An Old(er) Fellow's Musings about Building Envelopes and Energy Efficiency

André Desjarlais
Program Manager
Oak Ridge National Laboratory

Oak Ridge, Tennessee
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ORNL is managed by UT-Battelle
for the US Department of Energy

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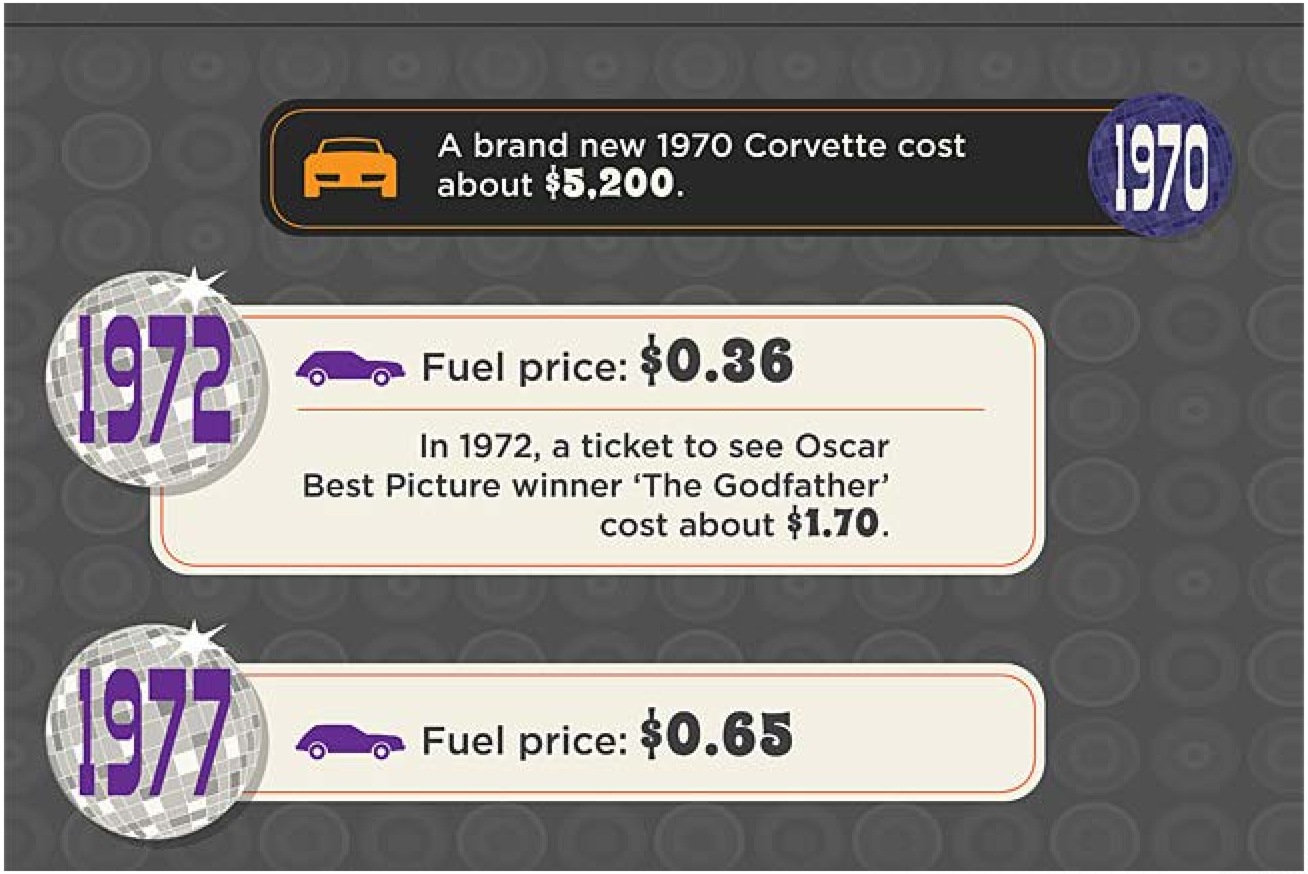
Safety portion of the presentation

Always secure cargo appropriately.
Courtesy of Bill Nash

The 1970s.....

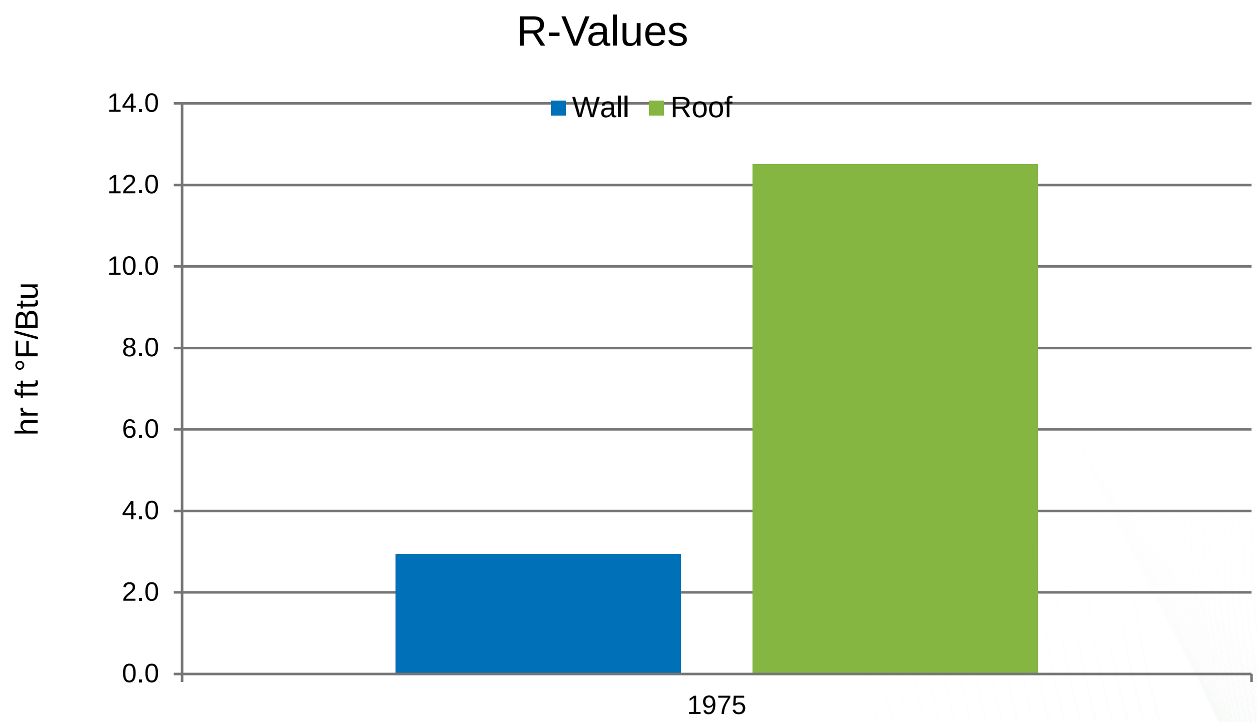
- The environmental movement
- Women's rights and Roe vs. Wade
- The antiwar movement
- Watergate
- Beatles break up
- NIBS founded

1970s trivia



1st version of ASHRAE Standard 90 adopted

Wall and Roof Requirements for Kansas City MO



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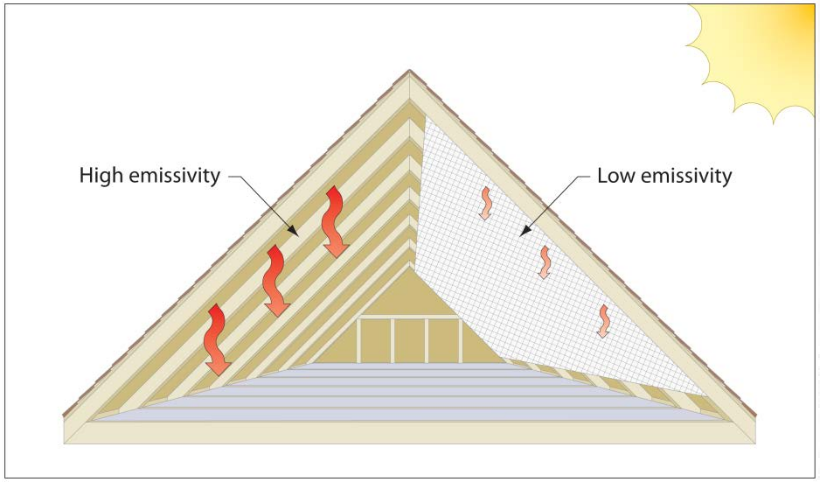
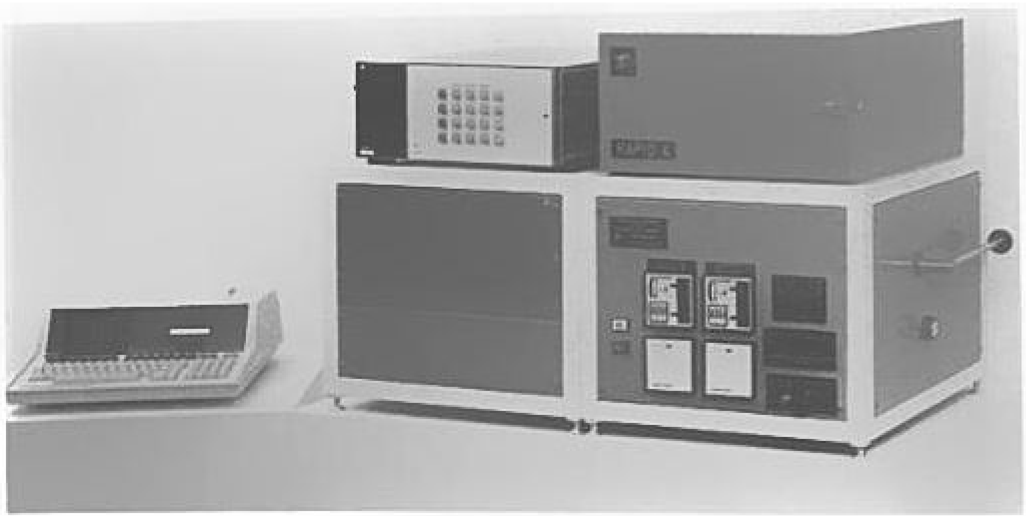
How do you measure R-value?

- Federal Trade Commission R-value Rule
- ASTM C177, C518, and C1363 greatly improved
- How do you test radiant barriers
- Insulation thickness effect
- Computer automation allows for in-situ testing



ORNL 10-G00921/abh



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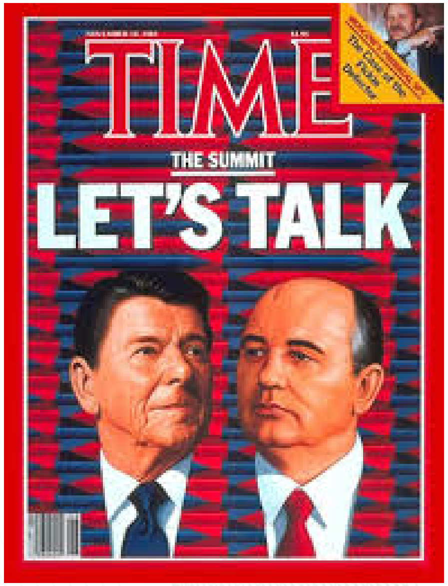
The 1980s.....

- Reaganomics and the end of the Cold War
- The Miracle on ice
- Space shuttle program's first flight and then Challenger
- George Bush Sr. announces he hates broccoli
- BETEC founded



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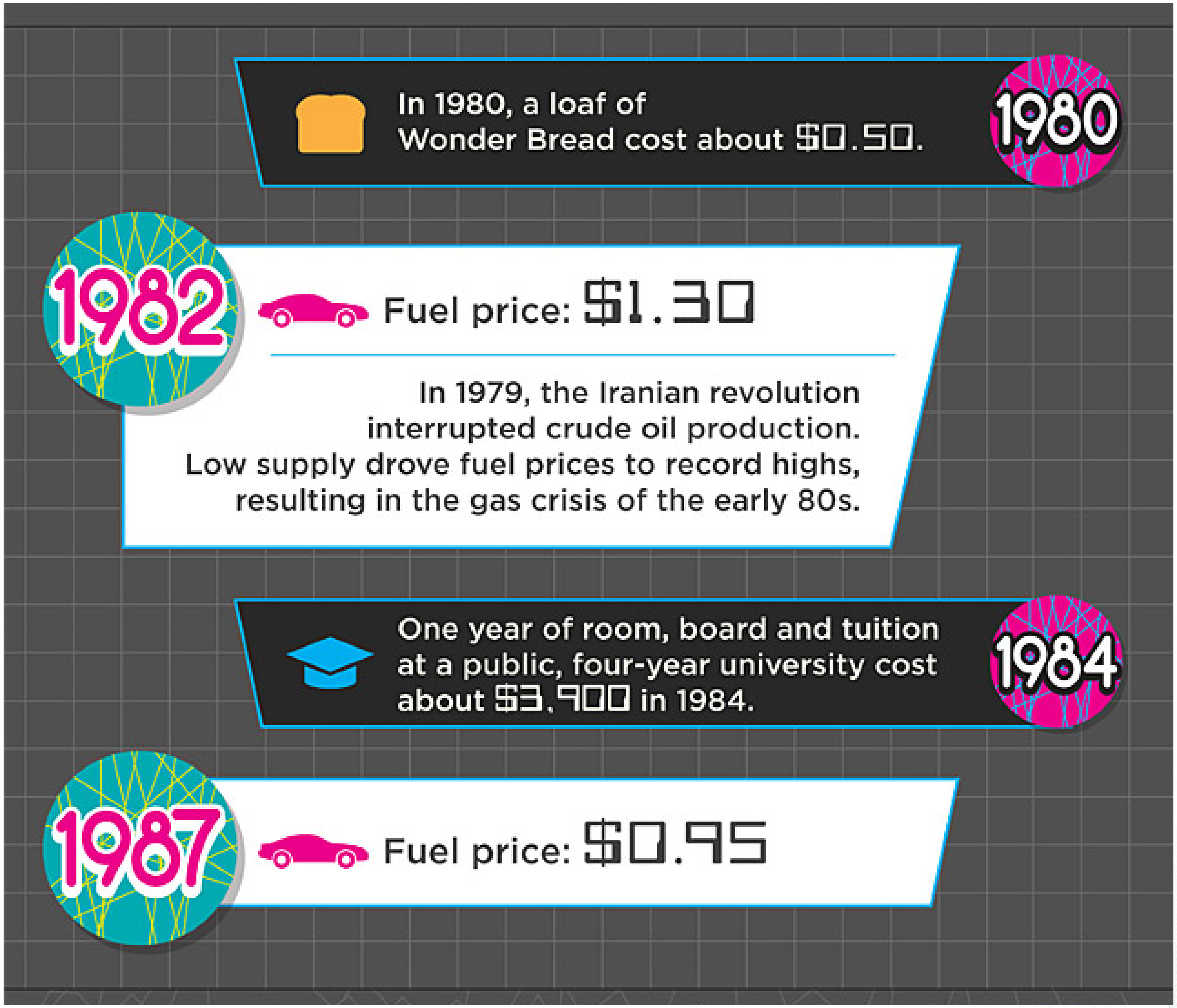
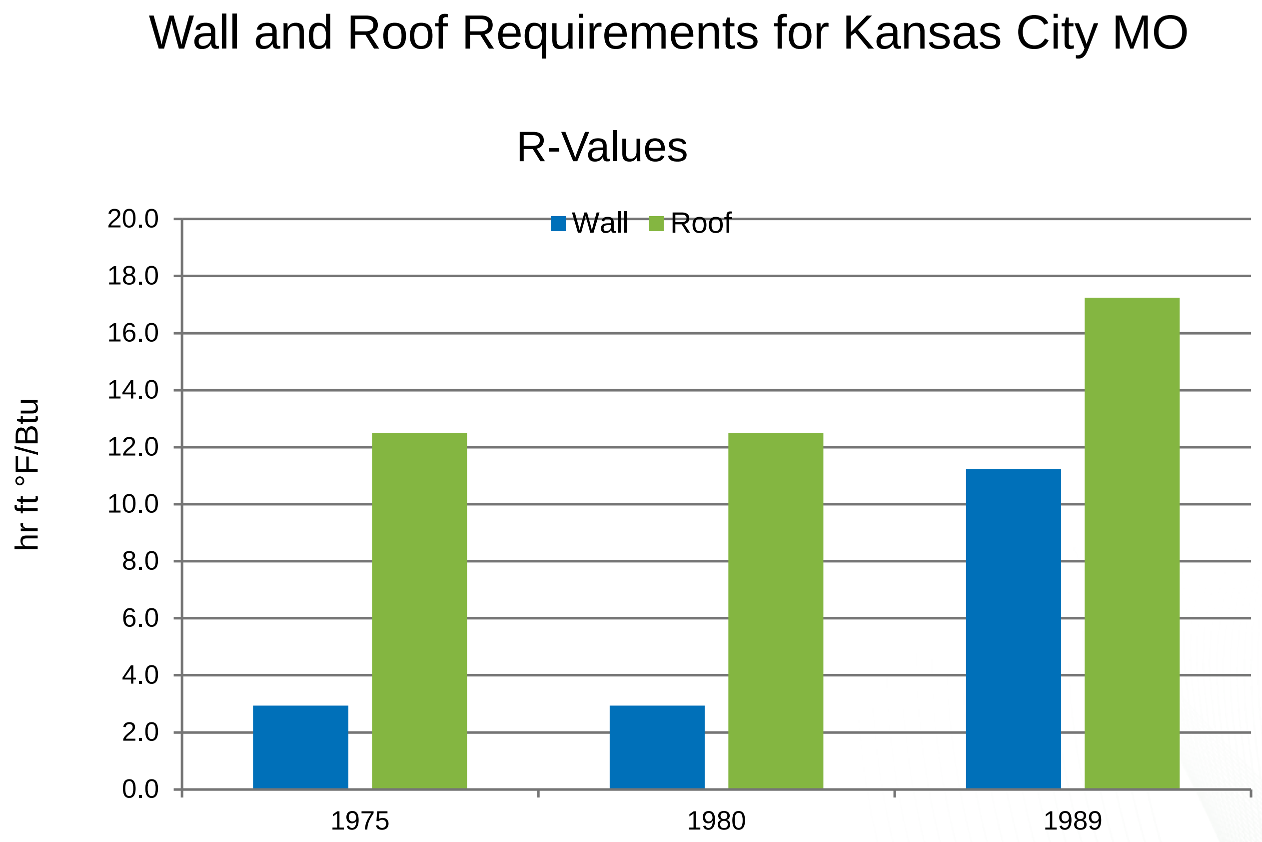
1980s trivia



