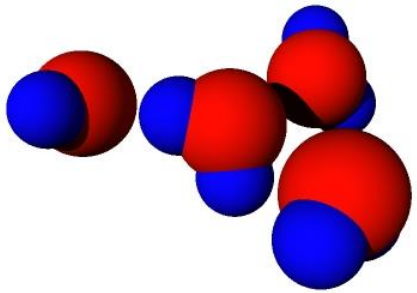
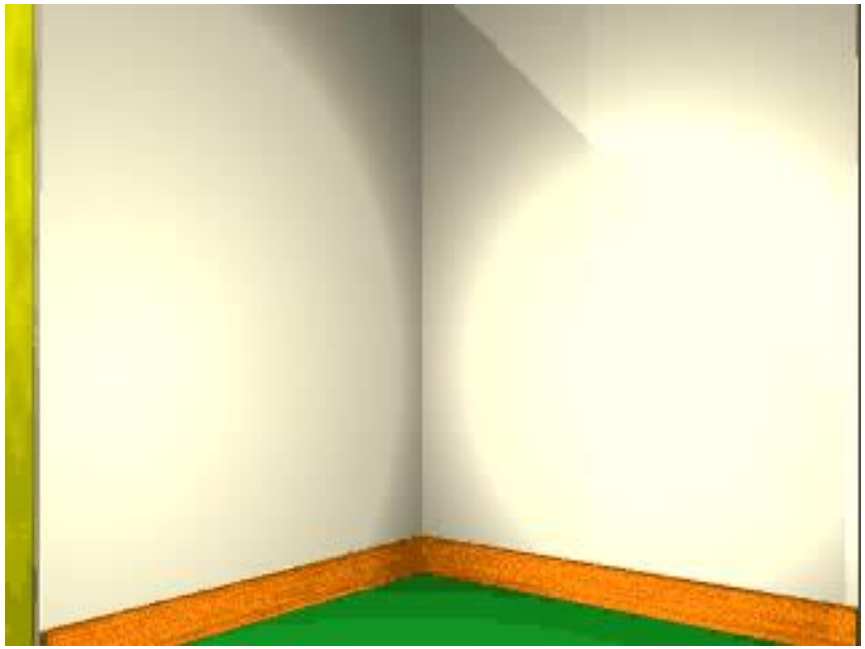
Condensation
The Real Story

Dan Tempas
Sr. Scientist





RESNET
Residential Energy Service Network

DOW®

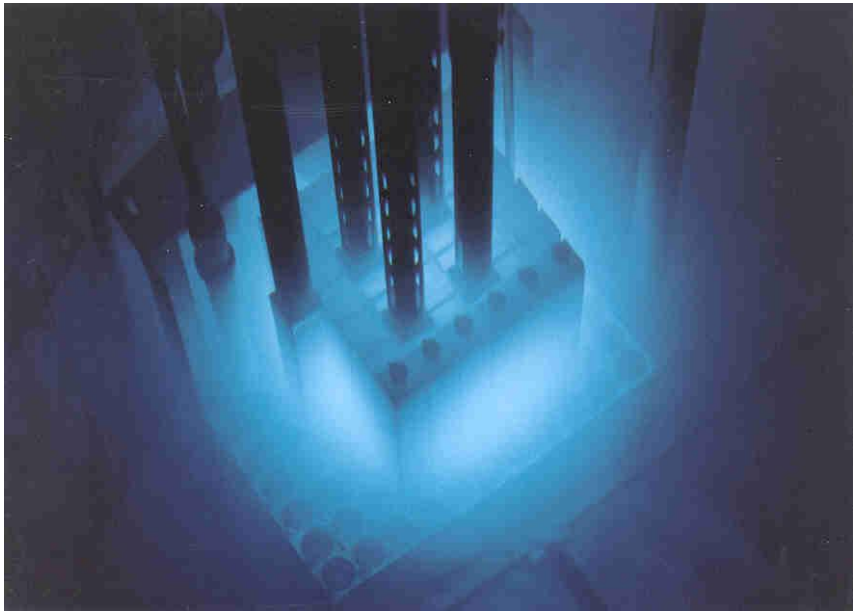
Condensation
The Real Story

1982

Chemical Engineering

Dan Tempas
Sr. Scientist

Condensation
The Real Story



1982

Nuclear Engineering

Dan Tempas
Sr. Scientist

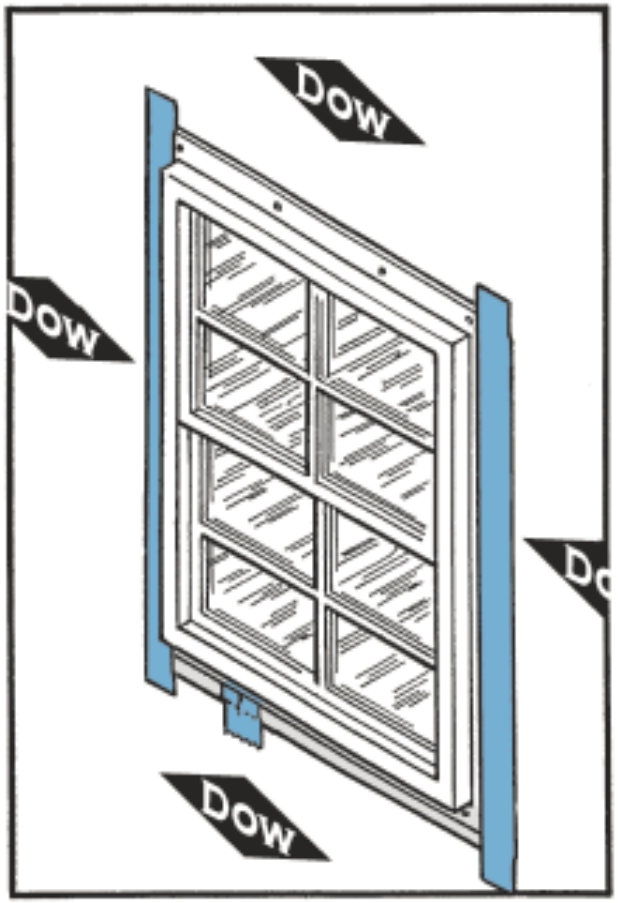
Condensation Scope

Why This Talk?

- Misconceptions
- Errors
- Incompleteness

Condensation
Scope

Not About Bulk Water



Condensation Scope

Bulk Water is Important!

Condensation: The Real Story

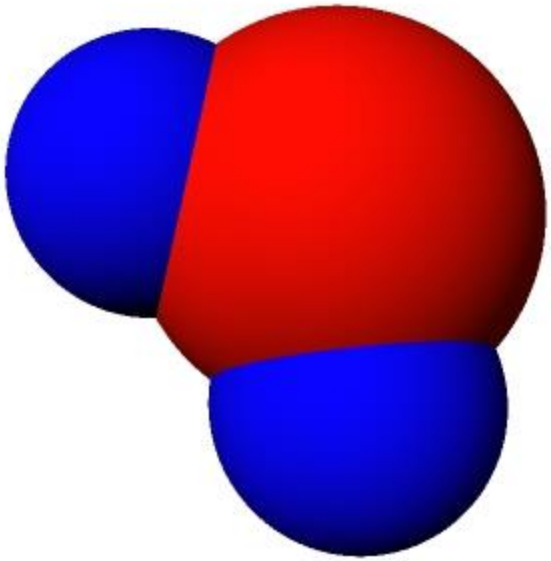
- Properties of Water
- Terms Relating to Condensation
- Wetting and Drying
- Analyzing Assemblies
- Wall Design

