High-performance buildings are more than low-energy buildings: they are comfortable, durable, and functional. The methods and strategies that make a big difference in the energy use of office, residential, and retail occupancy buildings are fairly well known, if not widely practiced. The energy benchmarking report created as result of New York City Local Law 84 in August 2012 provides solid and factual information that current design and construction approaches are not resulting in the energy performance expected. Energy use reported for some landmark large "Green" buildings such as 4 Times Square, Bank of America, and Solaire show little improvement. Other real-world buildings examples, with less effective marketing, are demonstrating energy use that is 1/4 to 1/2 that of the more famous examples, often at lower construction cost. The difference is in the design. This seminar will explore the reasons for the poor performance, and outline techniques and strategies required to get to high performance in both building enclosures and HVAC systems.

As he always does, John will provide thought provoking examples and analysis to shed light on what is truly important in a high performance building design.

- 1 kWhr=3.4 kBtu
- 100 kWh/m2= 31.6 kBtu/sf
- 100 kBtu/sf = 315.2 kWh/m2

Secret Lives of High Performance Buildings

John Straube, Ph.D., P.Eng.
University of Waterloo
Faculty of Engineering
Building Science Labs

High Performance Buildings

- Many definitions
- My definition
  - Comfortable
  - Durable
  - Energy Efficient
  - Healthy/Safe

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Energy

- Hard to measure “performance”
- Easy to measure energy

Measuring Energy Use

- EUI - Energy use per area
  - kBtu/sf/yr
  - $kWh_e/m^2/yr$
  - 100 $kWh_e/m^2/yr$ = 31.6 kBtu/sf/yr
- Energy use per person
  - Person=? = bedrooms+1
  - But.. Design vs actual occupancy?
  - Large houses, data centers, hospitals

See BSD-152 Energy Metrics

Building Science.com

Site vs Souce

- Or electricity is dirty

BSD-151 Site & Source Energy

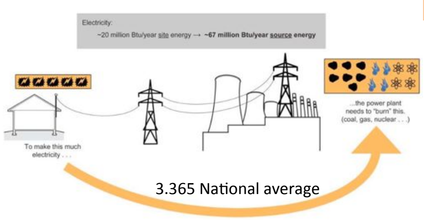
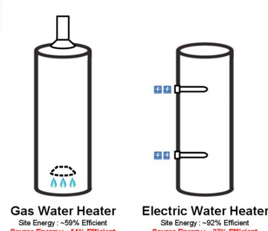


Figure 1: Source energy from power plant to electric service entrance



Building Science.com

Electric uses 2x

Example Buildings

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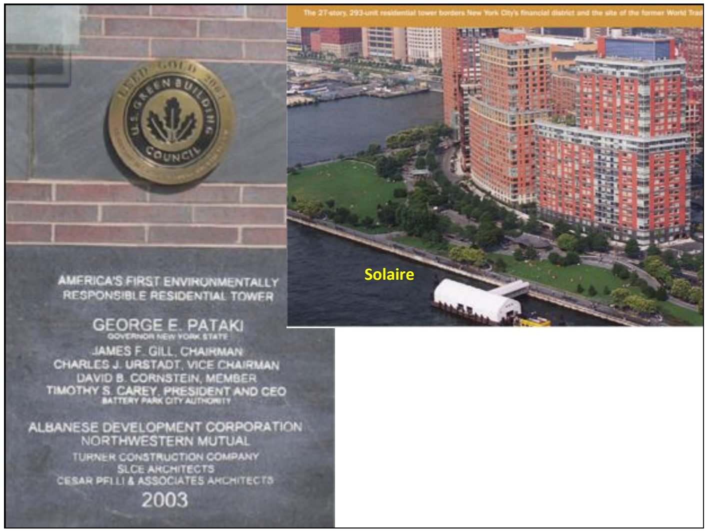

HIGH PERFORMING BUILDINGS

ASHRAE

Solaire

357000 sq ft

Solaire Resident Electrical Use

	Standard 90.1* Predicted kWh	2005–2007 Average Actual kWh		Standard 90.1* Predicted kWh	2005–2007 Average Actual kWh
January	159,712	118,331	July	137,221	109,934
February	149,336	116,989	August	138,283	101,832
March	167,516	110,128	September	129,274	112,438
April	152,494	102,863	October	152,637	114,529
May	132,852	104,974	November	166,048	122,583
June	130,349	107,979	December	151,399	123,970
			Total	1,764,120	1,346,551

* ANSI/ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings*

23.7% Les 12.9 kBtu/sf/yr

Solaire Energy Performance

	Total Gas MMBtu
2004*	42,179
2005	41,941
2006	41,267
2007	37,157
Predicted	35,736

In 2007, gas use was 3–4% higher than predicted, compared to 8% higher in 2004.