ASHRAE Standard 90.1-1989 requires 14% energy efficiency improvement



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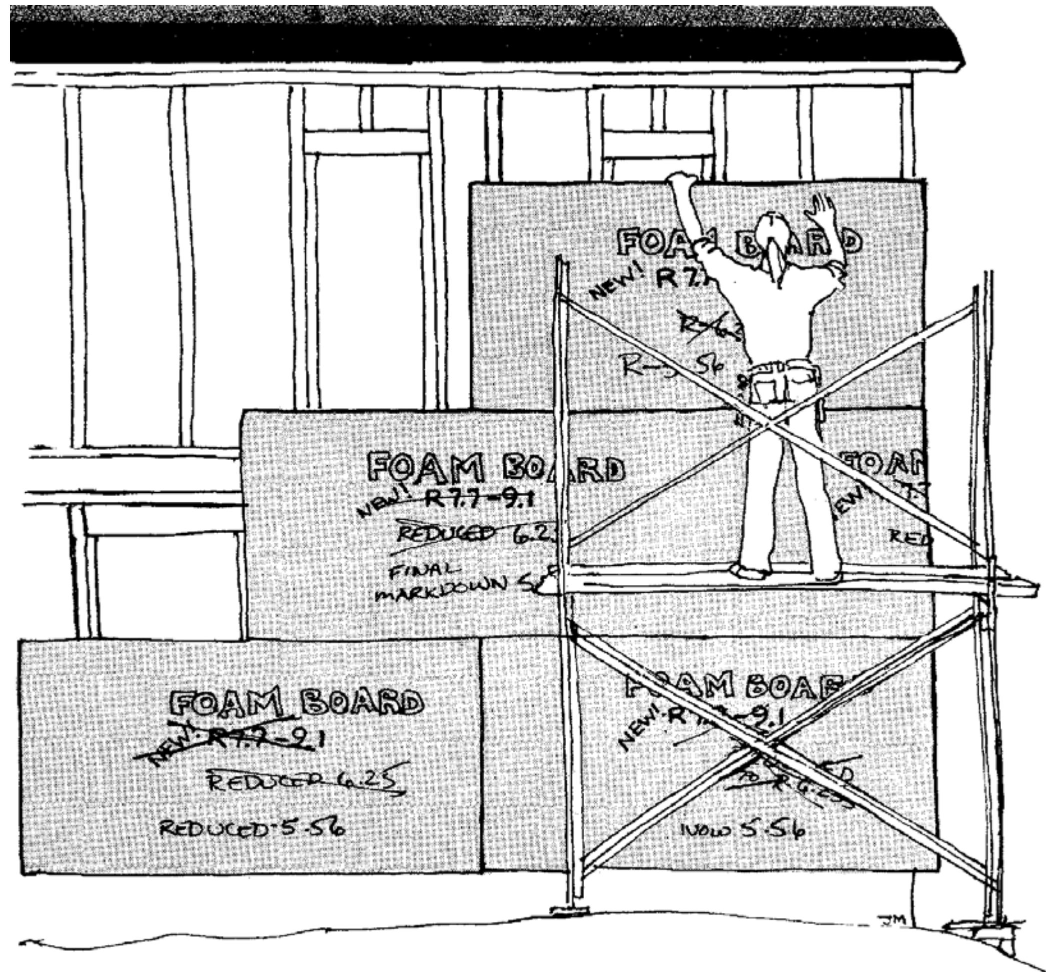
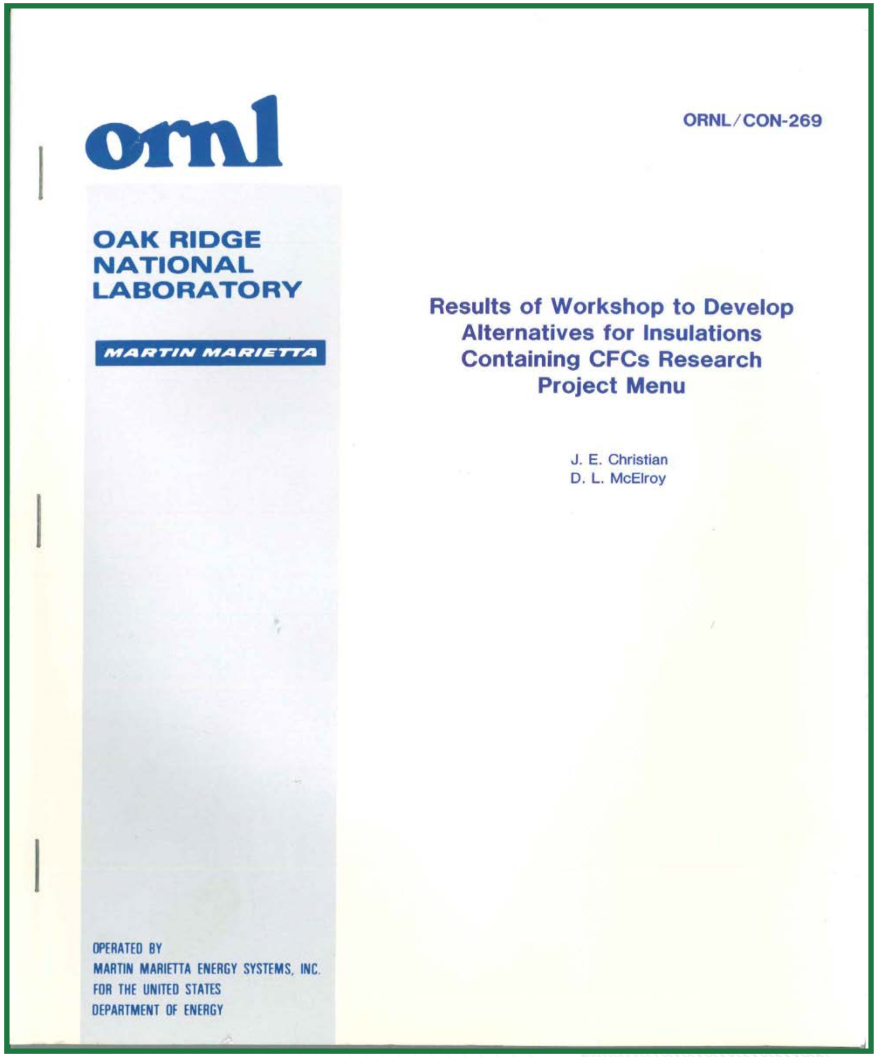
Thermal performance of foam plastics historically a contentious issue….

- NRCA/MRCA field study proposes R-value of 5.56
- PIMA protocol (Bulletin 101) proposed to deal with "thermal drift"
- ASTM C 518 test at 75°F after 180 day conditioning at 75°F and 50% RH



Public/private collaboration

- Stratospheric ozone shields against UV radiation
- Montreal Protocol calls for freeze in CFC-11 and CFC-12 production
- Public/private cooperative programs offer resources and clout needed
- Research agenda developed



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MARTIN MARIETTA

Results of Workshop to Develop
Alternatives for Insulations
Containing CFCs Research
Project Menu

J. E. Christian
D. L. McElroy

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

How do you test products whose R-value changes

- First proposed by Isberg in 1978
- Use geometric scaling to accelerate aging
- Allows collection of long term aged results quickly
- Task force formed in 1989; standard first adopted in 1995

Designation: C1303/C1303M – 12

**Standard Test Method for
Predicting Long-Term Thermal Resistance of Closed-Cell Foam Insulation[1]**

This standard is issued under the fixed designation C1303/C1303M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a procedure for predicting the long-term thermal resistance (LTTR) of unfaced or permeably faced rigid gas-filled closed-cell foam insulations by reducing the specimen thickness to accelerate aging under controlled laboratory conditions (**1-5**) .[2]

NOTE 1—See Terminology, 3.2.1, for the meaning of the word *aging* within this standard.

1.2 Rigid gas-filled closed-cell foam insulation includes all cellular plastic insulations manufactured with the intent to retain a blowing agent other than air.

1.3 This test method is limited to unfaced or permeably faced, homogeneous materials. This method is applied to a wide range of rigid closed-cell foam insulation types, including but not limited to: extruded polystyrene, polyurethane, polyisocyanurate, and phenolic. This test method does not apply to impermeably faced rigid closed-cell foams or to rigid closed-cell bun stock foams.

NOTE 2—See Note 8 for more details regarding the applicability of this test method to rigid closed-cell bun stock foams.

1.4 This test method utilizes referenced standard test procedures for measuring thermal resistance. Periodic measurements are performed on specimens to observe the effects of aging. Specimens of reduced thickness (that is, thin slices) are used to shorten the time required for these observations. The results of these measurements are used to predict the long-term thermal resistance of the material.

1.5 The test method is given in two parts. The Prescriptive Method in Part A provides long-term thermal resistance values on a consistent basis that can be used for a variety of purposes, including product evaluation, specifications, or product comparisons. The Research Method in part B provides a general relationship between thermal conductivity, age, and product thickness.

1.5.1 To use the Prescriptive Method, the date of manufacture must be known, which usually involves the cooperation of the manufacturer.

1.6 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.8 *Table of Contents*:

[1] This test method is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

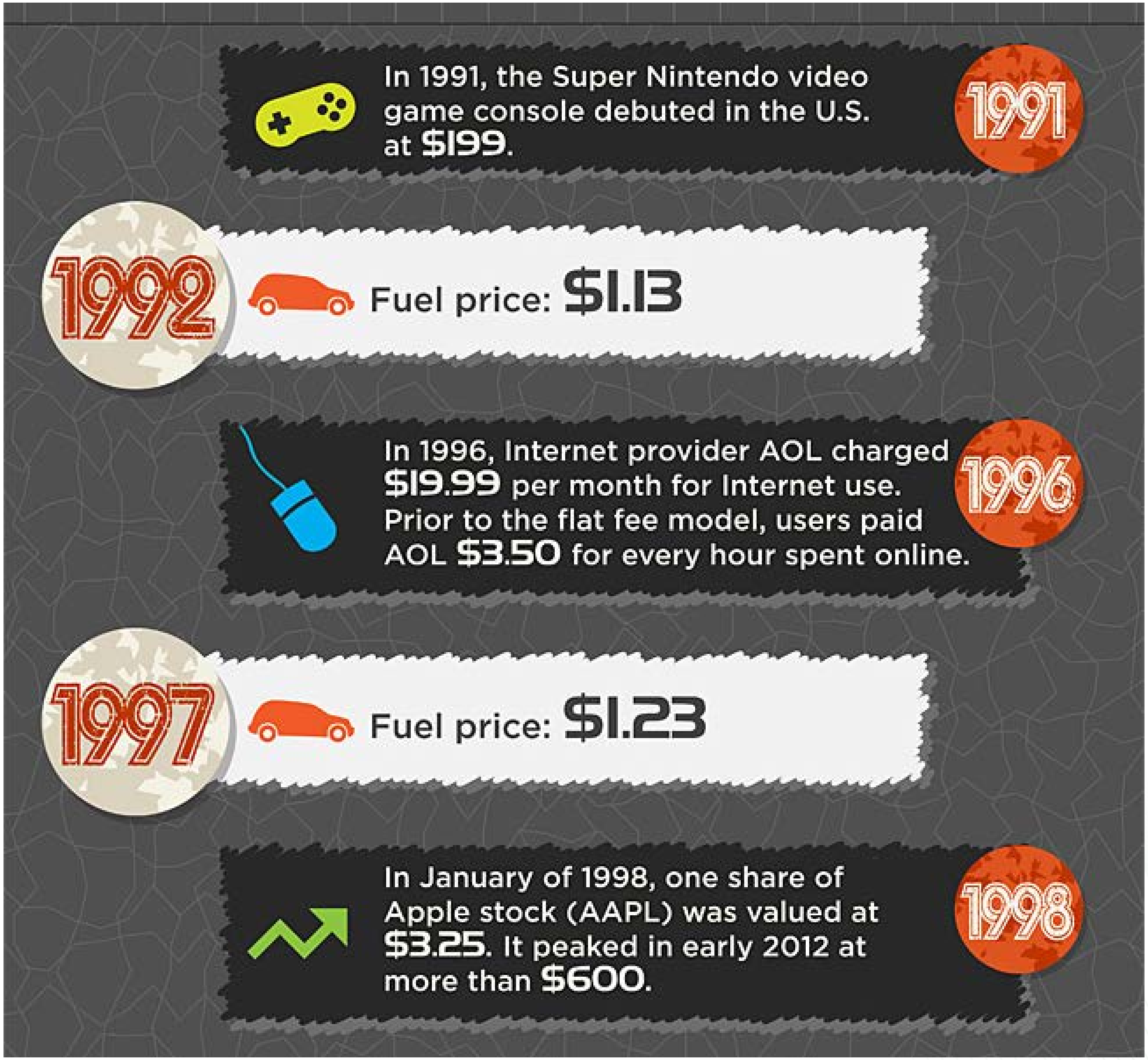
Current edition approved March 1, 2012. Published May 2012. Originally approved in 1995. Last previous edition approved in 2011 as C1303 – 11A. DOI: 10.1520/C1303_C1303M-12.

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

The 1990s.....

