Just Smart Solutions

Buildings XIII Workshop

December 5th 2016

Manfred Kehrer

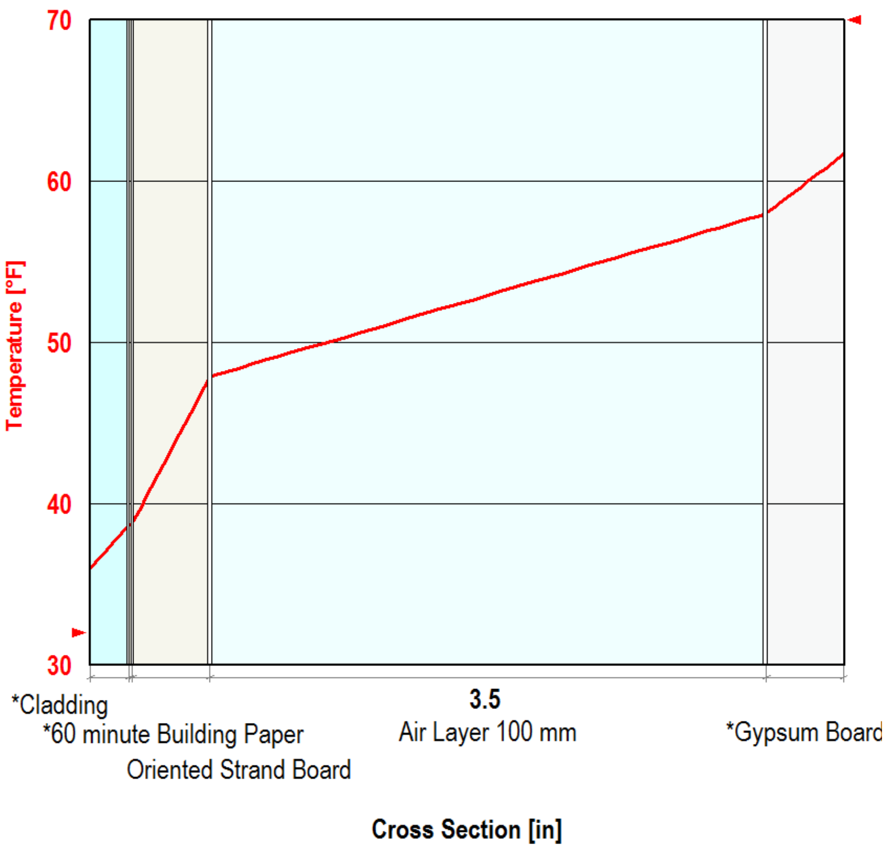
Modern Hygrothermal Engineering
Motivation, Basics, Examples

Why Hygrothermal Engineering?

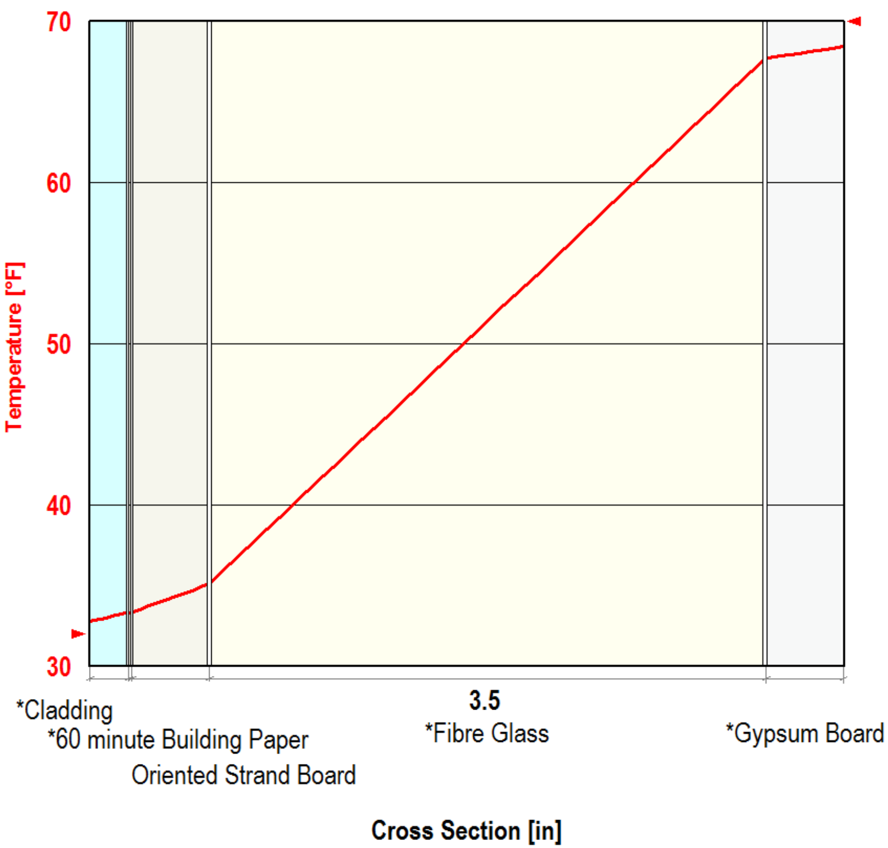
The Price of Energy Efficiency

Impact of Thermal Insulation on Moisture

No Cavity Insulation



Fibre Glass Insulation

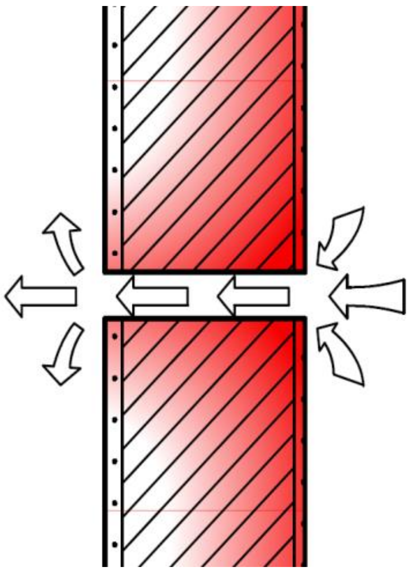


Higher Temperature Gradient has the result that cold spots are closer to warm spots ⇨ Higher condensation risk in case air tightness is not 100%

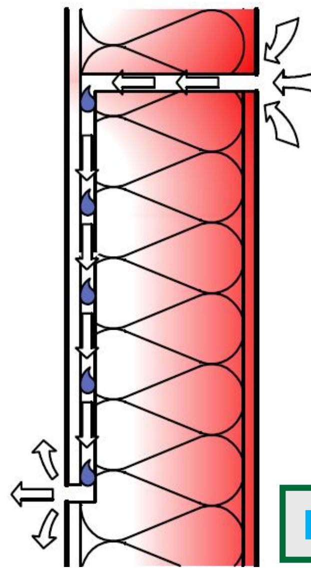
Impact of Air Tightness on Moisture

Moisture transport due to air infiltration into the envelope

Not Air Tight

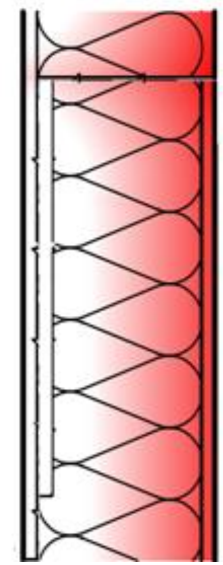


„Air Tight“



Risky

Air Tight



Energy leak

Warming of the leakage area in case of strong air flux

⇨ Only a little condensation

Moisture leak

Cooling of the air in case of slow and tortuous air flux

⇨Much more condensation

Good luck!

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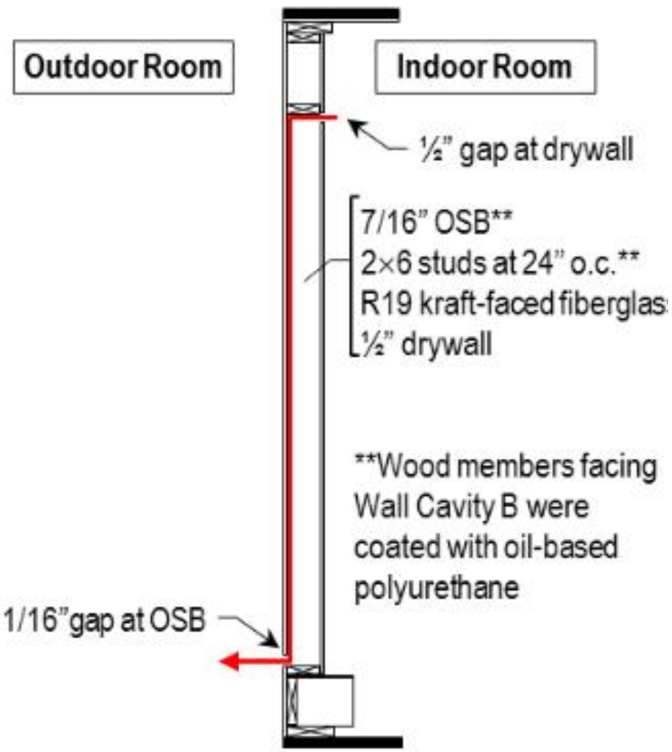
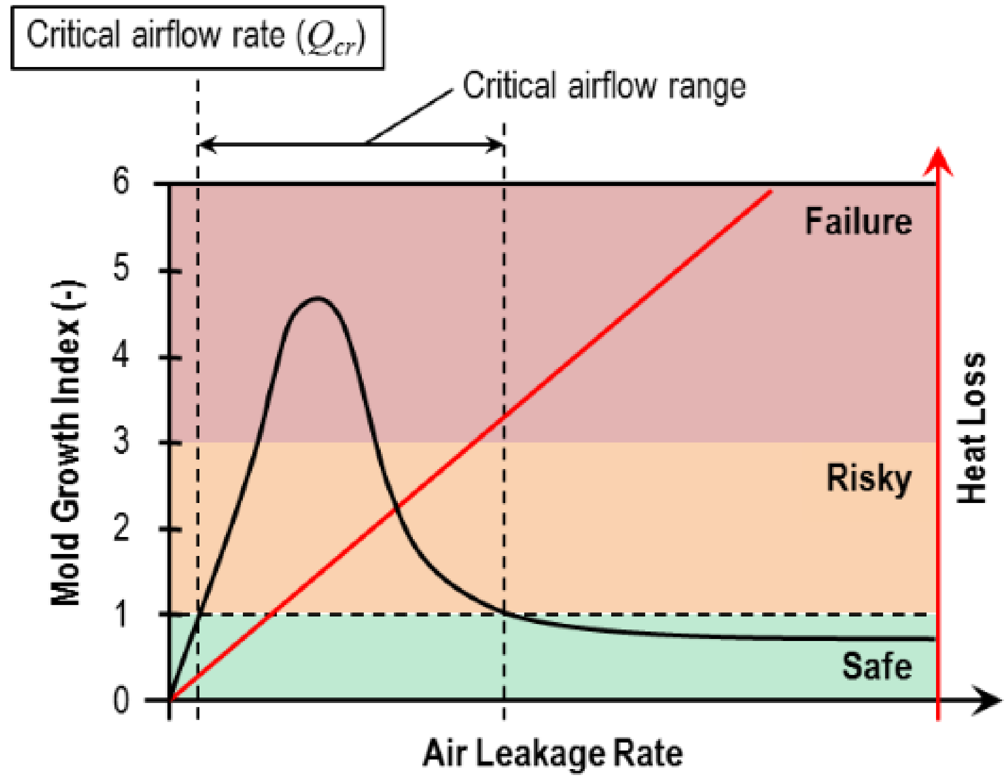
Impact of Air Tightness on Moisture