*F 104 kBtu/sf/yr

Total: 117 kBtu/yr

pay my bill
receive a 7% discount
view my account
submit a meter reading
enroll in special services
close my account
log off

my account | customer central | business center | investors | community | news | about us

my account

Billing History

Account Number: [redacted]
Customer Name: LESPMHA INC.
Service Address: 299 E 3 ST PLP

From Date	To Date	Elec Use	Elec Demand	Electric Bill Amt	Gas Use	Gas Bill Amt	Total Bill Amt
10/02/2006	10/31/2006	4,560	9.60	$751.59	859	$1,149.41	$1,901.00
08/31/2006	10/02/2006	5,120	9.20	$937.15	690	$1,013.10	$1,950.25
08/02/2006	08/31/2006	4,080	8.80	$772.66	489	$717.22	$1,489.88
07/03/2006	08/02/2006	4,360	9.60	$845.35	557	$813.69	$1,659.04
06/02/2006	07/03/2006	4,480	9.60	$905.43	685	$1,091.64	$1,997.07
05/03/2006	06/02/2006	4,560	9.20	$679.08	786	$1,264.53	$1,943.61
03/07/2006	05/03/2006	9,640	10.00	$1,411.57	--	--	$1,411.57
04/05/2006	05/03/2006	--	--	--	978	$1,666.79	$1,666.79
03/07/2006	04/05/2006	--	--	--	1,515	$2,392.41	$2,392.41
02/03/2006	03/07/2006	5,800	9.60	$757.40	2,483	$3,952.03	$4,709.43
01/04/2006	02/03/2006	5,440	10.00	$1,189.84	1,930	$3,632.26	$4,822.10
12/05/2005	01/04/2006	5,640	10.40	$1,093.60	2,244	$3,873.49	$4,967.09
11/01/2005	12/05/2005	5,680	9.60	$1,358.48	1,476	$2,768.50	$4,126.98
10/03/2005	11/01/2005	4,720	9.60	$1,011.54	863	$1,609.90	$2,621.44
09/01/2005	10/03/2005	4,400	8.40	$880.95	577	$940.32	$1,821.27
08/03/2005	09/01/2005	3,880	7.60	$698.76	451	$648.38	$1,347.14
07/05/2005	08/03/2005	3,920	7.60	$741.27	516	$719.47	$1,460.74
06/03/2005	07/05/2005	--	--	--	630	$859.01	$859.01
06/03/2005	07/05/2005	4,320	8.00	$756.07	--	--	$756.07
05/04/2005	06/03/2005	--	--	--	869	$1,140.72	$1,140.72
05/04/2005	06/03/2005	4,400	8.40	$741.85	--	--	$741.85
04/05/2005	05/04/2005	--	--	--	1,062	$1,540.13	$1,540.13
04/05/2005	05/04/2005	4,560	9.20	$721.74	--	--	$721.74

For electric and gas emergencies, please call our toll-free number 1-800-752-6633. DO NOT send an e-mail.

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June, July & August 2006 used 1,731 Therms x 4 = 6,924 Therms for Domestic Hot Water, leaving 7,768 for Heat for one year, divided by 41,945 SqFt x 100,000/4,848 HDD/Yr = 3.8 BTU/SqFt/HDD

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CHRIS BENEDICT, R.A.
P 212.477.6016 benedictra@aol.com F 212.477.6026

692400 kBtu/yr DHW
+776800 kBtu/yr heat
= 35.0 kBtu/sf gas

59360 kWh/yr elec
(202544 kBtu)
=4.8 kBtu/sf

Total: 40 kBtu/sf
(125 kWh/m²)

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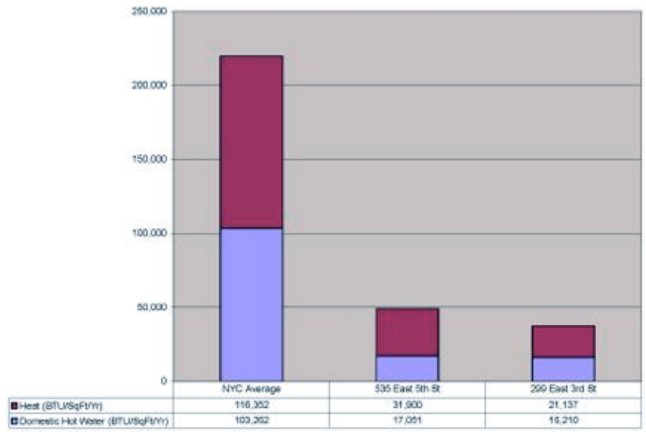

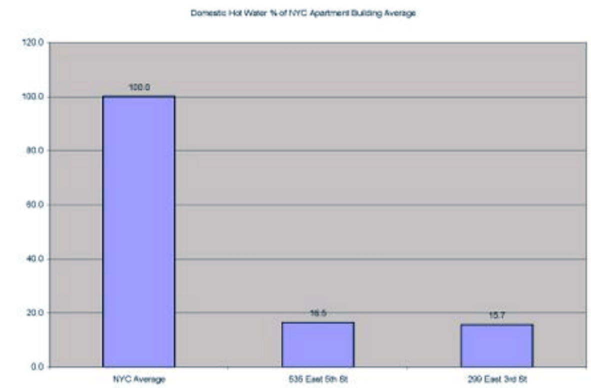

Dorset St- Waterloo, ON

- Colder Climate than NYC (8000HDD)
- First floor office, 11 residential units 20,000 sf
- 35 kBtu/sf/yr gas+electric

Site: 213 kBtu/sf

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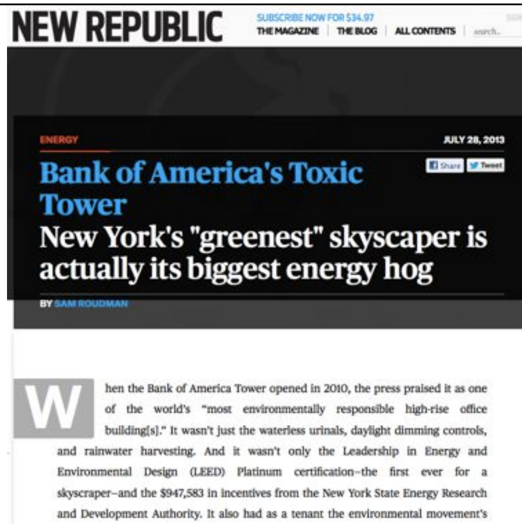