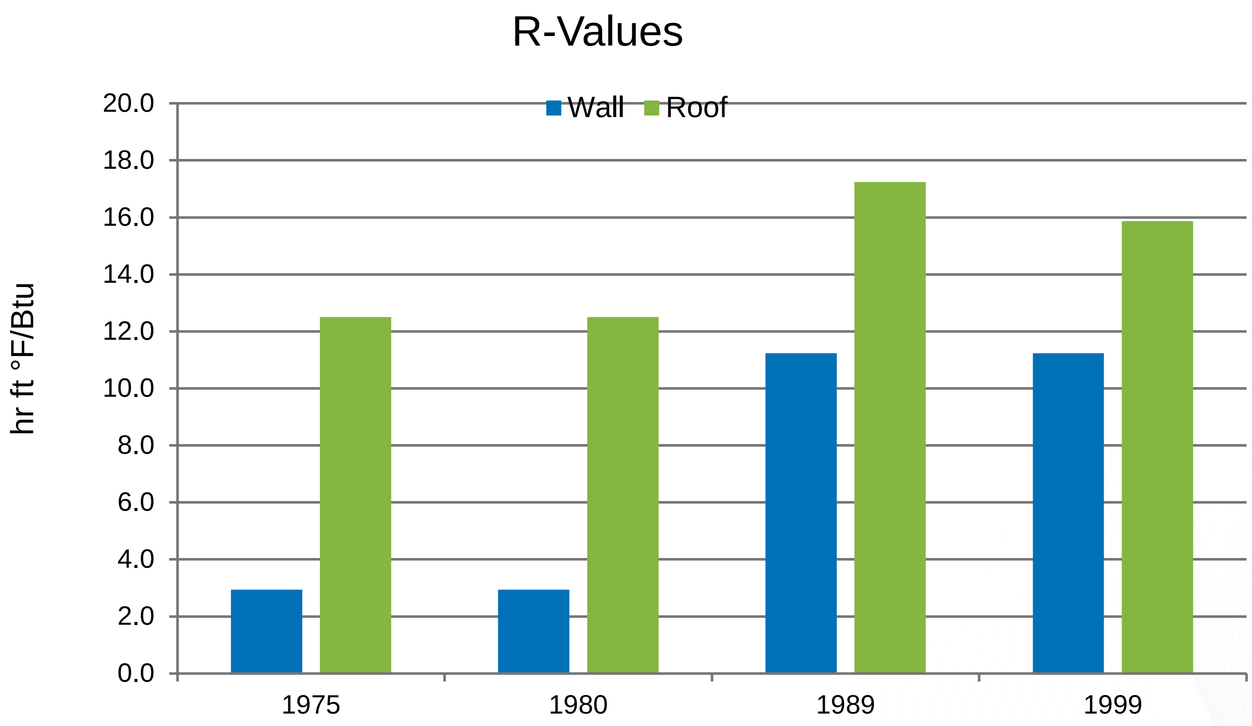
- The 1st Gulf War
- Soviet Union dissolves and Germany reunited
- Mandela freed and elected President
- OJ Simpson
- Columbine High School

1990s trivia

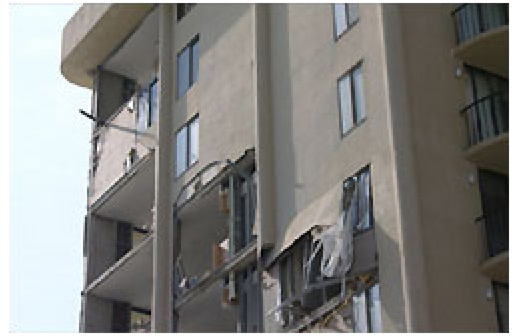


ASHRAE Standard 90.1-1999 requires 4% energy efficiency improvement

Wall and Roof Requirements for Kansas City MO



Moisture induced failures

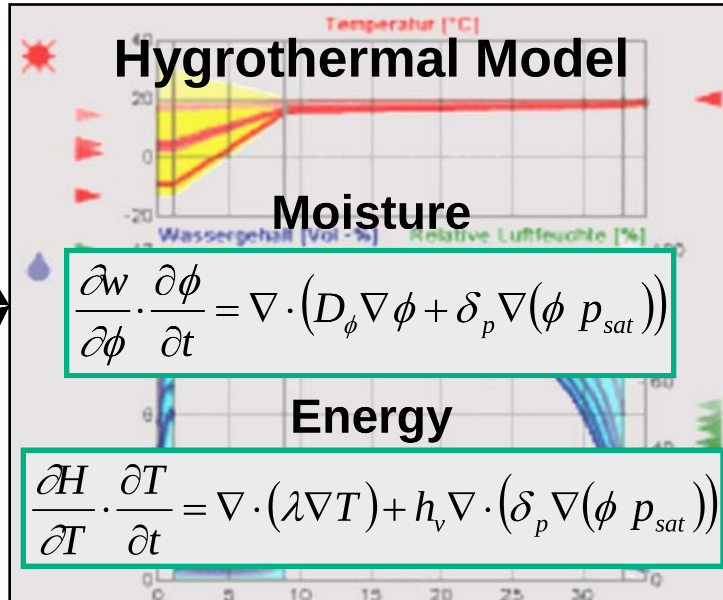


What is WUFI?

Hygrothermal models

Construction

Material properties



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

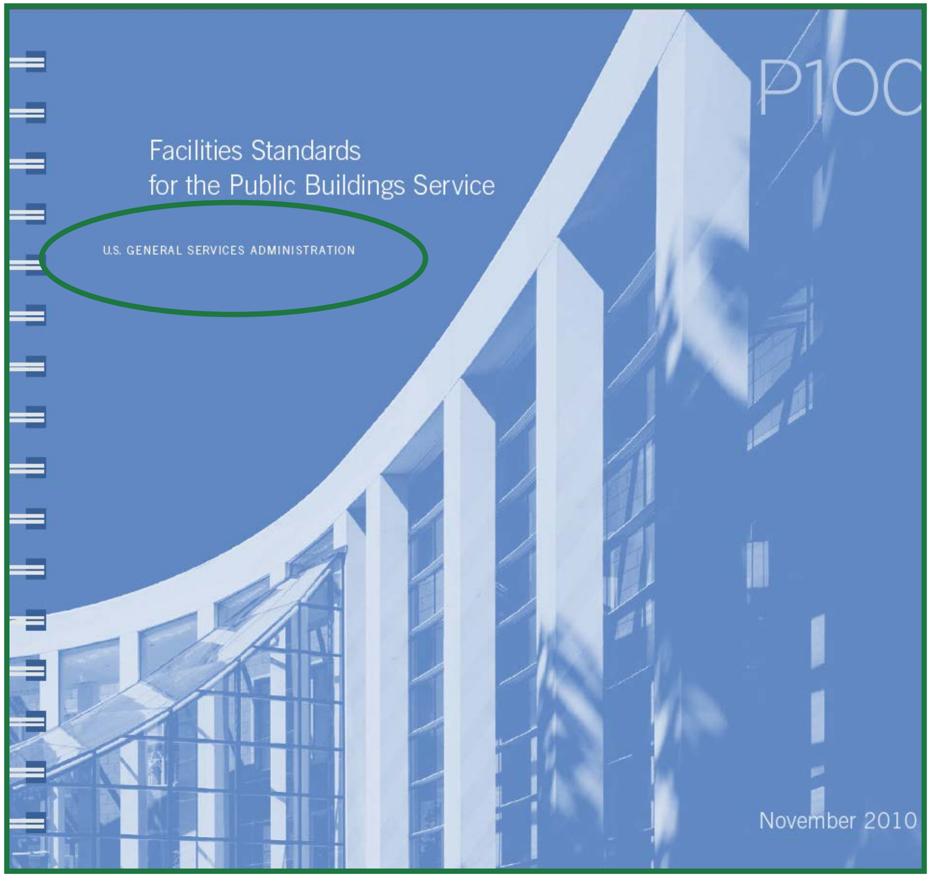
$$\frac{\partial H}{\partial T}\cdot\frac{\partial T}{\partial t} = \nabla\cdot\left(\lambda \nabla T\right) + h_v \nabla\cdot\left(\delta_p \nabla\left(\phi\, p_{sat}\right)\right)$$

Climate

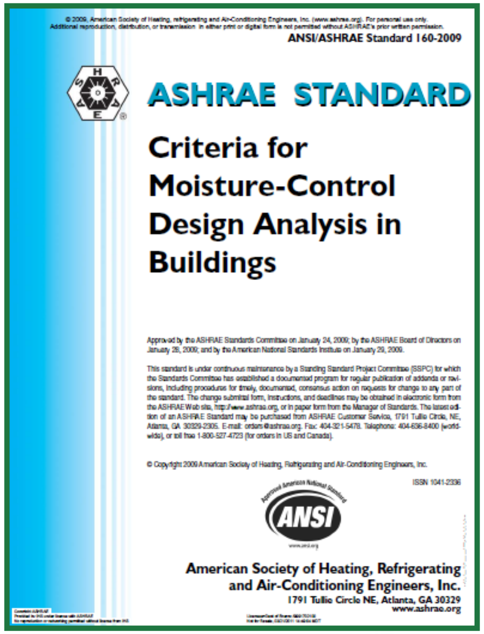
Boundary conditions

Temperature Field
Moisture Field
Heat Fluxes
Moisture Fluxes

Importance of moisture research



“Clearly conceived redundancy against water penetration…”



ANSI/ASHRAE Standard 160-2009

ASHRAE STANDARD

Criteria for Moisture-Control Design Analysis in Buildings

Approved by the ASHRAE Standards Committee on January 24, 2009; by the ASHRAE Board of Directors on January 28, 2009; and by the American National Standards Institute on January 29, 2009.

This standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE Web site, http://www.ashrae.org, or in paper form from the Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 404-321-5478. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada).

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American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
1791 Tullie Circle NE, Atlanta, GA 30329
www.ashrae.org

“Must follow ASHRAE Standard 160…”

“Hygrothermal behavior of all critical enclosure components must be demonstrated…”

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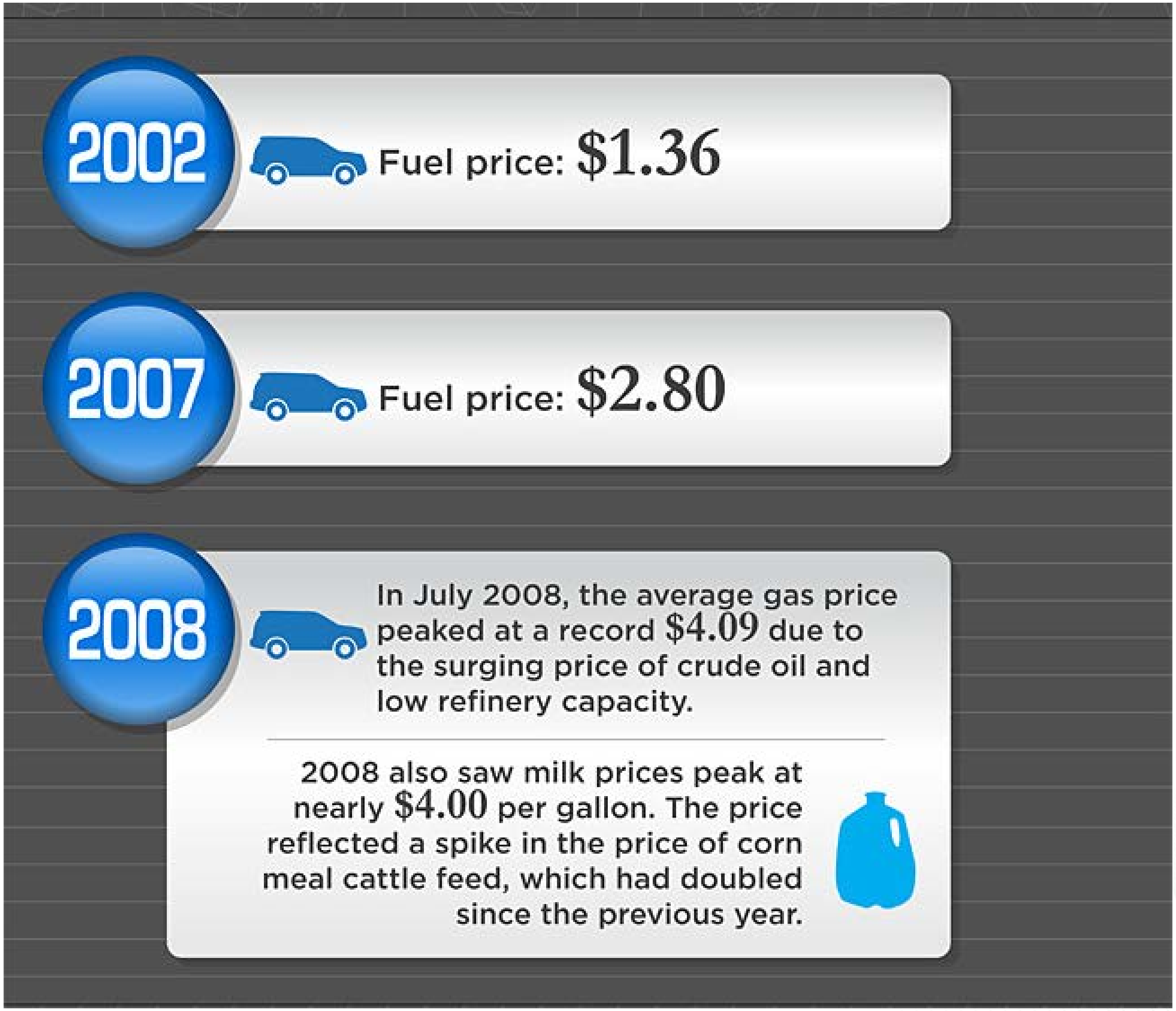
The 2000s.....

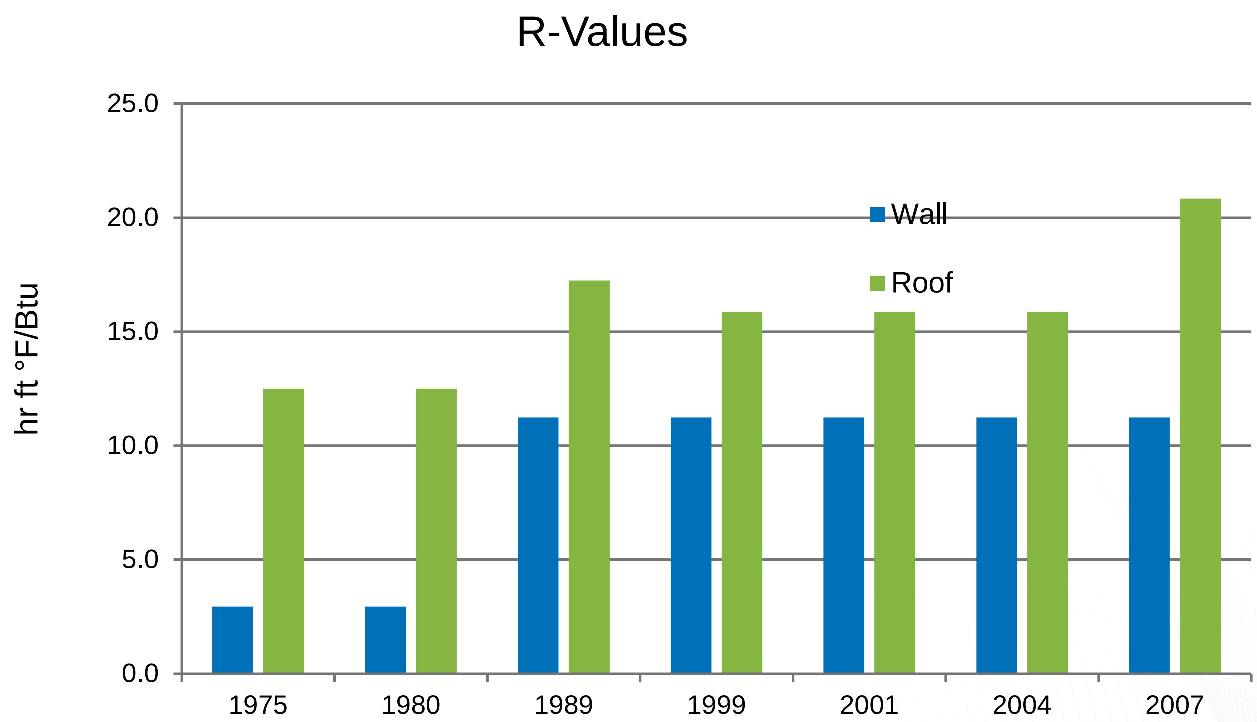
- 9/11 and invasions of Afghanistan and Iraq
- Hurricane Katrina
- Facebook, YouTube, and Twitter launched
- World economic downturn
- BEST 1 Conference held

