BUILDING INNOVATION 2019

National Institute of BUILDING SCIENCES

CONFERENCE & EXPO

Hygrothermal Performance Assessment by Simulation

Motivation & Remaining Challenges

National Institute of Building Sciences

Provider Number: G168

Hygrothermal Performance Assessment by Simulation – Motivation & Remaining Challenges

Course Number

Manfred Kehrer and Elizabeth Pugh

Date

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Course Description

Numerical simulation of the combined heat and water transfer in building enclosures has been an established practice for over 20 years. Besides other performance assessments like laboratory and field test measurements, numerical simulation is considered an essential tool in the toolbox for building enclosure design and forensic analysis. Most of the physical phenomena of heat and moisture transfer, such as heat conductivity, radiation, vapor, and capillary transport, are well understood. The majority of these physical phenomena can be fairly accurately simulated with hygrothermal analysis tools for practical application, although another phenomenon, convection, is still hard take into account for building practice. WJE is completing research using measured data from the instrumentation of a new facility as well as numerical simulation to acquire more knowledge about convection behind commercial building cladding systems, and to validate a finite element tool which simulates the combined conductive, radiative, and convective heat transfer on interior surfaces like windows and wall/roof surfaces. The presentation will show the basics and the importance of hygrothermal performance assessments, especially in today's world of high performance buildings and buildings enclosures. Furthermore, up to date results of the recent research project will be demonstrated.

Learning Objectives

At the end of the this course, participants will be able to:

1. Identify several analysis tools used for building enclosure simulation.

2. Understand the limitations of various analysis tools used for building enclosure simulation.

3. Understand challenges associated with simulating complex high performance building enclosures.

4. Discuss current research and development of new analysis techniques for complex high performance building enclosures.

Motivation

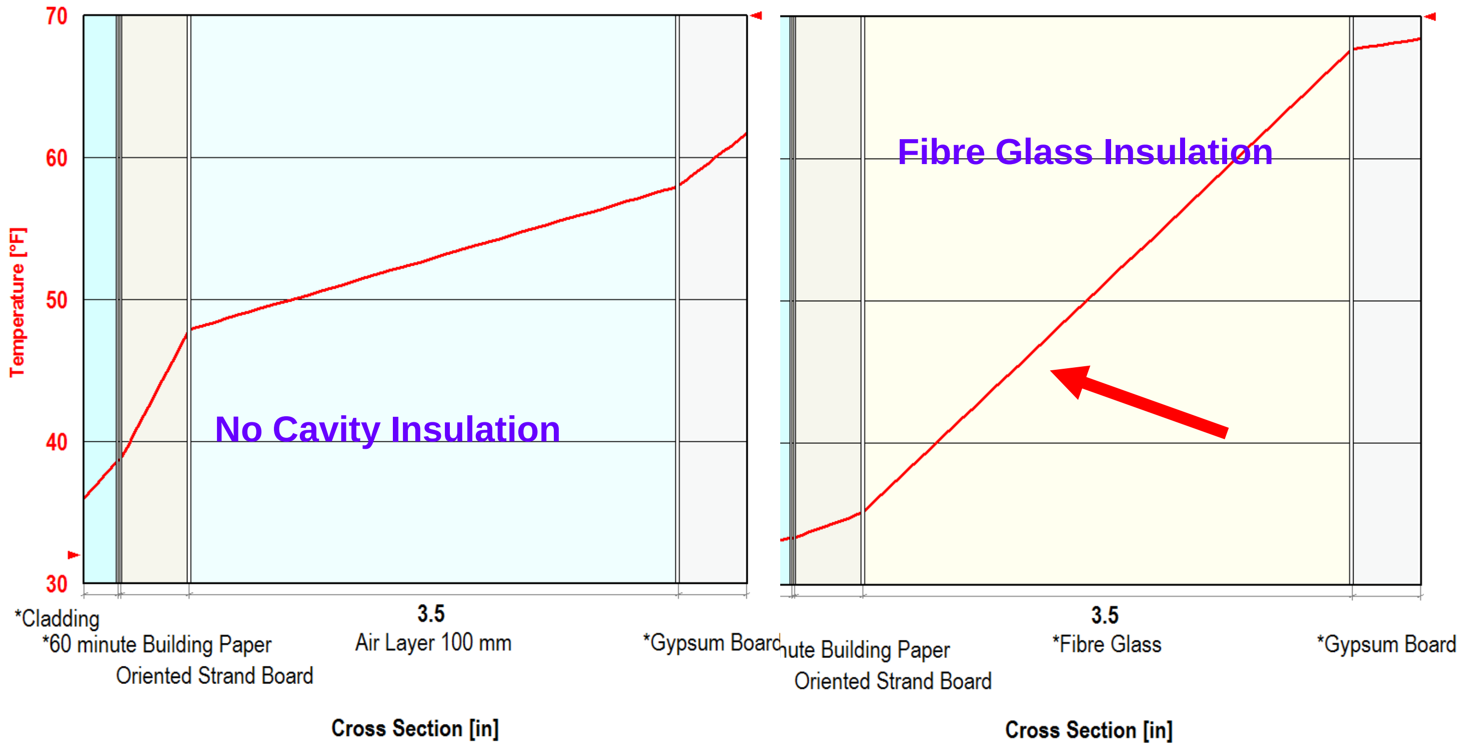
Motivation

Ask the Enclosure!

Motivation

Ask the Enclosure!

Impact of Thermal Insulation on Moisture

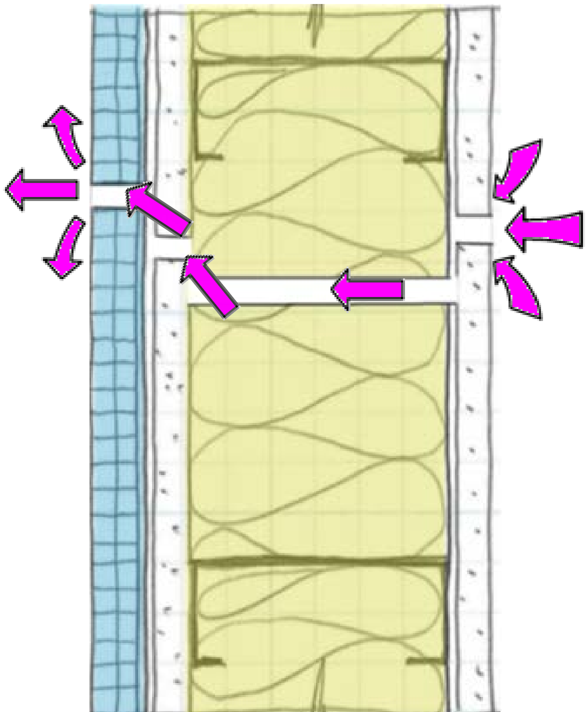


Higher Temperature Gradient has the result that cold spots are closer to warm spots
⇨ **Higher condensation risk**

