BUILDING SCIENCE
INSIGHTS
Physics to the Field™

The Science Behind Insulation Ignore It at Your Peril

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Building Science, Sustainability

BE-14

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Session Description

- If you think spec sheets tells you everything you need to know about the thermal performance of insulation, think again. You also need to know the science behind insulation. In this session two building science experts with a half-century combined experience review how insulation works (foam and fibrous) and explore how factors such as temperature, density and air infiltration impact thermal performance. You will come away with field-tested knowledge you can immediately apply to your projects.

Learning Objectives

- Identify the reasons for employing thermal insulation
- Understand its basic heat transfer principles
- Outline the heat transfer modes that take place in insulation and how they are relevant
- Understand how fiberglass is engineered to deliver outstanding insulation value
- The importance of insulation moisture performance.
- Understand the big impact of in-situ conditions to deliver insulation performance
- Expand understanding of Temperature dependency on insulation performance

PART A

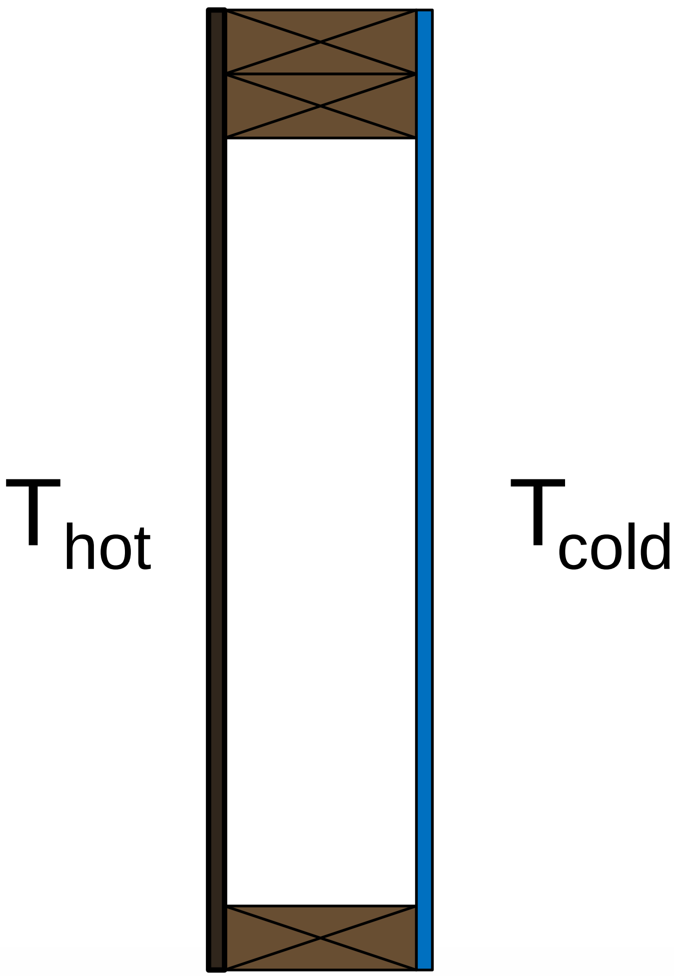
Basic Performance Attributes

Why Install Insulation in Buildings

Insulation

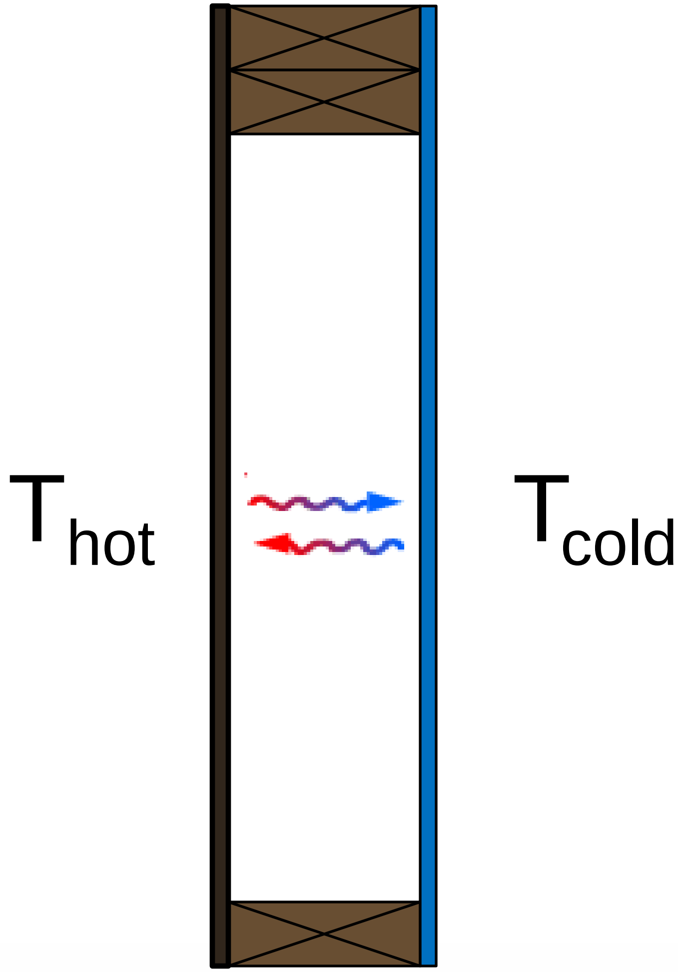
1. Provides comfort
2. Controls surface temperatures
3. Reduces energy use, operating costs, and pollution
4. Saves distribution & heating plant costs

Uninsulated Cavity



- To illustrate how insulation works, let’s first consider an uninsulated cavity in a building.
- Air is very transparent to infrared radiation
- A building cavity without insulation is not empty - air fills it and can move freely

Uninsulated Cavity: Radiation



Cavity walls have emissivity

Warmer surface emits more than colder surface

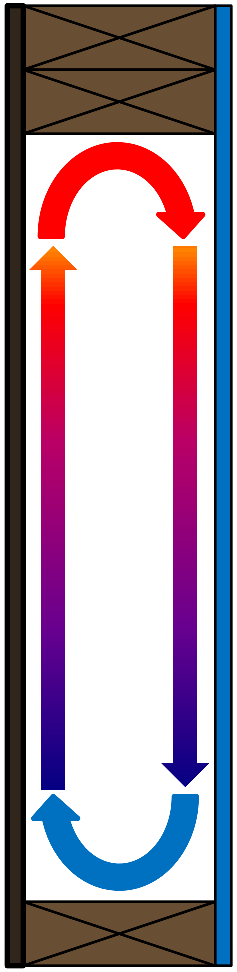
Thermal Radiation

Thermal Radiation

- The intensity of the thermal radiation exchange depends on the following properties of the surfaces
  - Temperatures
  - Emissivities

Uninsulated Cavity: Convection

T_{hot}



T_{cold}

Colder air is denser than warmer air

↓

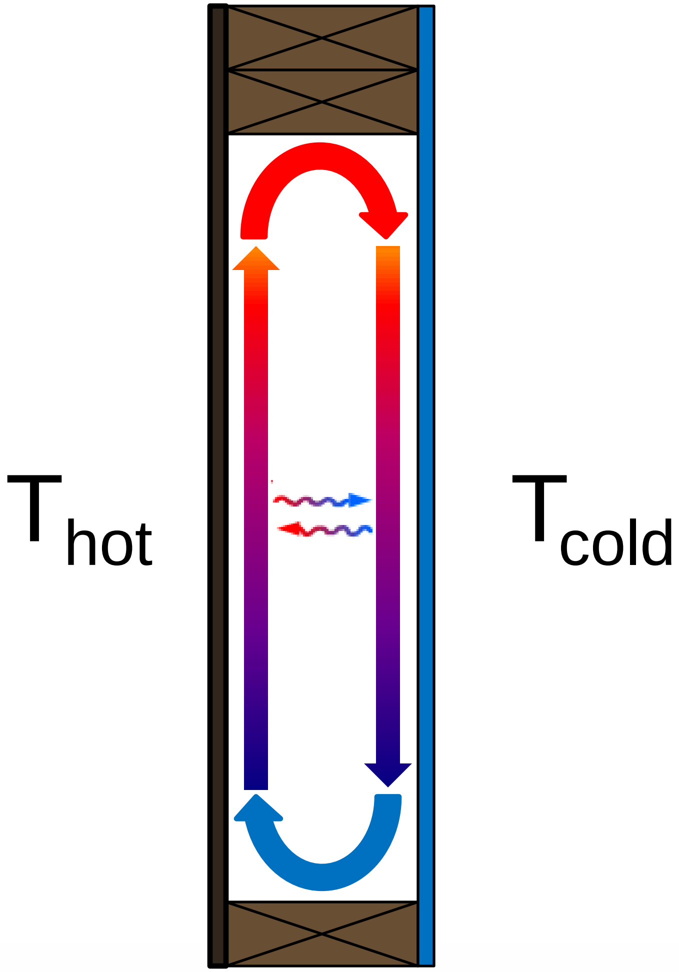
Recirculation

Natural convection

Natural Convection

- The intensity of the natural convection exchange depends on the following properties of the surfaces
  - Temperatures
  - Geometry
  - Cavity orientation

Uninsulated Cavity



- Radiation (~75%)
- Convection (~25%)
- Total ~ 190 W/m^2

Reflective Insulation Works

- Low emissivity materials, such as polished aluminum.
- By reducing the emissivity of the surfaces, thermal radiation exchange is significantly reduced.
- But it does not affect natural convection.

Add Fibrous Insulation

Fibers have two roles:

- Absorb and scatter thermal radiation; increase radiation extinction coefficient.

- Reduce the air permeability of the cavity; air encounters obstacles to move.

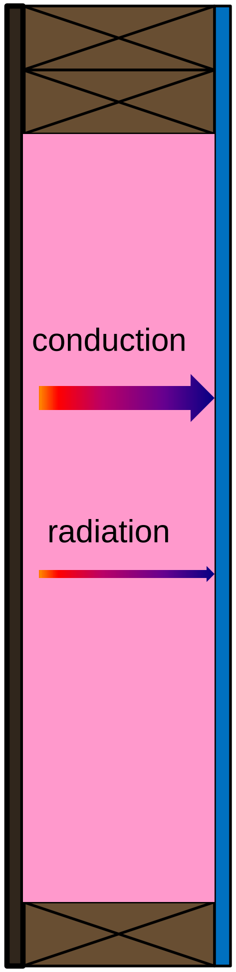
Add Fibrous Insulation

Fibers

- Absorb and scatter thermal radiation; increase radiation extinction coefficient.

- Reduce the air permeability of the cavity; air encounters obstacles so it does not move.

Insulated Cavity



T_{hot} T_{cold}

- Conduction (~75%)
- Radiation (~25%)
- Total ~ 7 W/m^2

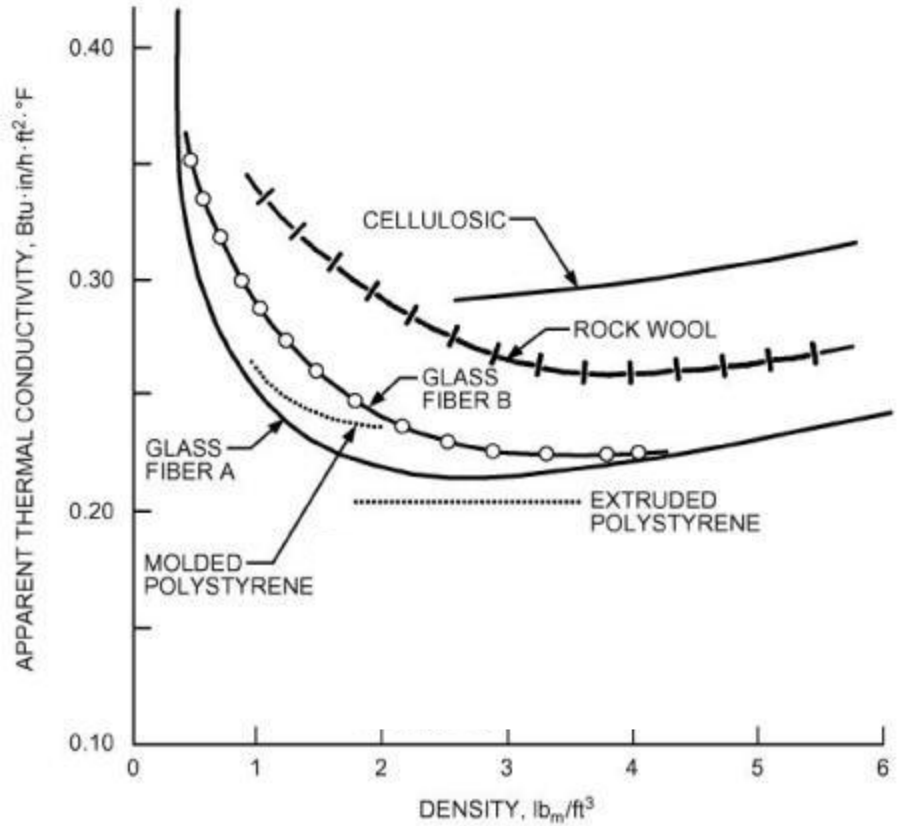
Heat flux is reduced by 96%

The Role of Density

- Glass is a better thermal conductor than air
- Why adding glass (increasing density) improves the thermal performance?
- An R-15 batt has a higher density than an R-13 batt.
  - It is the infrared radiation effect – more glass, more absorption and more scattering.
  - Yes, conduction through the glass increases, but much less than the decrease in radiation.

The Role of Density

Apparent Thermal Conductivity



Source: ASHRAE Handbook of Fundamentals

What Controls Radiation?

- Fiber diameter
- Glass chemistry
- Fiber orientation

By carefully engineering the fibers, we make the best insulation

What About Other Insulations?

- Cellulose = shredded newsprint
- SPF = manufactured in-situ
  - Temperature and humidity
  - Spray rigs
  - Installer

The Role of Temperature

- The higher the temperature, the higher is the infrared radiation exchange through the insulation.
- Additionally, air conduction is also higher at higher temperatures.
- Thus, one should expect a lower thermal resistance at higher temperatures and a higher thermal resistance at lower temperatures.
- This is also true for foams.

What about the R-value?

- It is a way to compare different insulation products
- It is determined for a given thickness, temperature difference, and mean temperature
- It is a configuration property
- No air infiltration

What is R-value?

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

- Determined experimentally by applying a temperature difference across a sample and measuring the heat flux
- All of the heat transfer modes that take place are included

What about Foams?

- The cell walls increase the extinction coefficient of the cavity and eliminate natural convection
- Closed-cell foams can have an **initial** apparent thermal conductivity lower than that of air
  - Pick a blowing agent that has a low thermal conductivity
  - Thermal conductivity of some gases:

Gas	Thermal conductivity (W/m.K)	Boiling point (°C)
Air	0.0259	-195
Carbon dioxide	0.0162	-56.6
Cyclopentane	0.0130	49.2
n-pentane	0.0120	36
HCFC-141b	0.0100	32.1

Conclusions

- There are many reasons for insulating a building
- Heat transfer in uninsulated wall cavities is dominated by infrared radiation and natural convection
- In insulated walls, air conduction and infrared radiation remain relevant, but the overall heat flux is much smaller
- Fiberglass (and foam) insulation is designed and manufactured to deliver a great insulation product

What is Building Science ?

Building Science uses the fundamental laws of physics to understand the response of a component or whole building to exterior or interior conditions.

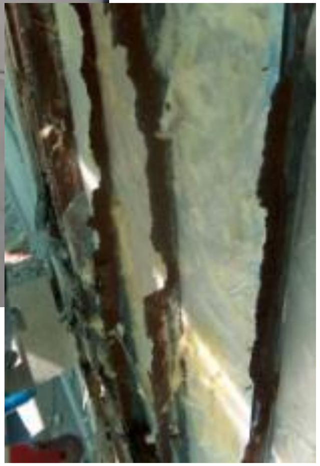
Building **S**cience is an element of **S**ustainability that deals with:

- **E**nergy Flows
- **W**ater Flows
- **A**ir Flows
- **A**coustics
- **F**ire

System Design Process

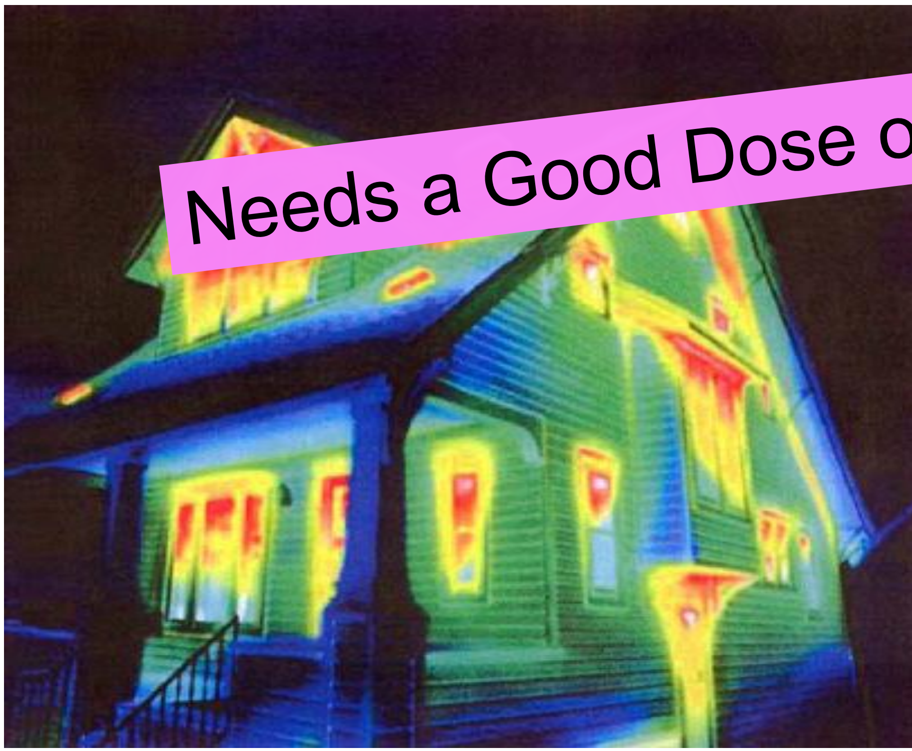
1) One needs to design the **system** first.
2) To design the system for proper performance, one needs to understand the LOADS
3) If one underestimates the loads, also material can fail
4) System failed.
   Design Inadequate

Moisture Damage



Thermal Damage

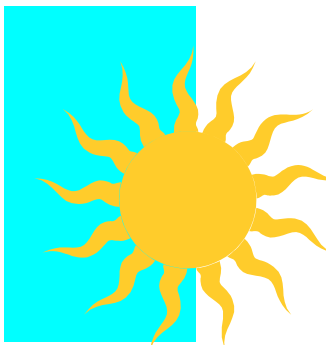
What if it looks like this at night?