2000s trivia



Three updates of ASHRAE Standard 90.1 requires 17% energy efficiency improvement

Wall and Roof Requirements for Kansas City MO



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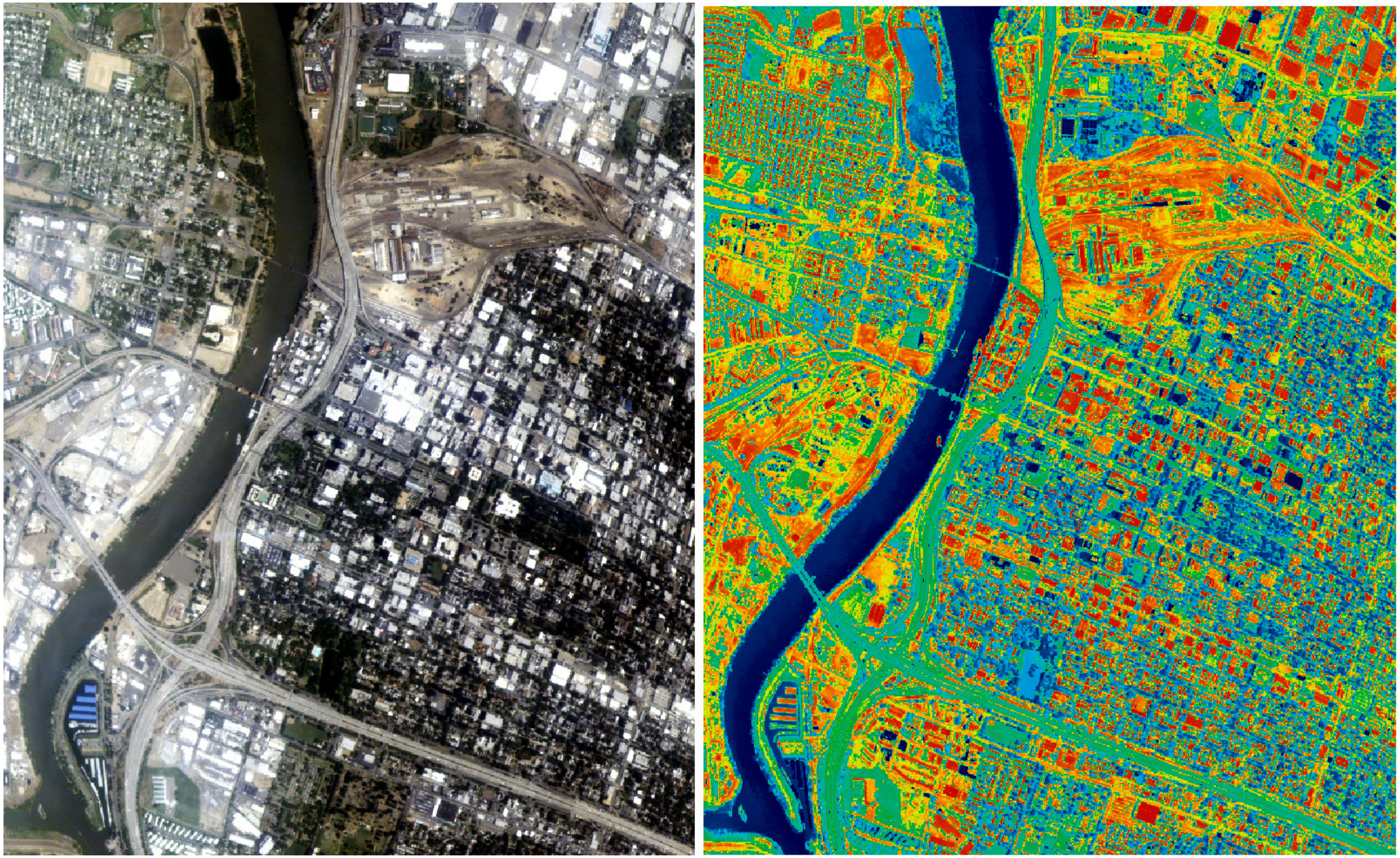
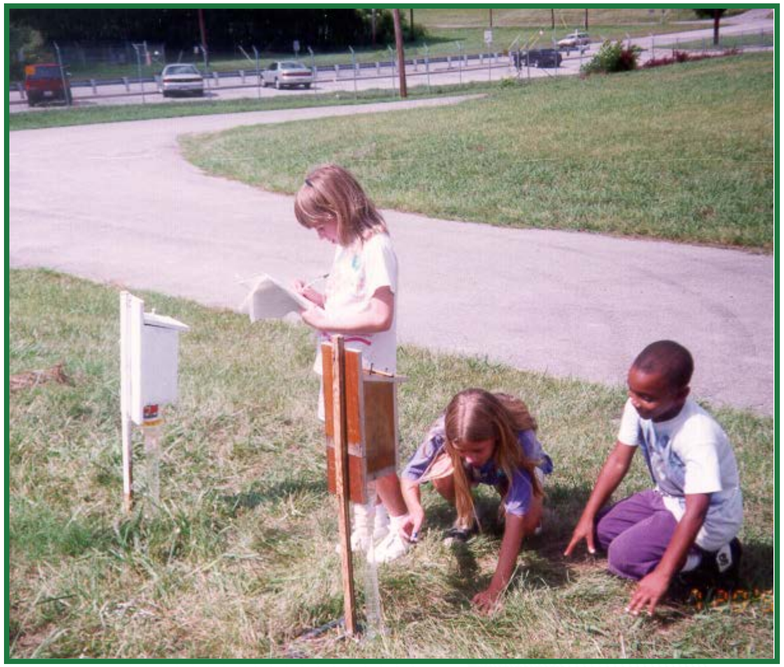
Cities can be HOT



NASA infrared Sacramento (1998)

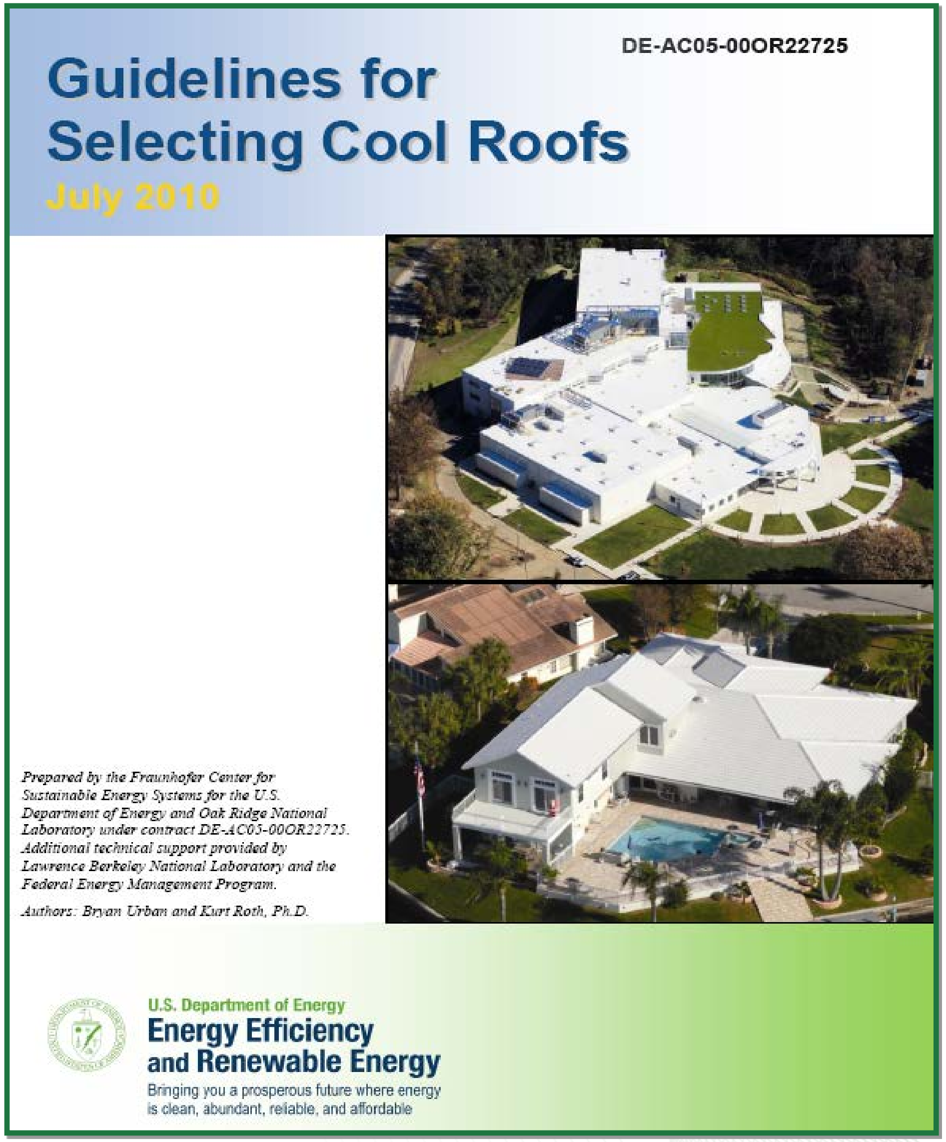
Image: NASA/Marshall Space Flight Center

Proof of concept



When do cool roofs save energy?

- What climate zone?
- What happens when they get dirty?
- How about more insulation…..
- Ballast……


DE-AC05-00OR22725

Guidelines for Selecting Cool Roofs

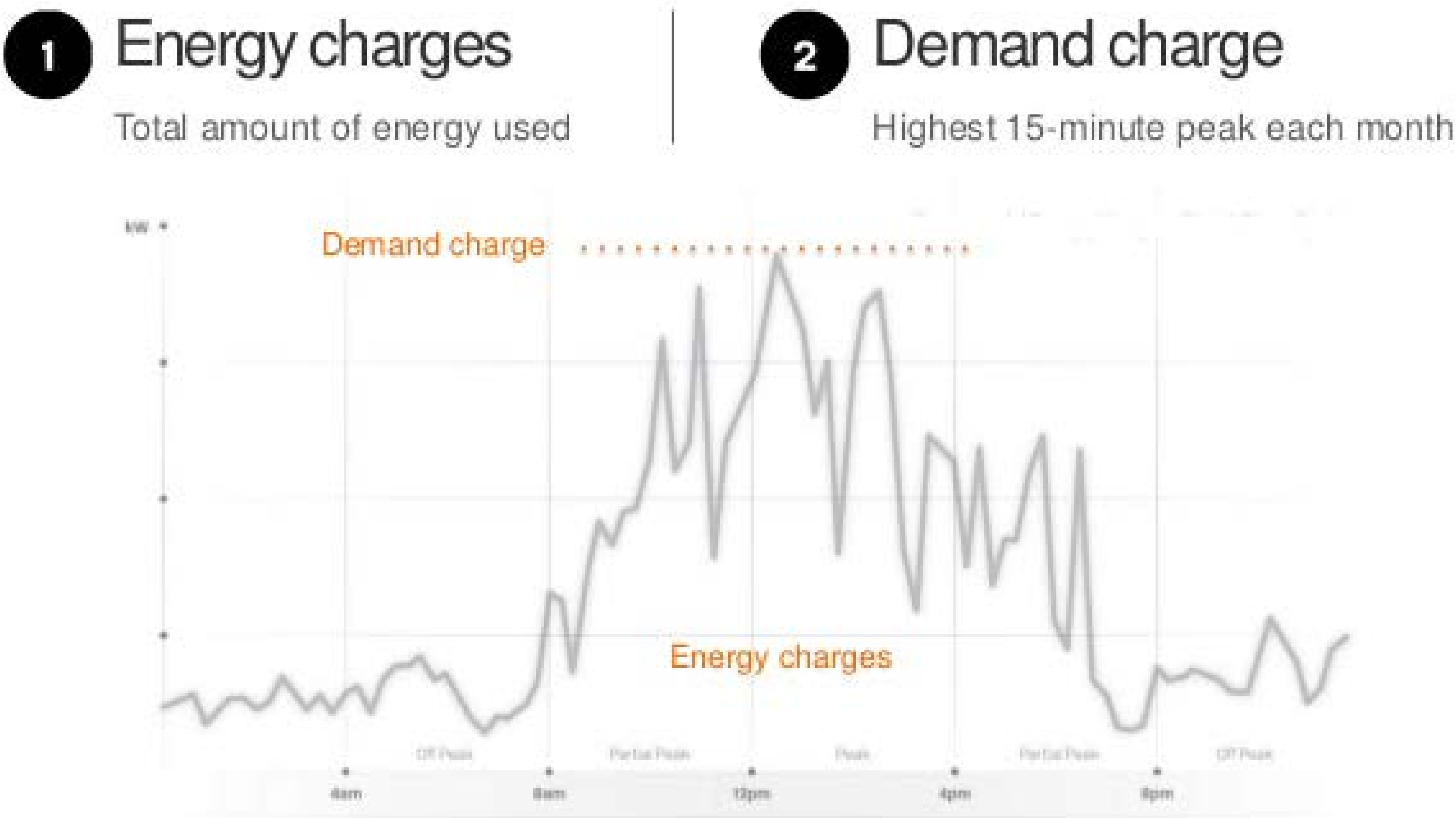
July 2010

Prepared by the Fraunhofer Center for Sustainable Energy Systems for the U.S. Department of Energy and Oak Ridge National Laboratory under contract DE-AC05-00OR22725. Additional technical support provided by Lawrence Berkeley National Laboratory and the Federal Energy Management Program.

Authors: Bryan Urban and Kurt Roth, Ph.D.

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

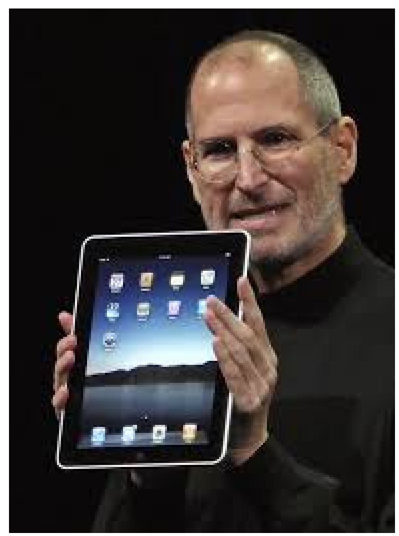
Two parts to an energy bill



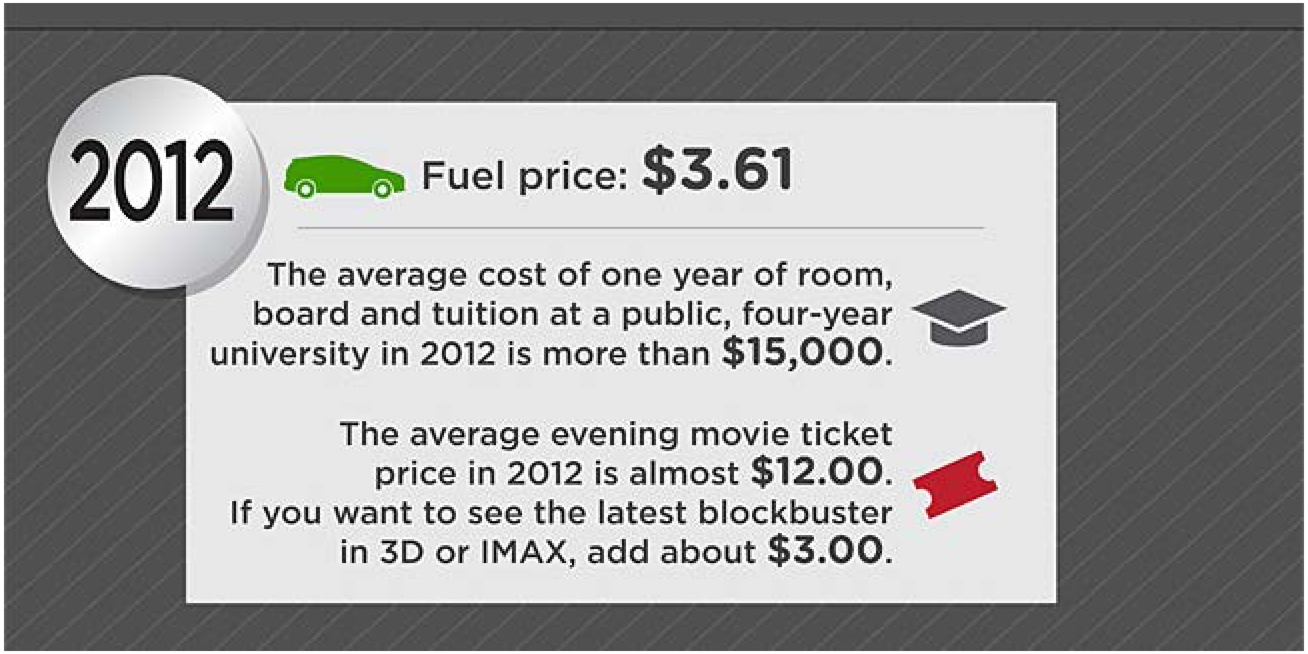
- http://web.ornl.gov/sci/roofs+walls/facts/CoolCalcPeak.htm

Today…..