Condensation: The Real Story

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

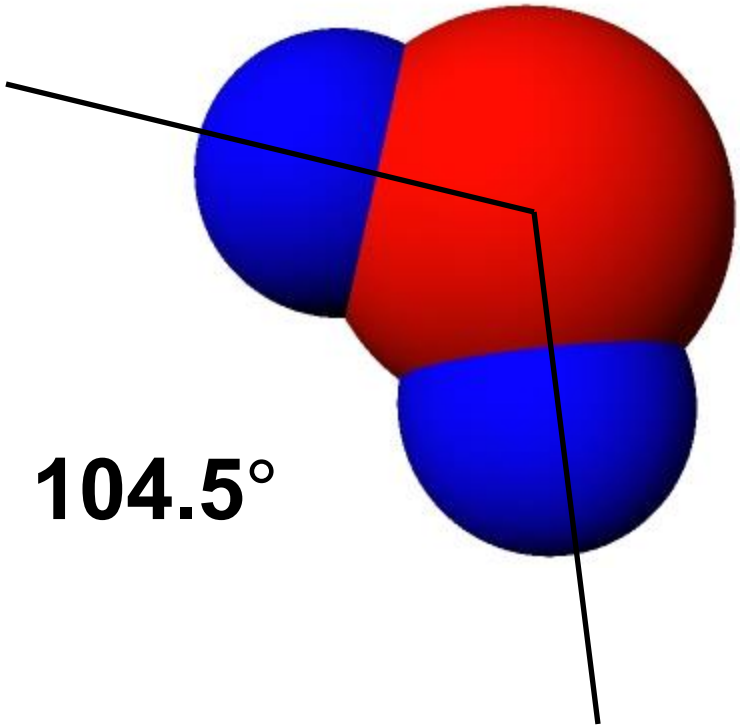
Condensation: Water Properties

Structure



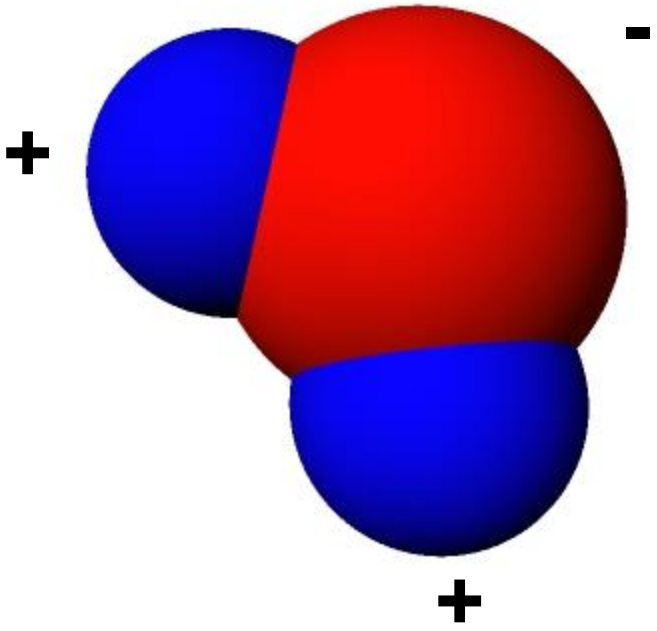
Condensation: Water Properties

Structure



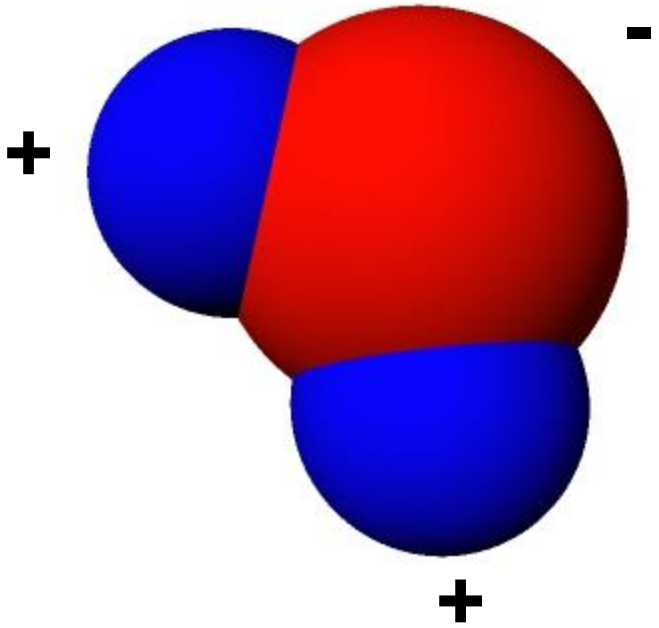
Condensation: Water Properties

Structure



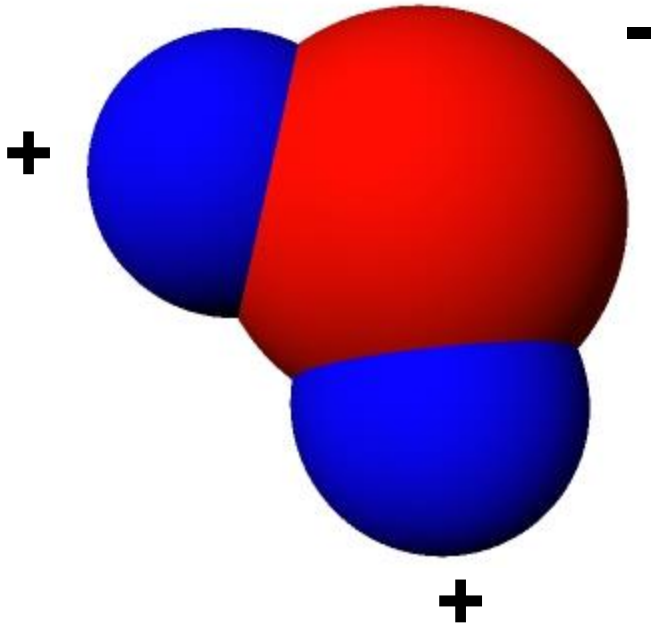
Condensation: Water Properties

Structure



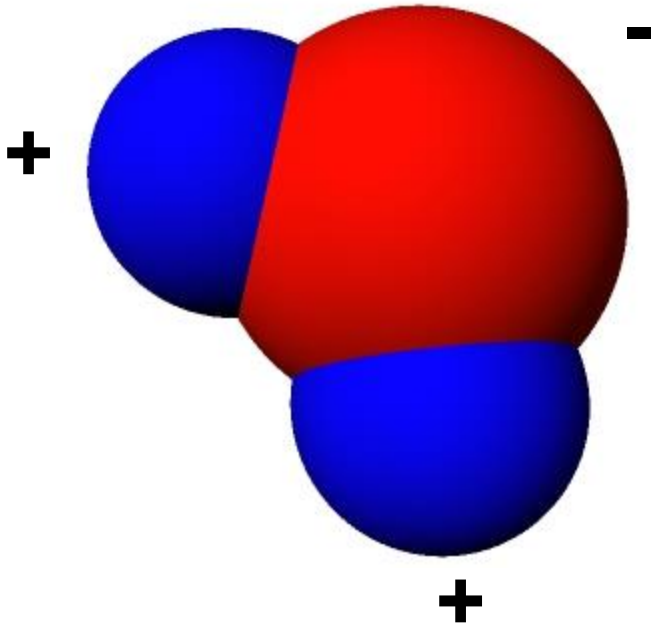
Condensation: Water Properties

Structure



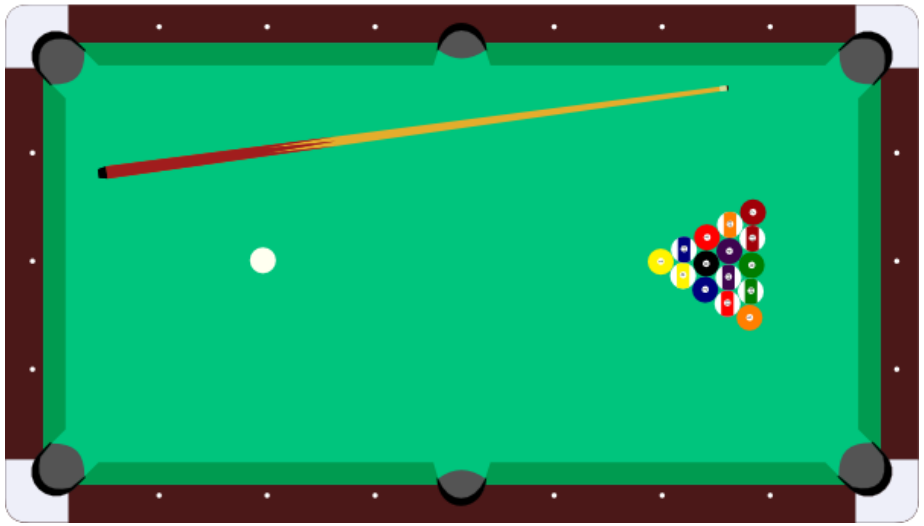
Condensation: Water Properties

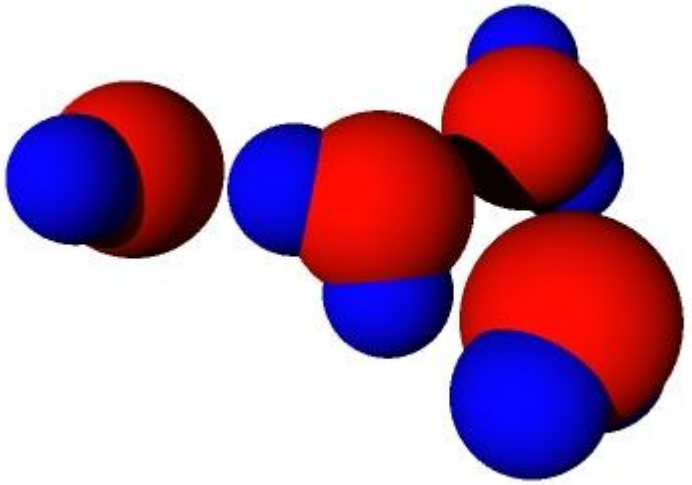
Structure



Condensation: Water Properties

Structure





Condensation: Water Properties

Structure

Condensation: Water Properties

Phases of Water

Gas

Condensation: Water Properties

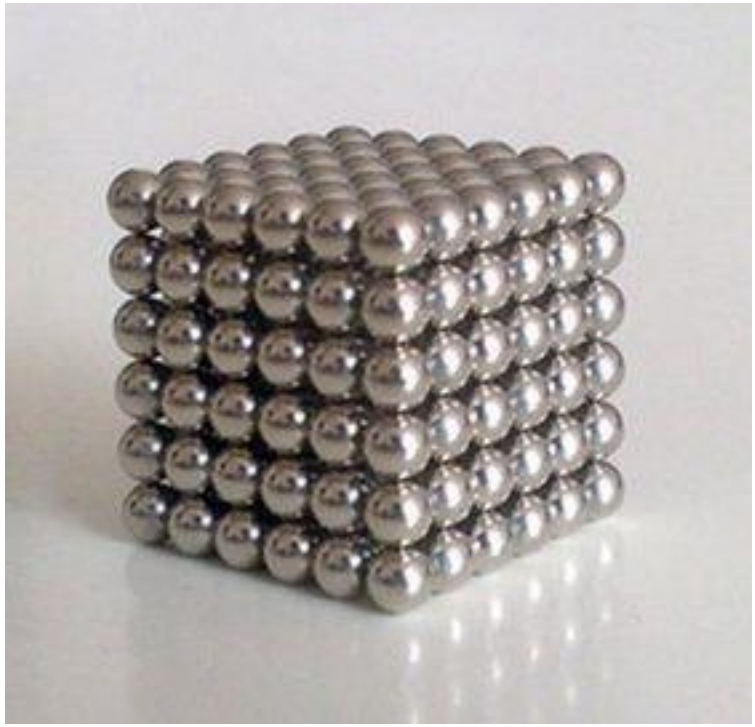
Phases of Water

Liquid

Condensation: Water Properties

Phases of Water

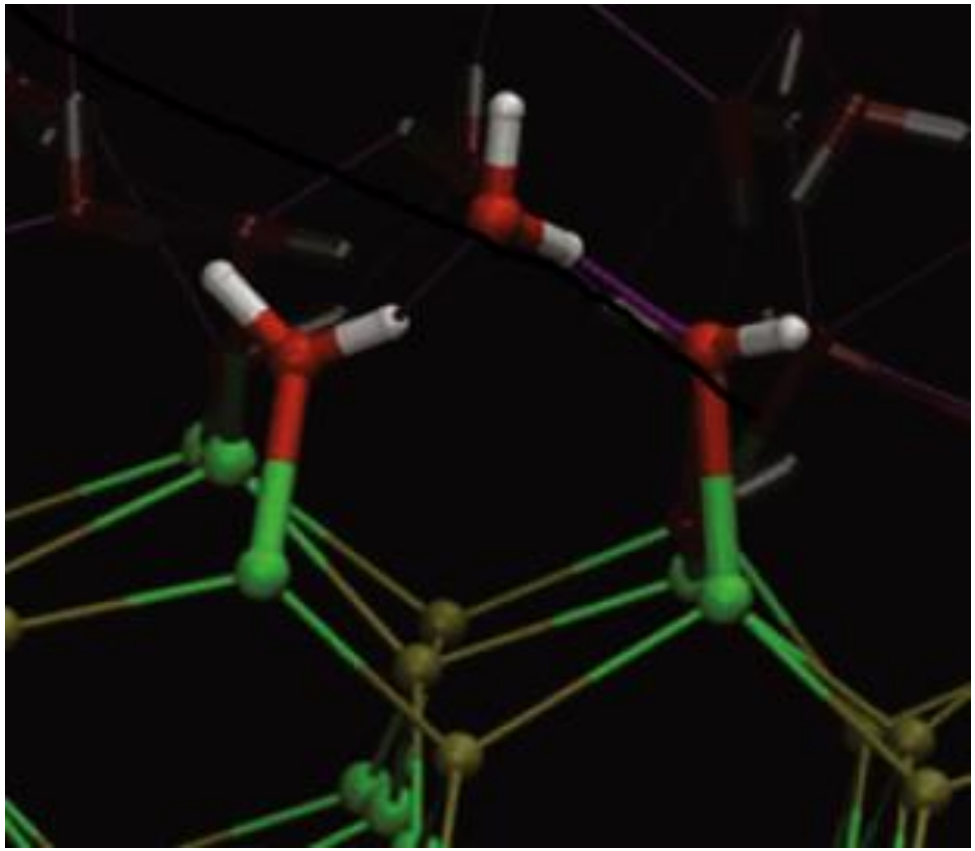
Solid



Condensation: Water Properties

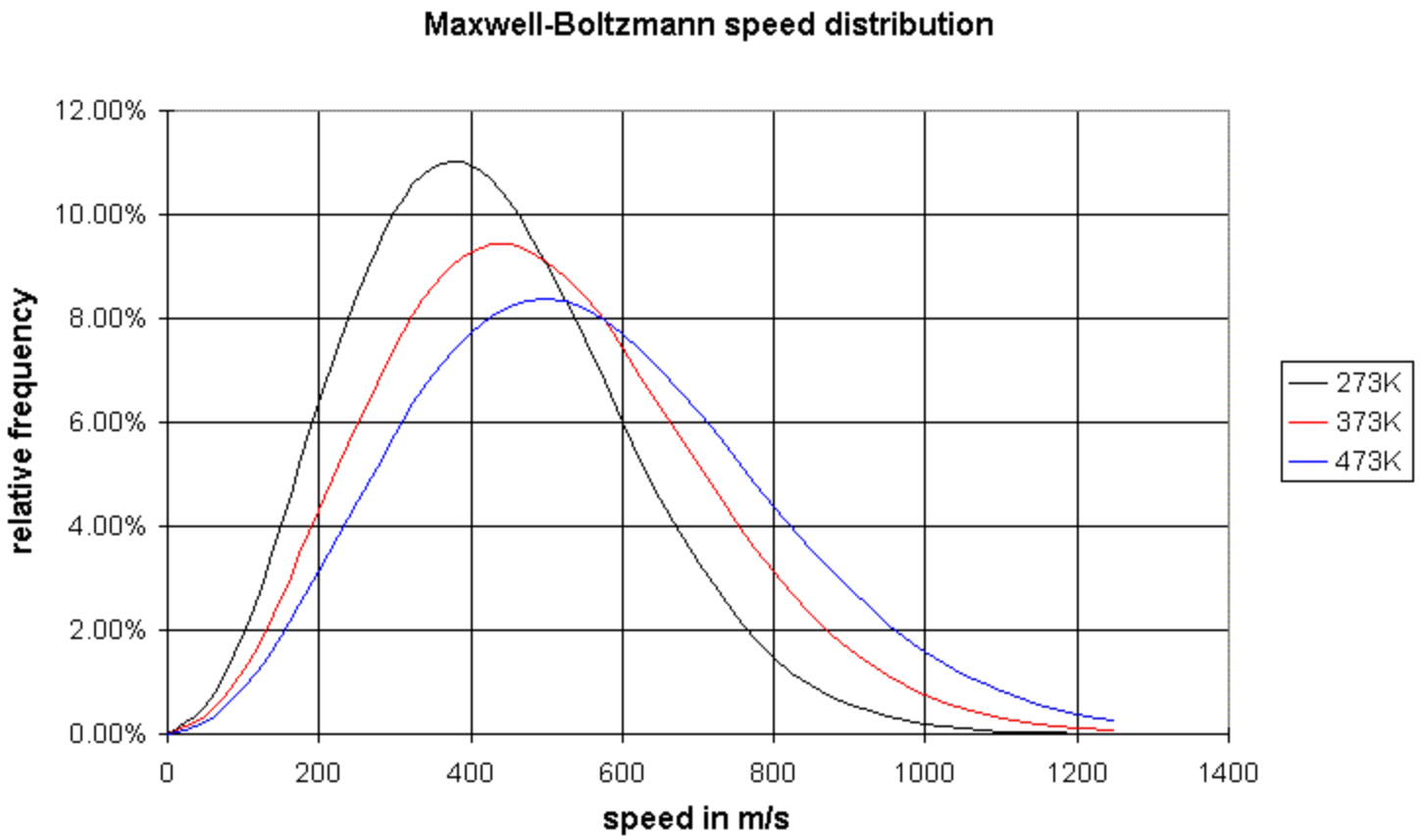
Phases of Water

Adsorbed



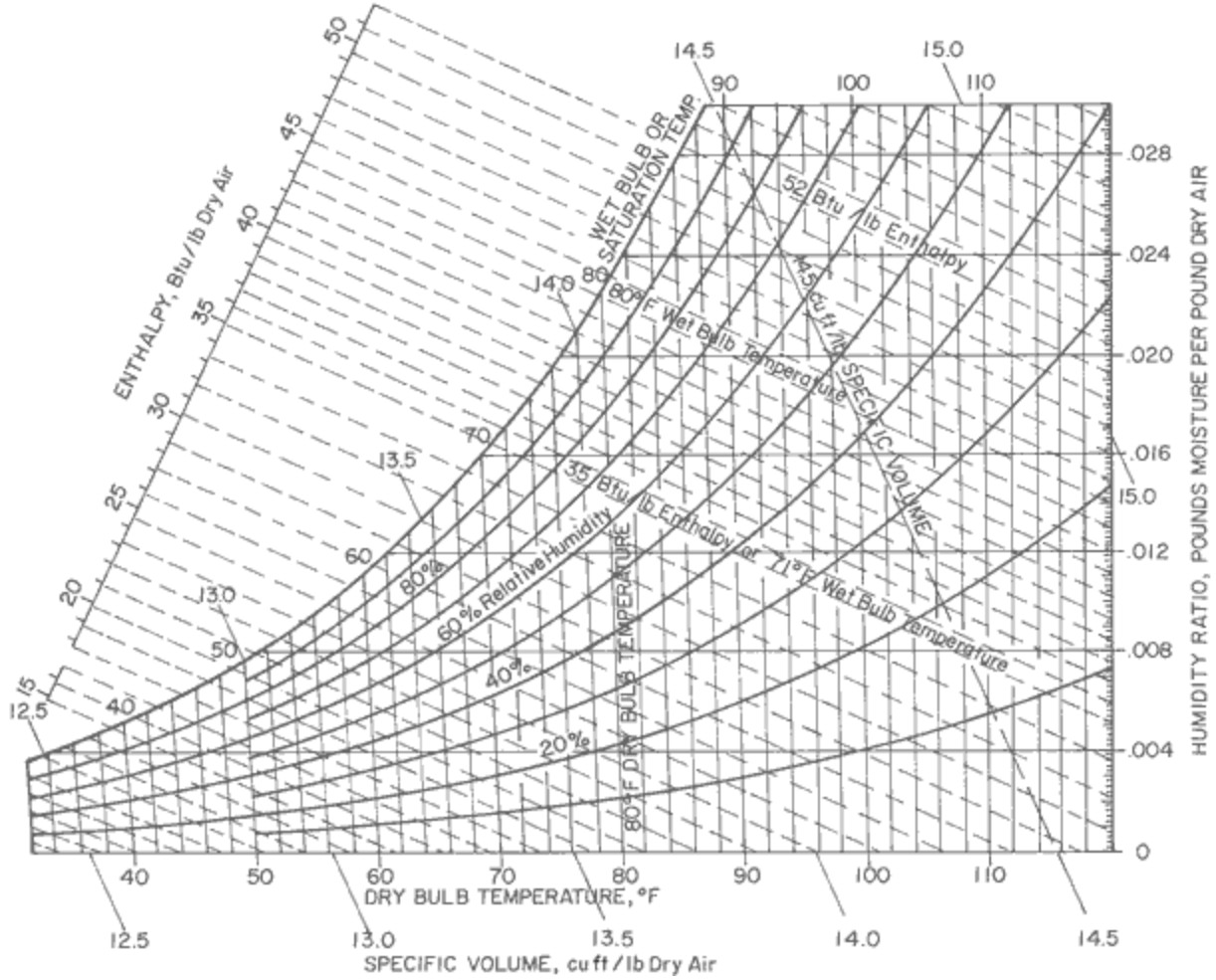
Condensation: Water Properties

Effect of Temperature



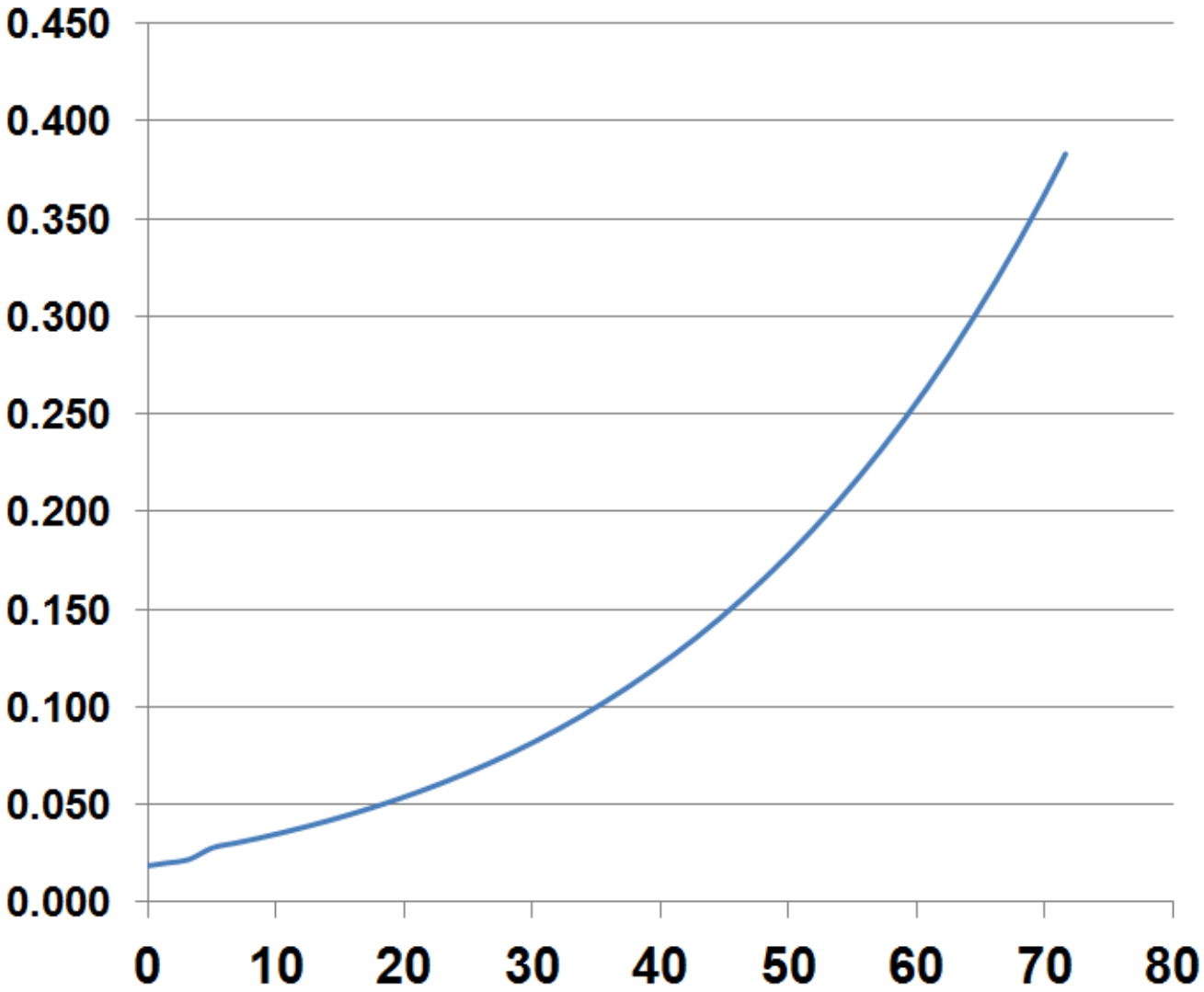
Condensation: Water Properties

Psychometric Chart



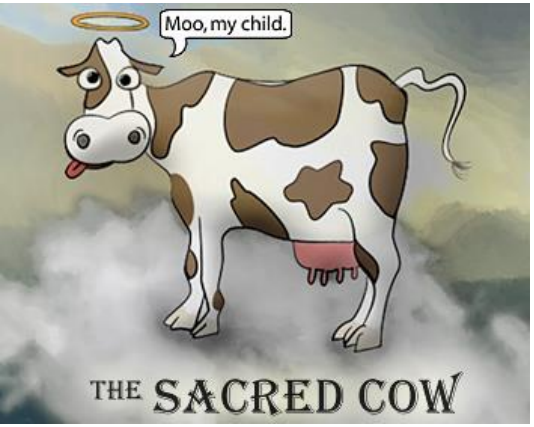
Condensation: Water Properties

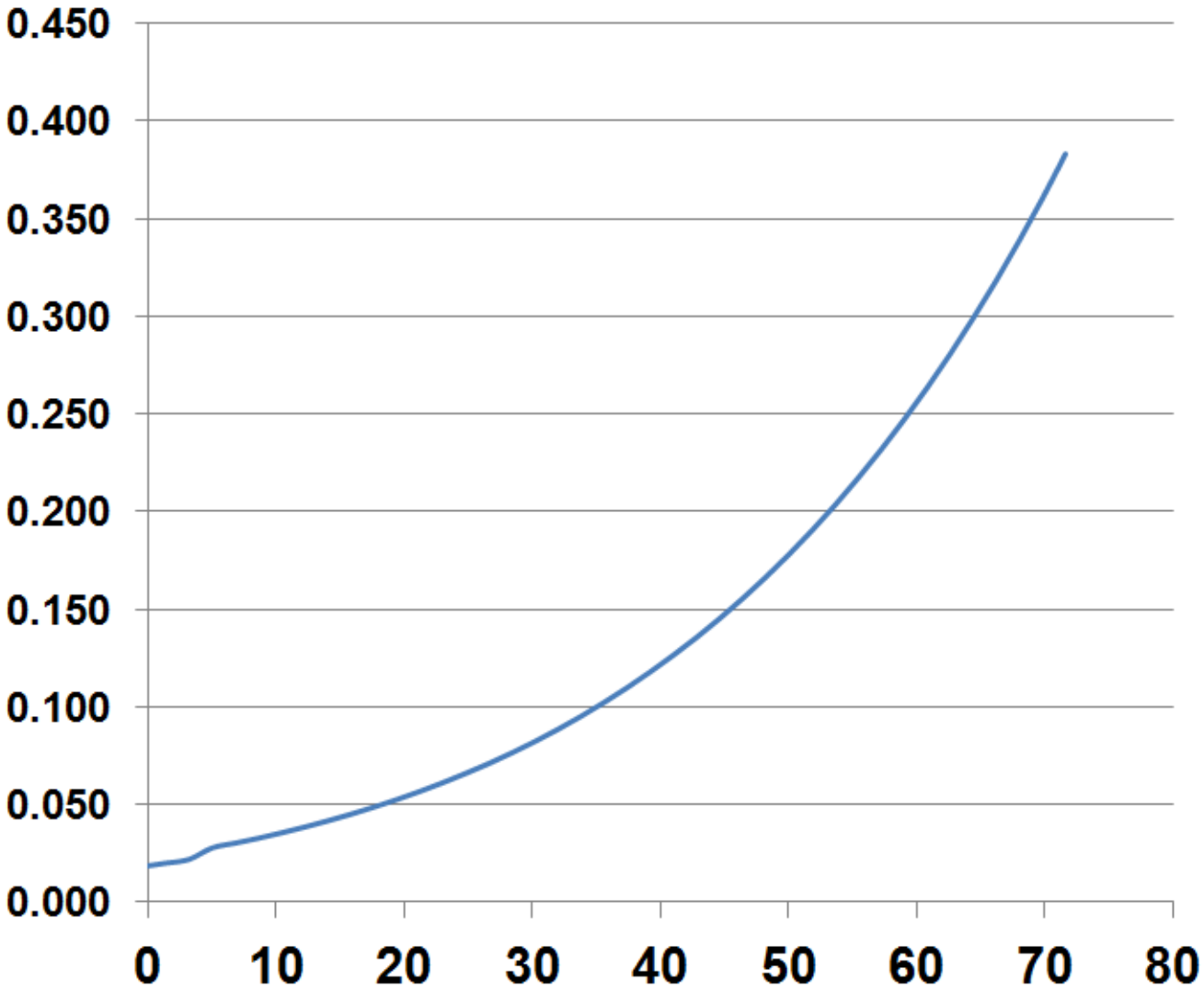
Psychometric Chart



Condensation: Water Properties

Psychometric 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:

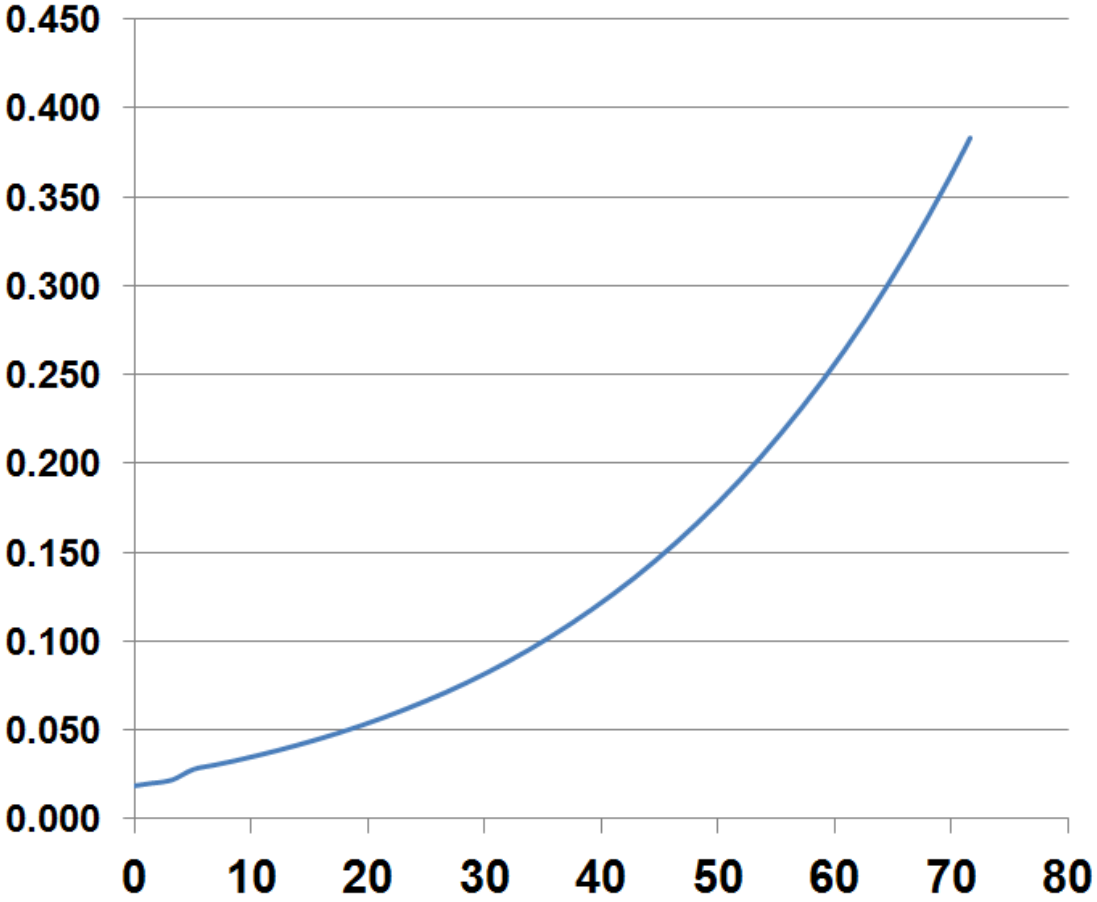
- Temperature (°F)
- Percent (%)

Condensation: Terms

Relative Humidity

Condensation: Terms

Relative Humidity

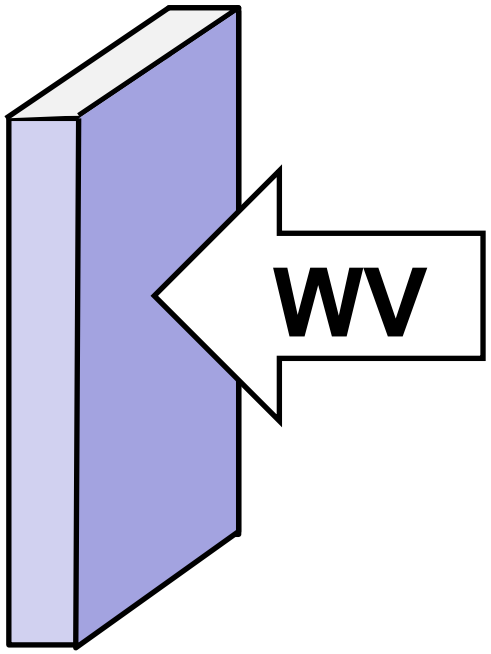


Condensation: Terms

Permeability: Diffusion

- Permeance
- Perms

gr/hr ft^2 in Hg



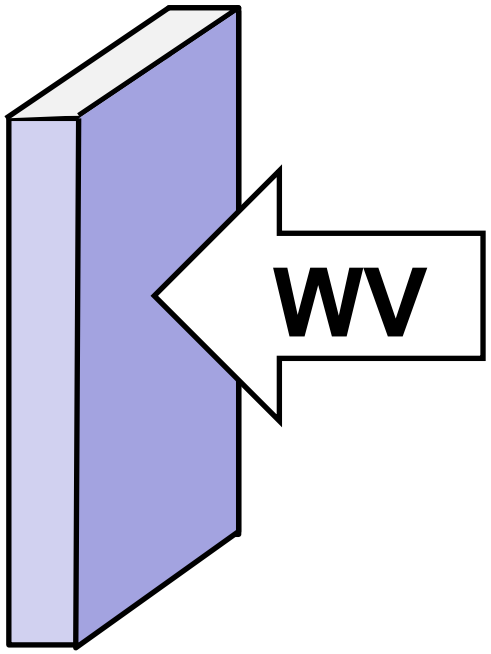
Condensation: Terms

Permeability: Diffusion

- Permeability
- Perm inch

gr in/hr ft^2 inHg

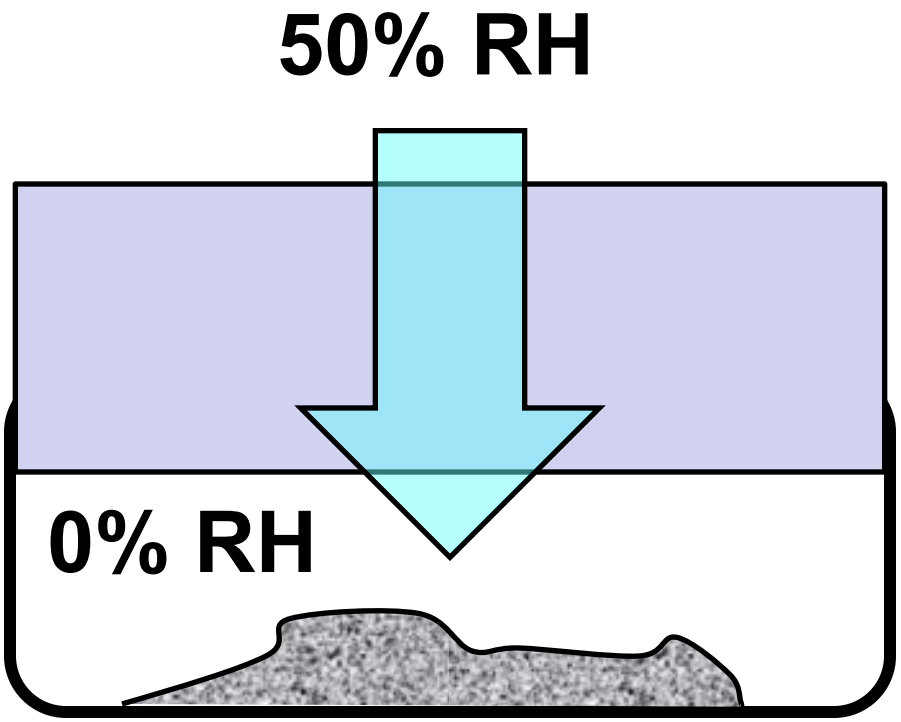
gr/hr ft inHg



Condensation: Terms

Permeability: Diffusion

ASTM E96

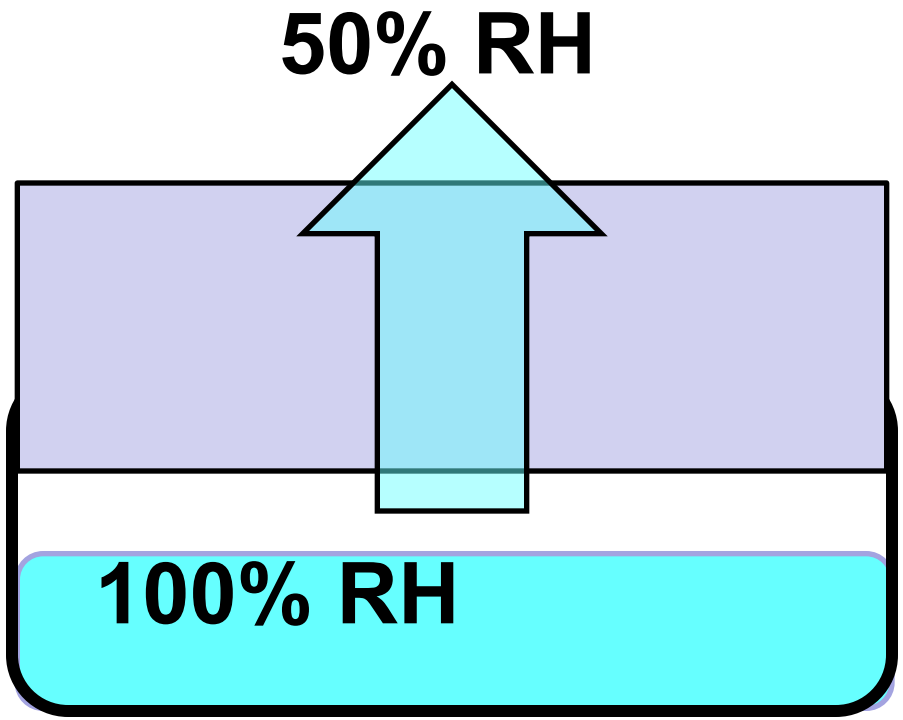


Dry Cup

Condensation: Terms

Permeability: Diffusion

ASTM E96

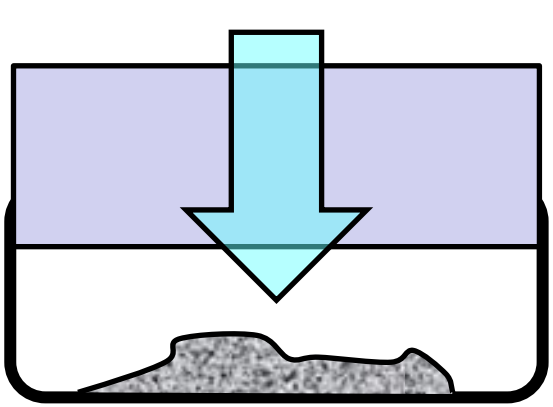


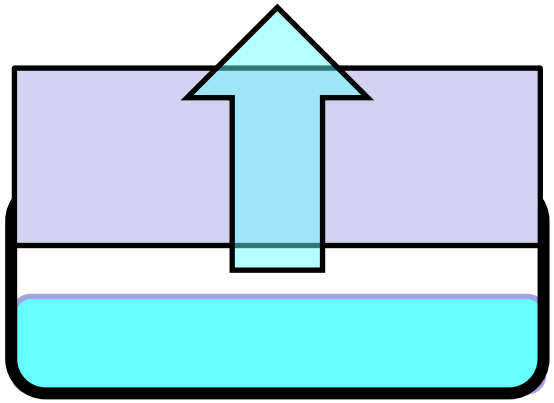
Wet Cup

Condensation: Terms

Permeability: Diffusion

ASTM E96





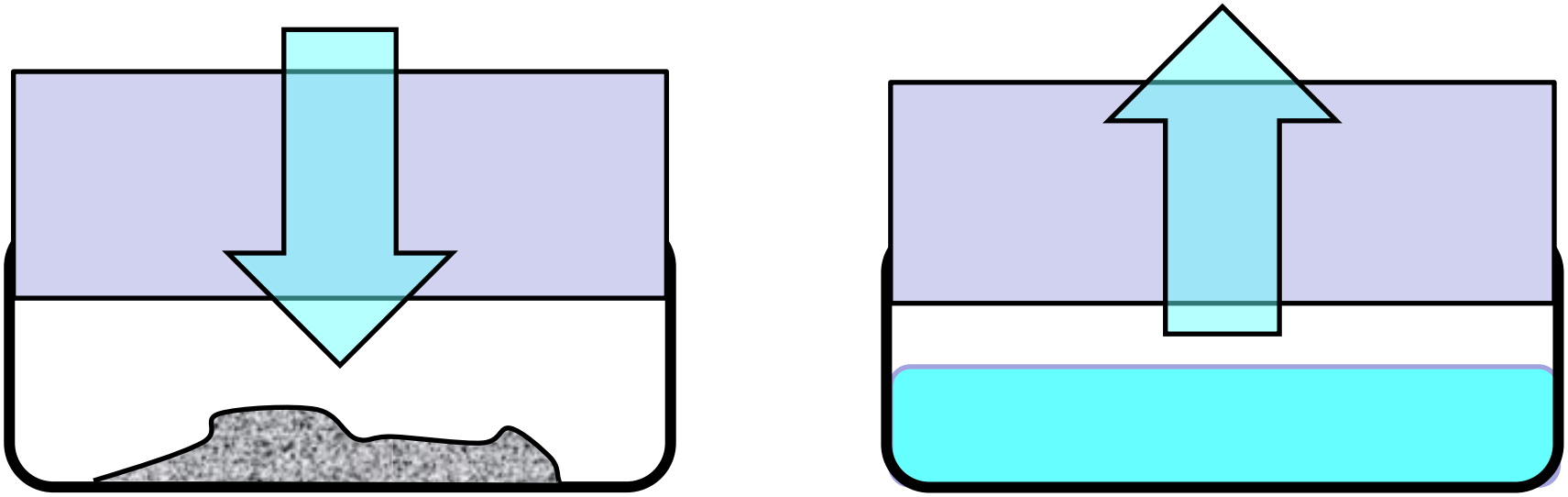
Dry Cup Wet Cup

"Unfortunately, results from ASTM E96 are not particularly dependable."

Condensation: Terms

Permeability: Diffusion

ASTM E96



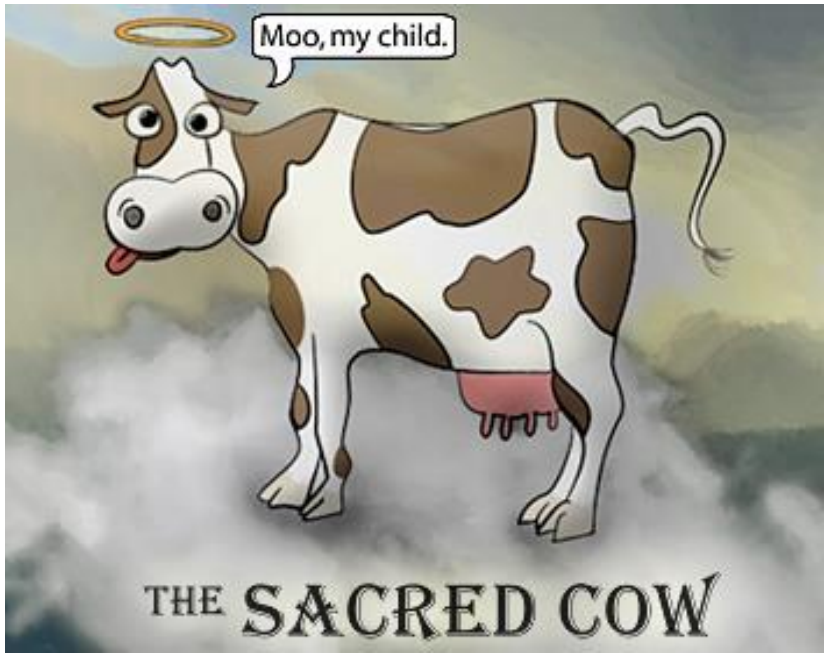
Dry Cup **Wet Cup**

Temperature?

Condensation: Terms

Permeability: Diffusion

Permeability = Breathability?



