Thermal Metric Project

Westford Symposium
2011.08.03

C. J. Schumacher
Building Science Corporation

Outline

- Objective
- Approach
  - Apparatus:
    - Double Guarded Hot Box
  - Method:
    - 3 key elements
- Some Results
- Test Program
- Lessons

2

Objectives

3

The Goal: a new metric

- Develop a thermal performance rating system or ***metric*** that provides a means of crediting 'properly' built assemblies while penalizing 'poorly' built assemblies

  (of all types)

  Means of crediting assemblies with good thermal control (materials, system design & construction quality)

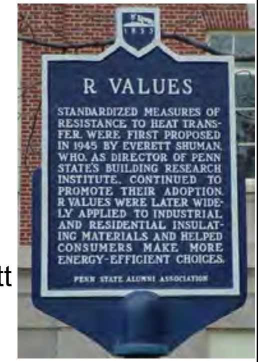
4

What about the old metric?

R-Value

- Property of a material
- Measurement of resistance to heat flow

- Proposed in 1945 by Everett Schuman, Penn State's Housing Research Institute



5

Benefits of R-Value

- Widely Accepted
  - FTC Regulation
- Simple to Measure
  - Commercially available test machines
- Easy to Communicate
  - ONE Number at standard temperature
  - Lumps all 3 modes of heat transfer into an *effective* conductivity
    - Conduction
    - Convection
    - Radiation

R-value Survey

Assume R30 insulation

Does insulation R-value change with outdoor temperature?

YES
or
NO

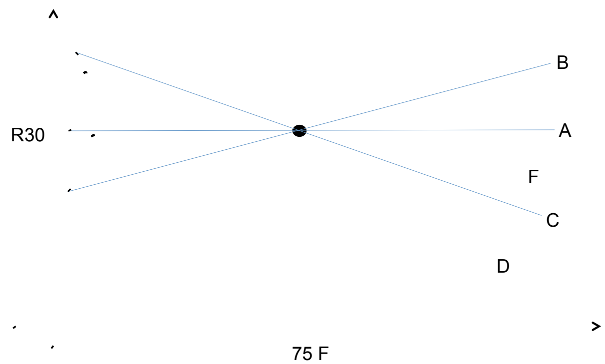
7

R-value Survey (pt 2)

As the outdoor temperature decreases does the R-value:

1. Increase
2. Decrease
3. Both 1 & 2
4. None of the above
5. I don't know, I'm still thinking about the BBQ & beer

8



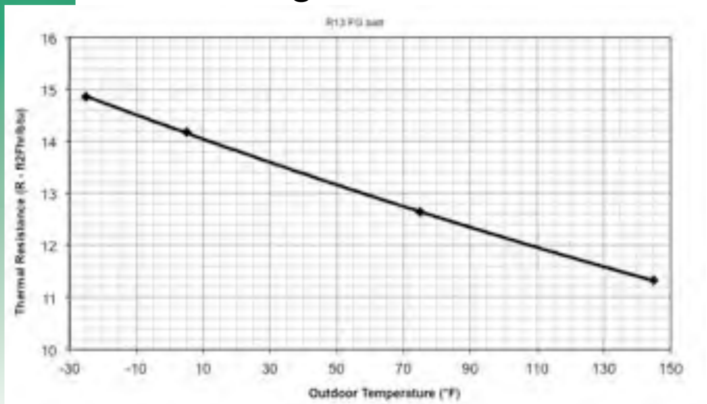
9

www.BuildingScience.com

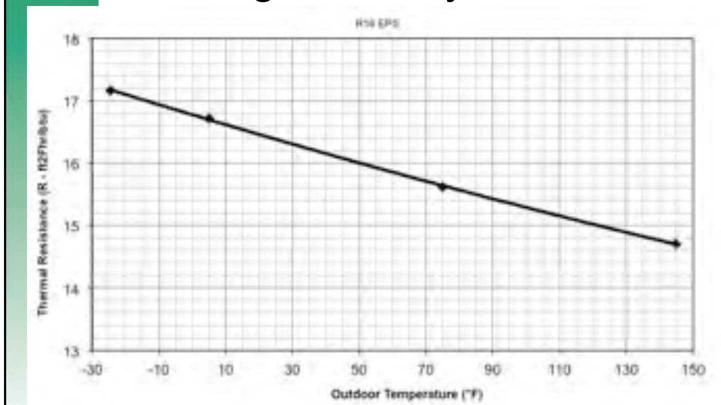
Some R-Value Measurements…

www.BuildingScience.com

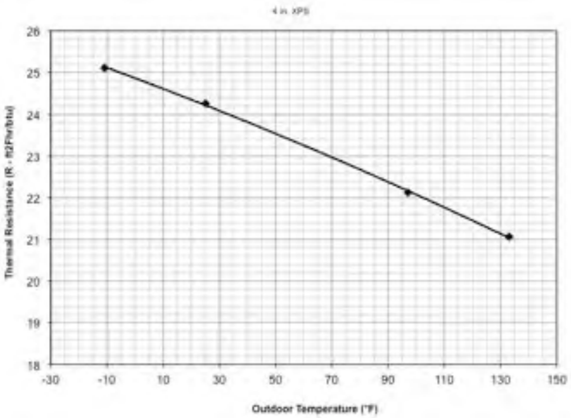
R13 Fiberglass Batt



R16 High Density EPS

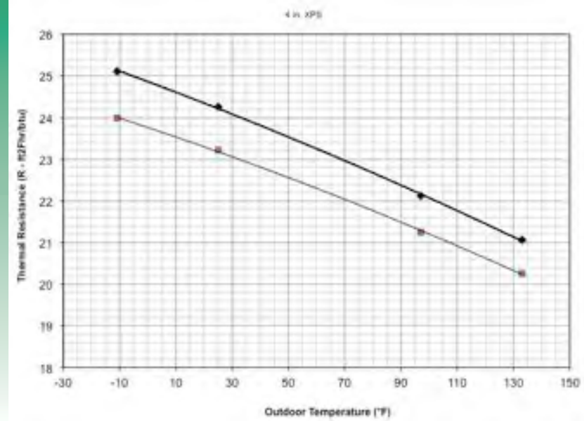


R20 XPS (2 months old)



