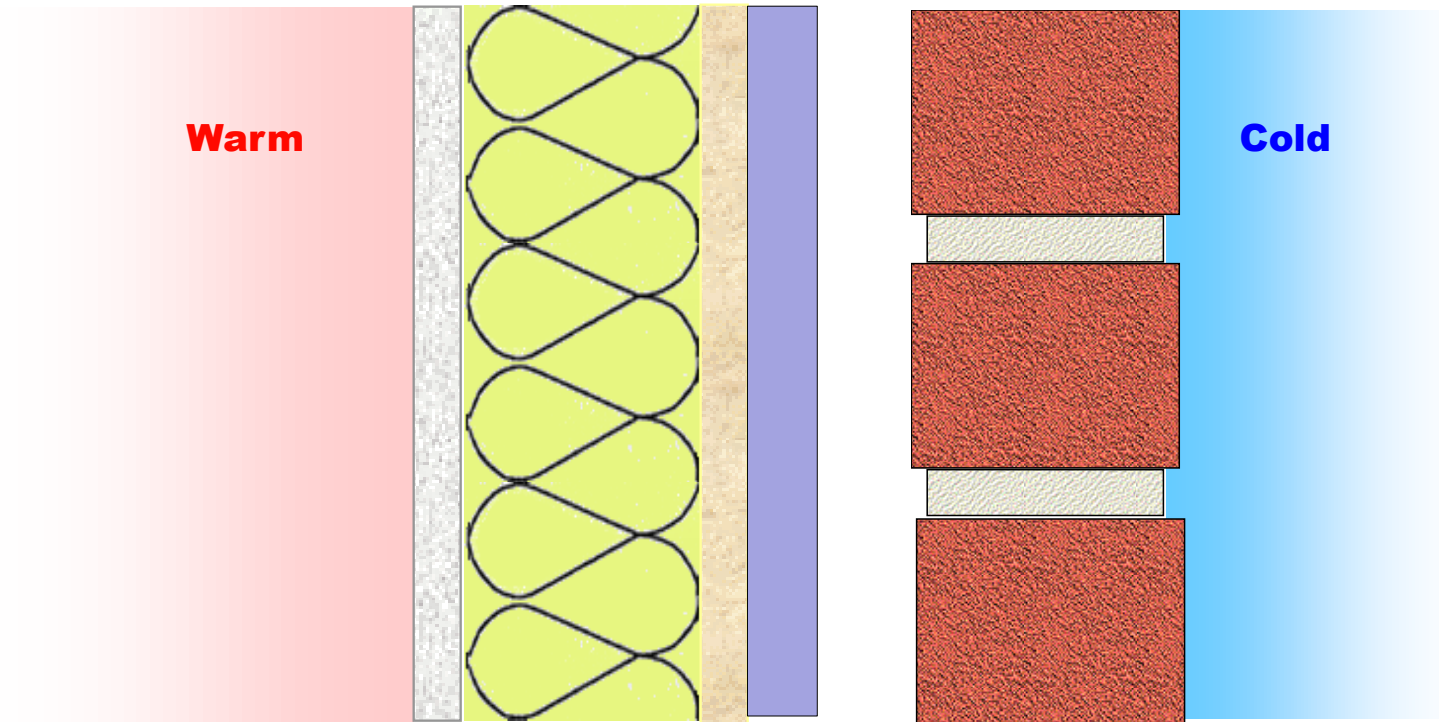
Old Wall



Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions