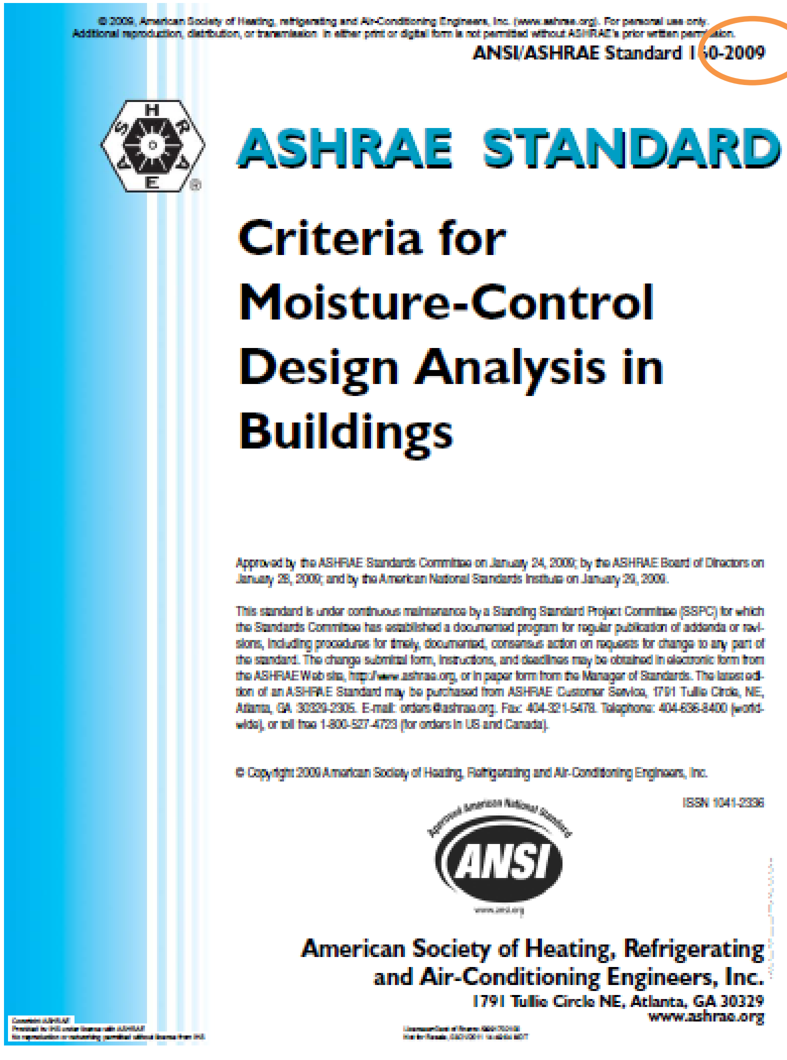
Result of ORNL studies about air flow



Airflow path through Wall Cavities A and B (cross section)



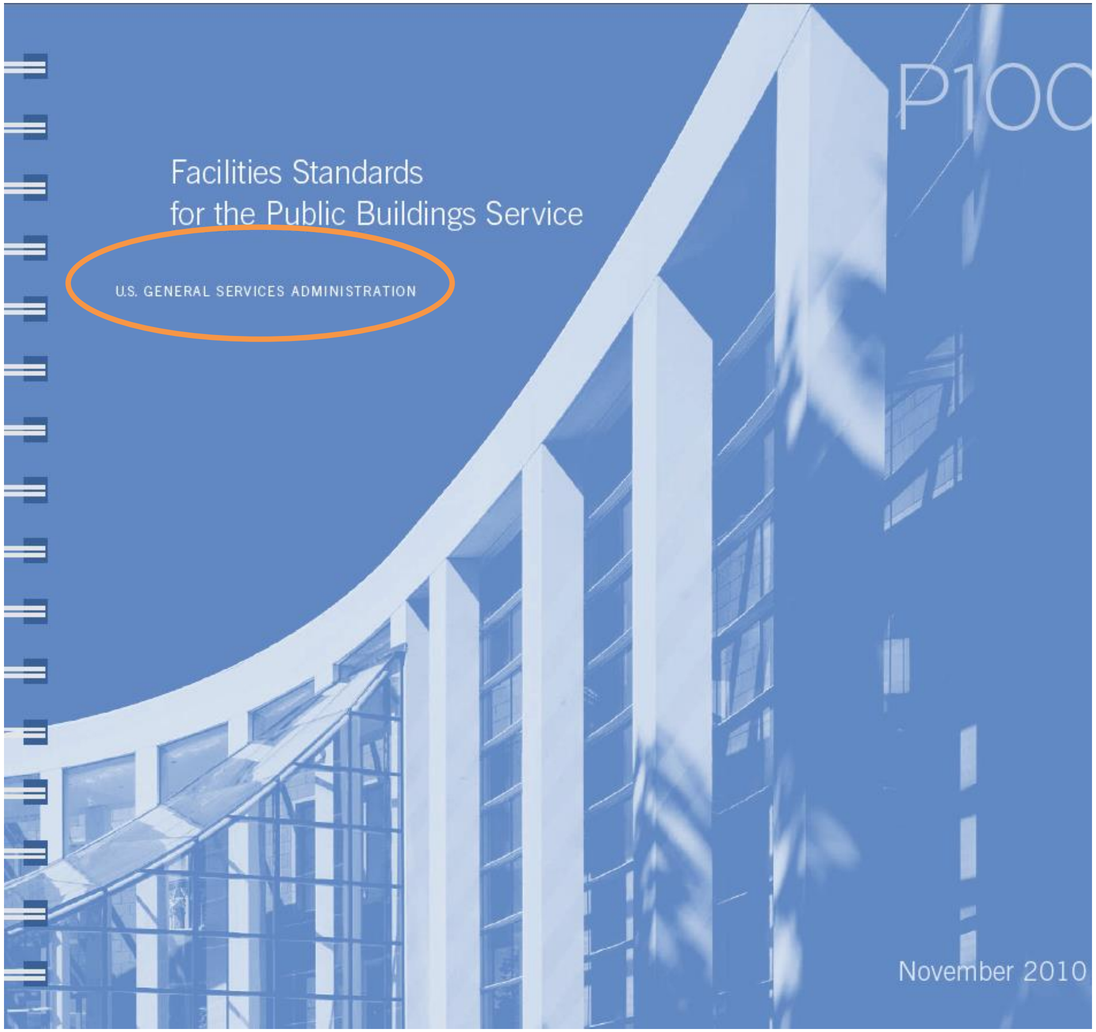
Importance of Moisture



To meet needs of industry on how to predict moisture behavior

But:
Has to be revised/improved in some particular points

Importance of Moisture



Importance of Moisture

Clearly conceived redundancy against water penetration

Must follow ASHRAE Standard 160

3D details to see joints to be sealed properly

Hygrothermal behavior of all critical enclosure components must be demonstrated

3.14 Exterior Building Elements

This section establishes design guidelines for exterior elements of the building. These may be individual materials, assemblies of materials, equipment, or assemblies of materials and equipment.

The A/E is responsible for specifying construction materials ...d systems appropriate to the final design that are ...sting, provide enduring quality, and are maintainable.

...lection of construction materials with these factors is ...al to building performance.

Building Enclosure

The building enclosure is an environmental separator for thermal, moisture, air, acoustic, and daylighting properties, and also provides structural protection for blast, seismic, wind, and other hazards.

Since the building enclosure has a major impact on energy conservation and on blast mitigation, the A/E must coordinate all systems selection and design with the requirements in Chapter 4, Structural Engineering, for blast mitigation and Chapter 5, Mechanical Engineering, for building energy analysis.

Exterior wall assemblies must be designed to work in concert with HVAC systems to optimize energy performance. Envelope load criteria are described in ASHRAE 90.1.

Moisture Control

Design of the above-grade build... demonstrated early in the desig... 160, *Criteria for Moisture Cont... Buildings* is an acceptable basis of design. Demonstration of the transient hygrothermal behavior of the various multi-layer building components for all critical building enclosure systems must be confirmed through modeling.

Design against water penetration with clearly conceived redundant systems. The A/E is responsible for the integrity of the overall moisture control system.

Construction documents must clearly depict all drainage and air passages. Detail in three dimensions where practical, indicating critical corner terminations, interface of all differing systems, proper sealant methodologies, etc.

Future Mainte...

The use of diffe... sun control dev... to the design ar... components, their use, and how they are combined on a building must be reviewed for future maintenance needs including replacement, repair, cleaning, weathering, and damage from bird roosts.

Consider the use of steeply sloped surfaces, limited use of horizontal surfaces at window sills, sun control devices or other design features or design approaches to minimize bird roosts.

Below Grade Systems

Ground Water Control

The drainage mat and soil filter should relieve hydrostatic ...age to ...e clay ...200.

...ded

Importance of Moisture

interface
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RCI was chartered, in part, to bridge the gap between the seemingly disparate elements of the roofing profession. It later expanded to include issues of waterproofing and of the entire building envelope. The goal of Interface is to connect these elements, educate and inform about related topics, establish a common ground for discussion, promote Association programs, and reach out to the industry at large. The articles contained in this publication are intended to provide information that may be useful to readers of Interface. RCI does not necessarily endorse this information. The reader must evaluate the information in light of the unique circumstances of any particular situation and independently determine its applicability. Entire contents, © RCI, Inc.

FEATURES

SPECIAL INTEREST

DEPARTMENTS

6

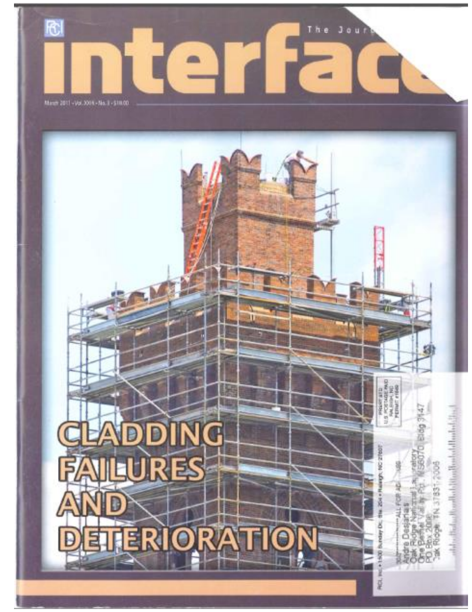
28

33

In This Issue: We examine various cladding failures and deterioration issues, from moisture migration in masonry to curtain wall failure, to problems with wood-framed buildings and issues with drift joints.

On the Cover: The masonry tower at the U.S. Penitentiary in Lewisburg, PA, was deteriorating after 75 years of exposure to the elements. Masonry Preservation Services (MPS) performed repairs under difficult conditions. See project profile, page 42.