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ENERGY

JULY 28, 2013

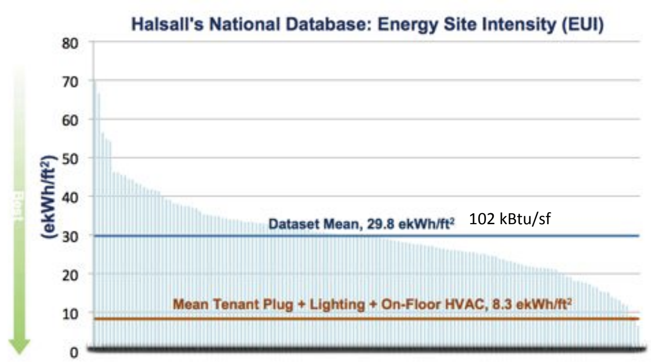
Bank of America's Toxic Tower

New York's "greenest" skyscraper is actually its biggest energy hog

BY SAM ROUDMAN

When the Bank of America Tower opened in 2010, the press praised it as one of the world's "most environmentally responsible high-rise office building[s]." It wasn't just the waterless urinals, daylight dimming controls, and rainwater harvesting. And it wasn't only the Leadership in Energy and Environmental Design (LEED) Platinum certification–the first ever for a skyscraper–and the $947,583 in incentives from the New York State Energy Research and Development Authority. It also had as a tenant the environmental movement's

Was 88 kBtu/sf
Report: 82
Retrofit: 57 target



Tenant Consumption = 30% of Building EUI

VISION • DEPTH • INNOVATION

Halsall

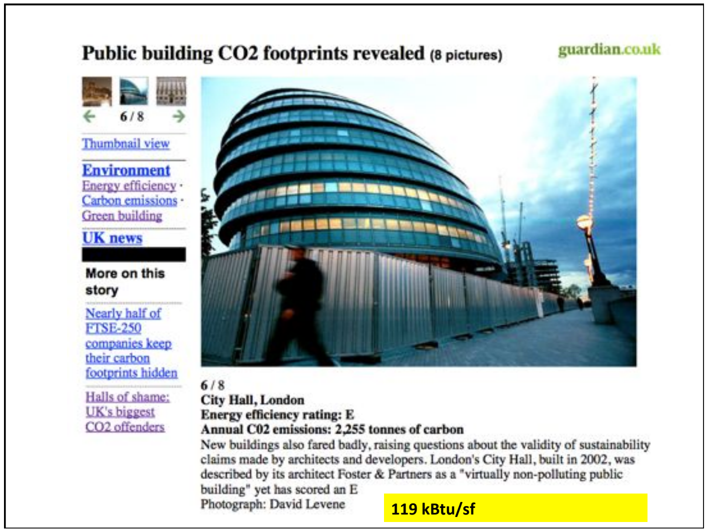
Bell Trinity Square

Lowest Energy Use Winner (>500,000 ft²)

- Built in 1983
- Downtown Toronto office building

EUI

53.7 kBtu/sf



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The New York Times

December 24, 2012

City's Law Tracking Energy Use Yields Some Surprises

By MIREYA NAVARRO

In courting tenants over the last six years, 7 World Trade Center has trumpeted its gold LEED rating, an emblem of sound environmental citizenship.

But when it comes to energy efficiency, the young 52-story tower is far from a top performer, according to data released under a city law that tracks energy use in New York buildings. It had a score of 74 — just below the minimum of 75 set for high-efficiency buildings by the federal Environmental Protection Agency's Energy Star program.

On the other hand, two venerated show horses from the 1930s, the Chrysler Building and the Empire State Building, sailed to an 84 and an 80 as a result of extensive upgrades of their insulation and mechanical systems.

