

The Built Environment Research Group

advancing energy, environmental, and sustainability
research within the built environment
at Illinois Institute of Technology



Assessing The Thermal Performance of Building Enclosure Materials Using A Medium-Size Hot Box Chamber

2014 Summer Meeting

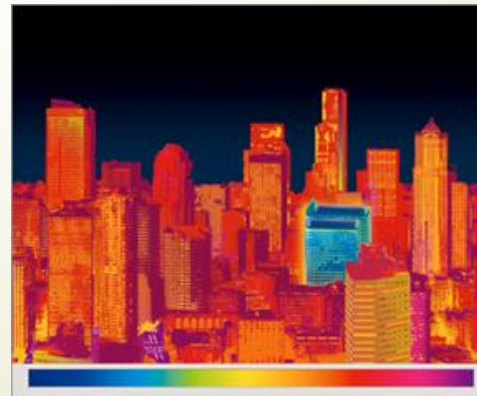
Torkan Fazli

Introduction

The building construction industry consumes significant amount of nonrenewable energy and also increases greenhouse gas emissions, which causes serious threats for natural environment.



High performance building enclosure materials help to decrease these negative consequences by reducing heat loss through building enclosure. However, there is limited thermal performance data for building materials, specially novel ones.



R-Value Definition

R-Value is the capacity of an insulating material to resist heat flow

$$R = \frac{\Delta T \cdot A}{Q} = \frac{\Delta T}{q} \left(\frac{m^2 \cdot k}{W} \right)$$

ΔT = Temperature differences between hot and cold surfaces (K or °C)

A = Effective area of the test specimen (m^2)

Q = Time rate of net heat flow through the specimen (W)

q = Time rate of heat flow through a unit area $\left(\frac{W}{m^2} \right)$

R-Value Measurement Methods

- ASTM C 177 “Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded –Hot-Plate Apparatus;
- ASTM C 518, “Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus;”
- ASTM C 1363 “Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus;”

ASTM C 177

(Thermal Transmission Properties by Means of the Guarded –Hot-Plate Apparatus)

This test method measures the steady-state heat flux through homogeneous flat specimens. Two test specimens (as identical as possible) are placed on both sides of a “guarded” hot plate and in contact on the other side with a “cold surface assembly”. Compliance with this test requires the establishment of steady-state conditions (same temperature across the assembly) and the measurement of the heat flow in one direction.

Cold Surface Assembly		
Specimen		
----Guard----	---Hot Plate--	--Guard--
Specimen		
Cold Surface Assembly		

ASTM C 518

(Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus)

This test method covers the measurement of steady-state thermal transmission through flat slab specimens using a heat flow meter.

Cold Plate
Specimen
Heat Flux Transducer
Hot Plate

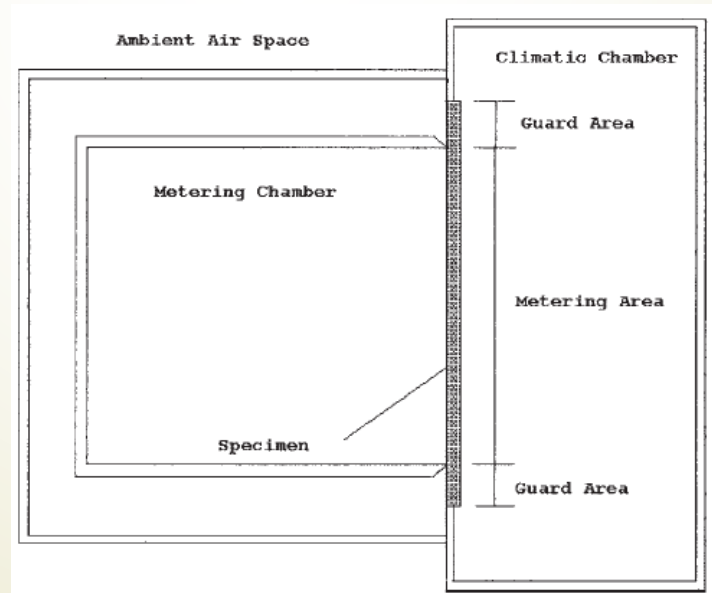
Cold Plate
Heat Flux Transducer
Specimen
Heat Flux Transducer
Hot Plate

Hot Plate
Specimen
Heat Flux Transducer
Specimen
Cold Plate

ASTM C 1363

(Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus)