INTERFACE • 1



4 out of 5 main articles deal with moisture

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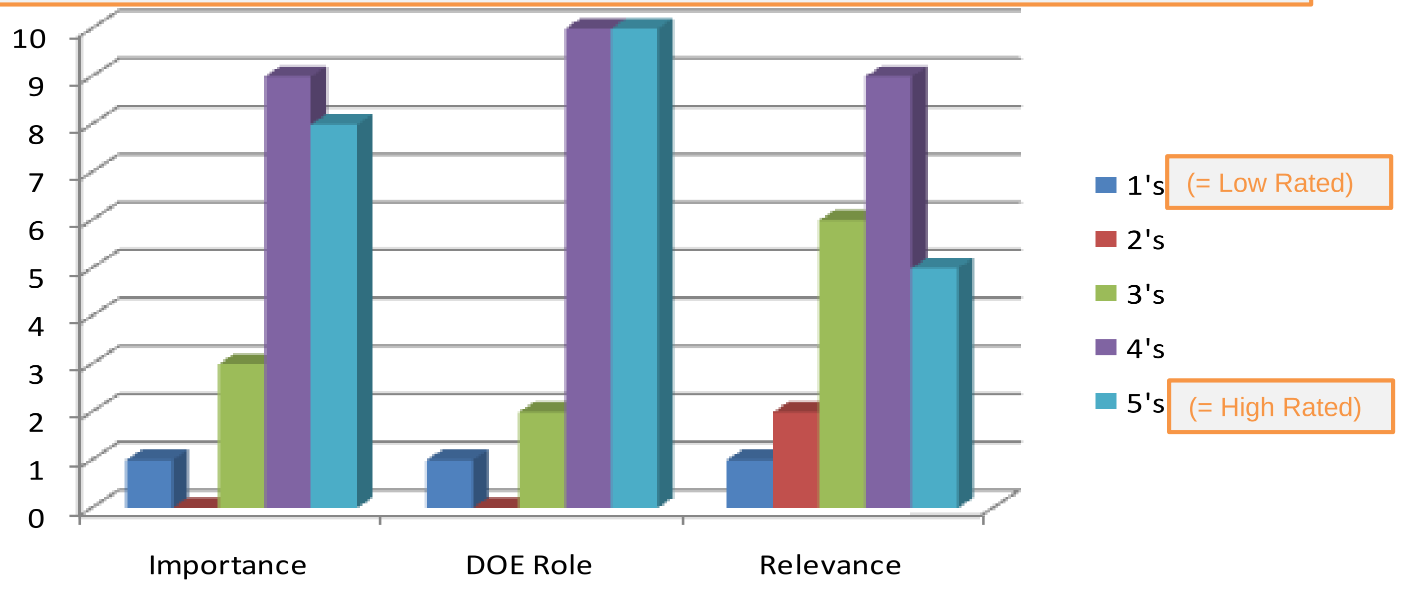
Importance of Moisture

Inspection of all papers of "Thermal Performance of the Exterior Envelopes of Whole Buildings XI International Conference 2010" results in: →

Moisture related Papers	
Practices	61%
Principles	55%

Official Participant's Feedback regarding Moisture Research.



Moisture Balance

Non Energy Efficient Envelope

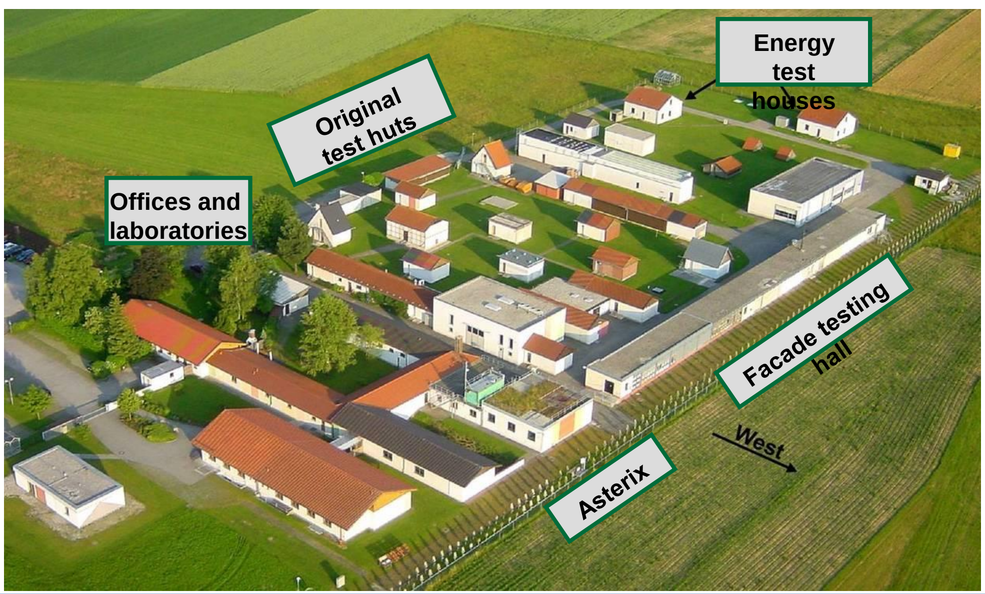
Energy Efficient Envelope

Previous Assessment

Field tests:

- **Very time consuming**
- **Very expensive**
- **Search for alternative ways to investigate hygrothermal performance**

Fraunhofer IBP, Germany



Previous Assessment

Field tests

- **limited transferability to another climate**

IBP outdoor test site in Holzkirchen

Coconut beach in Hawaii:

Previous Assessment

Field tests: solution to climate dilemma

- **new test sites**
- **search for alternative ways to investigate hygrothermal performance**

Vliet test building KULeuven

Field test site in Bangkok

BEG hut Waterloo Canada

Previous Assessment

Laboratory tests: climate chambers

(hot box / cold box)

- **realistic conditions (θ,φ)**
- **sky radiation and precipitation difficult to simulate**
- **limited capacity**
- **Time consuming**
- **expensive**

Hygrothermal Modeling

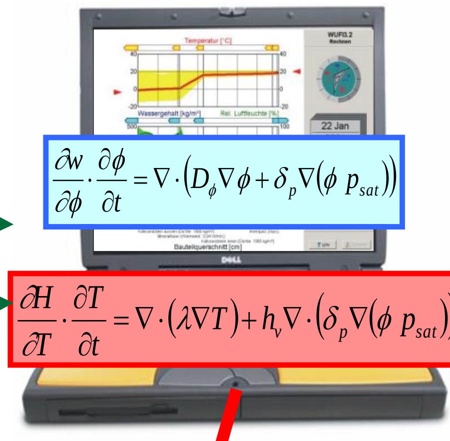
construction details

orientation inclination

initial conditions

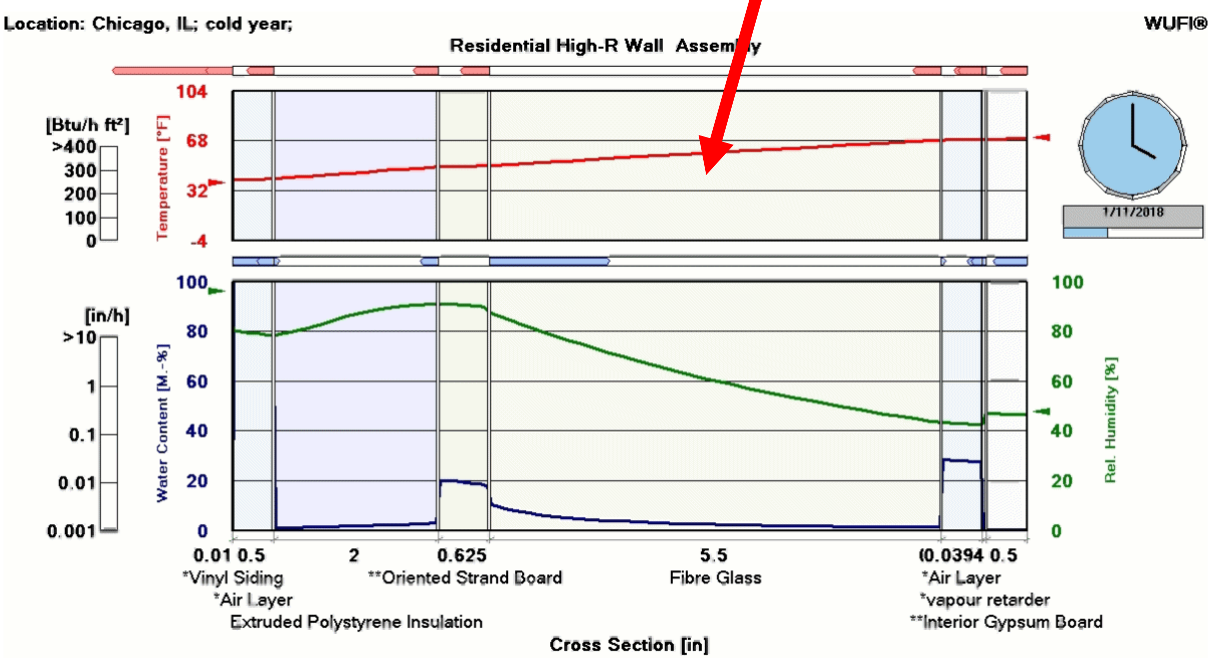
material properties

climate conditions



$$\frac{\partial w}{\partial \phi} \cdot \frac{\partial \phi}{\partial t} = \nabla \cdot \left(D_\phi \nabla \phi + \delta_p \nabla (\phi \, p_{sat}) \right)$$

$$\frac{\partial H}{\partial T} \cdot \frac{\partial T}{\partial t} = \nabla \cdot (\lambda \nabla T) + h_v \nabla \cdot \left(\delta_p \nabla (\phi \, p_{sat}) \right)$$



Basics

Heat Calc.

Total Heat Resistance

$$R = \frac{1}{\alpha_{Ext.}} + \sum_{AllLayers} \frac{d}{\lambda} + \frac{1}{\alpha_{Int.}}$$

Heat Flux

$$q = \frac{\Delta T}{R}$$

Temperature Differences

$$\Delta T_{Ext.} = \frac{1}{\alpha_{Ext.}} \cdot q$$

$$\Delta T_{Brick} = \frac{d_{Brick}}{\lambda_{Brick}} \cdot q$$

$$\Delta T_{Int.} = \frac{1}{\alpha_{Int.}} \cdot q$$

Vapor Calc. (very simplified)

Total Vapor Resistance

$$R_v = \frac{1}{\beta_{Ext.}} + \sum_{AllLayers} \frac{d}{\delta_P} + \frac{1}{\beta_{Int.}}$$

Vapor Flux

$$g_v = \frac{\Delta p}{R_v}$$

Vapor Pressure Differences

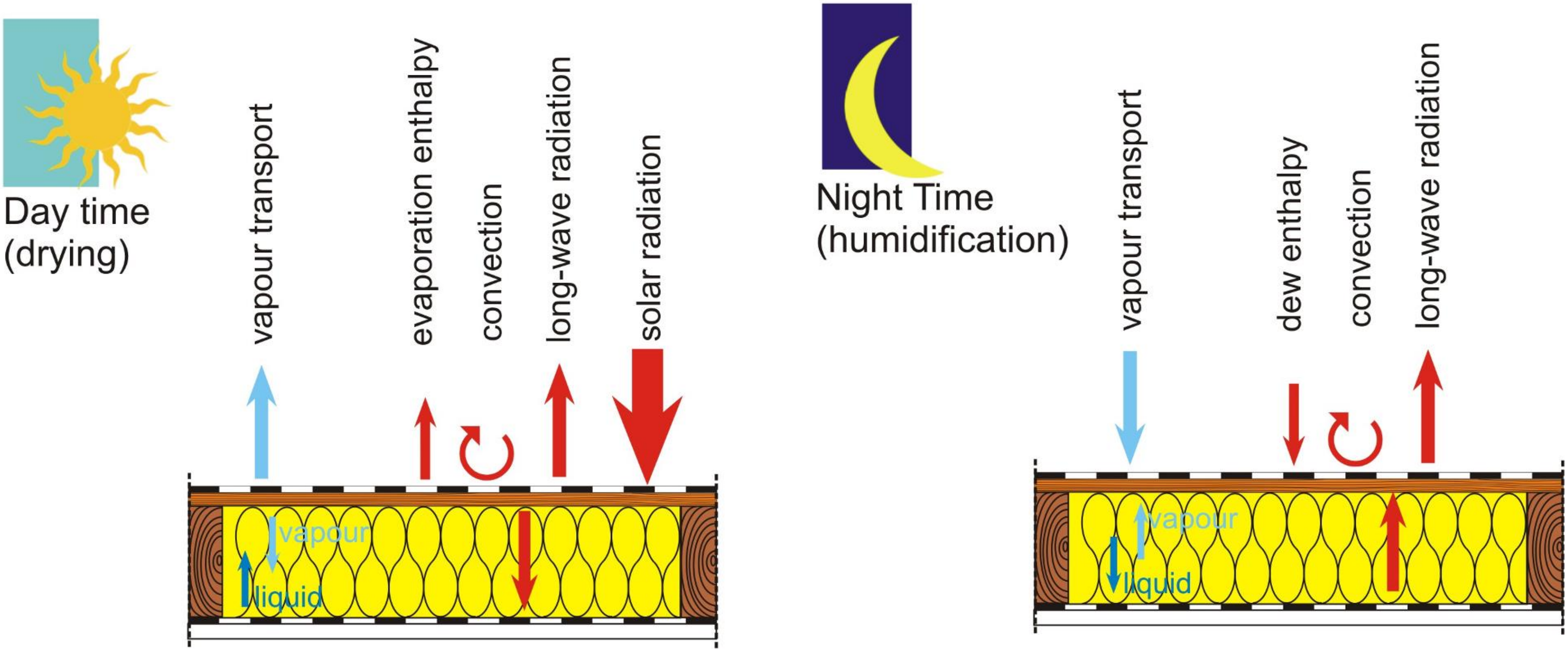
$$\Delta p_{Ext.} = \frac{1}{\beta_{Ext.}} \cdot g_v$$