Impact of Air Tightness on Moisture

Moisture transport due to air infiltration into the enclosure

Not Air Tight

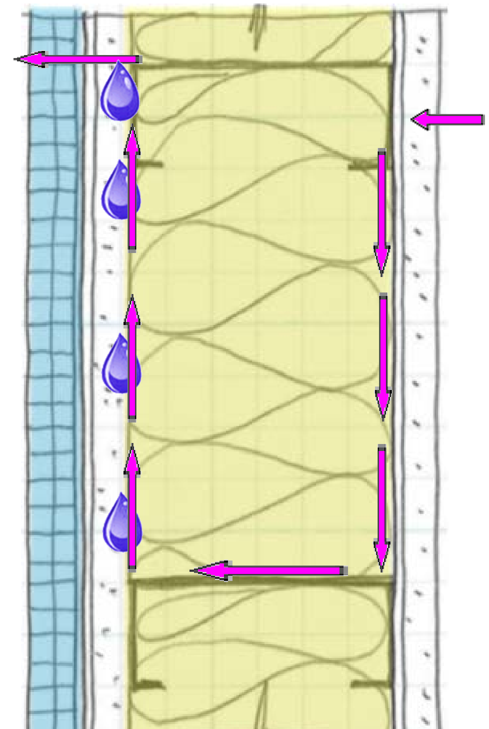


Energy leak

strong air flux

⇨ Only a little condensation

„Air Tight“

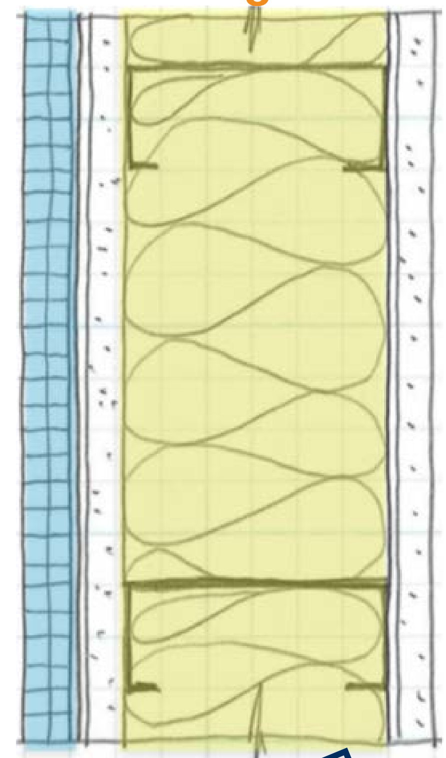


Moisture leak

slow and low speed air flux

⇨Much more condensation

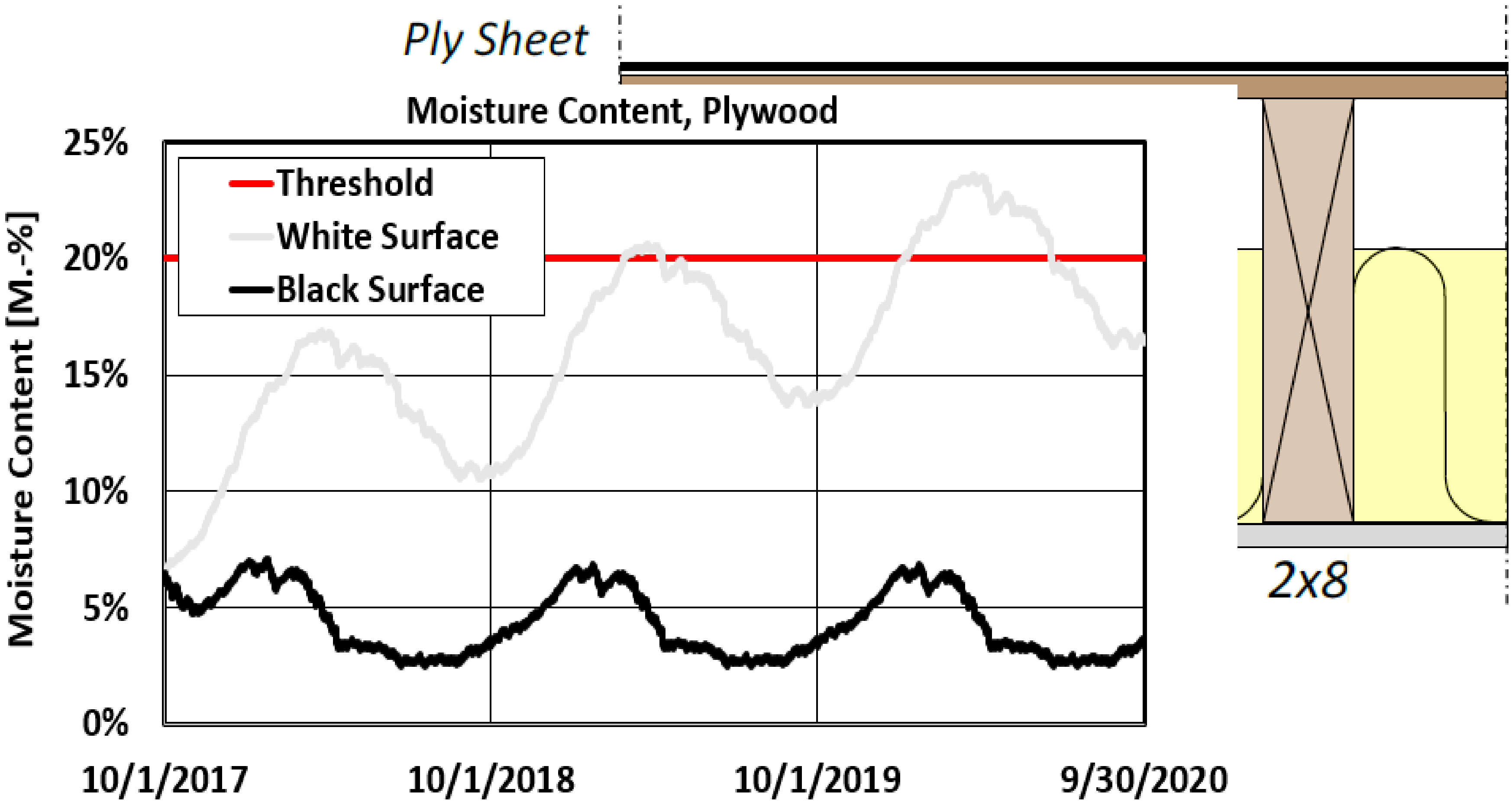
Air Tight



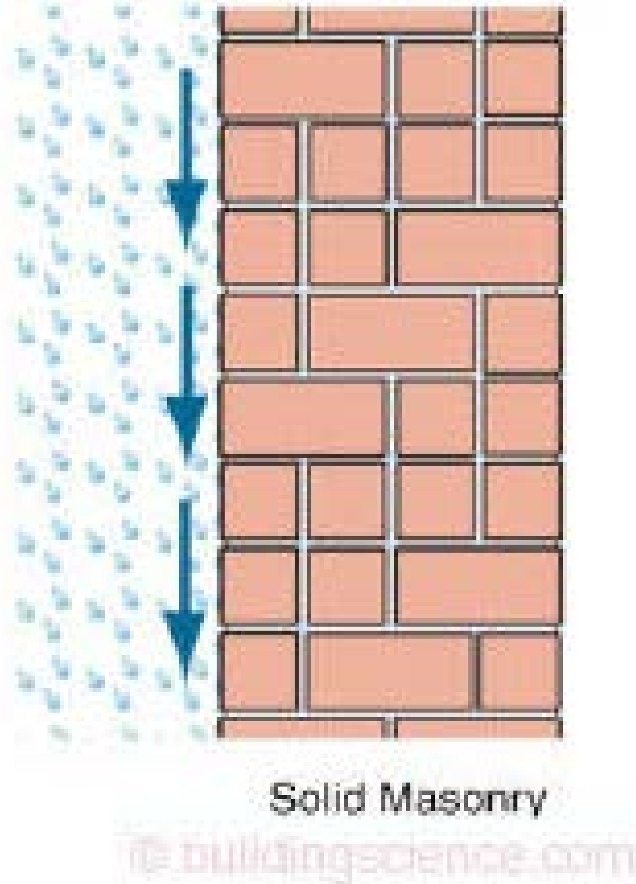
Good luck!