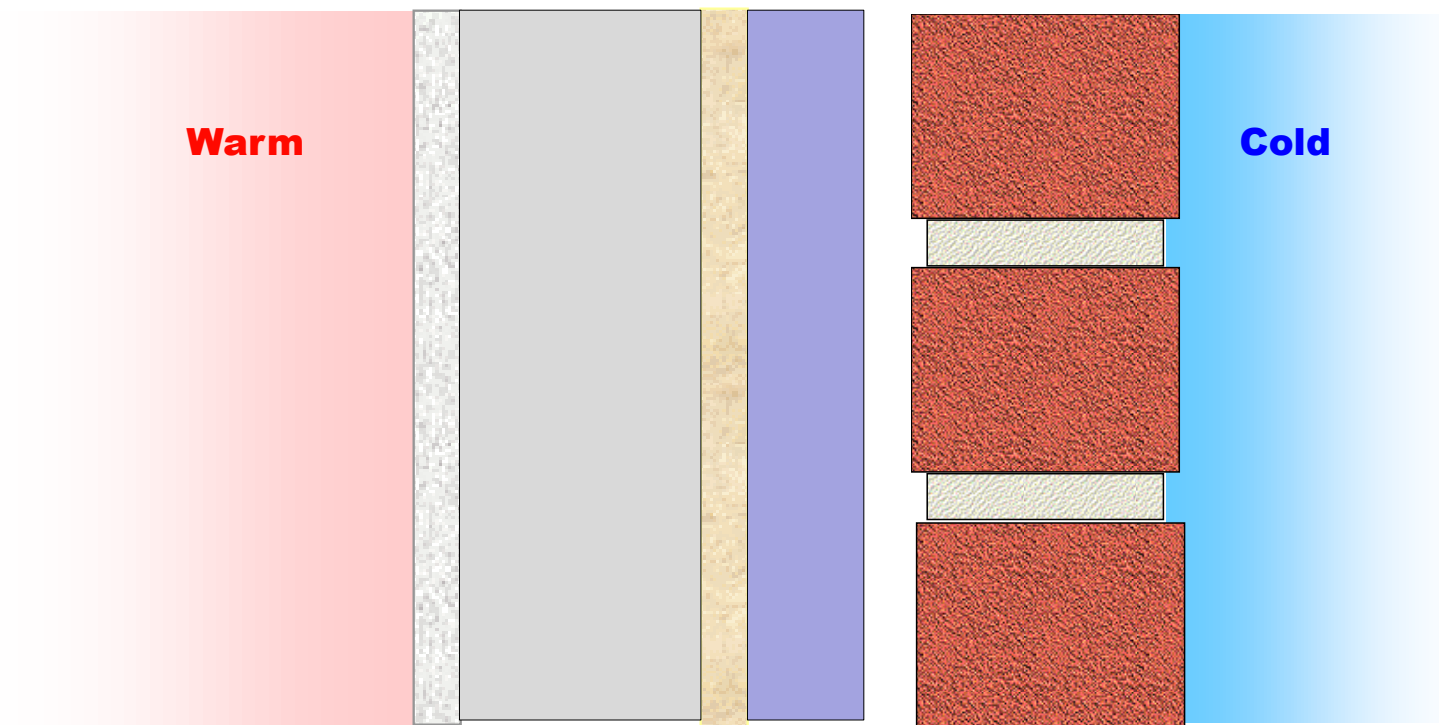
Medium Wall



Condensation: Analyzing Assemblies

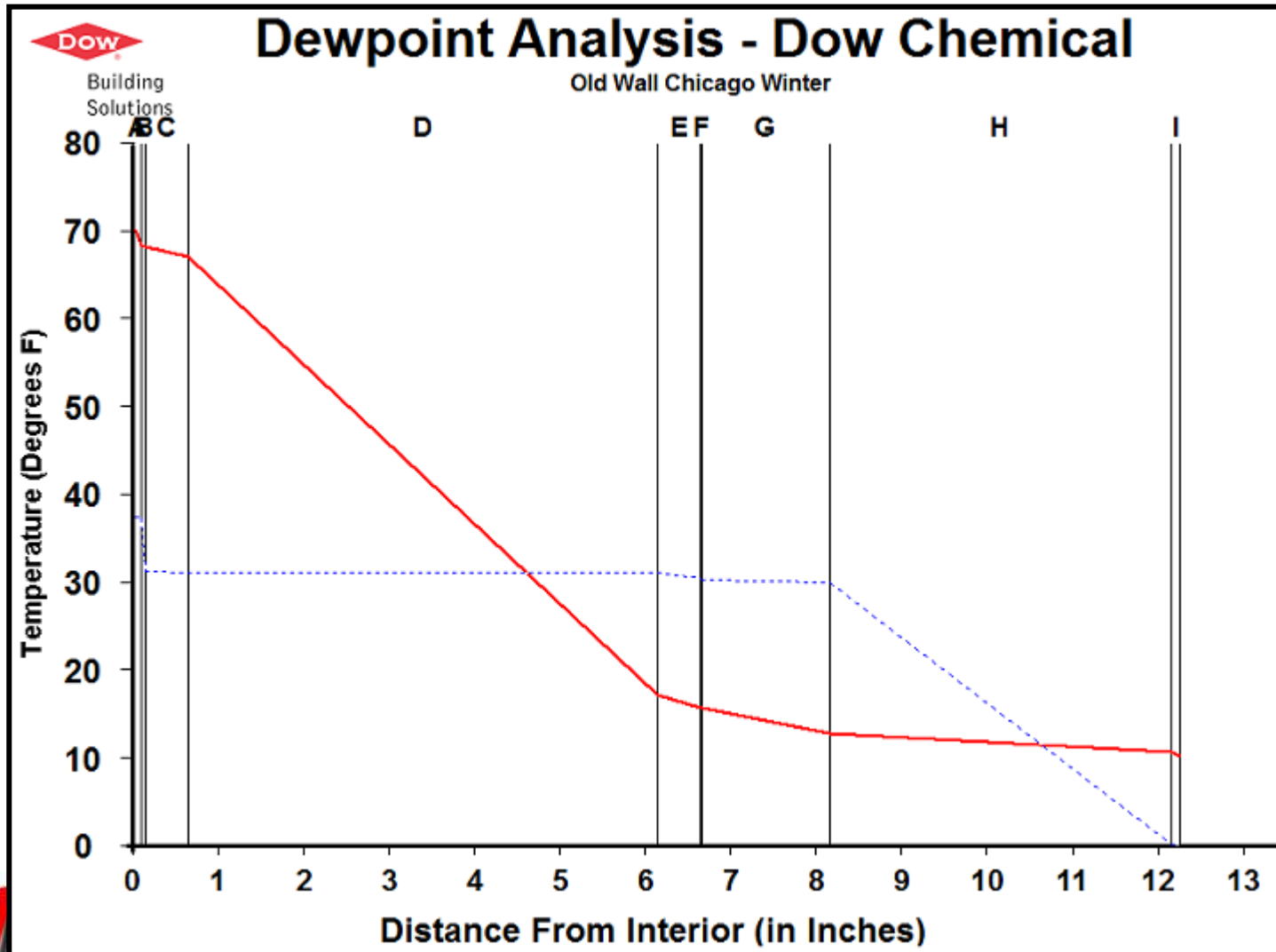
WUFI vs. Profile: Predictions