$$\Delta p_{Brick} = \frac{d}{\delta_p} \cdot g_v$$

$$\Delta p_{Int.} = \frac{1}{\beta_{Int.}} \cdot g_v$$

Transistent Hygrothermal Processes in Building Envelope

Example Flat Roof

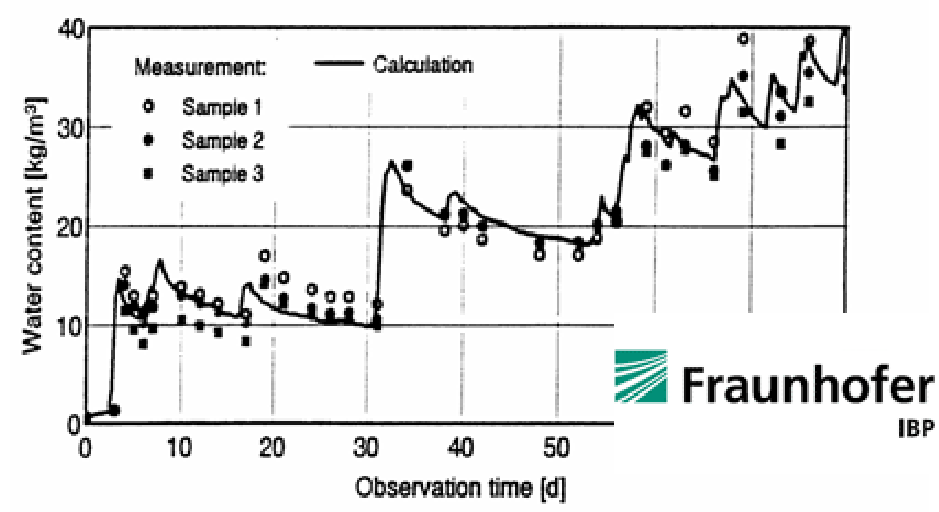


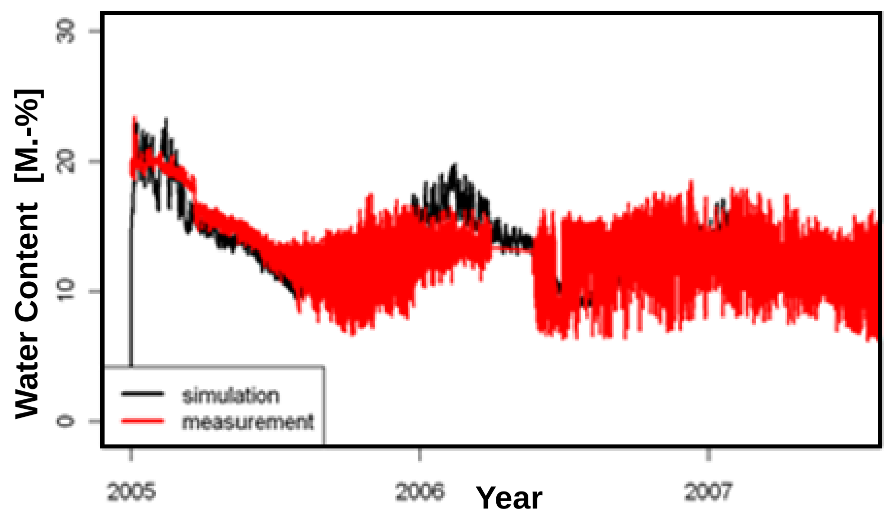
Material Properties Measurement

The complexity of heat and moisture analysis material properties can be approximated with the following rel. simple and standardized material properties:

⌘ **Density**	
⌘ **Porosity**	
⌘ **Heat Capacity**	**ASTM (Calorimeter)**
⌘ **Thermal Conductivity**	**ASTM C518, C177**
⌘ **Moisture Sorption Function**	**ASTM C1498, C1699**
⌘ **Water Vapor Permeability**	**ASTM E96**
⌘ **Free water saturation**	**ASTM C1699**
⌘ **Water Absorption Coefficient**	**ASTM C1794**

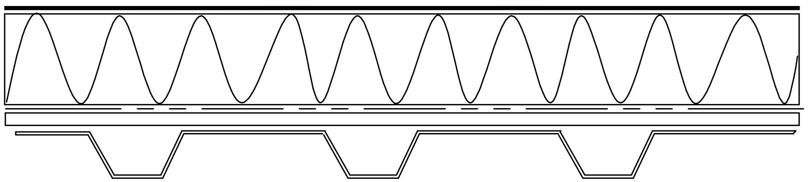
Model Validation





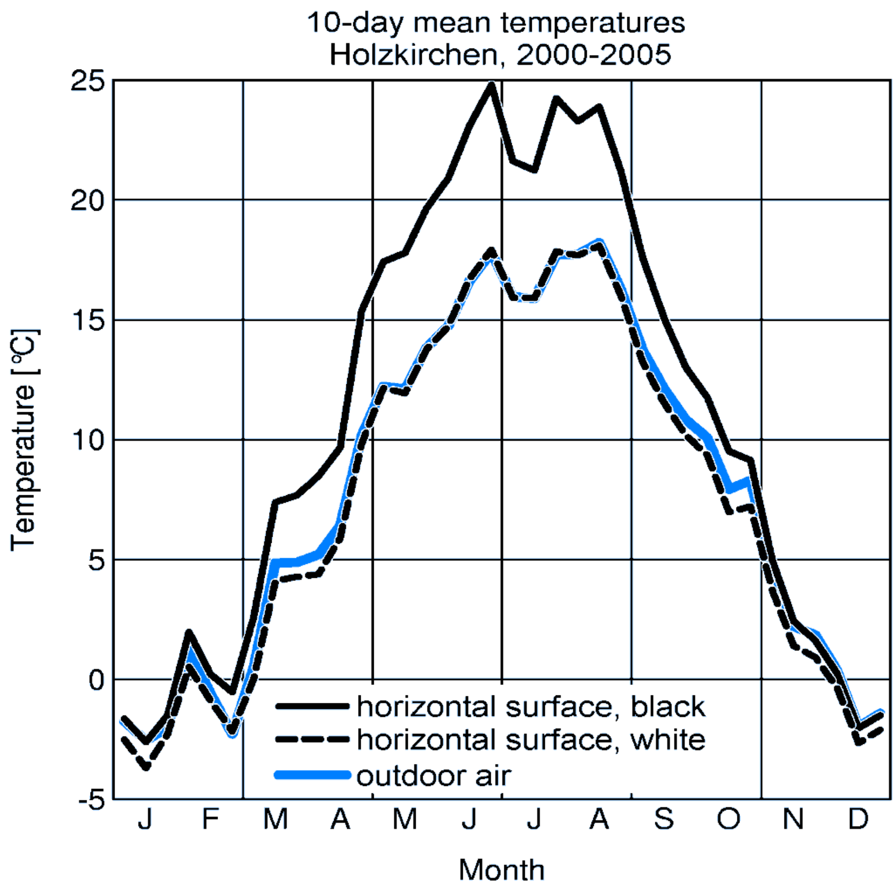
Condensation Risk of Cool Roofs

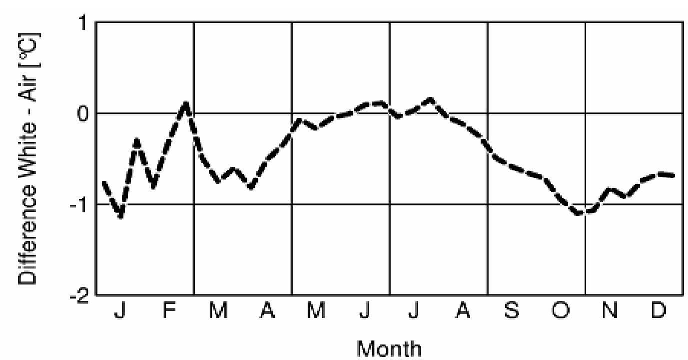
Mechanically attached Commercial Metal Deck Flat Roof



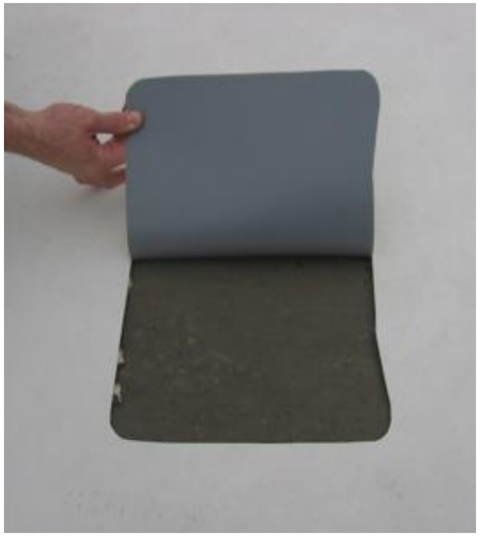
Analysis of meteorological data

Solar Radiation Impact



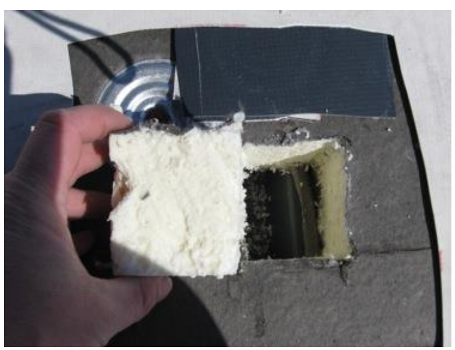


Condensation Risk of Cool Roofs



SPRI / ORNL Investigation

SPRI
SINGLE PLY ROOFING INDUSTRY



- White membranes to reduce the solar heat load
- Black membranes are typically 50 deg F warmer than white membranes on a sunny day
- Theorized impact
  - Location/occurance of dew point
  - Impact ability of system to dry out

Cool Roofs: Variation Scenario

Climate

Zone 4 – Baltimore, MD

Zone 5 – Chicago, IL

Zone 6 – Minneapolis, MN

Zone 7 – Fargo, ND

Solar Surface Absorptivity

α=0.30 (White Surface)

α=0.85 (Dark Surface)