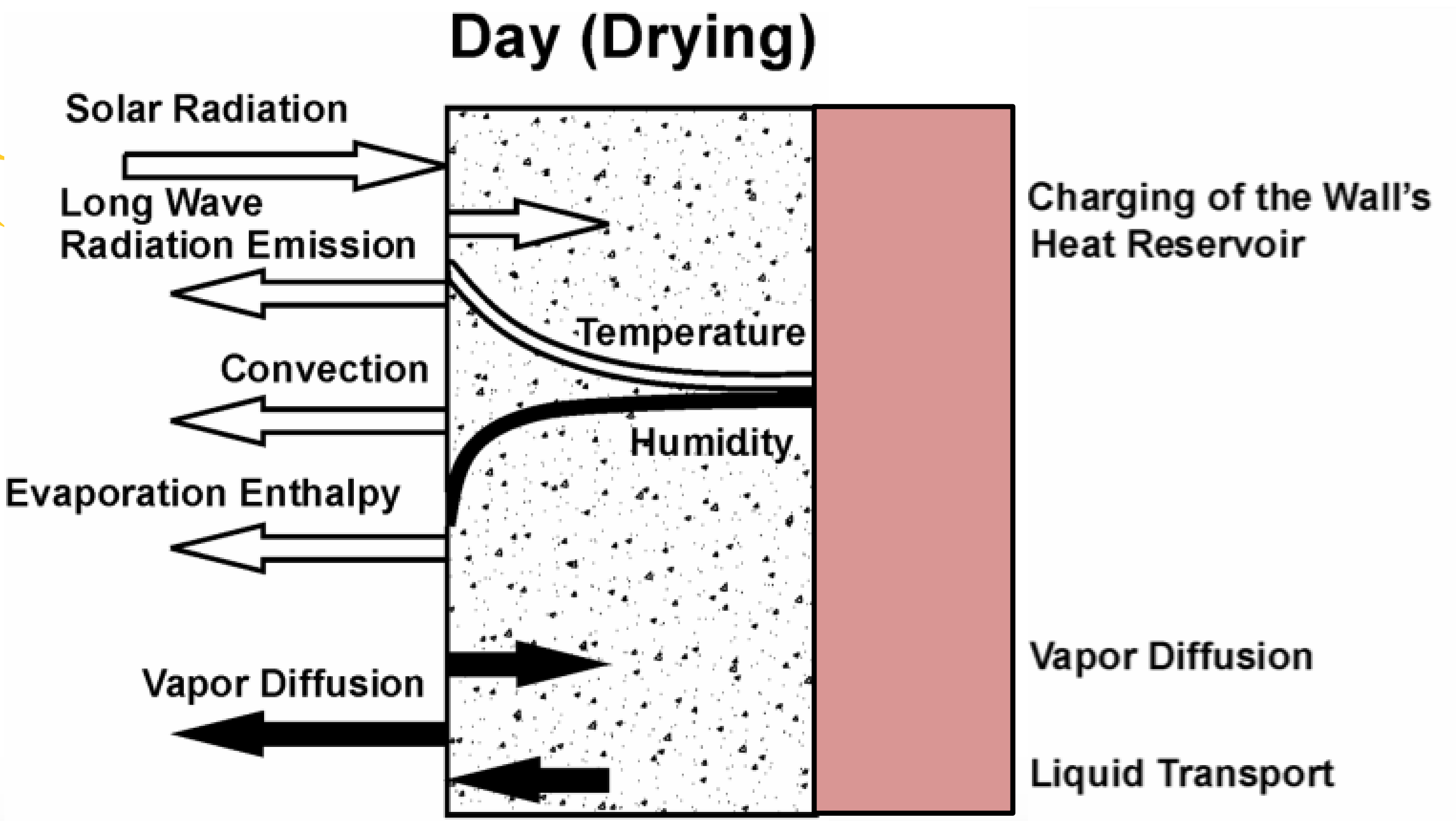


Needs a Good Dose of Building Science

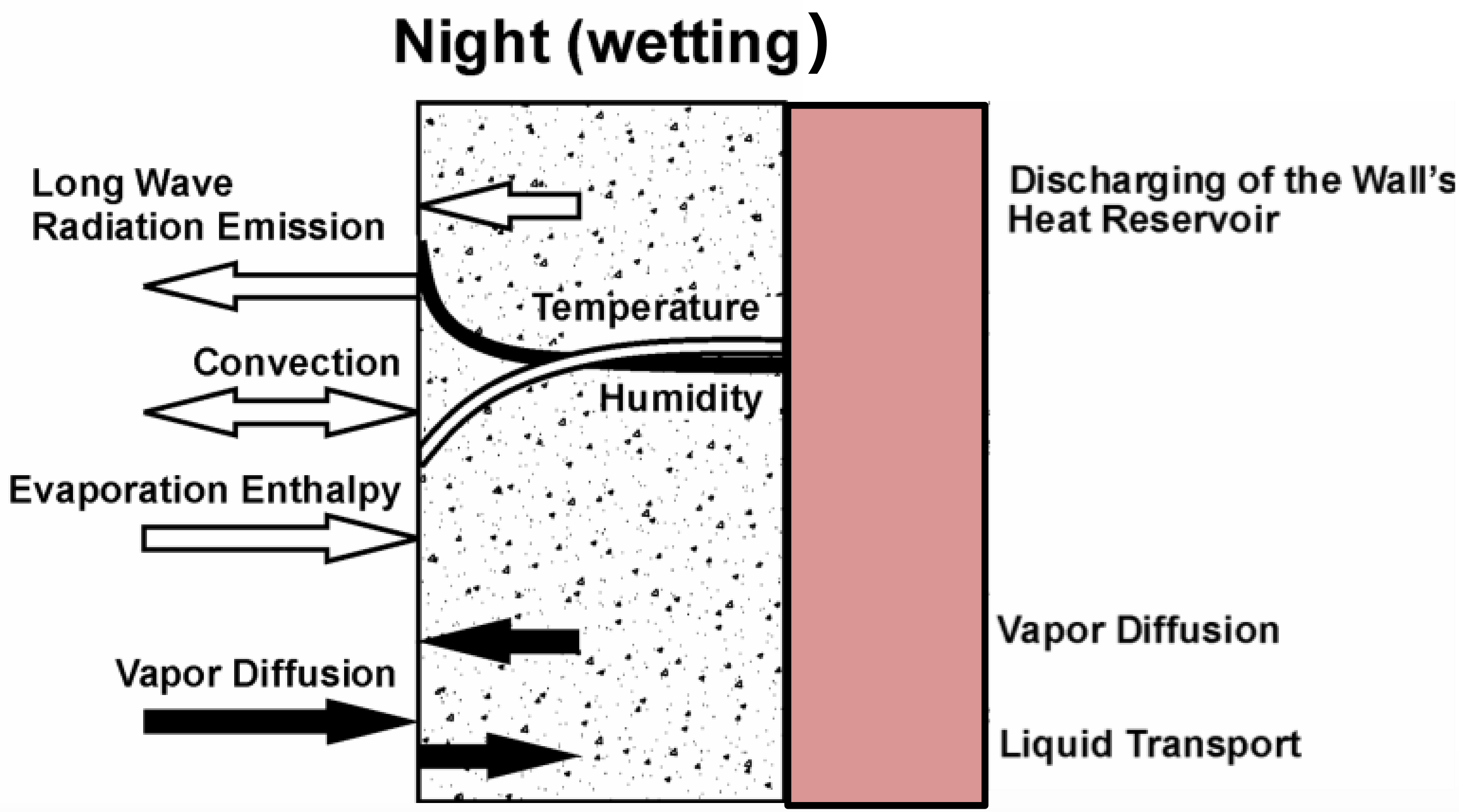
Infrared Thermography

Day Time




Day (Drying)
Solar Radiation
Long Wave
Radiation Emission
Convection
Evaporation Enthalpy
Vapor Diffusion
Temperature
Humidity
Charging of the Wall's
Heat Reservoir
Vapor Diffusion
Liquid Transport

Night Time


Night (wetting)
Long Wave
Radiation Emission
Convection
Evaporation Enthalpy
Vapor Diffusion
Temperature
Humidity
Discharging of the Wall's
Heat Reservoir
Vapor Diffusion
Liquid Transport

Models

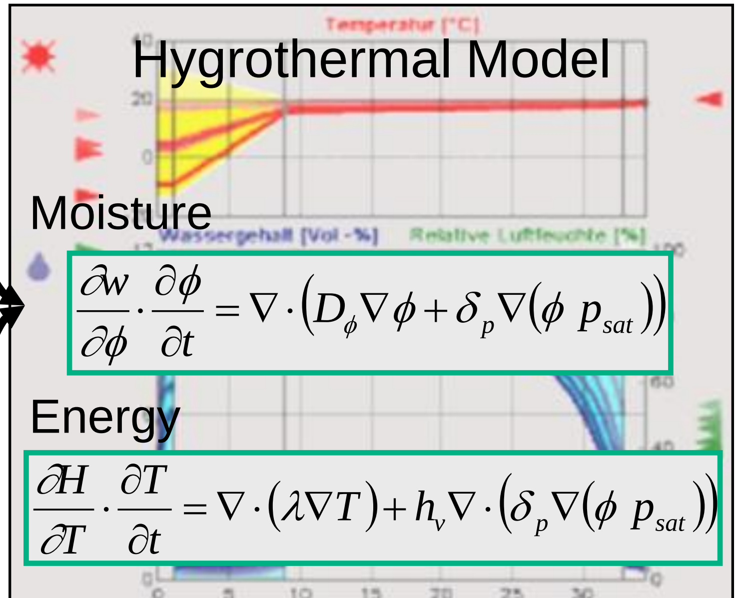
Construction

Material properties

Climate

Boundary conditions

Hygrothermal Model



Moisture

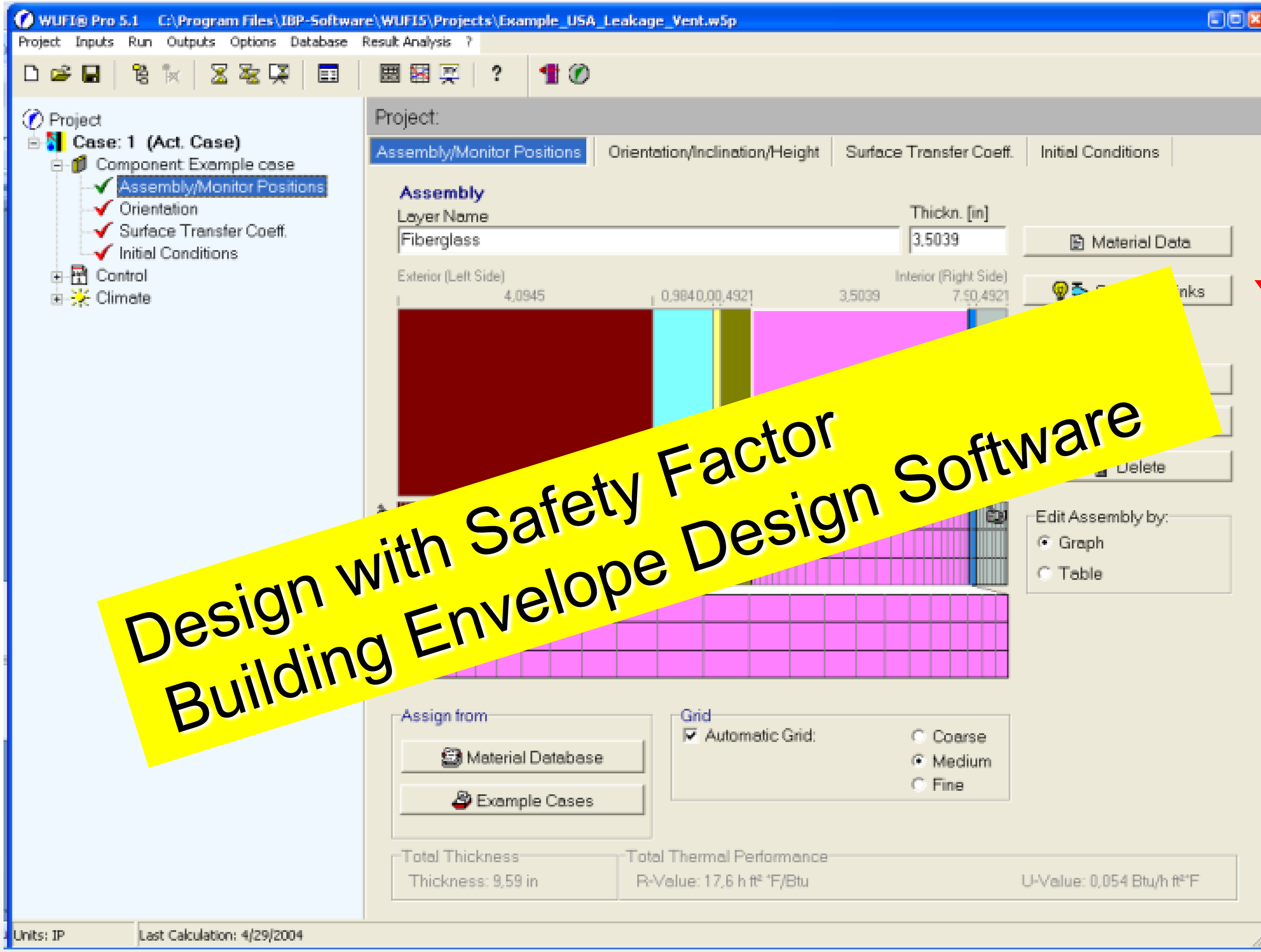
$$\frac{\partial w}{\partial \phi}\cdot\frac{\partial \phi}{\partial t}=\nabla\cdot\left(D_\phi \nabla \phi+\delta_p \nabla\left(\phi\, p_{sat}\right)\right)$$

Energy

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

Temperature Field
Moisture Field
Heat Fluxes
Moisture Fluxes

Hygrothermal Tool: WUFI-ORNL



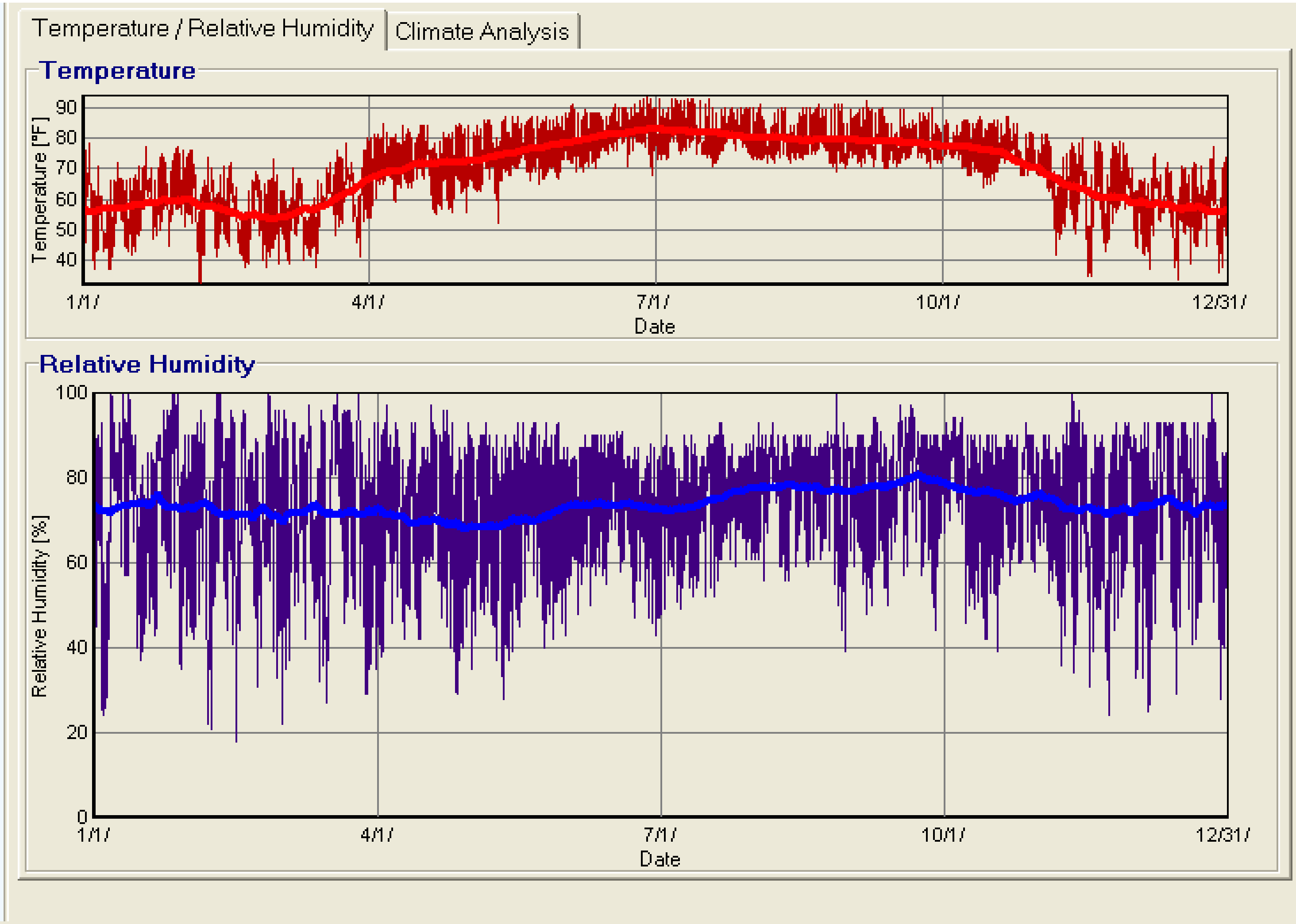
Industry Standard

Sources
Sinks
Ventilation

OC part of development Team

Location: Tampa Florida

Exterior Climate



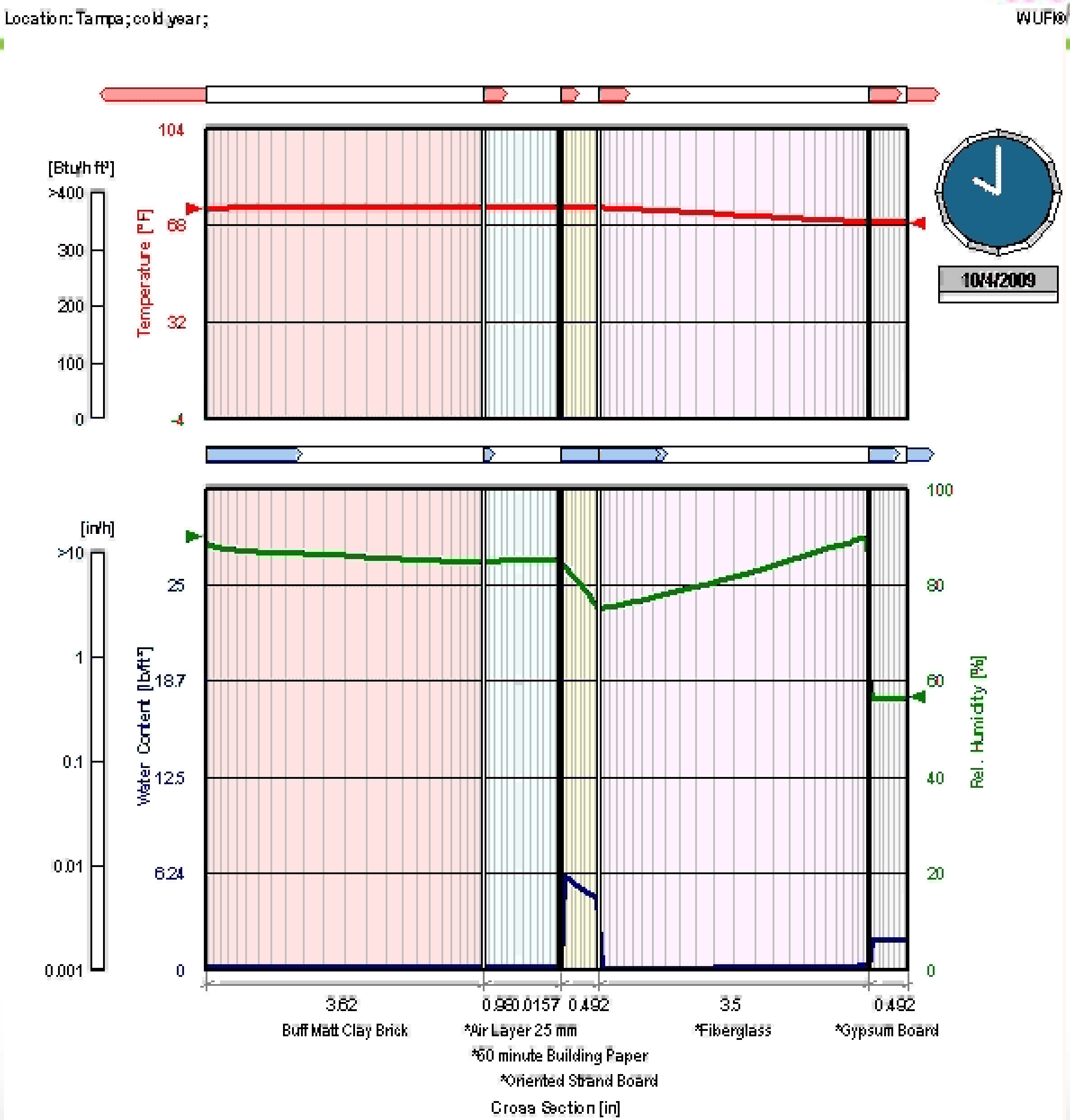
Climatically Tuned Analysis.