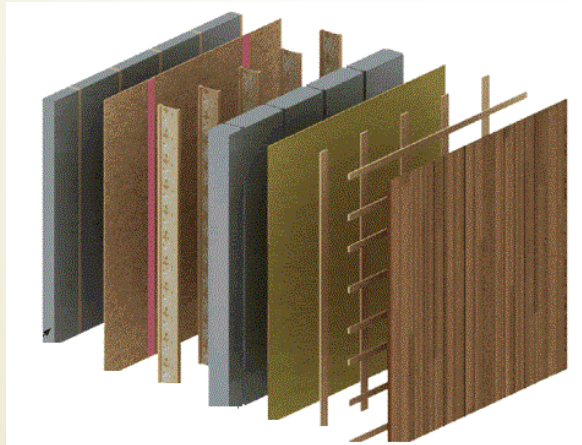
This test method is used for large homogeneous or non-homogeneous specimens. This test method applies to building structures or composite assemblies of building materials for which it is possible to build a representative specimen that fits the test apparatus.



The Scope of Hot Box Project

Measuring thermal resistance (R-Value) of novel materials according to ASTM standards

- Using smaller size Hot Box chamber compare to the one mentioned in ASTM C 1363
- Eliminating heat flux meter devices and using inexpensive devices with the lab facilities



<http://hammerandhand.com/field-notes/carissa-farkas-structural-engineer-passive-house-projects-portland-seattle/>

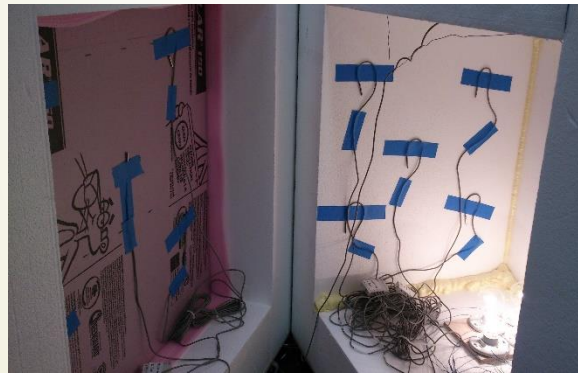


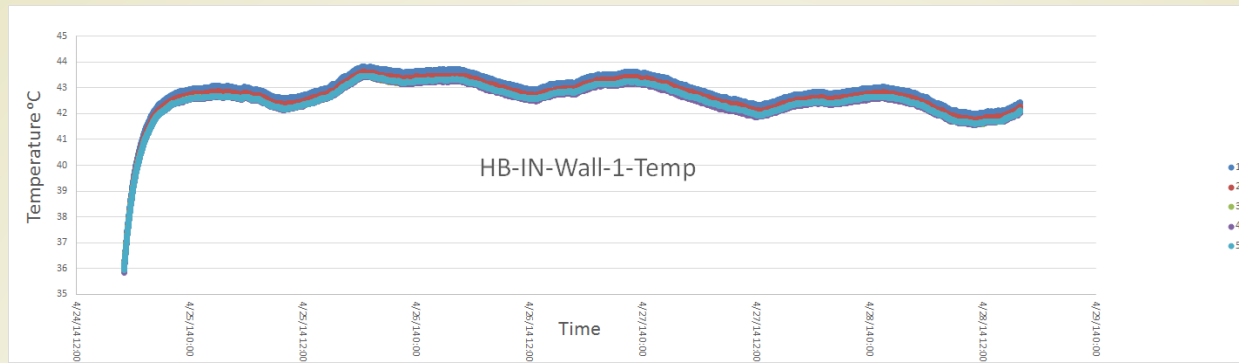
Tests Procedures

Step # 1

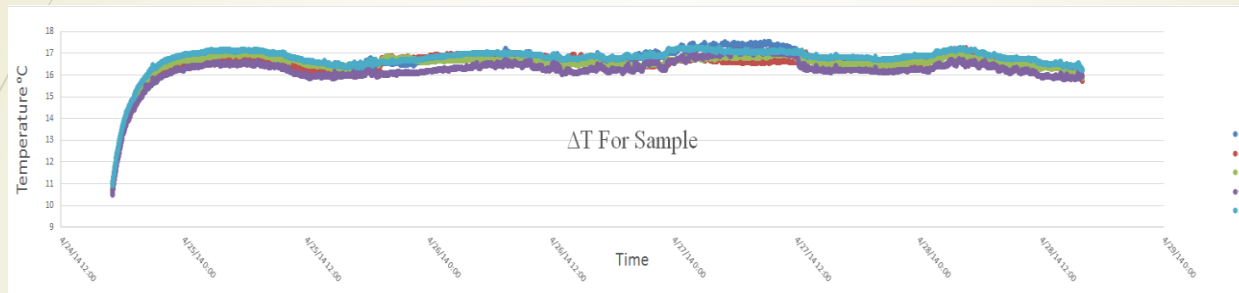
Temperature Measurement

In order to measure inside and outside temperature for both surfaces and air, 7 Onset HOBO dataloggers with 22 sensors are used at 1-minute intervals

