# Thermal Metric Project

Chris Schumacher & Dave Ober

17th Annual Westford Symposium
August, 2013 – Westford, MA

Building Science Corporation

## Thermal Metric Project

**OBJECTIVE:**



## Thermal Metric Project

**OBJECTIVE:**

- Develop a thermal performance rating system or ***metric***



## Thermal Metric Project

**OBJECTIVE:**

- Develop a thermal performance rating system or ***metric*** that ***accurately*** compares ***in-service performance*** of assemblies of all types

## Thermal Metric Project

**OBJECTIVE:**

- Develop a thermal performance rating system or ***metric*** that ***accurately*** compares ***in-service performance*** of assemblies of all types and thereby ***supports good*** design & construction practices



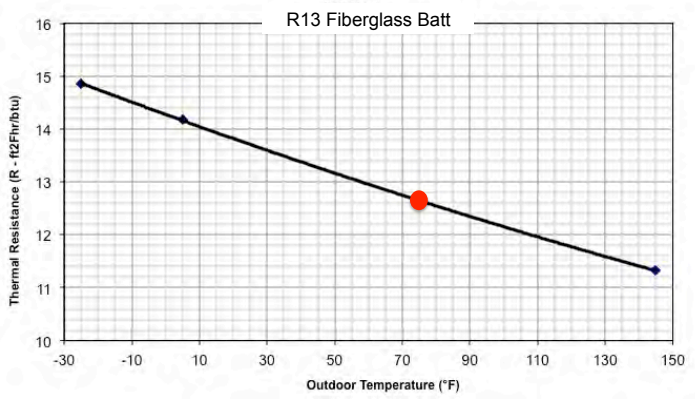
## Thermal Metric Project

**APPROACH:**

- ***Full-scale*** laboratory testing
- over ***realistic*** range of ***temperatures***
- with ***realistic*** induced ***air pressures***

