University of Waterloo

Low-Energy Commercial and Multi-Unit Residential Buildings

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www.BuildingScience.com

Outline

- Why low-energy / net-zero buildings
- How do we use energy
- Conservation & Efficiency
- Building Enclosures
- Mechanical Systems

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What is Green/Sustainable?

- Definitions
  - "Green"
  - Sustainable
  - Net Zero Energy
  - Net Zero Carbon

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Sustainable buildings

- "Can keep doing what we are doing indefinitely"
  - A sustainable society, process, or product is one that can be sustained or continue to be produced over the long term, without adversely affecting the natural conditions (e.g, soil, ecosystem, water quality, climate, etc) necessary to support those same activities in the future.
  - Even the greenest buildings today are not sustainable
- Low-Energy, Net-Zero, Zero-Carbon are all just on the path in the right direction

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So, Is it Green?

- Depends on answers to:
  - Does it use less non renewable energy to operate?
  - Will it last longer? (less life-cycle resources)
  - Does it use fewer non-renewable resources to build?
  - Does it pollute less?
- Compared to what?:
  - Zero (sustainable)
  - Better than average (move forward, "green")
    - What is average?
- LEED counts points, not resources/pollution

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Green Buildings require Change

- Must make them the new normal
- Need to use different thinking and process
- Different materials and systems secondary

"To achieve results never before accomplished, we must employ methods never before attempted."
- Sir Francis Bacon

"Great spirits have always been met with violent opposition from mediocre minds."
- Albert Einstein

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Damage Components

- Resource Extraction
  - Cutting trees, mining, drilling oil, etc.
- Processing
  - Refining, melting, etc. Pollutants and energy
- Transportation
  - Mass and Mode (ship/truck) and Mileage
- Construction
  - Energy, worker transport
- Operational Energy

The Majority of Impact

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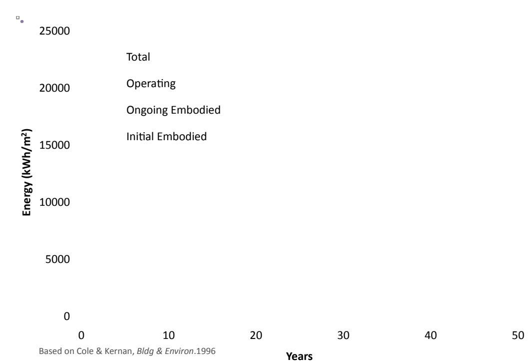
Office Example



Based on Cole & Kernan, *Bldg & Environ.*1996

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Embodied Energy

- *The energy used to mine, process, and manufacture a material & install in building*
  - Units usually Btu/lb or MJ/kg
- On-going repair and maintenance required for life of building
- Published values vary widely
  - Some research results available
- As we get to Net Zero, materials matter more

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INVENTORY OF CARBON & ENERGY (ICE)

Version 1.6a

Prof. Geoff Hammond & Craig Jones

Sustainable Energy Research Team (SERT)
Department of Mechanical Engineering
University of Bath, UK

This project was joint funded under the Carbon Vision Buildings program by:

CARBON TRUST EPSRC

Available from: www.bath.ac.uk/mech-eng/sert/embodied/

Source: *Canadian Architect*

MATERIAL	EMBODIED ENERGY MJ/kg	EMBODIED ENERGY MJ/m3
Aggregate	0.10	150
Straw bale	0.24	31
Soil-cement	0.42	819
Stone (local)	0.79	2030
Concrete block	0.94	2350
Concrete (30 Mpa)	1.3	3180
Concrete precast	2.0	2780
Lumber	2.5	1380
Brick	2.5	5170
Cellulose insulation	3.3	112
Gypsum wallboard	6.1	5890
Particle board	8.0	4400
Aluminum (recycled)	8.1	21870
Steel (recycled)	8.9	37210
Shingles (asphalt)	9.0	4930
Plywood	10.4	5720
Mineral wool insulation	14.6	139
Glass	15.9	37550
Fiberglass insulation	30.3	970
Steel	32.0	251200
Zinc	51.0	371280
Brass	62.0	519560
PVC	70.0	93620
Copper	70.6	631164
Paint	93.3	117500
Linoleum	116	150930
Polystyrene Insulation	117	3770
Carpet (synthetic)	148	84900
Aluminum	227	515700

NOTE: Embodied energy values based on several international sources - local values may vary.

Embodied Environmental Damage

- Pollution (air, water, etc)
- dangerous waste (end of life),
- habitat destruction,
- resource depletion
- Not well researched (Athena Institute)

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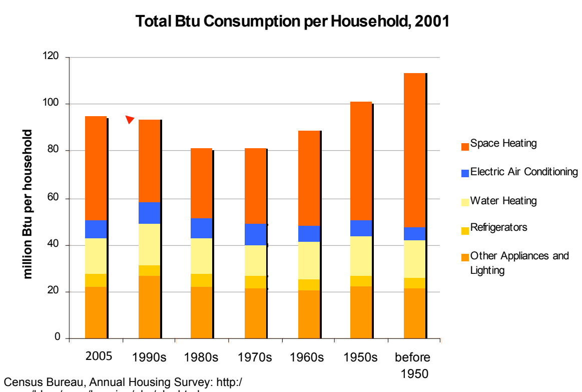
Old & New Houses Energy Use



Source: US Census Bureau, Annual Housing Survey: http://www.census.gov/hhes/www/housing/ahs/ahs.html

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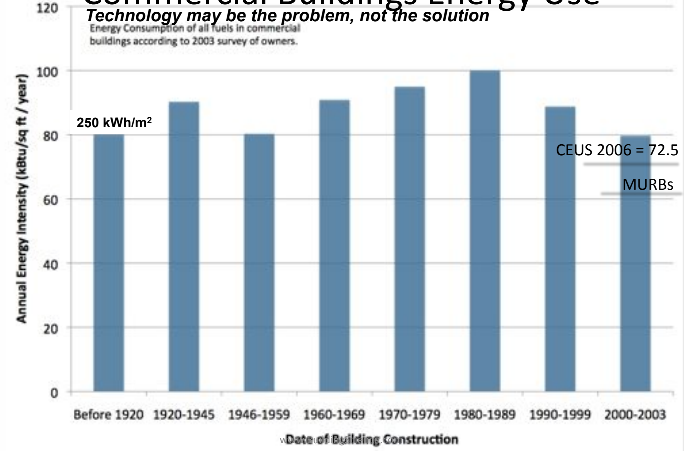
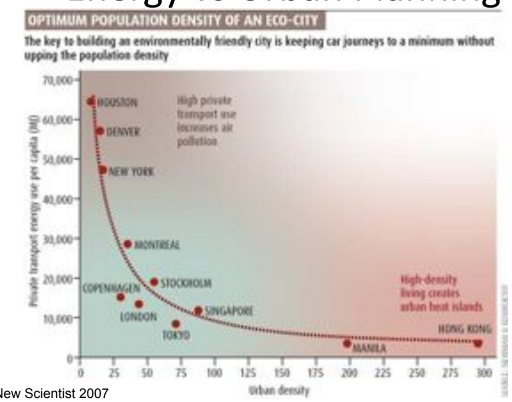
Commercial Buildings Energy Use



Energy vs Urban Planning



Source: New Scientist 2007

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What is this energy thing?

How to confuse people with facts and numbers

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Measuring Energy Use

- Energy use per area
  - kBtu/sf/yr
  - $kWh_e/m^2/yr$
  - 100 $kWh_e/m^2/yr$ = 33 kBtu/sf/yr
- Energy use per person
  - Person = bedrooms+1
  - But.. Design vs actual occupancy?
  - Large houses

See BSD-152 Energy Metrics

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Energy Cheat Sheet

- Ability to do work
  - Measured in Btu (IP) or J (SI) or kWh (SI)
    - MMBtu = 1 million Btu = 293 kWh
  - One Btu = heat one pound H_20 by 1°F
  - One kWh = 100 Watt lightbulb for ten hours
- Energy delivered at gas usually in therms/cf
    - Therm = 100 000 Btu = 29.3 kWh ≈ 100 cubic feet
- Energy delivered as electricity usually in kWh
    - One kWh = 3400 Btu

Efficiency

- Not a very precise or useful term
- Efficiency = desired effect / effort in
    - Heating energy out / energy in (gas, electric, sun)
    - Cooling energy out / energy in (electric, open window)
  - A small house needs less heating energy but a large house might use a "more efficient" furnace
- Efficiency = 1 happy person / Energy used?
- Capital efficiency? Resource efficiency?

Low Energy Targets

- Ed Mazria Architecture 2030
  - Website www.architecture2030.org
- PassivHaus
  - Primary 120 $kWh/m^2/yr$ (37 kBtu/sf/yr)
- Net Zero
  - Zero (Site, Facility, or Source)
- Avoid *non-quantitative* goals
  - $ saved, 30%? 75% ASHRAE, Title 24 etc
- Remember: Occupancy and Climate matters
  - Cold climates, 24/7 facilities use more

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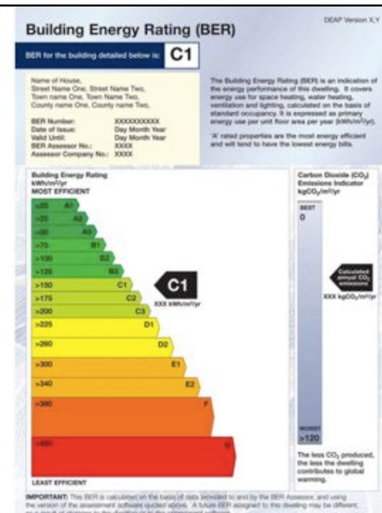
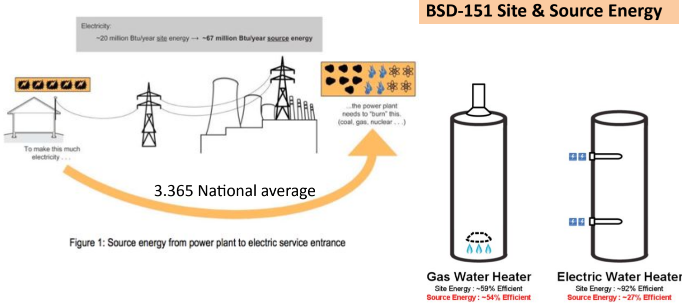