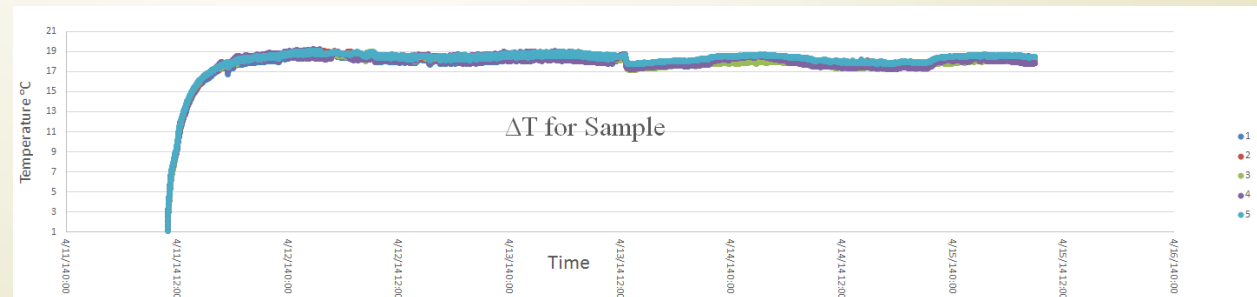
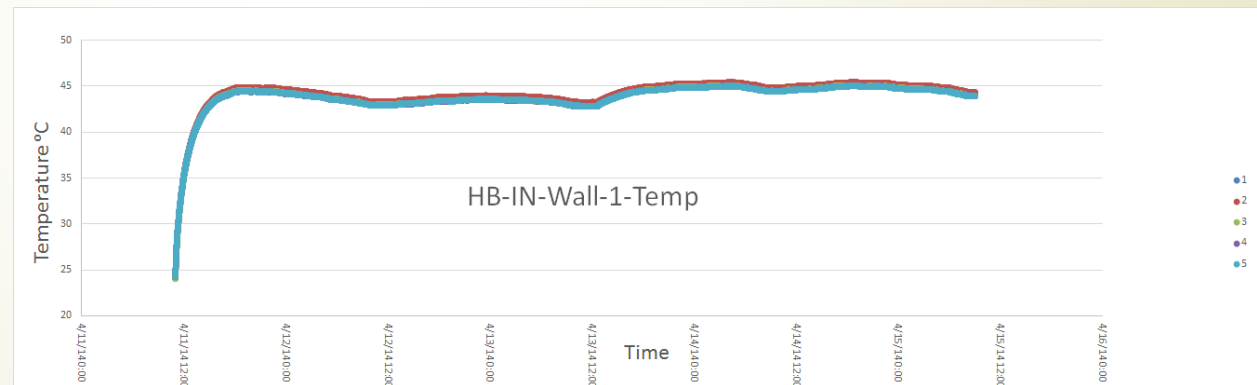