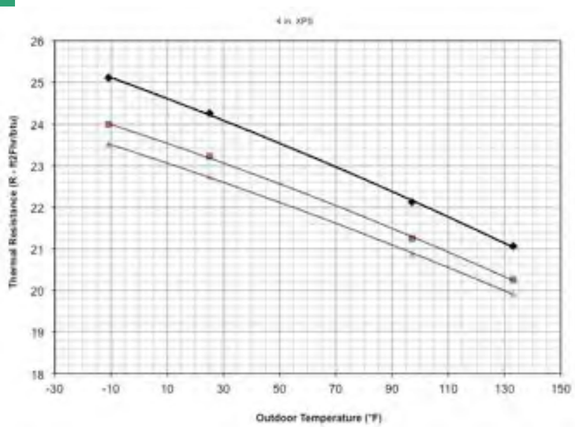
www.BuildingScience.com

R20 XPS (2, 4 months old)



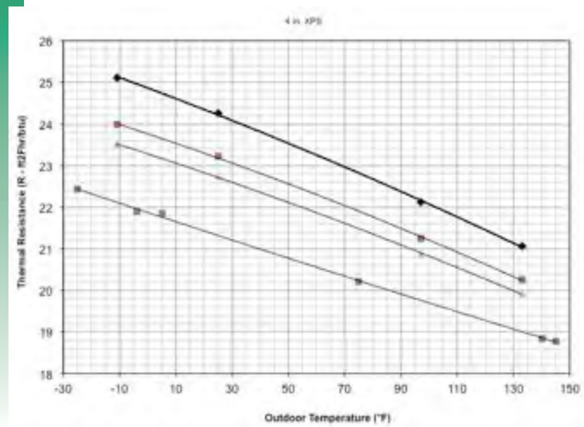
www.BuildingScience.com

R20 XPS (2, 4, 6 months old)



www.BuildingScience.com

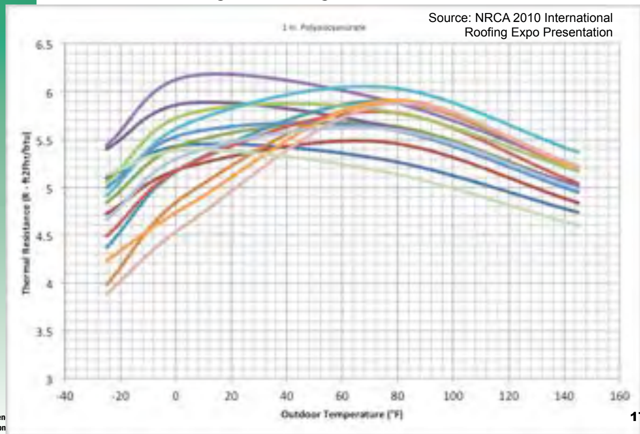
R20 XPS (2, 4, 6, 44 months old)



www.BuildingScience.com

bsc

1 in. Polyisocyanurate



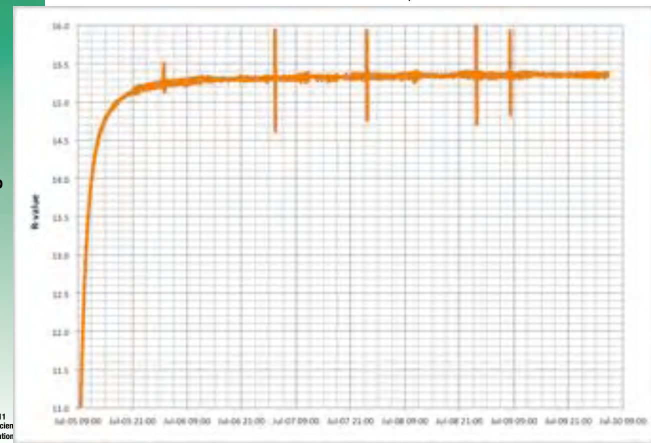
www.BuildingScience.com

17

bsc

Cellulose

Impact of moisture on measured conductance



www.BuildingScience.com

bsc

Limitations of R-Value

- Definition implies thermal performance is constant
- Only true if
  - *Effective* conductivity is constant
  - No temperature sensitivity
  - No airflow sensitivity
  - No moisture adsorption
  - Material is homogenous
- Reasonable for *some* materials
- Not reasonable for most *real* building assemblies under *real* conditions

www.BuildingScience.com

19

bsc

To develop a new metric

- Characterize *in-service* thermal performance
- Full-scale wood frame wall assemblies
- Realistic boundary conditions

www.BuildingScience.com

20

bsc

www.BuildingScience.com

Approach

21

bsc

www.BuildingScience.com

Approach

- Research work required the development of new apparatus:
  - a different type of Hot Box

new methods:
  - unique wall specimens
  - control of extra boundary conditions
  - measurement of extra variables

22

bsc

www.BuildingScience.com

Industry Partners

- Dow
- Greenfiber
- Honeywell
- Huntsman Polyurethanes
- Icynene Insulation System
- NAIMA (Certainteed & Johns Manville)