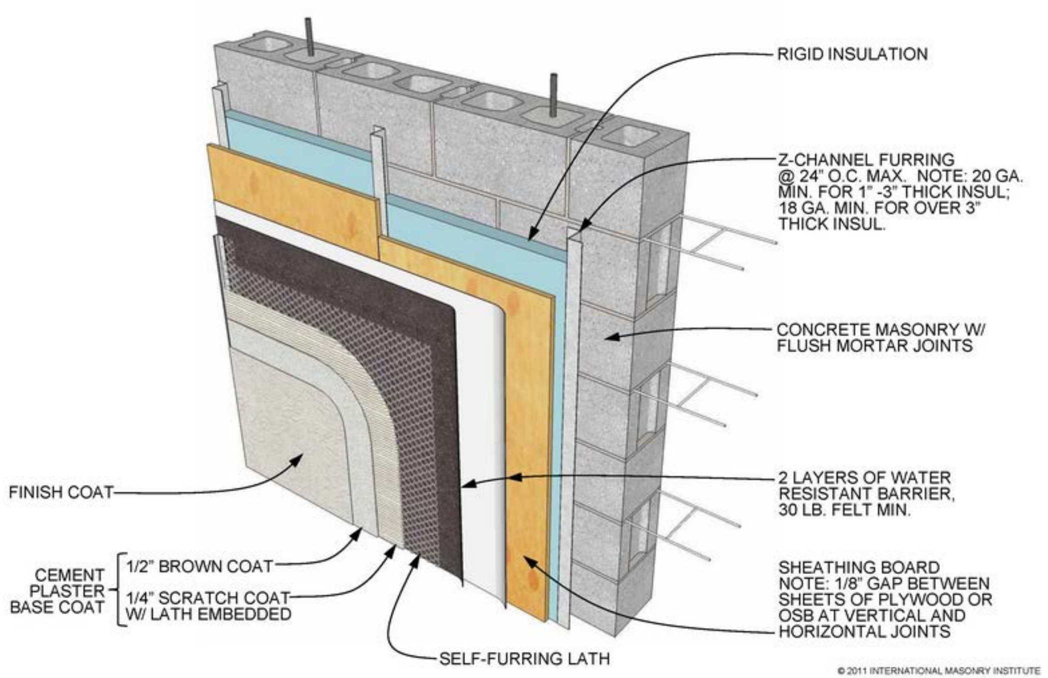
Impact of Cool Roofing on Moisture

Location: San Francisco



Buildings Enclosures changed





Building Science
A Composite of many Sciences

Observation / Measurement

Simulation / Modeling

$$M^T = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}$$

Building Science
A Composite of many Sciences

	Heat	Moisture
Measurement	Temperature Solar, IR Radiation Heat Flux Air Pressure, Velocity	Rel. Humidity (Air) Moisture Content (Material) ~~Moisture Flux~~ Air Pressure, Velocity
Material Properties	R-Value Heat Capacity Solar Absorptivity IR Emissivity	Perm Liquid Transport Coefficients Moisture Storage Function
Simulation	Conduction Radiation Convection (CFD)	Fick Diffusion Convection (CFD)

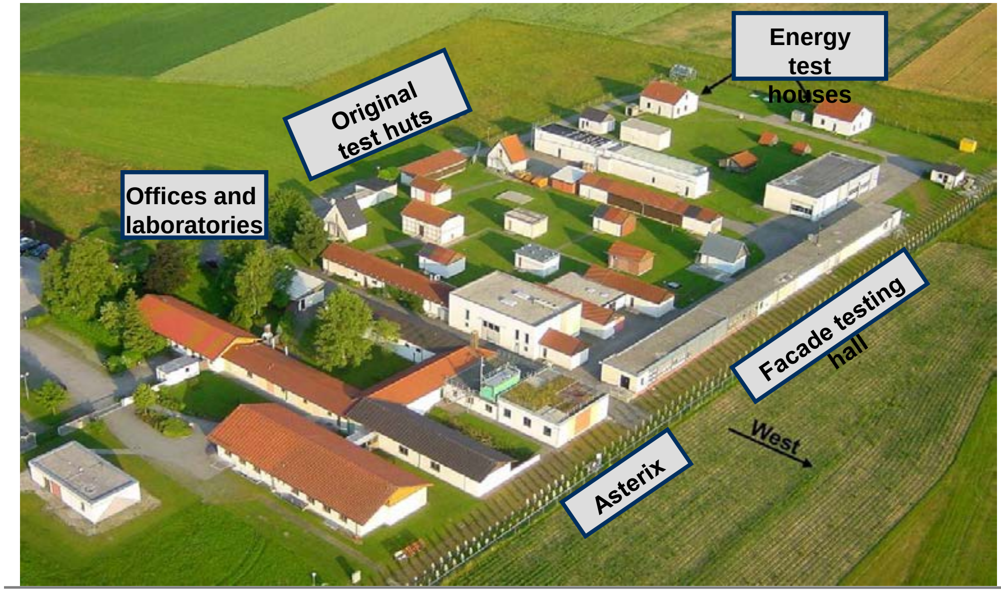
Heat and Moisture are COUPLED!

Previous Assessment

Field tests:

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

Fraunhofer IBP, Germany

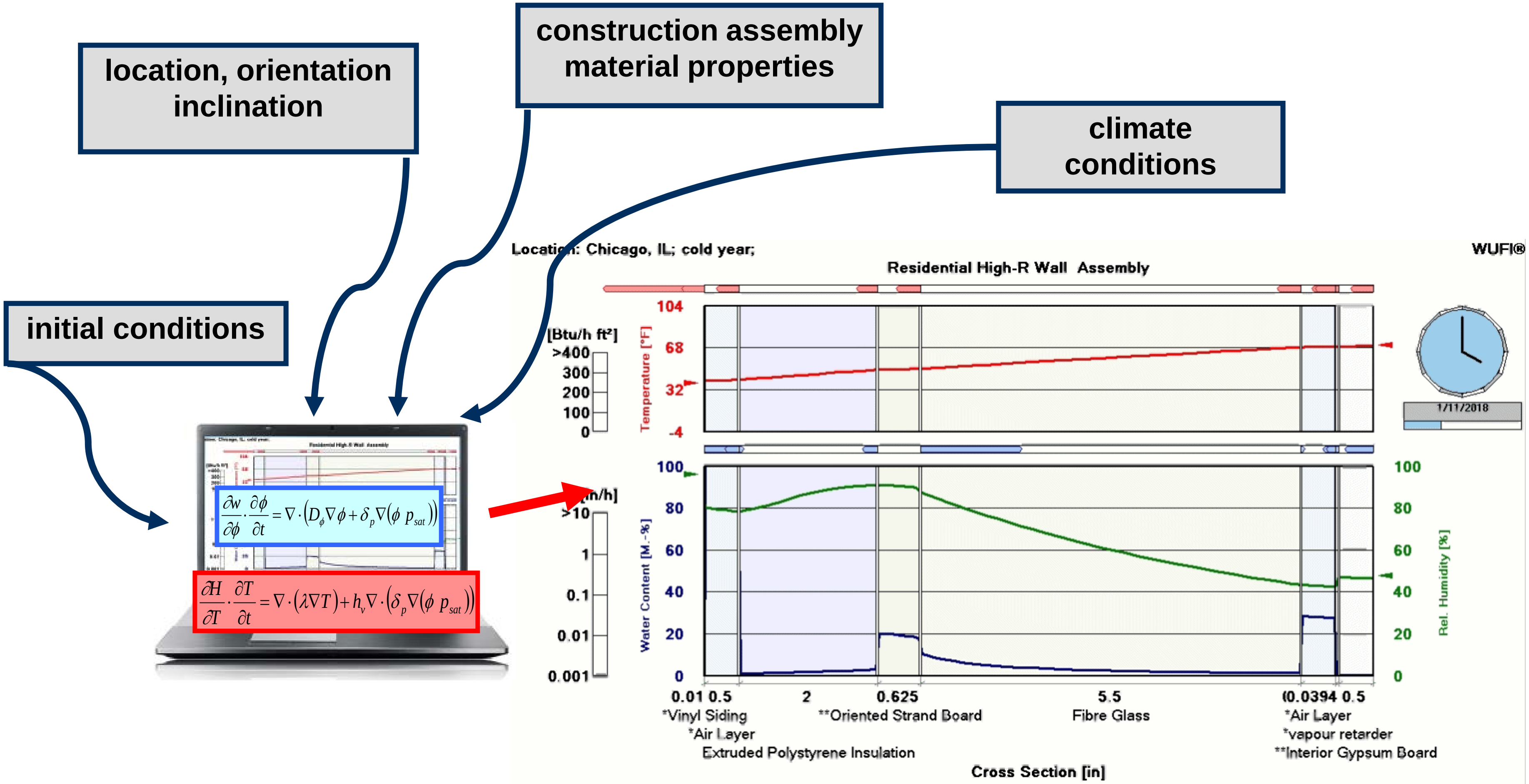


Previous Assessment

Laboratory tests: climate chambers
(hot box / cold box)