Each hour:

T,
RH,
U_wind,
U_orient,
Cloud Index
Rain,
Solar.

Combined heat and moisture

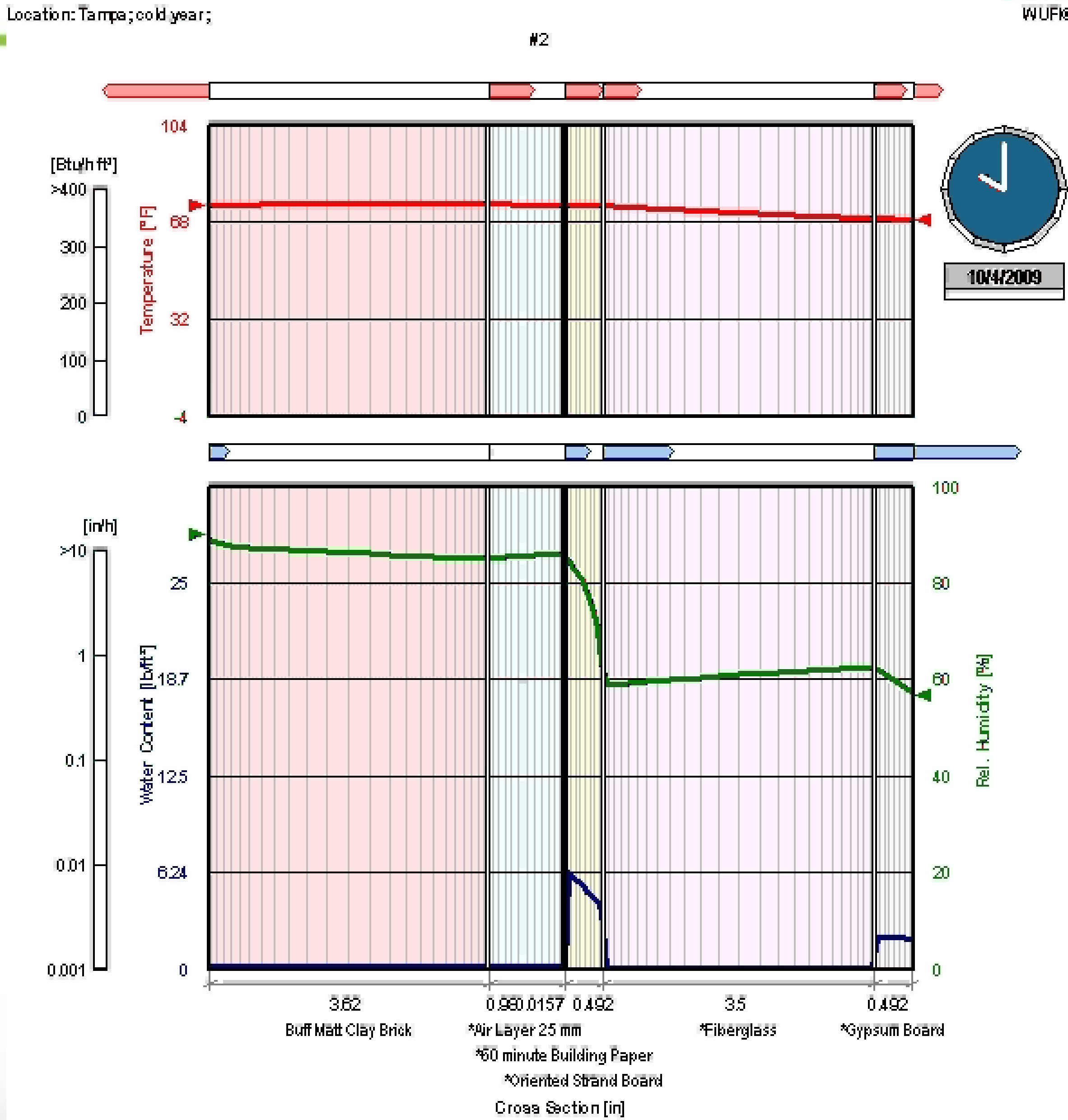
Climate:
Tampa



With an interior vapor retarder

Combined heat and moisture

Climate:
Tampa



Without an interior vapor retarder

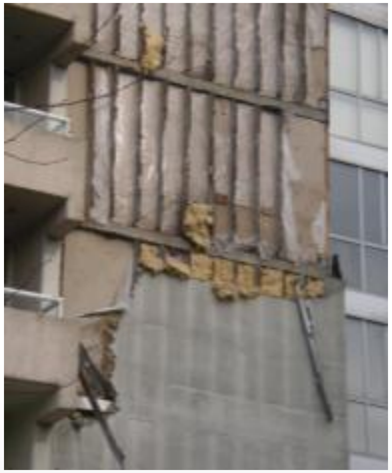
2x6 Steel Stud Wall in Boston

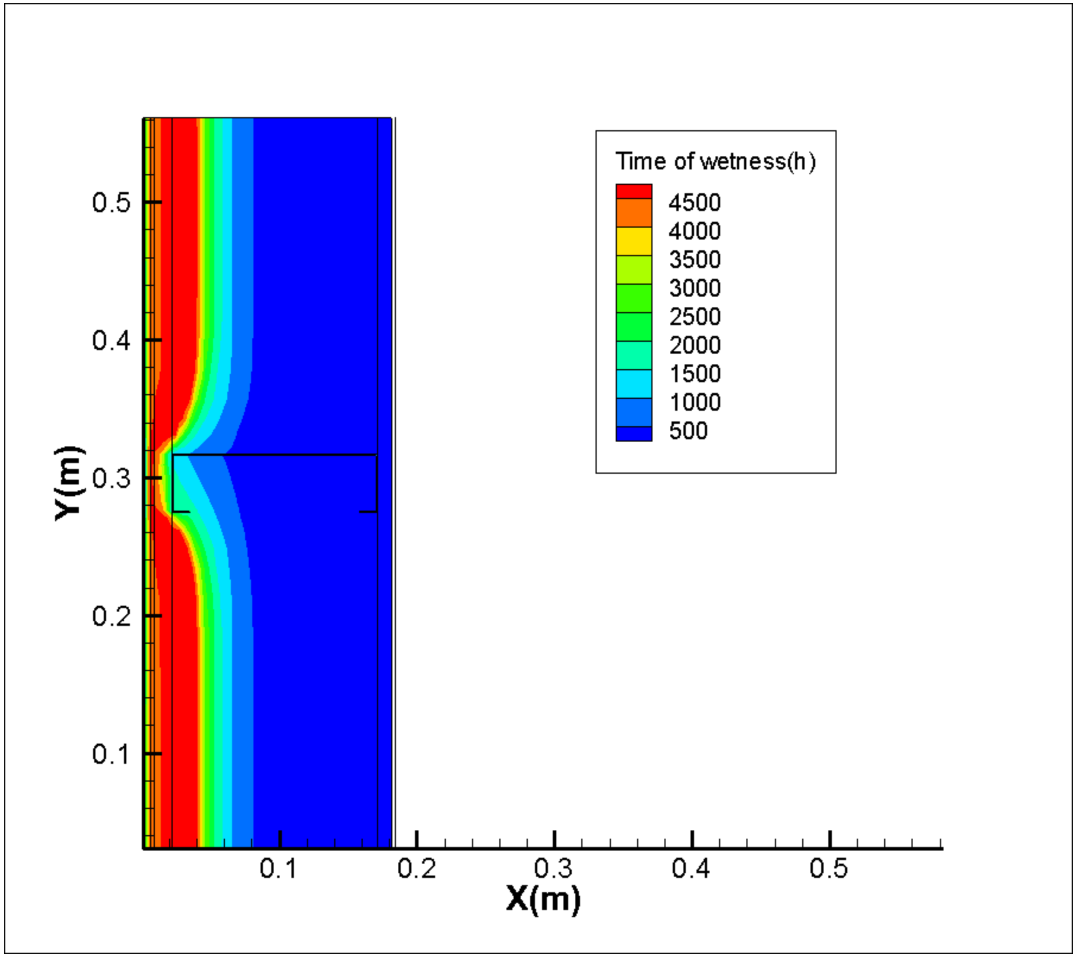
0", 1" and 2" of XPS

Standard steel stud & Thermally broken stud

TOW: Siding without venting

- Water intrusion 1% behind siding
- TOW class for the edge of steel: T4 (2500-5500)





research report

Development of Cost-Effective, Energy Efficient Steel Framing: Thermal Performance of Slit-Web Steel Wall Studs

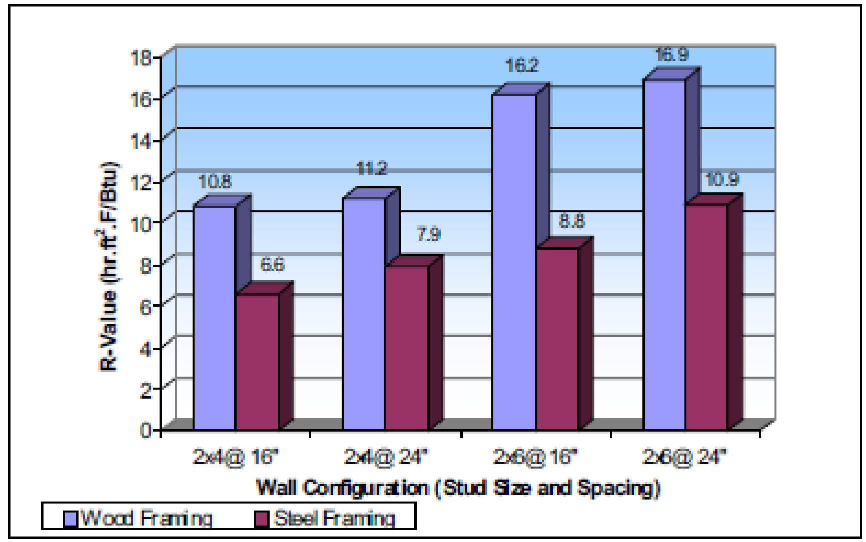
RESEARCH REPORT RP02-9

2002
REVISION 2006

American Iron and Steel Institute

Steel Framing Alliance

ORNL Kosny



Slit web studs 17 % better than solid web studs

Overall wall R-10.4 using R-13 Fiberglass (R_{org} -8.9)

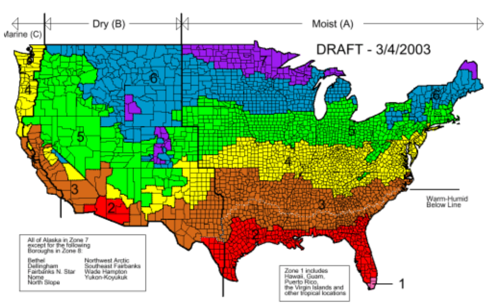
Even better performance:

Slit web studs with angles for top tracks (R-11.4)

Better performance achieved with **Exterior Foam**

Corrosion

- Understanding the conditions inside the wall adjacent to the steel stud we can estimate corrosion rates… with some additional information about the environment
- According to **ISO 9223**, It is possible to deduce the corrosivity of an environment by combining TOW categories with the chloride and sulfur dioxide categories



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Corrosion rate

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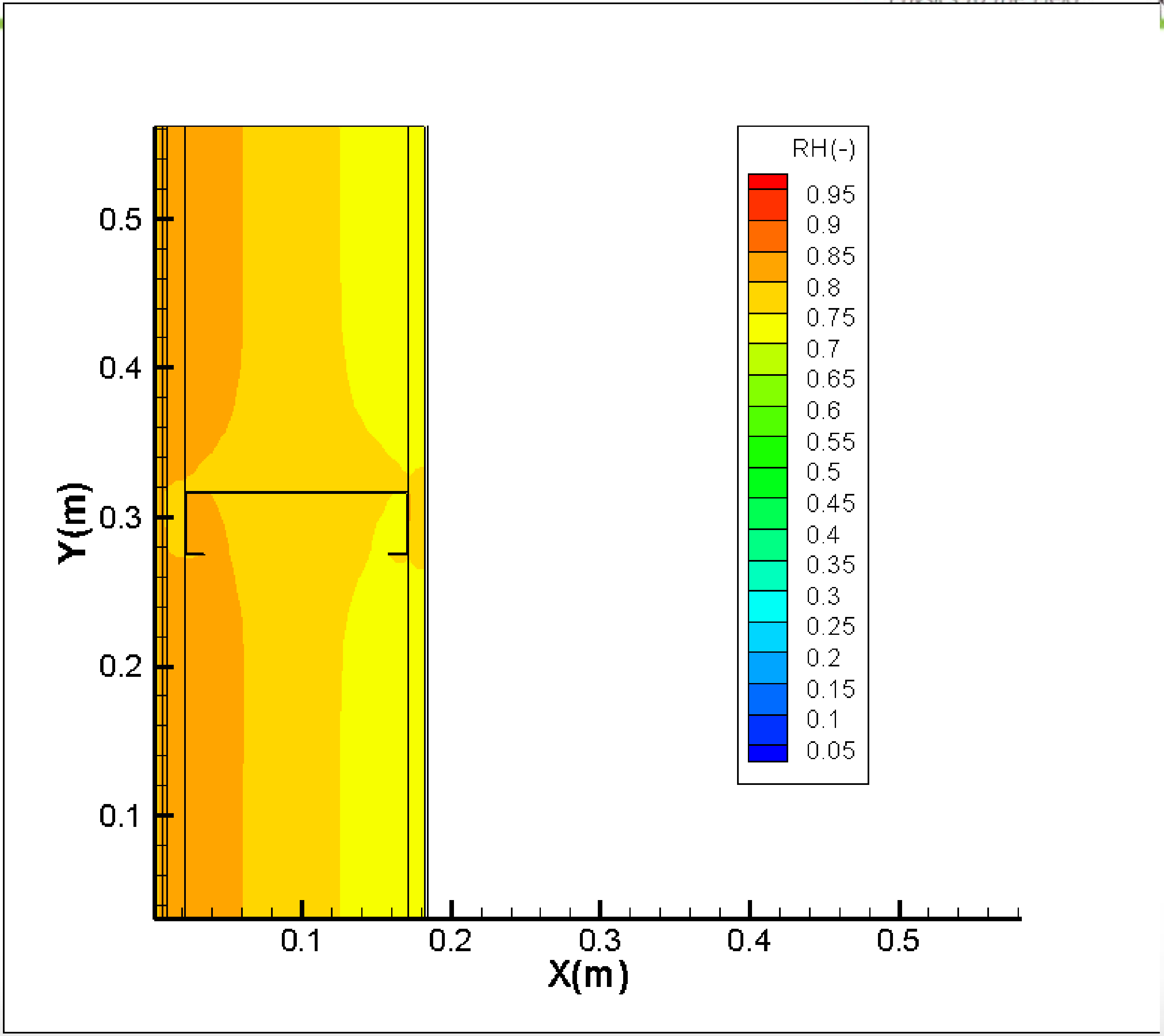
Converting these corrosivity ratings into short term corrosion rates (***g m***$^{-2}$ ***year***$^{-1}$) according to the following table:

Category	Steel	Copper	Aluminum	Zinc
C_1	CR <= 10	CR <= 0.9	negligible	CR <= 0.7
C_2	10 < CR <= 200	0.9 < CR <= 5	CR <= 0.6	0.7 < CR <= 5
C_3	200 < CR <= 400	5 < CR <= 12	0.6 < CR <= 2	5 < CR <= 15
C_4	400 < CR <= 650	12 < CR <= 25	2 < CR <= 5	15 < CR <= 30
C_5	650 < CR	25 < CR	5 < CR	30 < CR

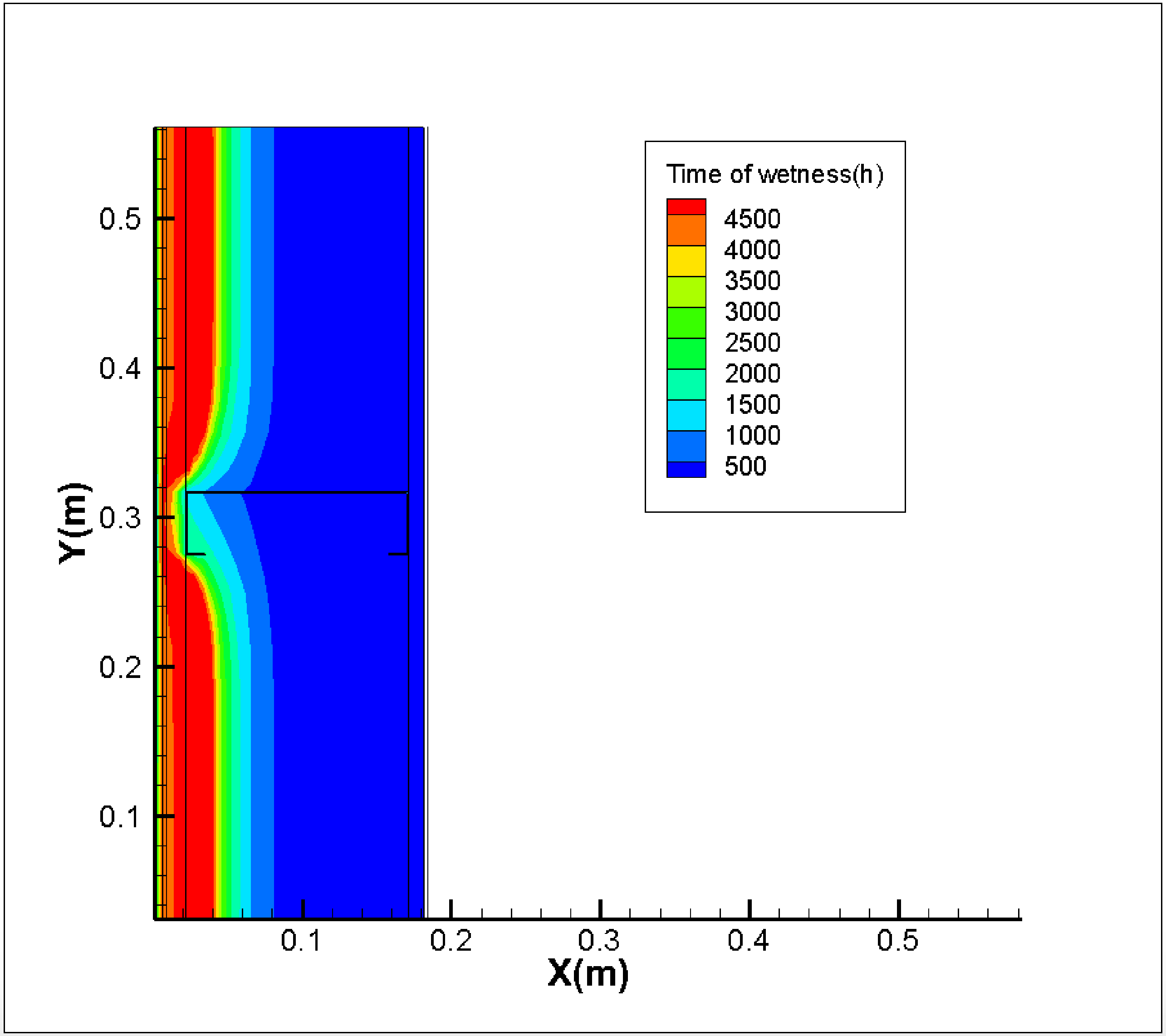
Corrosion rate and coating thickness

- At class C4 the corrosion rate is high resulting in 3-7 for zinc coatings.
  - The speed of corrosion of steel is
    - 400 to 650 g/m^2/year - Class C4
  - This would mean that a 16 gauge steel frame might corrode through in 10- 16 years (C4).