23

bsc

www.BuildingScience.com

24

www.BuildingScience.com

Apparatus

©2011 Building Science Corporation

25

www.BuildingScience.com

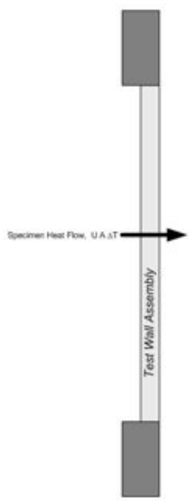
A Double Guarded Hot Box

- A Controlled, repeatable conditions
- Measure heat & mass flows

©2011 Building Science Corporation

26

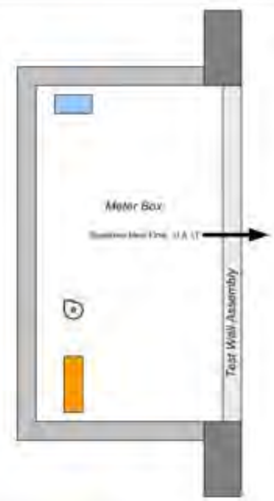
www.BuildingScience.com



©2011 Building Science Corporation

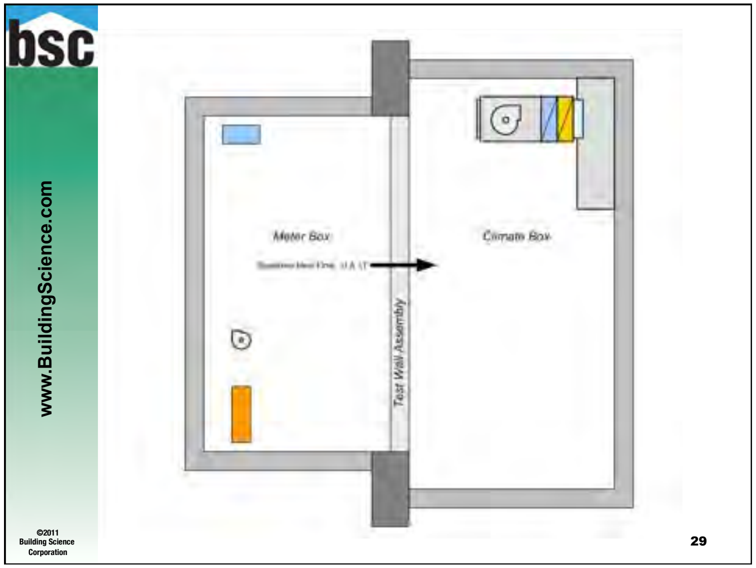
27

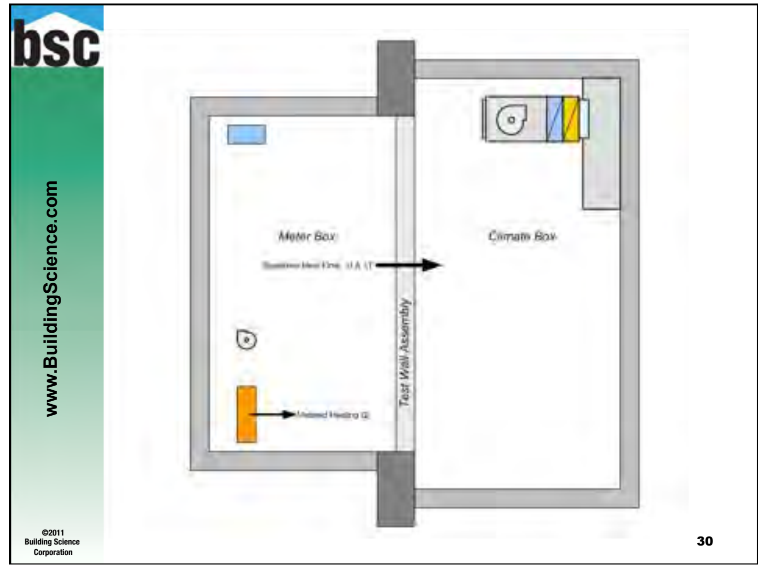
www.BuildingScience.com

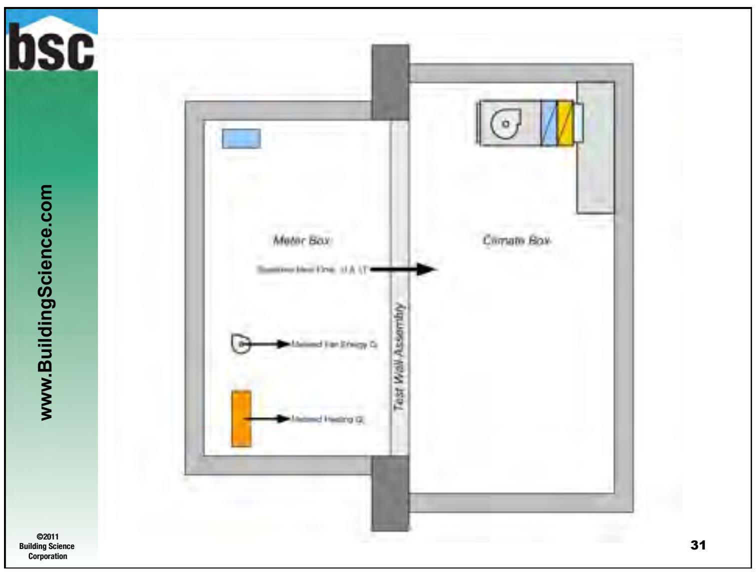


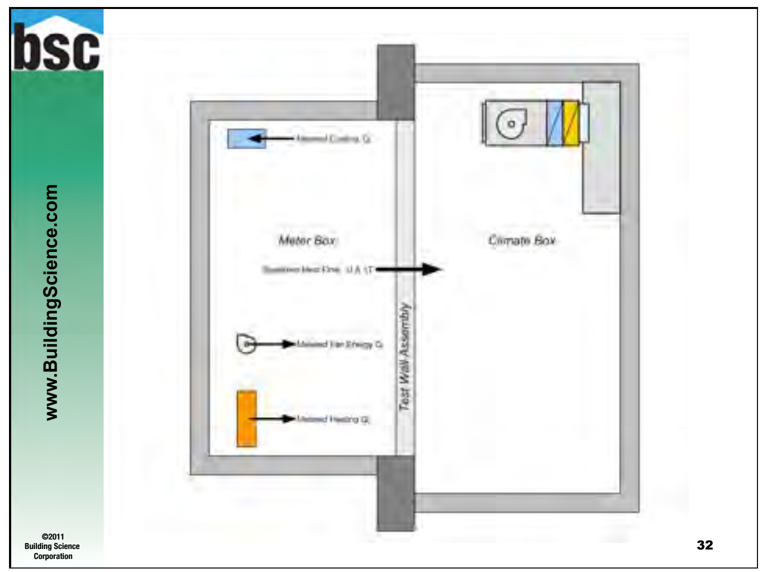
©2011 Building Science Corporation

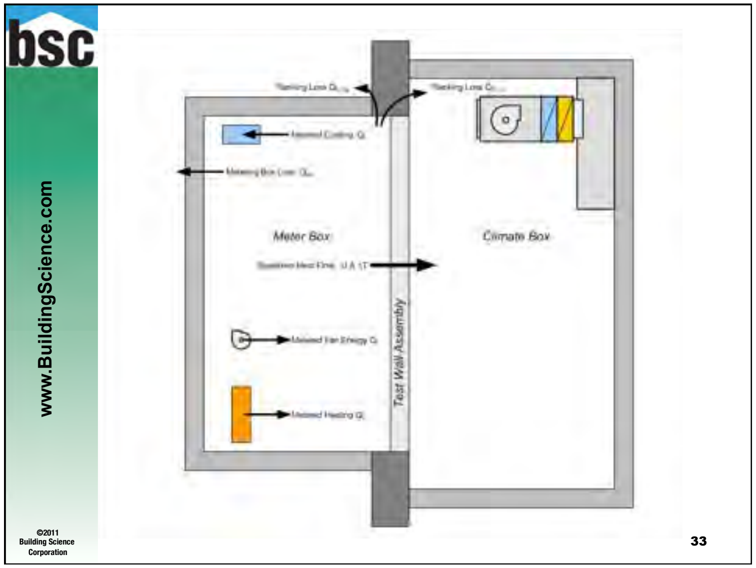
28

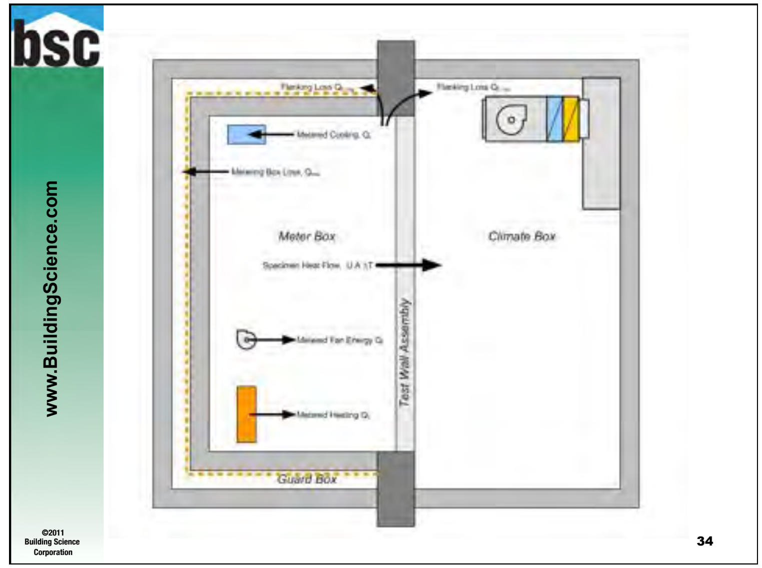