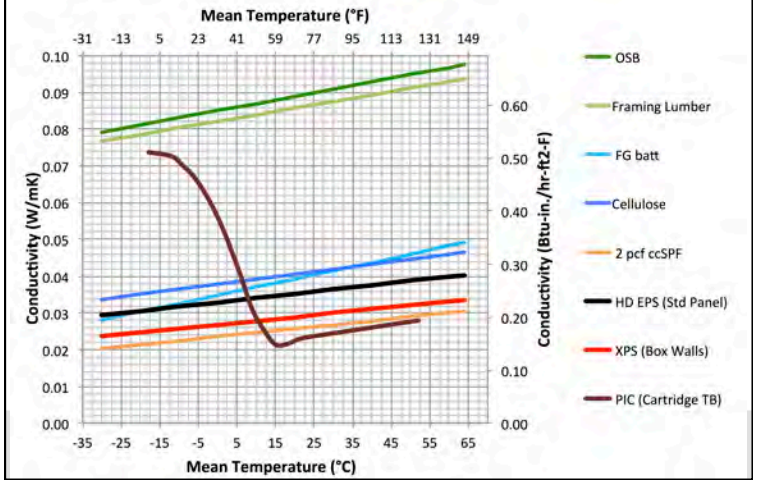


## Why a Realistic Temperature Range?

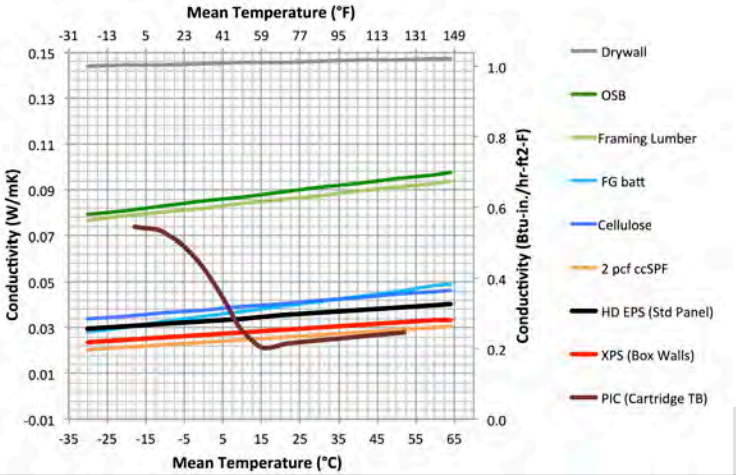




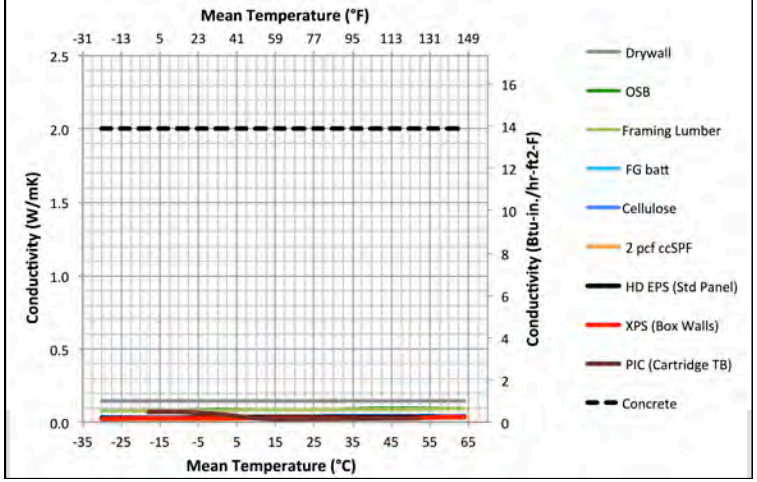

## Realistic Temperature Range



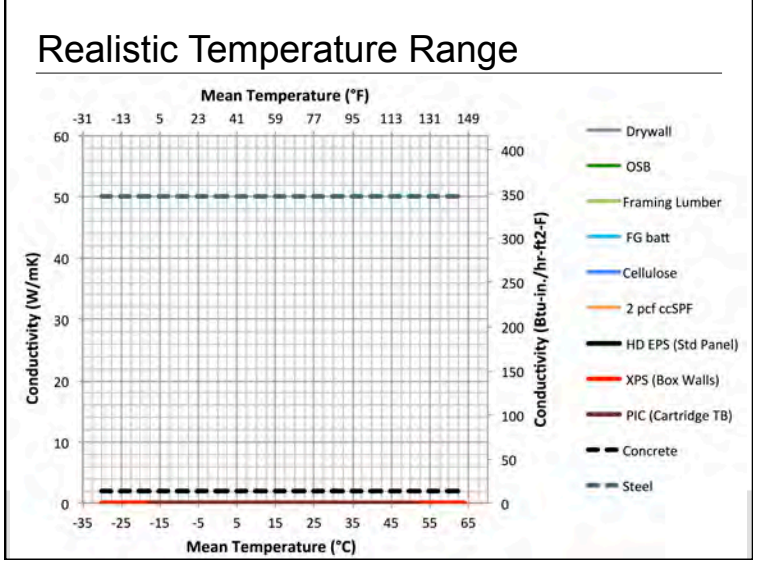
## Realistic Temperature Range



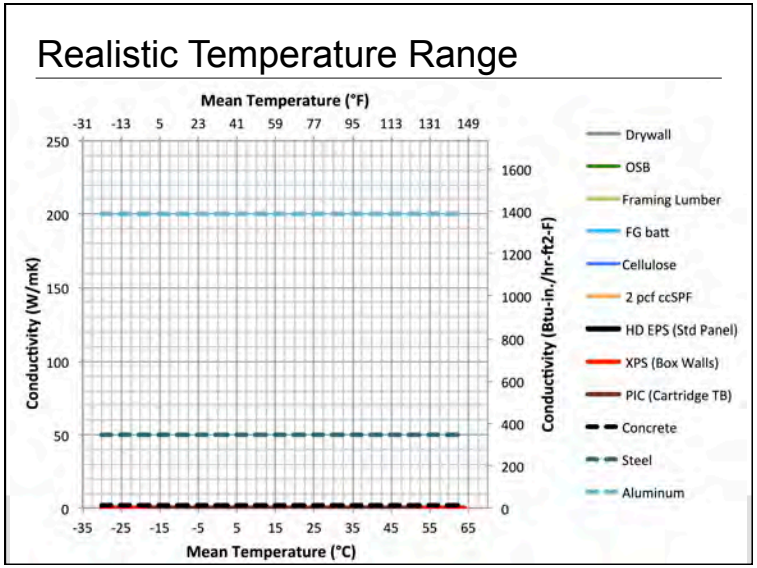

## Realistic Temperature Range



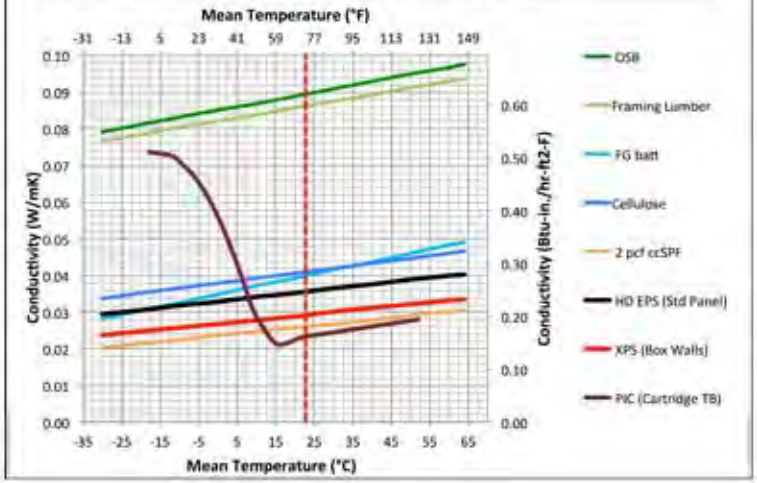

## Realistic Temperature Range



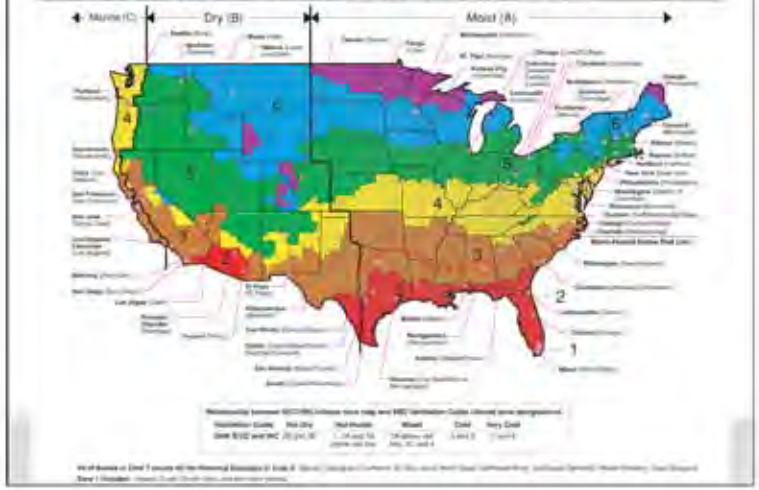

## Realistic Temperature Range



## Realistic Temperature Range




## Choosing Realistic Temperatures




## Choosing Realistic Temperatures

| | | Heating Dry Bulb (°F) | | Cooling Dry Bulb (°F) | |
|---|---|---|---|---|---|
| Zone | City | 99.6% | 99% | 0.4% | 1% |
| 1A | Miami | 47.7 | 51.6 | 91.8 | 90.7 |
| 2A | Houston | 29.1 | 32.9 | 96.8 | 95.0 |
| 2B | Phoenix | 38.7 | 41.4 | 110.1 | 108.1 |
| 3 | Atlanta | 20.7 | 25.7 | 93.9 | 91.4 |
| 4C | Seattle | 24.4 | 29.1 | 84.9 | 80.6 |
| 4 | St. Louis | 4.1 | 10.2 | 95.7 | 76.8 |
| 5 | Chicago | -4.0 | 2.1 | 91.9 | 88.9 |
| 5 | Boston | 7.5 | 12.4 | 90.9 | 87.6 |
| 6 | Minneapolis | -13.4 | -7.6 | 91.0 | 87.8 |
| 7 | International Falls | -26.9 | -20.9 | 86.2 | 82.8 |
| 7 | Anchorage | -8.9 | -4.4 | 71.4 | 68.4 |

Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
15

## Choosing Realistic Temperatures

| | | Heating Dry Bulb (°F) | | Cooling Dry Bulb (°F) | |
|---|---|---|---|---|---|
| Zone | City | 99.6% | 99% | 0.4% | 1% |
| 1A | Miami | 47.7 | 51.6 | 91.8 | 90.7 |
| 2A | Houston | 29.1 | 32.9 | 96.8 | 95.0 |
| 2B | Phoenix | 38.7 | 41.4 | 110.1 | 108.1 |
| 3 | Atlanta | 20.7 | 25.7 | 93.9 | 91.4 |
| 4C | Seattle | 24.4 | 29.1 | 84.9 | 80.6 |
| 4 | St. Louis | 4.1 | 10.2 | 95.7 | 76.8 |
| 5 | Chicago | -4.0 | 2.1 | 91.9 | 88.9 |
| 5 | Boston | 7.5 | 12.4 | 90.9 | 87.6 |
| 6 | Minneapolis | -13.4 | -7.6 | 91.0 | 87.8 |
| 7 | International Falls | -26.9 | -20.9 | 86.2 | 82.8 |
| 7 | Anchorage | -8.9 | -4.4 | 71.4 | 68.4 |

Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
16

## Choosing Realistic Temperatures

| | | Heating Dry Bulb (°F) | | Cooling Dry Bulb (°F) | |
|---|---|---|---|---|---|
| Zone | City | 99.6% | 99% | 0.4% | 1% |
| 1A | Miami | 47.7 | 51.6 | 91.8 | 90.7 |
| 2A | Houston | 29.1 | 32.9 | 96.8 | 95.0 |
| 2B | Phoenix | 38.7 | 41.4 | 110.1 | 108.1 |
| 3 | Atlanta | 20.7 | 25.7 | 93.9 | 91.4 |
| 4C | Seattle | 24.4 | 29.1 | 84.9 | 80.6 |
| 4 | St. Louis | 4.1 | 10.2 | 95.7 | 76.8 |
| 5 | Chicago | -4.0 | 2.1 | 91.9 | 88.9 |
| 5 | Boston | 7.5 | 12.4 | 90.9 | 87.6 |
| 6 | Minneapolis | -13.4 | -7.6 | 91.0 | 87.8 |
| 7 | International Falls | -26.9 | -20.9 | 86.2 | 82.8 |
| 7 | Anchorage | -8.9 | -4.4 | 71.4 | 68.4 |

Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
17

## Choosing Realistic Temperatures

| | | Heating Dry Bulb (°F) | | Cooling Dry Bulb (°F) | |
|---|---|---|---|---|---|
| Zone | City | 99.6% | 99% | 0.4% | 1% |
| 1A | Miami | 47.7 | 51.6 | 91.8 | 90.7 |
| 2A | Houston | 29.1 | 32.9 | 96.8 | 95.0 |
| 2B | Phoenix | 38.7 | 41.4 | 110.1 | 108.1 |
| 3 | Atlanta | 20.7 | 25.7 | 93.9 | 91.4 |
| 4C | Seattle | 24.4 | 29.1 | 84.9 | 80.6 |
| 4 | St. Louis | 4.1 | 10.2 | 95.7 | 76.8 |
| 5 | Chicago | -4.0 | 2.1 | 91.9 | 88.9 |
| 5 | Boston | 7.5 | 12.4 | 90.9 | 87.6 |
| 6 | Minneapolis | -13.4 | -7.6 | 91.0 | 87.8 |
| 7 | International Falls | -26.9 | -20.9 | 86.2 | 82.8 |
| 7 | Anchorage | -8.9 | -4.4 | 71.4 | 68.4 |

Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
18

## Choosing Realistic Temperatures

| | | Heating Dry Bulb (°F) | | Cooling Dry Bulb (°F) | |
|---|---|---|---|---|---|
| Zone | City | 99.6% | 99% | 0.4% | 1% |
| 1A | Miami | 47.7 | 51.6 | 91.8 | 90.7 |
| 2A | Houston | 29.1 | 32.9 | 96.8 | 95.0 |
| 2B | Phoenix | 38.7 | 41.4 | 110.1 | 108.1 |
| 3 | Atlanta | 20.7 | 25.7 | 93.9 | 91.4 |
| 4C | Seattle | 24.4 | 29.1 | 84.9 | 80.6 |
| 4 | St. Louis | 4.1 | 10.2 | 95.7 | 76.8 |
| 5 | Chicago | -4.0 | 2.1 | 91.9 | 88.9 |
| 5 | Boston | 7.5 | 12.4 | 90.9 | 87.6 |
| 6 | Minneapolis | -13.4 | -7.6 | 91.0 | 87.8 |
| 7 | International Falls | -26.9 | -20.9 | 86.2 | 82.8 |
| 7 | Anchorage | -8.9 | -4.4 | 71.4 | 68.4 |

Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
19

## Choosing Realistic Temperatures

| | | Heating Dry Bulb (°F) | | Cooling Dry Bulb (°F) | |
|---|---|---|---|---|---|
| Zone | City | 99.6% | 99% | 0.4% | 1% |
| 1A | Miami | 47.7 | 51.6 | 91.8 | 90.7 |
| 2A | Houston | 29.1 | 32.9 | 96.8 | 95.0 |
| 2B | Phoenix | 38.7 | 41.4 | 110.1 | 108.1 |
| 3 | Atlanta | 20.7 | 25.7 | 93.9 | 91.4 |
| 4C | Seattle | 24.4 | 29.1 | 84.9 | 80.6 |
| 4 | St. Louis | 4.1 | 10.2 | 95.7 | 76.8 |
| 5 | Chicago | -4.0 | 2.1 | 91.9 | 88.9 |
| 5 | Boston | 7.5 | 12.4 | 90.9 | 87.6 |
| 6 | Minneapolis | -13.4 | -7.6 | 91.0 | 87.8 |
| 7 | International Falls | -26.9 | -20.9 | 86.2 | 82.8 |
| 7 | Anchorage | -8.9 | -4.4 | 71.4 | 68.4 |

Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
20

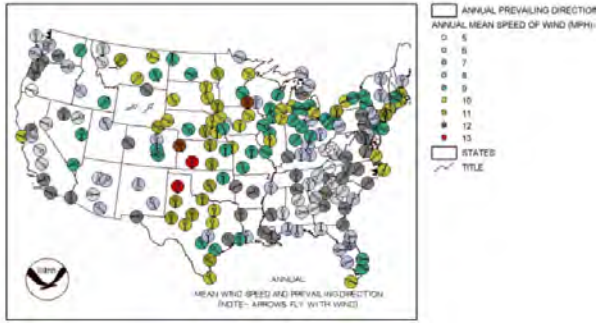
## Choosing Realistic Temperatures

| | Heating Dry Bulb (°F) | | Cooling Dry Bulb (°F) | | |
|---|---|---|---|---|---|
| Climate | (°F) | (°C) | (°F) | (°C) | |
| Very Cold | 72 | 22 | -18 | -28 | 6, 7, 8 |
| Cold | | | 0 | -18 | 4, 5, 6 |
| Cool | | | 36 | 2 | 2A, 2B, 3, 4C |
| Hot | | | 108 | 42 | 1A, 2A, 2B, 3 |
| Solar Heated Surface | | | 144 | 62 | ALL |