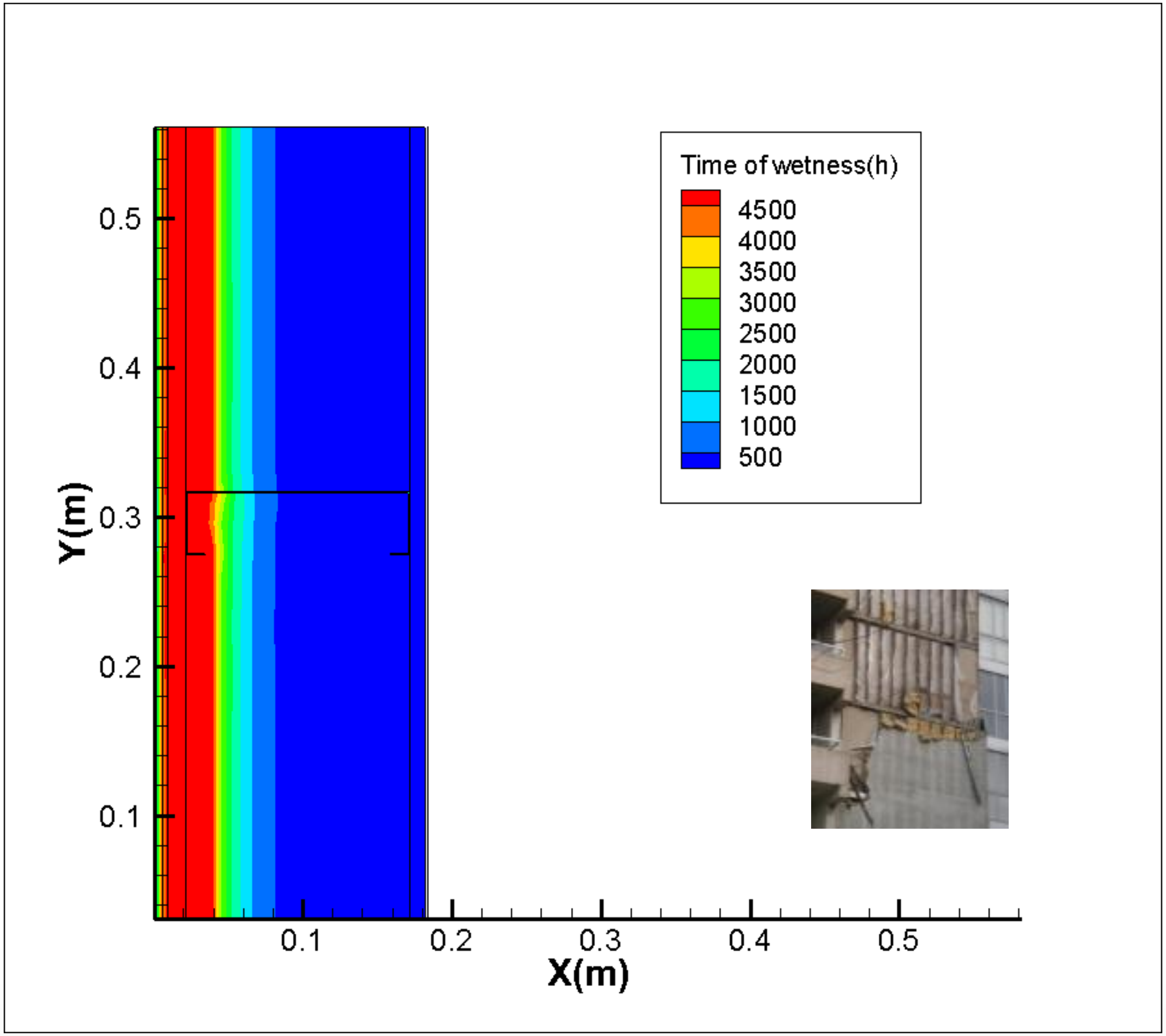
Boston Animations (Reg. Steel Studs)



Standard steel stud (No XPS)

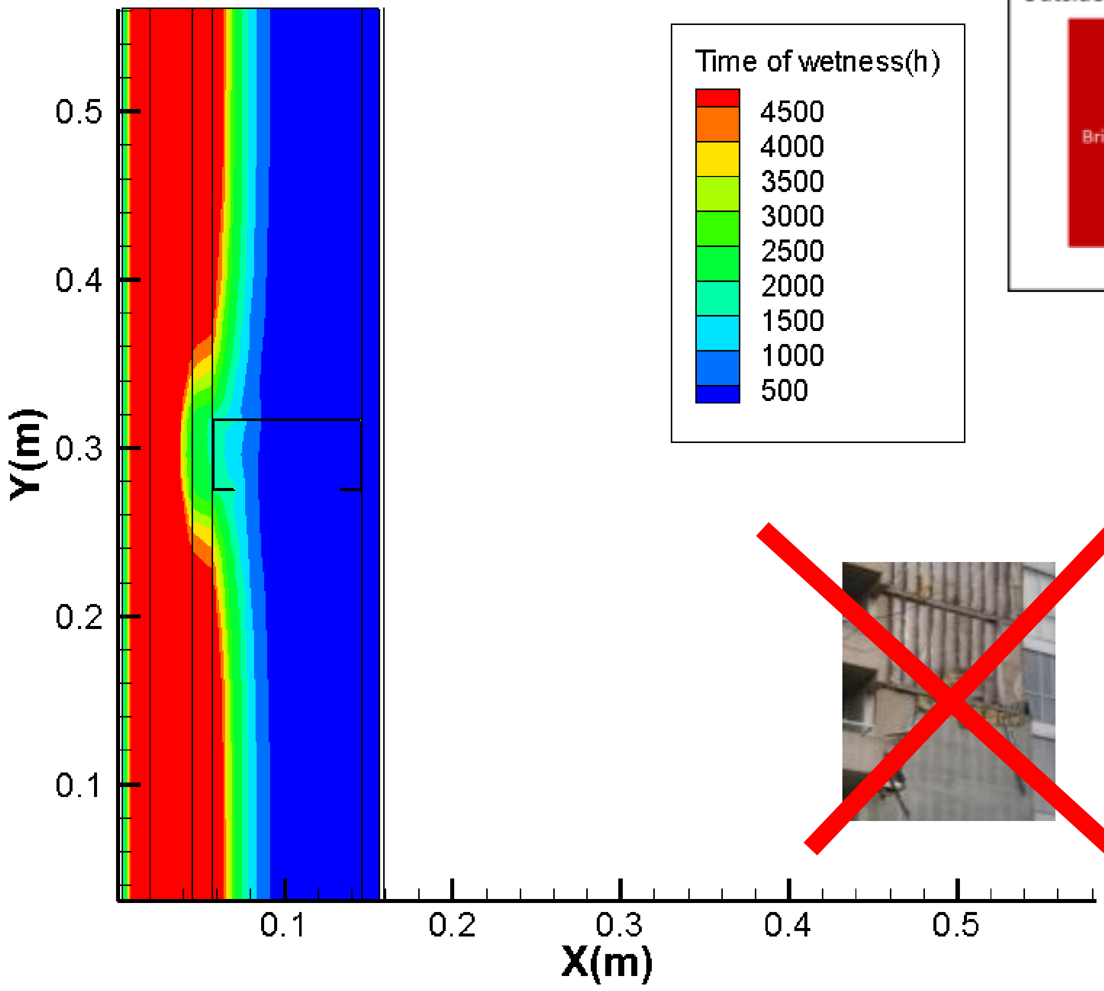


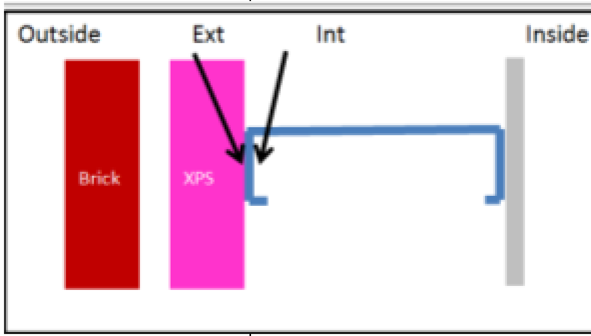
Thermally broken steel stud – no XPS



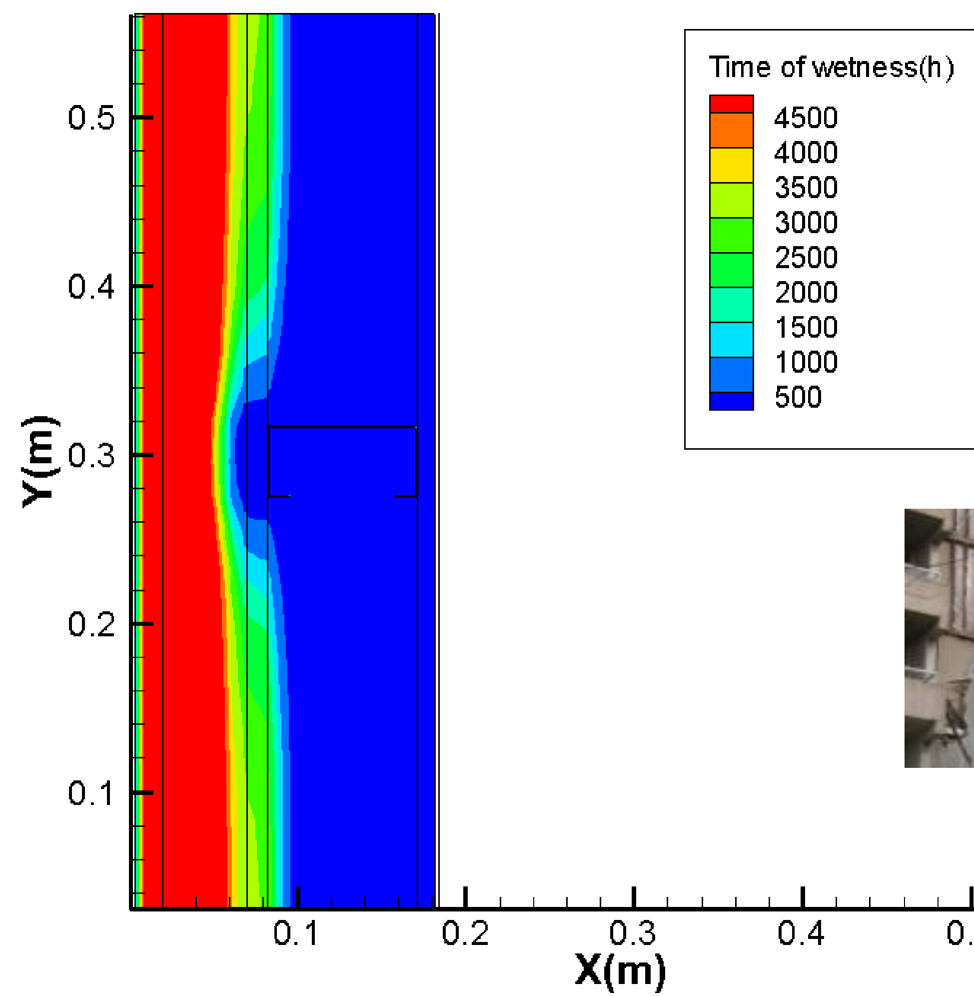
Slotted web to reduce thermal bridging – Thermally equal to wood stud

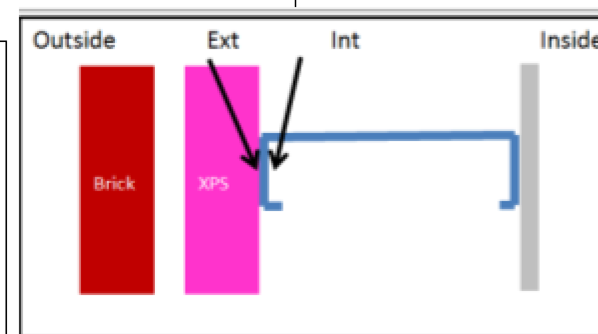
Thermally broken steel stud – 1" XPS

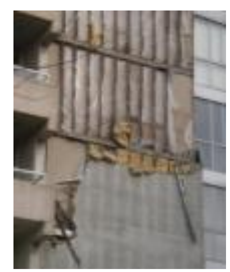




Thermally broken steel stud – 2” XPS







What is different !!

- XPS Exterior Foam Insulation helps solve moisture problems
- Insulation becomes the solution not the problem.
- **Do not overload the functions of insulation… allow bi-directional drying…**
- **New concepts needed to be vetted out with Building Science.**
- **XPS** and Fiberglass insulation+air sealing system are a great combination of products that can maximize Durability

Application # 2: Understanding The Thermal Choices in Insulation Materials

Use of Dynamic Modeling

Will not address ageing ! or Long Term Thermal Resistance (LTTR)

Why its important to Question everything ?

- R-Value/in of Polyiso is 6.0 to 6.5
- R-Value/in of   XPS is 5

Conclusion

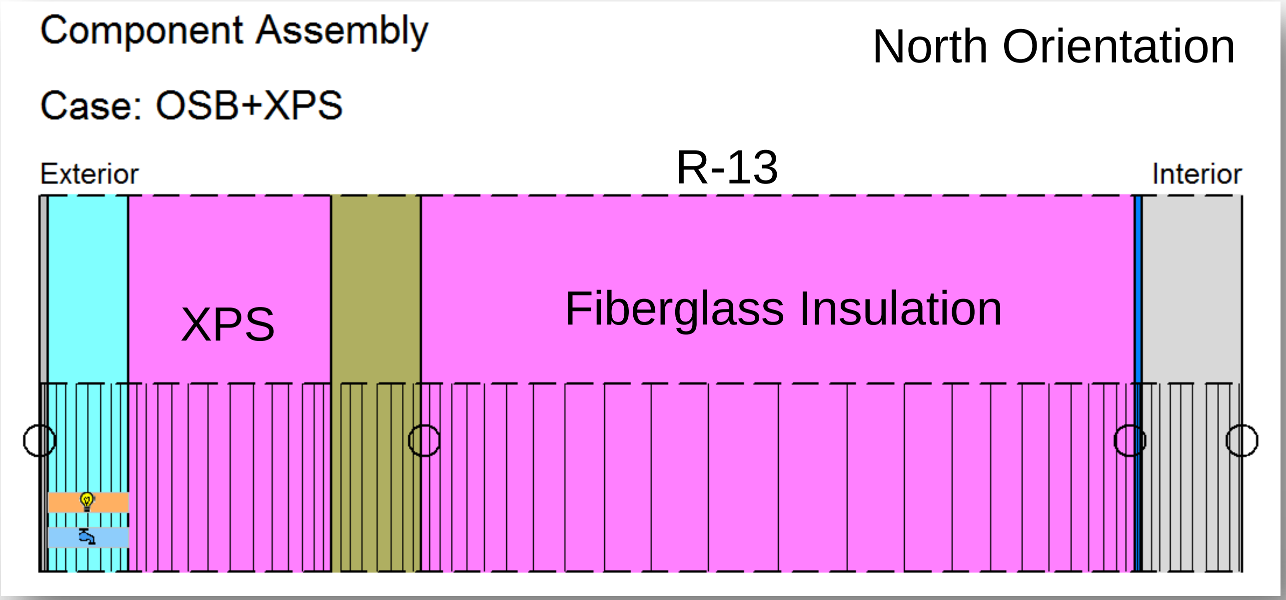
Use Polyisocyanurate
(20 to 30 % Better Performance)

Is this true ?

Wall Heat Loss

- **WUFI** Hygrothermal Calculations: 2x4 + 1” foam
  - XPS versus Polyisocyanurate insulation
  - Heat loss through a wall in Chicago

XPS = 5/in
PISO= 6/in



Heat Flows with ASHRAE 2 years

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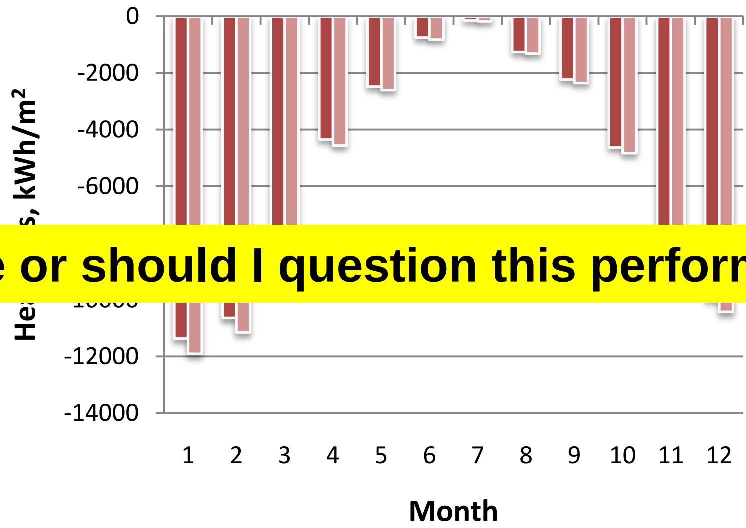
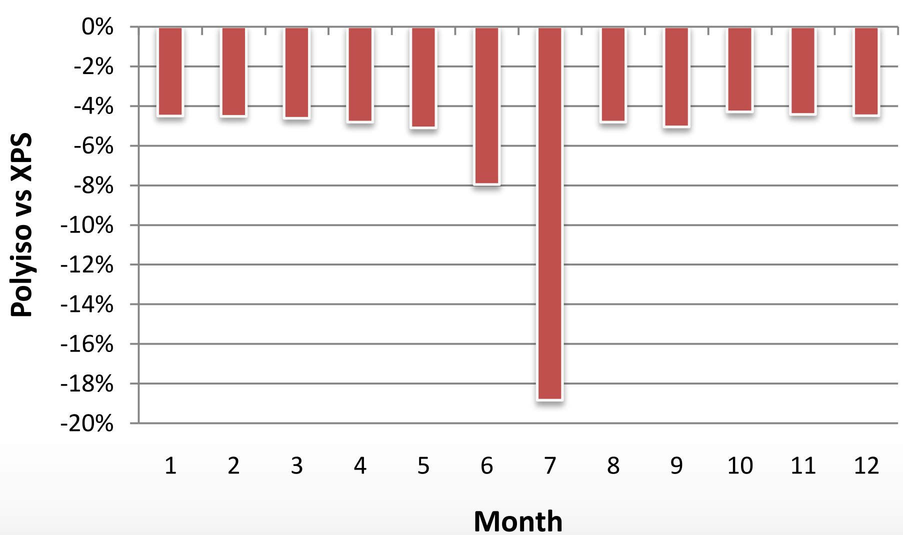
Vinyl Cladding

Chicago



Is this true or should I question this performance issue ?