Indoor Moisture Supply

ASHRAE 160, Low

EN-15026, Normal

EN-15026, High

ASHRAE 160, High

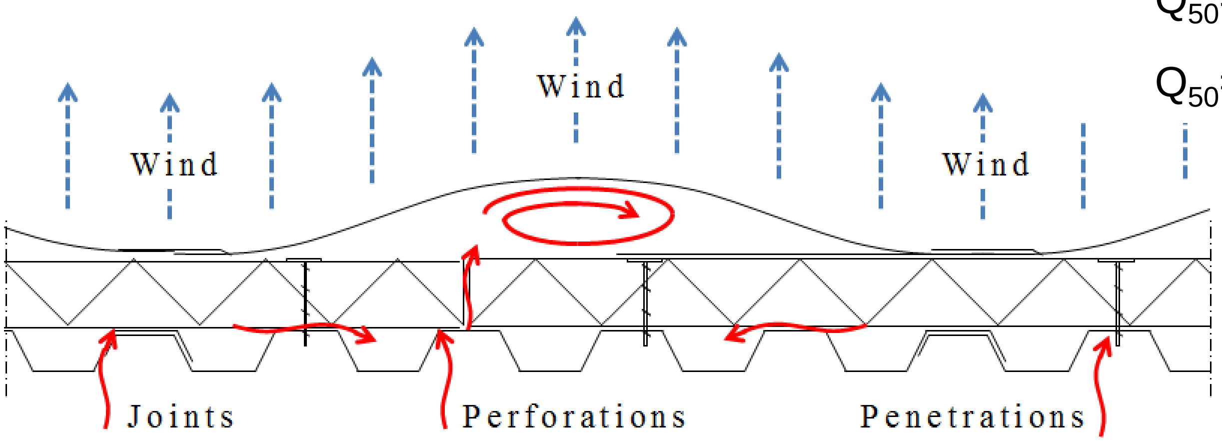
Air Tightness

Q_{50}=0.27 [l/s,m^2] – no perforations

Q_{50}=0.56 [l/s,m^2] – little leaky

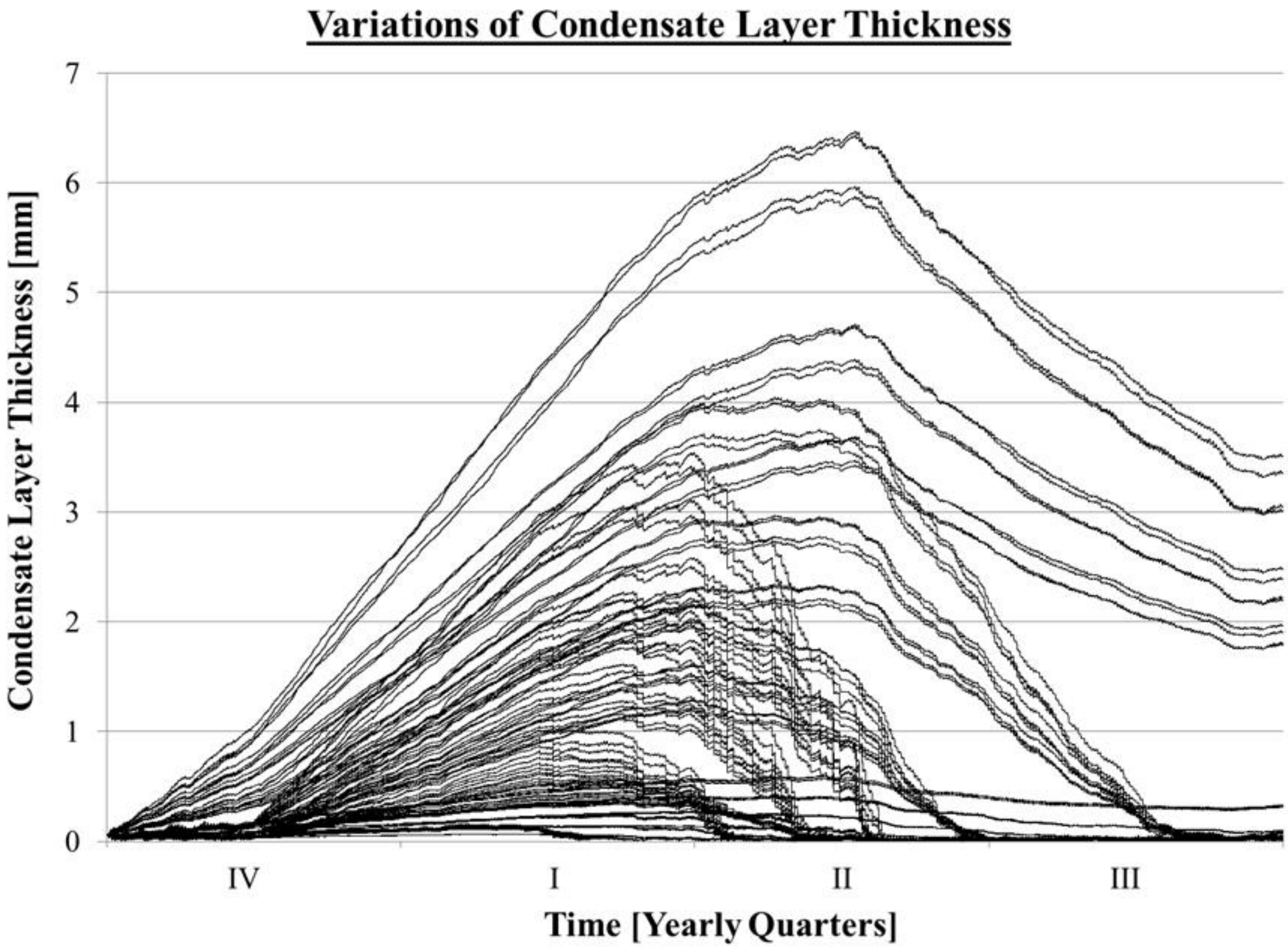
Q_{50}=1.0 [l/s,m^2] – average leaky

Q_{50}=2.0 [l/s,m^2] – totally leaky



→ Combination:
128 WUFI Simulations!

Cool Roofs: WUFI Results



Cool Roofs: Final Evaluation of Results

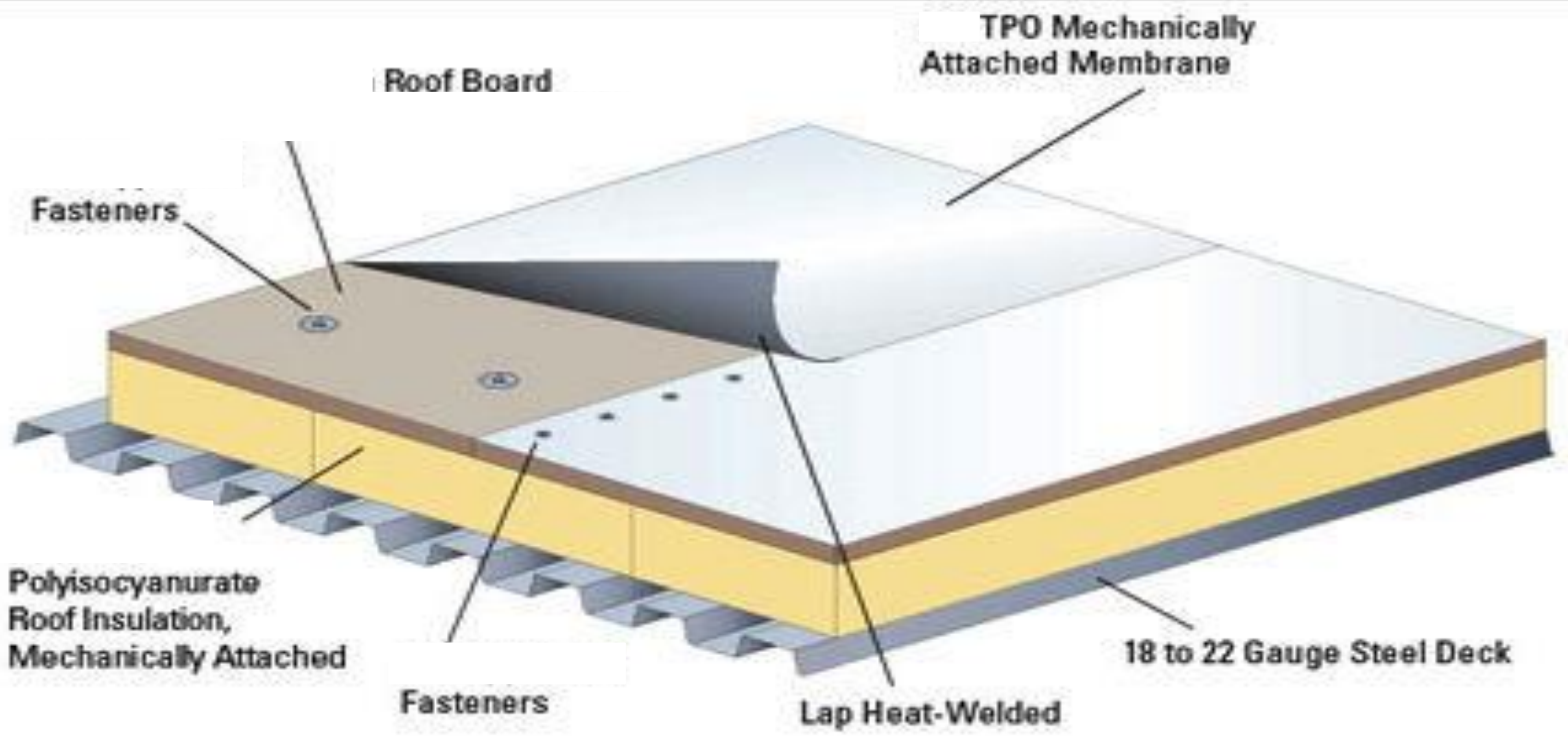
Indicators for the reliability of the roof construction at given conditions.