## Choosing Air Pressures Differences

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






## Choosing 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



## Choosing Air Pressure Differences

- Wind pressure: 3-5 Pa
- Stack effect: 1-2 Pa / floor
- Fan pressures: ? but assume negligible

- Test air pressure of 10 Pa is reasonable and repeatable

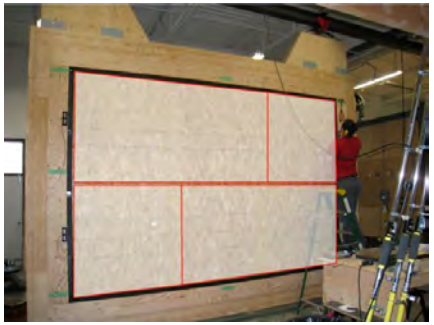
## Air Flow Paths

- Building models assume air leaks through a discrete hole
- No interaction with the building enclosure (i.e. no dynamic wall effect)
- Many different types of leaks exist
  - Some holes / cracks (short flow path)
  - Some through long flow path
  - Varying levels of conduction / convection interaction



## Airflow path 1

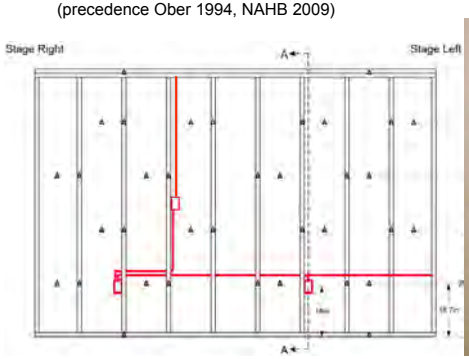
- 1/8 in. horizontal gap between sheathing
  (per APA installation recommendations)

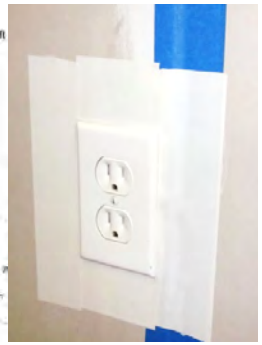




## Airflow path 2

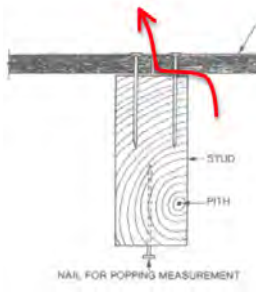
- Electrical boxes and associated wiring
  (precedence Ober 1994, NAHB 2009)





## Airflow path 3

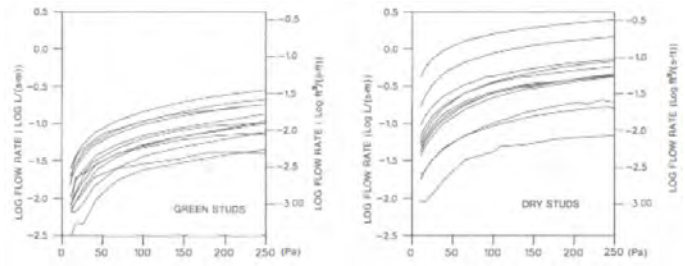



$$\Delta D = \frac{D_I(M_F - M_I)}{30(100)/S_I - 30 + M_I} \qquad (13\text{–}3)$$

| 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

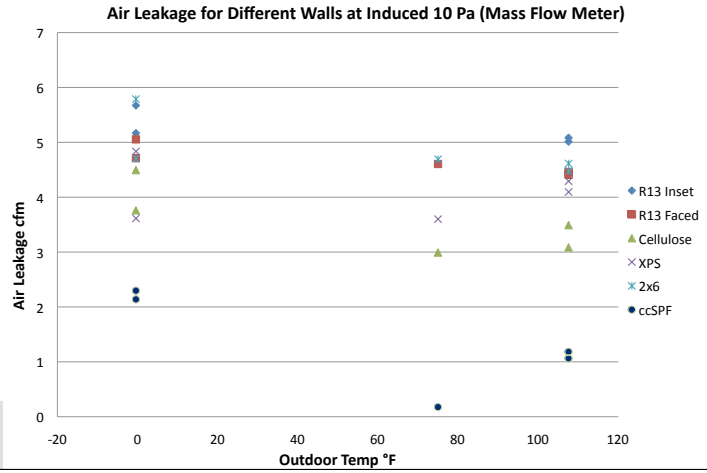
- At 10 Pa pressure difference shrinkage resulted in 4x increase in air leakage



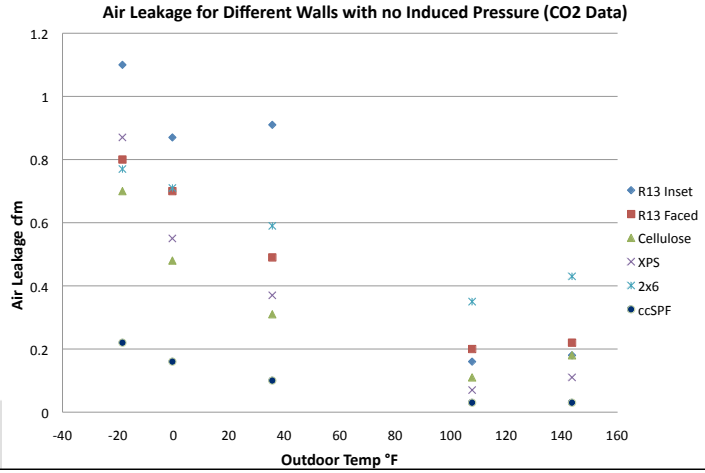

Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
29

## Airflow over range of temperatures




## Airflow over range of temperatures



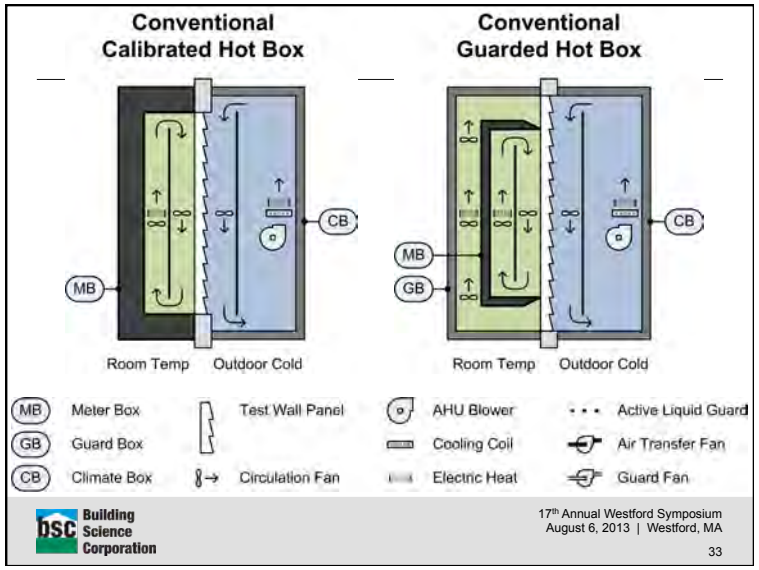

## Thermal Metric Project

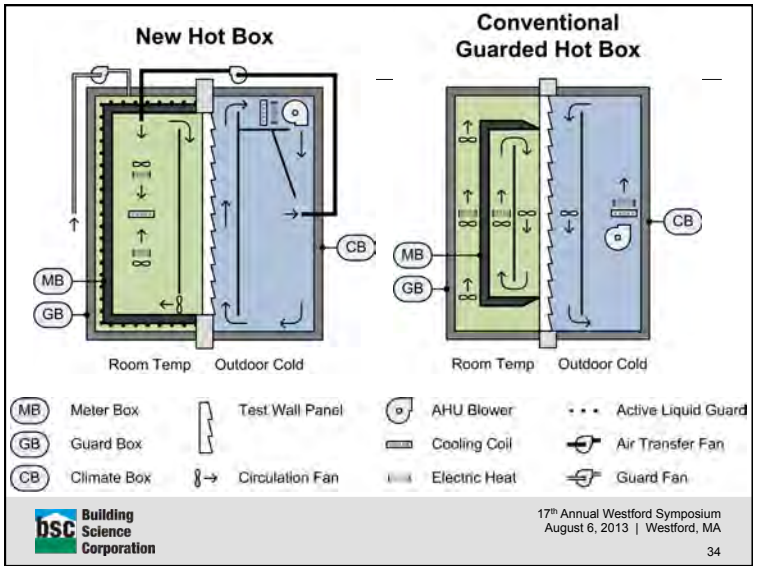
**REQUIRED:**

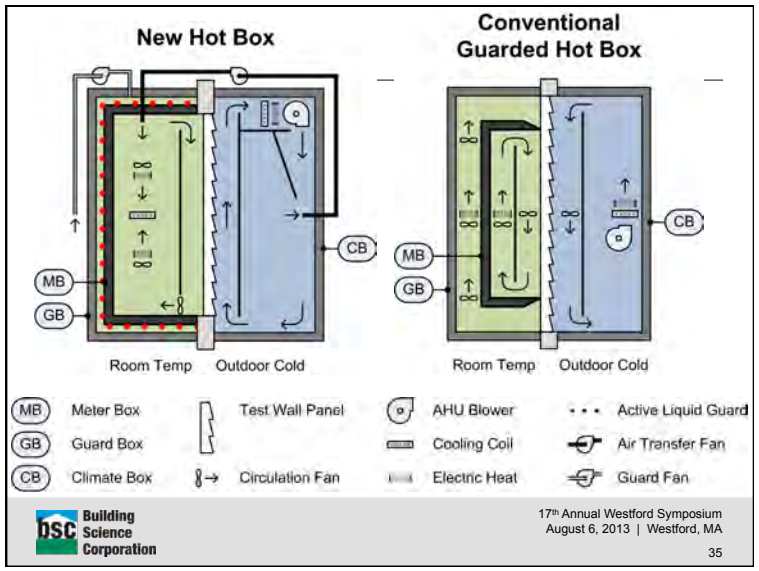
- Review of realistic air flow paths and driving pressures
- Investigation of interaction between heat flow and air (mass) flow
- Development of Hot Box apparatus with high-precision, broad temperature range, control of air pressures and ability to measure simultaneous ‘conductive’ and ‘convective’ heat flows.