Perfect Wall



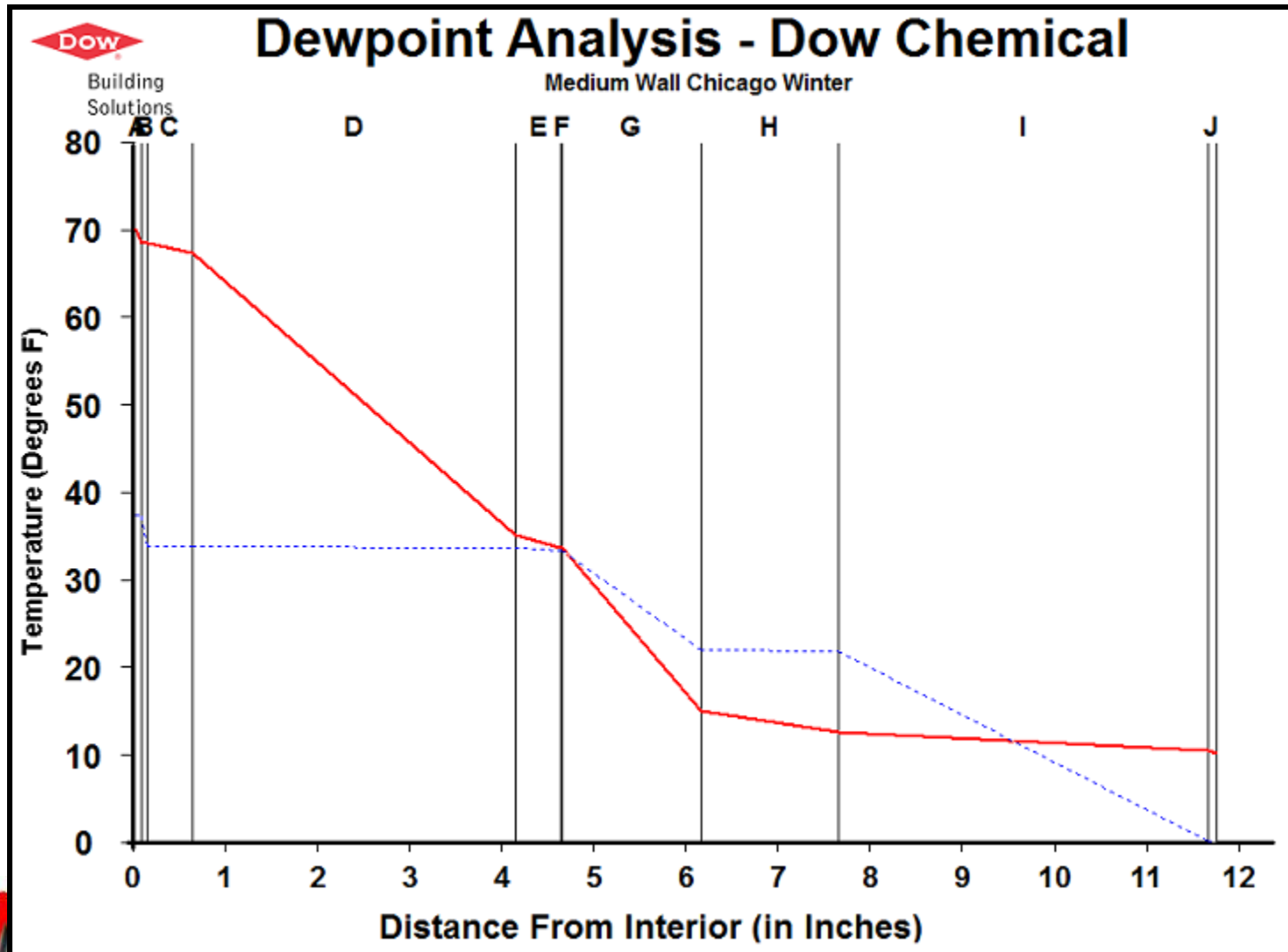
Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions