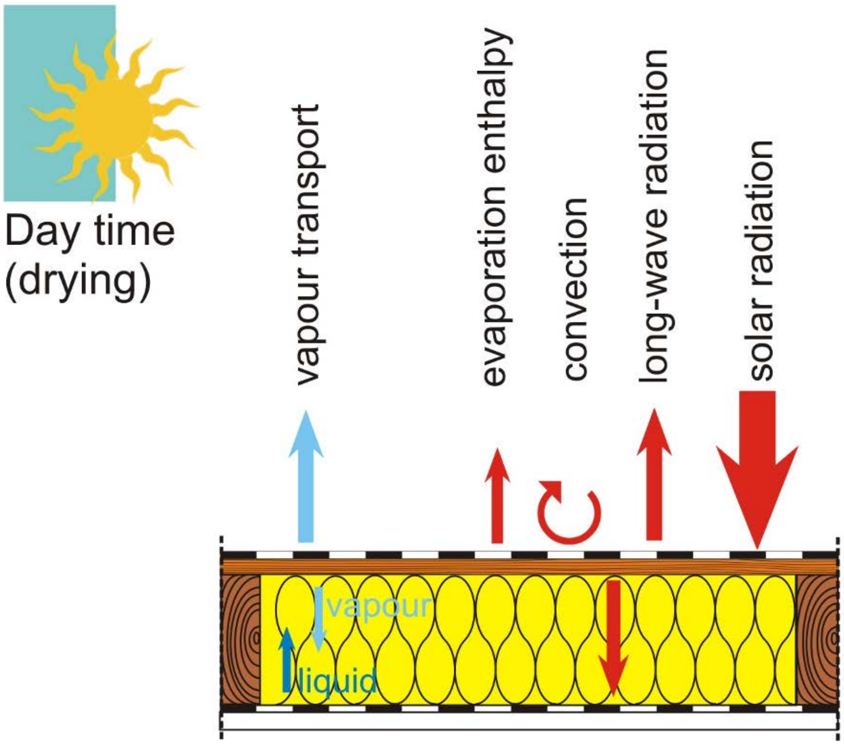
- **realistic conditions , Temp., RH**
- **sky radiation and precipitation difficult to simulate**
- **limited capacity**
- **Time consuming**
- **expensive**

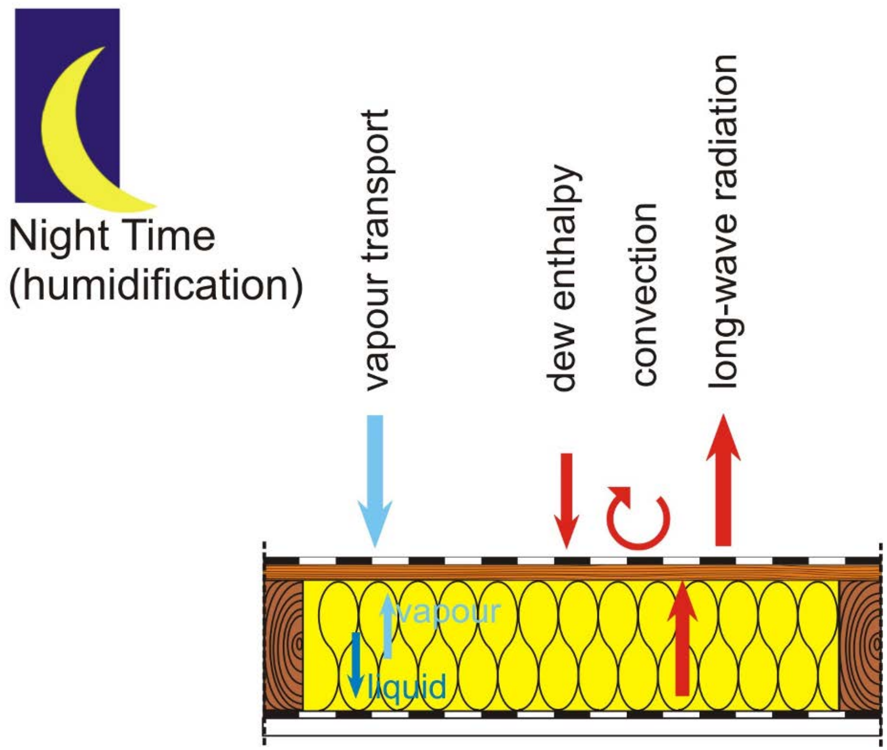
Today, Modeling
as an Addition/Alternative



Transient Hygrothermal Processes in Building Enclosure

Example Flat Roof



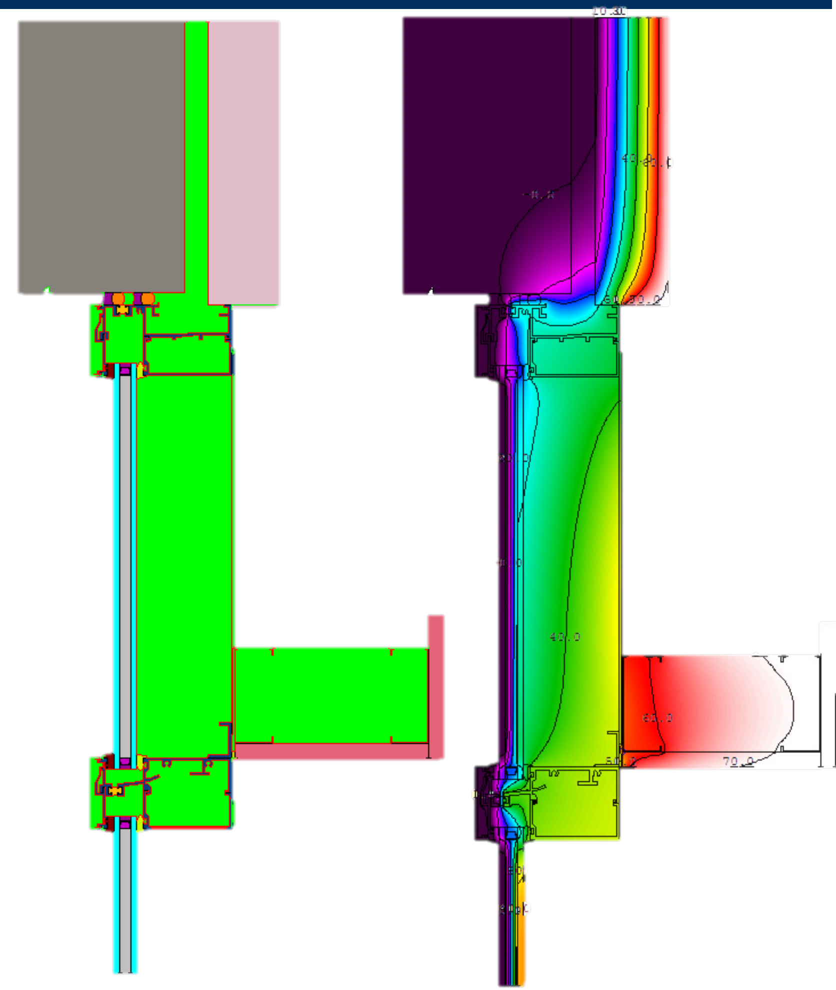


Building Science Tools
and their Capabilities

	Moist.	Dimensions	Time	Typ. Usage
	✓	→ X	Steady-State	Plausibility Check
THERM				
WUFI				
MAYA				
IESVE				
WUFI Plus				

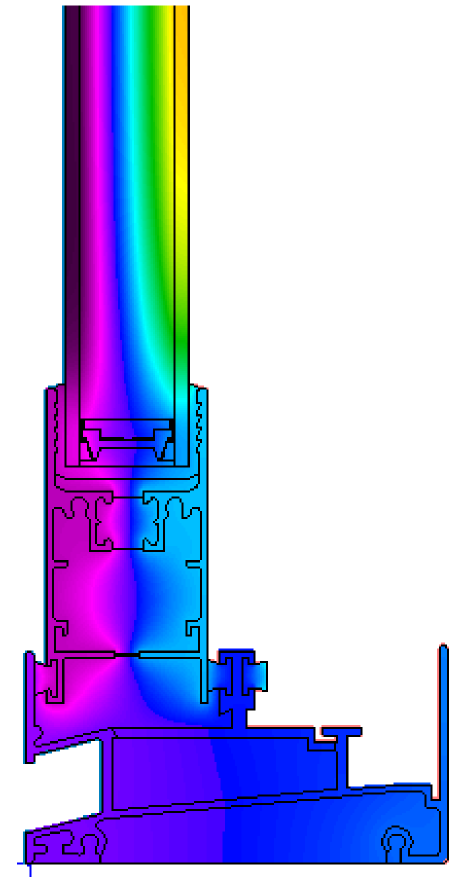
THERM: What is it?

- **Computer tool developed by LBNL**
- **Simulates thermal characteristics of complex 2D assemblies**
  - **Steady-state analysis**
  - **Conduction**
  - **Radiative exchange within components**
  - **Complex two-dimensional geometries possible**



THERM:
What is it good at?

- **Steady-state 2D analysis**
- **Complex geometry**
- **Conduction-dominated heat flow**
- **Extensive material database**
- **Free, fast, relatively easy to use**
- **Great for comparative analysis**



THERM:
What are its limitations?