Figure 10:Variation in Source Energy Use Intensity (EUI) Within Five Sectors

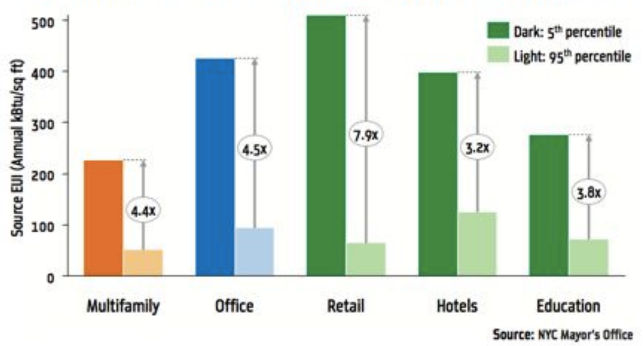


Figure 22: Scatter Plot of Multifamily Building EUI Versus Age

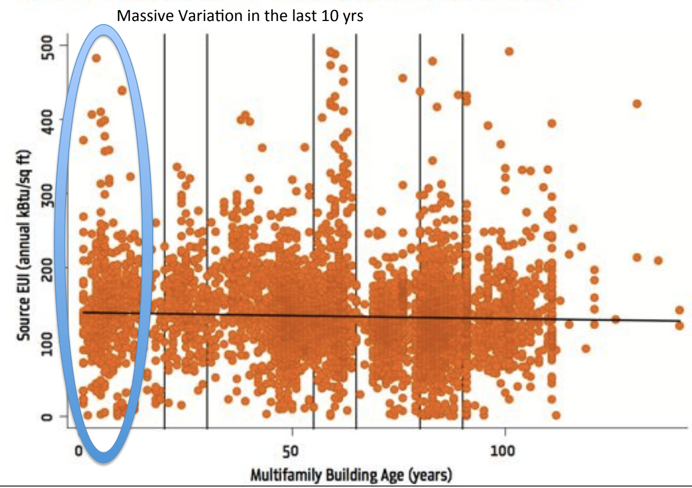
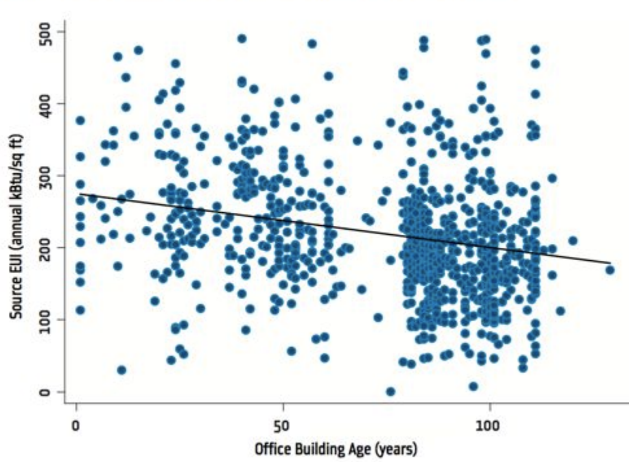


Figure 23: Scatter Plot of Office Building EUI Versus Age



- “When viewed in twenty year increments, a clear picture seems to emerge for the office sector: over the last hundred years, the median EUI for office buildings has steadily risen by almost 40% from a median EUI of 188.3 for offices built before 1930, to 262.1 for offices built since 1990, with the median EUI for the buildings of each 20 year period being higher than the preceding one.”

- “The multifamily properties seem to grow on average steadily more efficient from 1900 to 1940 and become steadily less efficient between 1945 and 1975, after which they exhibit more volatility.”

Why these trends?

How can “green” buildings use so much energy???

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Why?

- No one was measuring
- Building designs
  - Not enough insulation
    - Thermal bridging, windows
  - Too air leaky
  - Over ventilated
  - Not enough solar control
    - Windows
  - Complex, uncontrolled mechanical systems

Prescription of High Performance

- Good skin
  - Rain, air, heat, vapor control
  - Simple to understand/analyze assemblies
- Good HVAC
  - Control temperature, RH, Fresh air seperately
  - Simple to understand/analyze systems
- Good design
  - Daylight, view, program, enjoyment
  - Assume future changes will occur

Top Ten List

Commercial and institutional mid-size buildings

- **Limit window-to-wall ratio** (WWR) to the range of 30-40%, 50% with very high-performance windows
- **Increase window performance** (lowest U-value affordable in cold climates, including frame effects, low SHGC in sunny/warm)
- Increase wall/roof **insulation** (esp. by controlling thermal bridging) and **airtighten** (shade first in hot climates**)**
- **Reduce** lighting & equipment/plug **power densities**
- Separate **ventilation** air supply from **heating** and **cooling**.
- Use **occupancy** and **daylighting controls** for lights and equipment
- Don't over ventilate, use **heat recovery** & **demand controlled ventilation**
- Improve boiler and **chiller efficiency** & recover waste heat (eg IT rooms!)
- Use **variable speed controls** for all large pumps and fans and implement **low temperature hydronic** heating and cooling where practical.
- Use a simple and compact building form, oriented to the sun, with a depth that allows daylight harvesting.

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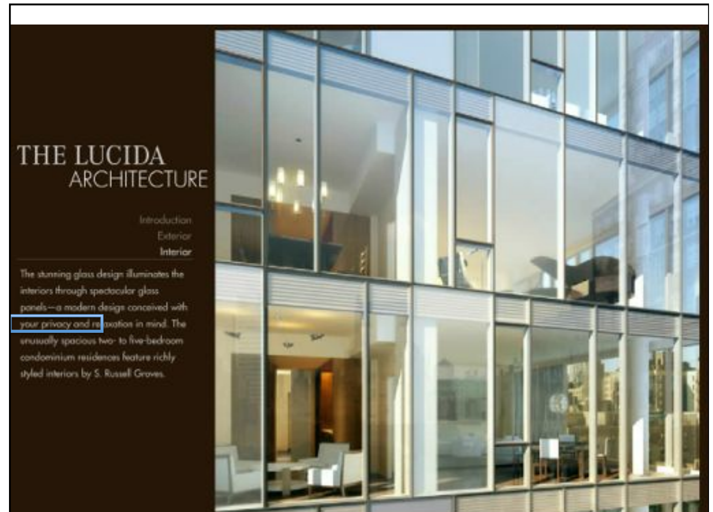
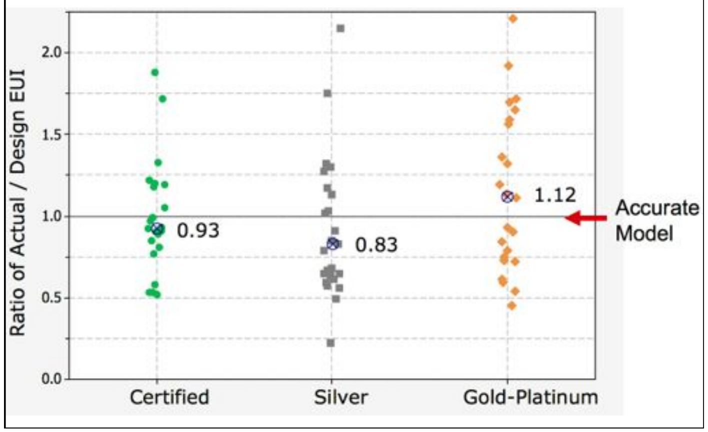
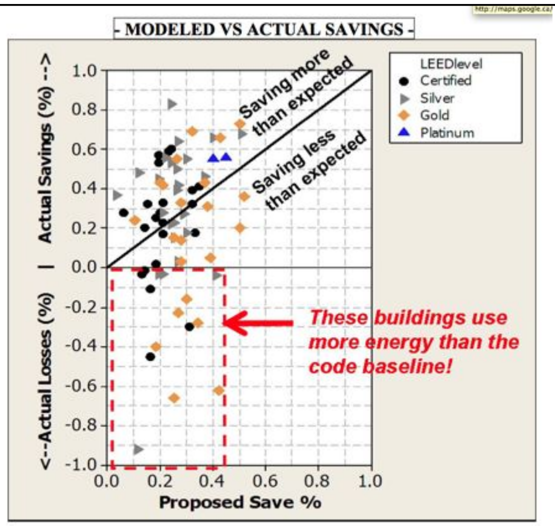