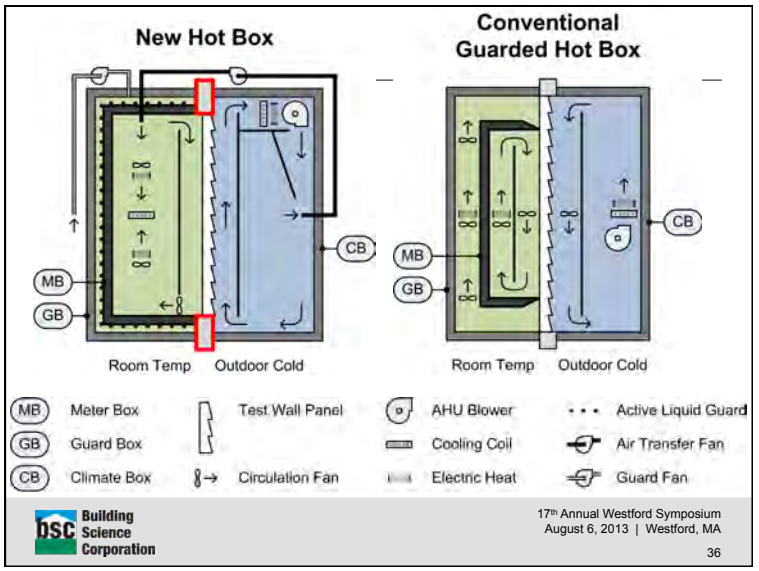
Building Science Corporation

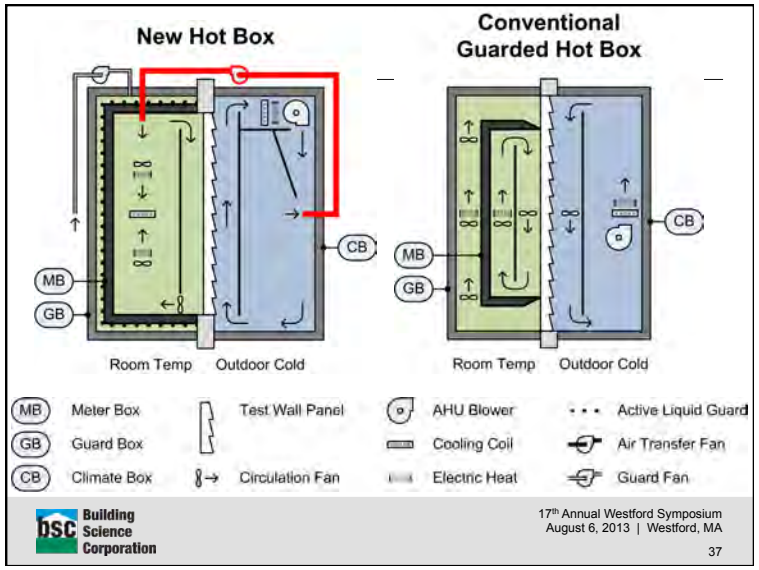
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
32

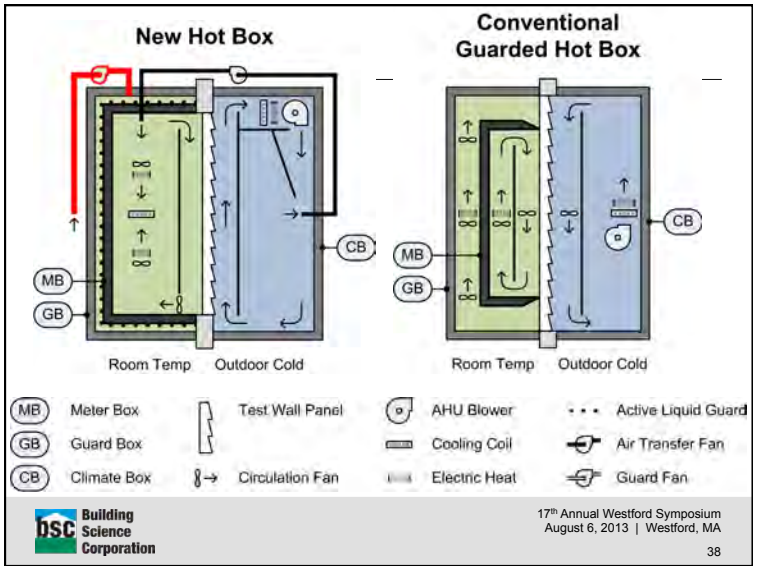

Conventional
Calibrated Hot Box
Conventional
Guarded Hot Box
MB
CB
GB
Room Temp
Outdoor Cold
MB Meter Box
GB Guard Box
CB Climate Box
Test Wall Panel
Circulation Fan
AHU Blower
Cooling Coil
Electric Heat
Active Liquid Guard
Air Transfer Fan
Guard Fan
Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
33

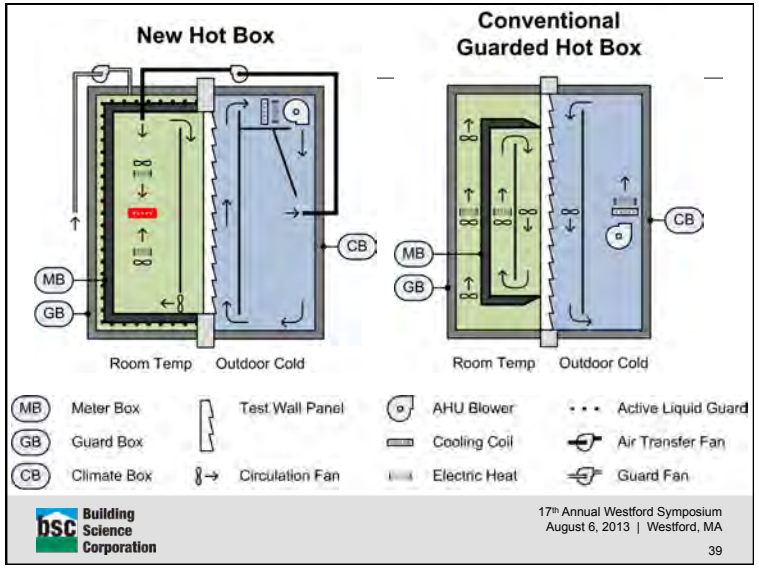

New Hot Box
Conventional
Guarded Hot Box
MB
CB
GB
Room Temp
Outdoor Cold
MB Meter Box
GB Guard Box
CB Climate Box
Test Wall Panel
Circulation Fan
AHU Blower
Cooling Coil
Electric Heat
Active Liquid Guard
Air Transfer Fan
Guard Fan
Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
34

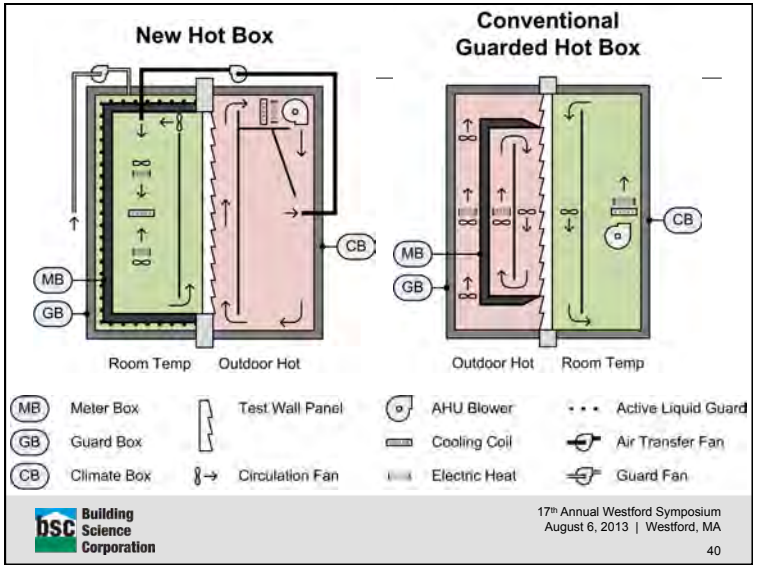

New Hot Box
Conventional
Guarded Hot Box
MB
CB
GB
Room Temp
Outdoor Cold
MB Meter Box
GB Guard Box
CB Climate Box
Test Wall Panel
Circulation Fan
AHU Blower
Cooling Coil
Electric Heat
Active Liquid Guard
Air Transfer Fan
Guard Fan
Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
35