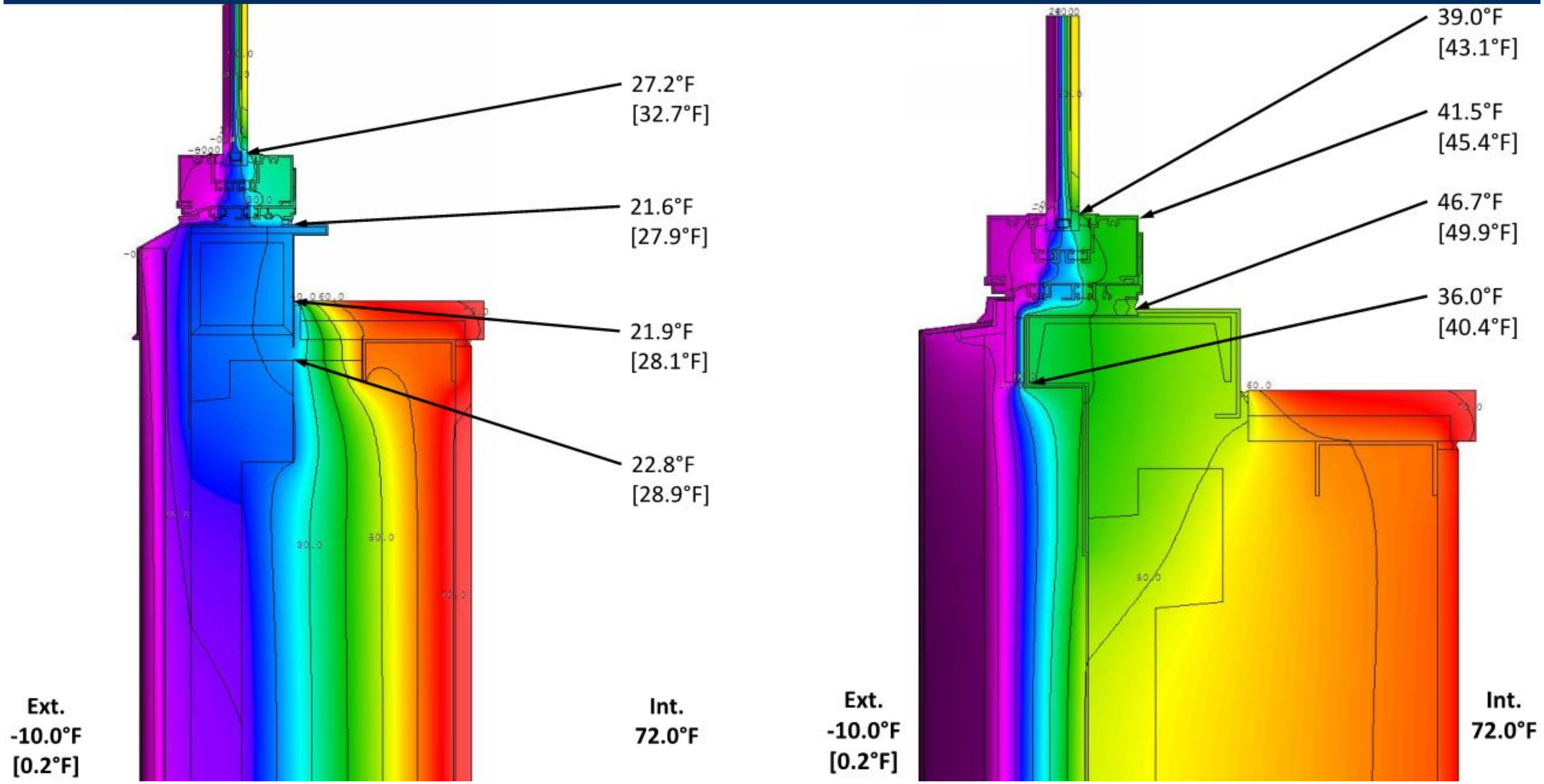
- **No 3D geometry**
- **Cannot explicitly simulate airflow, convection, or external heat sources**
- **Cannot accept 1st order boundary conditions**
- **Single analysis may not accurately predict in-service behavior**

THERM Project Example #1

- **15-story medical laboratory building in Chicago, IL**
- **Large renovation project:**
  - **New storefront windows**
  - **Exterior metal panels**
  - **Complete interior renovation, HVAC overhaul**
- **Thermal performance and condensation concerns**
- **Owner wants assistance in developing alternative detailing to address concerns**

WJE

THERM Project Example #1



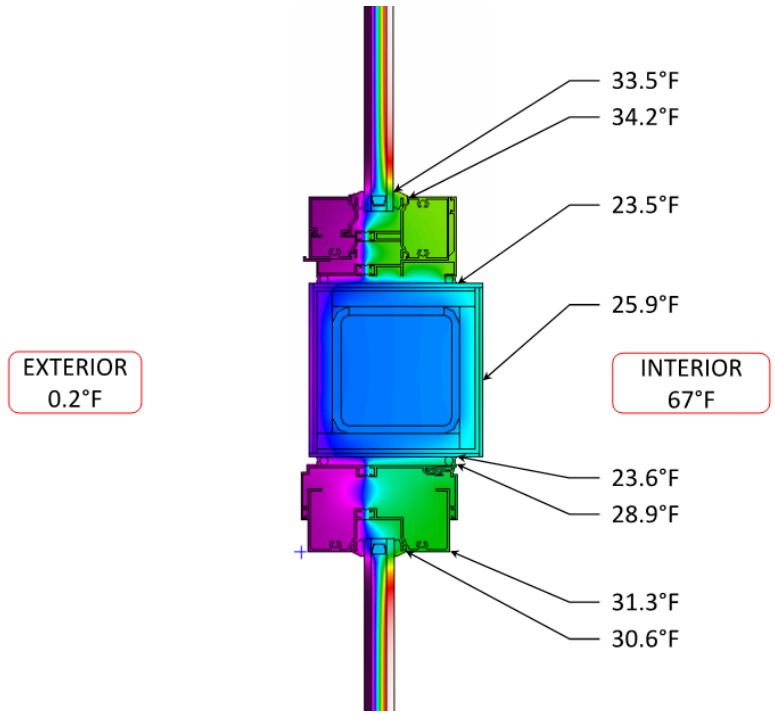
Alternatives developed at sill, head, and jamb using an iterative process (~20 simulations)

THERM Project Example #2

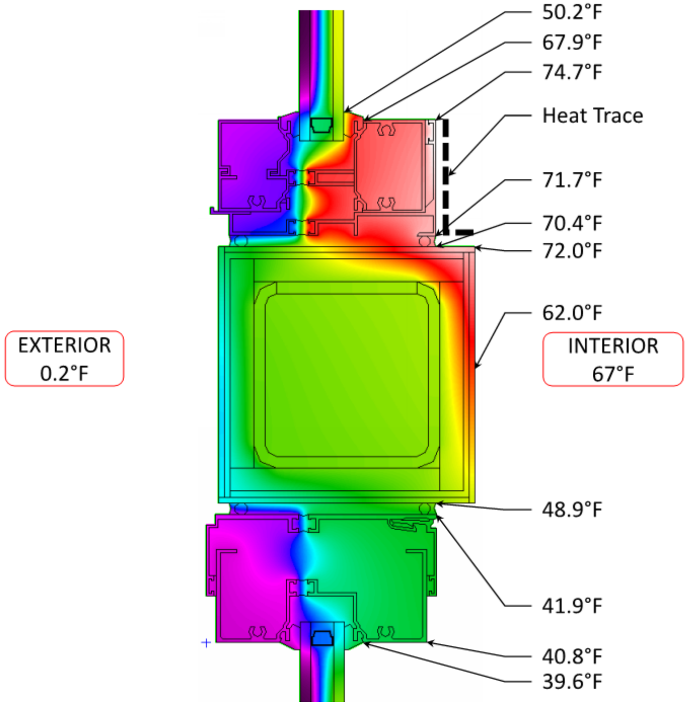
- **Garage/pavilion structure at private residence**
- **Steel framing with storefront windows**
- **Thermal bridging / very cold interior surface temperatures in winter**
- **Owner wants to warm framing while maintaining existing aesthetic**
- **Heat trace system?**