safe roof construction, gray indicates
risky construction
expected failure

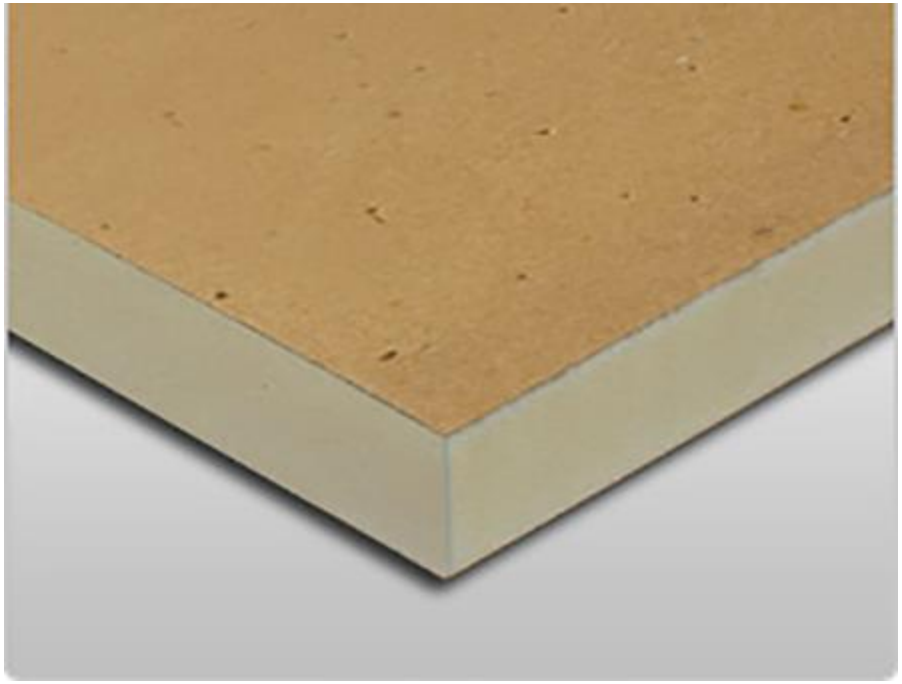
Black Surface
White Surface

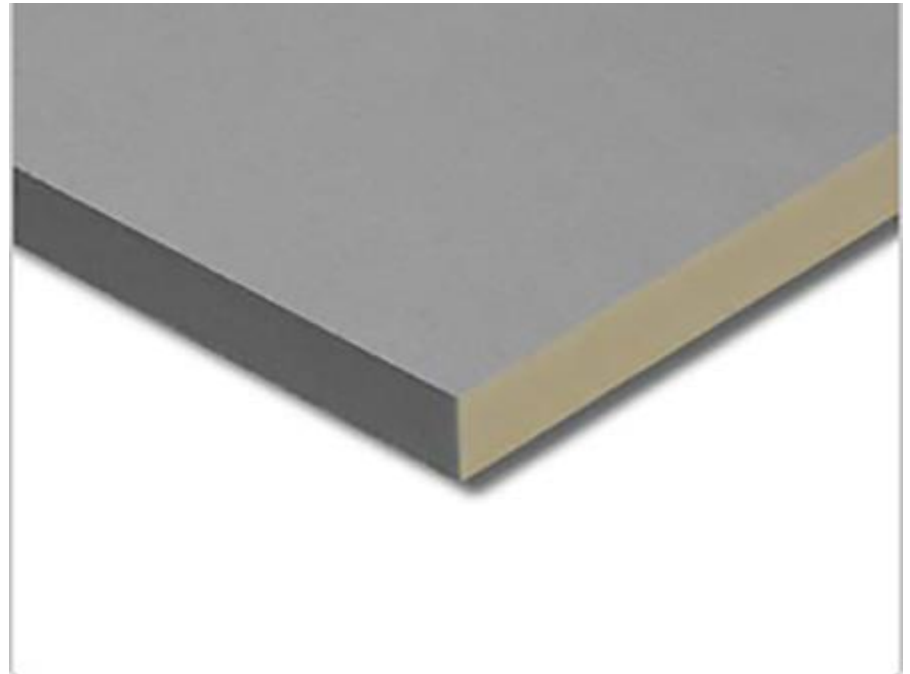
Climate Zone 4								
Indoor moisture supply	Not Leaky		Little Leaky		Avg. Leaky		Very Leaky	
ASHRAE - Low	B	W	B	W	B	W	B	W
EN - Normal	B	W	B	W	B	W	B	W
EN - High	B	W	B	W	B	W	B	W
ASHRAE - High	B	W	B	W	B	W	B	W

Mech. attached Roof, Sensitivity Analysis



Mech. attached Roof, Sensitivity Analysis





Step1: Measurement of Material Properties for
Polyiso, facers separately
Coverboard
TPO

Mech. attached Roof, Sensitivity Analysis

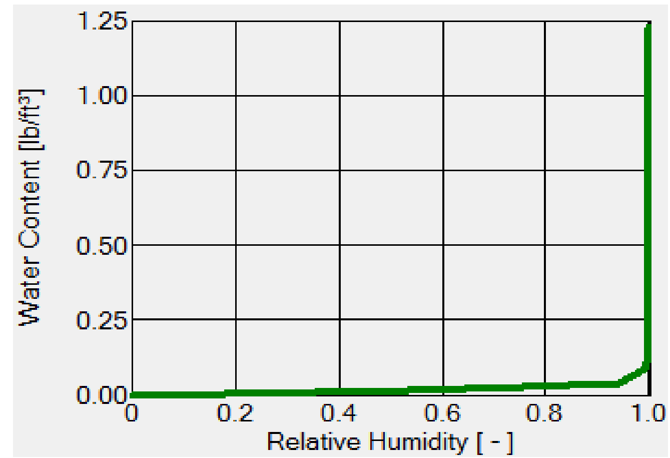
Measurement Methodology

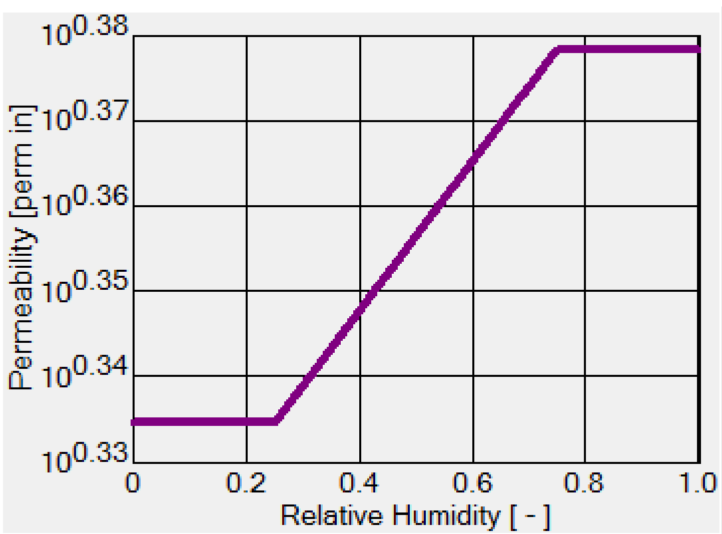
	Polyiso foam core	Facers	High density polyiso coverboard	Cellulosic coverboard	TPO membrane
Bulk density	ORNL	ORNL	ORNL	ORNL	Manufacturer
Porosity	est	est	est	est	est
Specific heat capacity	est	est	est	est	est
Thermal conductivity	Manufacturer	est	Manufacturer	Manufacturer	est
Water vapor permeability	Manufacturer	Manufacturer	Manufacturer	Manufacturer	Manufacturer
Moisture storage function	ORNL	ORNL	ORNL	ORNL	est
Water absorption coefficient	ORNL	ORNL	ORNL	ORNL	est
Thermal conductivity dependence on temperature	Manufacturer	Manufacturer	Manufacturer	Manufacturer	Manufacturer
Thermal conductivity dependence on moisture	est	est	est	est	est

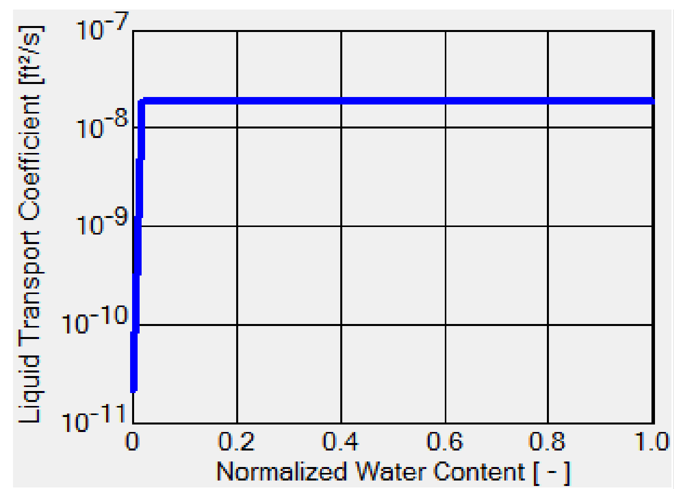
Mech. attached Roof, Sensitivity Analysis

Properties of polyiso insulation board

Basic Values	
Bulk density [lb/ft³]	1.6294
Porosity [ft³/ft³]	0.98
Specific Heat Capacity, Dry [Btu/lb°F]	0.3511
Thermal Conductivity, Dry, 50°F [Btu/h ft°F]	0.0149
Permeability [perm in]	2.1611







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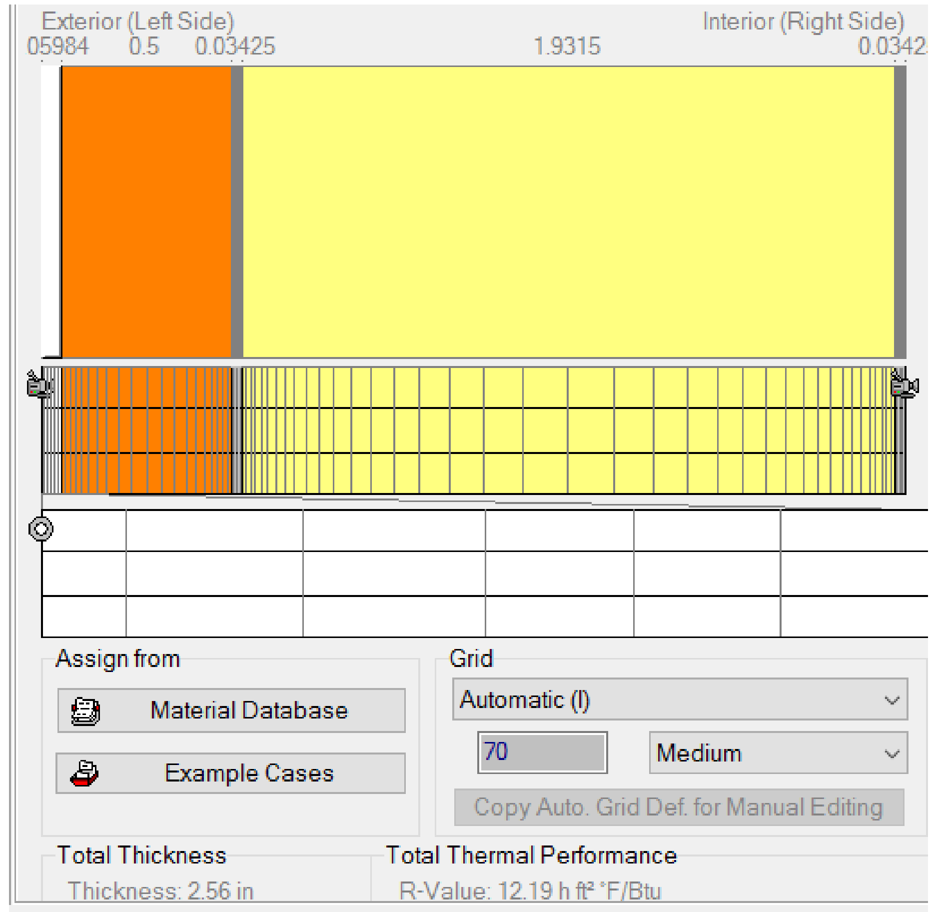
Mech. attached Roof, Sensitivity Analysis