bsc
www.BuildingScience.com
Meter Box
Climate Box
Test Wall Assembly
©2011 Building Science Corporation
29

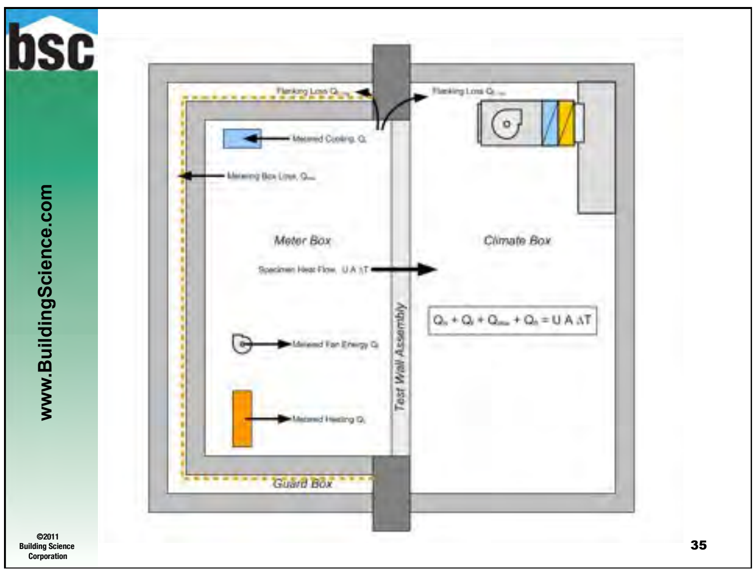

bsc
www.BuildingScience.com
Meter Box
Climate Box
Test Wall Assembly
©2011 Building Science Corporation
30


bsc
www.BuildingScience.com
Meter Box
Climate Box
Test Wall Assembly
©2011 Building Science Corporation
31


bsc
www.BuildingScience.com
Meter Box
Climate Box
Test Wall Assembly
©2011 Building Science Corporation
32







bsc

www.BuildingScience.com

Hot Box

- Double Guard
- Deep Meter Box
  - accommodate complex geometries
  - e.g. wall / floor intersections
- Meter Box heating & cooling
- Measure energy and mass flows
  - Air transfer system
  - Tracer gas system