THERM Project Example #2

- Existing Condition

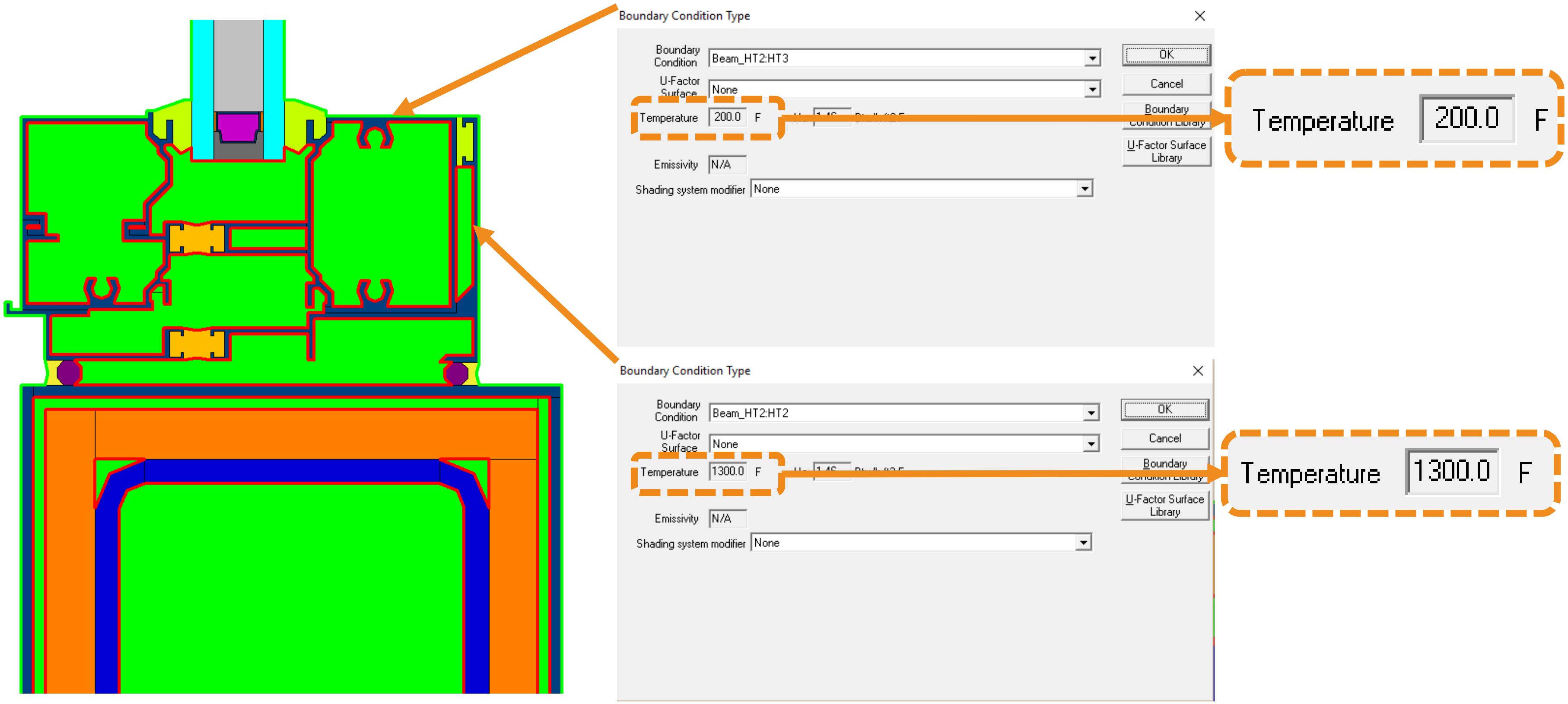


- Heat Trace
- (Simulated Surface Temp.)



NOTE: THERM does <u>not</u> allow input of 1st order boundary conditions.

THERM Project Example #2



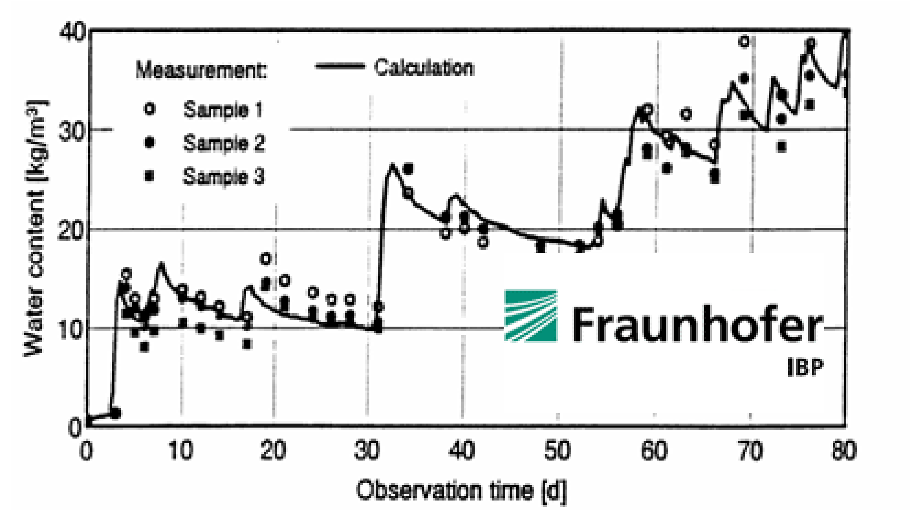
NOTE: THERM does <u>not</u> allow input of 1st order boundary conditions.

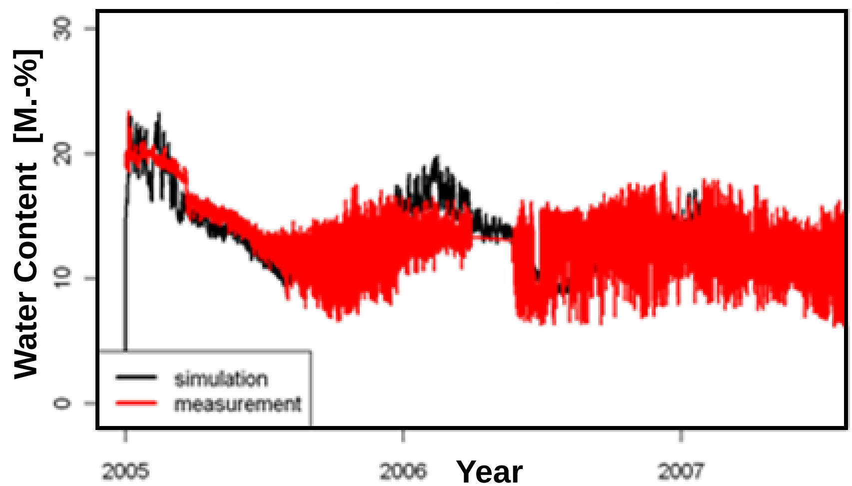
Hygrothermal Material Properties Measurement

Heat and moisture analysis is complex.
Material properties can be approximated with the following rel. simple and standardized material properties:

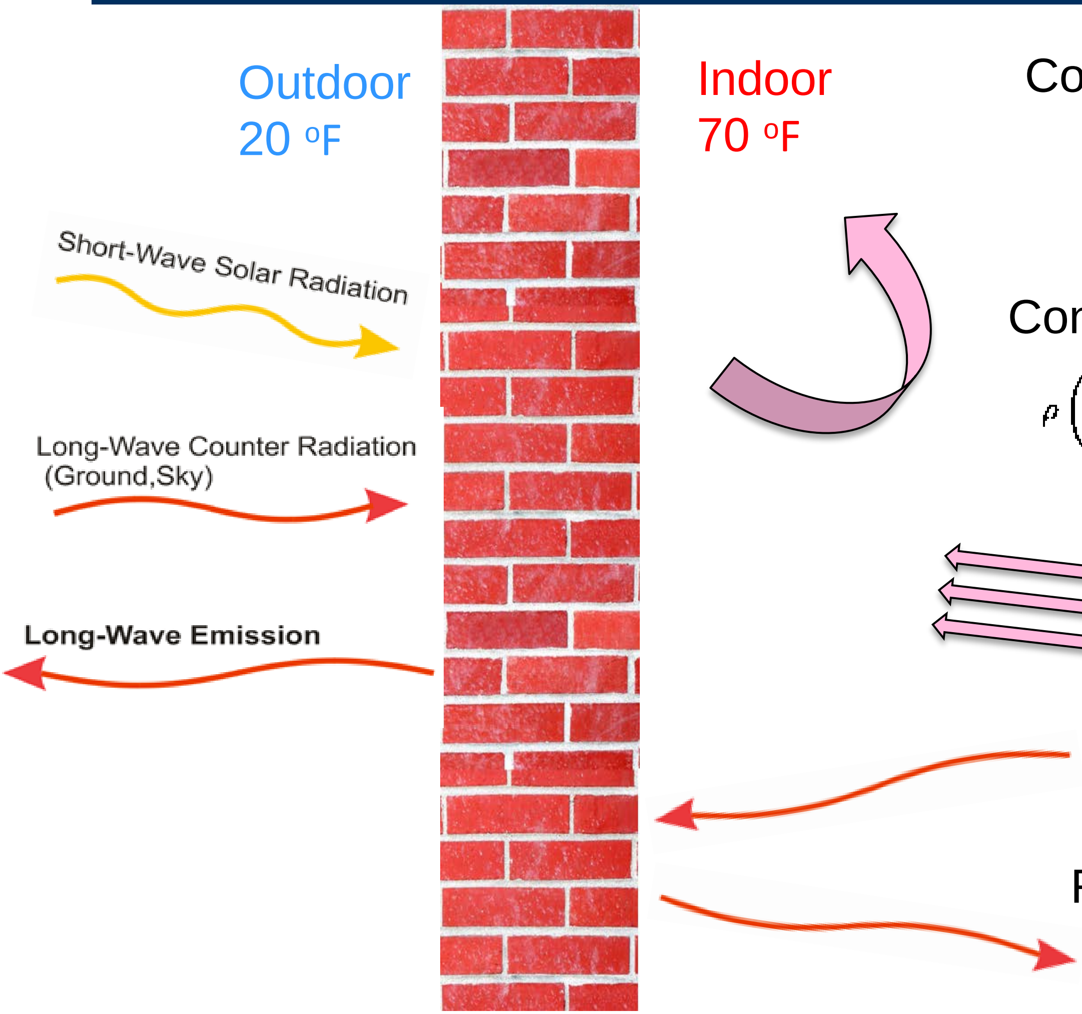
- **Density**
- **Porosity**
- **Spec. Heat Capacity** — **ASTM (Calorimeter)**
- **Thermal Conductivity** — **ASTM C518, C177**
- **Moisture Storage Function** — **ASTM C1498, C1699**
- **Water Vapor Permeability** — **ASTM E96**
- **Water Absorption Coefficient** — **ASTM C1794**

Model Validation, WUFI®





The Physics behind Thermal Simulation



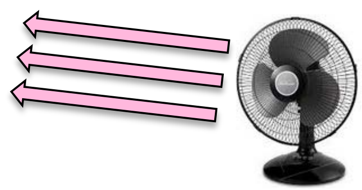
Conduction: Fourier's law

$$\rho c_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = \dot{q}_V$$

Convection: Navier-Stokes equations

$$\rho \left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) = -\nabla \bar{p} + \mu \nabla^2 \mathbf{u} + \tfrac{1}{3} \mu \nabla (\nabla \cdot \mathbf{u}) + \rho \mathbf{g}.$$

Natural Convection (Buoyancy)