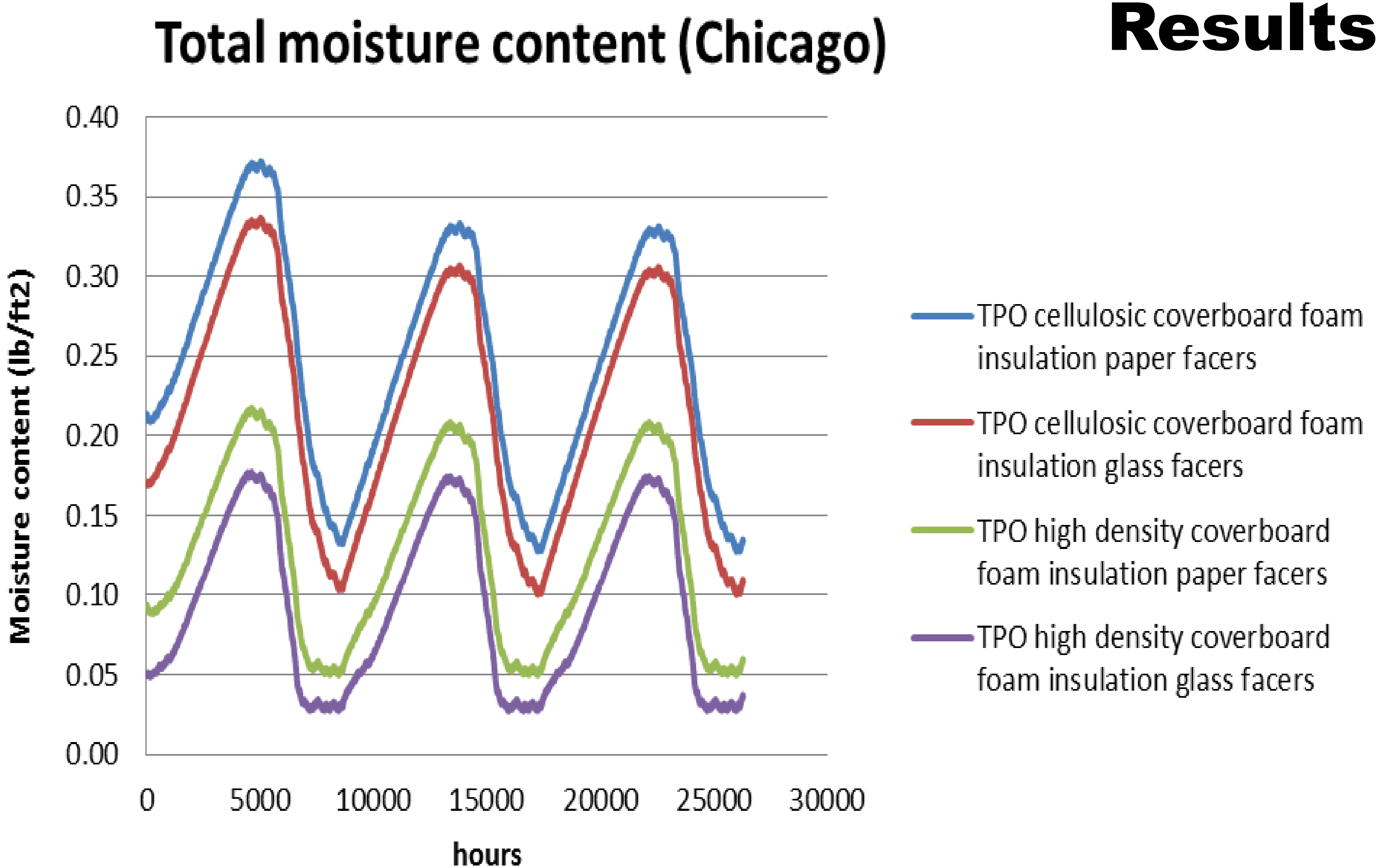
Initial and boundary conditions

- Horizontal flat roof
- White, reflective roof
- Metal roof deck – 1 perm
- EMC 80 – initial moisture content
- Interior climate: ASHRAE 160



Mech. attached Roof, Sensitivity Analysis

Results



Sensitivity Analysis

- Four systems – Polyiso, TPO, + two coverboards + with two facers
- Two climates – Miami and Chicago
- Properties were varied +/-20%
- Total moisture content maximum in the 3rd year compared to baseline

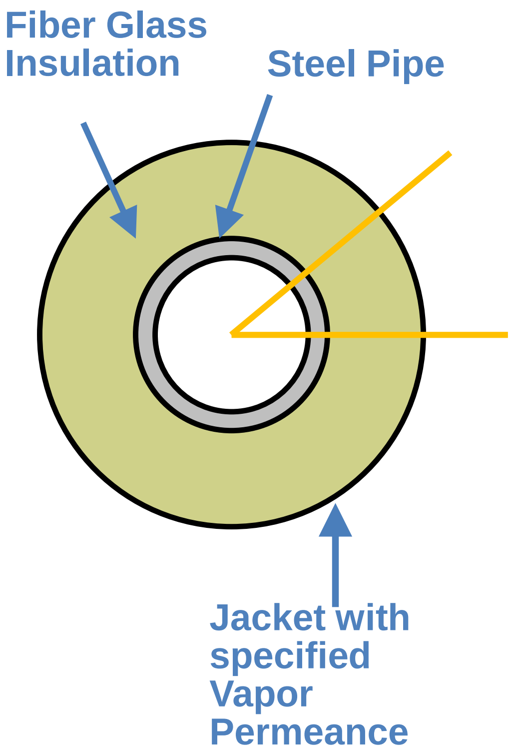
Mech. attached Roof, Sensitivity Analysis

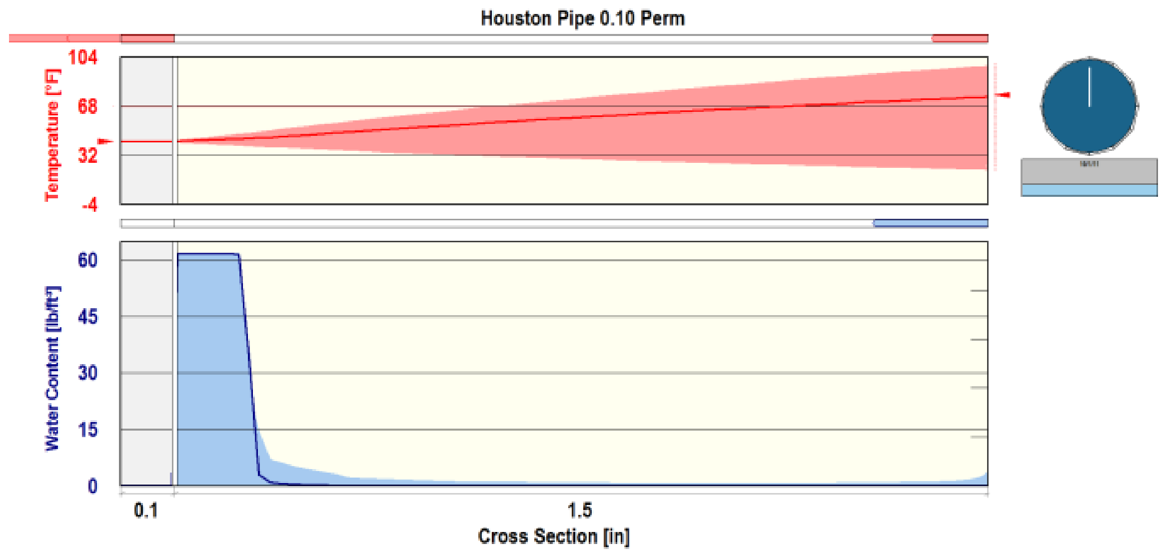
Sensitivity Analysis Results

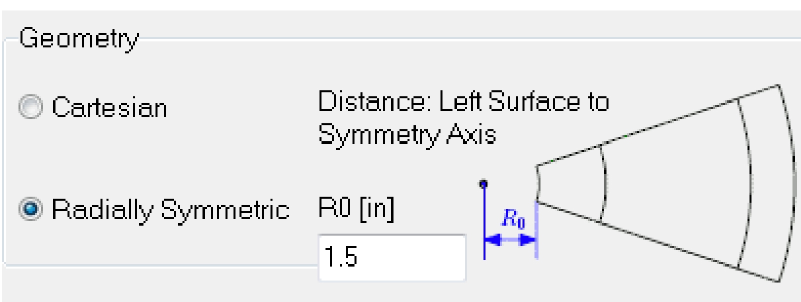
Assembly	High density/paper		High density/glass		Cellulose/paper		Cellulose/glass	
Climate	Chicago	Miami	Chicago	Miami	Chicago	Miami	Chicago	Miami
Density	0.7%	0.0%	0.6%	0.0%	0.0%	0.0%	0.3%	0.0%
Water vapor permeability	6.6%	0.6%	7.8%	0.0%	5.2%	1.4%	5.9%	1.3%
Thermal conductivity	0.7%	0.0%	0.8%	0.0%	0.6%	0.3%	0.6%	0.0%
Moisture storage	7.7%	18.6%	5.9%	18.3%	10.3%	17.8%	9.3%	18.1%
Liquid transport	0.2%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%

Table 8-*Variation in total moisture content with a variation of 20% in the measured property*