Temperature
distributions
for the test on
04.24.2014



Temperature
distributions
for the test on
04.11.2014



Tests Procedures

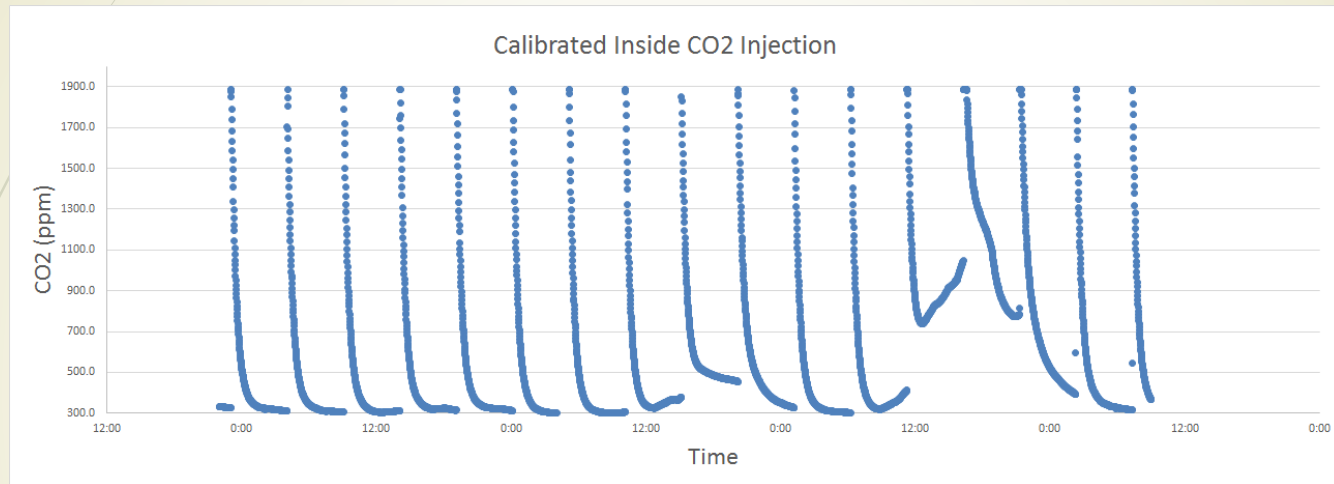
Step # 2

CO_2 Injection

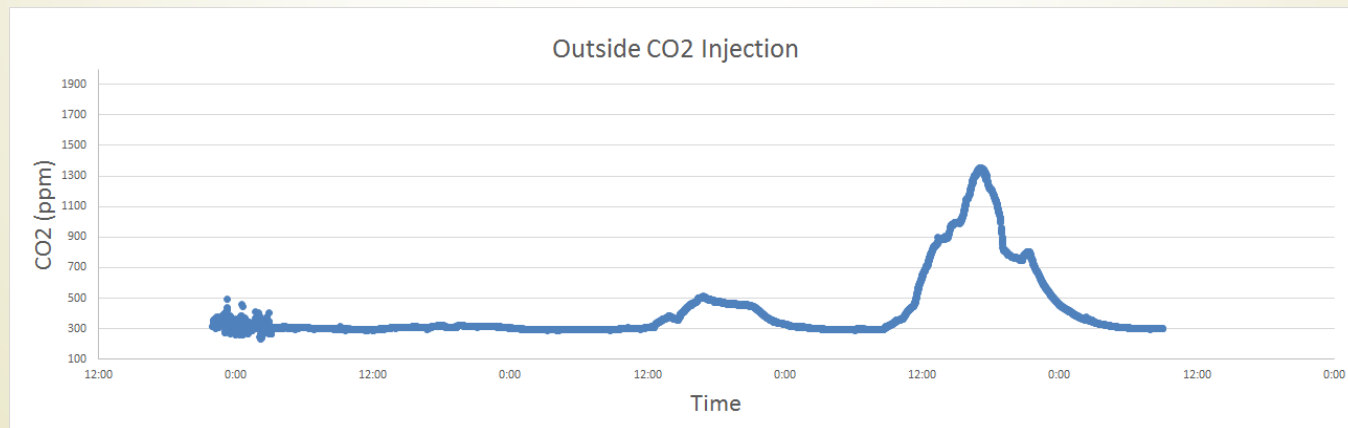
One of the important parameter in tests are measuring air exchange rate (AER). To estimate AER, certain amount of CO_2 is injected inside the box during period of time and 2 CO_2 gas analyzers and the Onset HOBO datalogger are used to record CO_2 concentration inside and outside of the box.



CO_2 concentration during 17 injection inside the hotbox



CO_2 concentration outside of the hotbox

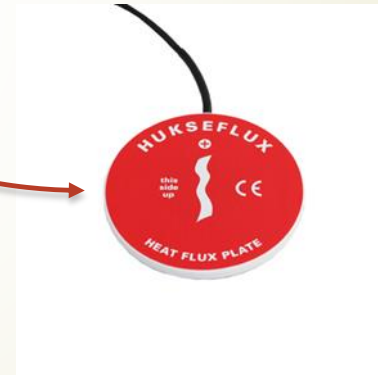
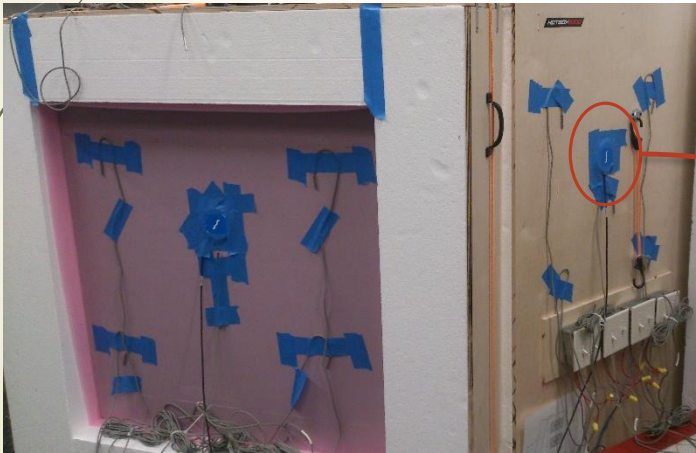