Electricity is Dirty

- Site vs Source (or Primary)

BSD-151 Site & Source Energy



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Electric uses 2x

Source-to-Site Conversion

- January 2009, NREL figures for Building America
- Of course, varies with source of electricity supply
  - Most coal plants are 35% efficient, new NG plants 60%+
  - 5% transmission loss

Energy Source	Source Energy Factor
Electricity	3.365
Natural Gas	1.092
Anthracite Coal	1.029
Bituminous Coal	1.048
Subbitumious Coal	1.066
Lignite Coal	1.102
Residual Fuel Oil	1.191
Distillate Fuel Oil	1.158
Gasoline	1.187
LPG	1.151
Kerosene	1.205

eGRID 2006 NERC Regional Interconnects

Electrical GHG Emissions

- April 2007, EPA eGRID files

NERC region acronym	NERC region name	Output emission rate CO_2 (lb/MWh)	SO_2 (lb/MWh)	NO_x (lb/MWh)	Ozone season NO_x (lb/MWh)	Hg (lb/GWh)
ASCC	Alaska Systems Coordinating Council	1,106	1.203	3.679	3.980	0.0014
ERCOT	Electric Reliability Council of Texas	1,421	3.174	0.981	0.950	0.0291
FRCC	Florida Reliability Coordinating Council	1,328	3.620	2.269	2.240	0.0091
HICC	Hawaiian Islands Coordinating Council	1,655	4.190	3.757	3.829	0.0117
MRO	Midwest Reliability Organization	1,820	6.107	3.734	3.578	0.0415
NPCC	Northeast Power Coordinating Council	908	2.924	1.019	0.915	0.0099
RFC	Reliability First Corporation	1,434	9.252	2.481	1.667	0.0419
SERC	SERC Reliability Corporation	1,387	6.369	2.114	1.537	0.0264
SPP	Southwest Power Pool	1,830	4.636	3.017	2.850	0.0350
WECC	Western Electricity Coordinating Council	1,107	1.170	1.622	1.560	0.0112
U.S.		1,363	5.436	2.103	1.704	0.0269

National **1.36 lb CO_2/kWh (0.91 to 1.83)**
WECCC **1.11 lb CO_2 / kWh**

Fossil Fuel GHG Emissions

- Assuming combustion @ 100% efficiency
- Nat gas
  - 117 pds CO_2 / MMBtu = 0.40 /kWh
  - 92% eff. = 0.435 lb/kWh
  - Around 3 times less GHG emission vs electric
- Propane
  - 139 pds CO_2/MMBtu = 0.475 /kWh
- Heating oil No. 2
  - 161 pds CO_2/MMBtu = 0.54 /kWh

Source: DOE EIA Emissions Coefficients

Different Targets and Different Things Targeted

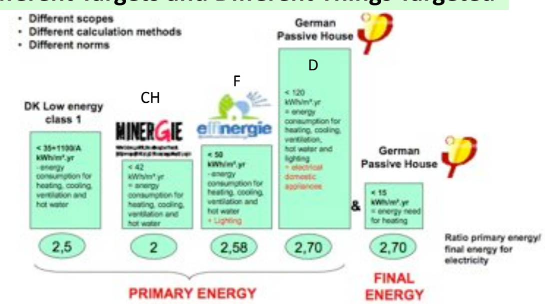
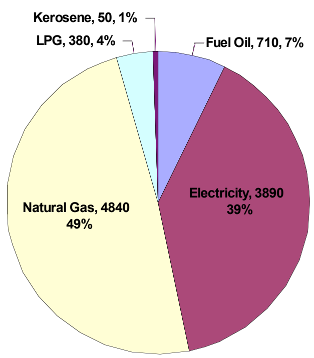
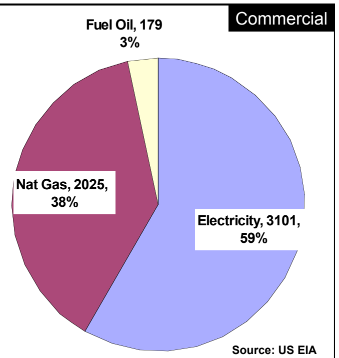


Figure 3. Comparison of the Danish low energy class 1, the Swiss energy calculation method (Minergie), French energy calculation methods (Effinergie), with the two energy frames as defined in the Passive House standard (total energy consumption and heating consumption per year). Source: Pascal Eveillard, Effinergie presentation « Enjeux et référentiel », March 2007.

[1] Energy used for lightning in a 150 m² house with traditional technology is approx. 1000 kWh/y (approx. 6 kWh/m²) while the energy used for appliances is approx. 3000 kWh/y, (approx. 20 kWh/m²).The Danish Electricity Saving Trust has estimated that with energy efficient equipment and optimized conditions lightning can be reduced to 500 kWh/y (3 kWh/m²) and to 1500 kWh/y (10 kWh/m²) for appliances.

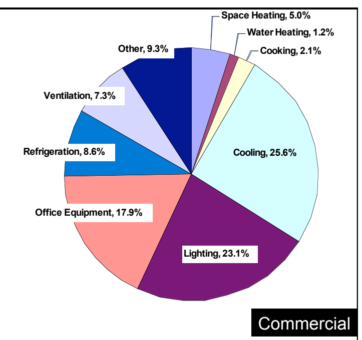
Building Energy Use

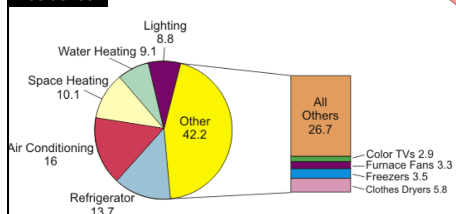




Mostly NG (heating, hotwater) and electricity (cooling, lighting, etc)

US Building *Electrical* Use





Source: Energy Information Administration, Form EIA-457A, B, C, E, and H of the 2001

California commercial (CEUS-06)

Building Type	Floor Stock (kft^2)	Annual Energy Intensities: Electricity (kWh/ft^2)	Annual Energy Intensities: Natural Gas (therms/ft^2)	Annual Energy Intensities: Natural Gas (kBtu/ft^2)	Total Annual Usage: Electricity (GWh)	Total Annual Usage: Natural Gas (Mtherms)
All Commercial	4,920,114	13.63	0.26	25.99	67077	1278.60
Small Office (<30k ft^2)	361,584	13.10	0.11	10.54	4738	38.10
Large Office (>=30k ft^2)	660,429	17.70	0.22	21.93	11691	144.80
Restaurant	148,892	40.20	2.10	209.98	5986	312.60
Retail	702,053	14.06	0.05	4.62	9871	32.50
Food Store	144,209	40.99	0.28	27.60	5911	39.80
Refrigerated Warehouse	95,540	20.02	0.06	5.60	1913	5.30
Unrefrigerated Warehouse	554,166	4.45	0.03	3.07	2467	17.00
School	445,106	7.46	0.16	15.97	3322	71.10
College	205,942	12.26	0.34	34.24	2524	70.50
Health	232,606	19.61	0.76	75.53	4561	175.70
Lodging	270,044	12.13	0.42	42.40	3275	114.50
Miscellaneous	1,099,544	9.84	0.23	23.34	10817	256.60
All Offices	1,022,012	16.08	0.18	17.90	16430	182.90
All Warehouses	649,706	6.74	0.03	3.44	4380	22.40

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Energy Intensity

kWhe/sf/yr	Total	Gas	Elec
All Commercial	21.25	7.62	13.63
Small office	16.32	3.22	13.10
Large office	24.15	6.45	17.70
Restaurant	101.73	61.53	40.20
Retail	15.53	1.47	14.06
Food Store	49.19	8.20	40.99
Refrig Warehouse	21.78	1.76	20.02
Warehouse	5.33	0.88	4.45
School	12.15	4.69	7.46
College	22.22	9.96	12.26
Health	41.88	22.27	19.61
Lodging	24.44	12.31	12.13
Misc	16.58	6.74	9.84
All Offices	21.35	5.27	16.08
All Warehouse	7.62	0.88	6.74

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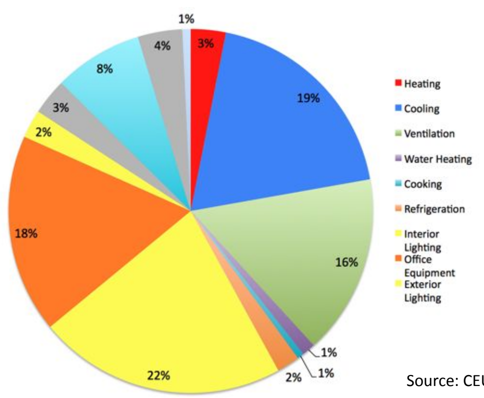
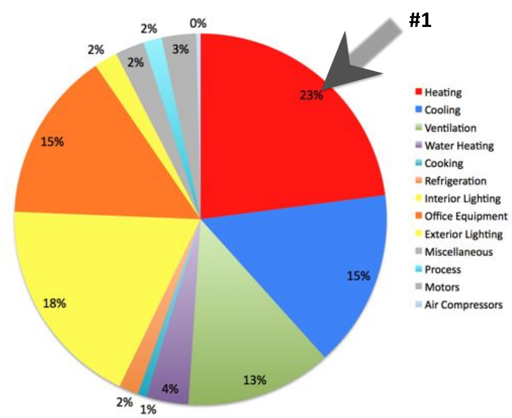
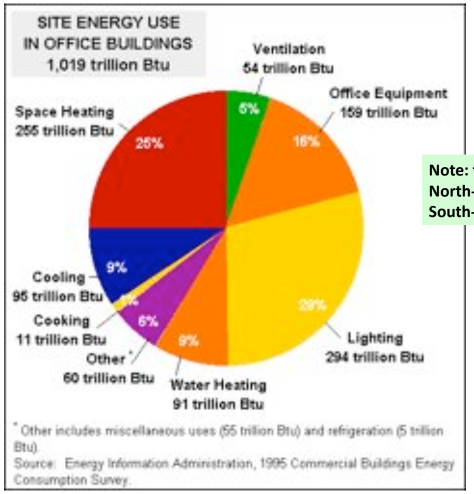
California Large Office Electric



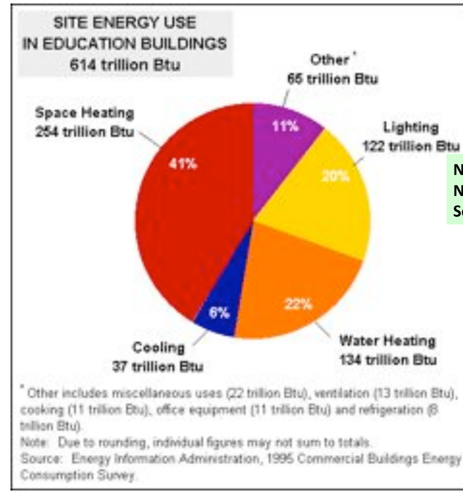
Source: CEUS 2006

California Large Office: All Energy





Note: this is US average
North-east has more heating
South-west more cooling



Note: this is US average
North-east has more heating
South-west more cooling

California Net Zero Buildings

- Goals
  - All new residential construction NZE by 2020
  - All new commercial construction NZE by 2030
- Definitions
  - NZE site?
  - NZE source? (3:1 elec to gas)
  - NZE on building only? Parking lot?
  - How to control renters energy use?