New Hot Box
Conventional
Guarded Hot Box
MB
CB
GB
Room Temp
Outdoor Cold
MB Meter Box
GB Guard Box
CB Climate Box
Test Wall Panel
Circulation Fan
AHU Blower
Cooling Coil
Electric Heat
Active Liquid Guard
Air Transfer Fan
Guard Fan
Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
36


New Hot Box
Conventional Guarded Hot Box
MB
GB
CB
Room Temp
Outdoor Cold
Meter Box
Guard Box
Climate Box
Test Wall Panel
Circulation Fan
AHU Blower
Cooling Coil
Electric Heat
Active Liquid Guard
Air Transfer Fan
Guard Fan
Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
37


New Hot Box
Conventional Guarded Hot Box
MB
GB
CB
Room Temp
Outdoor Cold
Meter Box
Guard Box
Climate Box
Test Wall Panel
Circulation Fan
AHU Blower
Cooling Coil
Electric Heat
Active Liquid Guard
Air Transfer Fan
Guard Fan
Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
38


New Hot Box
Conventional Guarded Hot Box
MB
GB
CB
Room Temp
Outdoor Cold
Meter Box
Guard Box
Climate Box
Test Wall Panel
Circulation Fan
AHU Blower
Cooling Coil
Electric Heat
Active Liquid Guard
Air Transfer Fan
Guard Fan
Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
39


New Hot Box
Conventional Guarded Hot Box
MB
GB
CB
Room Temp
Outdoor Hot
Outdoor Hot
Room Temp
Meter Box
Guard Box
Climate Box
Test Wall Panel
Circulation Fan
AHU Blower
Cooling Coil
Electric Heat
Active Liquid Guard
Air Transfer Fan
Guard Fan
Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
40

## Thermal Metric Project

**DEMONSTRATED:**

- Thermal bridging
- Temperature dependency of materials
- Air leakage Interaction



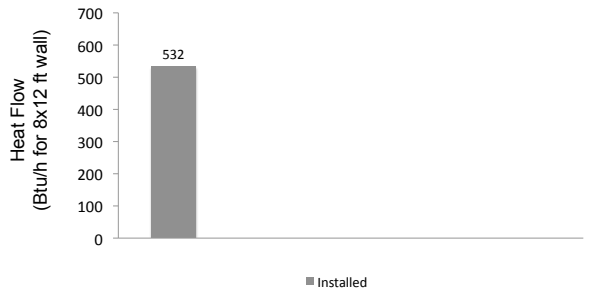
## Industry Standard Wall

- 2x4 w/ R13 FG batt, 7/16 OSB, vinyl Siding



## Industry Standard Wall

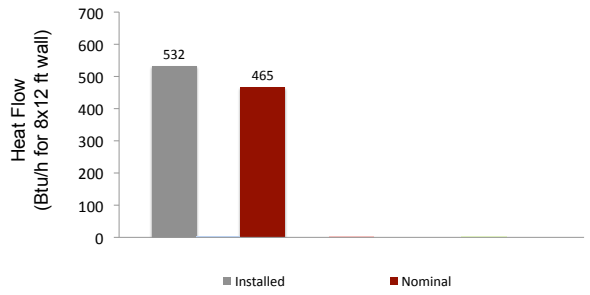
- 2x4 w/ R13 FG batt, 7/16 OSB, vinyl Siding
  (22°C | 72°F indoor, -18°C | 4°F outdoor temp)





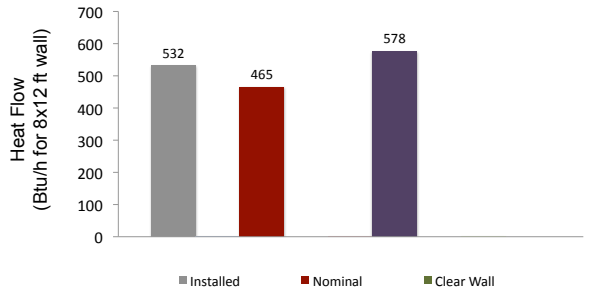

## Industry Standard Wall

- 2x4 w/ R13 FG batt, 7/16 OSB, vinyl Siding
  (22°C | 72°F indoor, -18°C | 4°F outdoor temp)



## Industry Standard Wall

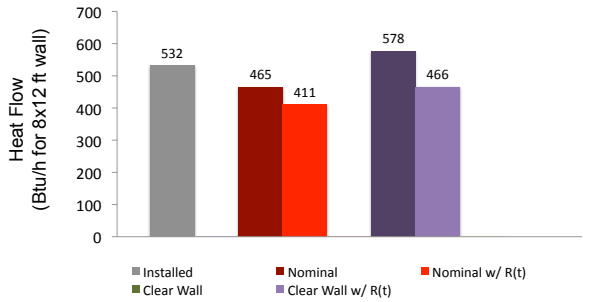
- 2x4 w/ R13 FG batt, 7/16 OSB, vinyl Siding
  (22°C | 72°F indoor, -18°C | 4°F outdoor temp)




Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
45

## Industry Standard Wall

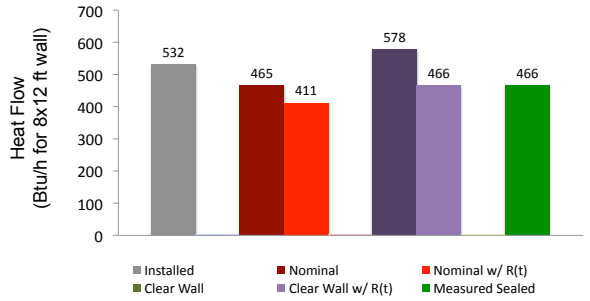
- 2x4 w/ R13 FG batt, 7/16 OSB, vinyl Siding
  (22°C | 72°F indoor, -18°C | 4°F outdoor temp)




Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
46

## Industry Standard Wall

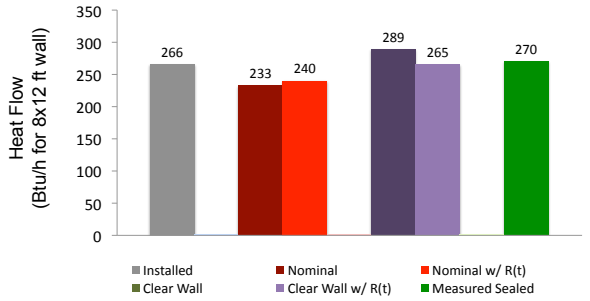
- 2x4 w/ R13 FG batt, 7/16 OSB, vinyl Siding
  (22°C | 72°F indoor, -18°C | 4°F outdoor temp)




Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
47

## Industry Standard Wall

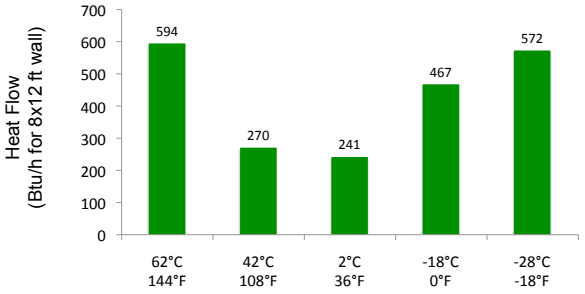
- 2x4 w/ R13 FG batt, 7/16 OSB, vinyl Siding
  (22°C | 72°F indoor, 42°C | 108°F outdoor temp)




Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
48

## Temperature Effect

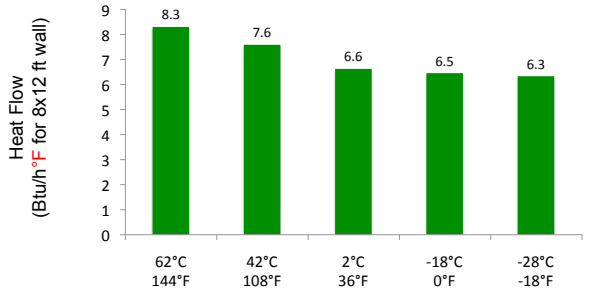
- 2x4 w/ R13 FG batt, 7/16 OSB, vinyl Siding
  (Measured heat flow, SEALED wall)




Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
49

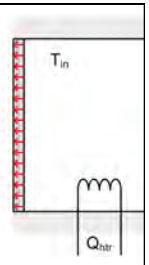
## Temperature Effect

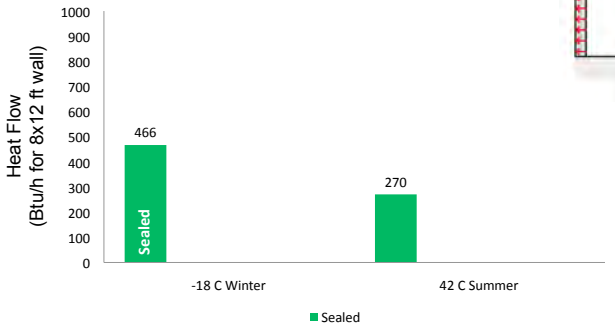
- 2x4 w/ R13 FG batt, 7/16 OSB, vinyl Siding
  (Measured heat flow, SEALED wall)




Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
50

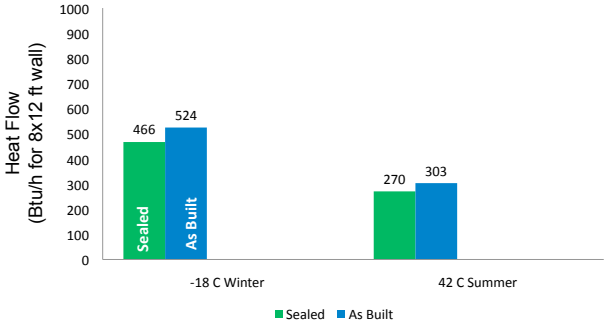
## Airflow Impact



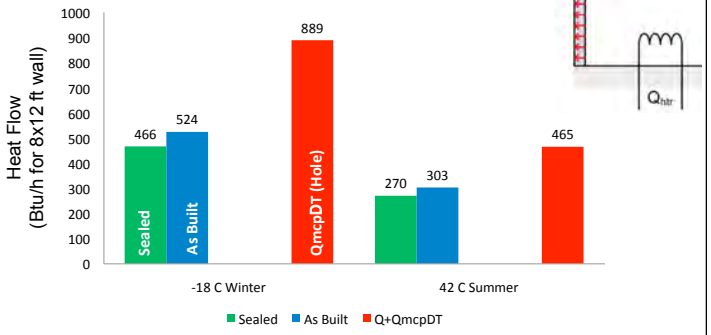

Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
51

## Airflow Impact




Building Science Corporation
17th Annual Westford Symposium
August 6, 2013 | Westford, MA
52

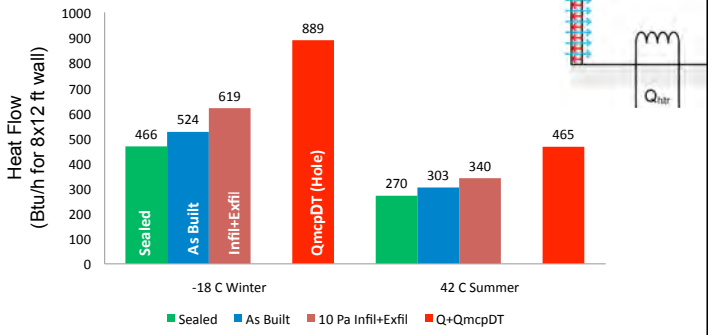
## Airflow Impact




Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
53

## Airflow Impact




Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
54

## Airflow impact complexities

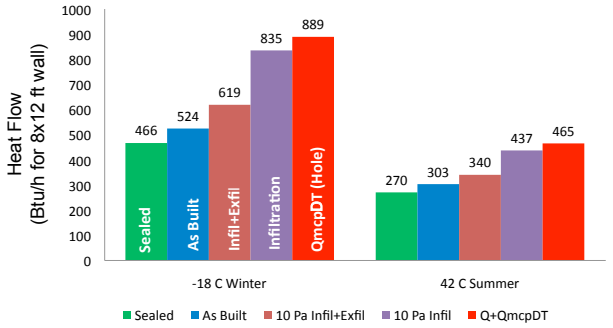
- All air infiltrates, massive exhaust fan
- E.g. PassivHaus 0.08 cfm/sf@50 Pa, 2 storey 1800 sf house
  - Requires 62 cfm exhaust to generate 10 Pa infiltration through walls
  - Say 100 cfm exhaust

Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
55

## Airflow impact complexities

- All air infiltrates, massive exhaust fan




Building Science Corporation

17th Annual Westford Symposium
August 6, 2013 | Westford, MA
56

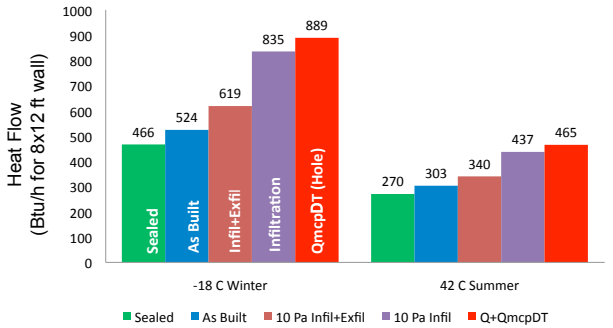
## Reality of our industry

- Modeling can be misleading
- Measurement trumps modeling
- Measurement is time consuming & expensive
- Measurement can be misleading
- Both are necessary. Do them intelligently.



## TM hot box Results

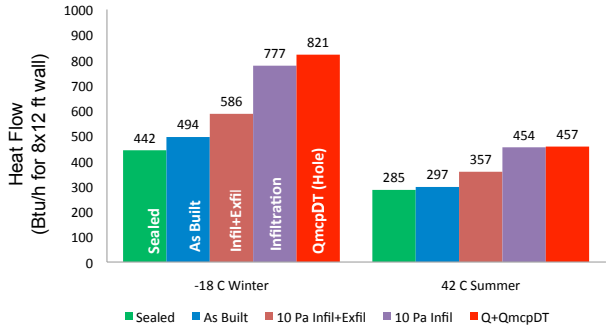
- 2x4 w/ ***inset***-stapled kraft-faced R13 FG batt






## TM hot box Results

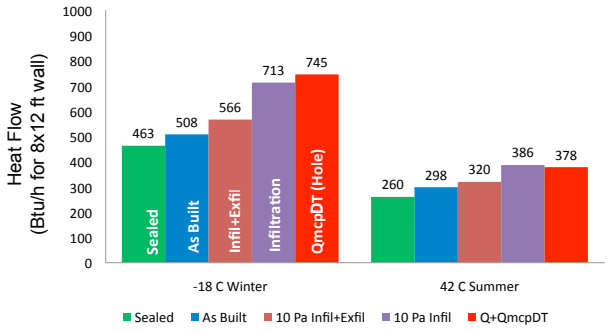
- 2x4 w/ ***face***-stapled kraft-faced R13 FG batt





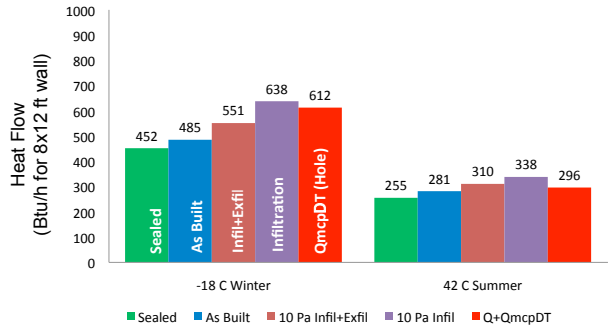

## TM hot box Results

- 2x4 w/ damp-spray cellulose



## TM hot box Results

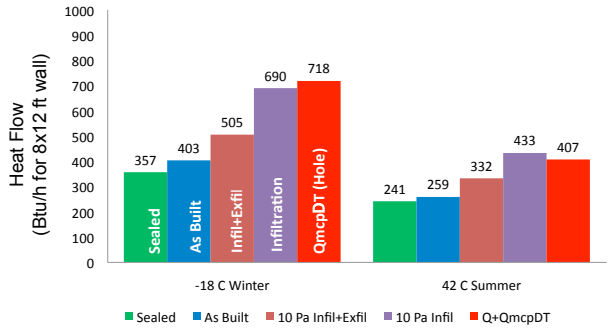
- 2x4 w/ 2 in. of 2 pcf ccSPF






## TM hot box Results

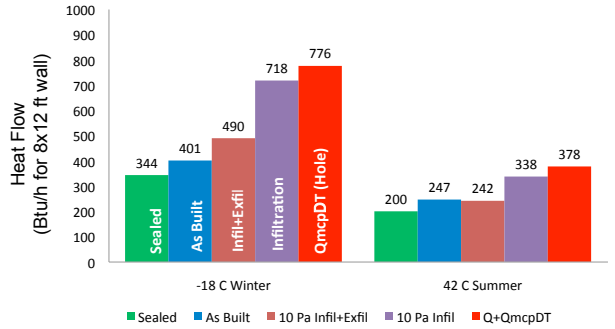
- 2x4 w/ R13 FG batt + R5 XPS






## TM hot box Results

- 2x6 w/ R21 FG batt






## Thermal Metric Project

**Where can we USE this INFORMATION:**

- Inform design strategies
- Improve energy models
- Quantify 'quality of installation'
- Justify code requirements

## Thermal Metric Project

**Where can we USE this INFORMATION:**

- Inform design strategies
- ~~Improve energy models~~ Explain Energy Models
- Quantify 'quality of installation'
- Justify code requirements



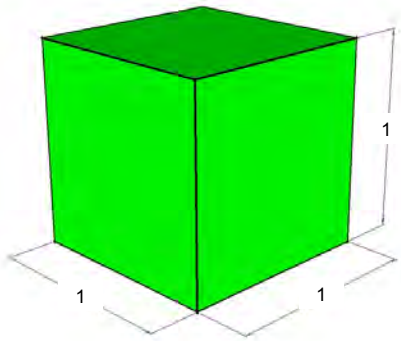
Consider a NEW

## Thermal Performance Metric

## Heatflow

- Material Conductivity

k or λ

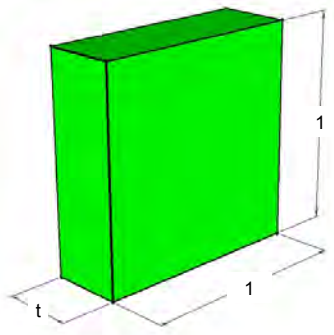





## Heatflow

- Material Conductance

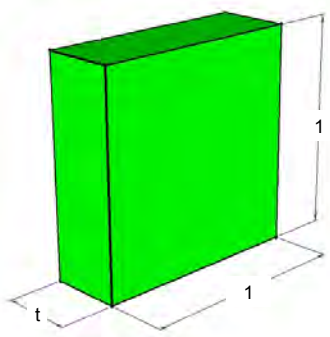
C



## Heatflow

- Material R-Value

R



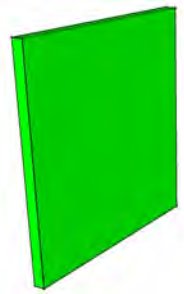



## Heatflow

- Assembly as a ***single***, ***continuous*** layer of insulation

R-value?