Tests Procedures

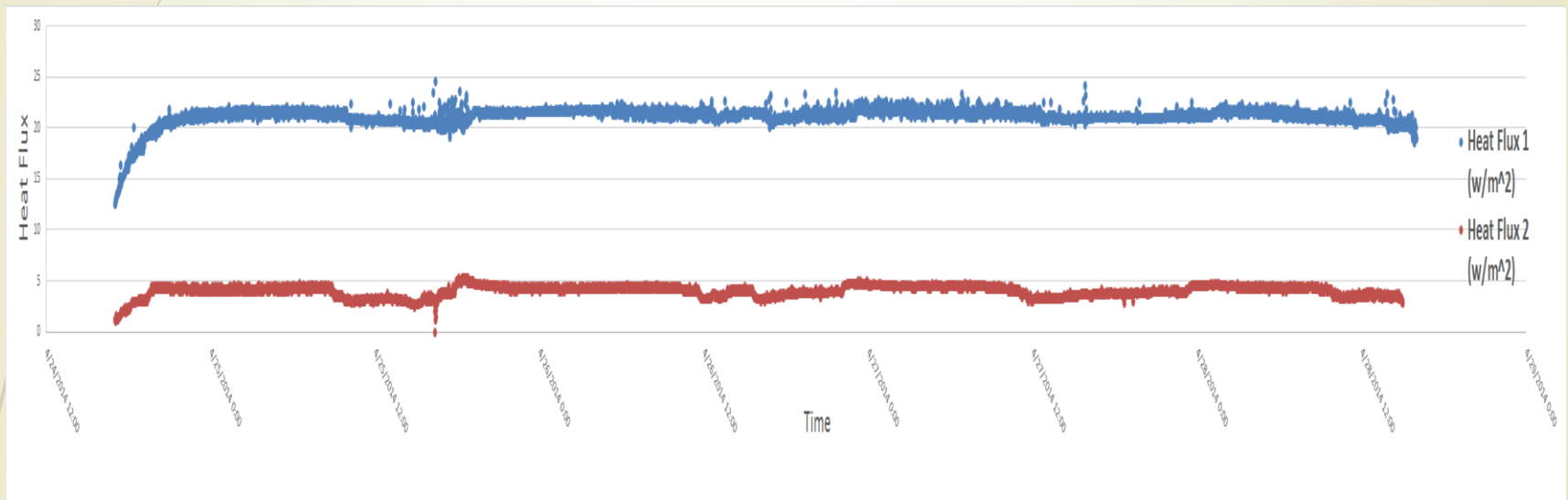
Step # 3

Heat Flux Measurement

- ▶ Heat flux meter apparatuses are used to measure heat flow through sample material and hotbox walls as well.



Heat flow measurement of sample and chamber wall by using heat flow meters



Methodology

Steady State Energy Balance On Hot Box Air

$$Q_{Source} - Q_{Chamber\ Loss} - Q_{Sample} = 0$$

$$Q_{Source} = Q_{Lamps} + Q_{Fan} (W)$$

$$Q_{Sample} = U_{Sample} A_{Sample} \Delta T = q A_{Sample} (W)$$

$$Q_{Chamber\ Loss} = U_{Chamber} A_{Chamber} \Delta T + \dot{V} c_p \rho \Delta T (W)$$



$$Q_{Lamps} + Q_{Fan} - U_{Chamber} A_{Chamber} \Delta T_{surfaces} - \dot{V} c_p \rho \Delta T_{air} - U_{Sample} A_{Sample} \Delta T_{surfaces} = 0$$

Q_{Lamps} = Heat input produce by lamps (W)

Q_{Fan} = Heat input produce by fan (W)

$U_{Chamber}$ = Thermal conductivity of the chamber ($W/m^2 \cdot K$)

$A_{Chamber}$ = Area of chamber walls where losses occur (m^2)

\dot{V} = Air exfiltration rate (m^3/s)

ρ = Air density (kg/m^3)

c_p = Specific heat capacity of air ($J/kg \cdot K$)

ΔT_{air} = Inside & outside temperature differences (K or °C)

U_{Sample} = Thermal conductivity of the sample ($W/m^2 \cdot K$)

A_{Sample} = Area of specimen (m^2)