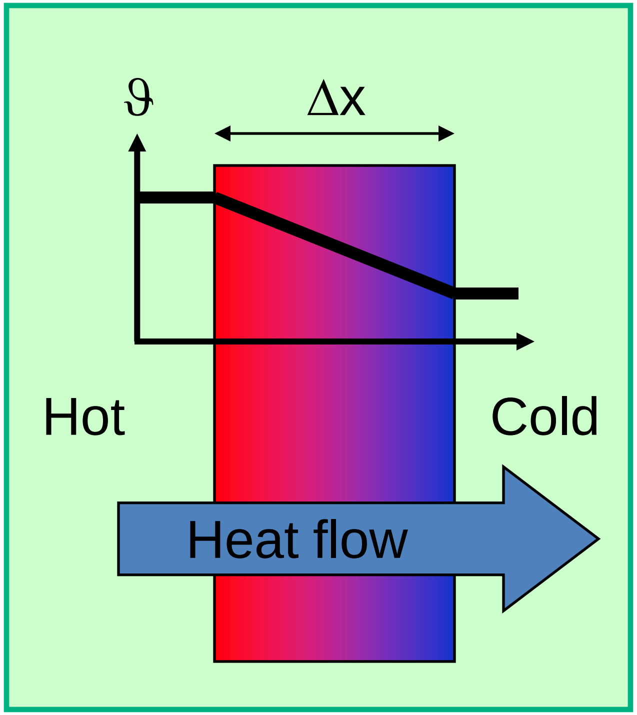
4.5 % better Performance For PSIO

Basic Properties

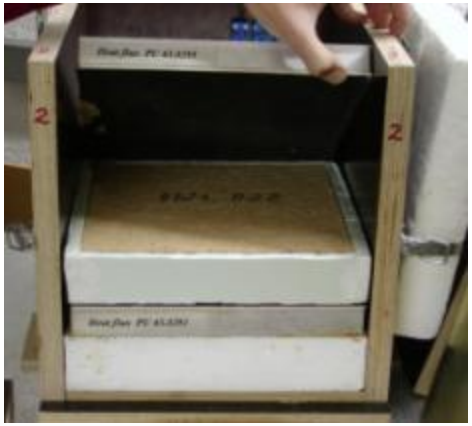
<u>Heat Conductivity</u>

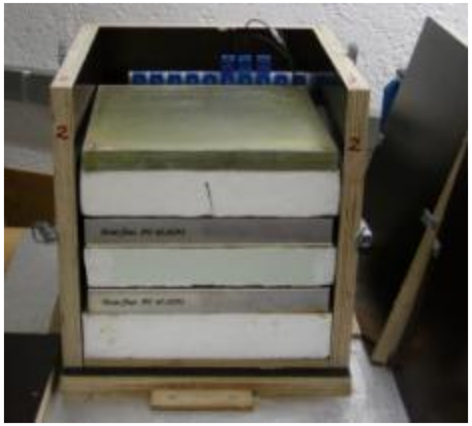
ASTM C-518

$$\lambda = -q \cdot \frac{\Delta x}{\Delta T} \quad \left[\frac{W}{mK} \right]$$



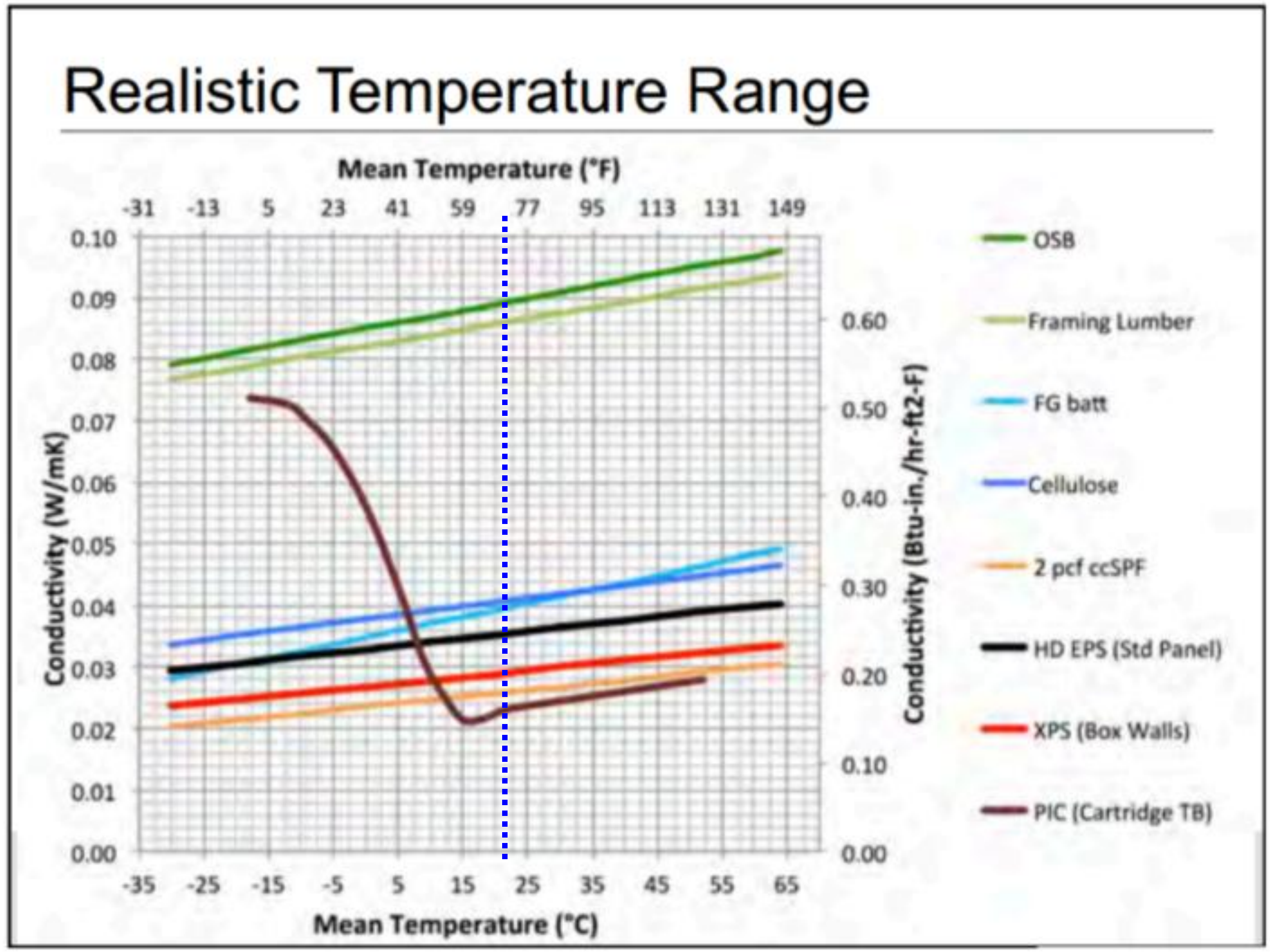
Measurement technique:
Guarded hot plate





Building Science Corp Data

ASTM C-518



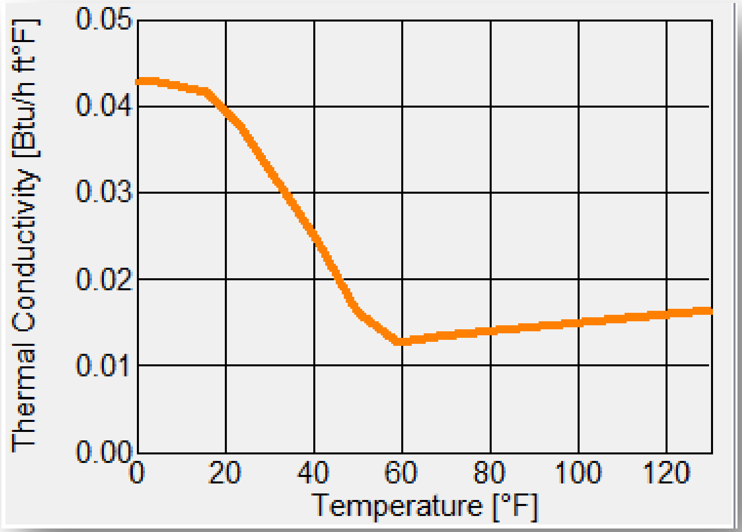
- Nominal values for design taken at mean temperature 75F (100F/50F)
- Service conditions can be very different

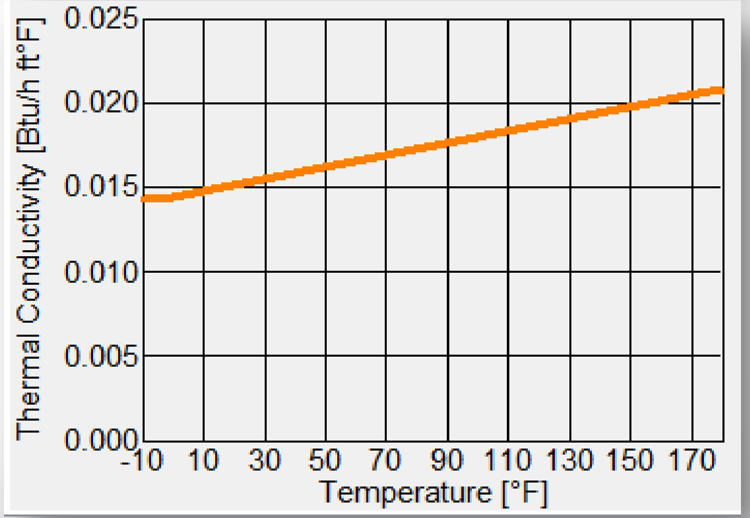
Building Science Corp

Thermal Conductivity and Temperature

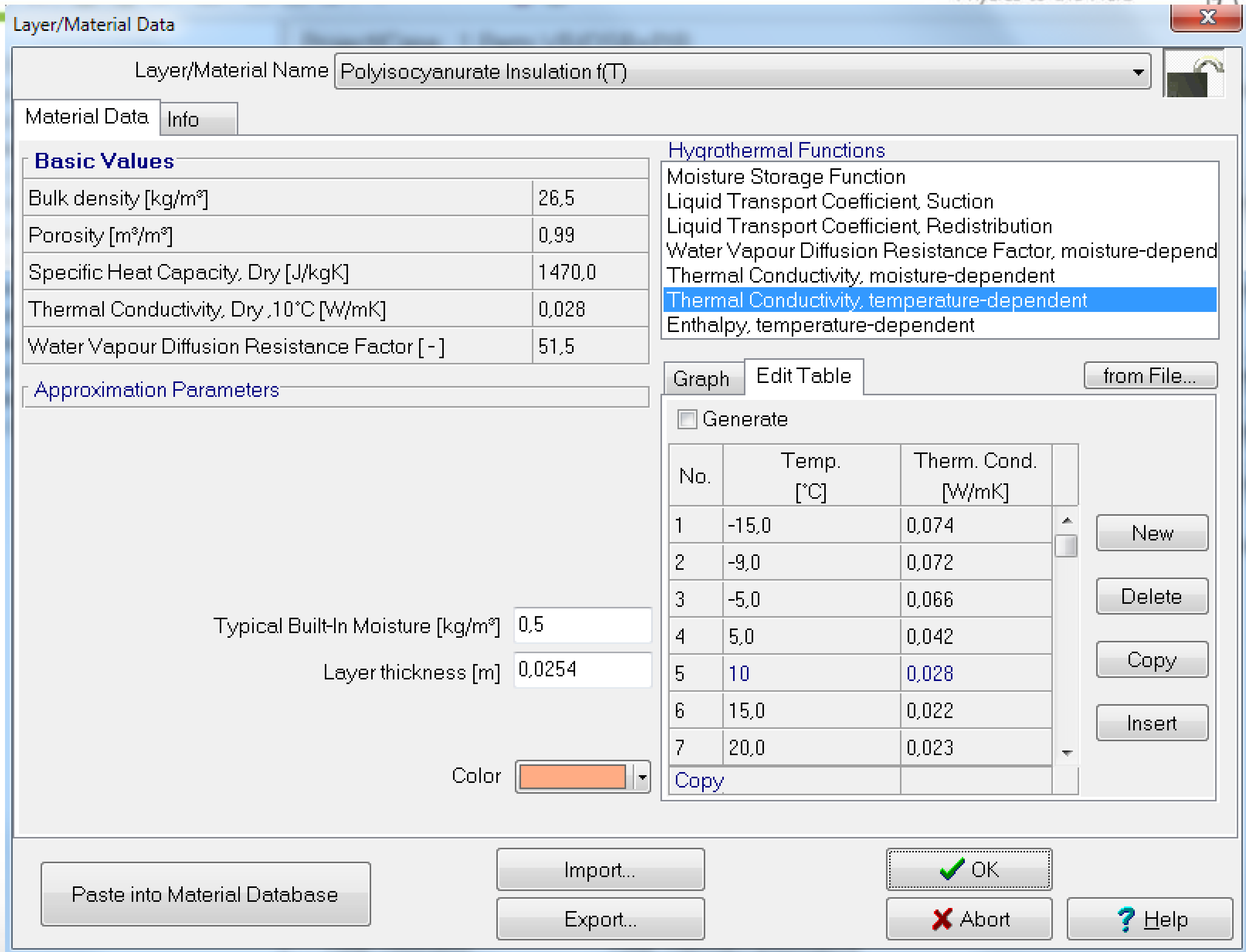
- Thermal conductivity of Polyisocyanurate goes up as temperatures go down (R-value decreases)

- Data based on measurements by Building Science Corp



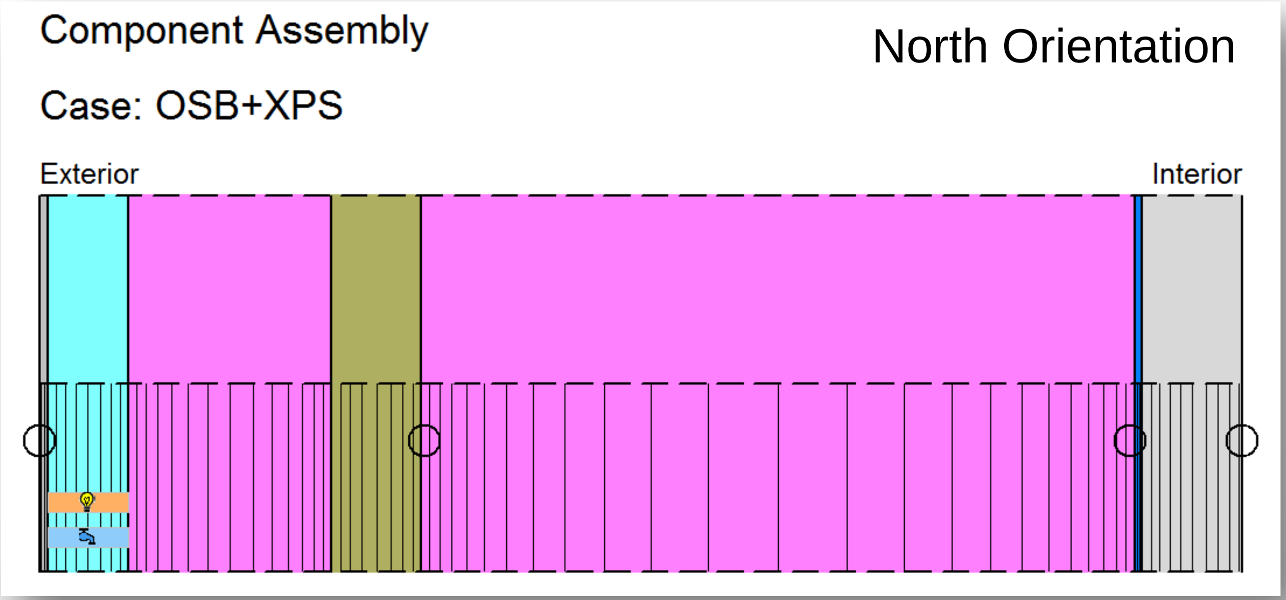


Material Properties



Wall Heat Loss

- **WUFI** Hygrothermal Calculations: 2x4 + 1” foam
  - XPS versus Polyisocyanurate insulation
  - Heat loss through a wall