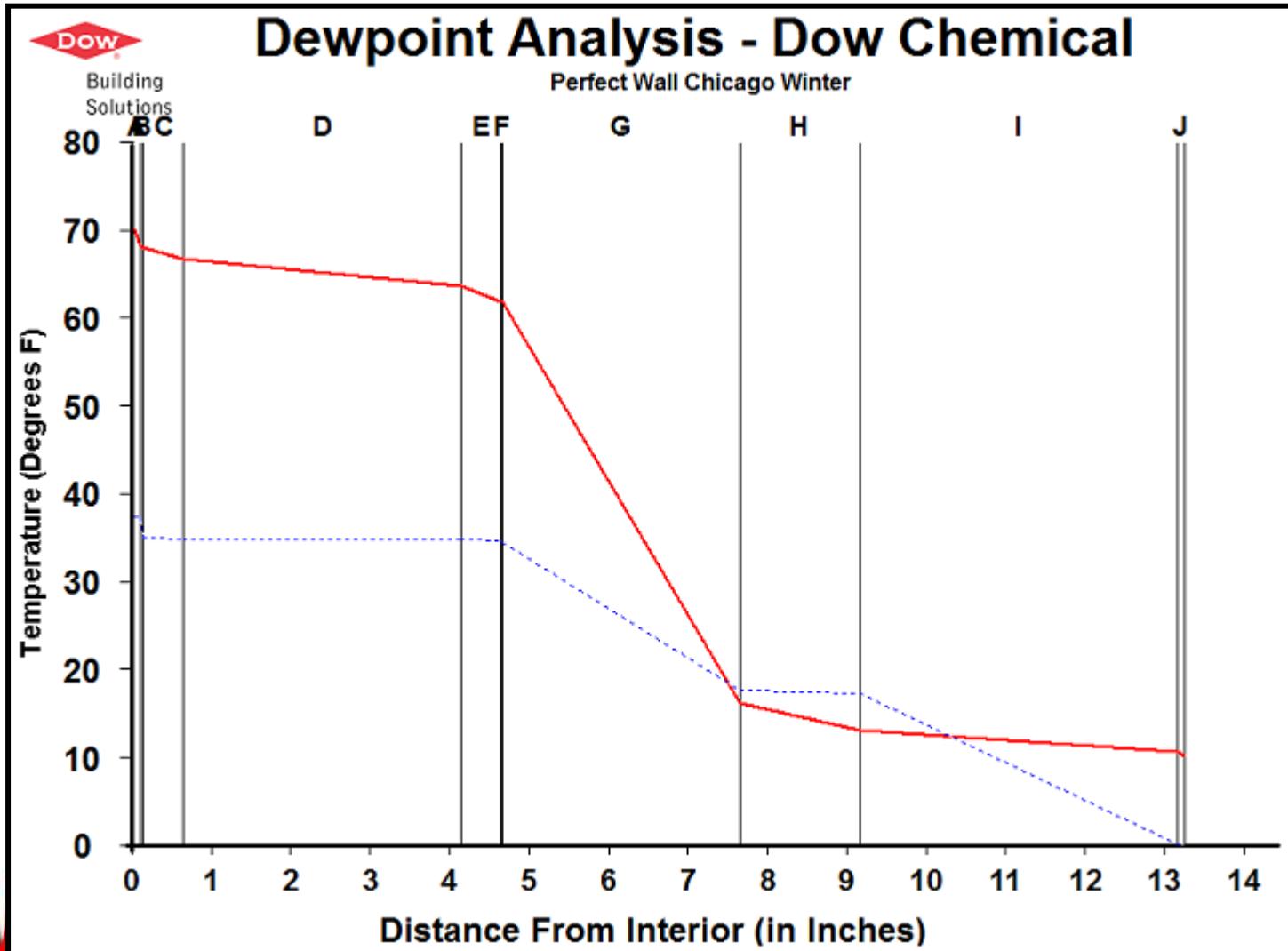
Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions



Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions



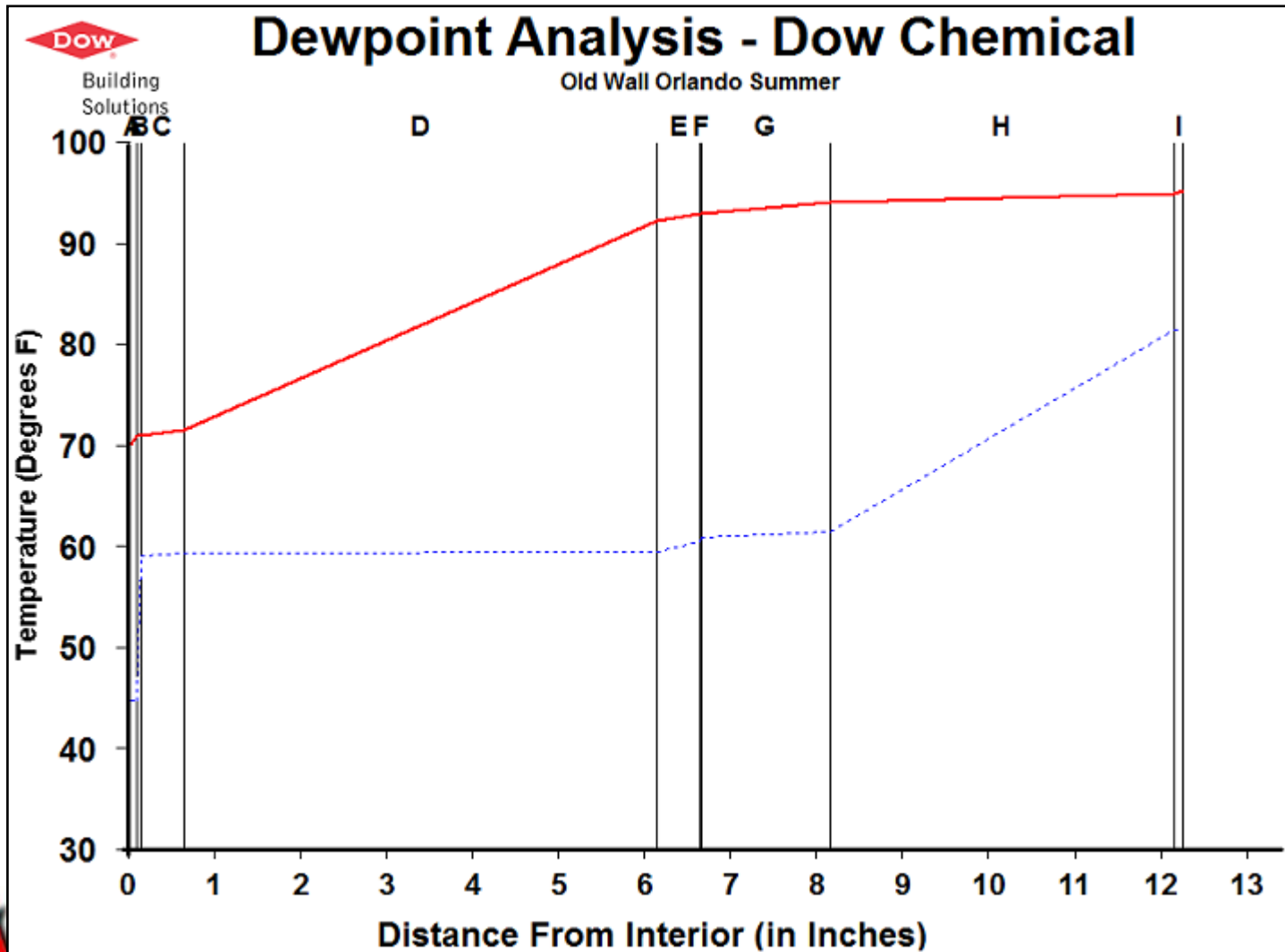
Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions

Perfect Wall > Medium Wall > Old Wall

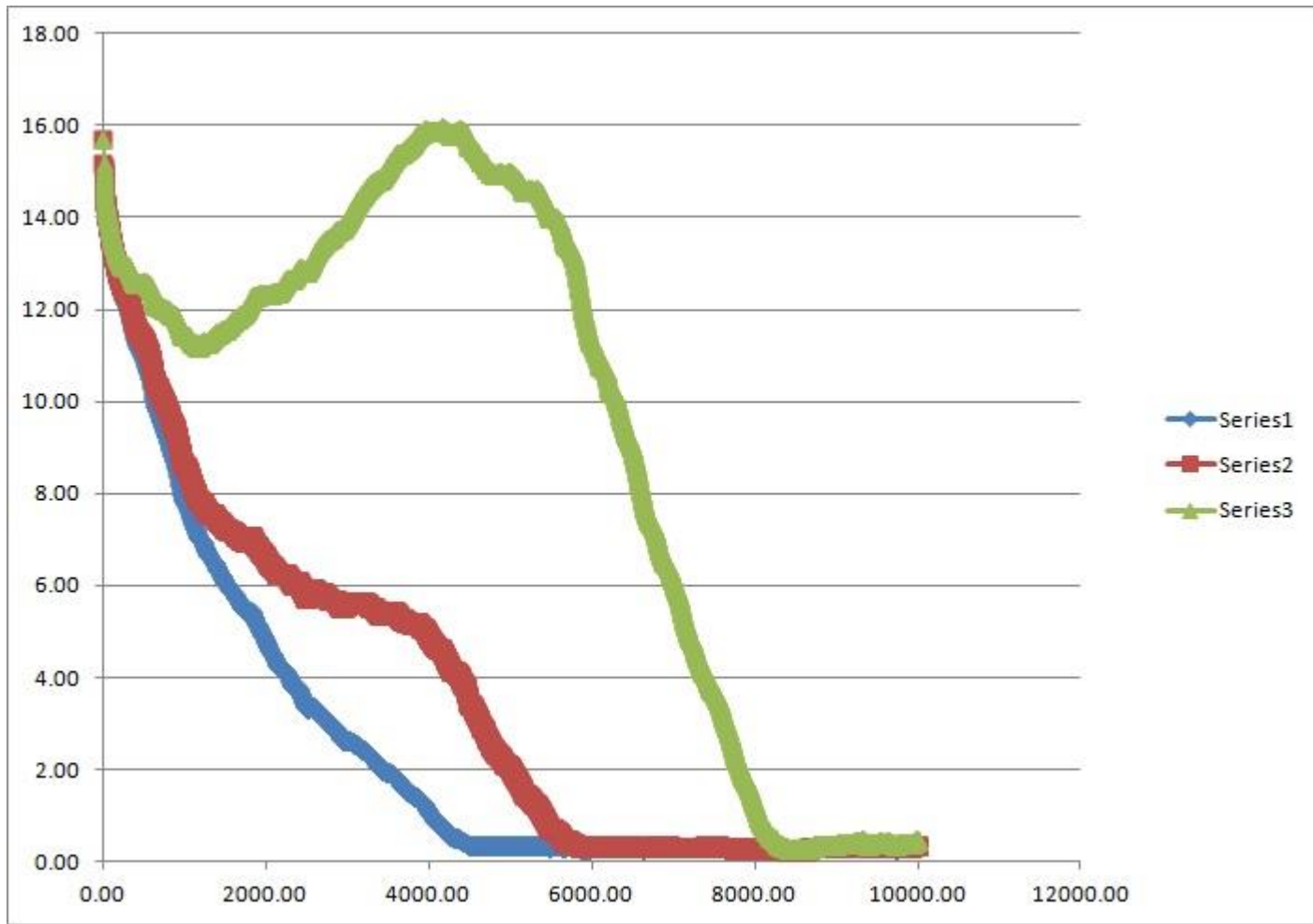
Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions



Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions



Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions

Perfect Wall > Medium Wall > Old Wall

Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions

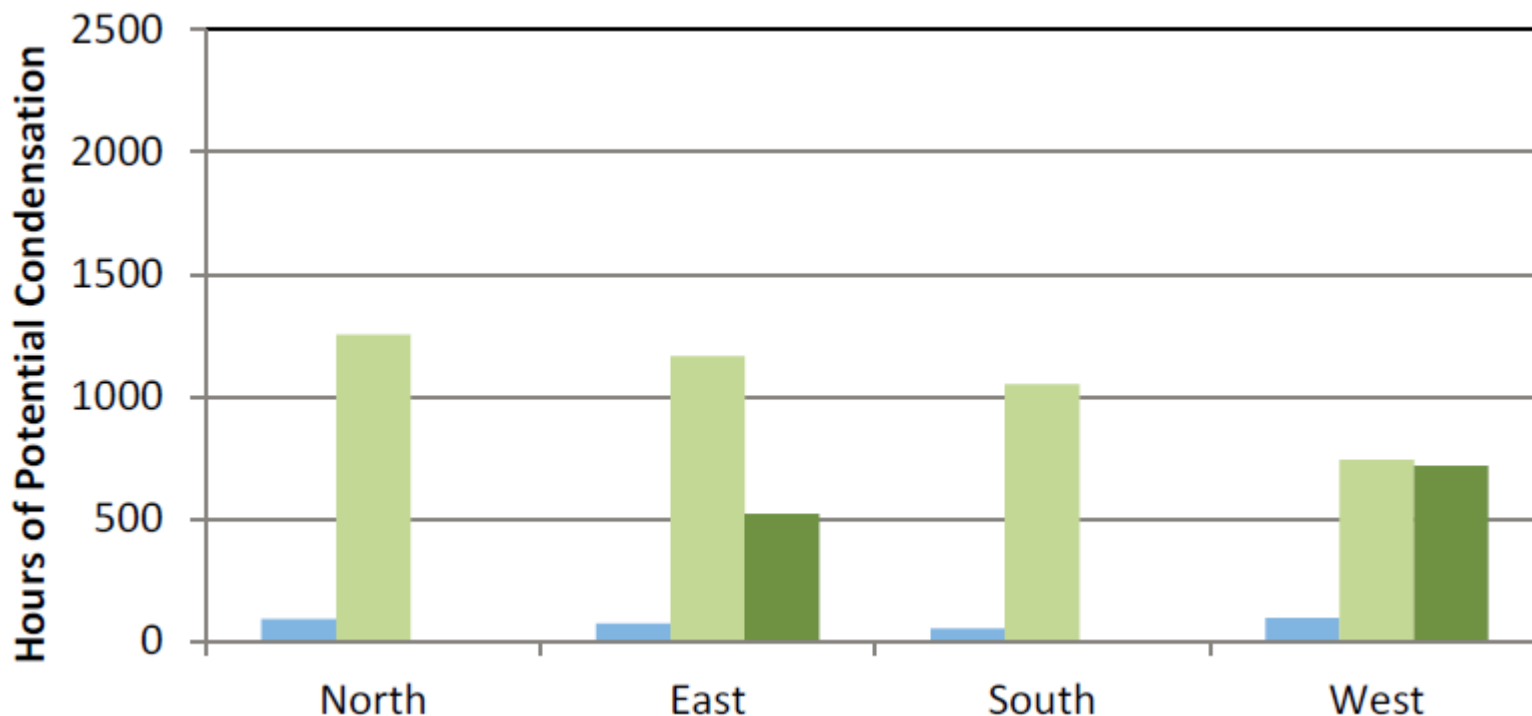
Perfect Wall > Medium Wall > Old Wall

	Wall 2 (direct applied stucco)	Wall 7 (XPS ext. ins.)
North	>106 days	68 days
East	>106 days	53 days
South	68 days	29 days
West	95 days	47 days

Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions

Perfect Wall > Medium Wall > Old Wall



Condensation: The Real Story

- Properties of Water
- Terms Relating to Condensation
- Wetting and Drying
- Analyzing Assemblies
- **Wall Design**

Condensation: Wall Design

Cold Climates: Permeability

What happens when we try to design a wall by altering the permeability of the materials?