Modeling

- Predict energy use
  - For compliance
  - For design
  - For assessment

Modeling Critical





Insulation

- Thermal bridges of concrete and steel dramatically reduce performance
  - 6” steel stud, R20 batt = R5!
  - 6” wood stud, R1 batt = R14
- Windows have R-values of around 2-3. Huge heat loss
- Airtightness becomes very important as enclosure insulation is increased

Building Science.com

Thermal Insulation

Insulation	R-value/inch	k (W/mK)
Empty airspace 0.75”-1.5” (20-40 mm)	R2.0 - 2.75	0.36 –0.50 W/m²K
Empty airspace 3.5”-5.5” (90-140 mm)	R2.75	0.50 W/m²K
Batt (mineral fiber)	3.5-3.8	0.034 - 0.042
Extruded polystyrene (XPS)	5.0	0.029
Polyisocyanurate (PIC)	6.0-6.5	0.022 - 0.024
Expanded polystyrene (EPS)	3.6-4.2	0.034 - 0.040
Semi-rigid mineral fiber (MFI)	3.6-4.2	0.034 - 0.040
Spray fiberglass	3.7-4.0	0.034 - 0.038
Closed-cell spray foam (2 pcf) ccSPF	5.8-6.6	0.022 - 0.025
Open-cell spray foam (0.5 pcf) ocSPF	3.6	0.040
Aerogel	8-12	0.012-0.018
Vacuum Insulated Panels (VIP)	20-35	0.004-0.008

Thermal Bridge Examples

- Balconies, etc
- Exposed slab edges

R-value Examples

- What overall average vertical enclosure R-value should be target?
  - R5?
  - R10?
- What component (wall, window) target values should we specify to meet this?
- $R_{avg} = 1 /(1/R_{wall} + 1/R_{window})$