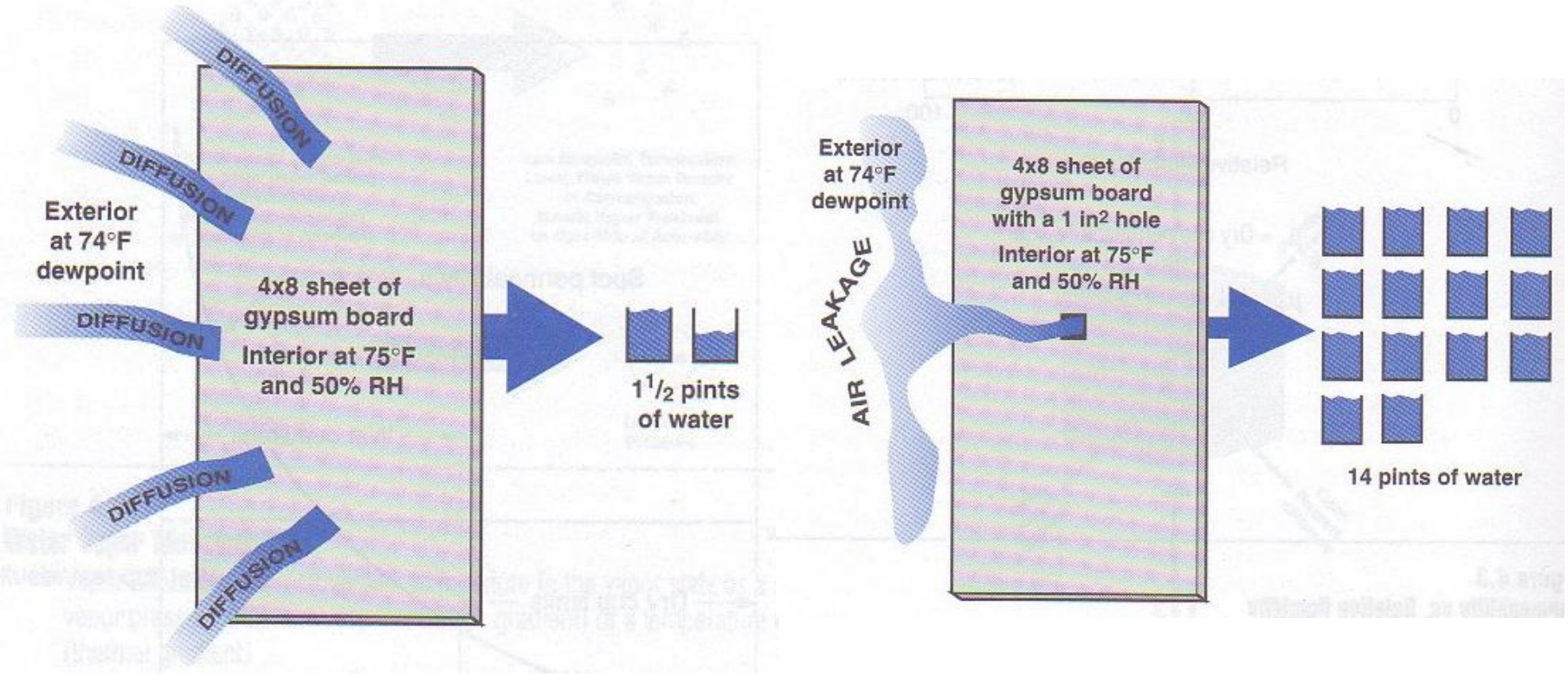
Condensation: Terms

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
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Condensation: Wetting and Drying