36

Hot Box

- Wall specimen size:
  8' x 12' (2.4 x 3.6 m)
- Temperature range:
  -40 to 150 F (-40 to 65 C)
- deltaP & air flow:
  +/-75 Pa & 30 cfm (300 lpm)

www.BuildingScience.com

37

Method

www.BuildingScience.com

38

Three Key Elements:

- Wall specimen 'blanks'
  - Wall frames with controlled, realistic & reproducible airflow paths
- Testing with imposed pressure difference
  - 10 Pa driving Exfiltration & Infiltration
- Measurement of the air movement
  - Tracer gas for ALL tests

www.BuildingScience.com

39

Wall specimen 'blanks'

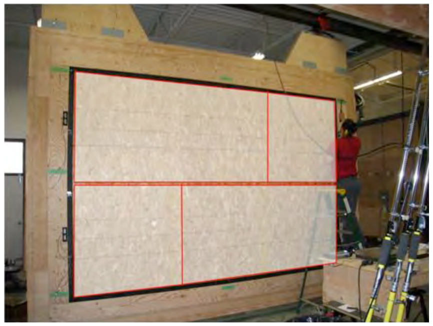
- Framed walls designed and constructed to allow airflow paths that are
  - Realistic
  - Controlled
  - Reproducible

www.BuildingScience.com

40

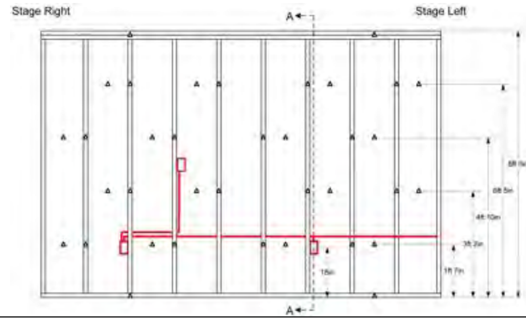
Airflow path 1 of 3

- 1/8 in. horizontal gap between sheathing
  (per APA installation recommendations)



Airflow path 2 of 3

- 3 standard (non-gasketed) electrical boxes and associated wiring (precedence Ober 1994, NAHB 2009)

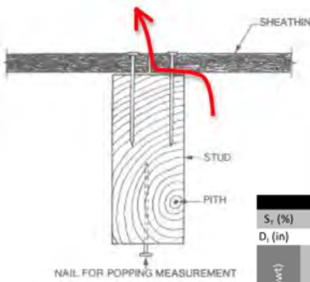


Airflow path 3 of 3

- 1/32 in. gaps between top & bottom plates and OSB & GWB
- *Controlled* – use high tolerance steel shims
- *Realistic* – representative of gaps that open as framing dries & shrinks (Onysko & Jones, 1989)
- *Reproducible* – air leakage for the same wall four constructed times:

  0.22 to 0.26 cfm50/ft^2

Onysko & Jones

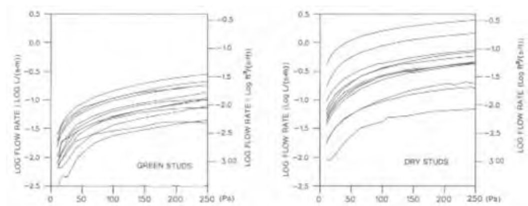


$$\Delta D = \frac{D_1(M_F - M_1)}{30(100)/S_T - 30 + M_1} \quad (13\text{–}3)$$

Predicted change in dimension (in/1000)							
S_T (%)	7	Starting Moisture Content (%wt)					
D_I (in)	3.5	20	18	16	14	12	10
Ending MC (%wt)	20	0	17	34	51	68	86
	18	-17	0	17	34	51	69
	16	-33	-17	0	17	34	51
	14	-50	-34	-17	0	17	34
	12	-67	-50	-34	-17	0	17
	10	-84	-67	-51	-34	-17	0
	8	-100	-84	-68	-51	-34	-17
	6	-117	-101	-84	-68	-51	-34