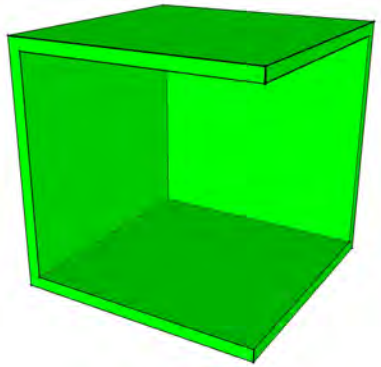
U-value?





## Heatflow

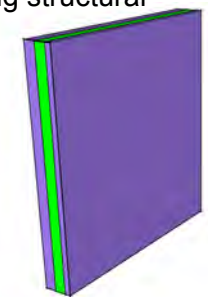
- Building as a box constructed using a ***single***, ***continuous*** layer of insulation material





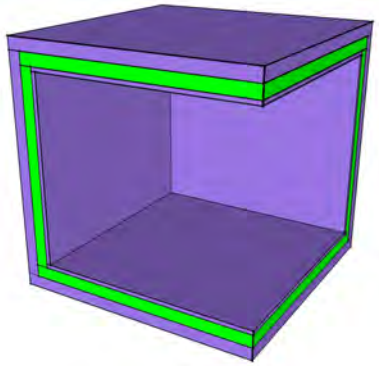
## Heatflow

- Assembly as a ***series*** of materials including insulation, sheathing, finishes, etc. (each a ***continuous*** layer) but excluding structural elements



## Heatflow

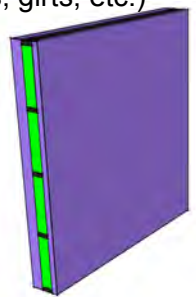
- Building as a box constructed with an assembly represented as a series of materials (each a continuous layer)



Building Science Corporation

## Heatflow

- Assembly as a compilation of sheathing, finishes, insulation materials, and ***regularly spaced structural elements*** (e.g. studs, girts, etc.)
- ***Parallel path***
- Clear-Wall R-value
- Clear-Wall U?

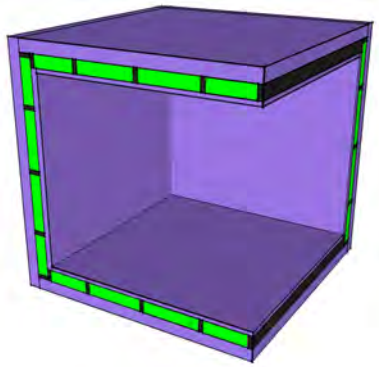


Building Science Corporation



## Heatflow

- Building as a box constructed with “parallel path” or “Clear-Wall” assemblies



Building Science Corporation

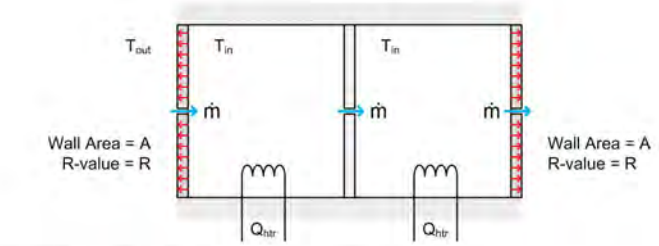
## Heatflow

- Other, potentially important factors to consider:
- Temperature Dependence
- Thermal Mass
- Moisture
- Airflow?

Building Science Corporation

## Airflow

- Treated separate from heat flow through assemblies. (e.g. as if airflow occurs through (a) discrete hole(s) so there is no interaction with the building enclosure.)

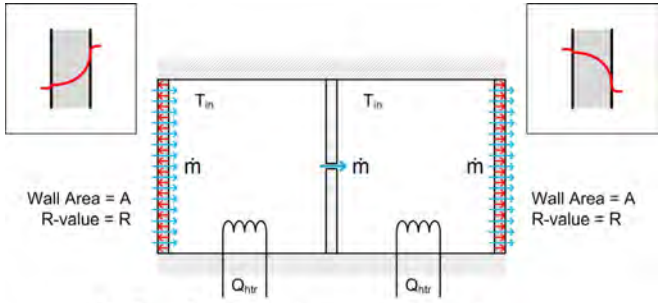



$$Q_{inf\ II} = \frac{A \cdot (T_{in} - T_{out})}{R} + \dot{m} \cdot c_p (T_{in} - T_{out})$$

$$Q_{exf} = \frac{A \cdot (T_{in} - T_{out})}{R}$$

## Airflow

- Addressing interaction




$$Q_{inf} = \frac{A \cdot (T_{in} - T_{out})}{R} + F_i \cdot \left[\dot{m} \cdot c_p (T_{in} - T_{out})\right]$$

$$Q_{exf} = F_2 \cdot \frac{A \cdot (T_{in} - T_{out})}{R}$$

## Roadmap to a new Thermal Metric

- A new Thermal Metric must:
  1. Account for thermal bridging (5-50% impact)
     (Ready to implement)
  2. Account for temp affect on R-value (10-30% impact)
     (Ready to implement)
  3. Account for airflow affects (10-50% impact)
     (More complex than $Q_{airflow} = mc(T_{in}-T_{out})$)
- and might account for
  1. Moisture affects
  2. Time dependency (thermal mass / phase change)
  3. Quality of installation



## New Thermal Metric(s)

- NRC-IRC's Wall Energy Rating (WER)
- Approach
  - Construct 'sealed wall'
  - Measure air leakage of sealed wall (at room temp)
  - Measure heat flow of sealed wall at one temperature
  - Season wall by subjecting it to series of pressure loadings (800 and 1000 Pa)
  - Measure air leakage of seasoned wall (at room temp)
  - Measure heat flow of seasoned wall at one temperature

## New Thermal Metric(s)

- NRC-IRC's Wall Energy Rating (WER)
- Take a small number of measurements and incorporate them into a CFD model to extrpolate
- Concerns
  - Accelerated aging tests that have not been correlated to real (field) loads and response
  - No measurement of heat flow + airflow
  - Airflow calculated at 75 Pa



## An Alternate Thermal Metric: $U_{tam}$

- Use a U-value that accounts for ***thermal bridging***
- $U_t$ also accounts for temperature dependence
- $U_{ta}$ also accounts for airflow interaction
- $U_{tam}$ could also account for
  moisture ($_m$?)
  or mass ($_M$?)



## An Alternate Thermal Metric: $U_{tam}$

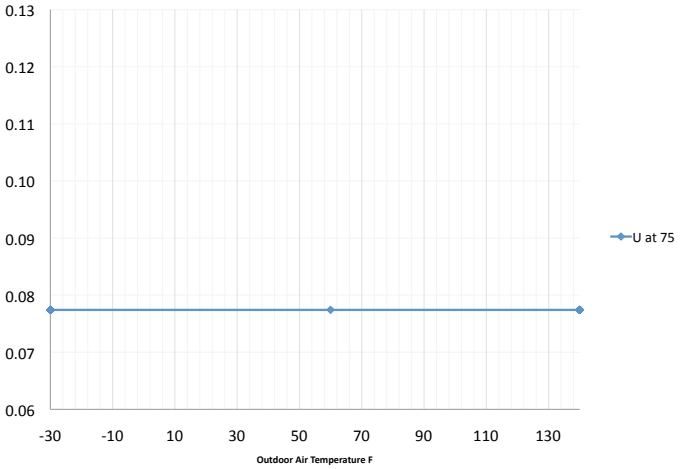
- Test full-scale assembly
- over a range of temperatures
- airflow at different temperatures
- with combined temperature difference and air pressure difference
- Test a total of 14 'setpoints' (combinations of temperature and air pressures)



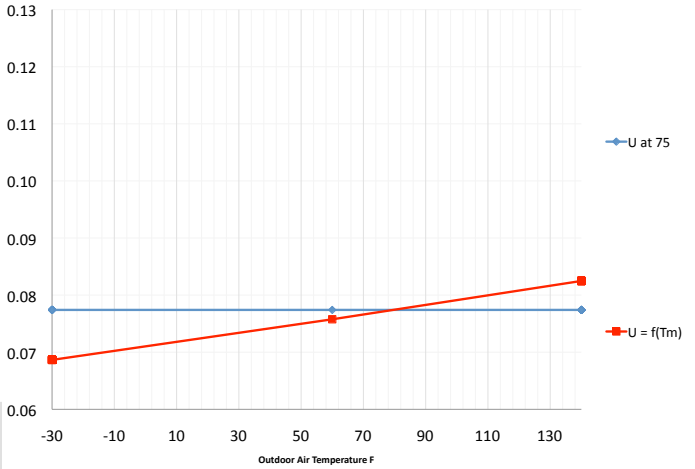
## An Alternate Thermal Metric: $U_{tam}$

- Plot results from 14 'setpoints'
- Model to extend curves to other air pressures using hot box measurements, air leakage measurements and material properties vs temperature

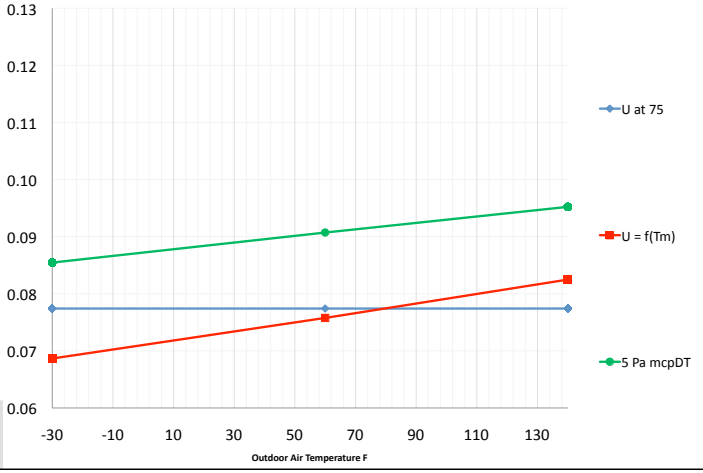
## U : only accounts for bridging (mean °75F)