- Japan hit with 9.0 earthquake
- The iPad
- US credit rating lowered
- Mayan calendar reaches end….
- BEST 4 Conference!

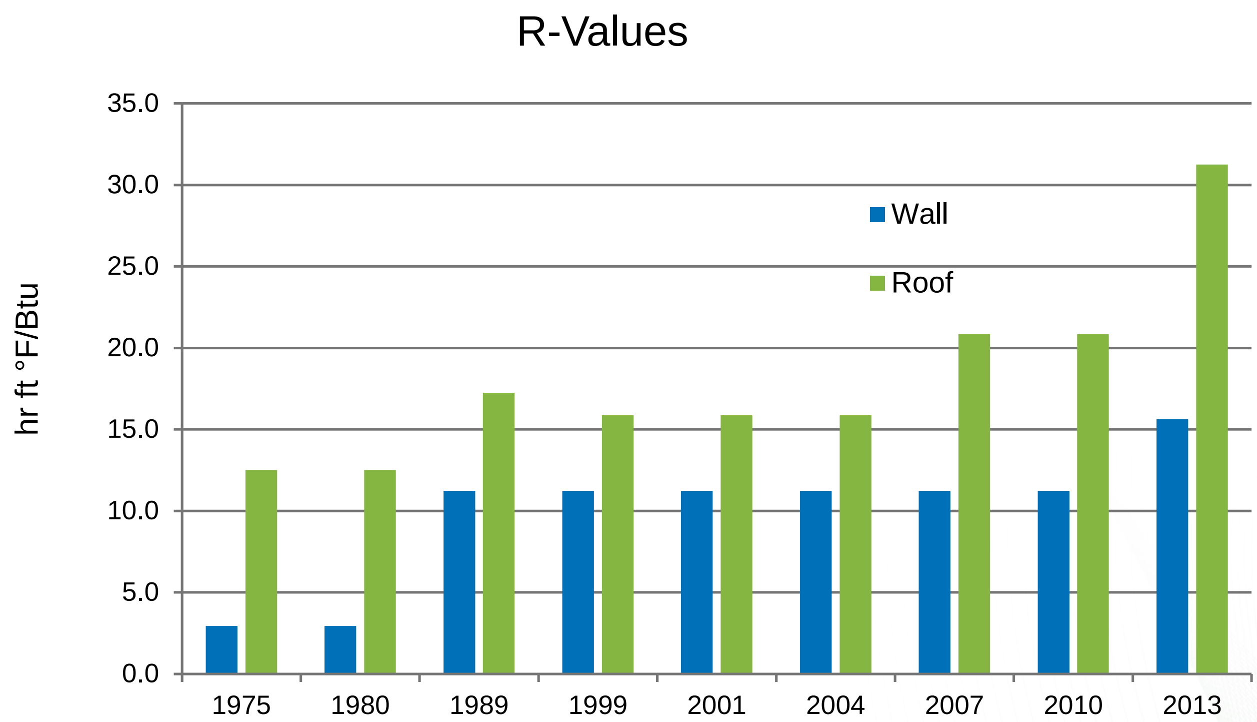


2010s trivia



Two updates of ASHRAE Standard 90.1 requires 30% energy efficiency improvement

Wall and Roof Requirements for Kansas City MO



Facing our energy challenges

"We're using 19th and 20th century technologies to battle 21st century problems like climate change and energy security."

Remarks of President Barack Obama,
Signing of the American Recovery and Reinvestment Act, February 17, 2009

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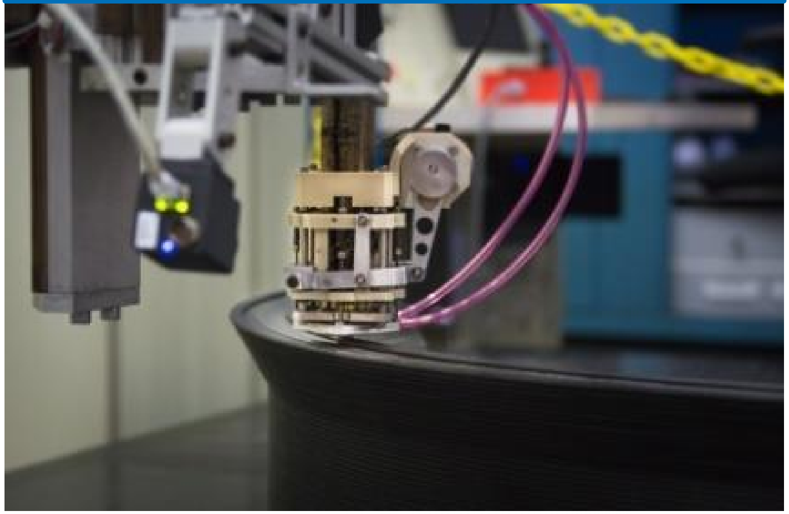
Accelerating emerging building technologies to market by leveraging additive manufacturing

Technology Solution

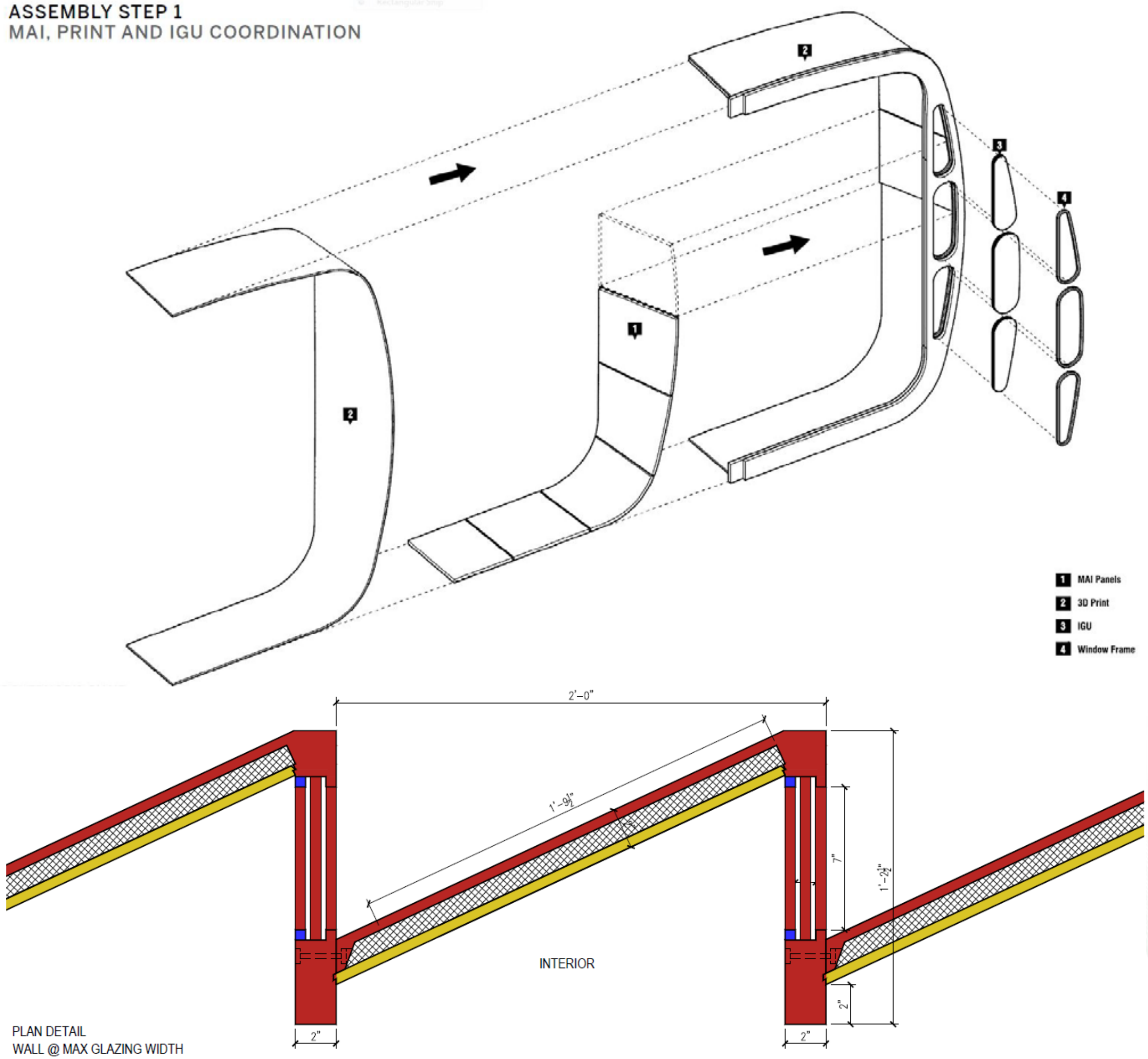
- Modified Atmosphere Insulation (MAI), emerging technology being developed under BTO FOA
- Achieves vacuum insulated panel performance at half the cost

Enabling Tool



- Big Area Additive Manufacturing
- Design and integration challenges can be determined and resolved rapidly

Creating a energy efficient shell



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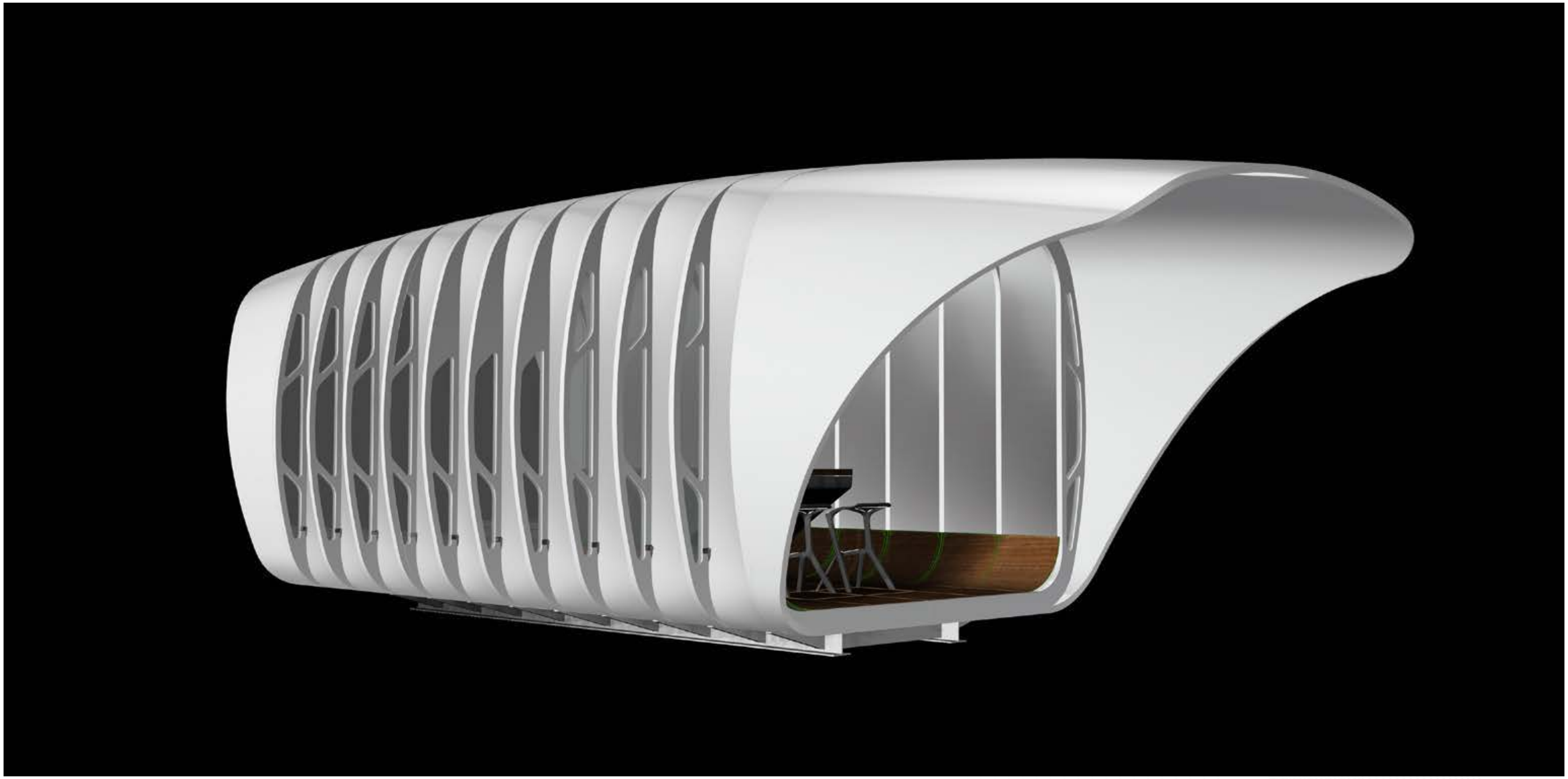
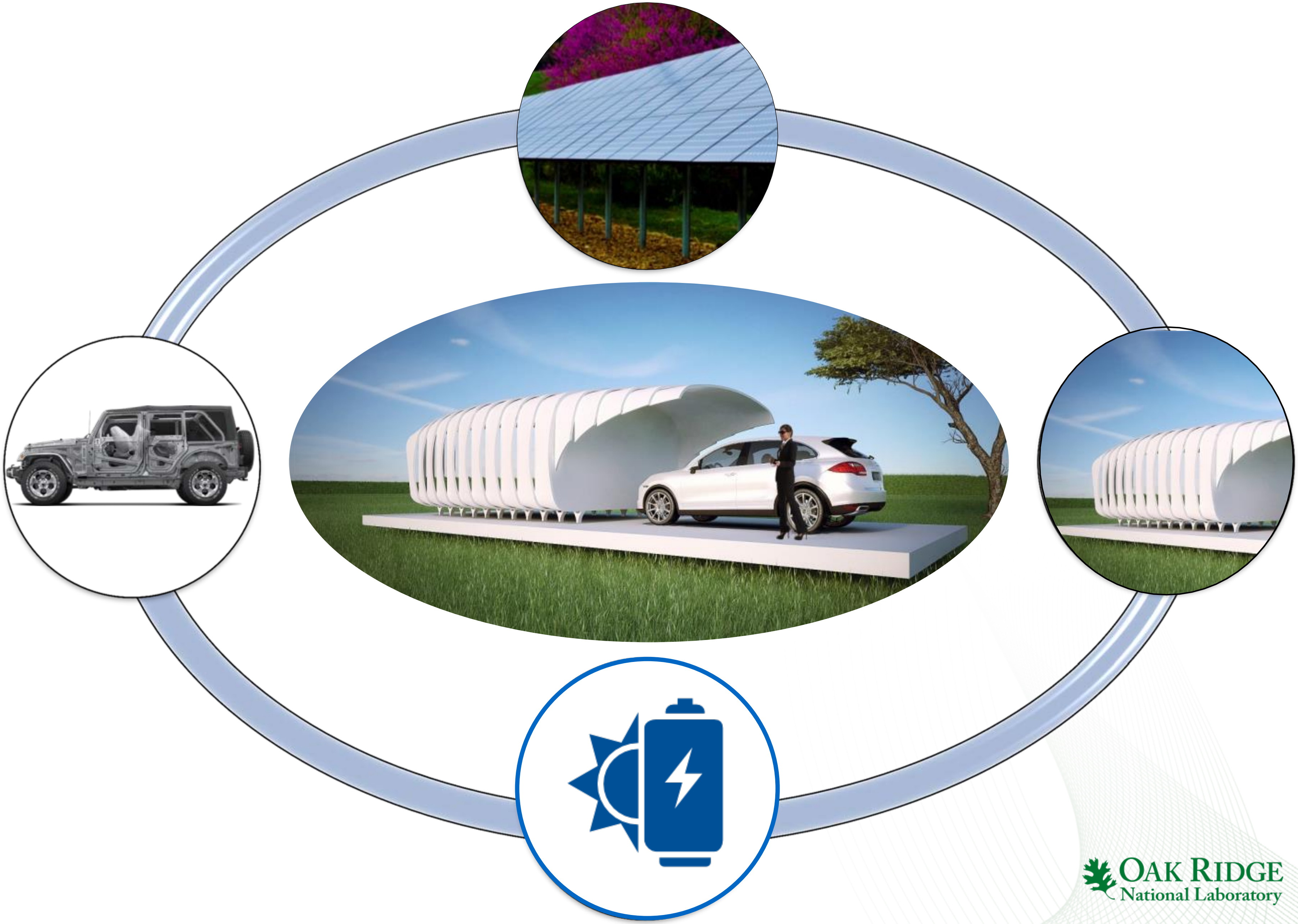
Creating a energy efficient shell



Extreme innovation demonstration



Buildings still use a lot of energy

40% of all energy and 75% of all electricity used in the US

Source: US Department of Energy

Questions?