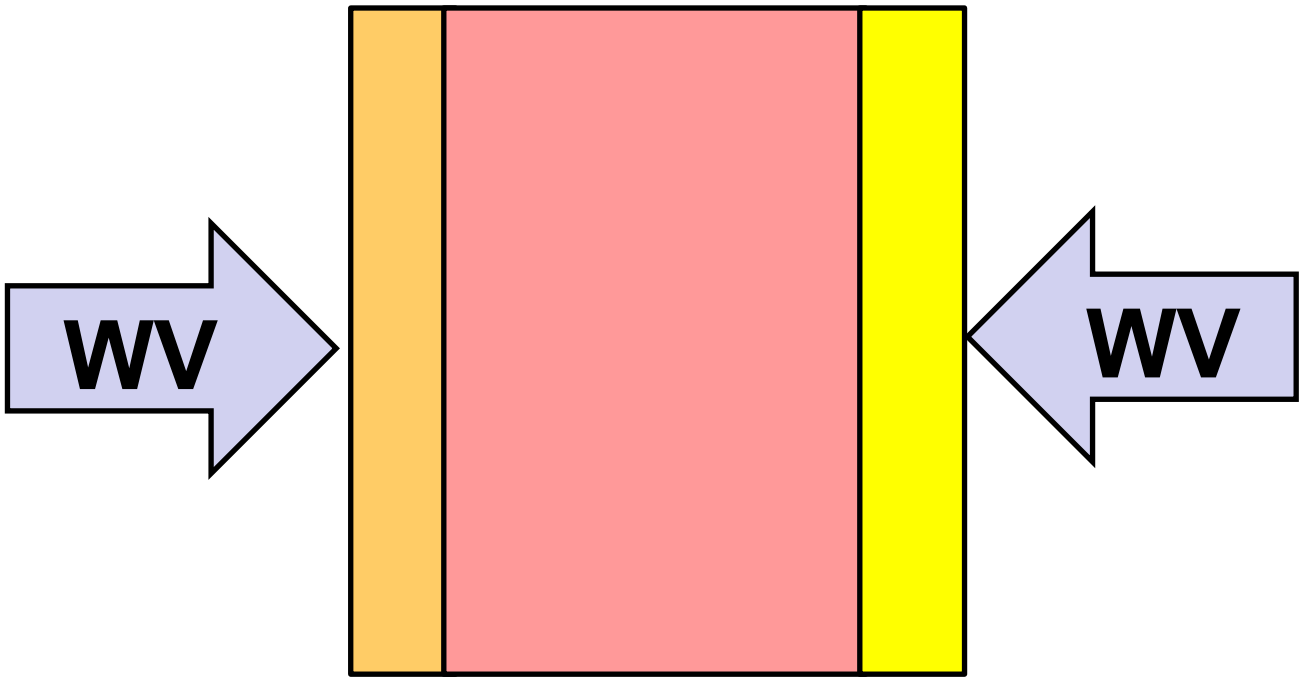
Two Sides of the same coin

Condensation: Wetting and Drying

Two Sides of the same coin

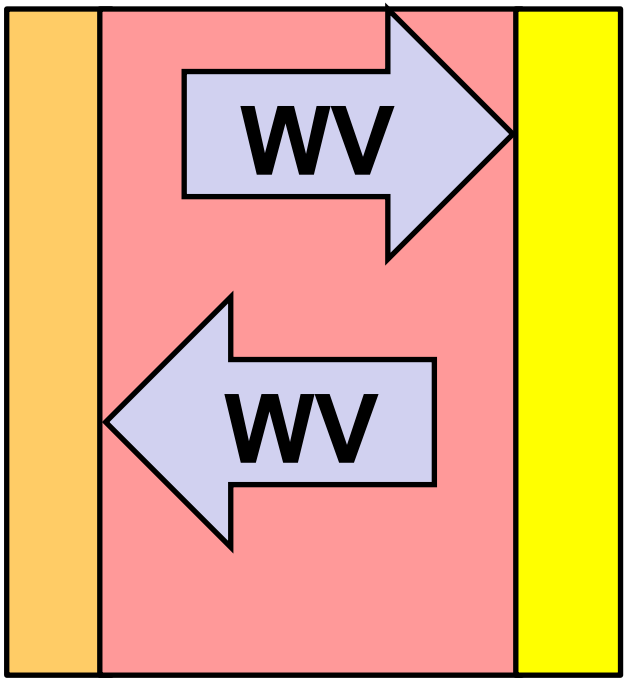
Condensation: Wetting and Drying

Two Sides of the same coin: Permeability



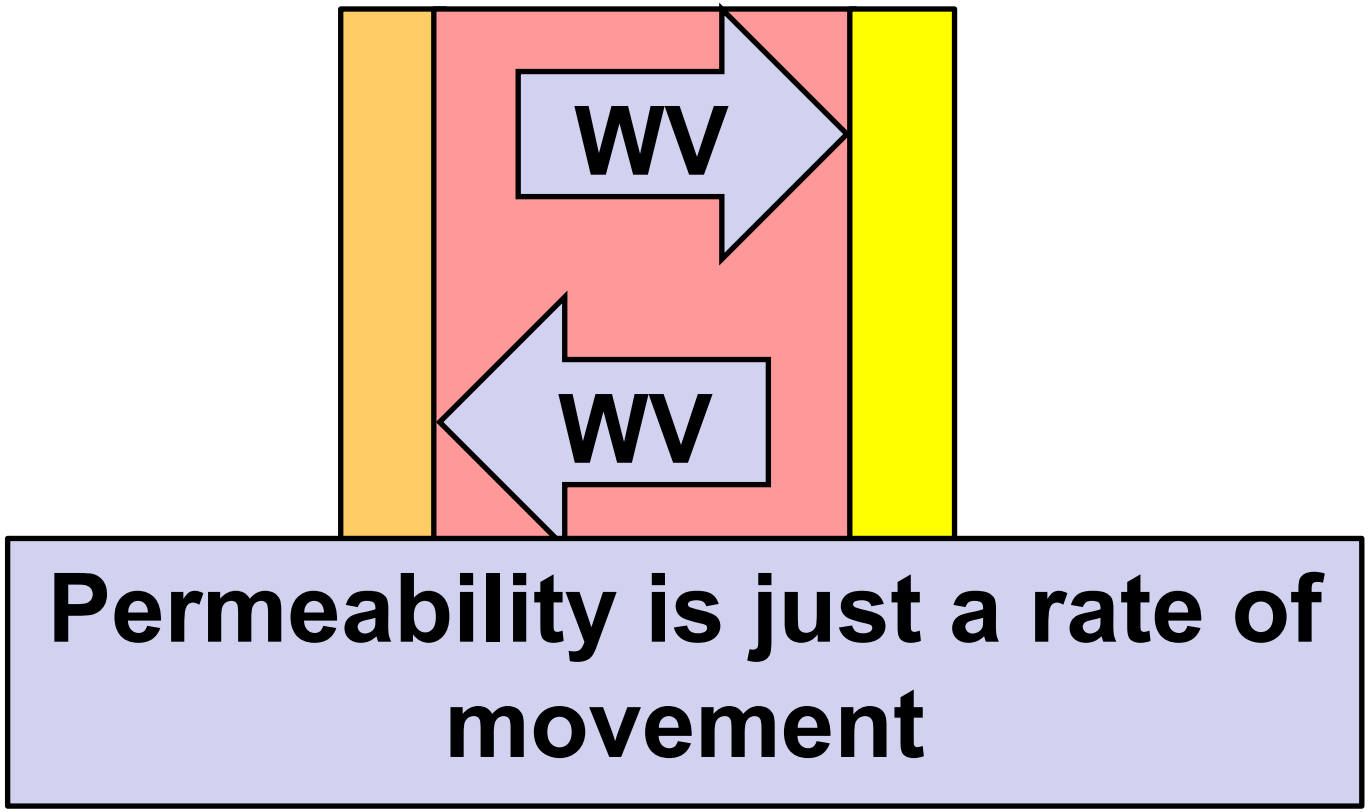
Condensation: Wetting and Drying

Two Sides of the same coin: Permeability



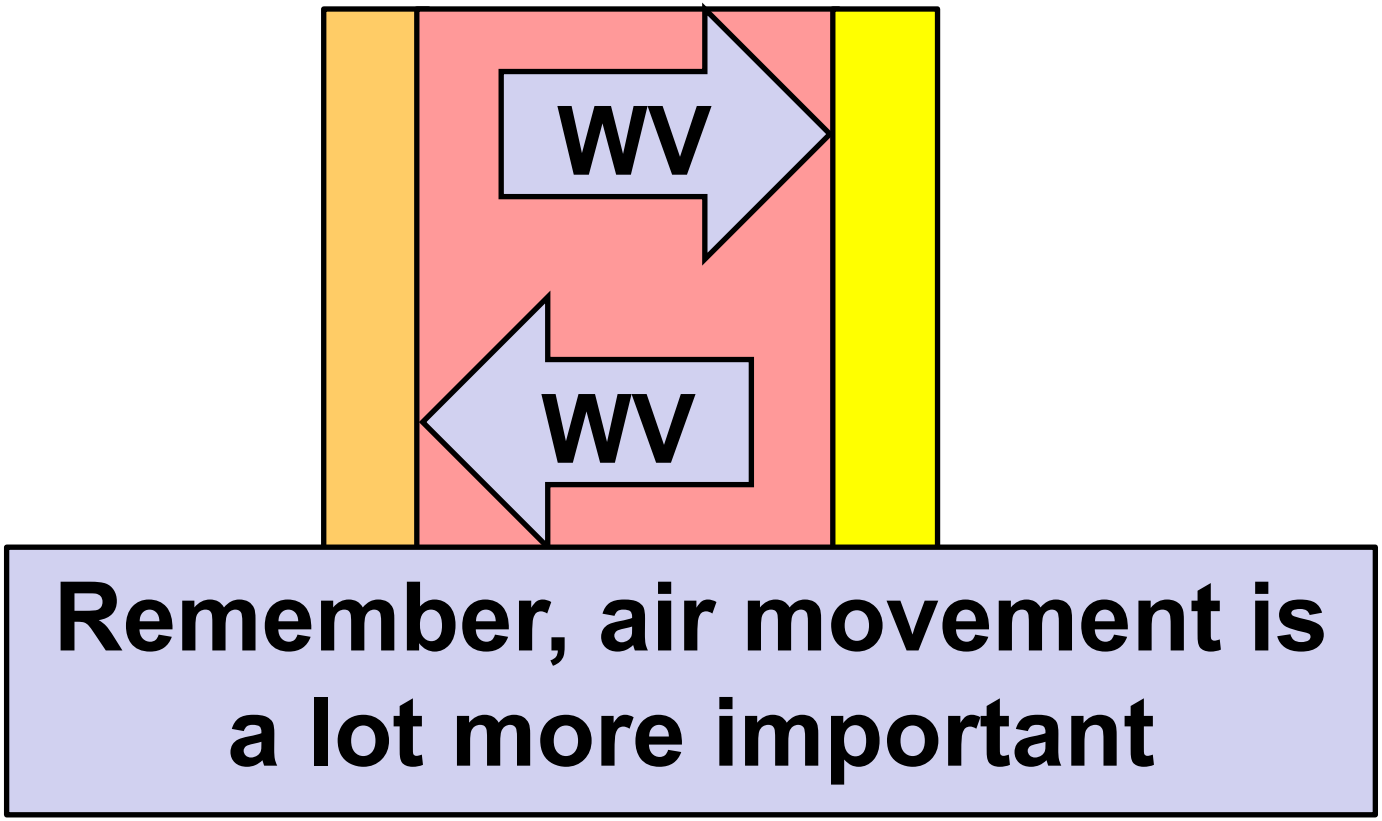
Condensation: Wetting and Drying

Two Sides of the same coin: Permeability



Condensation: Wetting and Drying

Two Sides of the same coin: Permeability

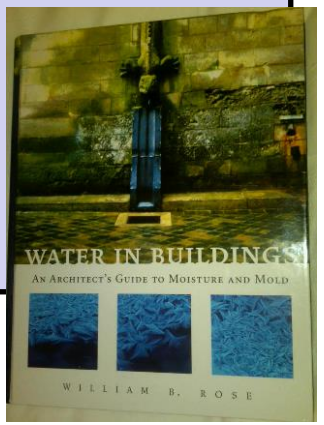


Condensation: Wetting and Drying

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

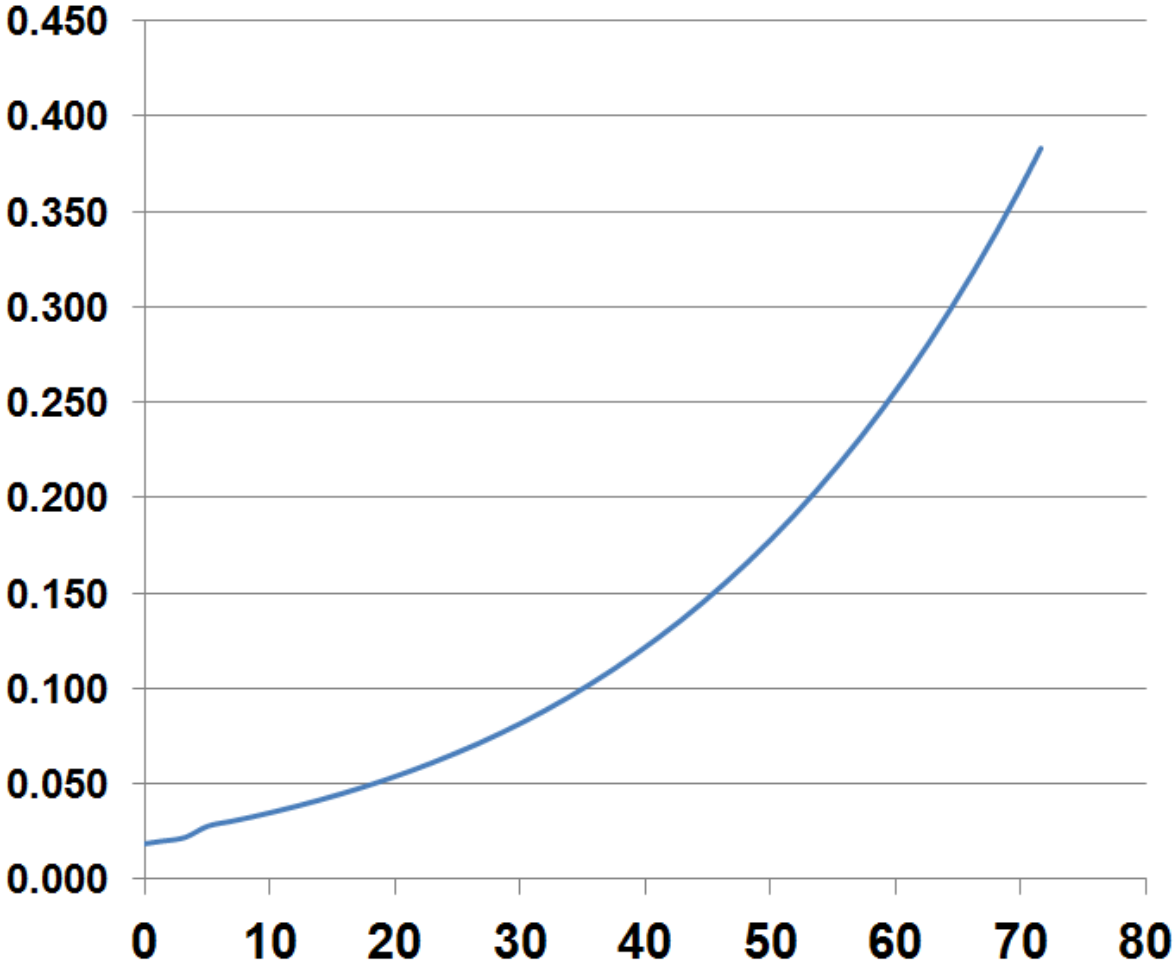
Two Sides of the same coin: Temperature

Condensation: Wetting and Drying

Two Sides of the same coin: Temperature

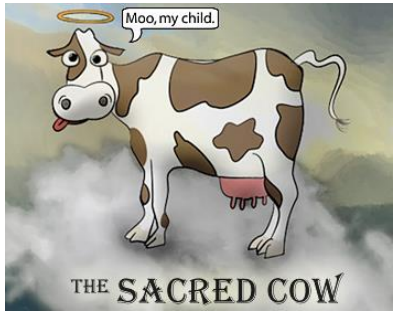
Condensation: Wetting and Drying

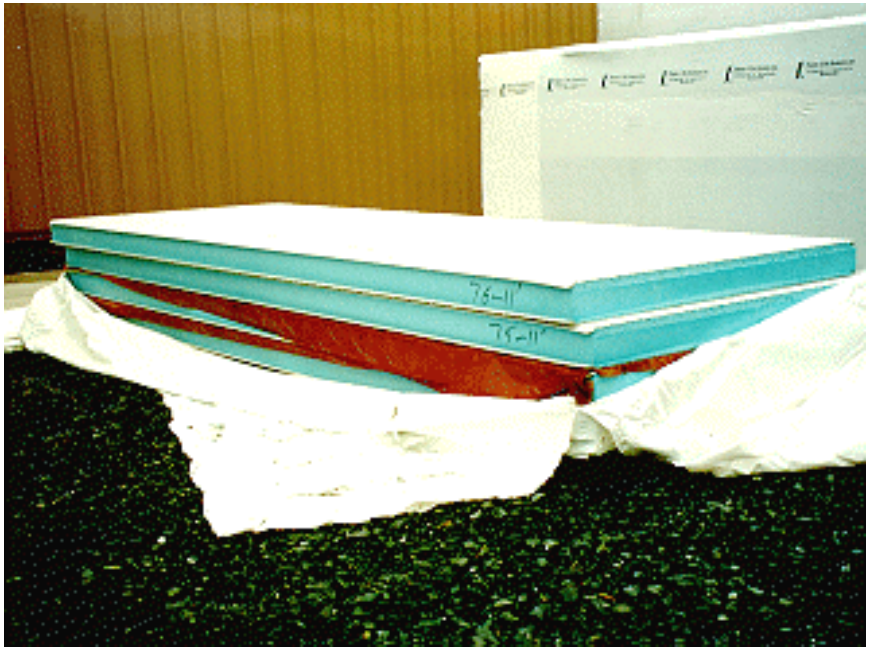
Temperature



Condensation: Wetting and Drying

Myth of Breathability





Condensation: The Real Story

- Properties of Water
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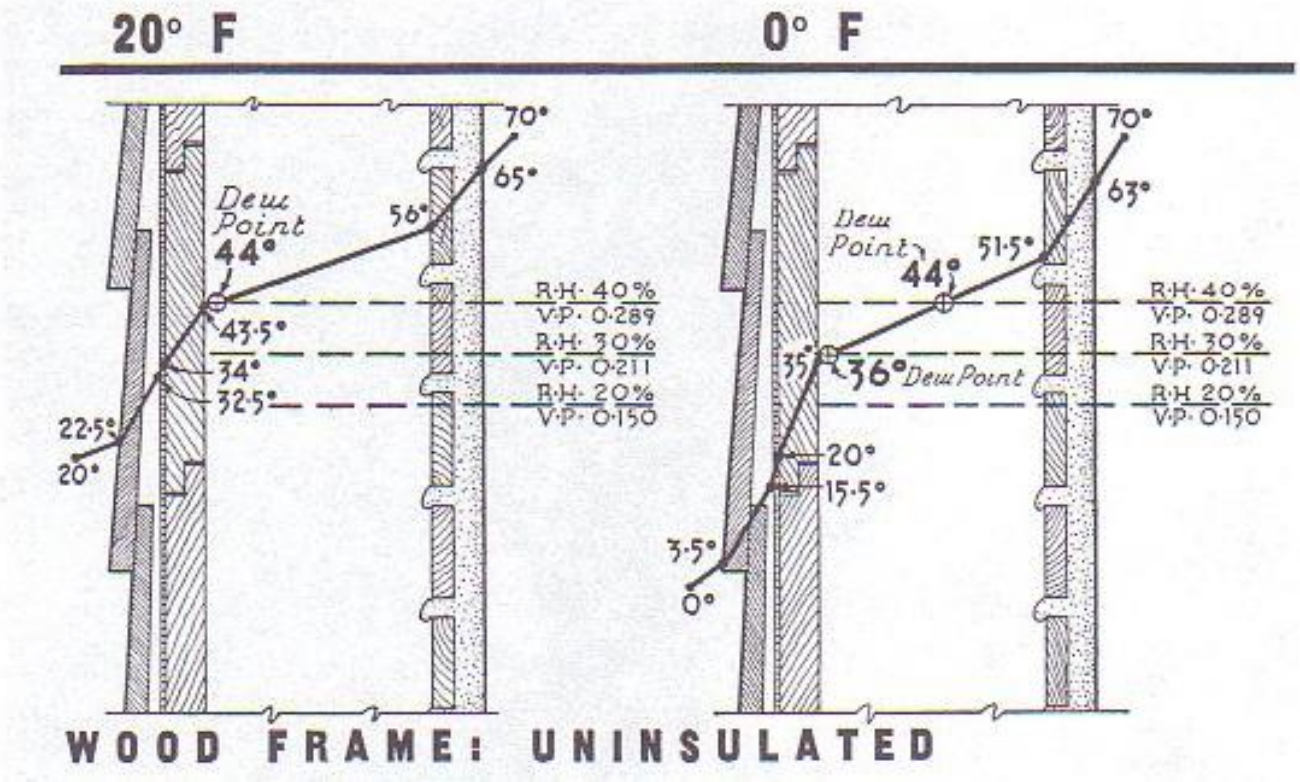
- Wall Design

Condensation: Analyzing Assemblies

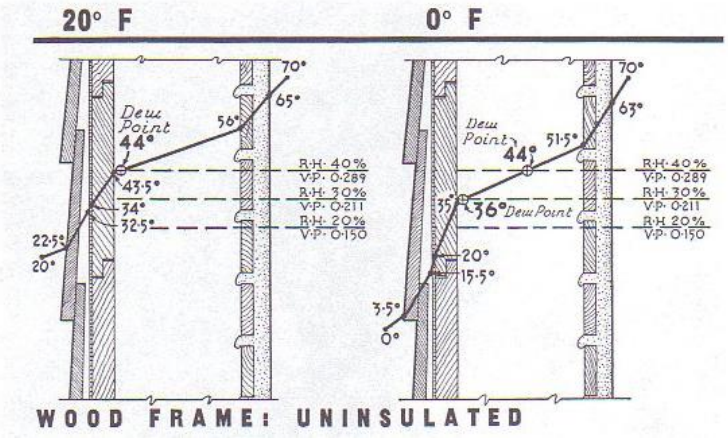
Profile Method



Teesdale, 1938 (Water in Buildings, Rose)

Condensation: Analyzing Assemblies

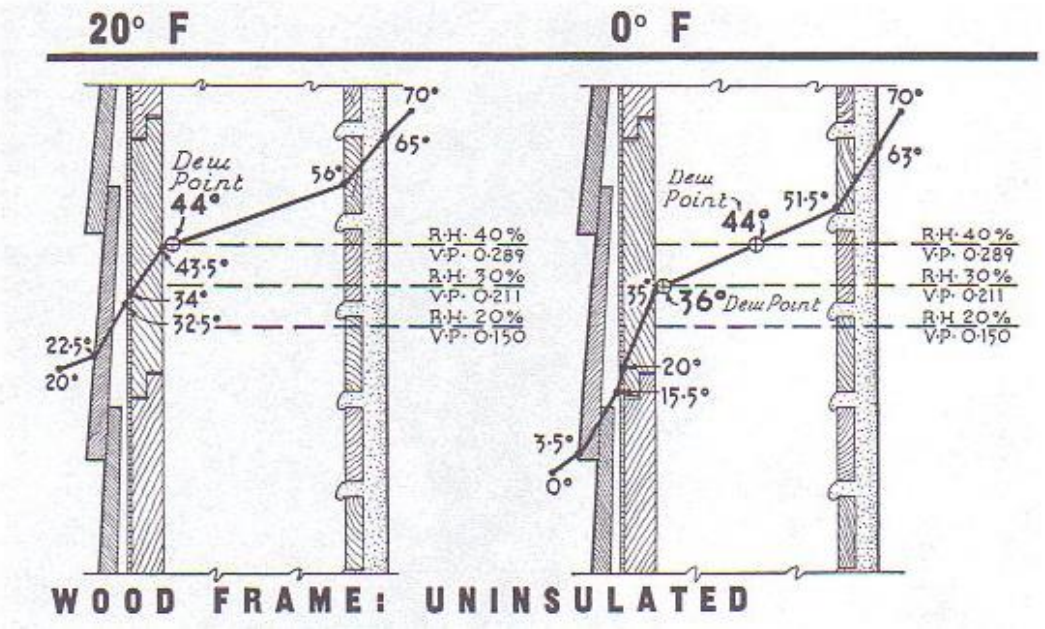
Profile Method



No infiltration
Not dynamic
Water movement
RH or Temperature Dependencies
Adsorption