Thermal bridging- windows

R-20
50% of Area

+

R-2
50% of Area

=

R-3.6
100% of Area

Thermal bridging- windows

R-20 50% of Area + **R-4** 50% of Area

=

R-6.6 100% of Area

Add R-2 to windows, get almost half the heat loss/gain from building

Thermal bridging- windows

R-40 50% of Area + **R-2** 50% of Area

=

R-5.8 100% of Area

Adding R-20 to wall reduces less heat loss/gain than improving windows

Thermal bridging- Windows

R-20 69% of Area + **R-2** 31% of Area

=

R-5.3 100% of Area

Thermal bridging- Windows

R-20 69% of Area + **R-4** 31% of Area

=

R-8.9 100% of Area

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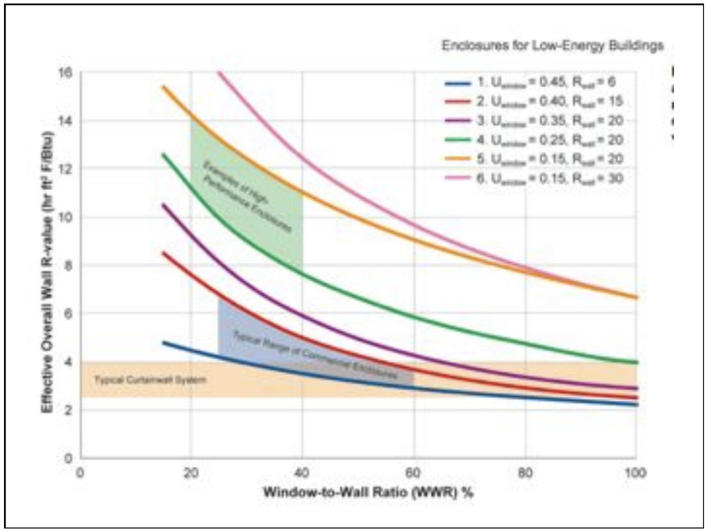
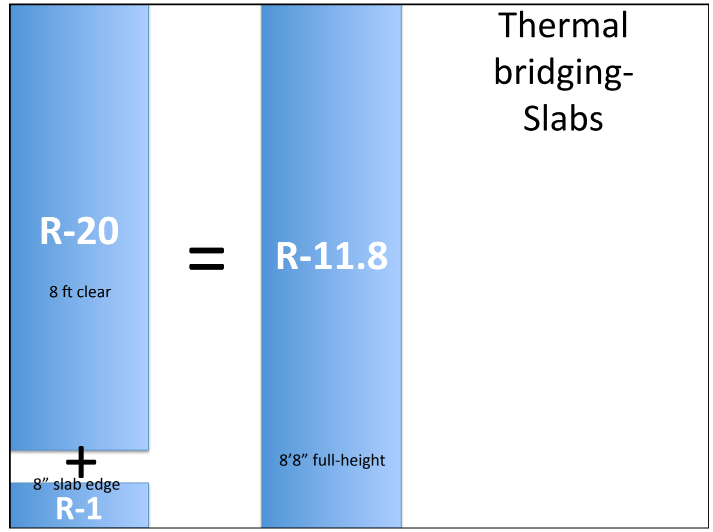
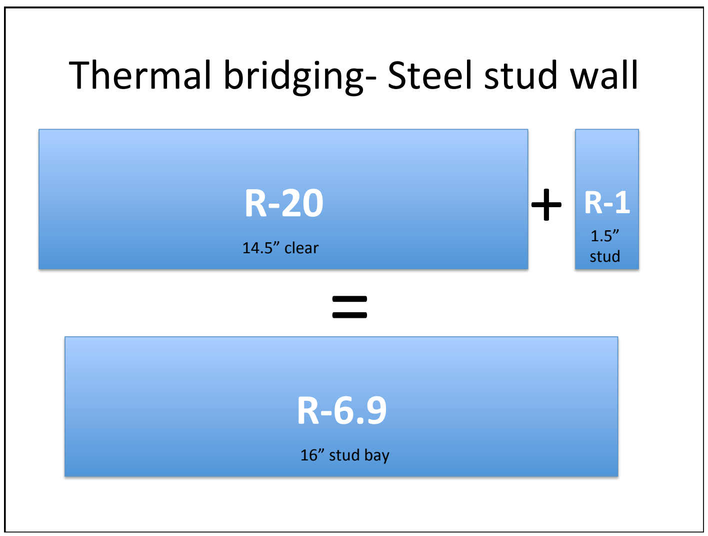
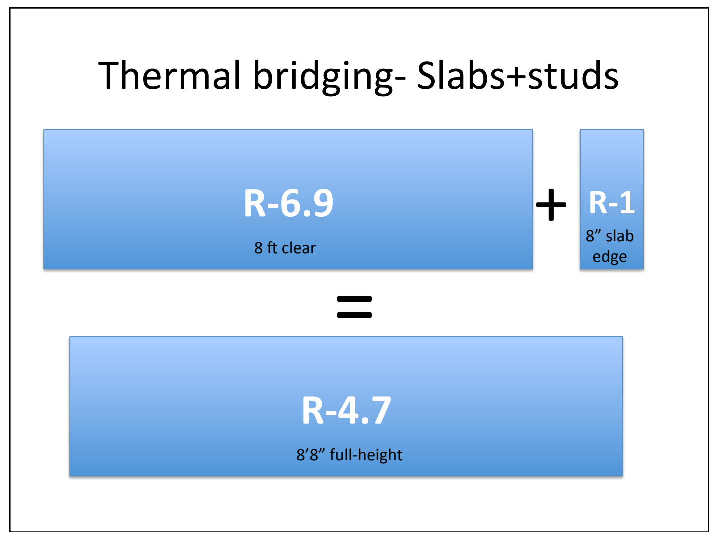

Enclosures for Low-Energy Buildings
1. U_{window} = 0.45, R_{wall} = 6
2. U_{window} = 0.40, R_{wall} = 15
3. U_{window} = 0.35, R_{wall} = 20
4. U_{window} = 0.25, R_{wall} = 20
5. U_{window} = 0.15, R_{wall} = 20
6. U_{window} = 0.15, R_{wall} = 30
Examples of High-Performance Enclosures
Typical Range of Commercial Enclosures
Typical Curtainwall System
Effective Overall Wall R-value (hr ft² F/Btu)
Window-to-Wall Ratio (WWR) %


Thermal bridging- Slabs
R-20
8 ft clear
+
8″ slab edge
R-1
=
R-11.8
8′8″ full-height


Thermal bridging- Steel stud wall
R-20
14.5″ clear
+
R-1
1.5″ stud
=
R-6.9
16″ stud bay


Thermal bridging- Slabs+studs
R-6.9
8 ft clear
+
R-1
8″ slab edge
=
R-4.7
8′8″ full-height

Thermal Continuity

- Some short circuiting is normally tolerated.
- High-performance walls tolerate few
- Major offenders / weak spots
  - Penetrating slabs (<R1)
  - Steel studs (<R1)
  - Windows (R2-R3)
- Area and low R matter to overall significance

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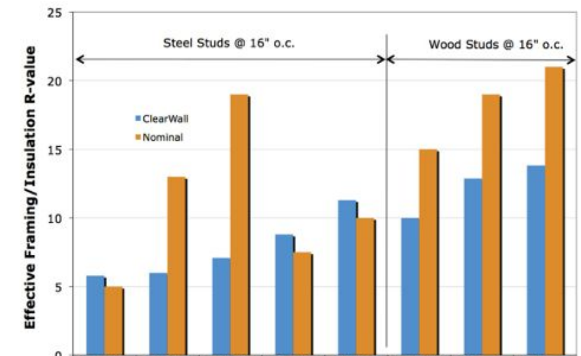
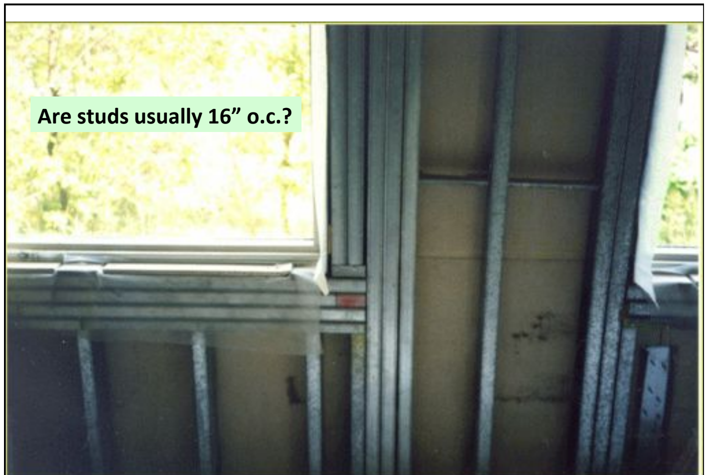
Best-case R-values for stud walls