Andre Desjarlais

Building Envelopes Group

Oak Ridge National Laboratory

desjarlaisa@ornl.gov

Three updates of ASHRAE Standard 90.1 requires 17% energy efficiency improvement

Credit: Mark Halverson, PNNL

Improvements in stringency from Standard 90-75 to 90.1-2010.

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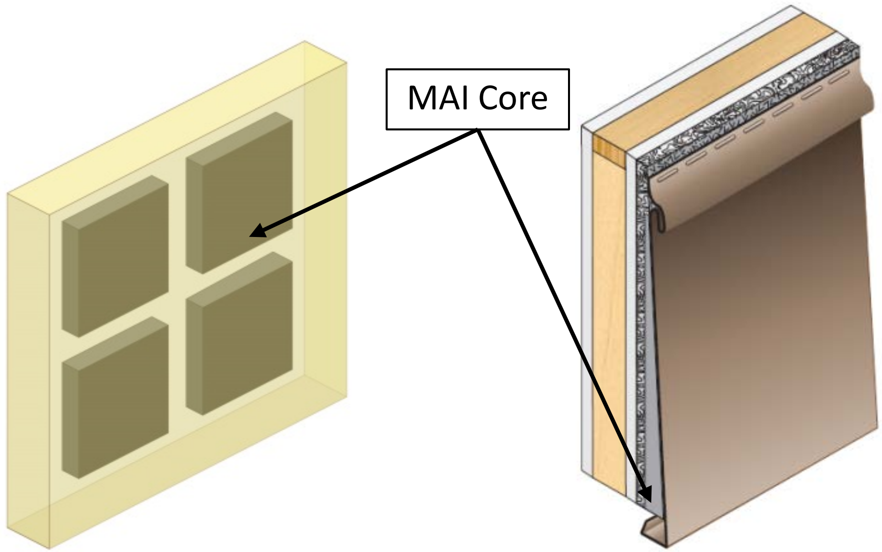
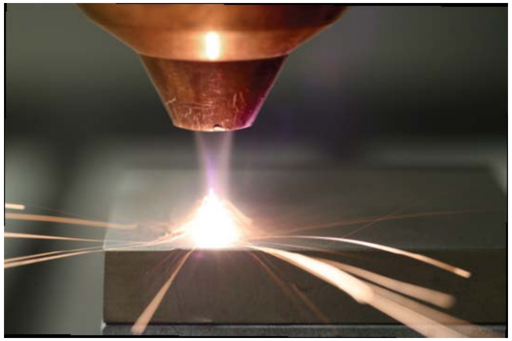
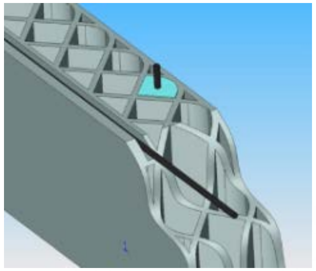
Potential MAI-composite Insulation Applications



MAI-foam composite

MAI-siding composite





- “Continuous exterior insulation” applications
  - Eliminate thermal bridges
  - Required by newer building codes

- **Additively-manufactured walls with MAI cores**
  - **Highly thermally-resistant walls**
  - **Walls formed around apertures – no infiltration**

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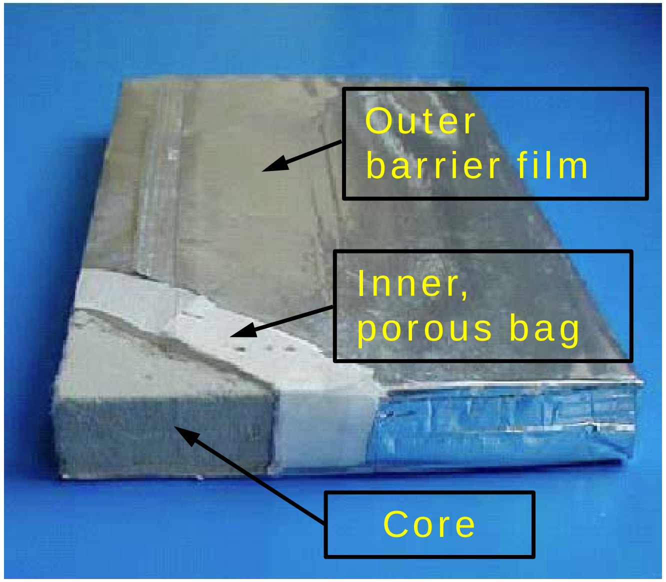
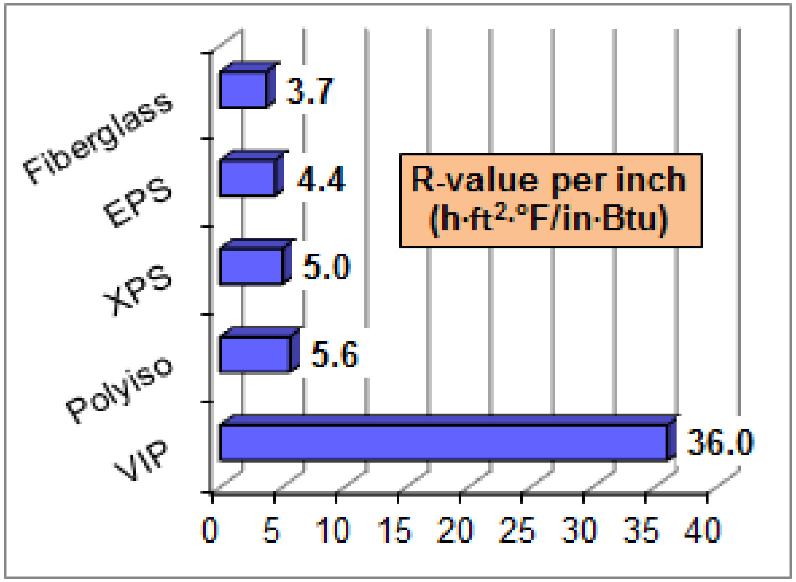
Vacuum Insulation Panels (VIPs)





- Vacuum insulation provides a significantly higher R-value that current insulation materials.
- VIPs usually comprise of a nano/micro-porous core (e.g., fumed silica) encapsulated in an air and vapor impermeable barrier film and evacuated (~ 5 mbar).

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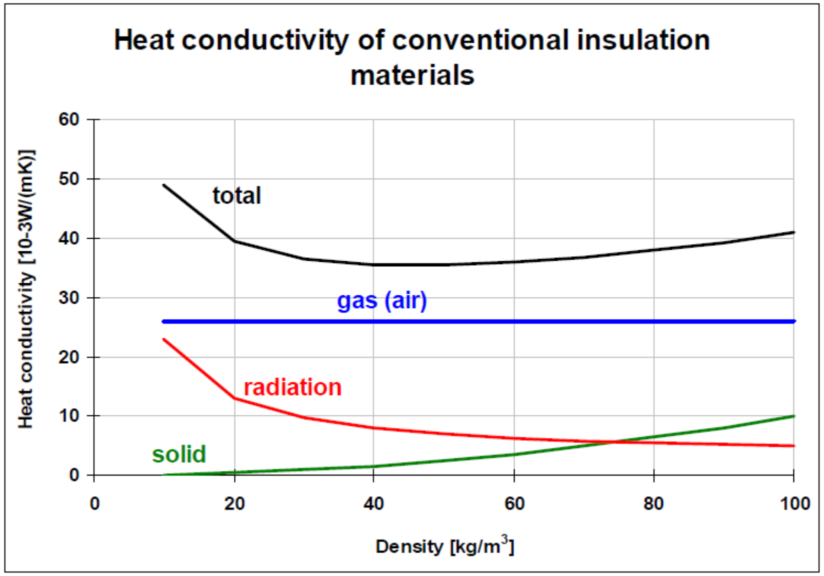
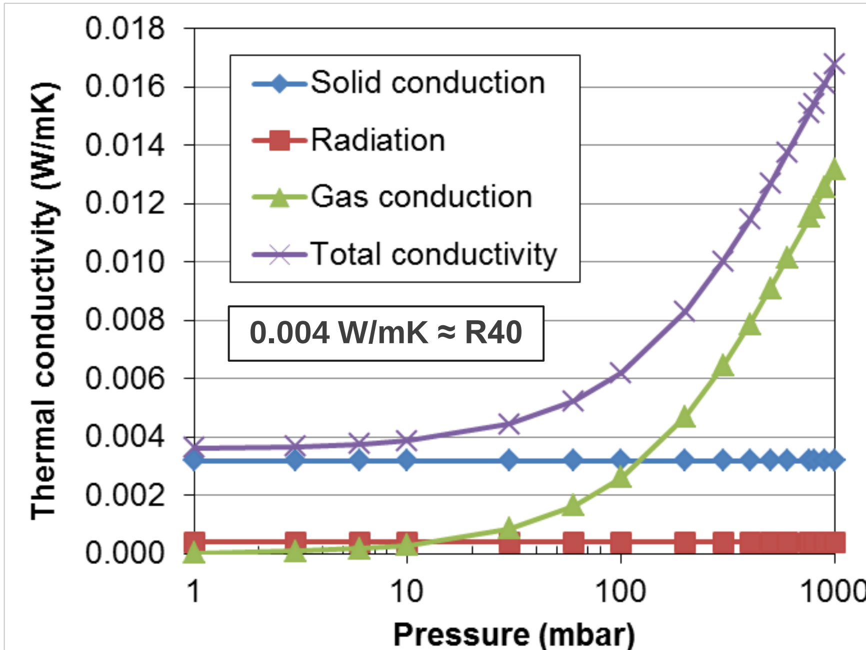
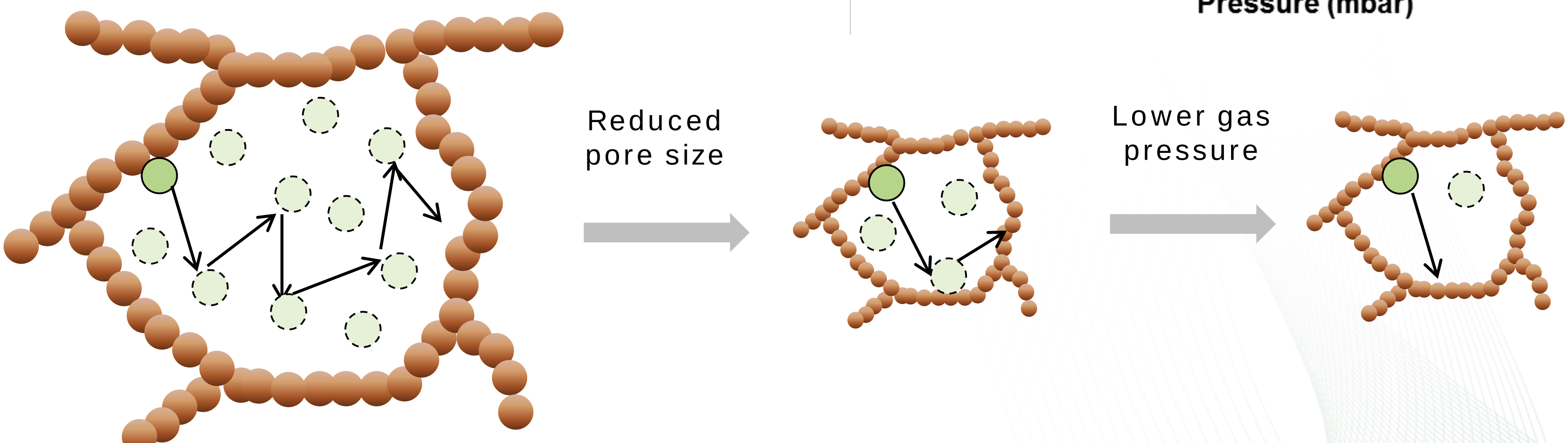
Heat Transfer in Insulation Materials







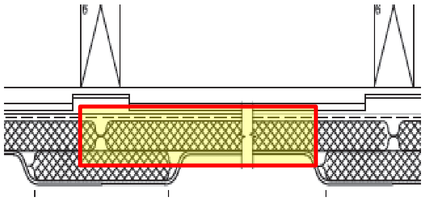
Sources: Shukla et al., 2013, Buildings XII International Conference; Doug Smith (NanoPore).