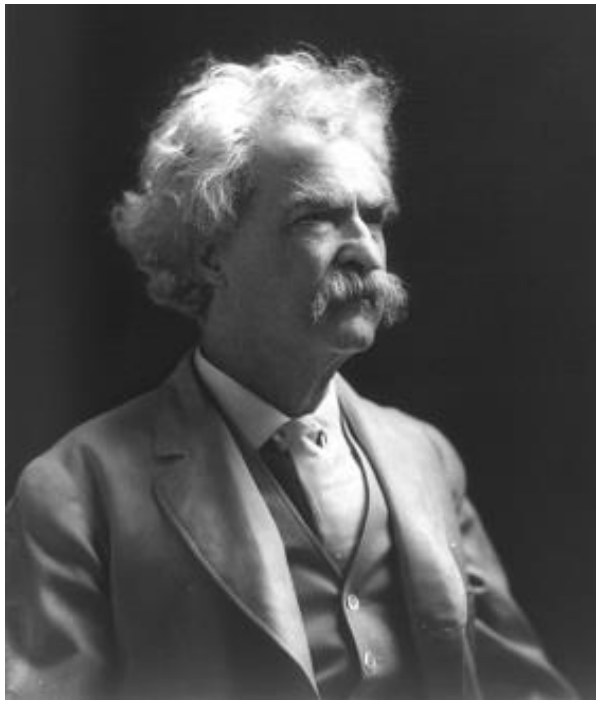
Condensation: Analyzing Assemblies

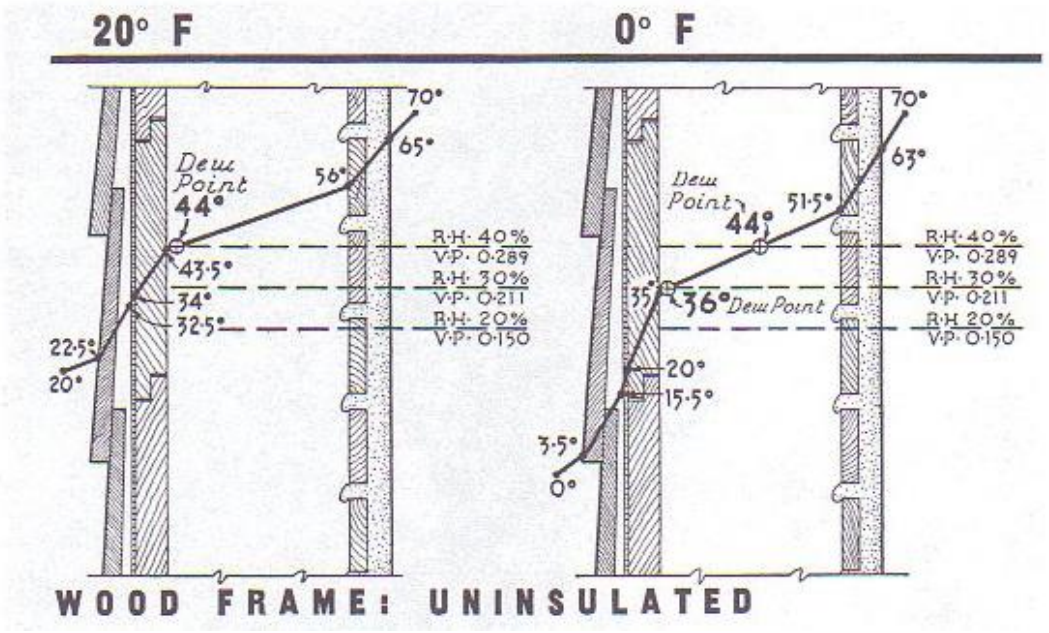
Profile Method



Condensation: Analyzing Assemblies

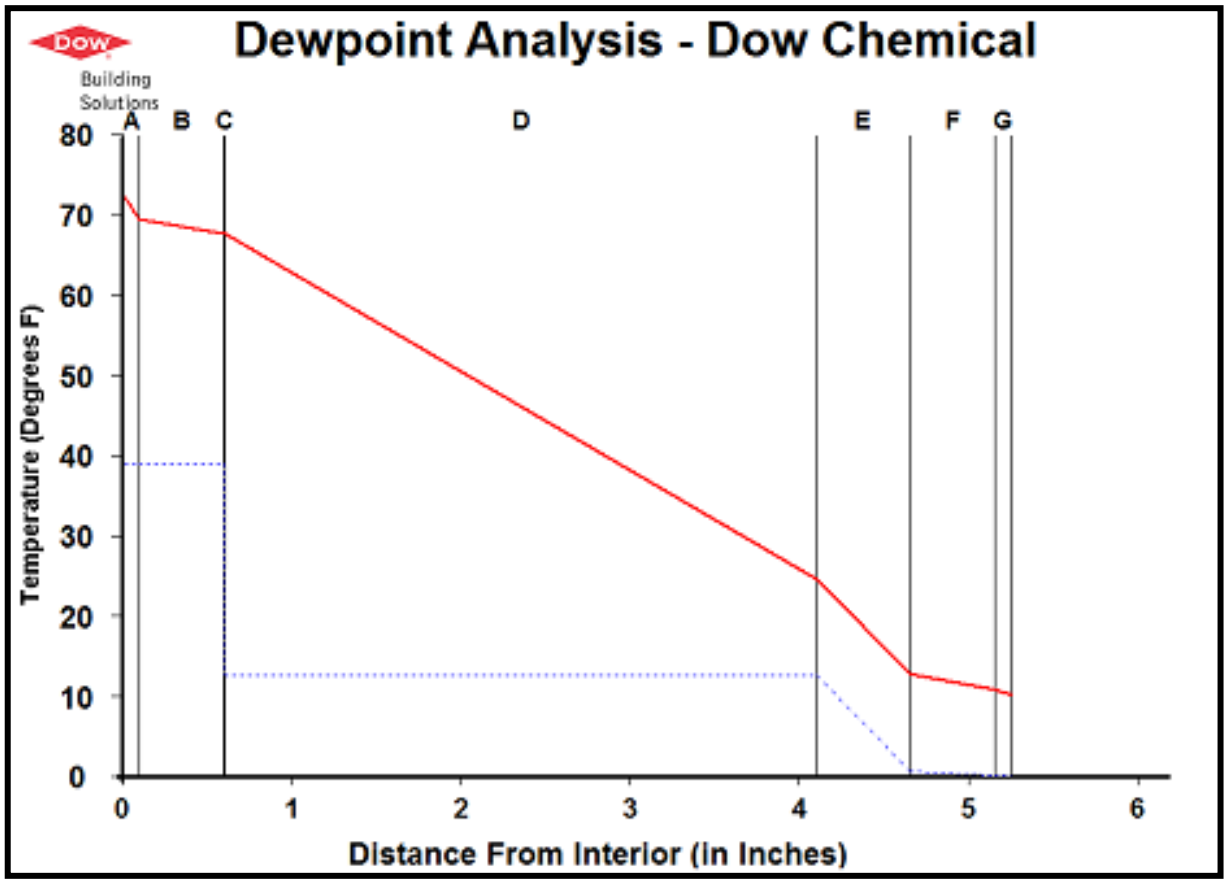
Profile Method





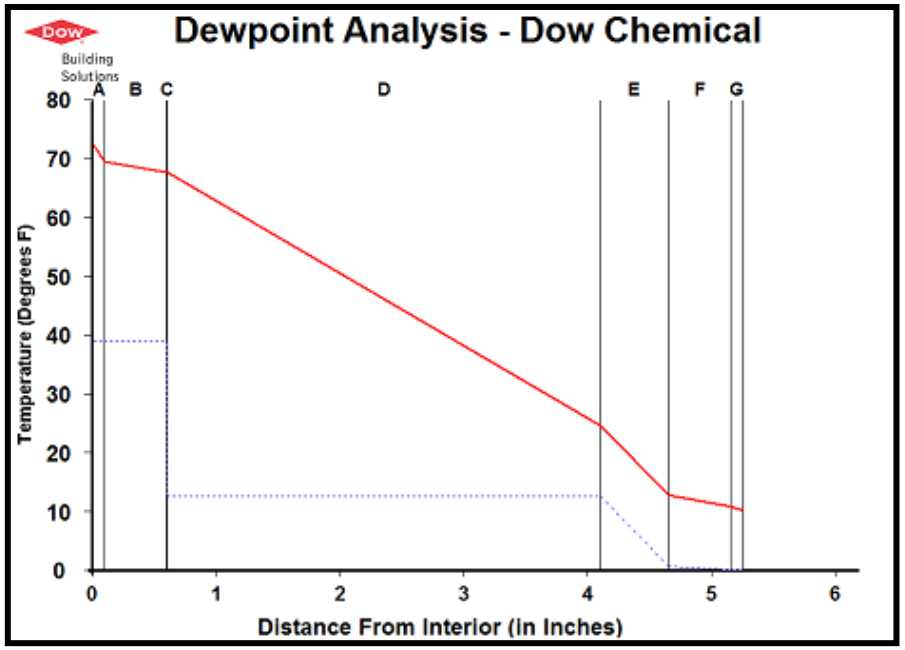
Condensation: Analyzing Assemblies

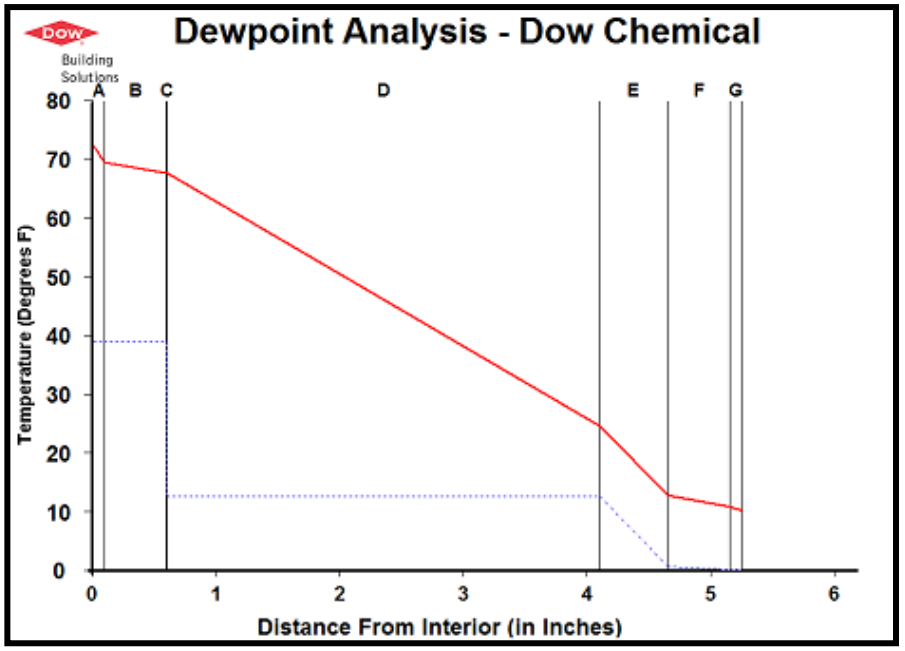
Profile Method



Condensation: Analyzing Assemblies

Profile Method

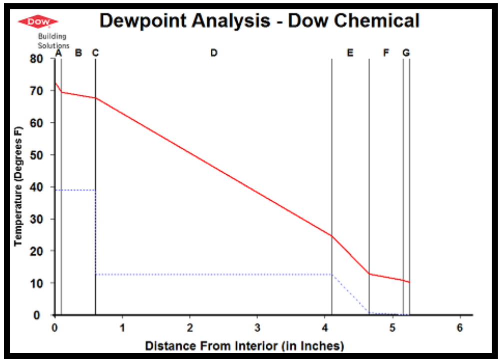


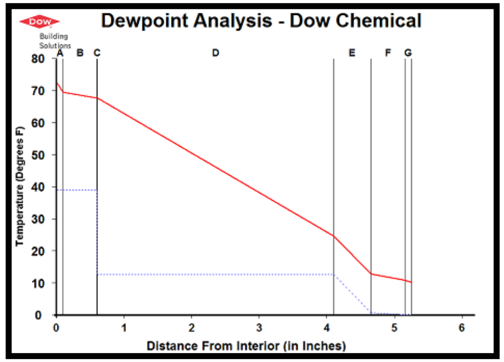


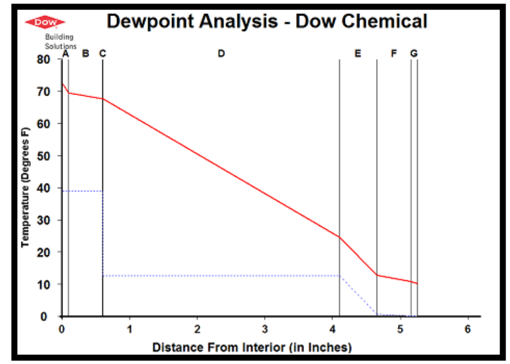
Compare Assemblies

Condensation: Analyzing Assemblies

Profile Method







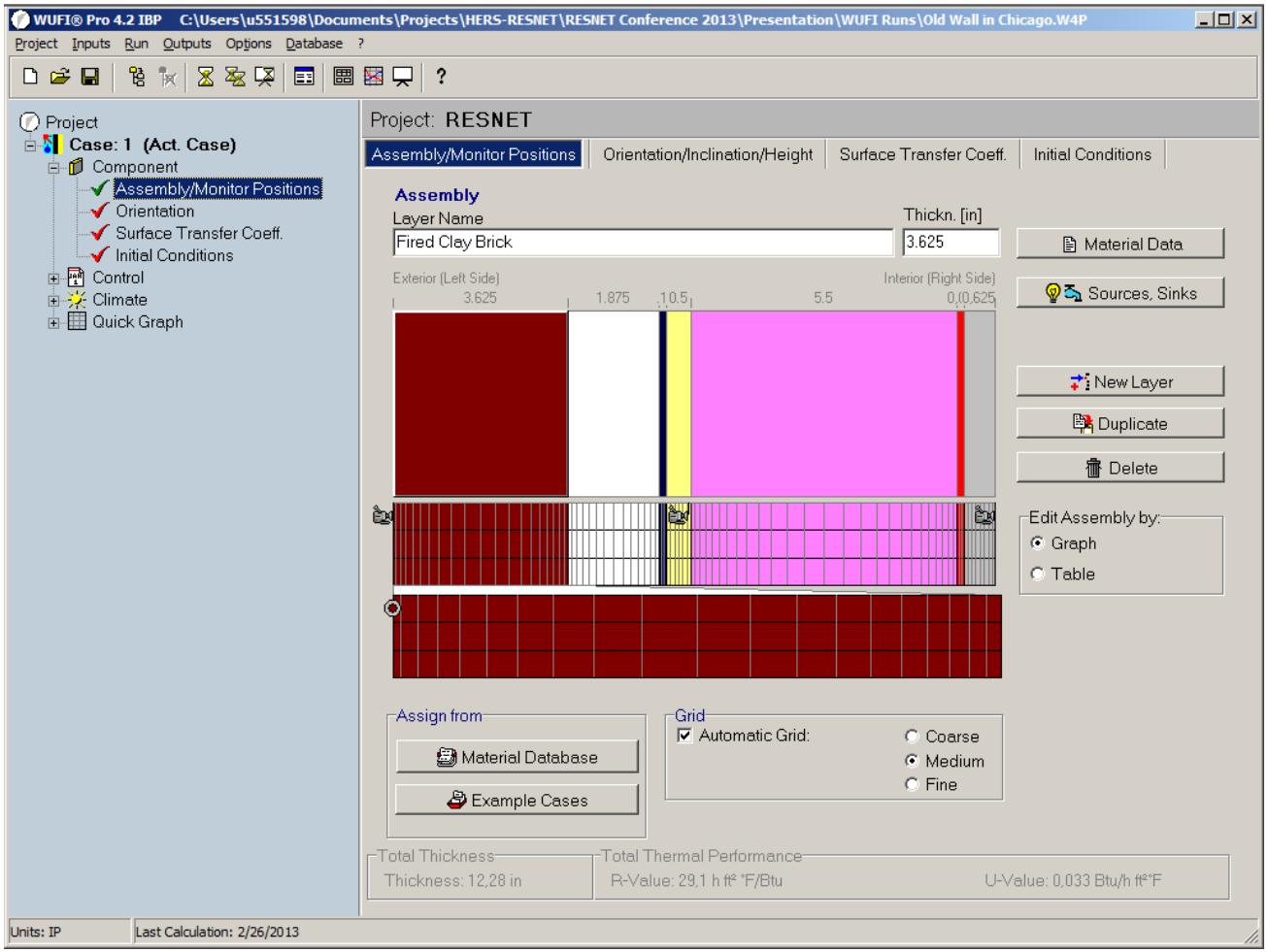
"The results from transient modeling do a much better job of replicating physical processes. They have entirely supplanted the profile method as a design tool. This comes at the expense, however, of tinkering."