	R5ci 3.5in	R-13 3.5in	R-19 6in	R7.5ci 6in	R10ci 6in	R-15 3.5in	R-19 6in	R-21 6in
ClearWall	5.8	6.0	7.1	8.8	11.3	10.0	12.9	13.8
Nominal	5	13	19	7.5	10	15	19	21

Source: ASHRAE 90.1-2007, Table A9.28. ci denotes a layer of continous insulation with no framing penetrations



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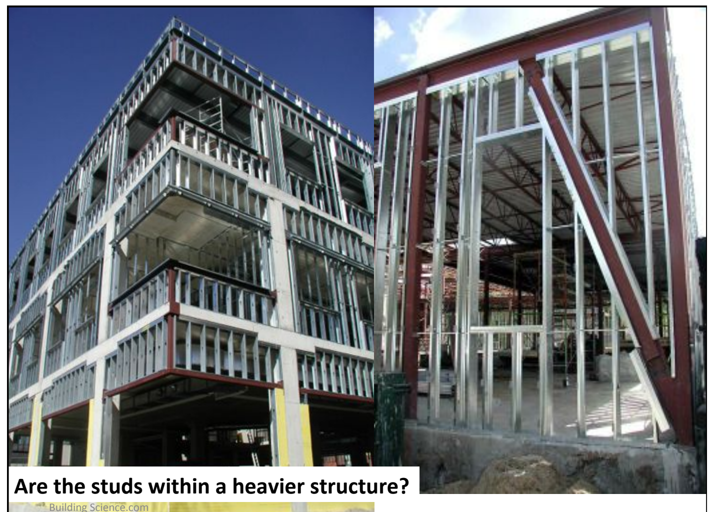

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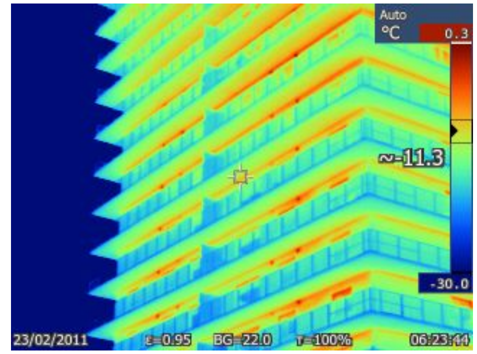

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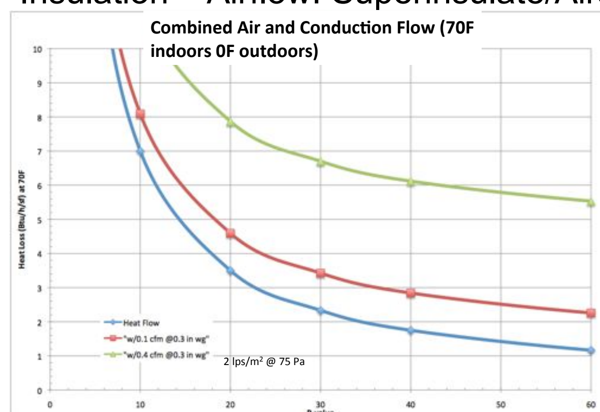
Airtighten

- Must increase airtightness
  - Improve air quality: where is it coming from
  - Demand controlled ventilation
  - Typical buildings leak energy, humidity
- Codes and standard are beginning to demand it
- Can only really know tightness by testing
  - Must begin to test large buildings

Building Science.com

Insulation + Airflow: Superinsulate/Airseal



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Air Barrier Systems

- Need an excellent air barrier in all buildings
  - Comfort & health
  - Moisture / condensation
  - Energy
  - Sound, fire, etc.
- Can't make it too tight.
- Multiple air barriers improve redundancy

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Air Barriers and Energy

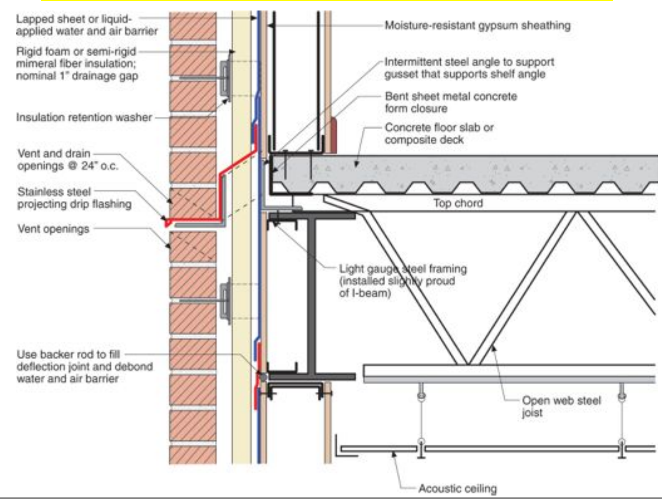
- Requirements
  - **Continuous (most important)**
  - **Strong**
  - **Stiff,**
  - **Durable,**
  - **Air Impermeable (least important)**
- Easily 1/3 of total heat loss is due to air leakage in well-insulated building