$\Delta T_{surfaces}$ = Temperature differences between hot & cold surfaces (K or °C)

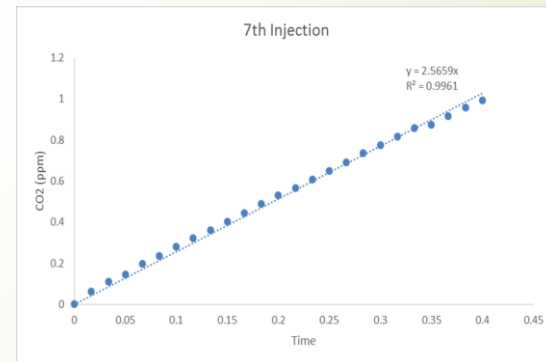
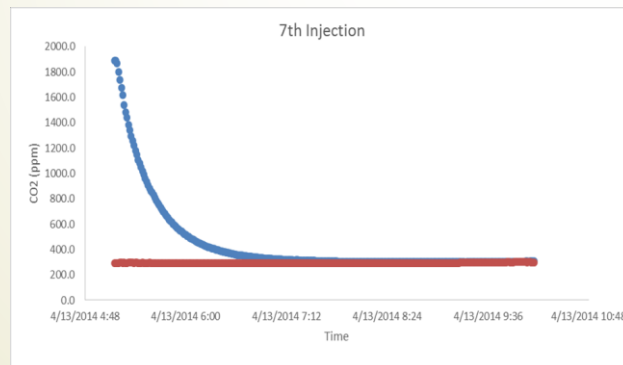
$U_{Chamber}A_{Chamber}$ Calculation

$$U_{Chamber}A_{Chamber} = \frac{Q_{Lamps} + Q_{Fan} - \dot{V}c_p\rho\Delta T_{air} - U_{Sample}A_{Sample}\Delta T_{sample\ surfaces}}{\Delta T_{chamber\ surfaces}}$$

Air Exfiltration Rate (\dot{V}) Calculation

$$\dot{V} = V_{chamber} \times AER$$

We calculate Air Exchange Rate (AER) of the hot box during steady state period in two ways: Analytical solution to concentration decay and discrete solution methods. These are used when we have steady CO_2 concentration outside the box which only happens in an unoccupied environment.



Seventh injection					
R-squared = 1.0000					
Adj R-squared = 1.0000					
Total	60696801.8	245	247742.048	Res. dev.	= 1093.112

Cin	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
-----+-----					
/AER	2.510627	.0291553	85.43	0.000	2.433198 2.548055

AER Results Measurements

Results from the last test on
04.24.2014

	Discreet Method Without Calibration	Ln Method	
1	3.0884	2.8015	1
2	3.1886	3.3692	2
3	3.0144	2.9791	6
4	2.7124	3.5218	7
5	3.0917	3.6322	8
6	3.2340	3.3498	9
7	3.4662	3.1619	10
8	3.3061	3.4727	11
9	3.3061	2.9739	14
10	3.2580	3.3902	16
11	3.4556		
12	3.4925		
13	3.3027		
14	3.1545		
15	3.2194		
16	3.4399		
17	3.3682		
Standard Deviation	0.19	0.26	
Relative S.D %	5.87	7.92	
Average AER for Discreet Method		3.24	
Average AER for Ln Method		3.27	
Average AER for Discreet Method for the injections same as Ln Method		3.29	

Total AER results from
last 3 tests

	04.03.2014	04.11.2014	04.24.2014
Average AER	2.20	2.31	3.24
Standard Deviation	0.18	0.07	0.19
Relative S.D	8.23	3.06	5.87

Specimen Thermal Conductivity (U-Value) Measurement

$$U_{Sample} = \frac{Q}{\Delta T \cdot A} = \frac{q}{\Delta T} = \frac{1}{R} \left(\frac{W}{m^2 \cdot K} \right)$$

	04.03.2014	04.11.2014	04.24.2014
U-Value ($\frac{W}{m^2 \cdot K}$)	1.27	1.24	1.28
R-Value ($\frac{m^2 \cdot K}{W}$)	0.79	0.80	0.78
R-Value (IP)	4.48	4.56	4.44

$U_{Chamber} A_{Chamber}$ Calculation

$$U_{Chamber} A_{Chamber} = \frac{\overset{\checkmark}{Q_{Lamps}} + \overset{\checkmark}{Q_{Fan}} - \overset{\checkmark}{\dot{V}} \overset{\checkmark}{c_p} \overset{\checkmark}{\rho} \overset{\checkmark}{\Delta T_{air}} - \overset{\checkmark}{U_{Sample}} \overset{\checkmark}{A_{Sample}} \overset{\checkmark}{\Delta T_{sample\ surfaces}}}{\underset{\checkmark}{\Delta T_{chamber\ surfaces}}}$$