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NREL Report

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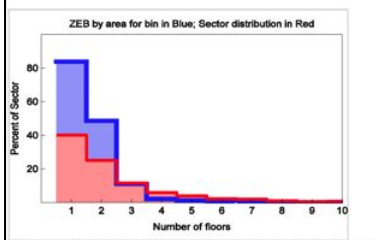
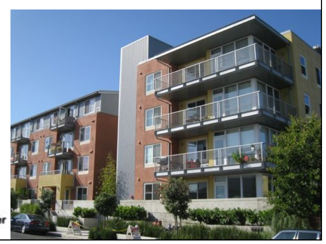
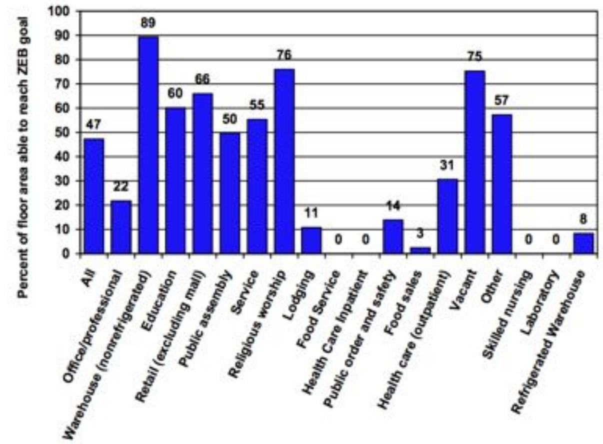
NetZero

- NZE is not likely a desirable goal
- Someone needs to pay for Grid
- Who produces in winter?
- High density fights against Net Zero
  - Car however uses a lot of energy



4-6 Percentage of floor area that can reach ZEB as a function of number of floors in building: Max Tech scenario





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Net Zero

- Many buildings can be built as NZE
  - NREL estimates about 50% of commercial floor area can be built to NZE
- Large offices, health care, most restaurants, can't get there
- Someone needs to use energy to pay for grid
- Therefore, true low-energy buildings are fine too

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Low Energy Buildings

- Holistic Approach
  - Reduce loads
  - Improve efficiency of meeting demand
  - Never sacrifice safety, health, durability
- Use numerical targets and track performance
- Net Zero may not always be the goal

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How?

To reduce operational energy use

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Process and Philosophy

- Decide to value low energy consumption
- Set ***measurable targets***, predict usage, measure performance
- Stamp out waste everywhere
- Use energy efficiently when you need to use it
- *Do not* sacrifice safety, comfort, health and durability

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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**
- **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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Building Energy Determinants

Requirements	**Client**	Restrictions about min size, must use technology, etc
Loads	**Architecture**	Massing, window area, enclosure details, selection of HVAC,
Systems/ Equipment	**Mech Eng**	System design, controls, equipment selection
Demand	**Occupant**	Temperature, humidity ranges, operation of appliances, turning off lights, etc
Energy Source	**Utility?**	Generation technology, pricing structure, efficiency of operations

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Strategies

- Siting & Orientation (small impact)
  - Orient with sun, wind, rain, earth shelter?
- Shape and Form (small to moderate impact)
  - Small, Compact, simple
- Exceptional building enclosure (mod to large impact)
  - Insulated, airtight, solar control, daylight
- Efficient Equipment (mod impact)
  - Not there or off is best, controls help
- Renewable Energy Generation (impact varies)

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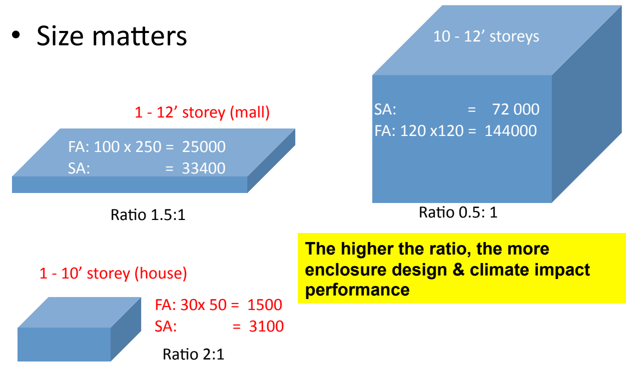
Size: Surface Area to Floor Area

- Size matters



The higher the ratio, the more enclosure design & climate impact performance

Small, Compact Form

- Fewer resources
- Less heat loss and gain

Form & Massing

- Keep it simple
- Cheaper, easier, faster
- Fewer
  - thermal bridges, air leaks
  - Material volumes
  - construction challenges

vs.

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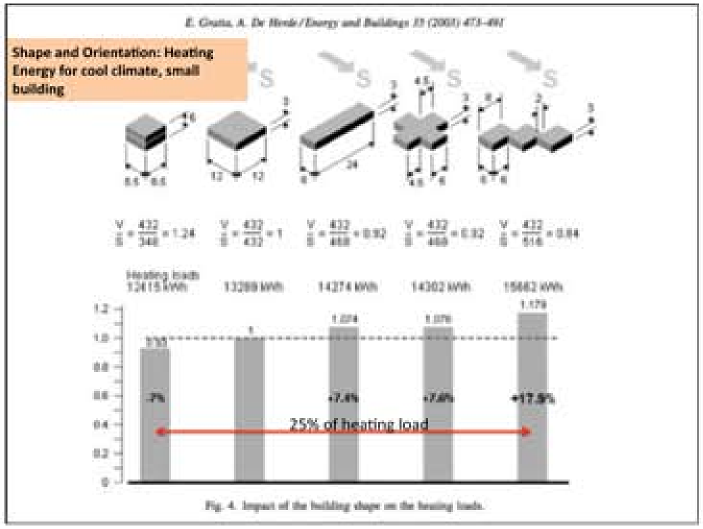


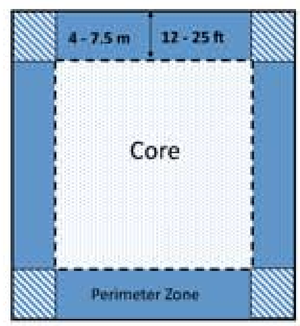
Building Shape

- Alphabet Soup
  - H I A B E

Large Buildings

Many buildings with large cores require cooling in winter while heating the perimeter

Core / Perimeter



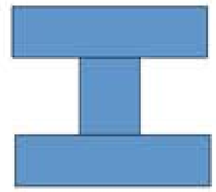
- Perimeter Zone
  - performance dominated by climate and enclosure
- Core Zone
  - dominated by interior use. Climate/enclosure almost irrelevant
- In most occupancies, core needs ***cooling and lighting all year long, all day***

Define "perimeter"

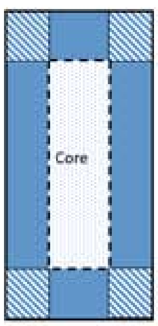
- Maximum distance about 25 ft/ 7.5 m
  - Classrooms often 25-30 ft, open plan office
- Minimum often set by walls/partitions of exterior offices
  - Cellular offices often 15 ft/ 4.5m deep

Expanded Plans

- Better daylight, easier ventilation but more enclosure heat loss and gain and air leaks



Skin Dominated Building

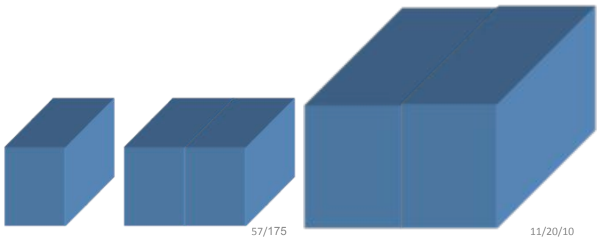


- Perimeter Zone over most of floor area
- Excellent daylighting and cross ventilation opportunities
- Termed "Skin Dominated"
- ***Demands good building enclosure***

Skin dominated

Grouping buildings

- Grouping units reduces heat loss/gain through shared walls
- Reduces resource use per unit



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Grouping housing

Daylighting

Adding enjoyment while saving electricity

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Daylighting

- Natural light can offset artificial lights
- Natural light almost always preferred
- BUT,
  - **Must** use daylight controls and sensors to capture energy savings
  - Need to control glare and solar heating caused by too much glass on sunny days

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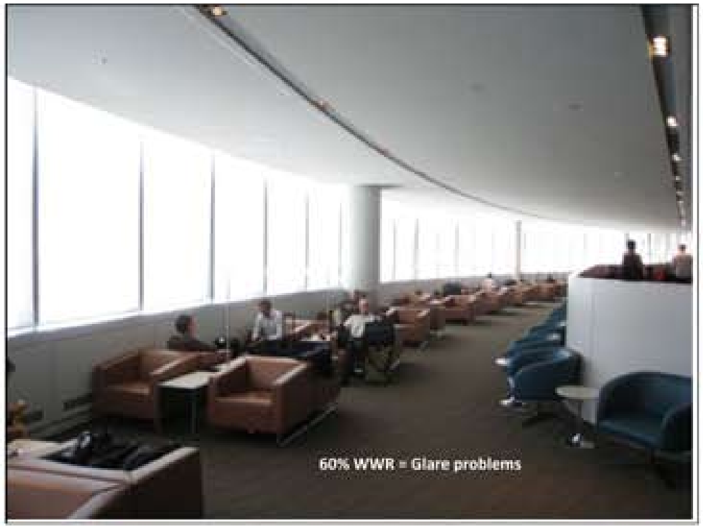