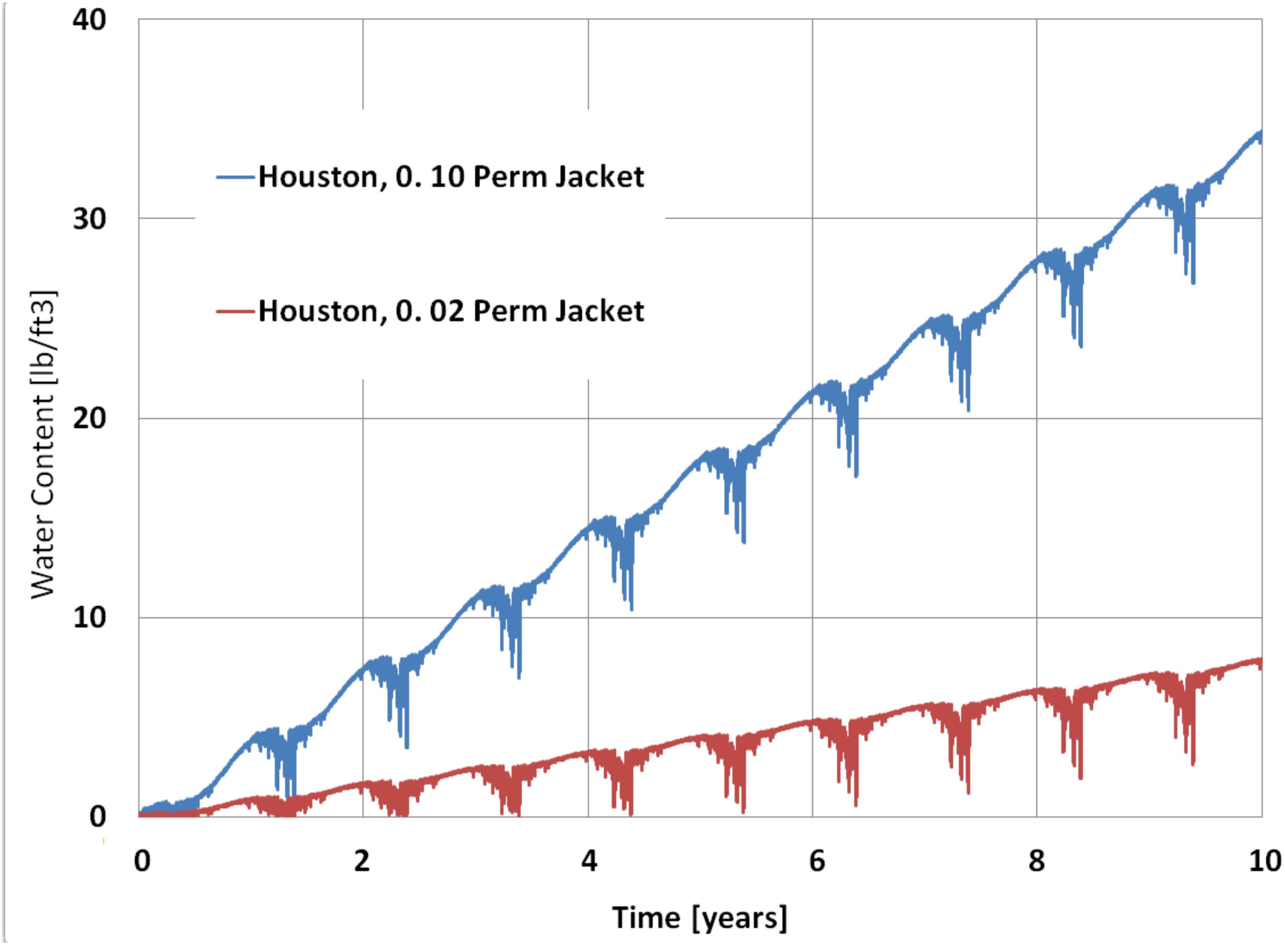
WUFI Application for Pipe Insulation



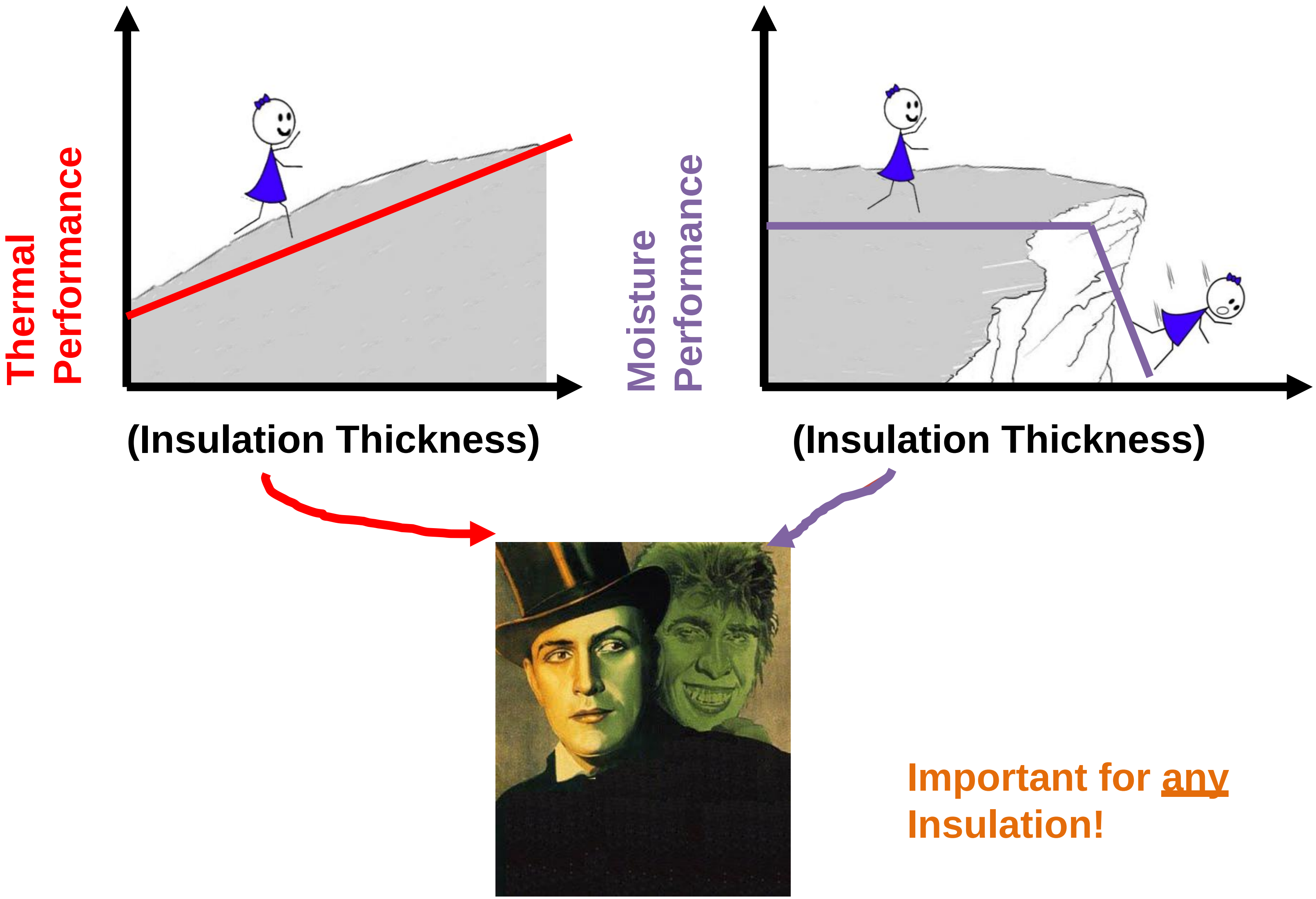




WUFI Application for Pipe Insulation



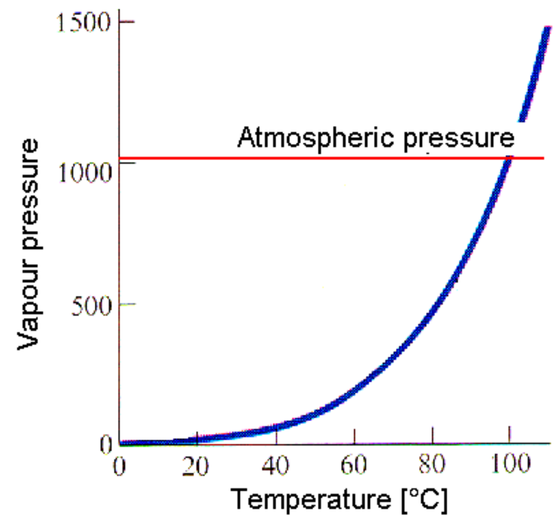
Heat vs. Moisture

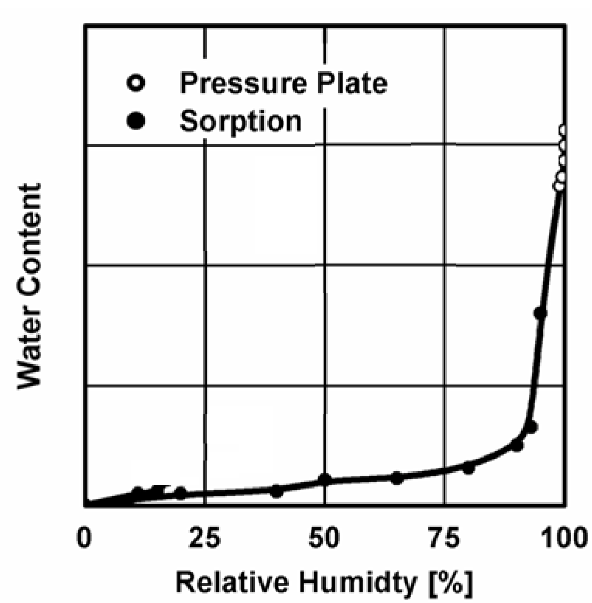


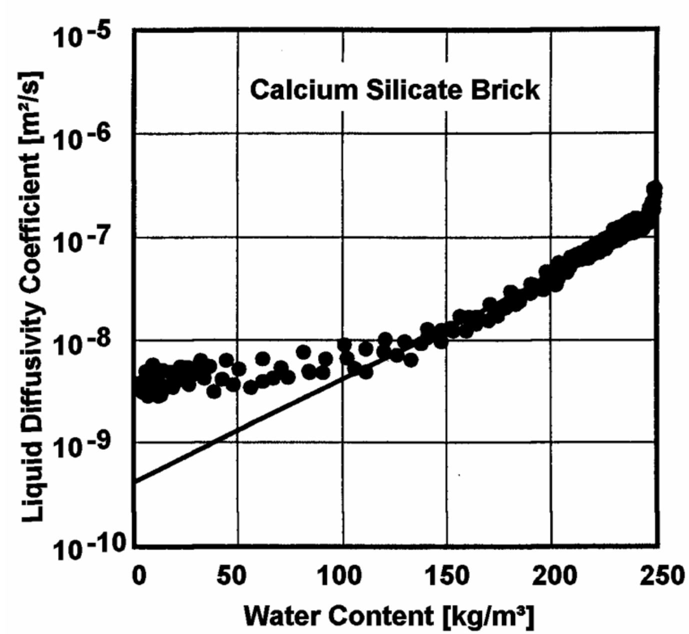
Important for <u>any</u> Insulation!

Heat vs. Moisture

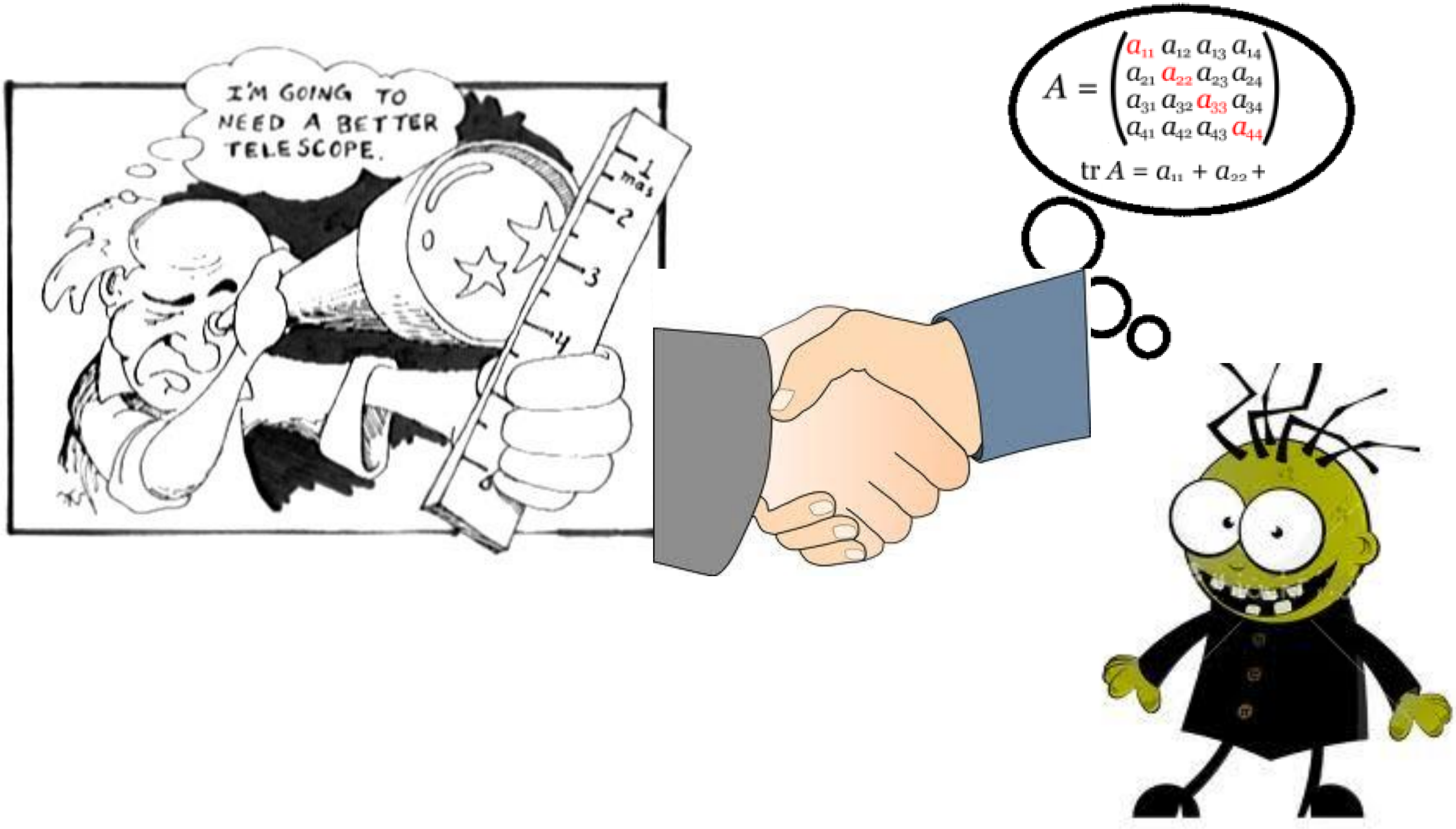
Hygrothermal material properties are highly non-linear.
(unlike thermal material properties)







Measurement & Calculation



Just Smart Solutions

Buildings XIII Workshop

December 5th 2016

Manfred Kehrer

Modern Hygrothermal Engineering Motivation, Basics, Examples