Onysko & Jones

- At 10 Pa pressure difference shrinkage resulted in 4x increase in air leakage



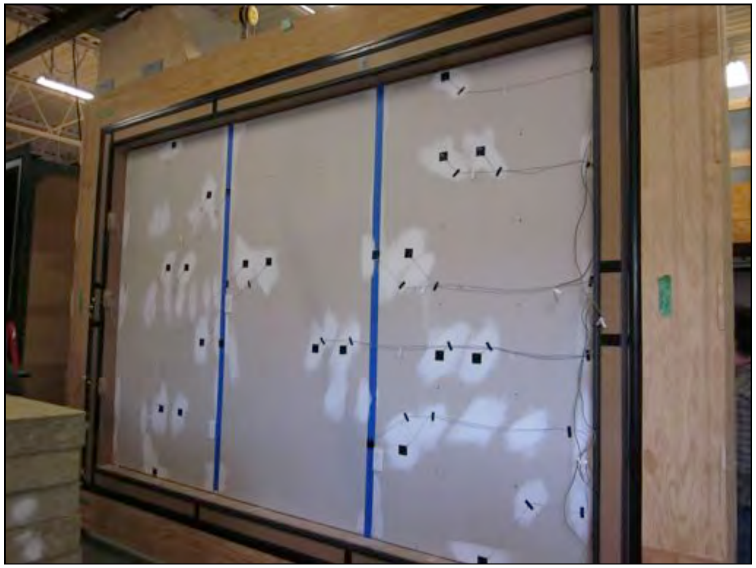
www.BuildingScience.com

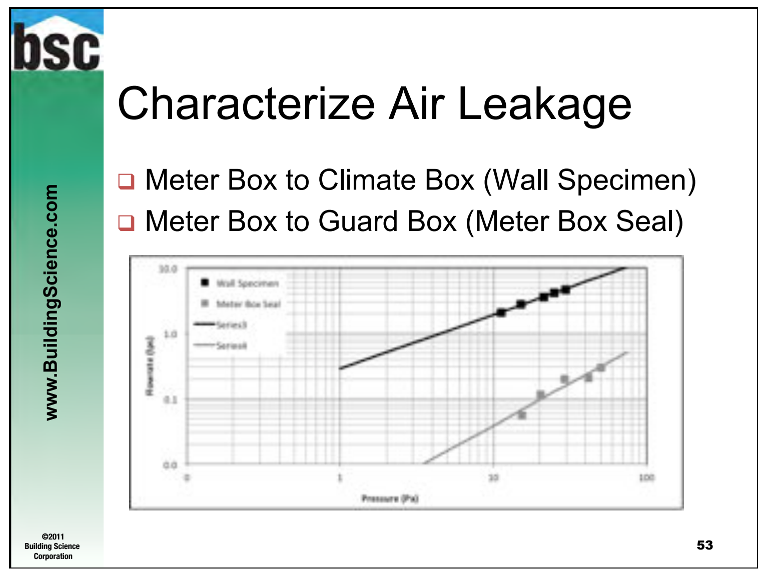
45

Shims

www.BuildingScience.com

46




bsc
Characterize Air Leakage
Meter Box to Climate Box (Wall Specimen)
Meter Box to Guard Box (Meter Box Seal)
Pressure (Pa)
www.BuildingScience.com
©2011 Building Science Corporation
53

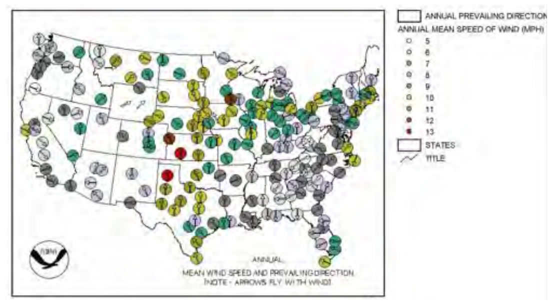
Realistic boundary conditions

Test Segment	1	2	3	4	5	6	7	8	9
MB	72	72	72	72	72	72	72	72	72
CB	-18	0	0	0	33	108	108	108	144
ATS			Infil	Exfil			Infil	Exfil	

- 9 Test Segments:
  - 5 without intentionally induced airflow
  - 4 with intentionally induced airflow
- But what air pressure difference should be used to induce the airflow?

Air Pressures Differences

- Weather station wind pressures typically 8-13 Pa
- House wind pressures typically 3-5 Pa



Air Pressure Differences

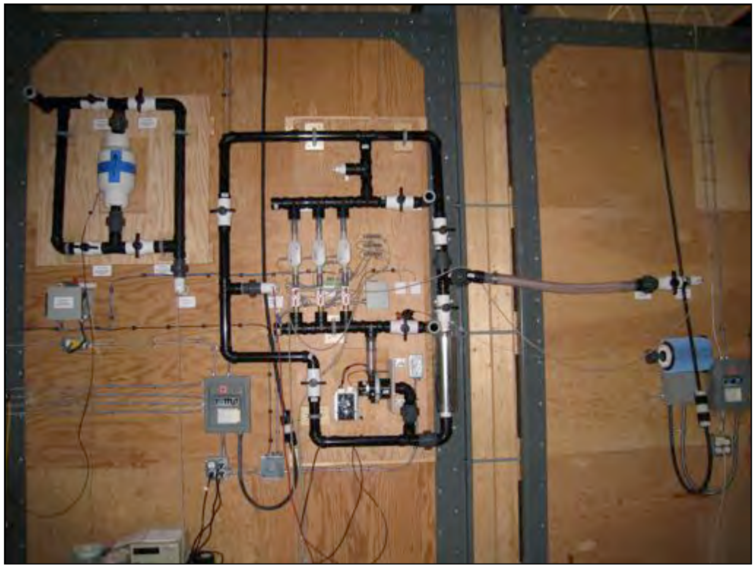
- Stack effect pressures typically 1-2 Pa /floor

Tout		Stack
C	F	Pa
30	86	-0.95
10	50	1.24
0	32	2.45
-10	14	3.75
-20	-4	5.16

*Stack effect pressures for a 2 storey house

Air Pressure Differences

- Wind pressure: 3-5 Pa
- Stack effect: 1-2 Pa
- Fan pressures: ? but assume negligible
- Test air pressure of 10 Pa is reasonable and repeatable



Challenges testing *real* walls

- Realistic wall with airflow paths
- Generate realistic temperature conditions
- Induce realistic pressure differences
- Measure heat & mass

- But… airflow can occur in hot boxes even when we don't *intentionally* induce it

www.BuildingScience.com

59

Unintended Pressures

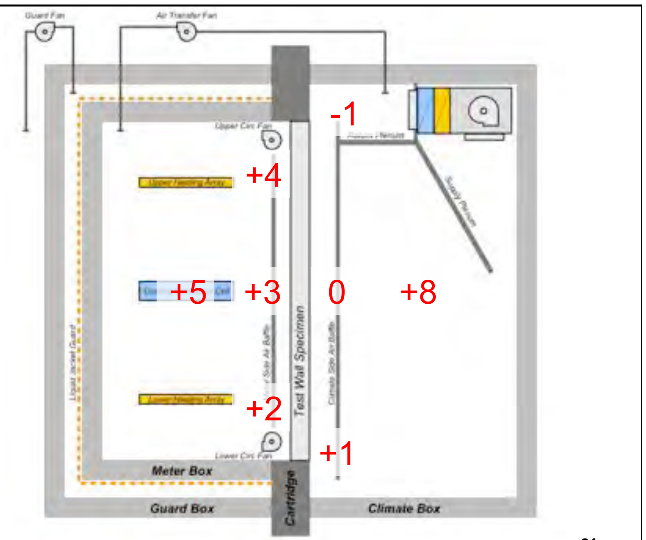
- Air pressure differences exist even when we don't intentionally induce them