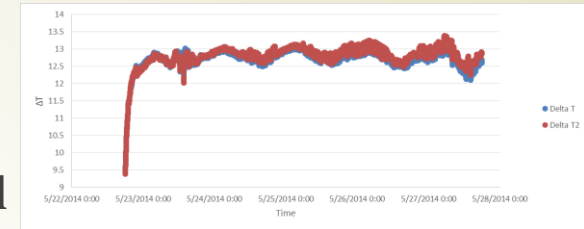
$U_{Chamber}A_{Chamber}$ Results of last 3 Tests

	04.03.2014	04.11.2014	04.24.2014	Total
Average $U_{Chamber}A_{Chamber}$	0.95	0.93	0.89	0.92
Standard Deviation	0.04	0.05	0.06	0.02
Relative S.D %	4.73	4.84	7.13	2.70

Problems and Limitations

➤ Steady State Mode

Steady state condition have never occurred during our tests perfectly



➤ Q_{source}

Amount of heat input significantly change the $U_{Chamber}A_{Chamber}$. Currently used wattmeter does not read the wattages accurately.



➤ R-Value of Sample

According to manufacturer the R-value of XPS as a sample is R-5 which is different from our outputs.



<http://www.foamular.com/foam/products/foamular-150.aspx>

Solutions

- Steady state Mode:

Adding cold side instead of using room temperature

- Q_{source} :

Using more accurate wattmeter which is able to log data during a test period

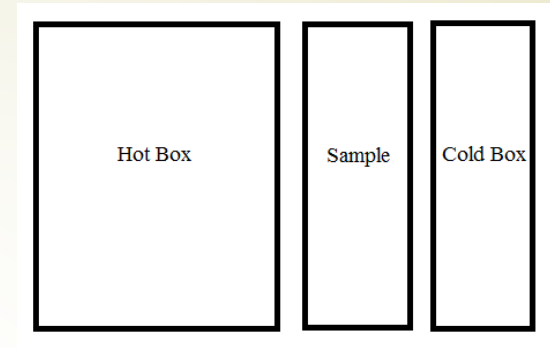
- R-Value of Sample:

As mentioned in ASTM standard R-values vary depending on many factors including the mean temperature at which the test is conducted, and the age of the sample at the time of testing.

The value printed on the product is the R-value at 180 day real-time age and 75°F (24 °C) mean temperature.

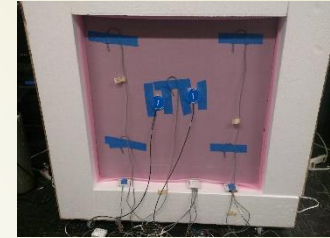
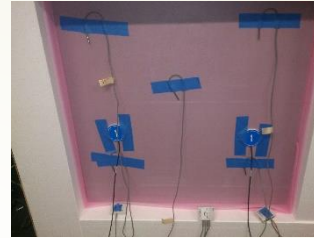
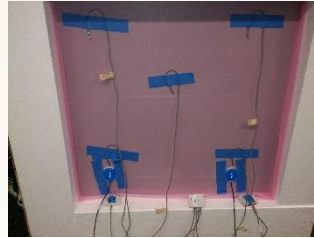
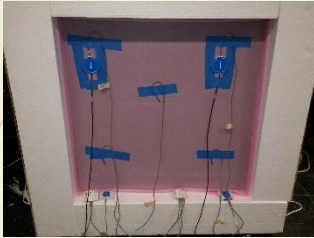
Also R-value reductions caused by thermal bridging, humidity, temperature changes, air infiltration and wind

According to manufacturer instructions they test the material according to ASTM C 518. By using each standard method different R-value amounts are calculated.