Daylight Penetration

- Many simple design tools available
  - Work well for standard shapes
- Effective Aperture
  - Visual transmittance x Glass area
  - Recommended: (window ht/ ceiling ht) * VT > 0.20
- Daylight zone depends on window head height
  - Eg penetration 1.5 – 2.5 window head height
- Software such as Ecotect Radiance DaySim quantify complex shapes

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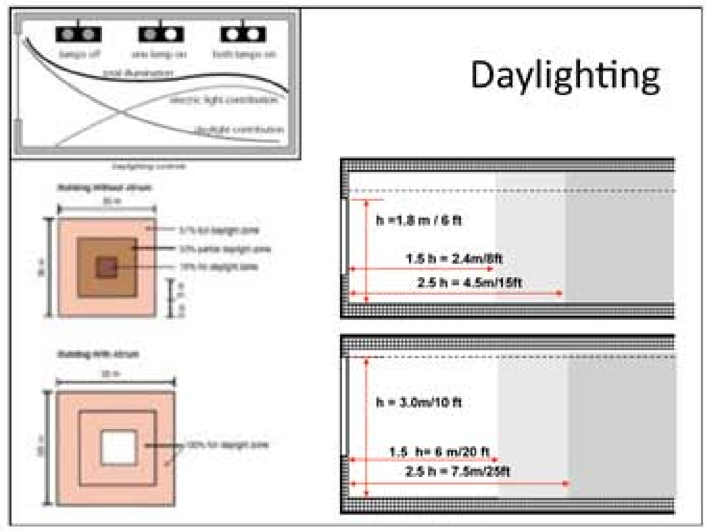

Daylighting

- Direct solar penetration is NOT desirable
  - Creates glare and discomfort.
  - MAY be useful for free solar heating if desired
  - High on south in winter, W/E in summer
- Design for *diffuse* light
  - Almost the same on all four orientations
  - Bright sky is about 10 000 lux on horizontal

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Lighting Goals

- 300 lux on desktop (500 for special apps)
  - Often this means a Daylight Factor of 2%
- Lighting power density has dropped tremendously (3X) in last 30 yrs
- Now possible to do 0.8 W/ft^2 (10 W/m^2)
  - Future LED offer even lower lighting
  - Smarter task and general lighting
- **Energy Benefit of daylighting is decreasing**

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Reinhart C F, "A SIMULATION-BASED REVIEW OF THE UBIQUITOUS WINDOW-HEAD- HEIGHT TO DAYLIT ZONE DEPTH RULE-OF-THUMB". *Ninth International IBPSA Conference, 2005*

Daylight Autonomy

- % of annual use hours when daylight is sufficient without glare

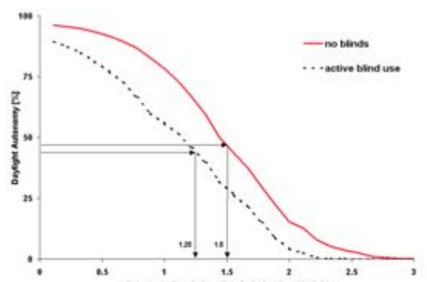
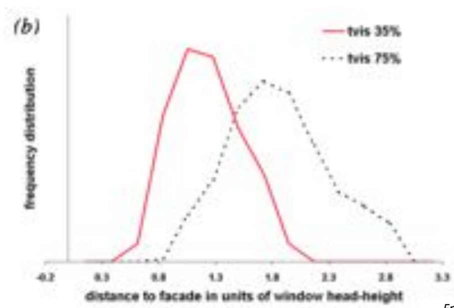


Figure 2: Daylight autonomy distributions for a rectangular room located in New York City facing South. The facade is fully glazed above work plane height and features a solar protective glazing with a visual transmittance of 35% . The minimum illuminance level in the office is 500lux and office hours are Monday to Friday from 8AM to 5 PM. Daylight autonomies are shown with and without the use of a generic venetian blind

From: C Reinhart, 2005

Daylight Design

- Next to head height and window area, window transmittance (T_{vis} or VT)



From: C Reinhart, 2005

Daylight Design

- Head height, not ceiling height. Low glass is essentially useless for daylighting.

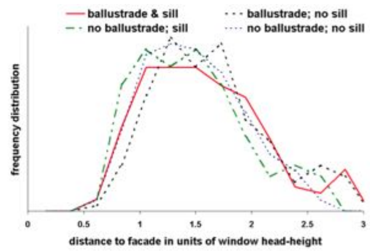
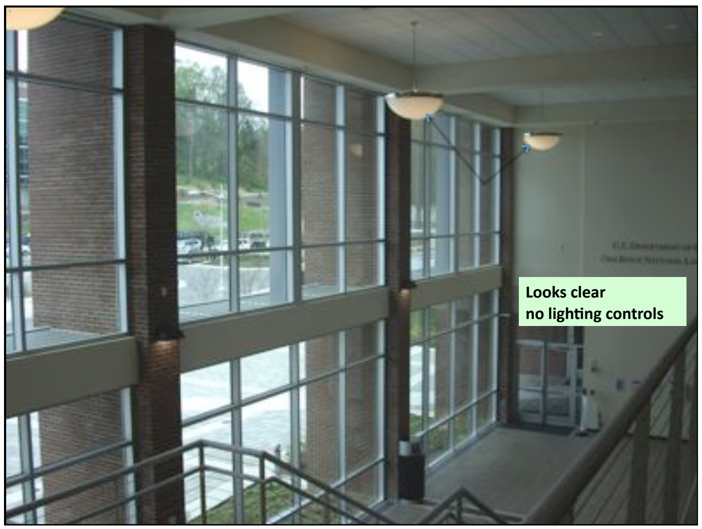
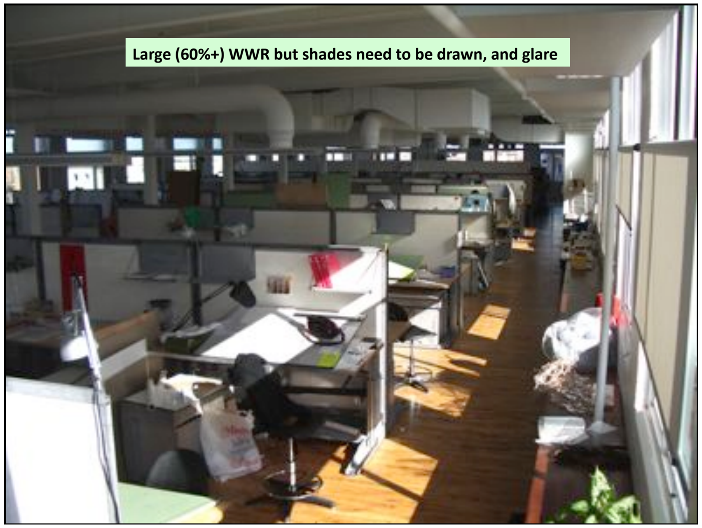
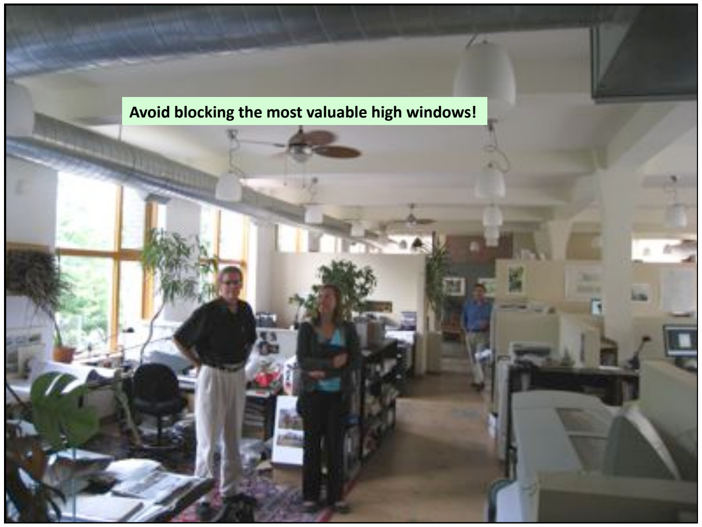


Figure 6: Frequency distributions of predicted daylit zone depths with blinds for varying facade

From: C Reinhart, 2005







Enclosure Intro Summary

- Enclosure often defines the Heat/Cool load
  - Architecture defines massing, orientation, enclosure
- Enclosure **more critical** for skin-dominated
  - Heat flow, Solar control, air tightness
- Lighting, ventilation critical for deep plan
- Control windows to get quality daylight, combine with controls to save energy

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University of Waterloo

High Performance Enclosures

Dr John Straube, P.Eng.
Associate Professor
University of Waterloo
Building Science Corporation

Building Science Corporation

www.BuildingScience.com

Enclosures in Context

- Enclosures **reduce** space heating/cooling
  - and help with lighting, ventilation
- We still need **energy** for other things
  - Lights, appliances, computers, elevators, etc
- Still need to provide some **HVAC**!
- Hence, good mechanicals and renewables will *also* be needed for net zero
- Great enclosures reduce demand & hrs of operation

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Top Ten List

Commercial and institutional mid-size buildings, Canadian climates

- **Limit window-to-wall ratio** (WWR) to the range of 20-40%, 50% with ultra-performance windows
- **Increase window performance** (lowest U-value affordable in cold climates, including frame effects)
- Increase wall/roof **insulation** (esp. by controlling thermal bridging) and **airtighten**
- Separate **ventilation** air supply from heating and cooling.
- Use **occupancy** and **daylighting controls** for lights and equipment
- **Reduce** equipment/plug & lighting **power densities**
- 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 appropriate.
- Use a simple and compact building form, oriented to the sun, with a depth that allows daylight harvesting.

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Design Principles

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Buildings: Why do we Build?