- Typically between 0.5-3 Pa

- Can have a significant impact on 'leaky' walls

www.BuildingScience.com

60



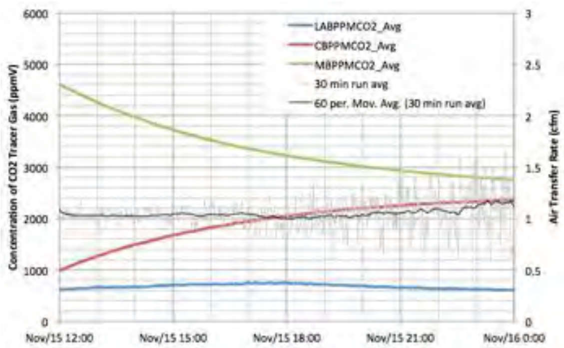
www.BuildingScience.com

61

bsc

www.BuildingScience.com

Tracer Gas Measurement



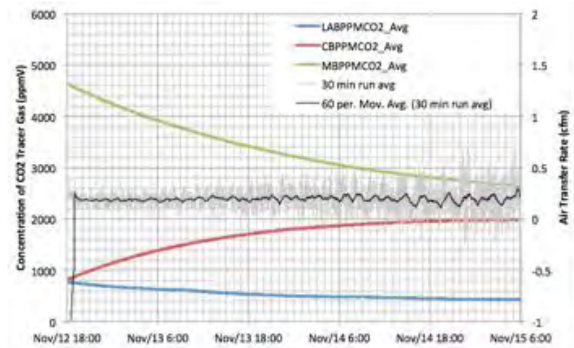
©2011 Building Science Corporation

62

bsc

www.BuildingScience.com

Tracer Gas Measurement



©2011 Building Science Corporation

63

bsc

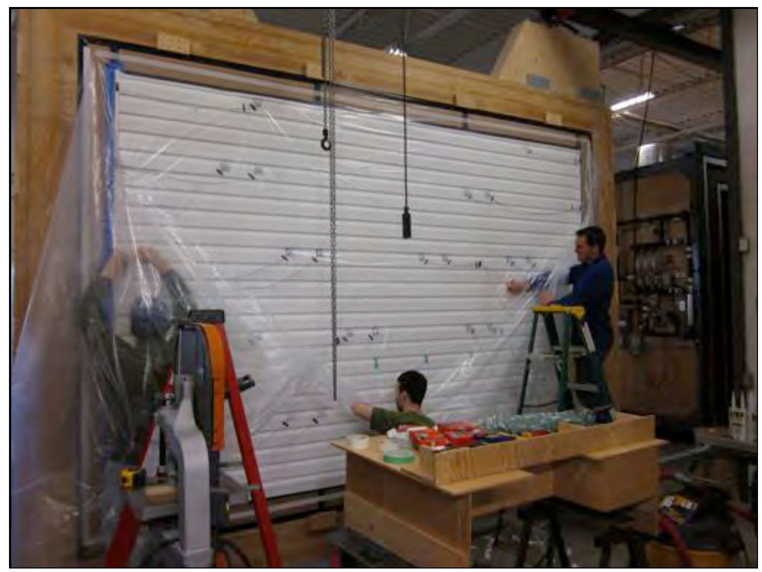
www.BuildingScience.com

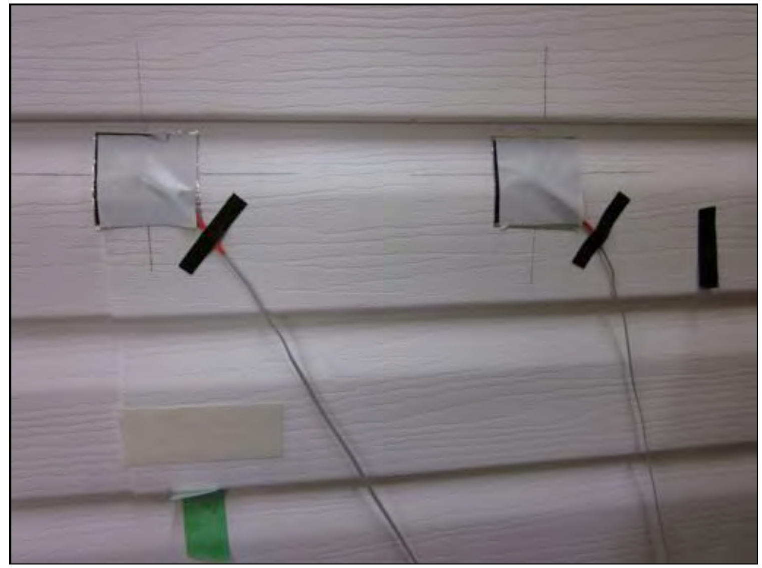
Can impact of air leakage be assessed?