Rapid innovation in building technologies

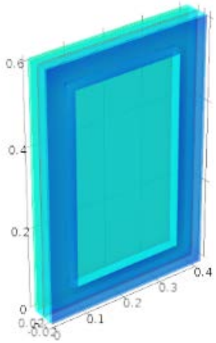
Initial design

Modeled Performance

Prototype



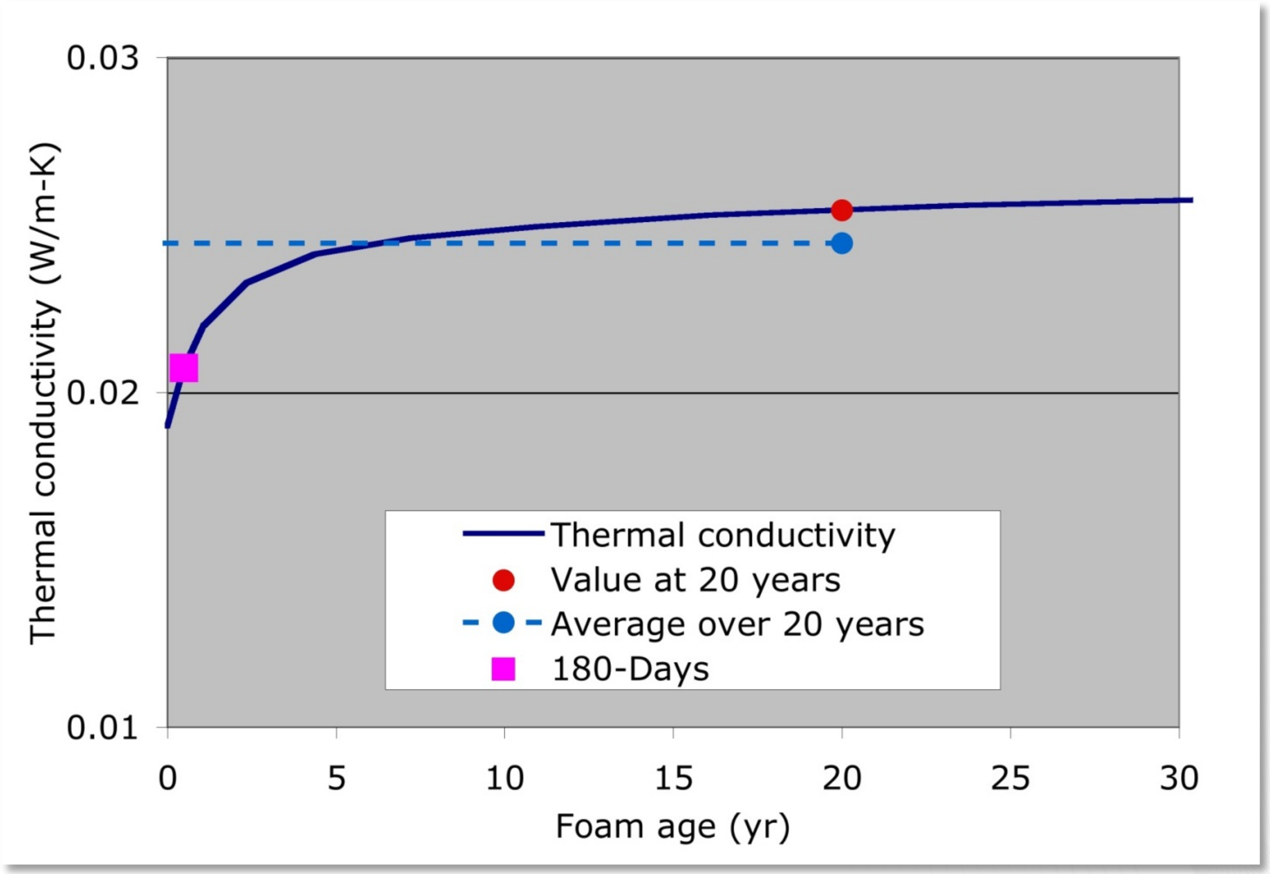
New design reduces thermal bridging



Increases thermal performance from ~R-15 to ~R-30

From design to prototype < 3 hours

Which k-value for a product that ages?



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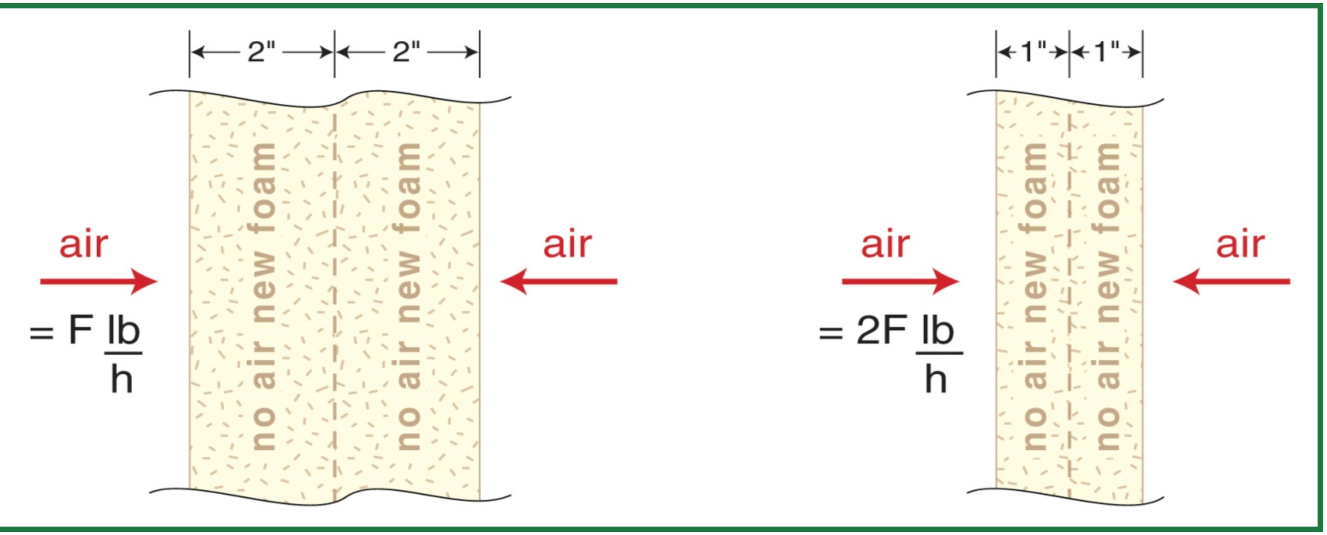
How does geometric scaling work?

- Aging follows Fick's Law of gas diffusion
- Cutting thickness by 2 reduces aging time by factor of 4

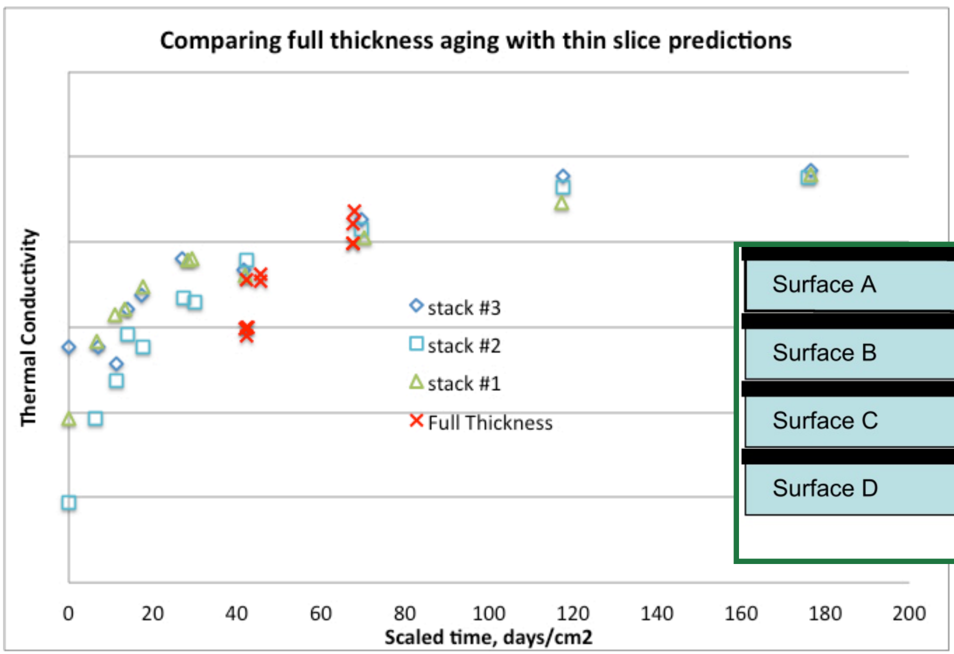


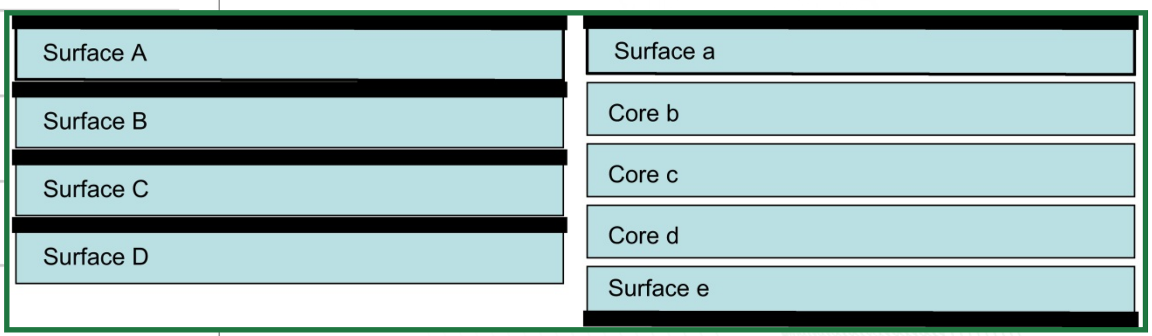
Gas at centerline same as outside in 4 years

Gas at centerline same as outside in 1 year

ASTM C1303

- Does theory work for ‘real’ products?
- 2006 - 2012
  - Four manufacturers
  - Eight products
  - Comparing predictions to 5 year lab aging
  - Learning which test parameters work best for each product



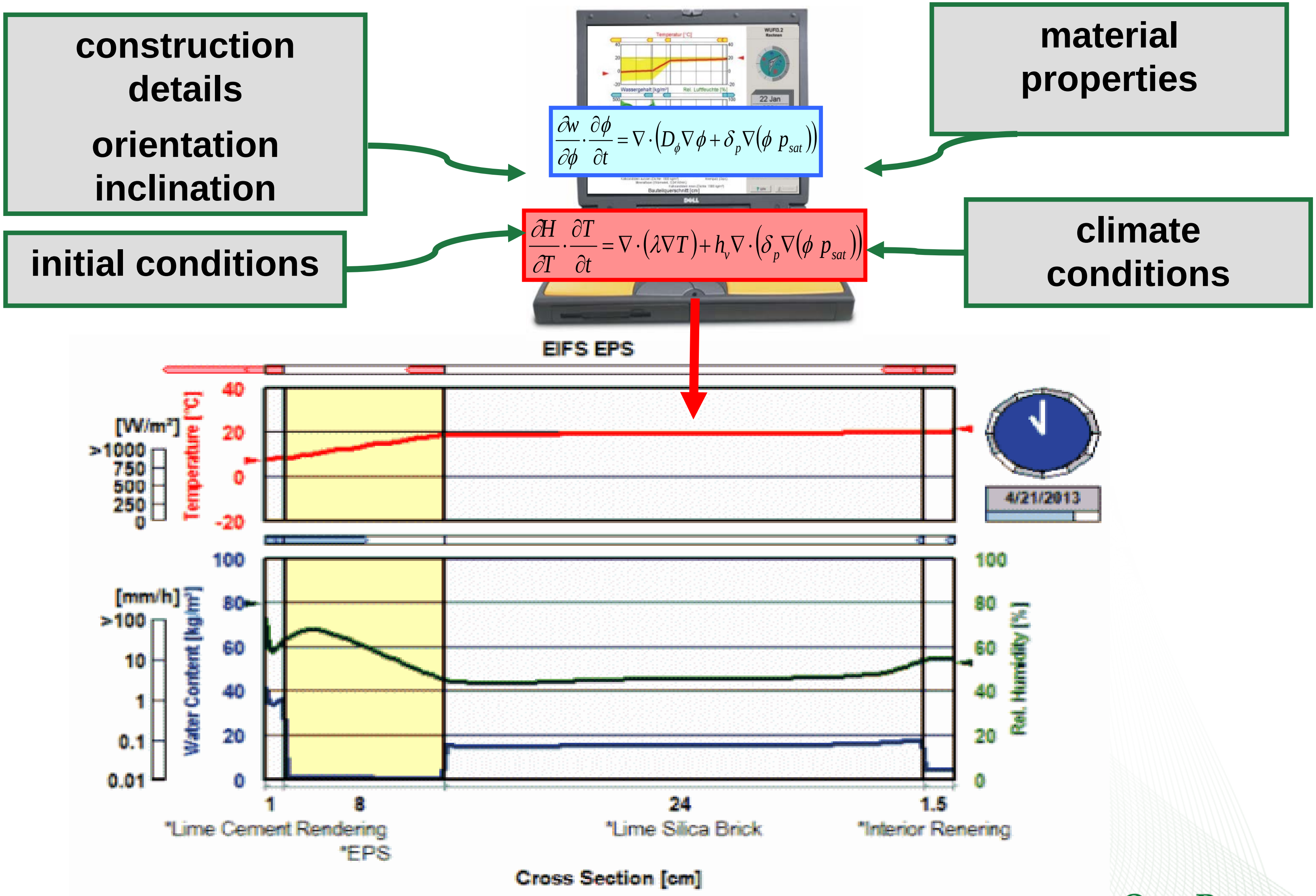


Constructing the data set: ~ 1300 observations

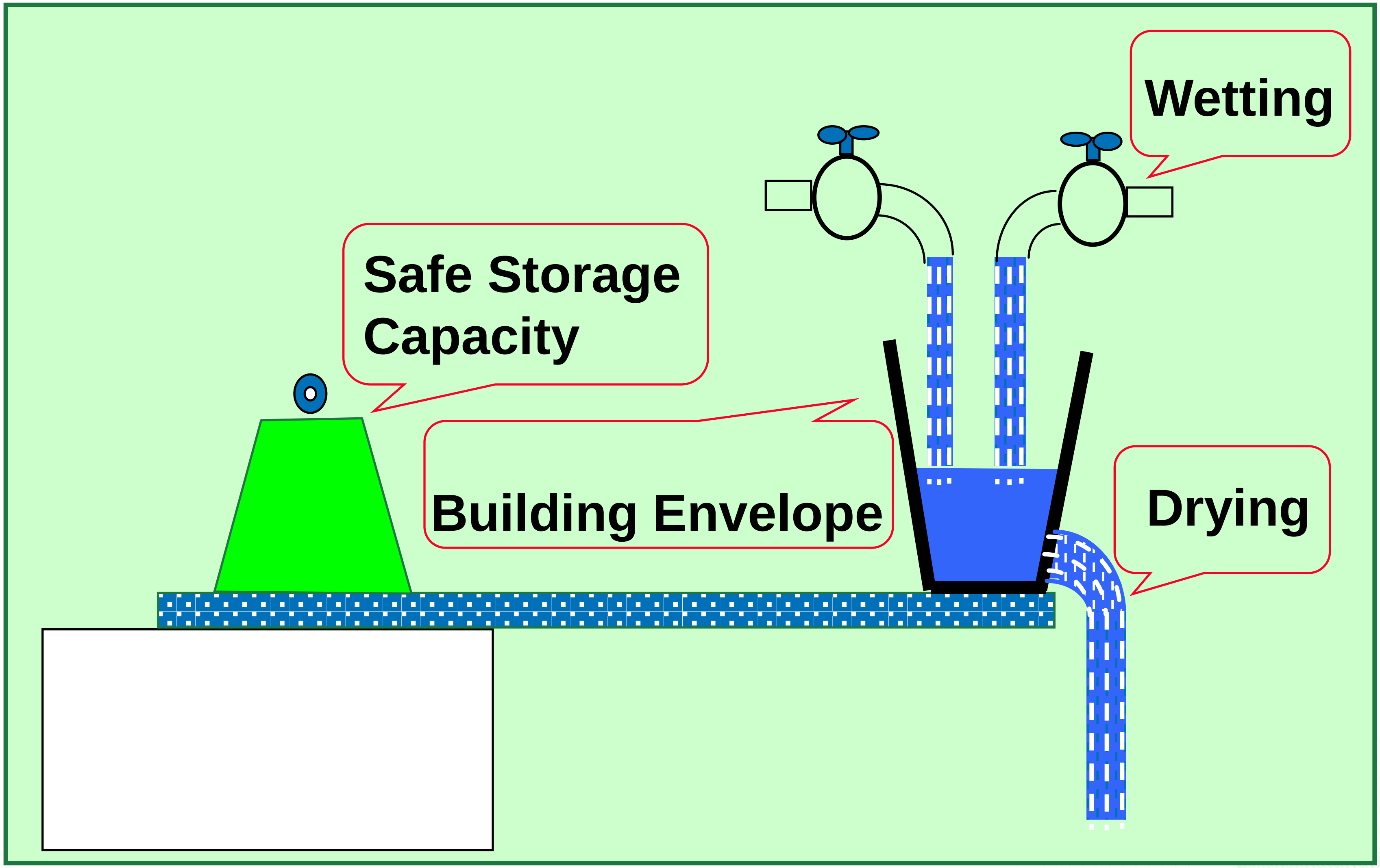
Alternate product thickness		PIR	XPS
Stack	Surface	2.2	-1.0
	Core	-0.8	5.5
	Mixed	1.5	2.4
	Profile	Not app	Not app
	Math	0.9	2.1
Slice origin product thickness	1 inch	-1.0	Not sig.
	2 inch	0.6	.8
	3 or 4 inch	3.5	4.9