Condensation: Analyzing Assemblies

WUFI Method

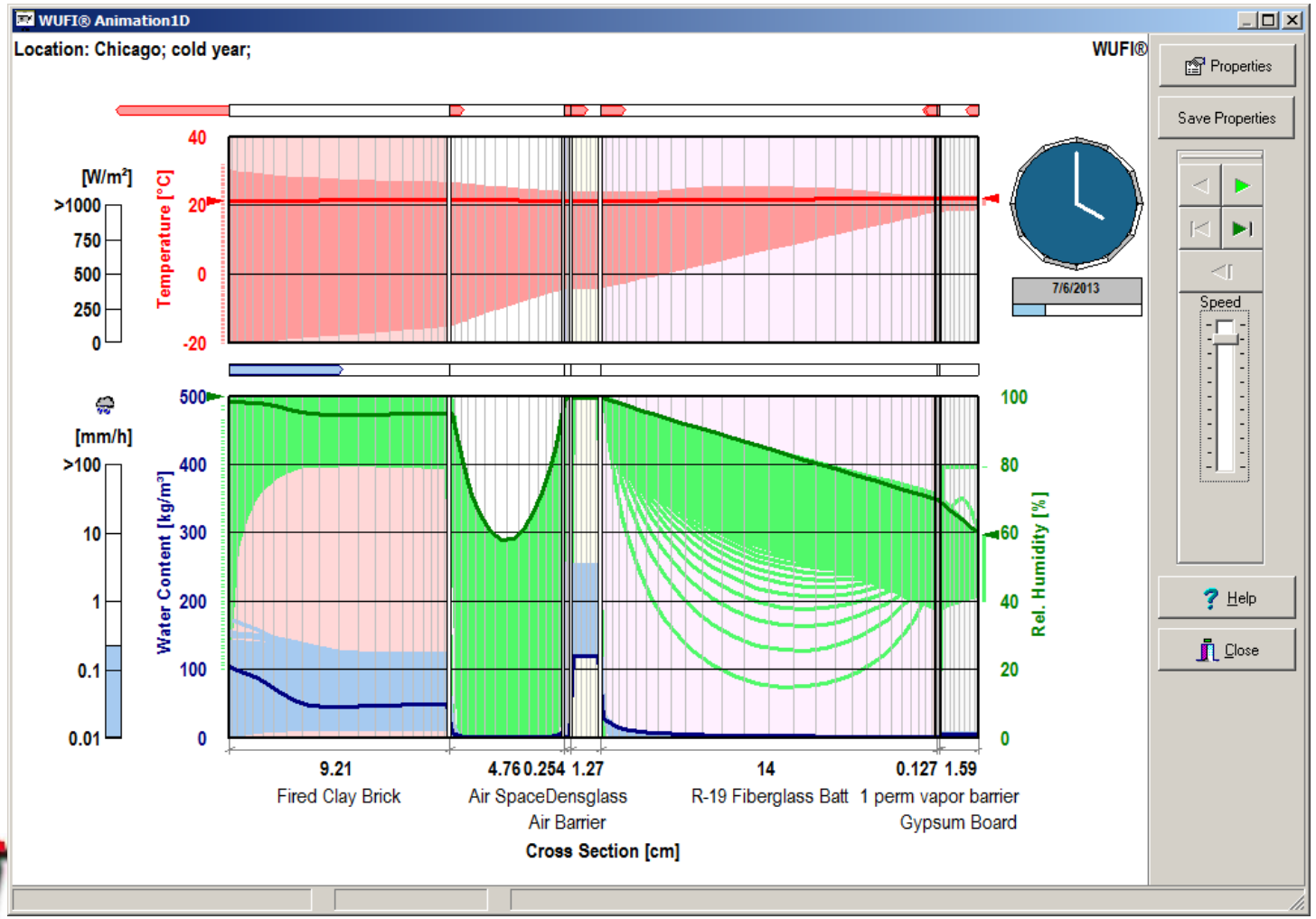
Condensation: Analyzing Assemblies

WUFI Method



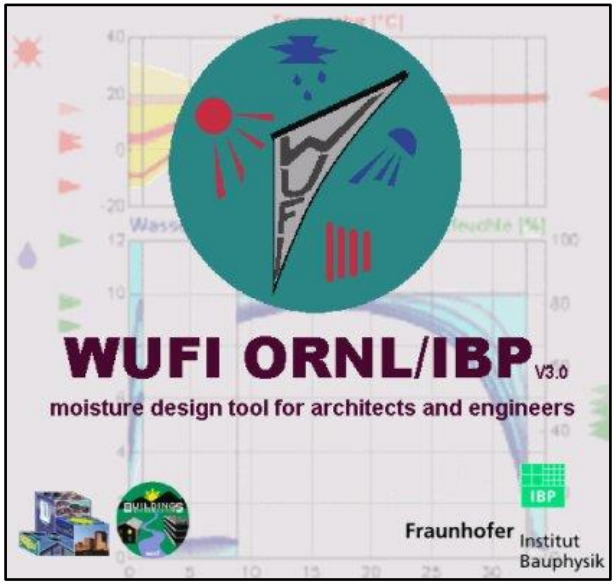
Condensation: Analyzing Assemblies

WUFI Method



Condensation: Analyzing Assemblies

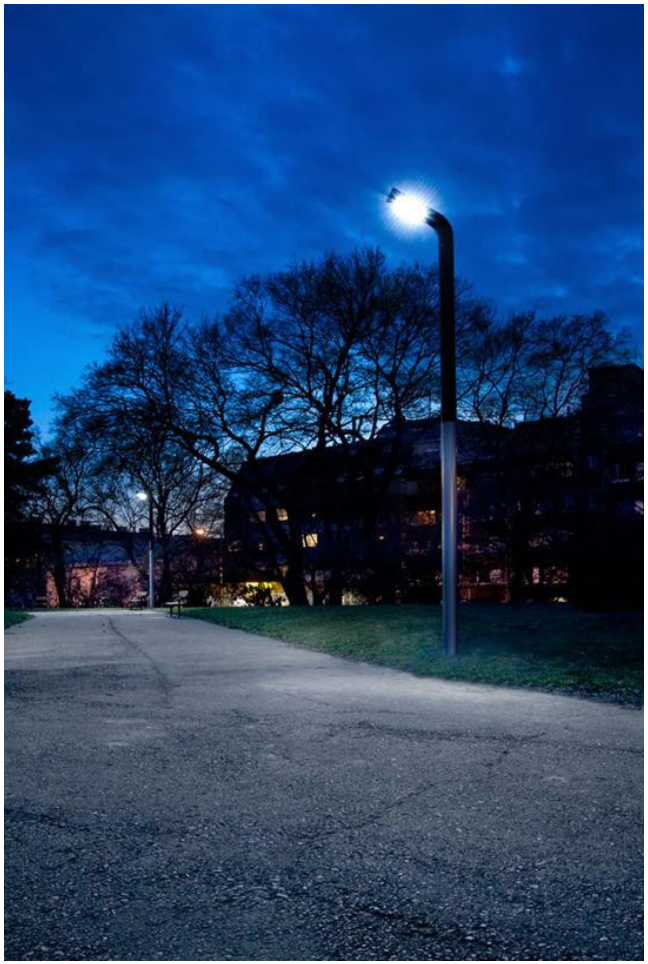
WUFI Method



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

Condensation: Analyzing Assemblies

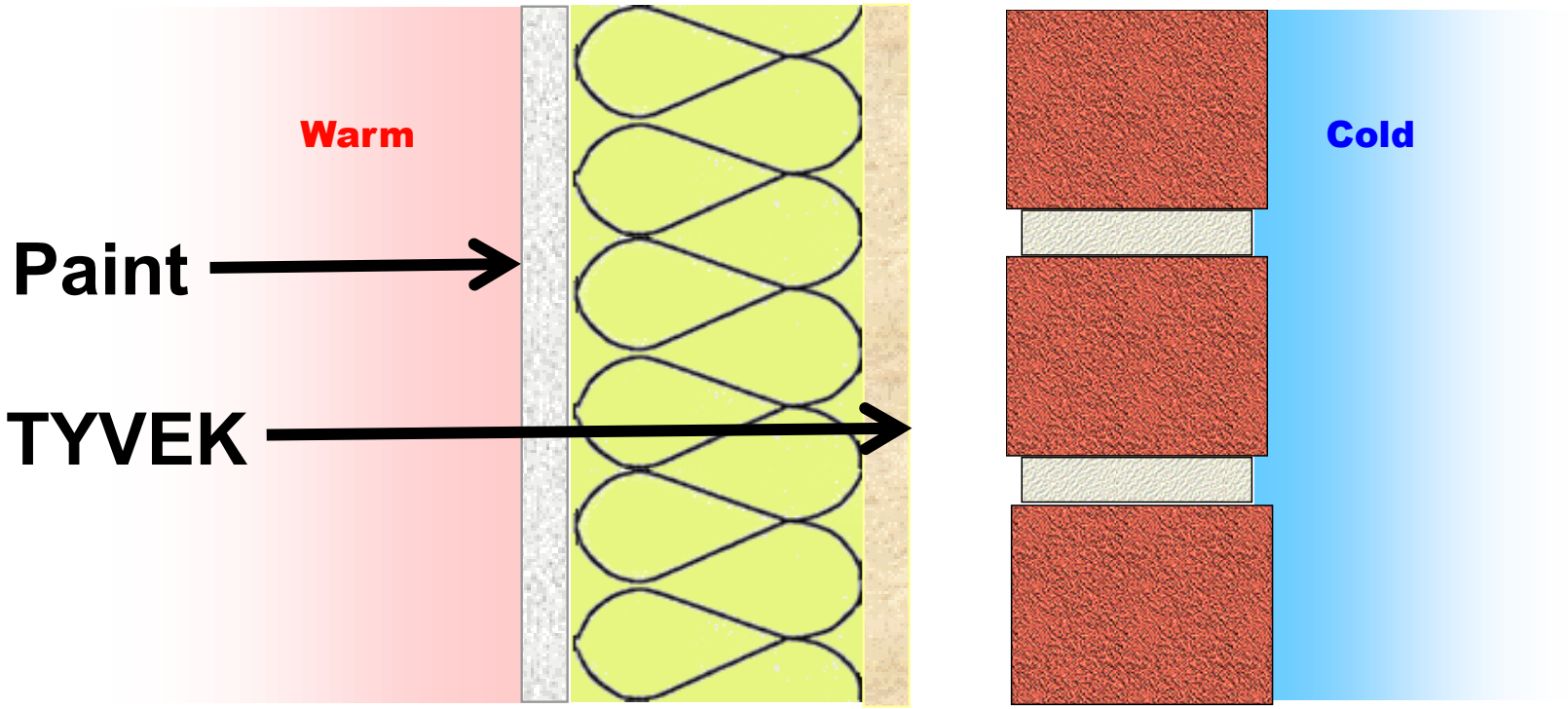
WUFI vs. Profile: Predictions



Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions

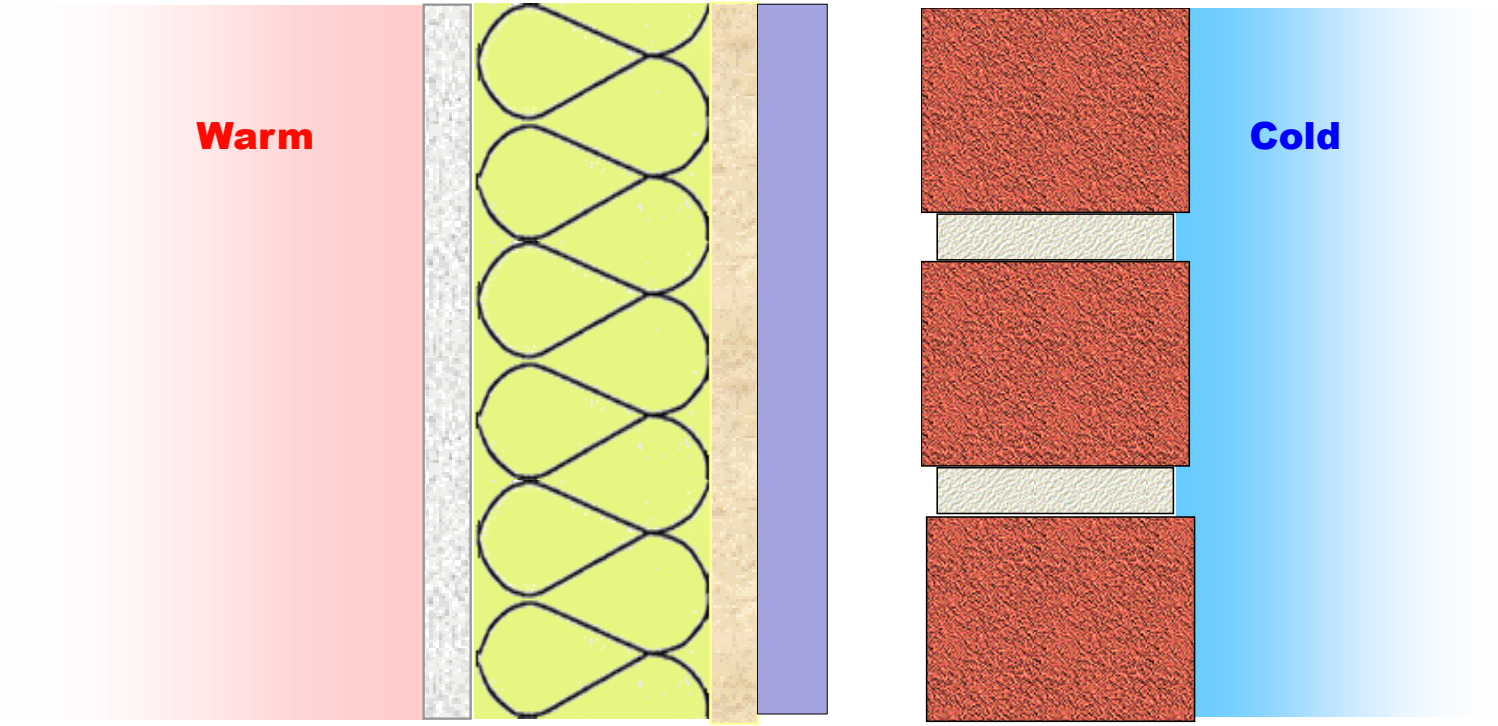
Old Wall



Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions

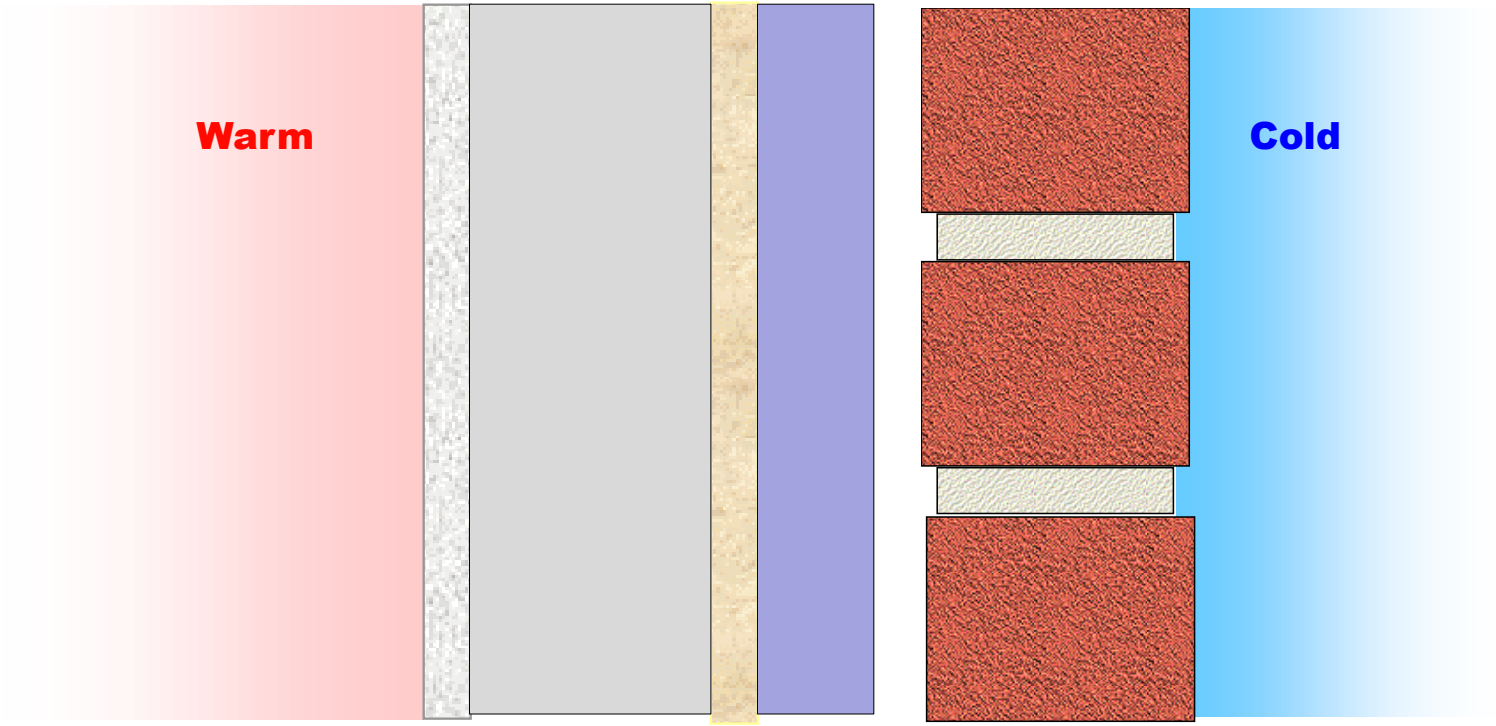
Medium Wall



Condensation: Analyzing Assemblies

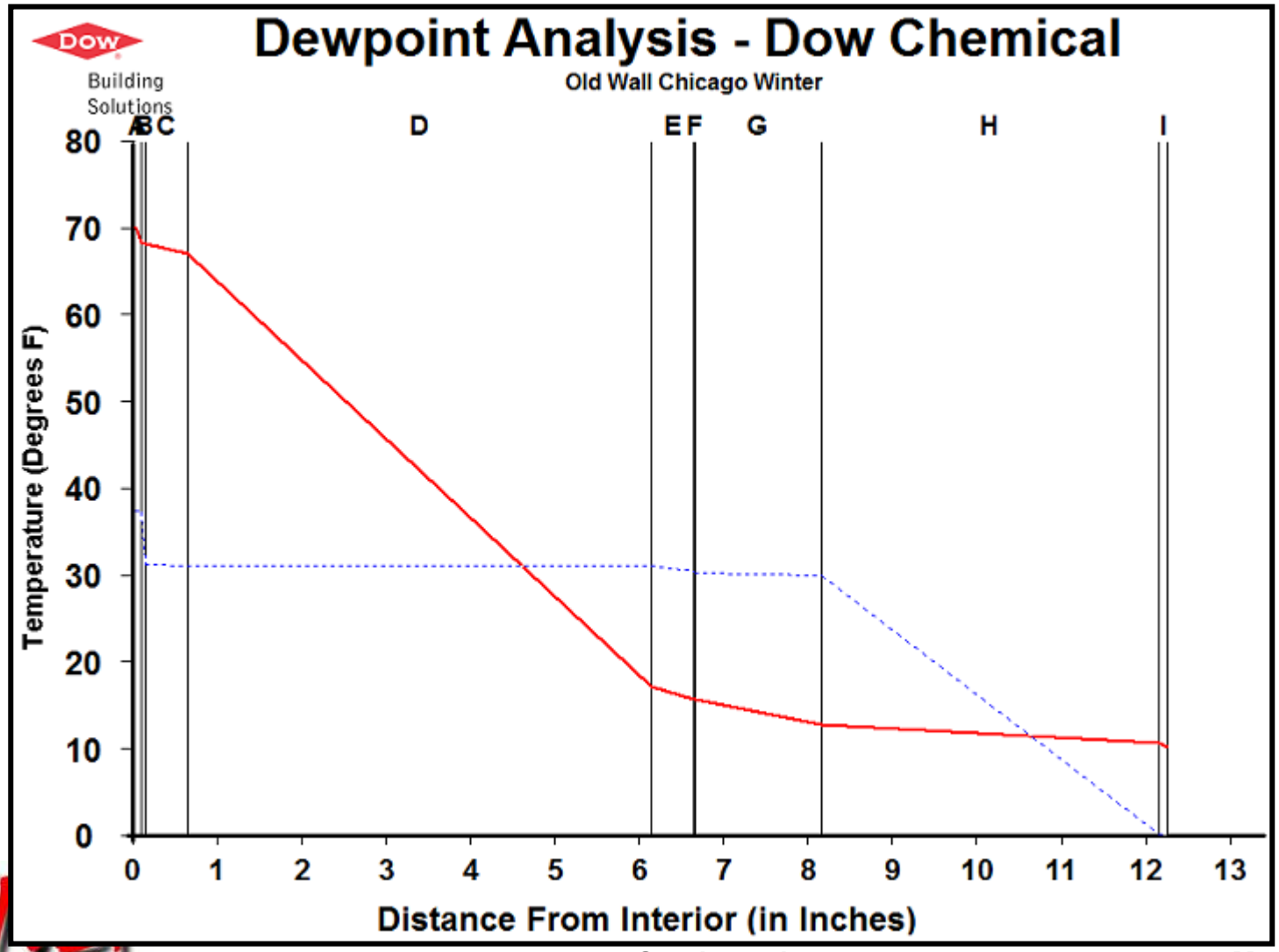
WUFI vs. Profile: Predictions

Perfect Wall



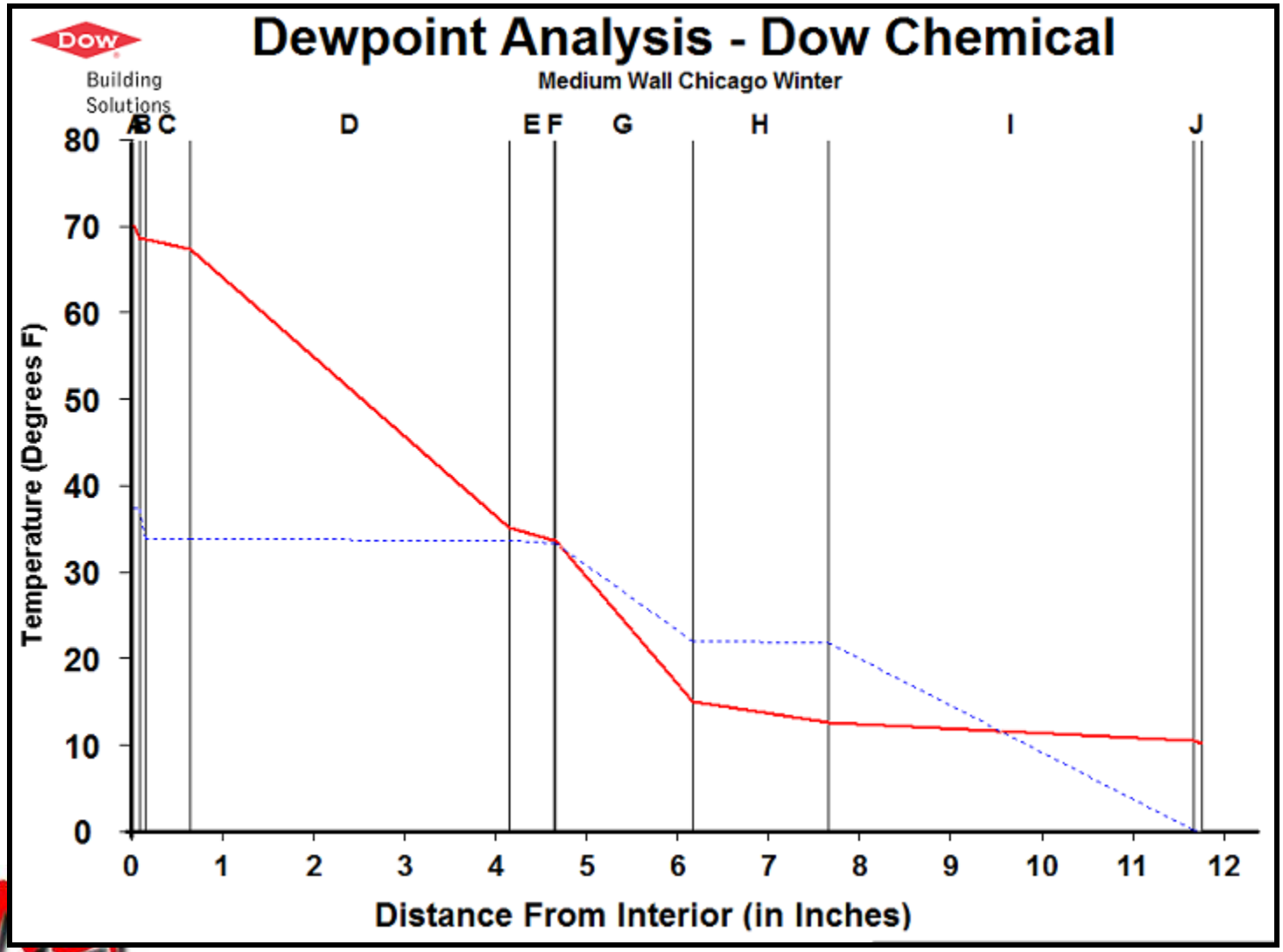
Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions



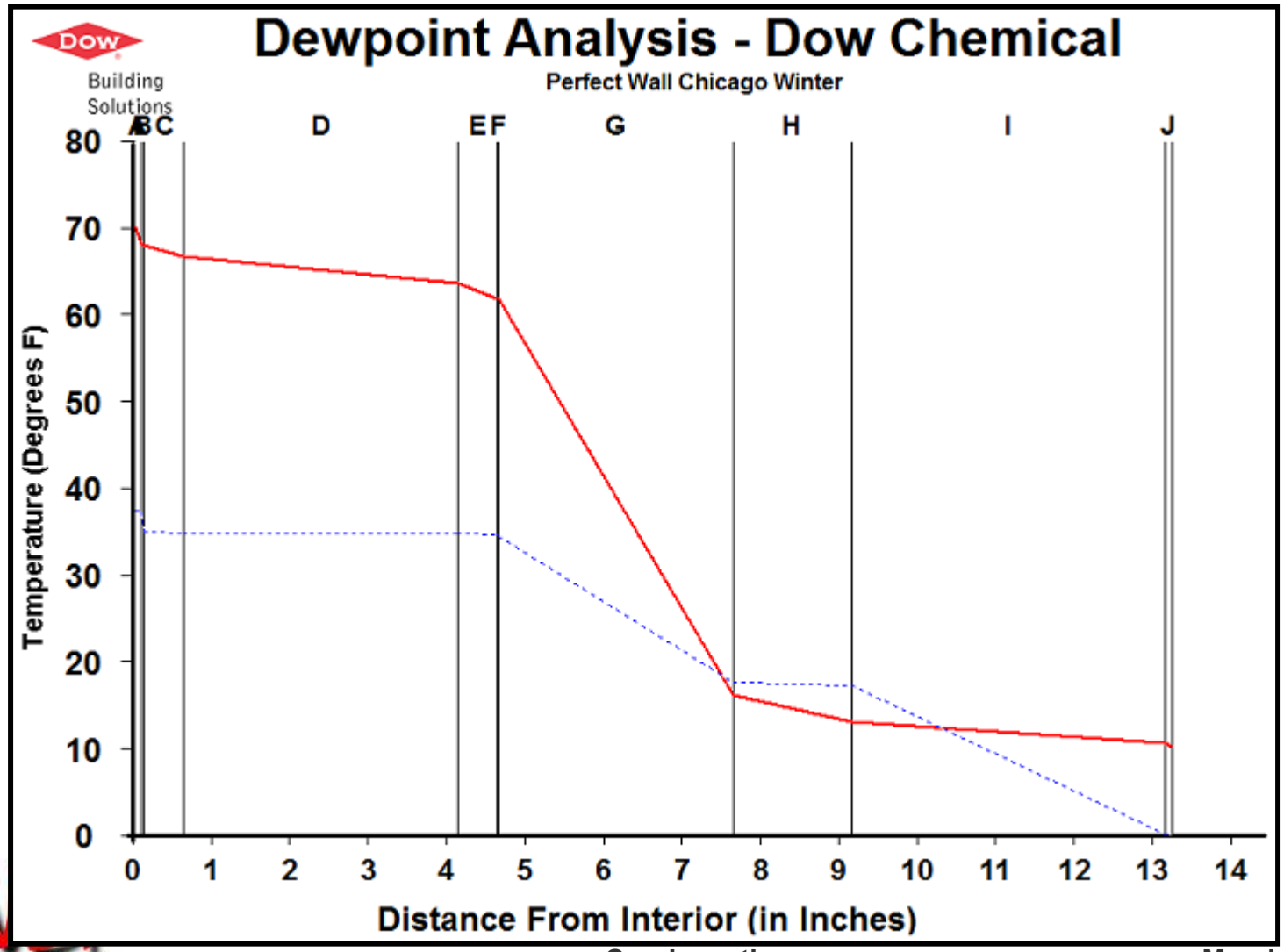
Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions



Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions



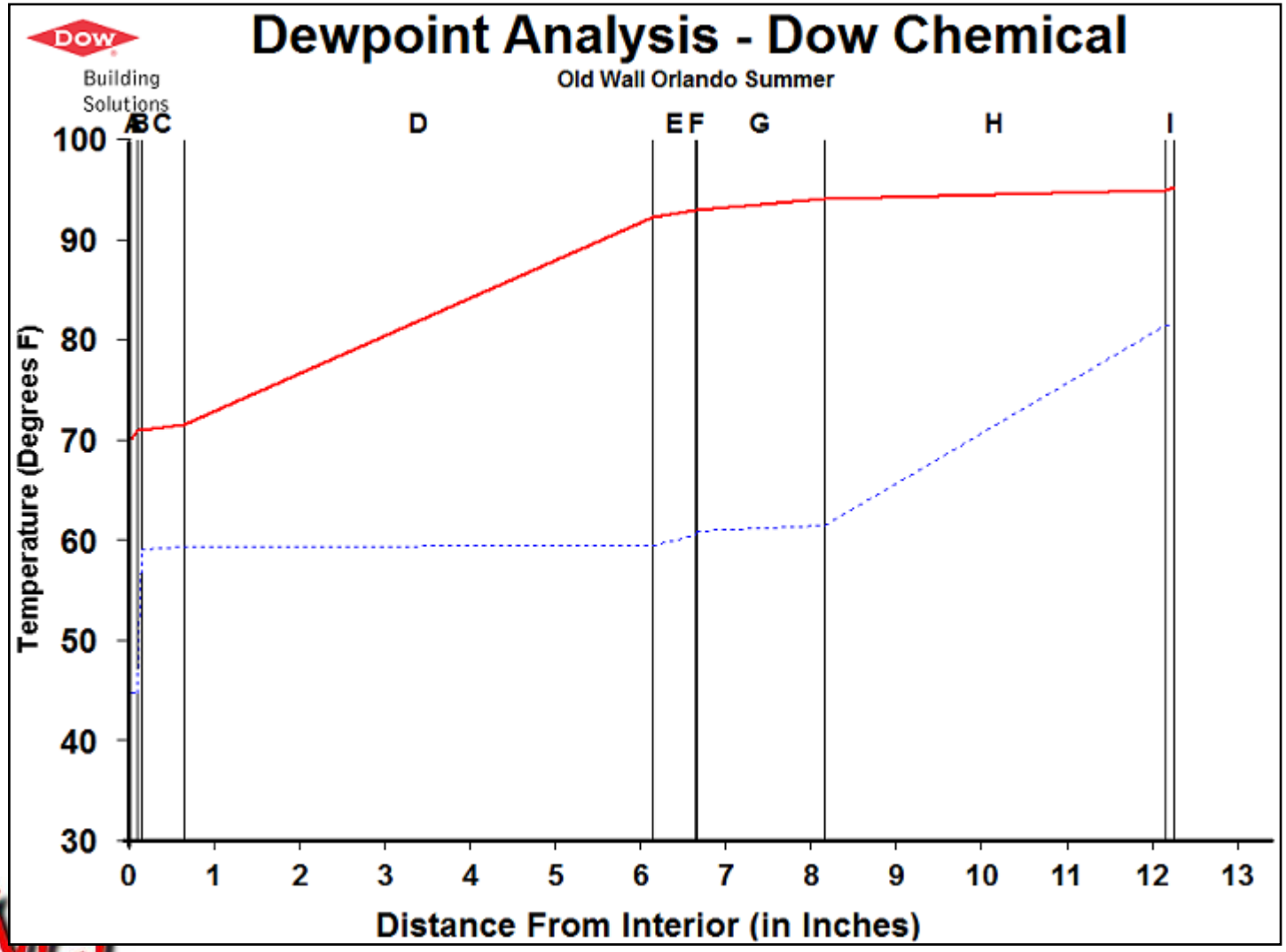
Condensation: Analyzing Assemblies

WUFI vs. Profile: Predictions

Perfect Wall > Medium Wall > Old Wall

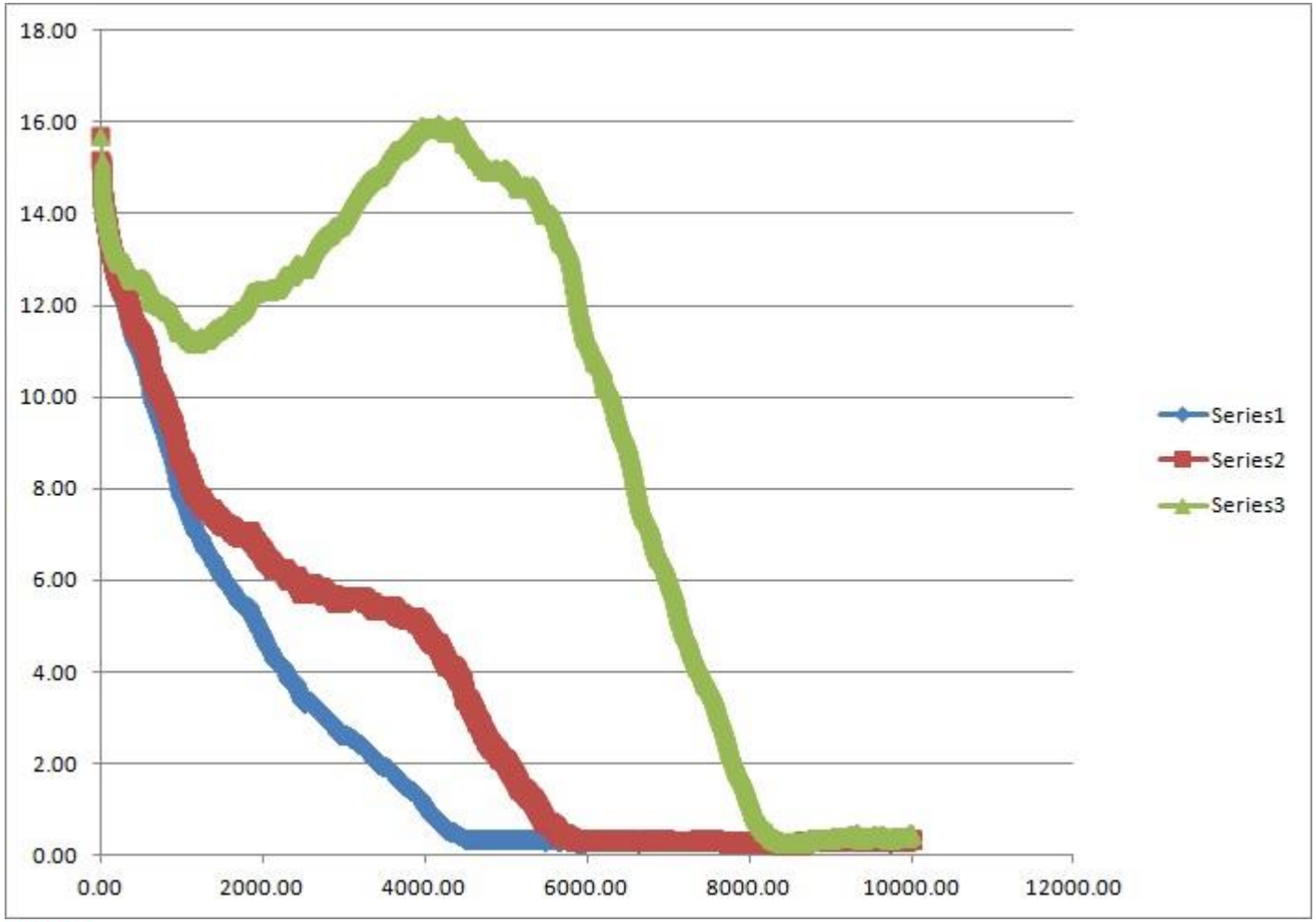
Condensation: Analyzing Assemblies

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

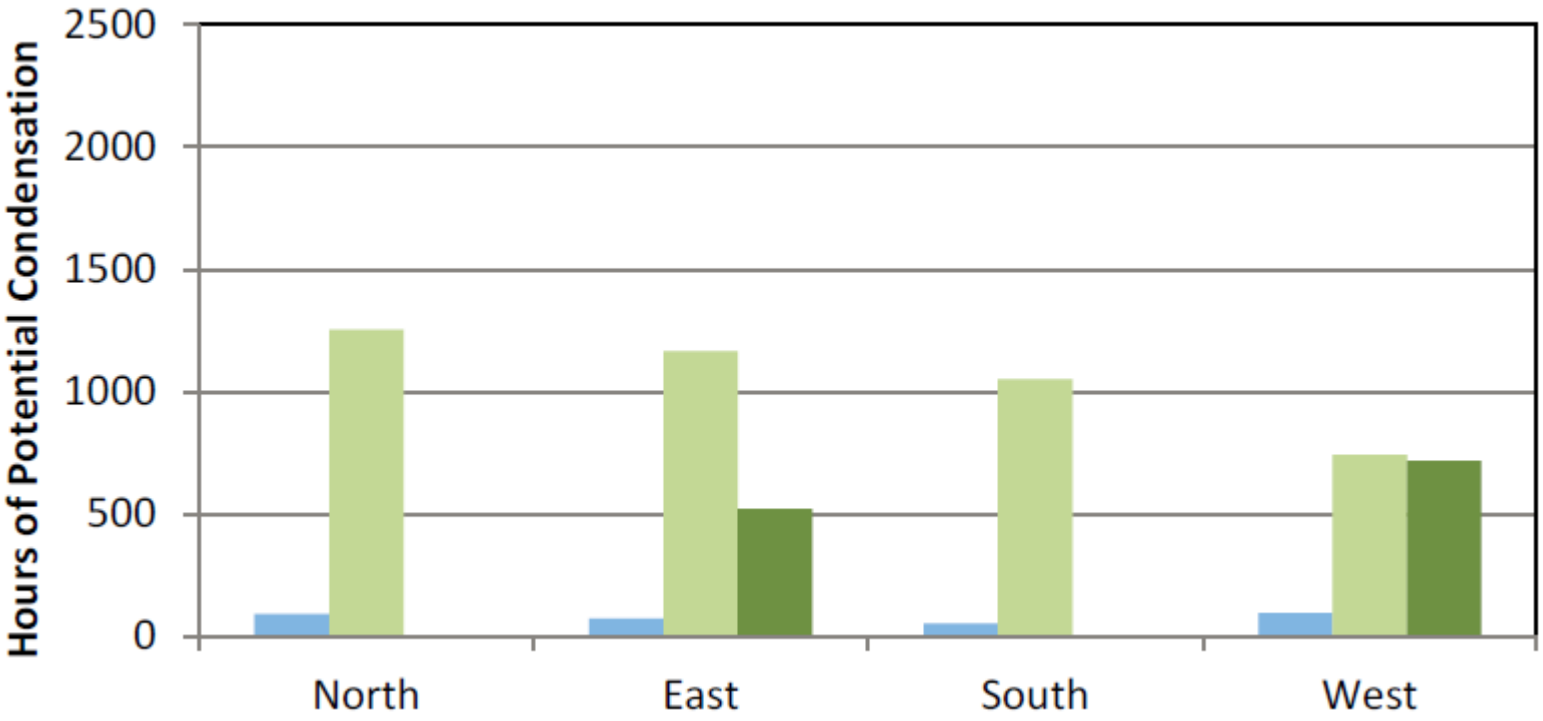
Perfect Wall > Medium Wall > Old Wall

	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

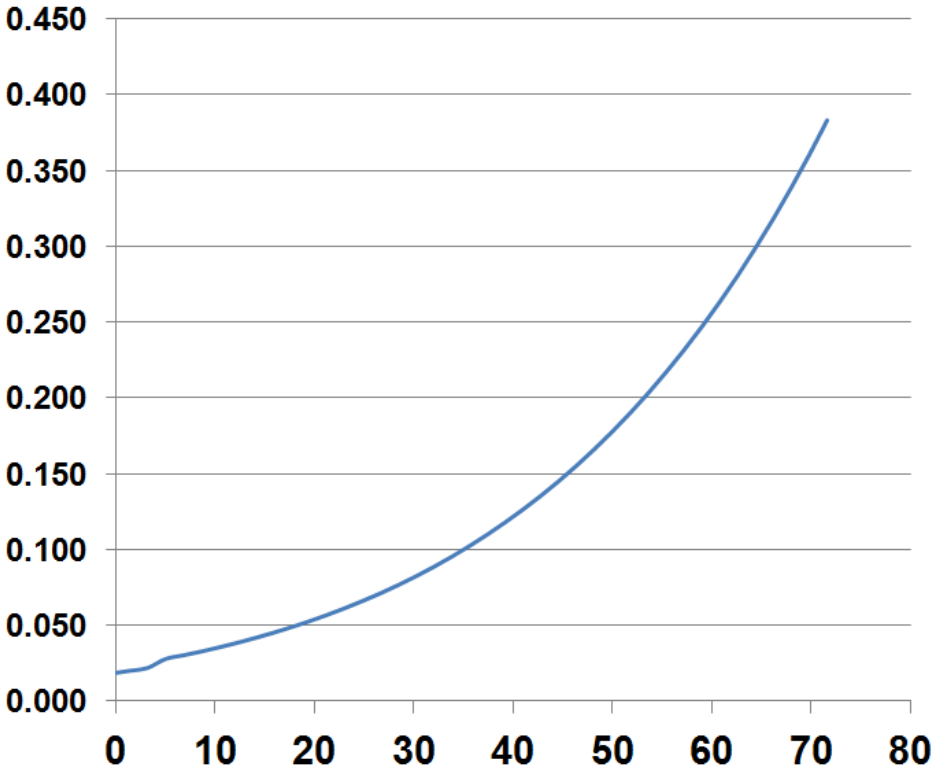
Condensation: Wall Design

Warm Climates: Temperature

No VB
Easier installation
Effective Drying

Condensation: Summary

- Properties of Water

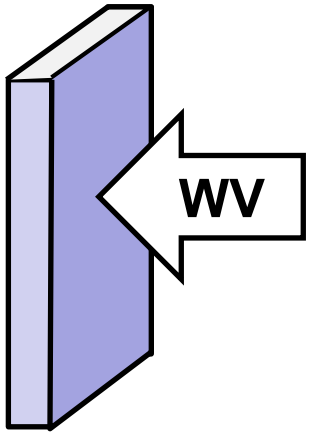


Condensation: Summary

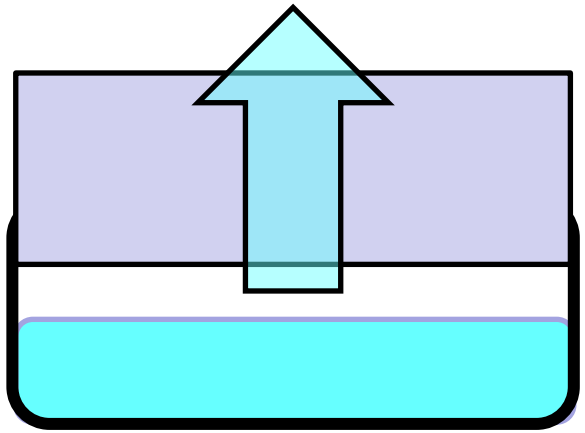
- Properties of Water
- Terms Relating to Condensation

Relative Humidity

- Permeance
- Perms



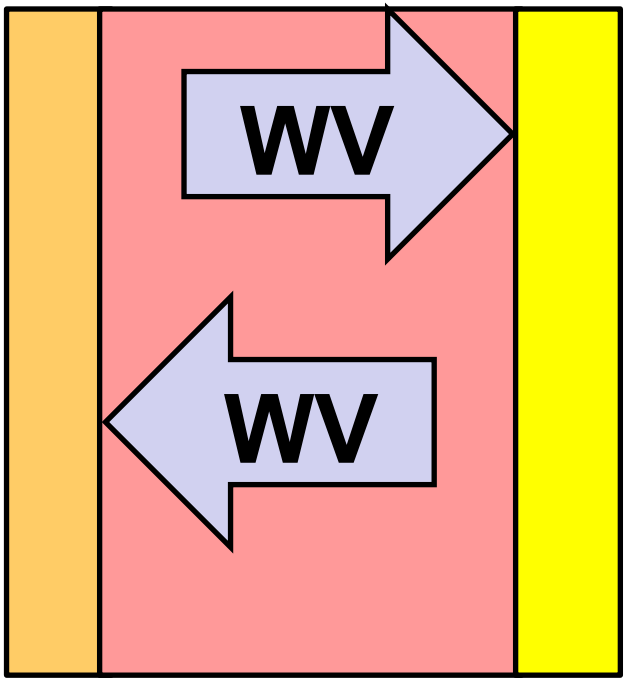
gr/hr ft^2 in Hg



Wet Cup

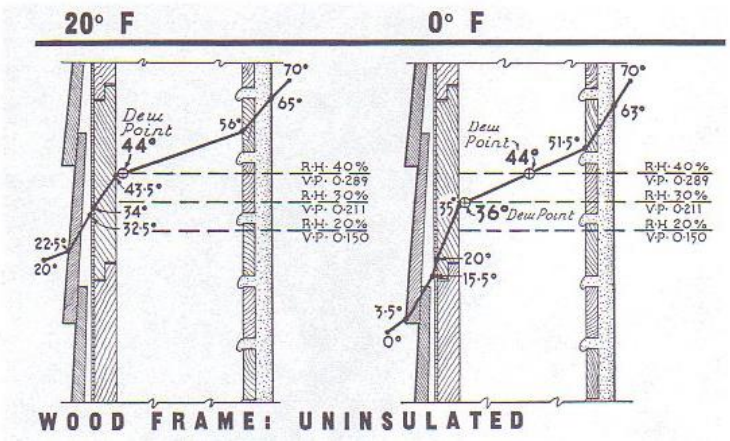
Condensation: Summary

- 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
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- Wall Design

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

Condensation: References

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Condensation: The Real Story

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Sr. Scientist

Questions?