- To keep the wind, sun, rain, snow, heat, cold, dust, bugs, animals, and nasty people outside.
- But we let in some things
  - Nice people, pets, sunshine, daylight, clean air, clean water, supplies
- And let some things out
  - Views, polluted water and air

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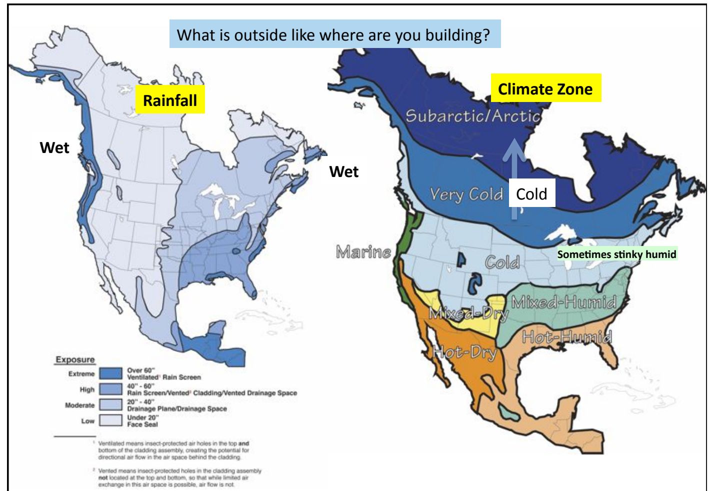


Building Science 2008 Enclosures No. 6 /

The Enclosure: An Environmental Separator

- The part of the building that physically ***separates*** the ***interior*** and ***exterior*** environments.
- Includes all of the parts that make up the wall, window, roof, floor, caulked joint etc.
- Sometimes, interior partitions also are environmental separators (pools, rinks, etc.)

Building Science 2008 Enclosures No. 7 /

Climate Load Modification

- Building & Site (overhangs, trees…)
  - Creates microclimate
- Building Enclosure (walls, windows, roof…)
  - Separates climates
  - Passive modification
- Building Environmental Systems (HVAC…)
  - Use energy to change climate
  - Active modification

Enclosure Intro Summary

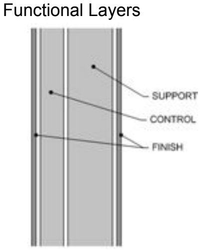
- Enclosure often defines the H/C load
  - Architecture defines massing, orientation, enclosure
- Enclosure **more critical** for skin-dominated
  - Heat flow, Solar control, air tightness
- Lighting, ventilation critical for deep plan

Basic Functions of the Enclosure

- 1. Support
  - Resist and transfer physical forces from inside and out
- 2. Control
  - Control mass and energy flows
- 3. Finish
  - Interior and exterior surfaces for people

- Distribution – a building function

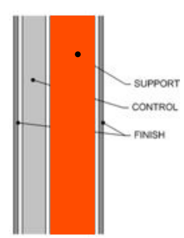
Functional Layers



Basic Enclosure Functions

- **Support**
  - **Resist & transfer physical forces from inside and out**
    - Lateral (wind, earthquake)
    - Gravity (snow, dead, use)
    - Rheological (shrink, swell)
    - Impact, wear, abrasion
- Control
  - Control mass and energy flows
- Finish
  - Interior and exterior surfaces for people

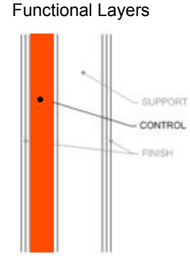
Functional Layers



Basic Enclosure Functions

- Support
  - Resist & transfer physical forces from inside and out
- **Control**
  - **Control mass and energy flows**
    - **Rain** (and soil moisture)
      - Drainage plane, capillary break, etc.
    - **Air**
      - Continuous air barrier
    - **Heat**
      - Continuous layer of insulation
    - **Vapor**
      - Balance of wetting/drying
- Finish
  - Interior and exterior surfaces for people

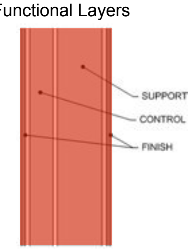
Functional Layers



Other Control . . .

- Support
- **Control**
  - **Fire**
    - **Penetration**
    - **Propagation**
  - **Sound**
    - **Penetration**
    - **Reflection**
  - **Light**
    - **Diffuse/glare**
    - **View**
- Finish

Functional Layers



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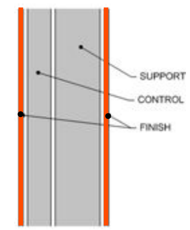
Basic Enclosure Functions

- Support
  - Resist & transfer physical forces from inside and out
- Control
  - Control mass and energy flows
- **Finish**
  - **Interior & exterior surfaces for people**
    - Color, speculance
    - Pattern, texture

Functional Layers



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History of Control Functions

- Older Buildings
  - One layer does everything
- Newer Building
  - Separate layers,

    . . . separate functions

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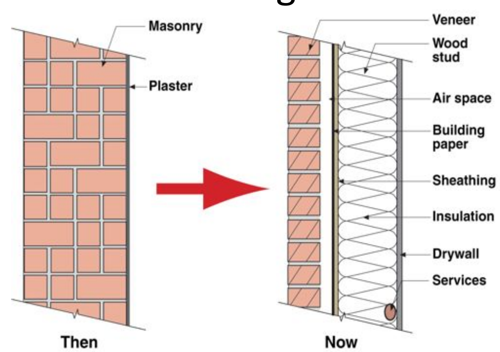
Changes



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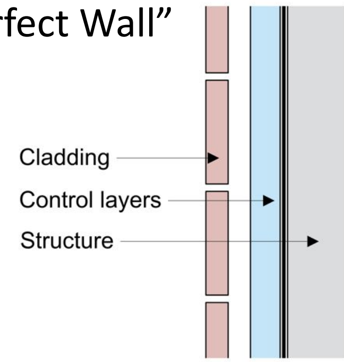
The "Perfect Wall"

- Finish of whatever
- Control continuity
  - Rain control layer
    - Perfect barrier
    - Drained with gap
    - Storage
  - Air control layer
    - Air barrier
  - Thermal control layer
    - Aka insulation, radiant barriers
  - Vapor control layer
    - Retarders, barriers, etc
- Structure can be anything



Fire Control may be needed
Sound Control optional

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What is a high performance enclosure?

- One which provides high levels of control
- Poor continuity limits performance
- Poor continuity causes most problems too:
  - E.g. air leakage condensation
  - Rain leakage
  - Surface condensation
  - Cold windows
- This course: continuity + high levels

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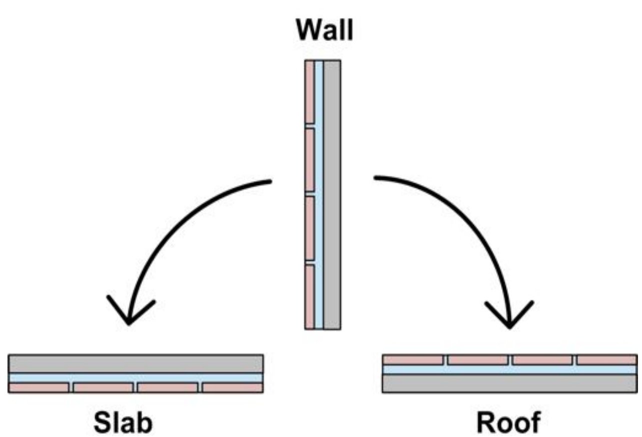

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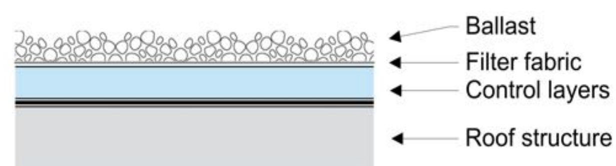