Same product thickness		PIR	XPS
Stack	Surface	1.6	-2.2
	Core	-0.5	3.4
	Mixed	0.9	0.8
	Profile	0.9	0.7
	Math	0.3	1.1
Product thickness	1 inch	-2.1	2.4
	2 inch	2.4	0.7
	3 or 4 inch	5.0	2.3

WUFI software

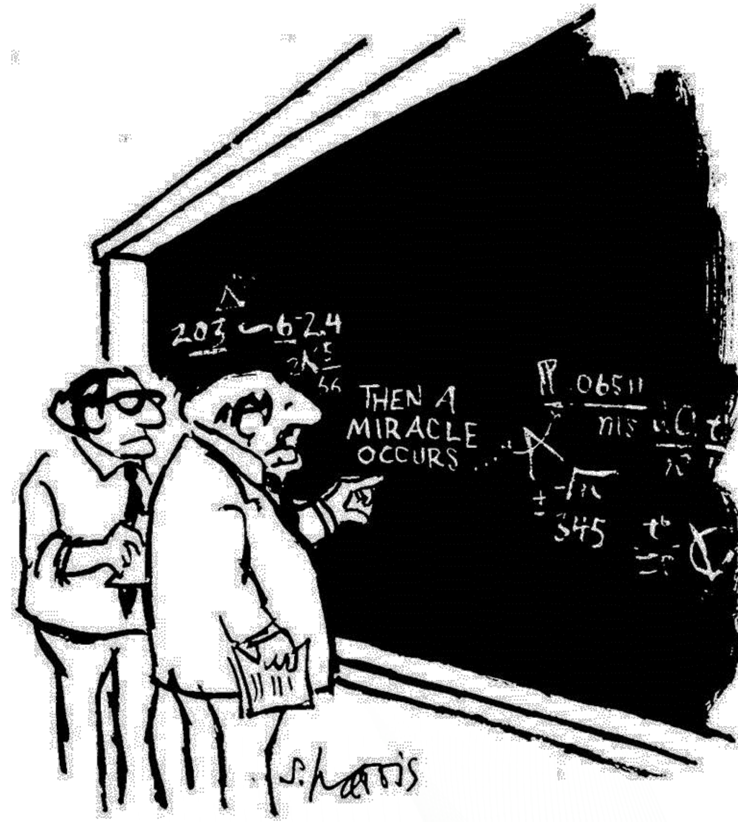


Hygrothermal balance



Hygrothermal models

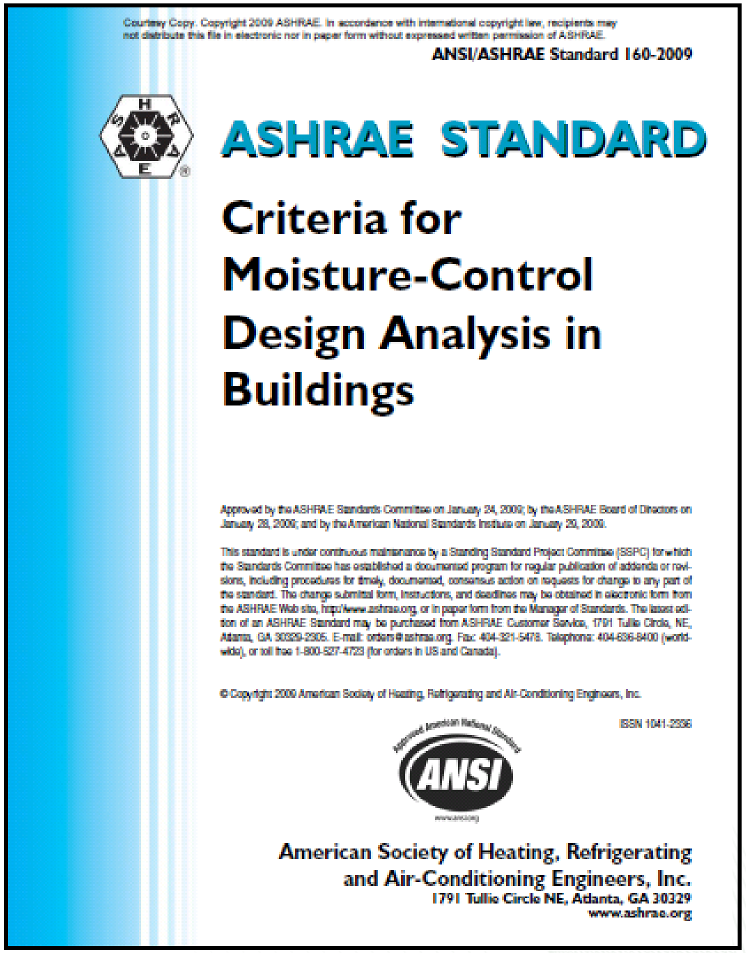
- The operator requires knowledge, skill, and experience
- Important to balance input data and results with engineering experience and judgement
- Must understand
  - boundary conditions
  - material properties
  - transport mechanism
  - deterioration/damage mechanism
  - construction realities
- Most models are presently 1-D



"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

ASHRAE standard available

ASHRAE 160 Standard: *Criteria for Moisture Control Design Analysis in Buildings*



ANSI/ASHRAE Standard 160-2009

ASHRAE STANDARD

Criteria for Moisture-Control Design Analysis in Buildings

Approved by the ASHRAE Standards Committee on January 24, 2009; by the ASHRAE Board of Directors on January 28, 2009; and by the American National Standards Institute on January 29, 2009.

This standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE Web site, http://www.ashrae.org, or in paper form from the Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 404-321-5478. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada).

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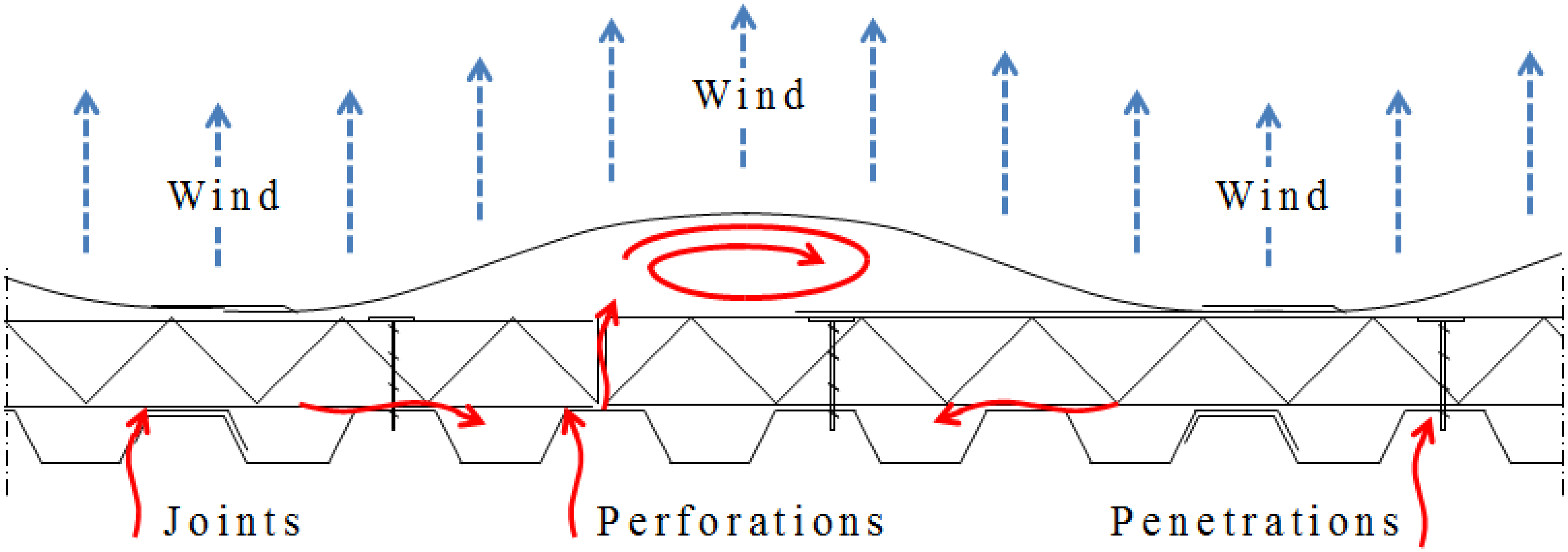
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
1791 Tullie Circle NE, Atlanta, GA 30329
www.ashrae.org

Oak Ridge National Laboratory

WUFI modeling of cool roofs



OAK RIDGE National Laboratory

Model scenario: inputs

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

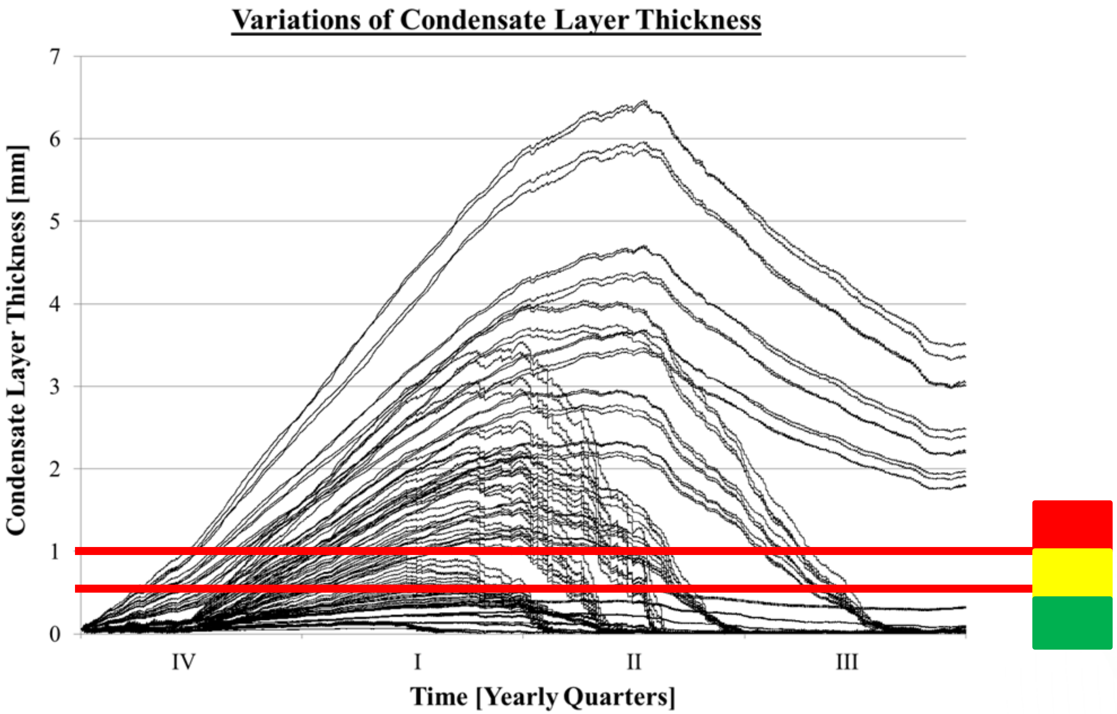
Q_{50}=0.56 [l/s,m^2] – slight leak

Q_{50}=1.0 [l/s,m^2] – average leak

Q_{50}=2.0 [l/s,m^2] – real leaky

Combination: 128 WUFI Simulations

Model scenario: evaluation of results



Thresholds

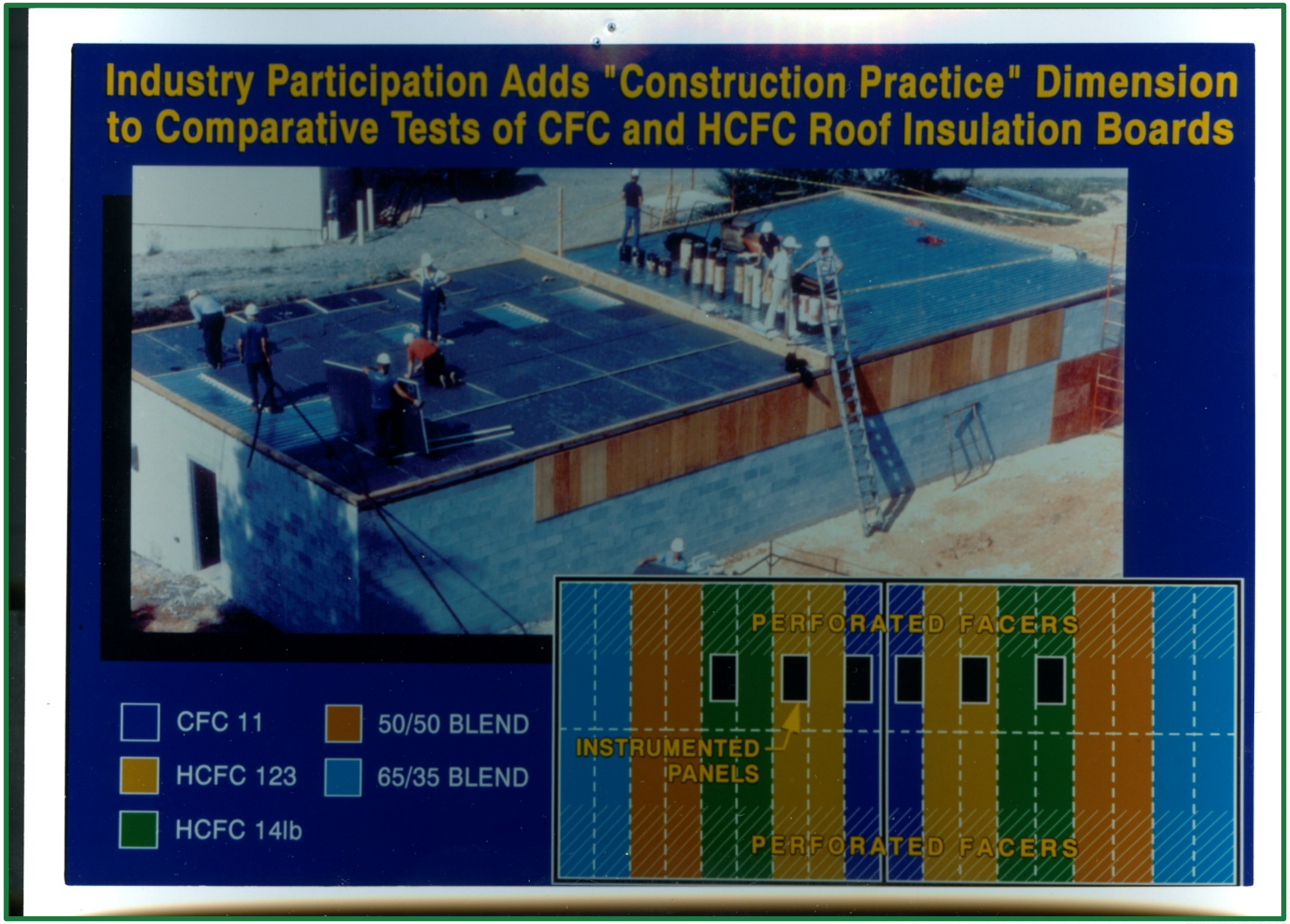
0.5 mm: **from German Standard DIN 4108-3, (Hens et al, 2003)**

1.0 mm: **from German Standard DIN 4108-3**

Model scenario: evaluation of results

Climate Zone - 4								
Indoor moisture supply	$Q_{50} = 0.27$		$Q_{50} = 0.56$		$Q_{50} = 1.0$		$Q_{50} = 2.0$	
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
Climate Zone - 5								
Indoor moisture supply	$Q_{50} = 0.27$		$Q_{50} = 0.56$		$Q_{50} = 1.0$		$Q_{50} = 2.0$	
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
Climate Zone - 6								
Indoor moisture supply	$Q_{50} = 0.27$		$Q_{50} = 0.56$		$Q_{50} = 1.0$		$Q_{50} = 2.0$	
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
Climate Zone - 7								
Indoor moisture supply	$Q_{50} = 0.27$		$Q_{50} = 0.56$		$Q_{50} = 1.0$		$Q_{50} = 2.0$	
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

Working together.......



Quiz

With Comfort and Energy Efficiency in mind, which car do you select to drive in the summer?