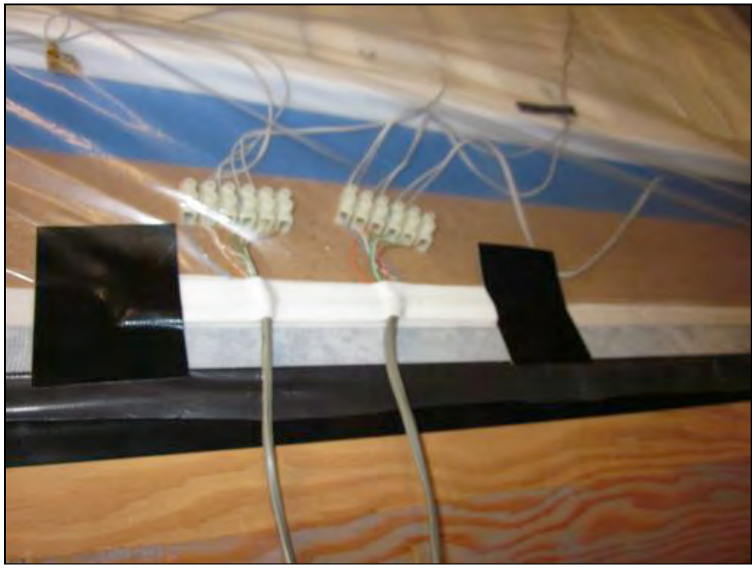
- Not easily!
- We can't assess the impact of the airflow (i.e. the interaction effect) unless we know how a perfectly airtight wall performs (i.e. when there is no airflow through it)
- So… test the wall again with ***inside and outside sealed***.

©2011 Building Science Corporation

64







‘Sealed’ wall test conditions

- Again start by characterizing leakage
- Test 5 temperature differences

Test Segment	1	2	3	4	5
MB	72	72	72	72	72
CB	-18	0	33	108	144
ATS					

- No intentionally induced airflow
- Tracer gas measurement of air change

72

Thermal Metric Test Method

1. Construct wall frame
2. Complete construction of wall specimen
3. Test ‘air leaky’ wall thermal performance
   a) Characterize leakage (PvsQ)
   b) 5 climate temps w/ NO* imposed deltaP
   c) 2 climate temps w/ +ve & -ve 10 Pa deltaP
4. Seal the wall specimen (inside & out)
5. Test ‘sealed’ wall thermal performance
   a) Characterize leakage (PvsQ)
   b) 5 climate temps w/ NO* imposed deltaP

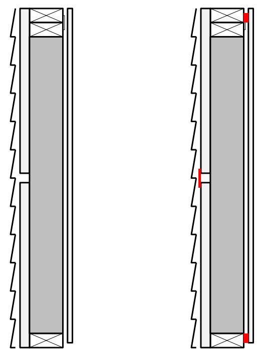
73

Some Test Results

74

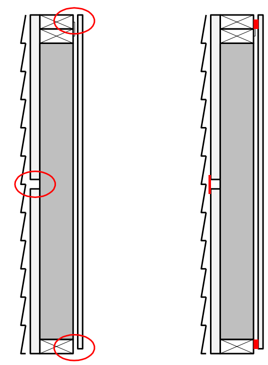
A proof of concept wall

- Wall comparison: (Leaky) vs (Tight)
  - GWB
  - 2x4 w/ air permeable insulation
  - 1.5” air impermeable exterior insulation
  - Vinyl Siding
- NONE of the products produced by the TM industry partners



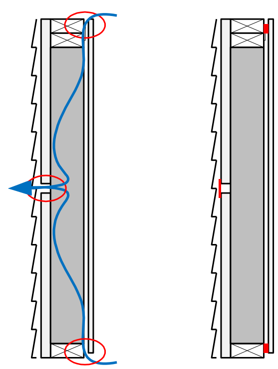
A proof of concept wall

- Wall comparison: (Leaky) vs (Tight)
  - GWB
  - 2x4 w/ air permeable insulation
  - 1.5” air impermeable exterior insulation
  - Vinyl Siding
- NONE of the products produced by the TM industry partners



A proof of concept wall

- Wall comparison: (Leaky) vs (Tight)
  - GWB
  - 2x4 w/ air permeable insulation
  - 1.5” air impermeable exterior insulation
  - Vinyl Siding
- NONE of the products produced by the TM industry partners



Lessons

83

Lesson 1: Material R-values

- Temperature effects R-value
- Density effects R-value
- Moisture content effects R-value

www.BuildingScience.com

84

Lesson 2: Assembly R-value

- Hand Calculations (parallel path)
  - Works if
    - materials have similar R-value (e.g. wood frame wall)
  - Does not work if
    - materials have very different R-value
    - highly conductive layers perpendicular to flow
- Computer Simulations (Therm, Heat2, etc.)
  - Works if there is NO air movement

www.BuildingScience.com

85

Lesson 3: Hot Box Testing

- Airflow impacts common hot box tests!
- Tracer gas can be used to measure incidental airflows

Description	SI Units *		British Units	
Specimen Area	5.946	m^2	64.00	ft^2
Specimen thickness	153.00	mm.	6.024	in.
Average cold side surface temperature	-22.91	°C	-9.24	°F
Average warm side surface temperature	15.66	°C	60.20	°F
Temperature differential	38.57	°C	69.43	°F
Mean specimen temperature	-3.62	°C	25.48	°F
Rate of heat flux through the specimen	43.126	W/m^2	13.670	$Btu/h.ft^2$
Thermal conductance of the specimen	**1.118**	$W/m^2.K$	**0.197**	$Btu/h.ft^2.°F$
Thermal resistance of the specimen	**0.894**	$K.m^2/W$	**5.079**	$°F.ft^2.h/Btu$
Thermal conductivity of the specimen	0.171	W/m.K	1.186	$Btu.in./h.ft^2.°F$
Thermal resistivity of the specimen	5.846	K.m/W	0.843	$°F.ft^2.h/Btu.in.$
Uniform Baffle Air Velocity (Warm Side)	0.22	m/s	0.98	ft/sec
Uniform Air Velocity (Cold Side)	3.0	m/s	9.84	ft/sec
Pressure Differential Across Specimen	Nil	Pa	Nil	psi
Warm Side Chamber Relative Humidity	10.1	% RH	10.1	% RH
Steady-State Temperature Differential Between Guard & Metering Chamber	-0.02	°C	-0.036	°F

www.BuildingScience.com

86

Thank You

www.BuildingScience.com

88