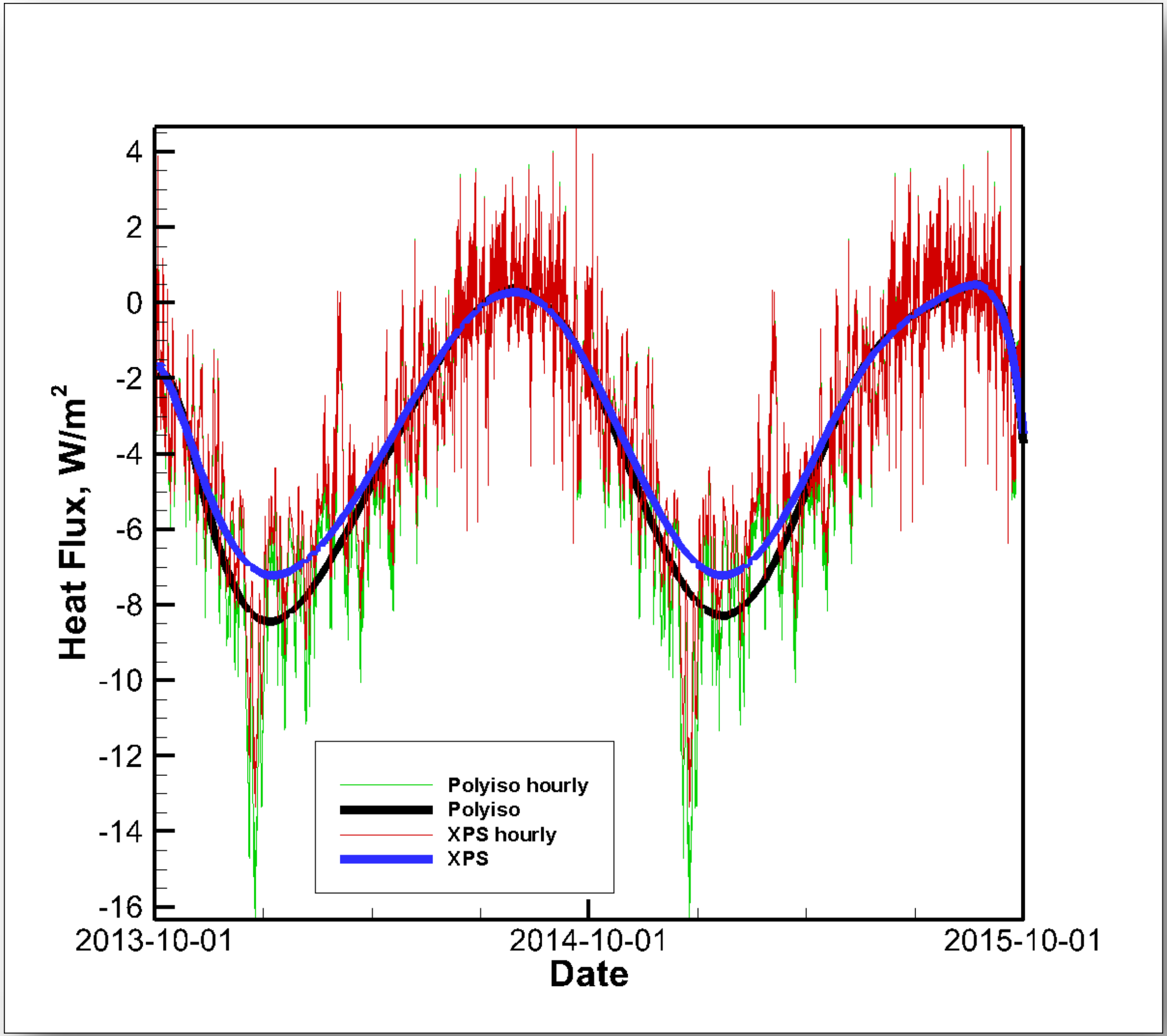
Climatic Locations

- Chicago
- Toronto
- Minneapolis
- Miami

Heat flux through the wall

Chicago

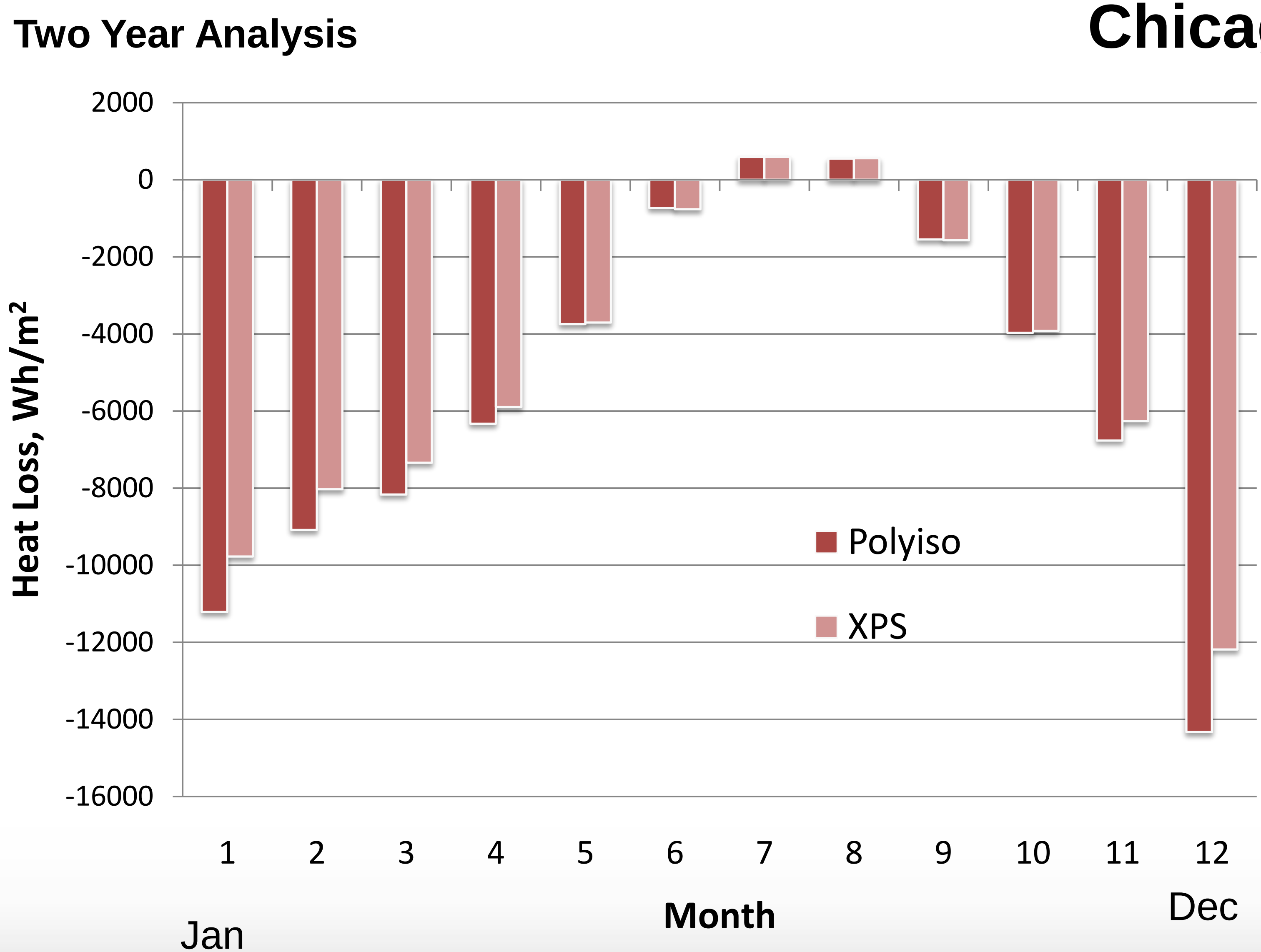
2x4 + 1in



Heat Loss: Polyiso vs XPS

Chicago

2x4 + 1in



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Heat Loss: Polyiso vs XPS

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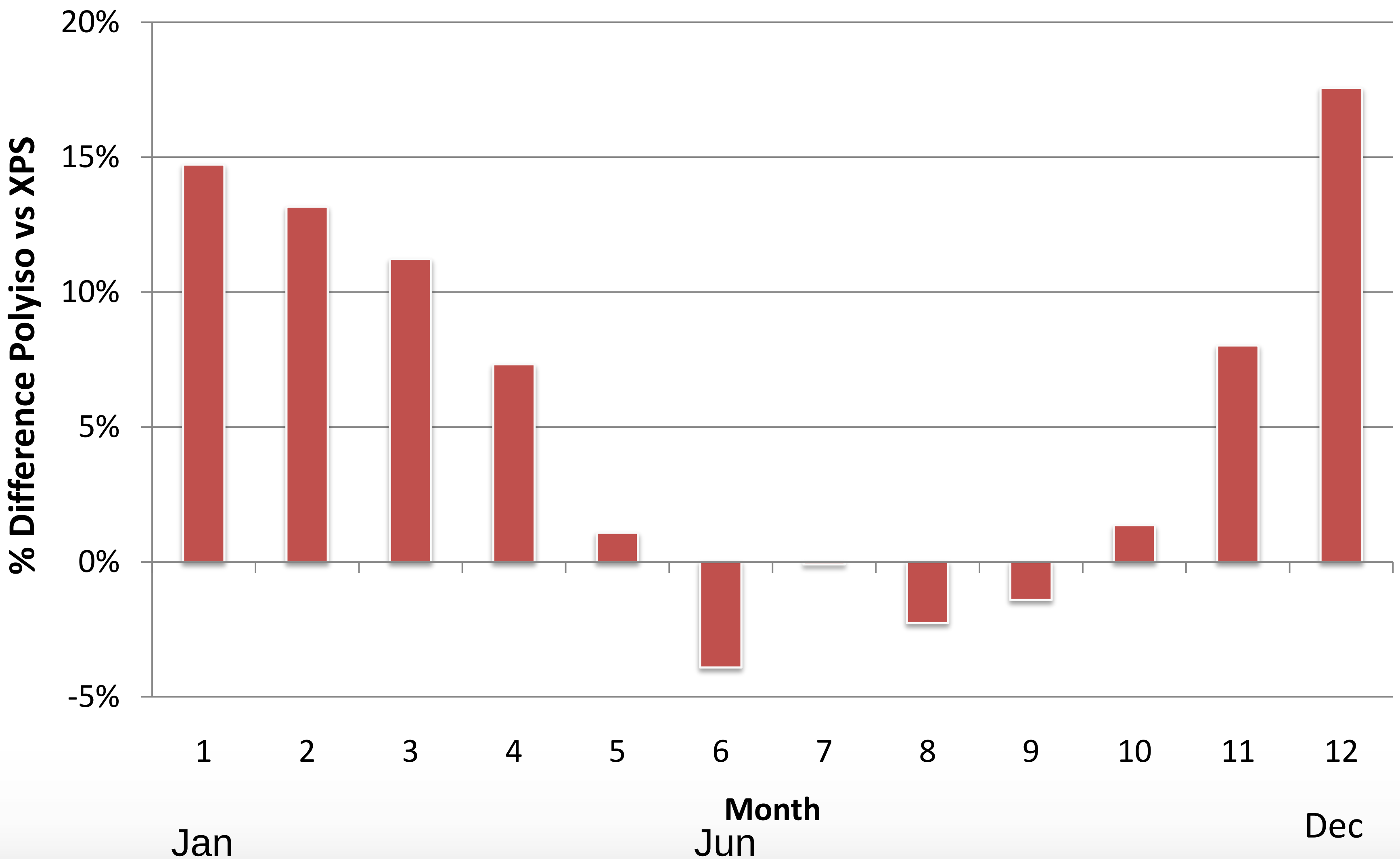
2x4 + 1in

Chicago

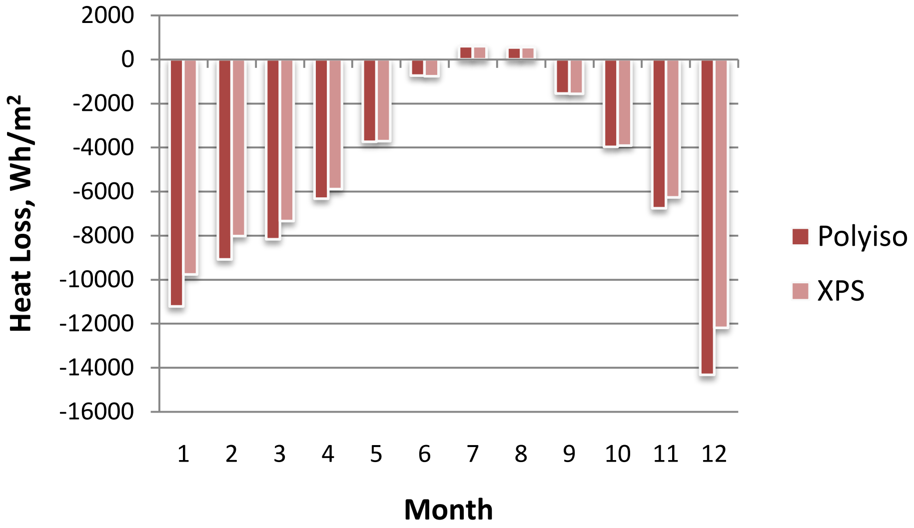


Owens Corning Innovations for Living

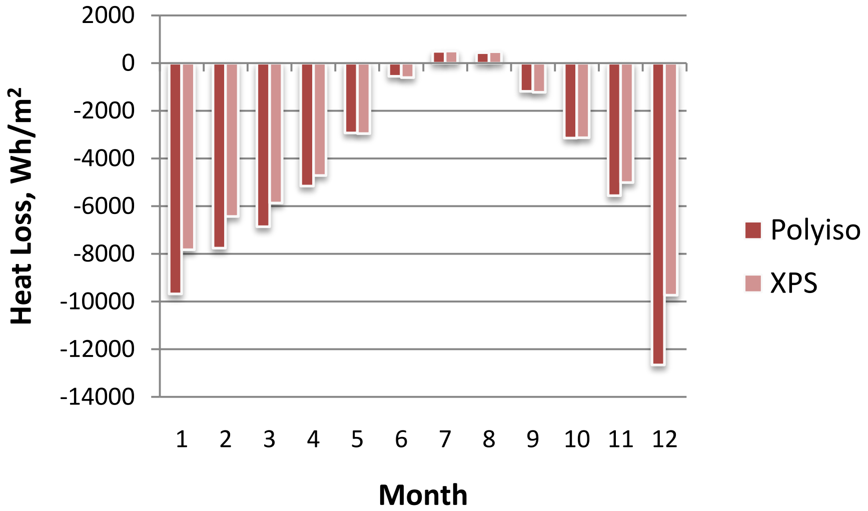
Exterior Cladding **Vinyl** **Chicago**

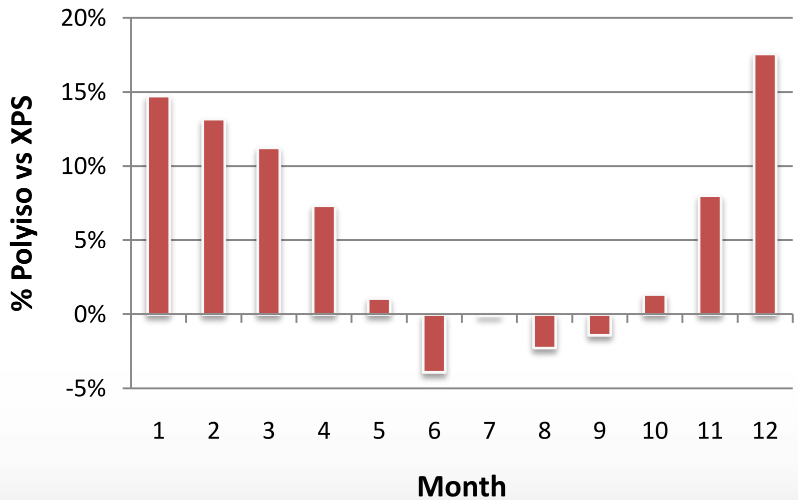
Building Science Insights Physics to the Field™