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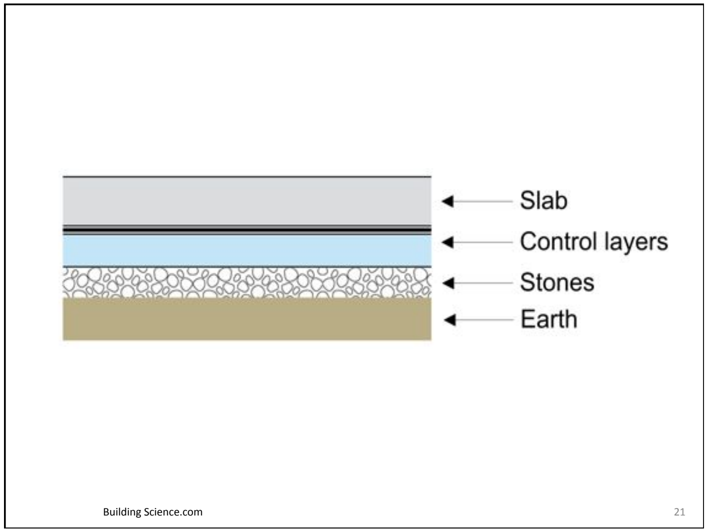
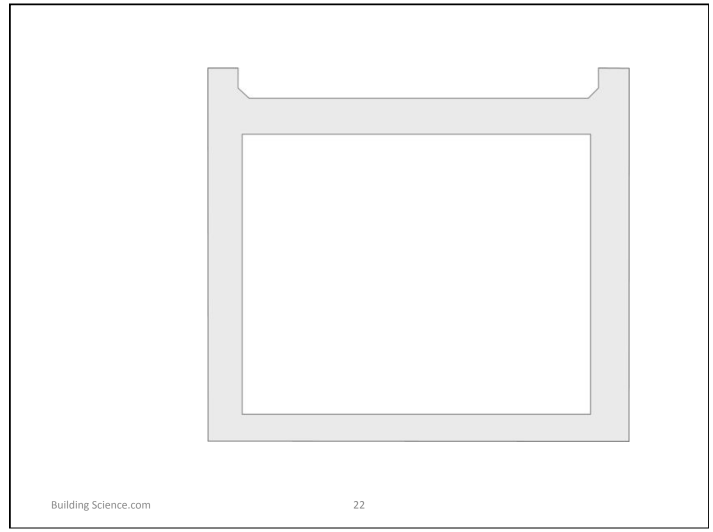
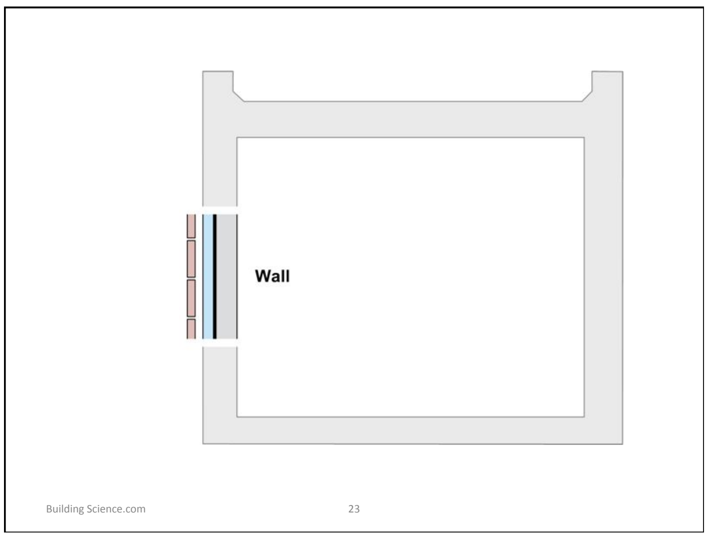
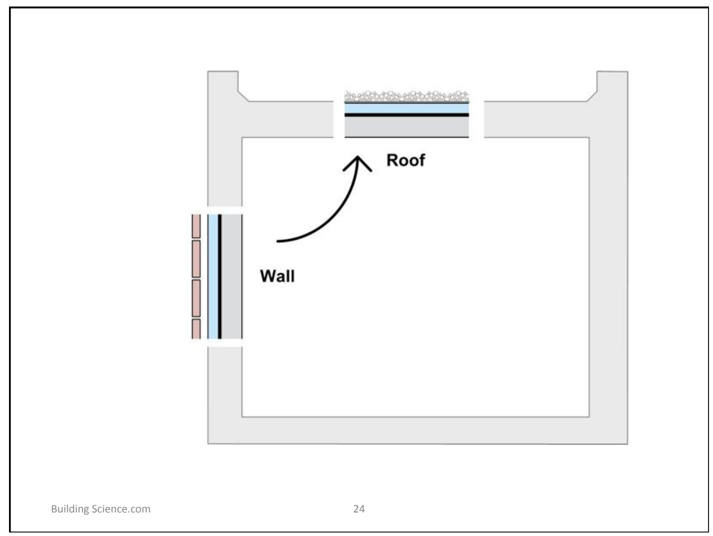
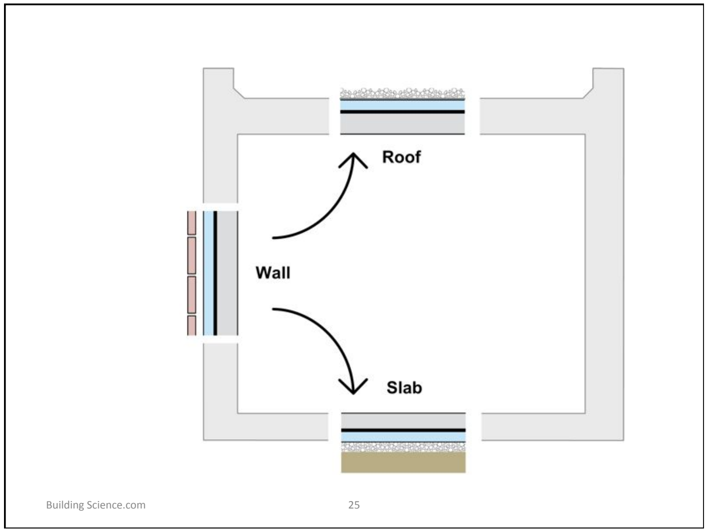
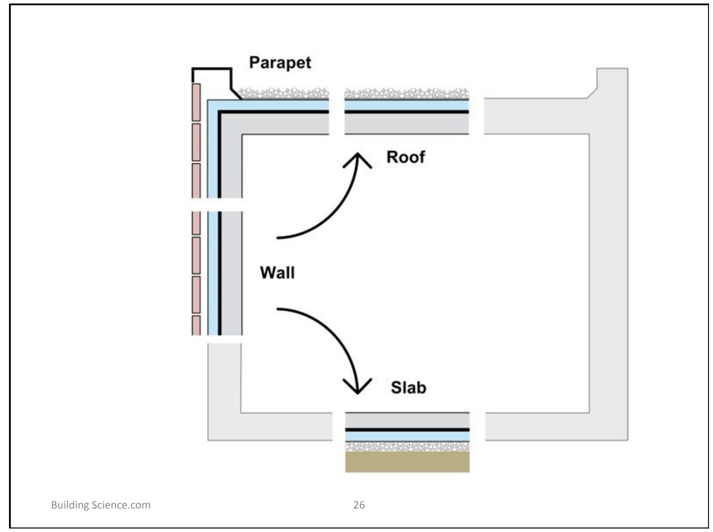

Slab
Control layers
Stones
Earth
Building Science.com
21

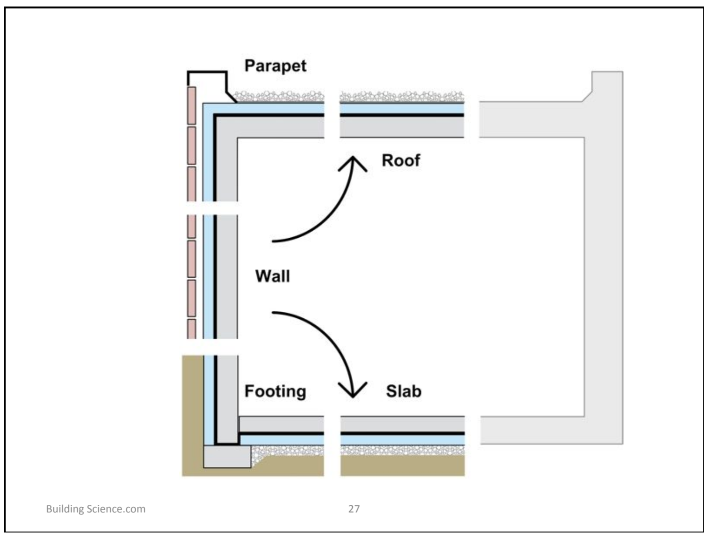

Building Science.com
22

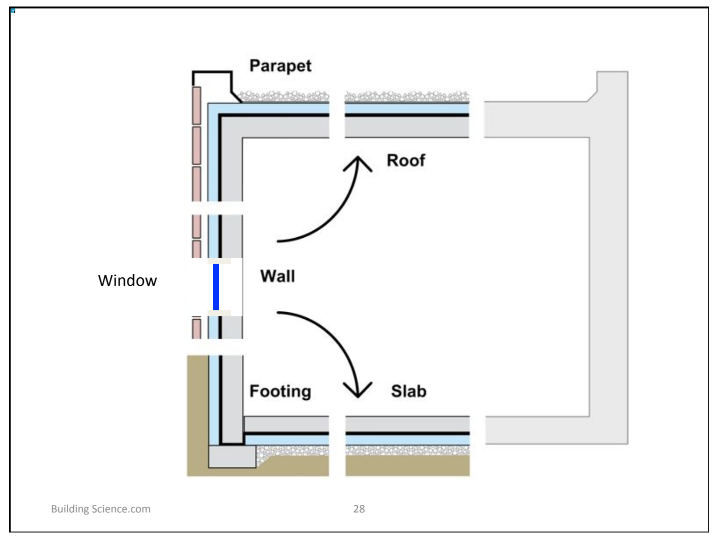

Wall
Building Science.com
23


Roof
Wall
Building Science.com
24

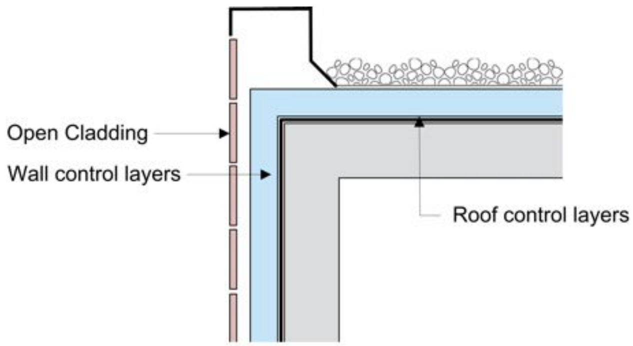

Roof
Wall
Slab
Building Science.com
25


Parapet
Roof
Wall
Slab
Building Science.com
26


Parapet
Roof
Wall
Footing
Slab
Building Science.com
27


Parapet
Roof
Window
Wall
Footing
Slab
Building Science.com
28

Connections: Who is in charge



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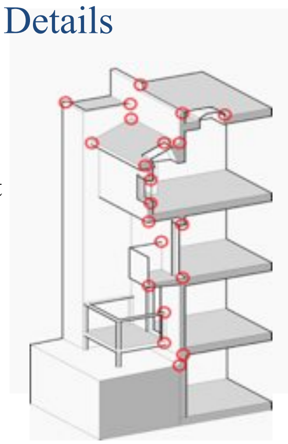
Building Science.com Enclosures No. 30 /

Enclosure Design: Details

- Details demand the same approach as the enclosure.
- Scaled drawings required at



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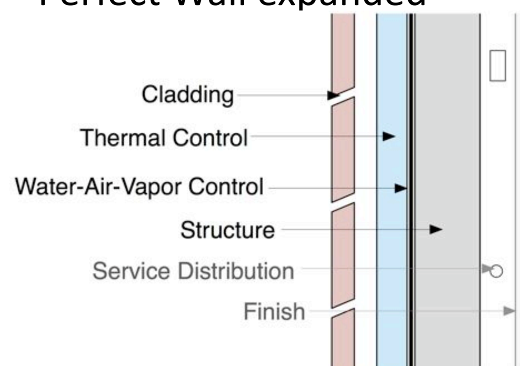
Perfect Wall expanded