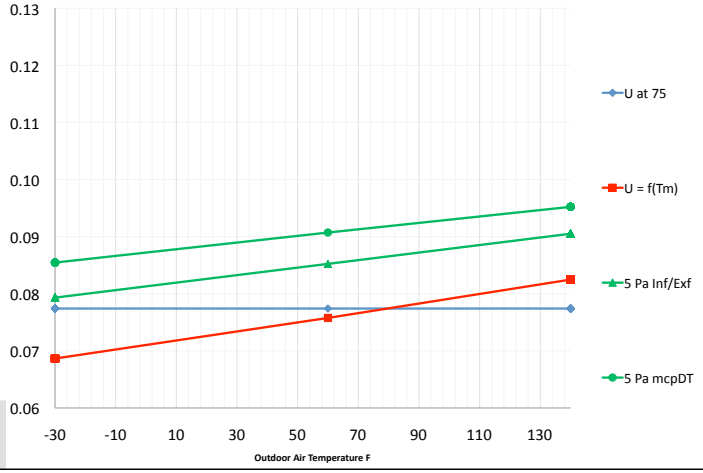

## $U_t$ : also accounts for temperature



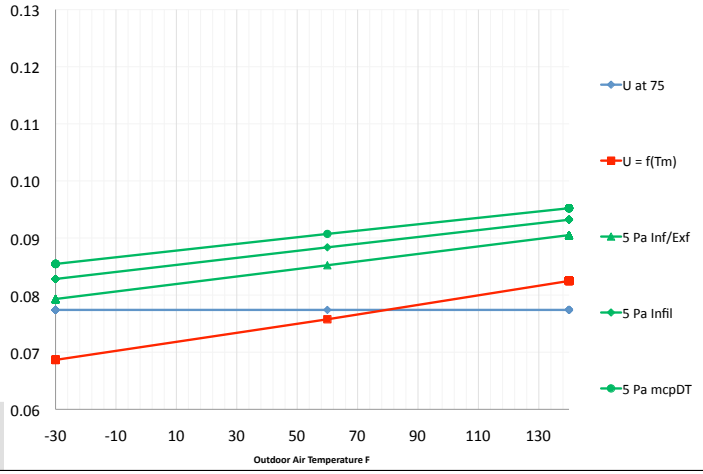

## $U_{ta}$ : also accounts for air pressures



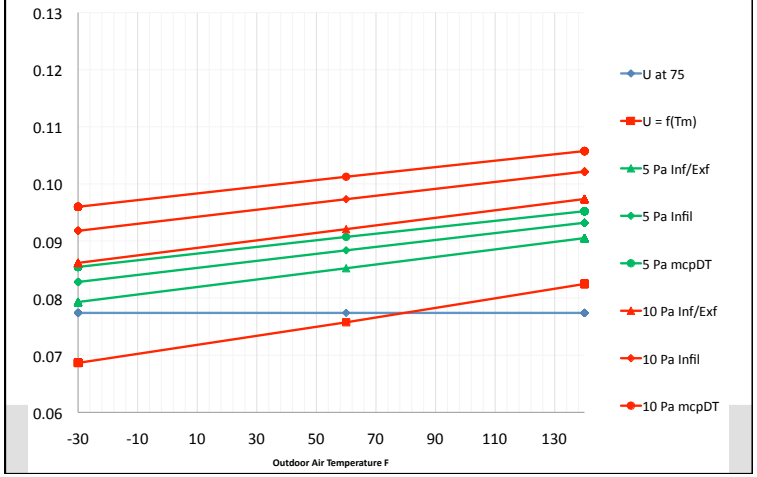

## $U_{ta}$ : also accounts for air pressures



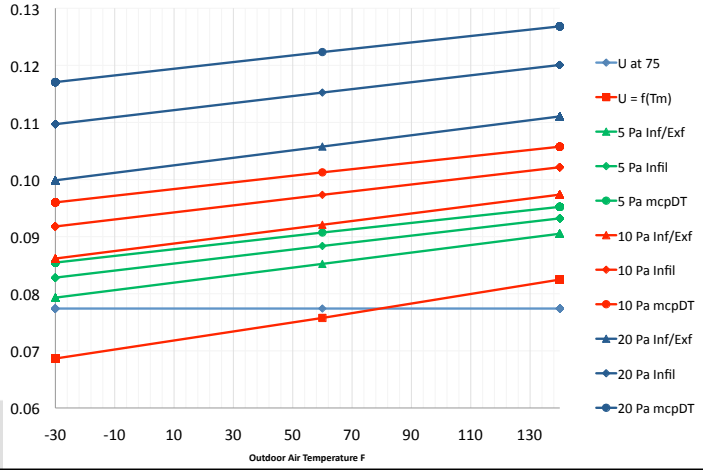
## $U_{ta}$ : also accounts for air pressures



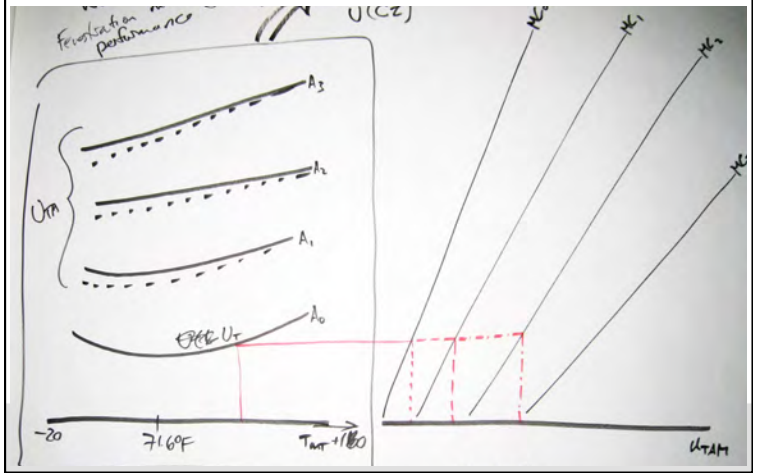

## $U_{ta}$ : also accounts for air pressures




## $U_{ta}$ : also accounts for air pressures




## $U_{tam}$ : could also accounts for moisture



## $U_{tam}$ Applications

- Graphical
  - Designers hand calculations
- Tabular
  - Computer calculations
  - Building energy models
- Single Number
  - Standards, Codes, etc.
  - City or climate zone specific



**Conceptual Demonstration of Heating Only Annual $U_{ta}$ For Different Cities**

| City | Rat75 | R=f(MT) | Inf/Exfil | Infil | mcpDT |
|---|---|---|---|---|---|
| **Miami** | 0.077 | 0.075 | 0.087 | 0.090 | 0.093 |
| **Houston** | 0.077 | 0.074 | 0.083 | 0.086 | 0.088 |
| **Phoenix** | 0.077 | 0.075 | 0.081 | 0.083 | 0.085 |
| **Atlanta** | 0.077 | 0.074 | 0.088 | 0.092 | 0.096 |
| **Seattle** | 0.077 | 0.074 | 0.085 | 0.089 | 0.091 |
| **St Louis** | 0.077 | 0.074 | 0.089 | 0.094 | 0.097 |
| **Chicago** | 0.077 | 0.073 | 0.090 | 0.095 | 0.099 |
| **Minneapolis** | 0.077 | 0.073 | 0.088 | 0.093 | 0.097 |
| **International Falls** | 0.077 | 0.072 | 0.084 | 0.088 | 0.090 |
| Denver | 0.077 | 0.073 | 0.083 | 0.086 | 0.089 |
| Fairbanks | 0.077 | 0.072 | 0.077 | 0.079 | 0.080 |
| Casper | 0.077 | 0.073 | 0.097 | 0.104 | 0.109 |
| Jackson Hole | 0.077 | 0.073 | 0.083 | 0.086 | 0.088 |
| Dallas | 0.077 | 0.074 | 0.089 | 0.094 | 0.098 |
| **Avg** | **0.077** | **0.074** | **0.086** | **0.090** | **0.093** |

## Conclusions

- Thermal Metric Reference Walls Research and Analysis Completed
- Airtight 'R-13' Walls have similar performance, regardless of insulation technology
- ALL air leakage increases energy use
- Interaction between convective and conductive heat flow causes actual energy use to be less than predicted (models overestimate)



## Conclusions

- Air leakage changes with temperature. Room temperature air leakage vs pressure measurements may not capture the real air leakage performance of a wall.
- All materials exhibit temperature dependent conductivity / R-value. (15-30% impact)
- Walls with higher insulation levels exhibit reduced heat flows and energy use
- Higher R-value walls are more sensitive to any air leakage

## Conclusions

- The higher the performance of the system, the larger the relative impact of each of the mechanisms (thermal bridging, temperature affects & airflow)
- Developed a framework for a new thermal metric

$$U_{tam}$$



## So What is it Good For?

- Allows for fair comparison of different wall systems
- Improves precision of energy models, explains field observations
  - More important for high-R walls
- Climate-specific code targets



## So What is it Good For?

- HERS-type ratings, +/- points for quality of installation, blower door results
  - Rational basis for acceptance/rejection at commissioning
- Better predictions of cost-benefit for installation, airtightness, insulation etc.



## Thank You