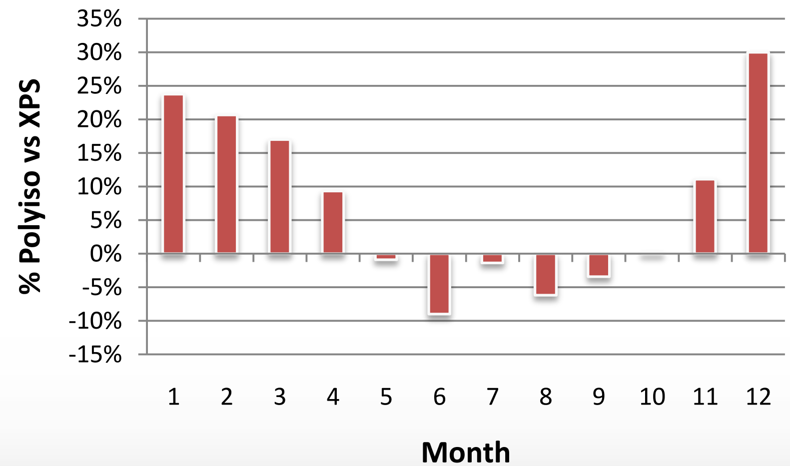
Insulation Board **1 in**



Insulation Board **2 in**

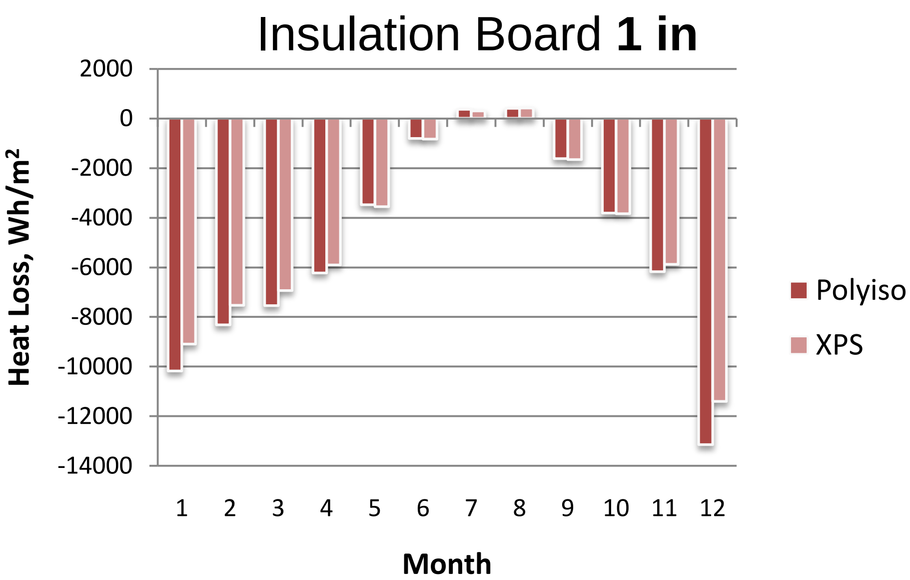


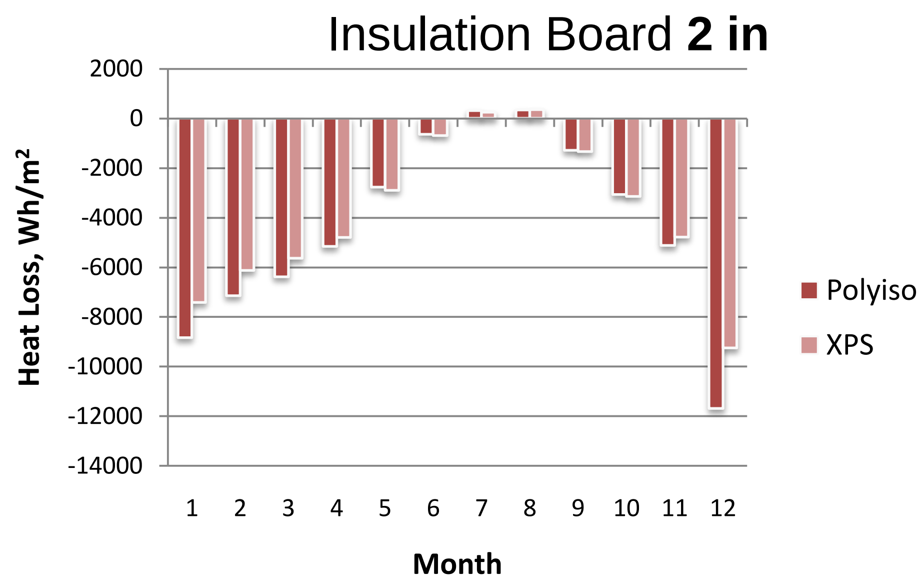


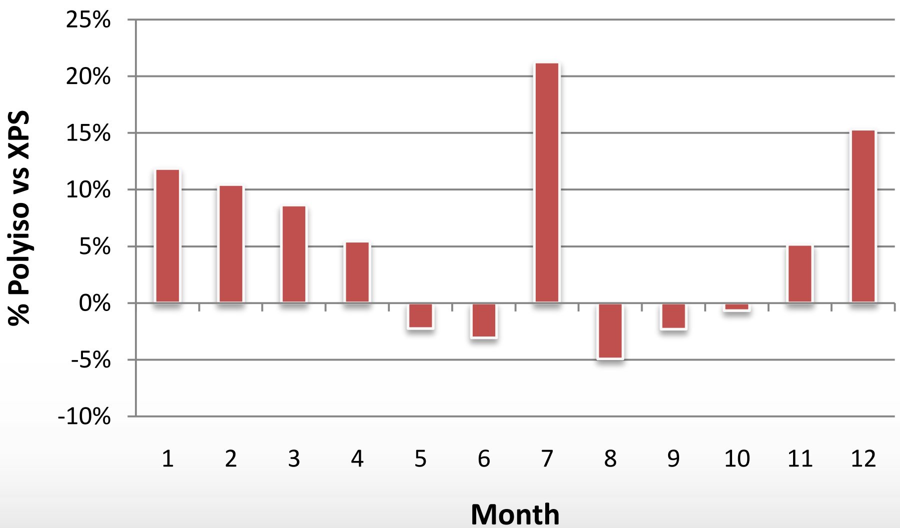


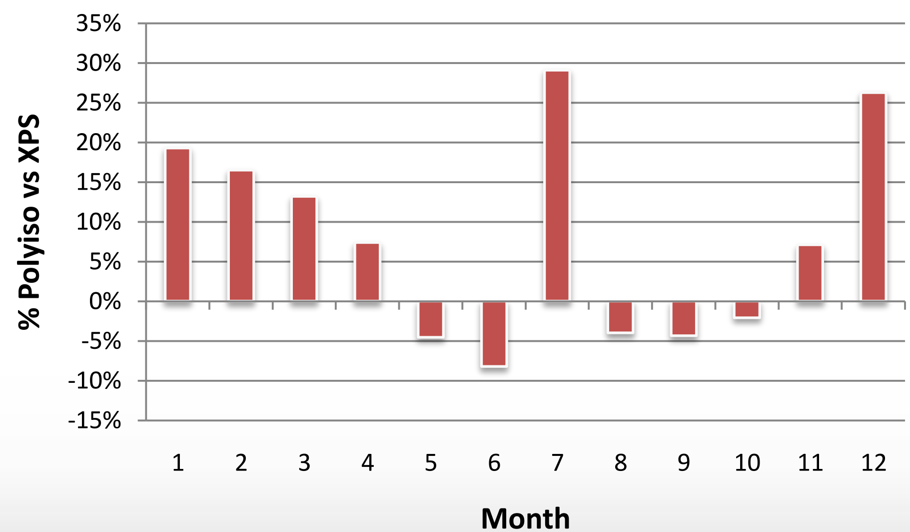
Exterior Cladding: **Brick**

Chicago









Minneapolis

Exterior Cladding: **Vinyl**

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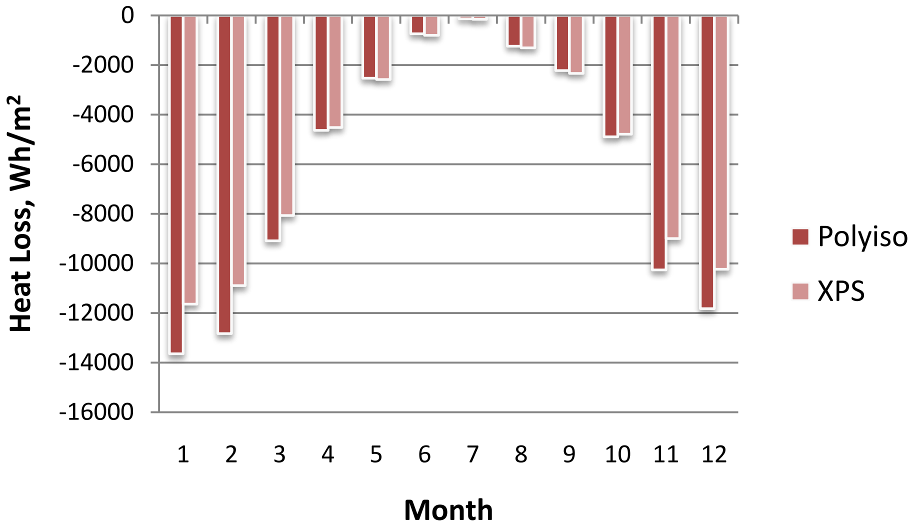
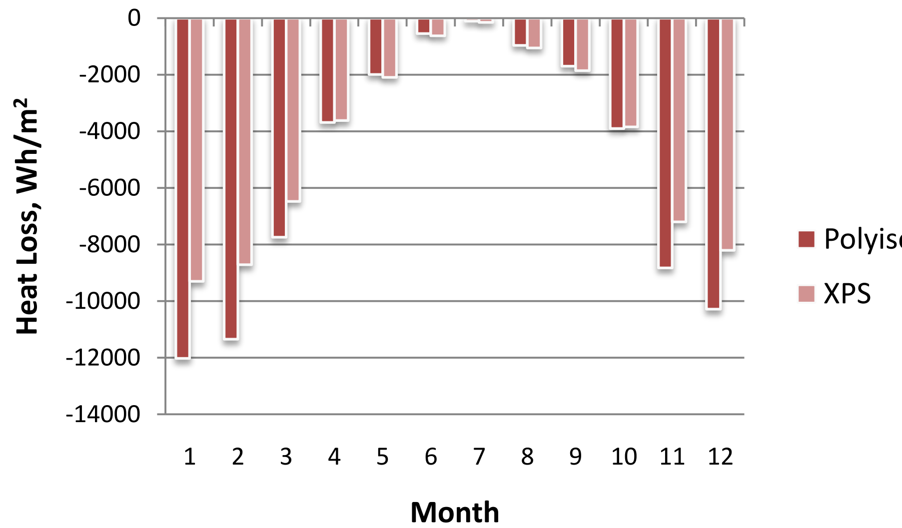
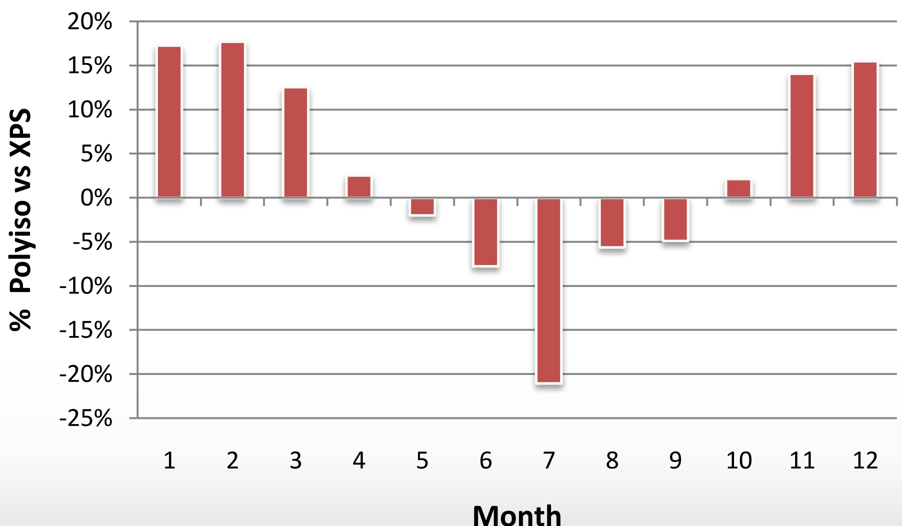
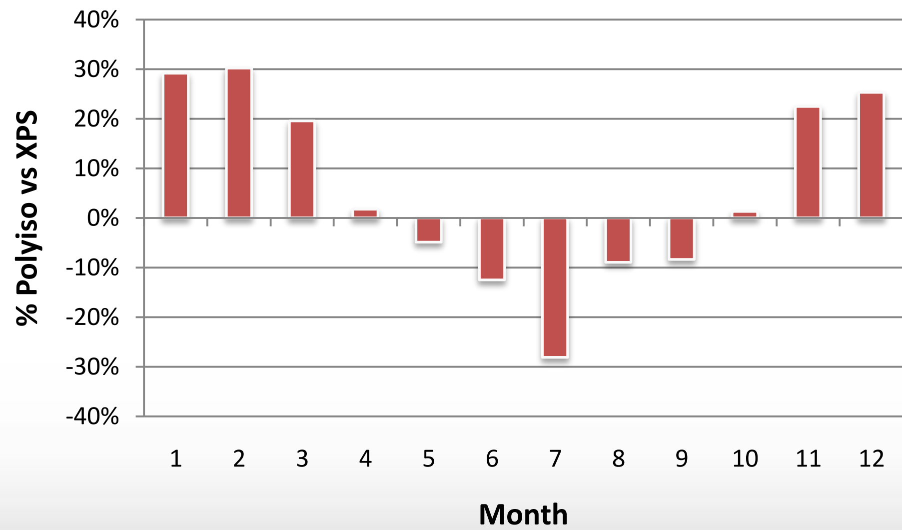
Insulation Board 1 in



Insulation Board 2 in







Exterior Cladding: **Brick**

Minneapolis

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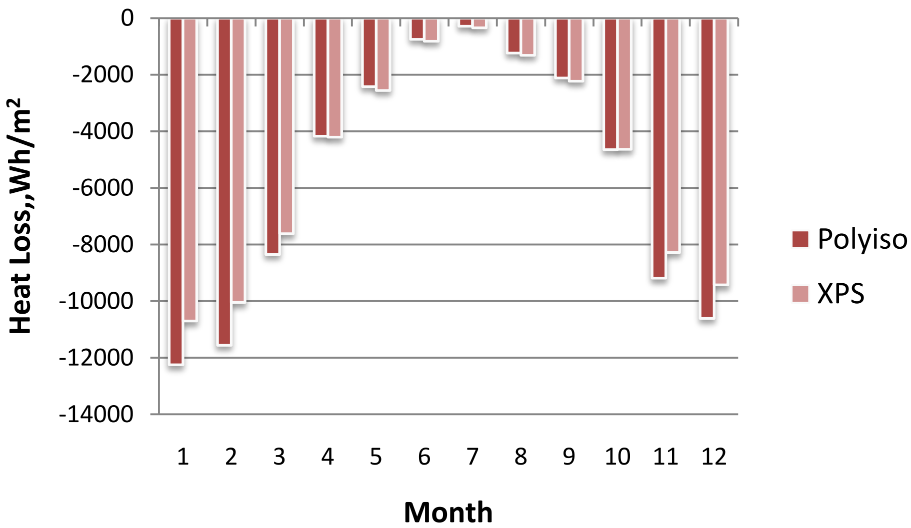
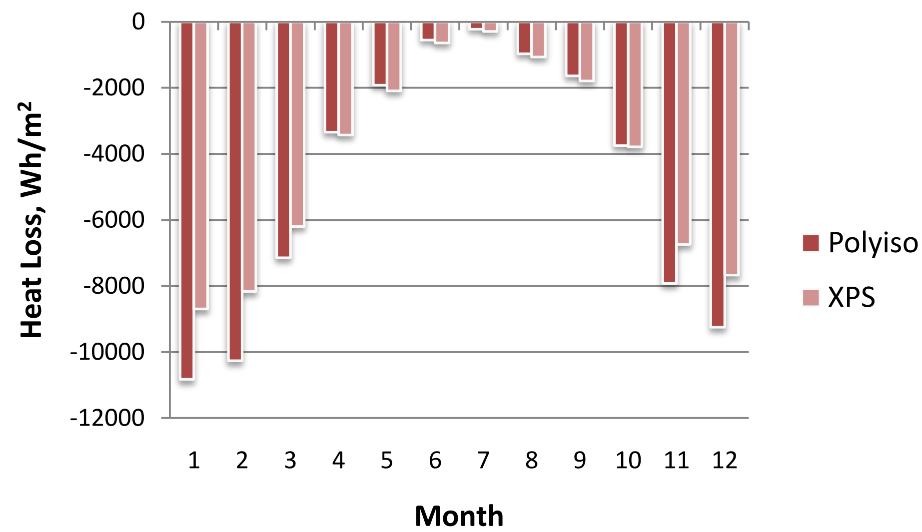
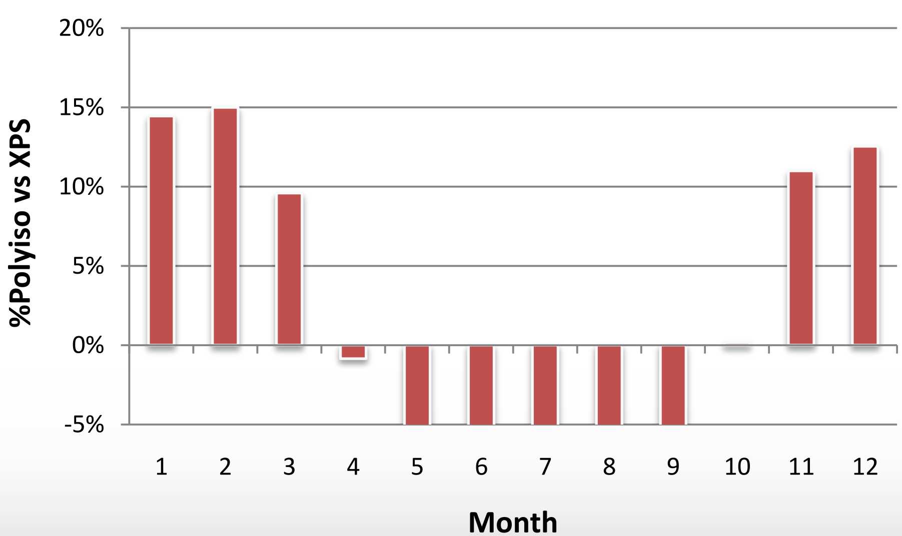
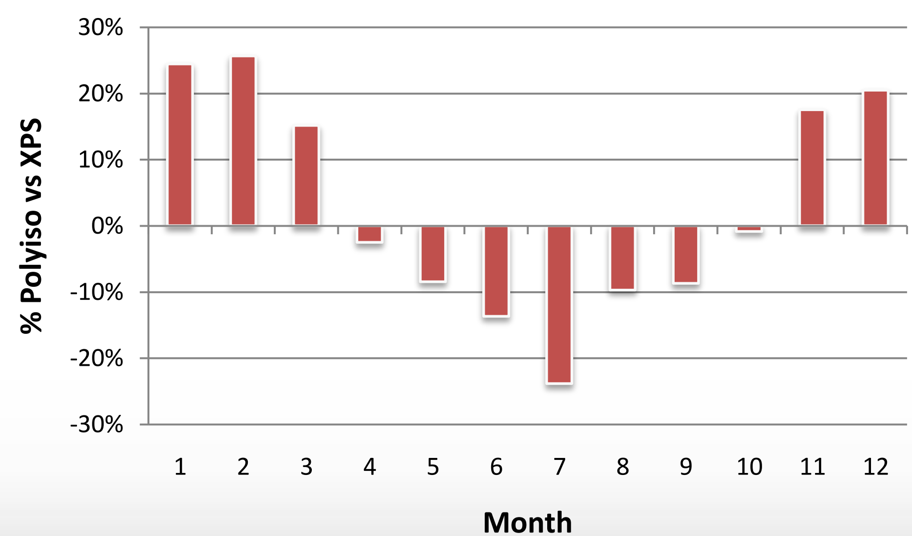
Insulation Board **1 in**



Insulation Board **2 in**







2x6
Exterior Cladding: **Vinyl**

Toronto

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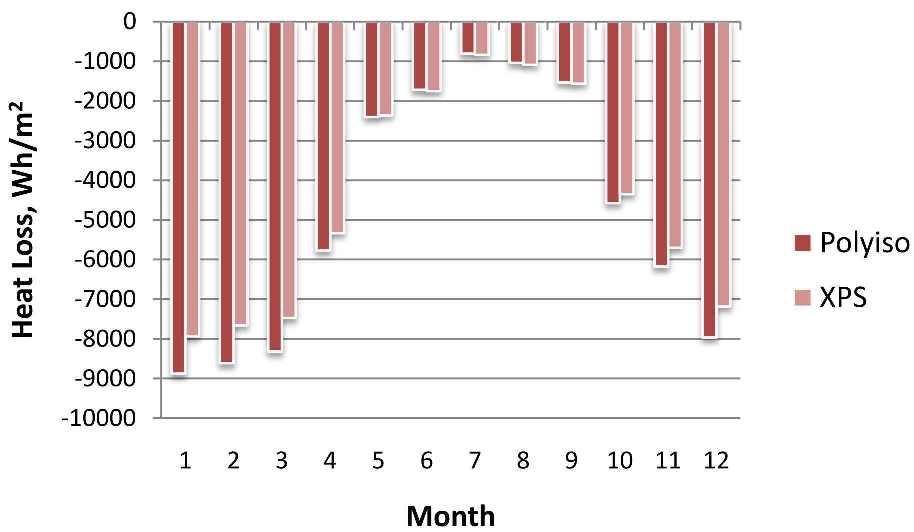
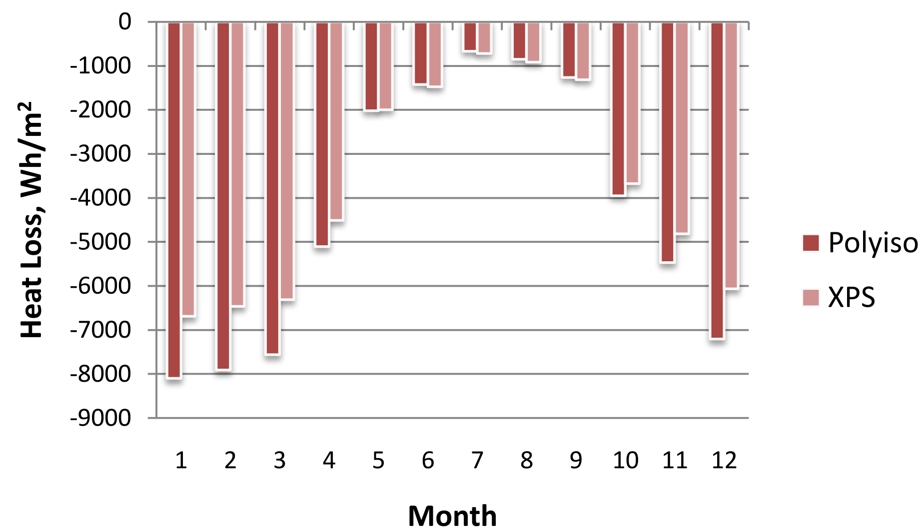
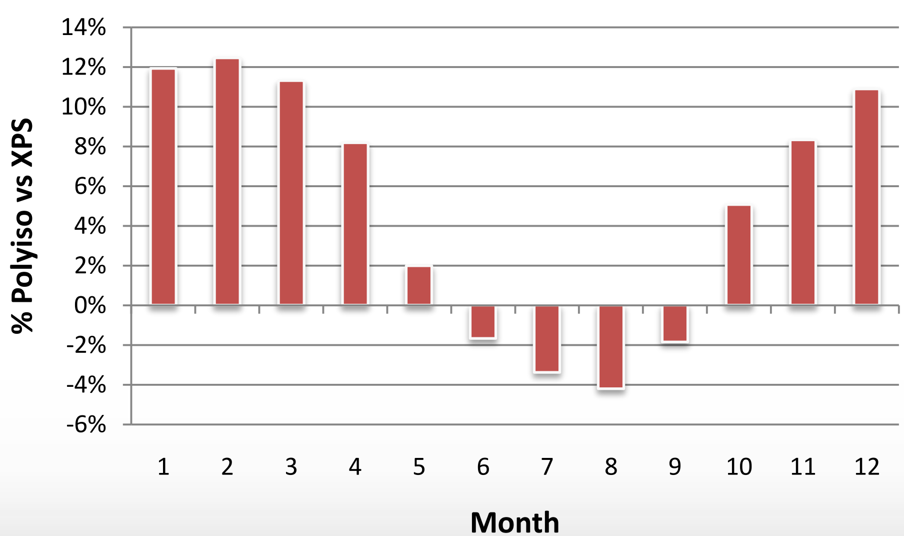
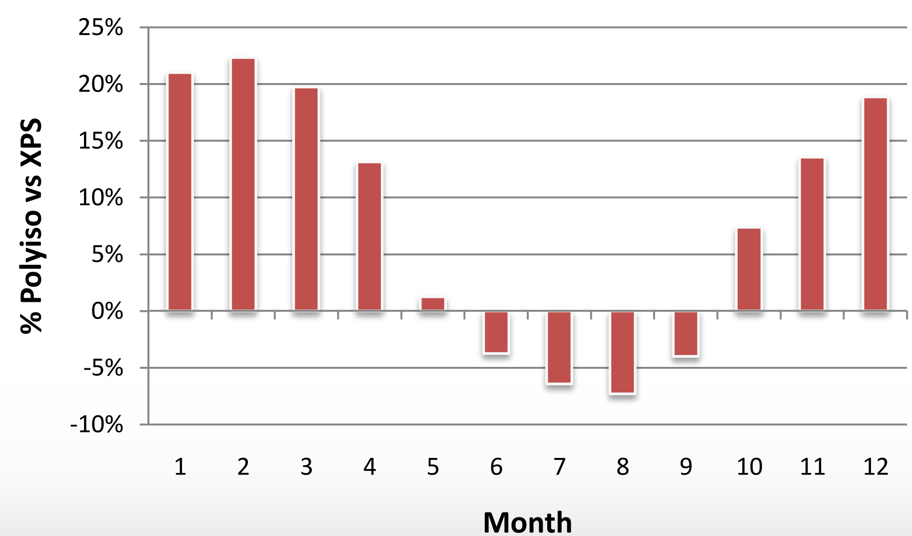
Insulation Board **1 in**