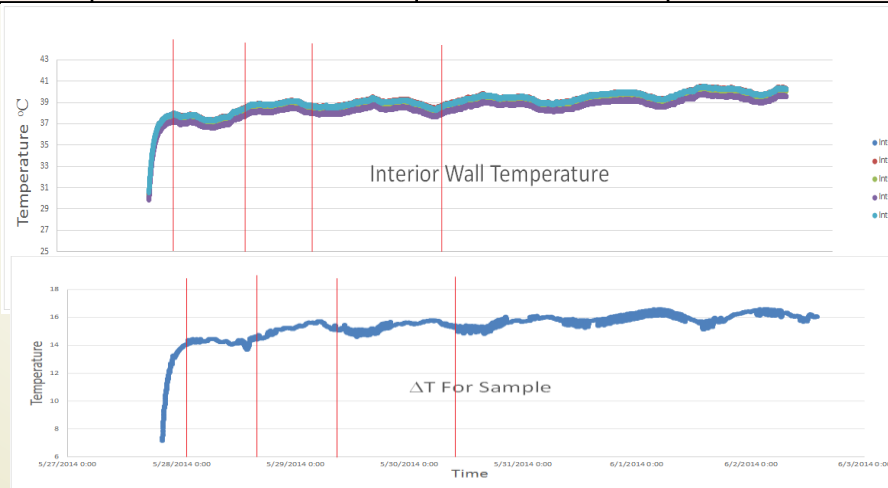


Tests For R-Value Measurement of Sample

1- Test without covering the gaps of box (2 Heat Fluxes and 10 Sensors)



Heat Flux 1		Heat Flux 2	
R-Value (Ave Temp)	R-Value (Related Sensor Temp)	R-Value (Ave Temp)	R-Value (Related Sensor Temp)
4.78	4.71	4.70	4.73
4.97	4.99	5.11	5.09
4.81	4.85	4.90	4.85
4.71	4.70	4.92	4.90
4.82	4.81	4.91	4.89

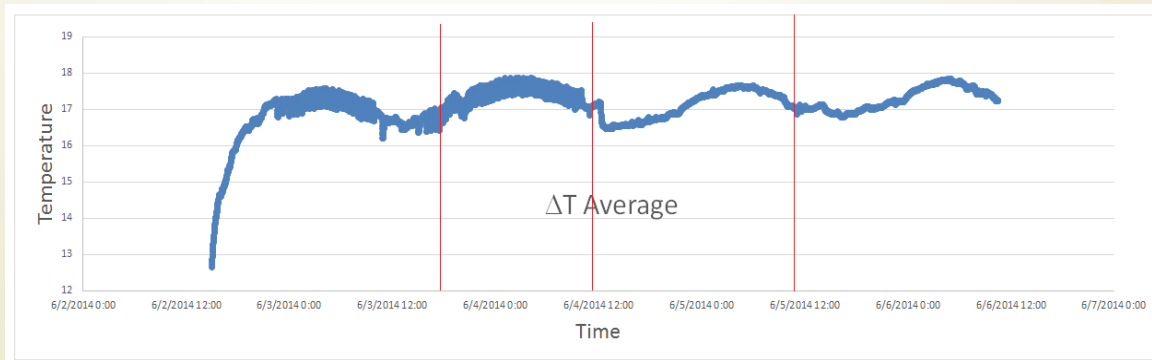
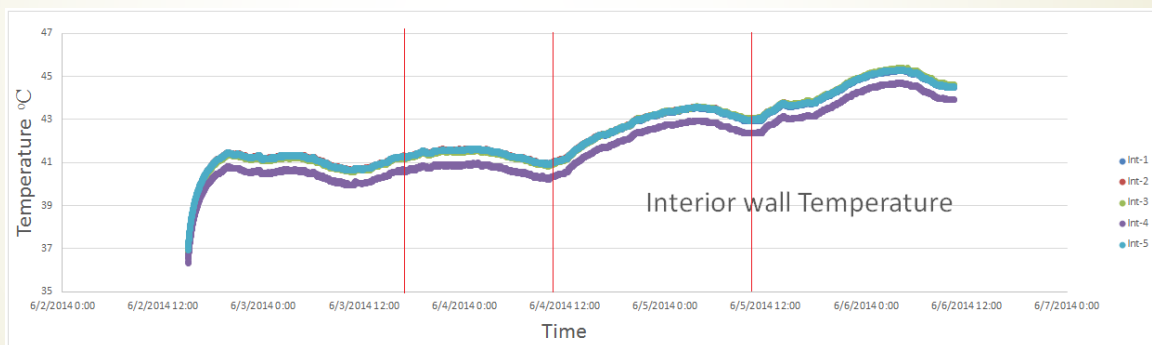


Tests For R-Value Measurement of Sample

2- Test with covering the gaps of box by tape (2 Heat Fluxes and 10 Sensors)



	Heat Flux 1		Heat Flux 2	
	R-Value (Ave)	R-Value (Related Sensor)	R-Value (Ave)	R-Value (Related Sensor)
	4.83	4.79	4.92	4.88
	4.68	4.78	4.80	4.72
	4.60	4.60	4.64	4.61
Average of Last two Period	4.64	4.69	4.72	4.66





Thank You!

Questions?