Fire Control may be needed
Sound Control optional

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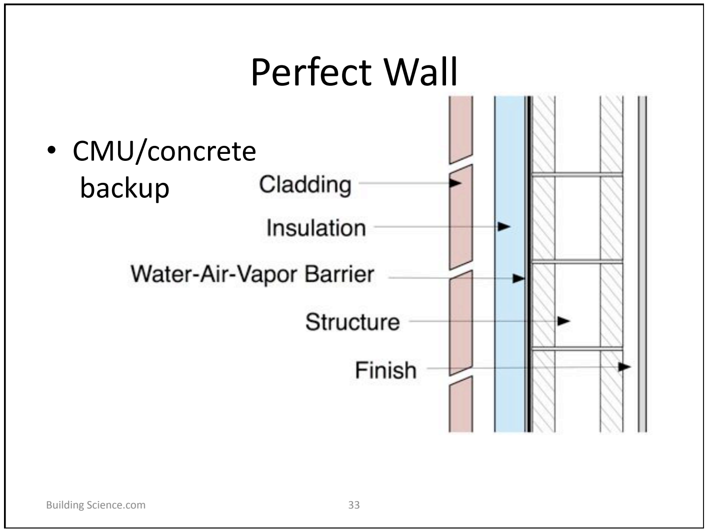
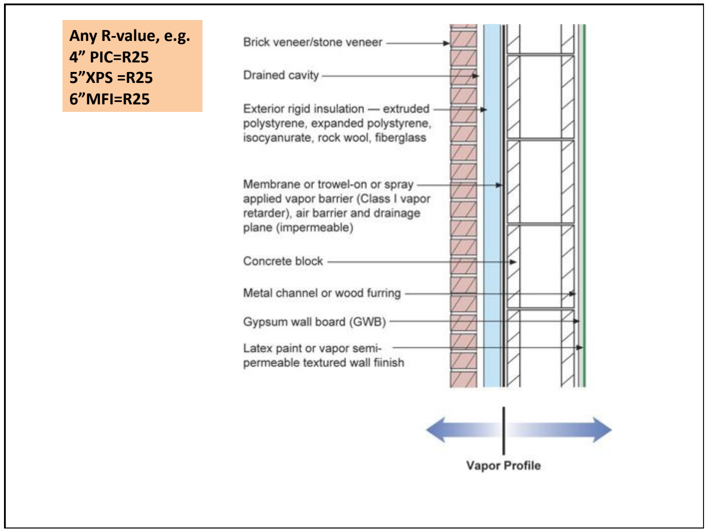
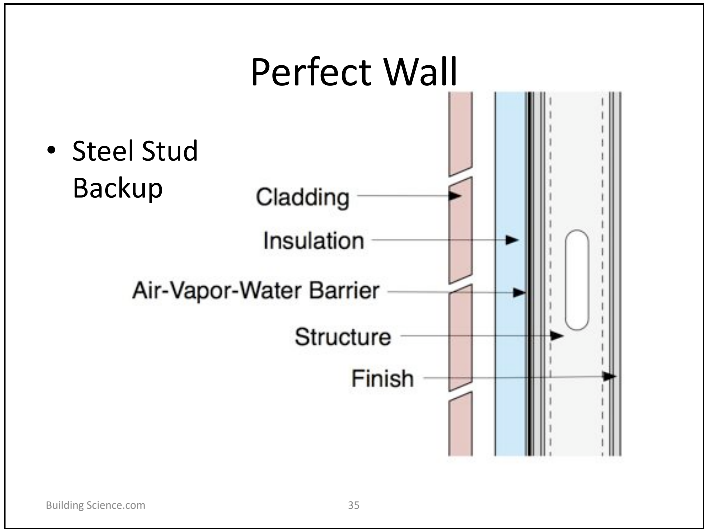
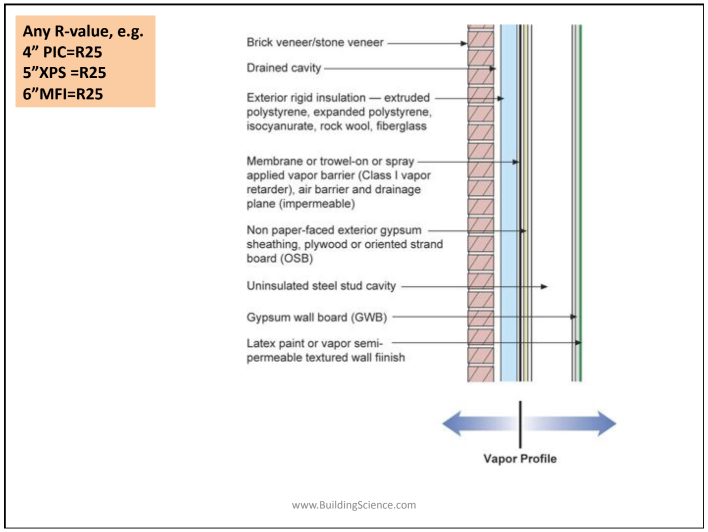

Perfect Wall
• CMU/concrete backup
Cladding
Insulation
Water-Air-Vapor Barrier
Structure
Finish
Building Science.com
33


Any R-value, e.g.
4” PIC=R25
5”XPS =R25
6”MFI=R25
Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Concrete block
Metal channel or wood furring
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall finish
Vapor Profile


Perfect Wall
• Steel Stud Backup
Cladding
Insulation
Air-Vapor-Water Barrier
Structure
Finish
Building Science.com
35


Any R-value, e.g.
4” PIC=R25
5”XPS =R25
6”MFI=R25
Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied vapor barrier (Class I vapor retarder), air barrier and drainage plane (impermeable)
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Uninsulated steel stud cavity
Gypsum wall board (GWB)
Latex paint or vapor semi-permeable textured wall finish
Vapor Profile
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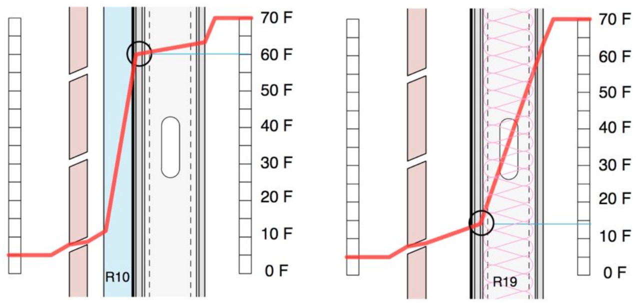
Condensation & Drying



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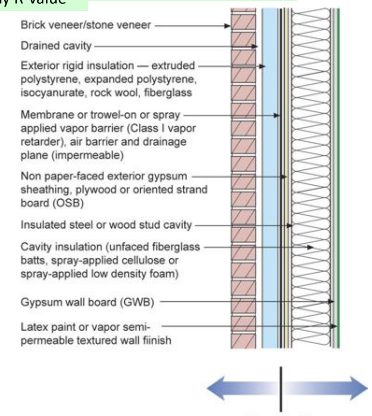
Ratio: Exterior R-value / Studbay R-value controls risk of condensation



Steel studs compromise the thermal performance Wood studs, not so much

Any R-value, e.g.
6" wood stud+
2" PIC= R30
3"XPS= R32
4"SPF= R40

Compromise

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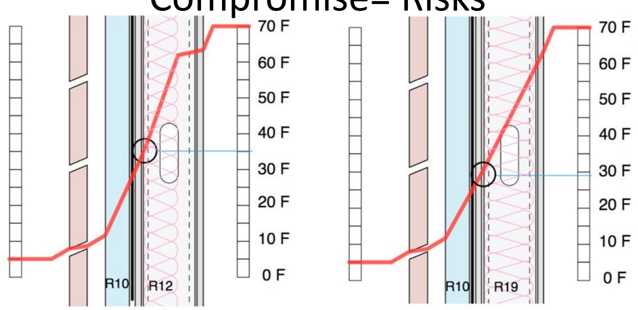
Compromise= Risks



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Specifics

- Now we will look at
  - Rain Control
  - Air Flow Control
  - Thermal Control
- In some detail

Air Flow Control, Thermal Control: Energy & Comfort
Rain Control, Air Flow Control, Thermal Control: Durability, Health

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Rain Control

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Rain Control

- Next to structure, the most important, fundamental requirement
- Source of many serious building problems
- Major impact on durability
- Low-energy buildings & rain
  - Different enclosure assemblies
  - Reduced drying ability

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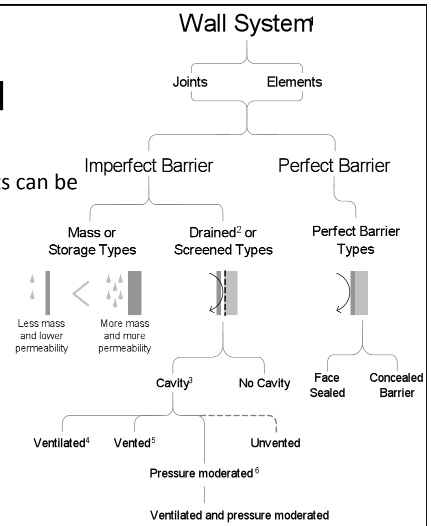
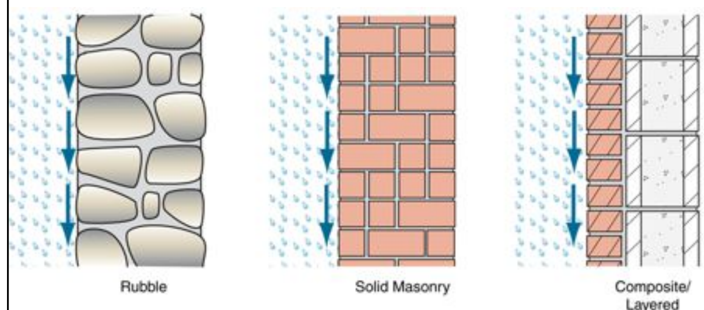
Rain Control