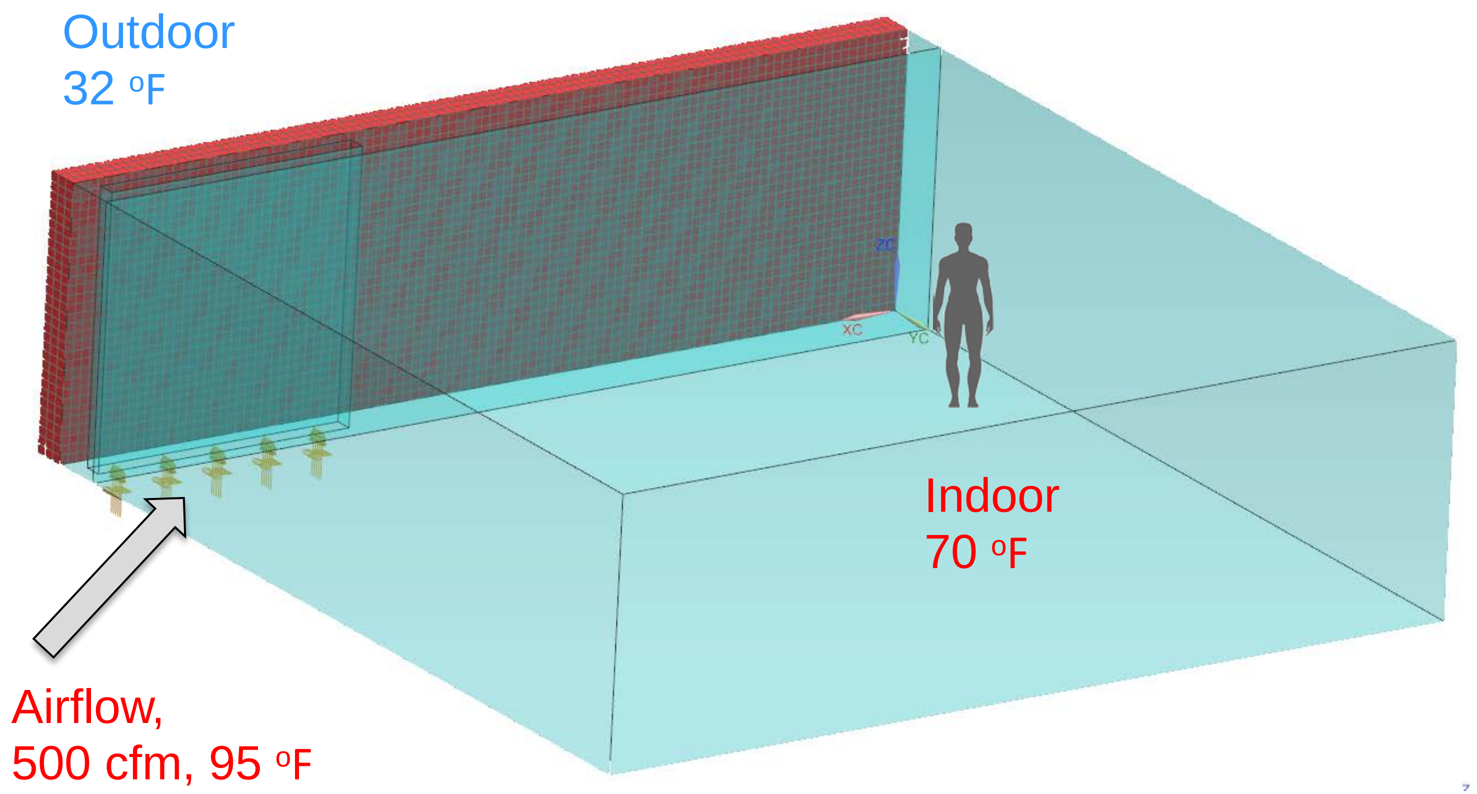


Forced Convection

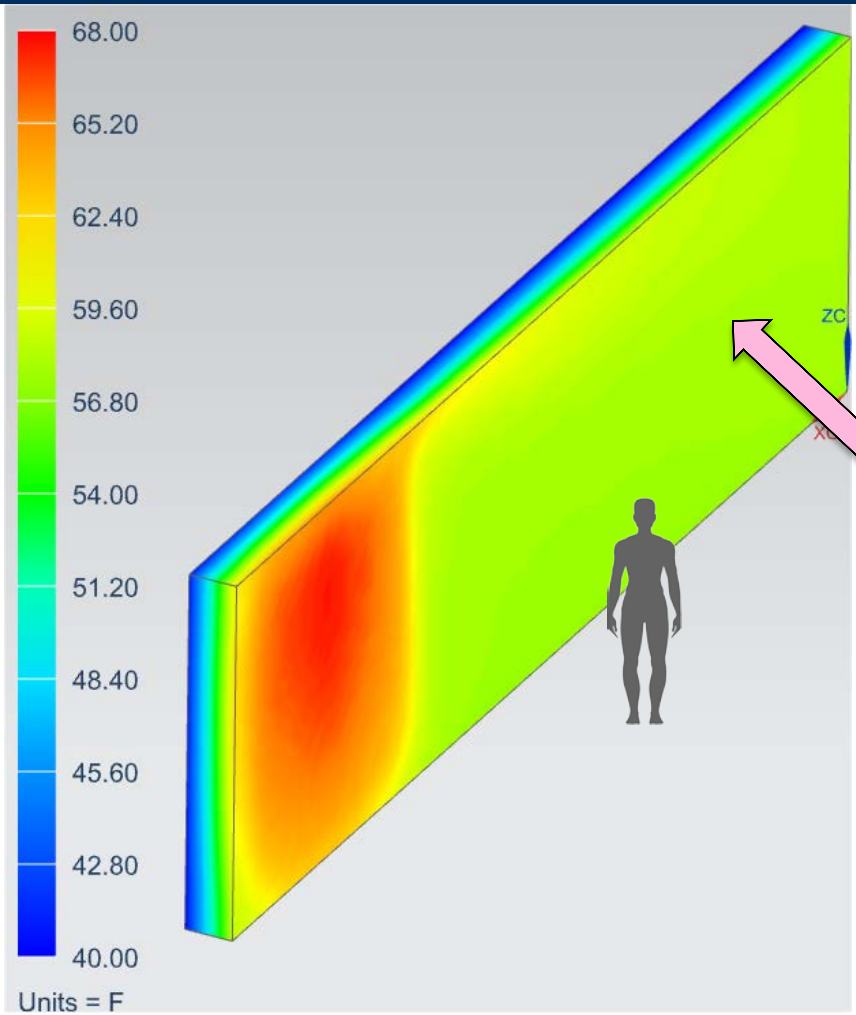
Radiation: Stefan Boltzmann law

$$j^{\star} = \varepsilon \sigma T^4.$$

Application for a Simple Room



Simple Room, Result, Wall Temperature



Steady-State

- **Plausibility Tests possible**
- **Hand Calculation**
- **Energy Conservation**

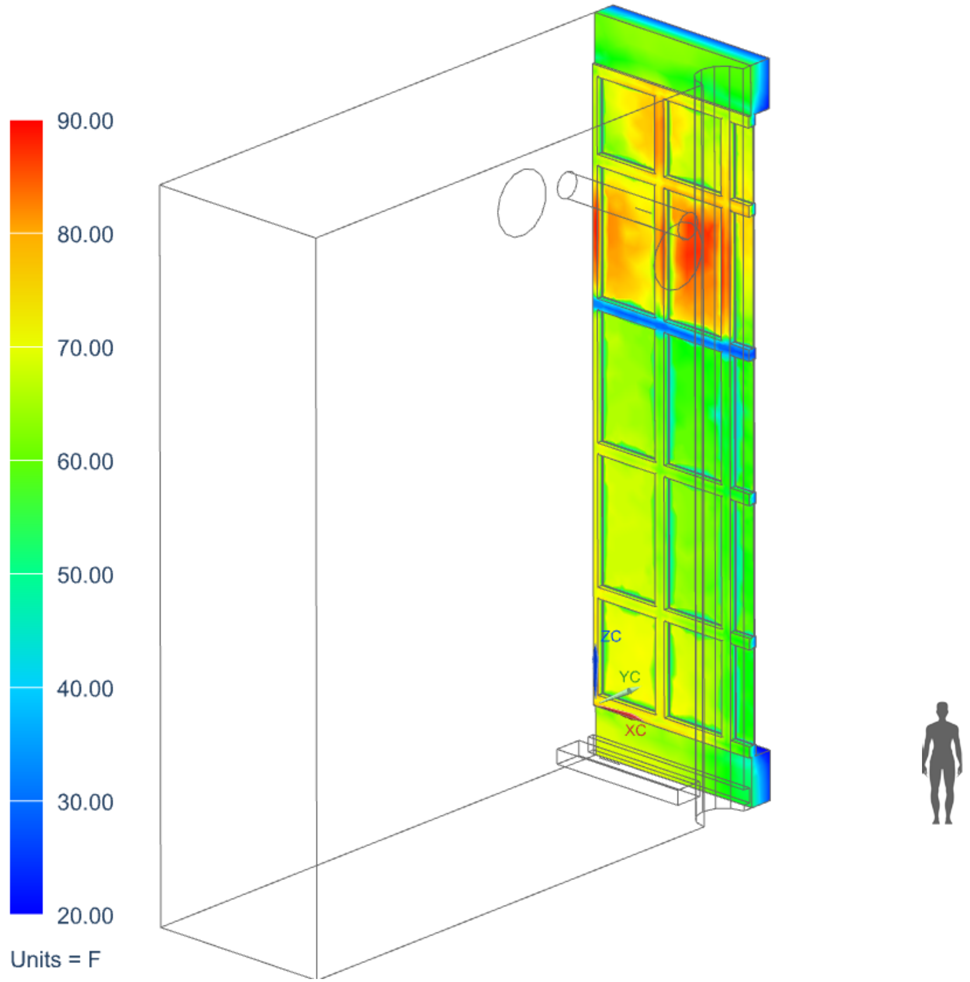
- **1D homogeneous Heat Flux**

Simple Room, Result, Air Flow

Natatorium

wn at the
from the
to avoid

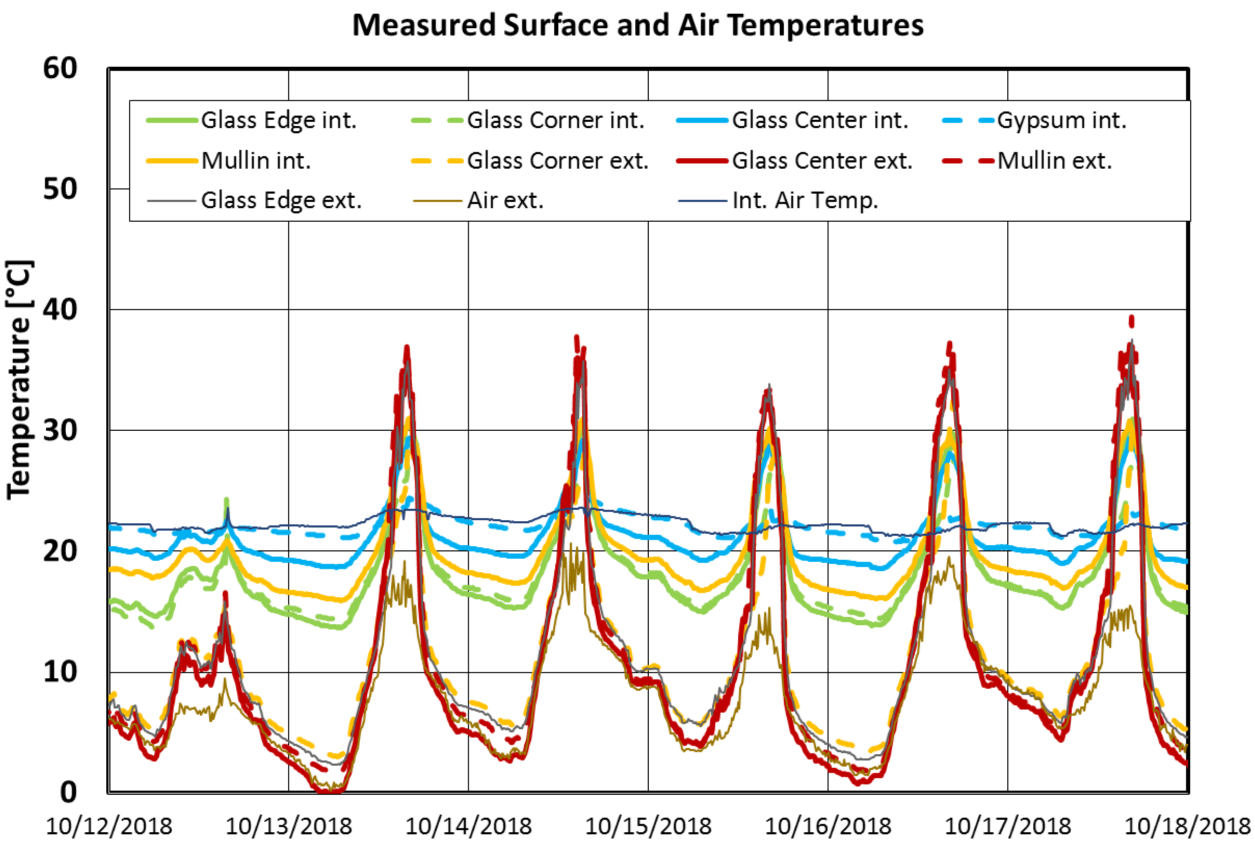
Natatorium



Validation of Thermal Simulation
WJE In-House Project

Validation of Thermal Simulation
WJE In-House Project

Validation of Thermal Simulation WJE In-House Project



- Solar Radiation Impact in the afternoon hours result in relatively high outside surface temperatures
- Early morning data look reasonable

Remaining Challenges

- Education
- Technical research
- Validation of analytical tools

This concludes The American Institute of Architects Continuing Education Systems Course

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