Insulation Board **2 in**







2x6 Construction
Exterior Cladding: **Brick**

Toronto

BUILDING SCIENCE INSIGHTS
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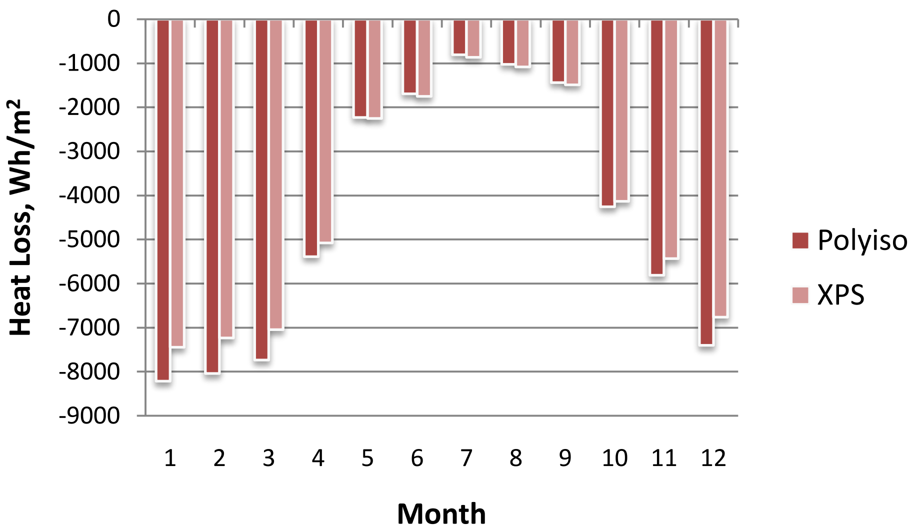
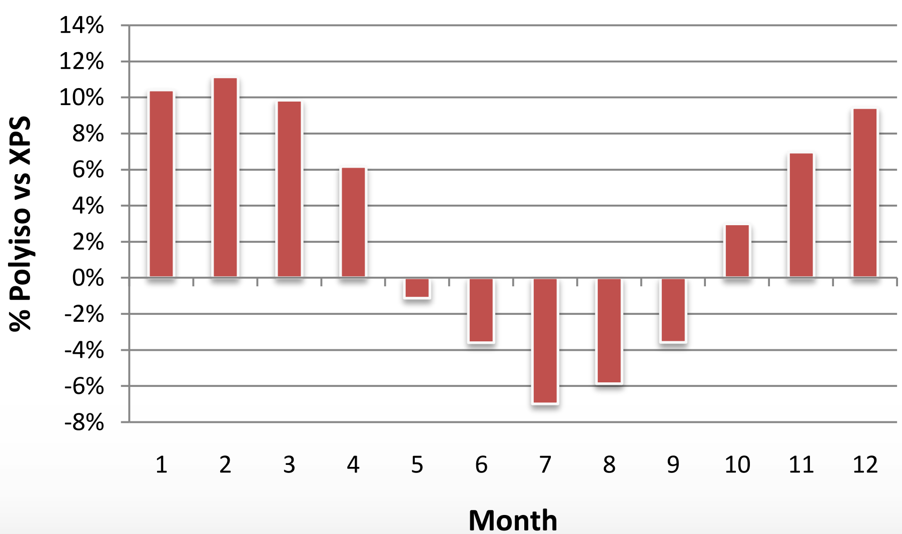
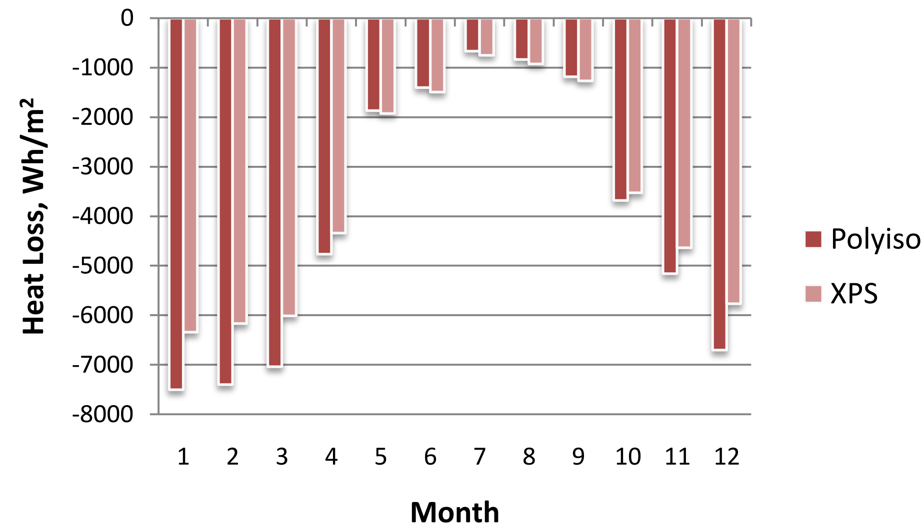
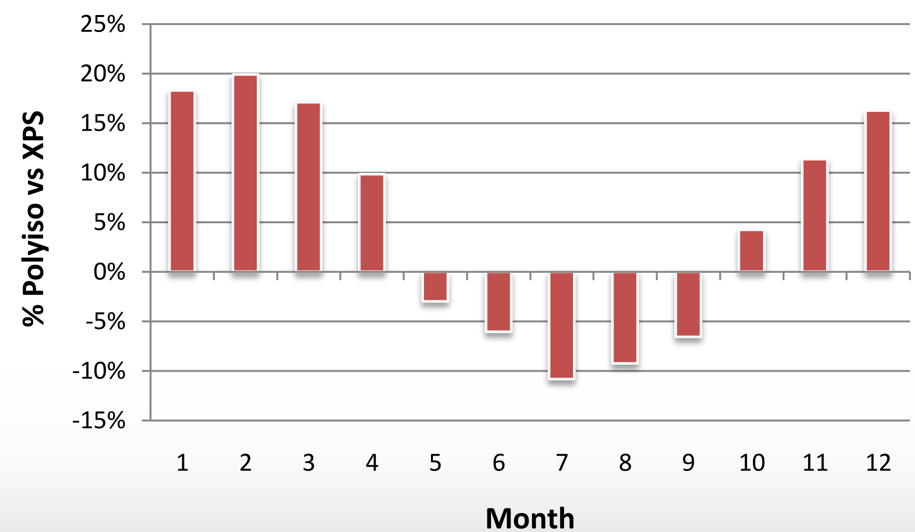
Insulation Board **1 in**





Insulation Board **2 in**





More…..

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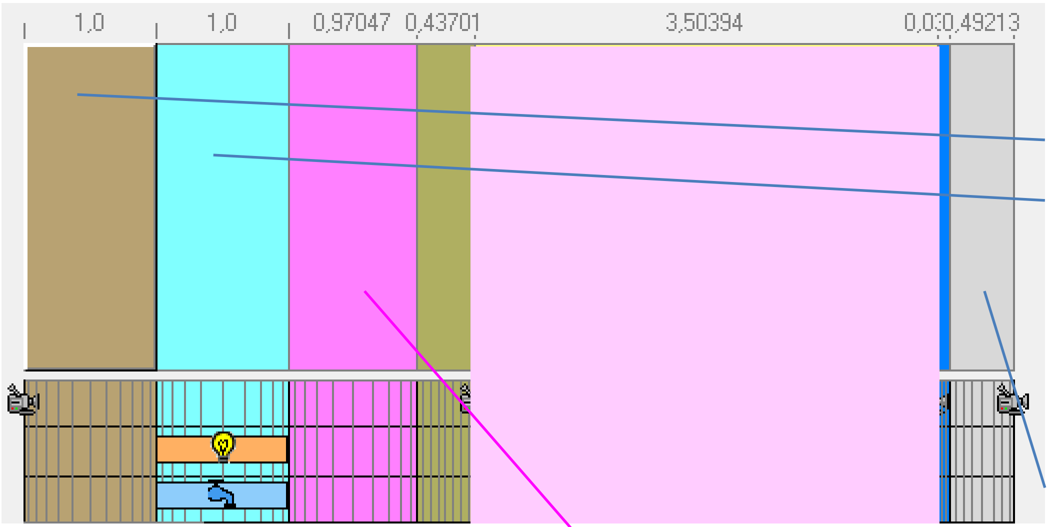
Brick Wall with R5 (XPS) exterior insulation

Outside



Inches

Layers from Outside
-Brick
-Air
-XPS
-OSB
-Fiberglas
-Vapor retarder
-Interior Gypsum Board

Inside

All assemblies to be simulated:

Brick – R5;	Brick – R7.5;	Brick – R10;	Brick – R15
Vinyl– R5;	Vinyl– R7.5;	Vinyl– R10;	Vinyl– R15

→ All 8 cases are simulated once with XPS and once with Polyiso

→ total amount of simulation per city = 16

Input parameters for the 1D simulations

→ Further input parameters

- Simulation period = 2 years → average values are used for comparison
- Inclination = 90°
- Driving Rain coefficients = low (short building)
- Orientation = North → extreme cases for cold temp. (low sun irradiation)
- Initial relative humidity of materials = 80%
- Initial temperature of materials is 68°F

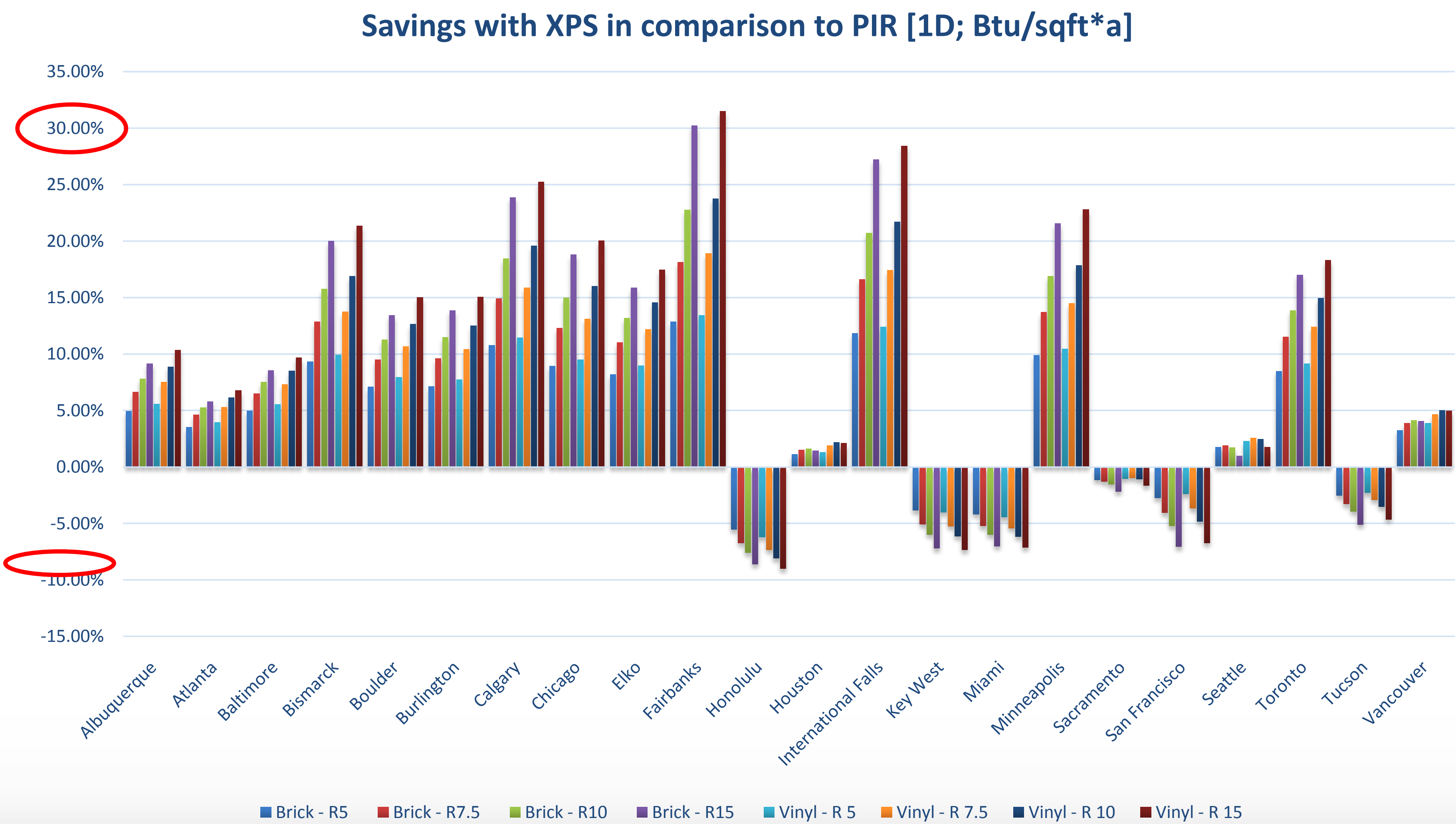
- Weather file type used = Ashrae Year 1

- Thickness of exterior insulation layer is always adapted to the R-value
→ XPS and Polyiso layer have always the same R-value but do not have the same thickness!!!

Comparison of all Cities

Cities	Savings with XPS in Comparison to PIR [% of Btu/sqft*a]								
	Brick - R5	Brick - R7.5	Brick - R10	Brick - R15	Vinyl - R 5	Vinyl - R 7.5	Vinyl - R 10	Vinyl - R 15	Average
Albuquerque	4,96%	6,63%	7,82%	9,15%	5,58%	7,51%	8,87%	10,36%	7,61%
Atlanta	3,52%	4,61%	5,27%	5,77%	3,95%	5,30%	6,14%	6,78%	5,17%
Baltimore	4,97%	6,50%	7,53%	8,55%	5,55%	7,31%	8,50%	9,67%	7,32%
Bismarck	9,32%	12,86%	15,78%	19,99%	9,94%	13,76%	16,88%	21,34%	14,98%
Boulder	7,08%	9,50%	11,27%	13,42%	7,93%	10,67%	12,66%	15,02%	10,95%
Burlington	7,14%	9,61%	11,49%	13,87%	7,73%	10,44%	12,50%	15,07%	10,98%
Calgary	10,77%	14,93%	18,45%	23,86%	11,45%	15,86%	19,58%	25,24%	17,52%
Chicago	8,94%	12,29%	14,99%	18,80%	9,51%	13,12%	16,02%	20,06%	14,22%
Elko	8,18%	11,04%	13,19%	15,86%	8,99%	12,19%	14,56%	17,47%	12,68%
Fairbanks	12,86%	18,13%	22,77%	30,23%	13,42%	18,93%	23,75%	31,49%	21,45%
Honolulu	-5,53%	-6,74%	-7,58%	-8,59%	-6,21%	-7,32%	-8,08%	-8,99%	-7,38%
Houston	1,13%	1,52%	1,63%	1,44%	1,29%	1,91%	2,19%	2,12%	1,65%
International Falls	11,83%	16,62%	20,73%	27,21%	12,42%	17,41%	21,71%	28,44%	19,55%
Key West	-3,84%	-5,06%	-5,98%	-7,20%	-4,00%	-5,23%	-6,13%	-7,34%	-5,60%
Miami	-4,17%	-5,21%	-5,99%	-7,00%	-4,44%	-5,41%	-6,15%	-7,12%	-5,69%
Minneapolis	9,90%	13,71%	16,88%	21,58%	10,45%	14,50%	17,86%	22,79%	15,96%
Sacramento	-1,15%	-1,29%	-1,54%	-2,16%	-1,02%	-0,97%	-1,08%	-1,62%	-1,35%
San Francisco	-2,73%	-4,05%	-5,22%	-7,06%	-2,39%	-3,66%	-4,82%	-6,71%	-4,58%
Seattle	1,76%	1,89%	1,71%	0,98%	2,28%	2,56%	2,47%	1,76%	1,93%
Toronto	8,49%	11,51%	13,86%	17,01%	9,15%	12,41%	14,95%	18,31%	13,21%
Tucson	-2,52%	-3,26%	-3,93%	-5,10%	-2,29%	-2,90%	-3,50%	-4,63%	-3,52%
Vancouver	3,26%	3,89%	4,14%	4,07%	3,89%	4,68%	5,02%	4,99%	4,24%

Graphical Comparison for all Cities



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INNOVATIONS FOR LIVING

What have we learned

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- Thermal insulation should be evaluated with in-situ temperature ranges

- Using **Design value** or any other “**German**” way does not help.

- **Now I know the critical importance of temperature dependencies and why 1 inch of R-5 XPS insulation performs better than 1 inch R-6 Polyisocyanurate in mixed and cold climates.**

Questions?

This concludes the American Institute of Architects Continuing Education Systems Program

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