Condensation: Wall Design

Cold Climates: Permeability

Cavity insulation forces interior vapor retarders.

Condensation: Wall Design

Cold Climates: Permeability

Very hard to deal with the various kinds of penetrations



Condensation: Wall Design

Cold Climates: Permeability

Poor effective drying because it is too often cold.

Condensation: Wall Design

Cold Climates: Permeability

**Delicate system.
What about changes by the owner?
Maintenance?**

Condensation: Wall Design

Cold Climates: Temperature

**Easier to make right.
Reduced cavity insulation
Sheathing Insulation
Broader applicability
Effective Drying
ROBUST!**

Condensation: Wall Design

Warm Climates: Permeability

Easier VB design
Easier installation
Effective Drying

Condensation: Wall Design

Warm Climates: Temperature

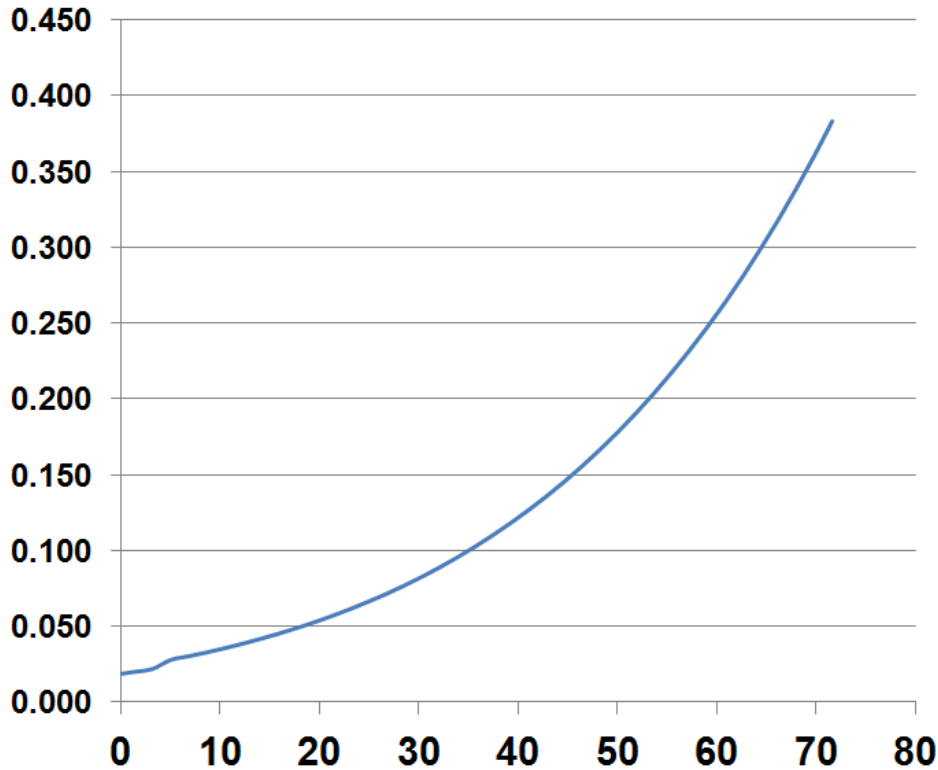
No VB

Easier installation

Effective Drying

Condensation: Summary

- Properties of Water



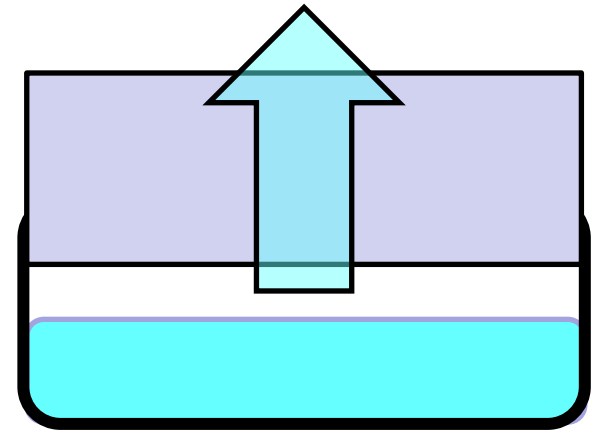
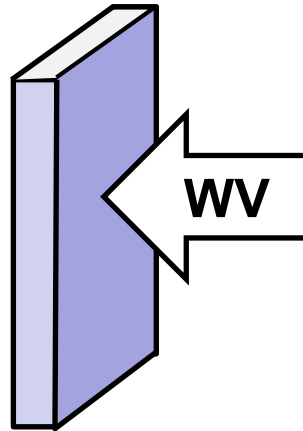
Condensation: Summary