62/175 2013-09-12

Commercial Buildings: Often exterior air barrier is only practical solution

Building Science.com

Exterior, fully-adhered air barriers are much easier to reach high performance



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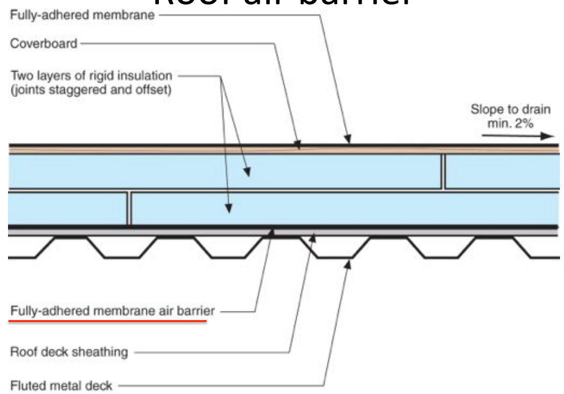
Deck level vapor control membrane rarely required if closed cell foam used

Roof air barrier



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Solar Gain

- Measured by SHGC
- Solar gain useful during cold sunny weather
- But least heating is needed during daytime for commercial buildings
- Overheating discomfort is a real risk
- Must size glass Area x SHGC carefully
  - High values = air conditioning and discomfort

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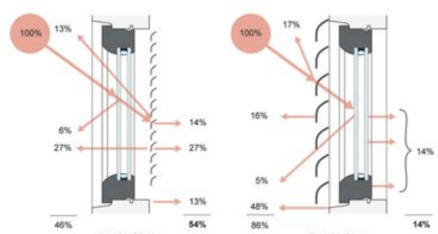
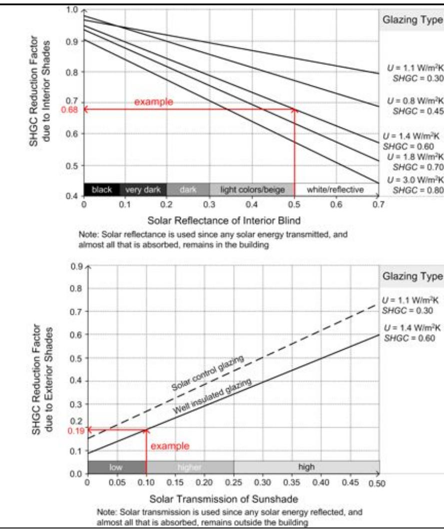
Interior or Exterior Shade

- Operable Solar Control of windows may be necessary for ultra-low energy buildings
- Exterior Shades always beat low SHGC glazing
  - But the cost capital and maintenance
- Interior shades don't work well with good windows



Building Science.com

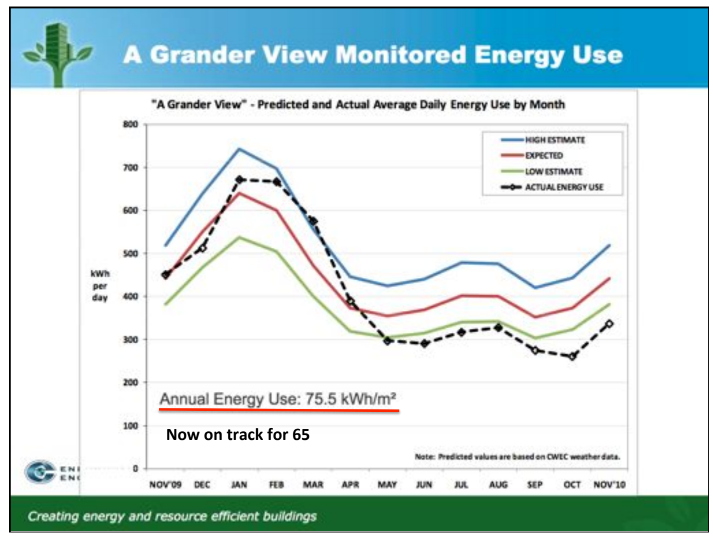
Chriesbach Building: Switzerland



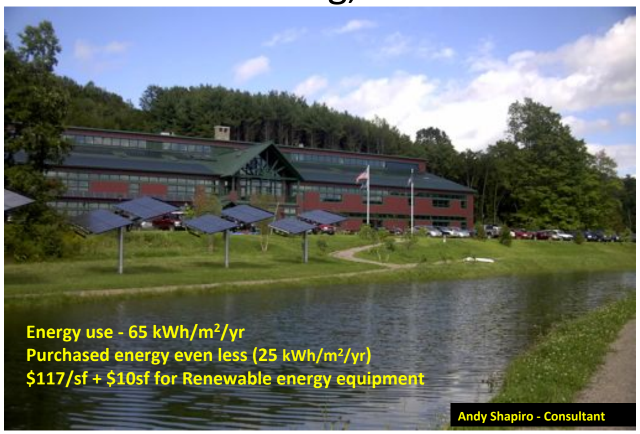
Grander View, Waterloo region

- Mostly simple, standard technology
- Modest cost premium
- Designed for 65 kWh/m^2/yr

4000 HDD18
1250 CDD10



NRG Building, Vermont



California Large Office: All Energy