- Properties of Water
- Terms Relating to Condensation

Relative Humidity



- Permeance
- Perms

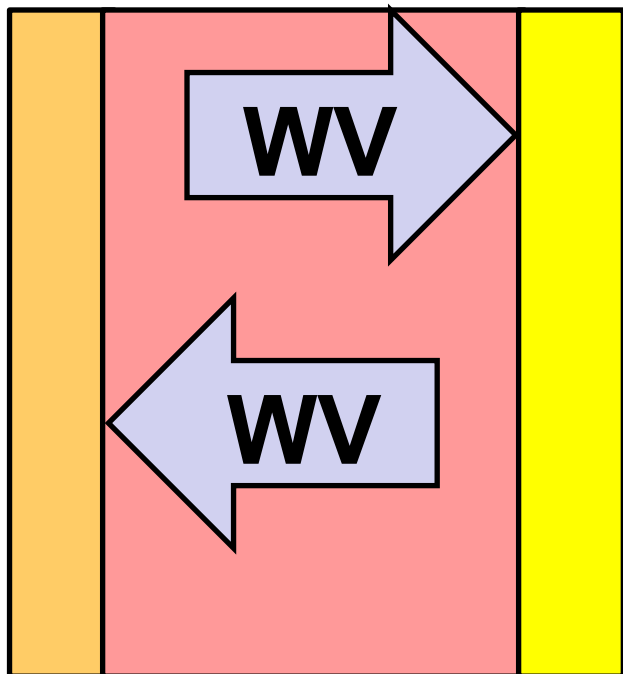


Wet Cup

gr/hr ft² in Hg

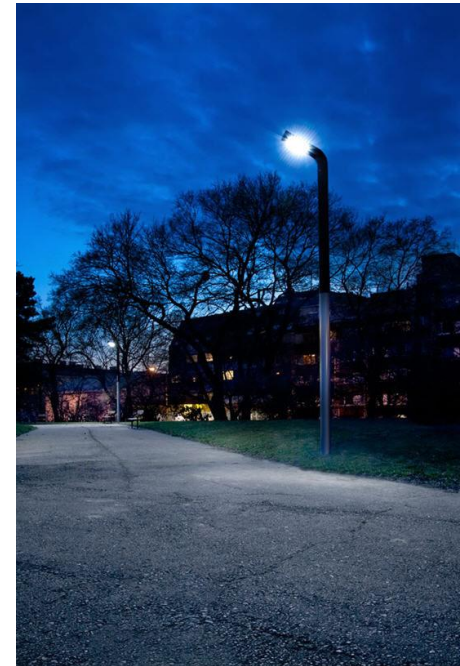
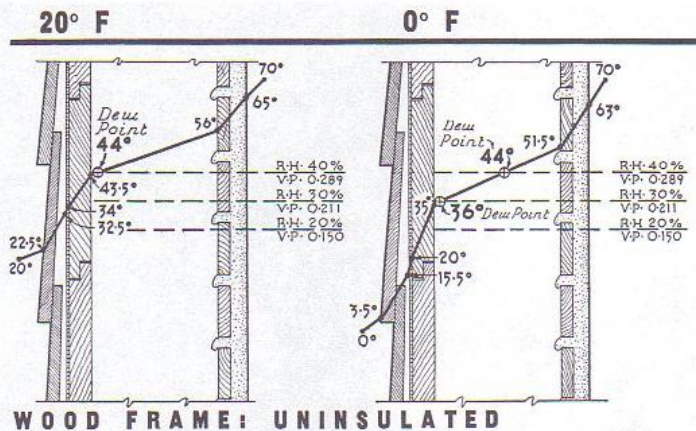
Condensation: Summary

- Properties of Water
- Terms Relating to Condensation
- Wetting and Drying



Condensation: Summary

- Properties of Water
- Terms Relating to Condensation
- Wetting and Drying
- Analyzing Assemblies



Condensation: Summary

- Properties of Water
- Terms Relating to Condensation
- Wetting and Drying
- Analyzing Assemblies
- Wall Design

**Easier to make right.
Reduced cavity insulation
Sheathing Insulation
Broader applicability
Effective Drying
ROBUST!**

Condensation: References

- Rose, W.B., 2005. *Water in Buildings*. Wiley, Hoboken, NJ.
- CRC, 1998. *Handbook of Physics and Chemistry*, Weast.
- Atkins, P., 2001. *Physical Chemistry*. Freeman
- Collin Murphy, 2002, *Moisture Within Walls*, Interface
- Brad Carpenter, 2010, *Modern Performance Expectations and Historic Masonry Walls*, RCI
- ABCB, 2009, *The Condensation Handbook*, Australian institute of Architects
- Nusser and Teibinger, 2012, *Coupled Heat and Moisture Transfer - Implementing WUFI*, COMSOL Conference
- DOE, 2011, *Air Leakage Guide*, DOE
- Joseph Lstiburek, 2006, *Understanding Vapor Barriers*, BSC
- Joseph Lstiburek, 2010, *Mind the Gap*, BSC/Insight
- Maria Spinu, 2012, *Design Without Compromise*, Construction Specifier
- Smegal and Straube, 2011, *Hygrothermal Analysis of Exterior Rockwool Insulation*, BSC
- Smegal, Lstiburek, Straube, Grin, 2012, *Vancouver Field Exposure Facility: Phase III Exterior Insulation Analysis*, BSC
- Straube, 2002, *The Influence of Low Permeance Vapor Barriers on Roof and Wall Performance*, Buildings VIII
- DOE, 2004, *5.C.2.1 Vapor Barrier Journal Paper*, DOE

Condensation: The Real Story

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Questions?