- Elements and joints can be different



Mass/Storage/Reservoir Walls

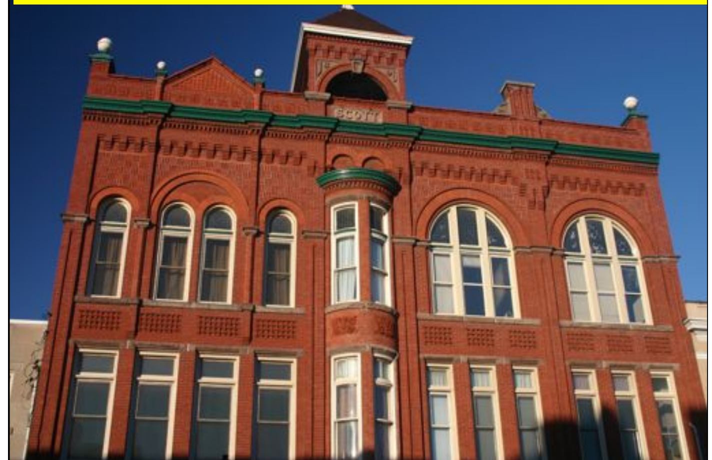


John Straube

No building paper, flashing, weepholes

Rain Control 45

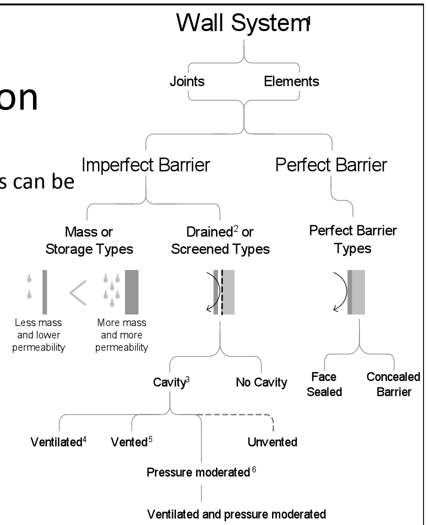
Surface features such as Overhangs, Drips, etc are important for mass walls



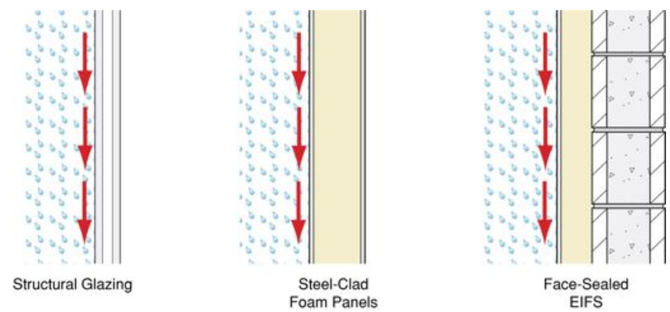
Rain Control 46

Categorization

- Elements and joints can be different



Perfect Barrier / Face Sealed



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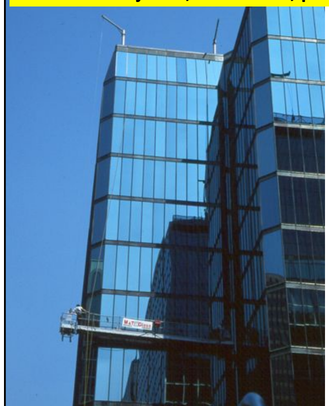
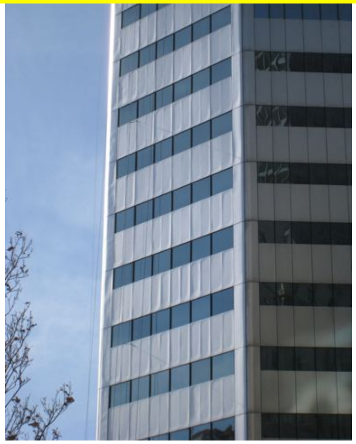
It is all about joints, transitions, penetrations





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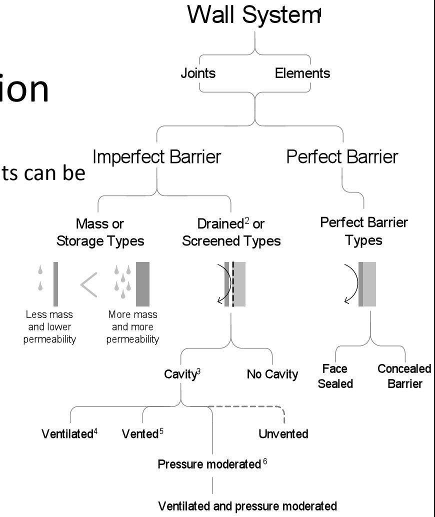
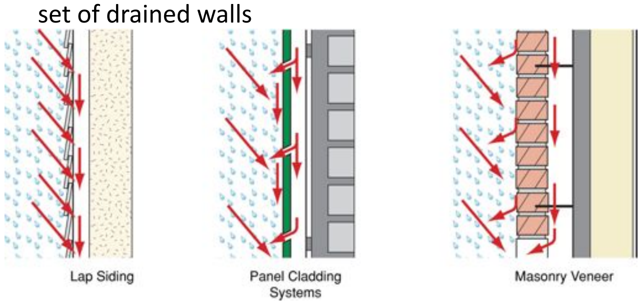
Categorization

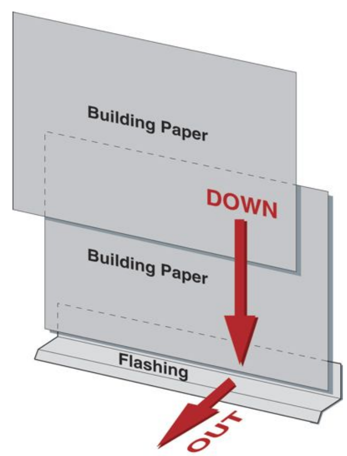
- Elements and joints can be different



Drained Walls

- "Pressure Equalized Rainscreen" are a fictional sub-set of drained walls





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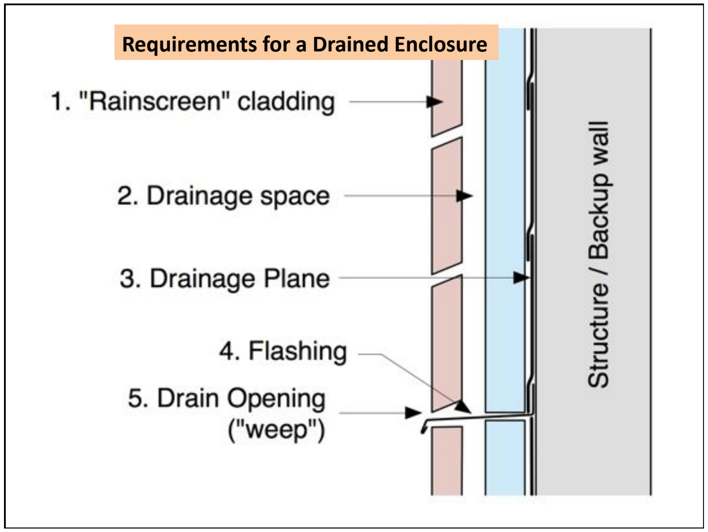


Air-Water-Vapor

- Often thin layers
- *Can be*
  1. Water control (vapor permeable, not airtight), **or**
  2. Air & water control (vapor permeable), **or**
  3. Air, water & vapor (vapor impermeable).
- Examples
  – Building paper, untaped housewrap, sealed and supported housewrap, fluid applied, peel and stick

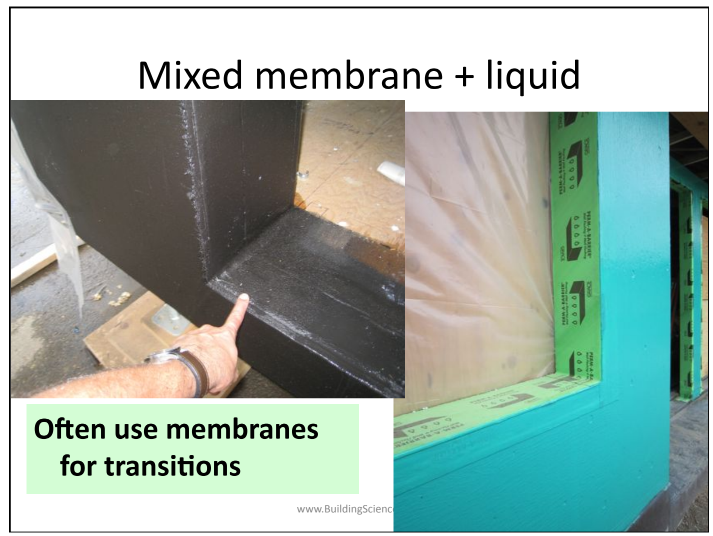
Air-Water Control Layers

Sloped and complex surfaces demand very high performance


Fluid-applied products avoids laps


Details
• Air & water & vapor transition membranes


Non-adhered, vapor permeable =modest performance
Supported flexible membrane is better
Tyvek


Mixed membrane + liquid
Often use membranes for transitions

Spray/Trowel Applied Air/water

- Semi-permeable

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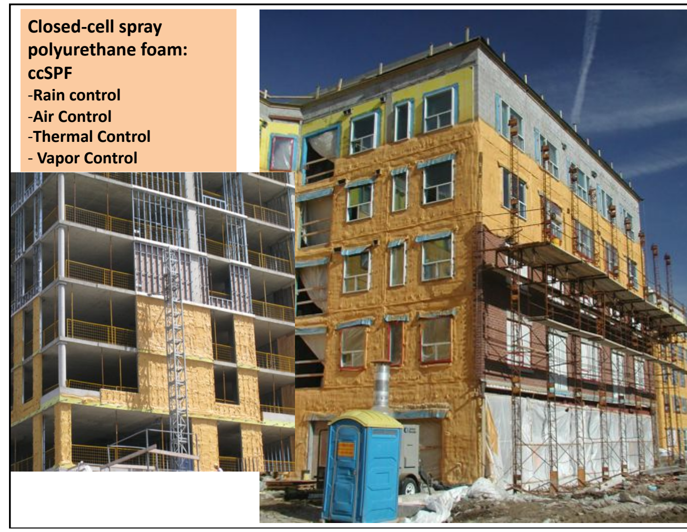
Closed-cell spray polyurethane foam: ccSPF
-Rain control
-Air Control
-Thermal Control
- Vapor Control



Continuity is key!

- Must ensure no rain leaks
- Airflow control should be as continuous as practical
- Thermal control
  – We live with penetrations
  – Minimize steel and concrete to small local
- Vapor control
  – Not that important to ensure continuity

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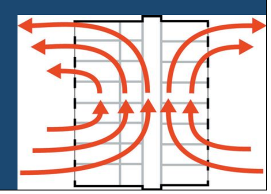
Air Flow Control



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Air Barrier Systems

- Need an excellent air barrier in all buildings
  - Comfort & health
  - Moisture / condensation
  - Energy
  - Sound, fire, etc.
- Cant make it too tight.
- Multiple air barriers improve redundancy

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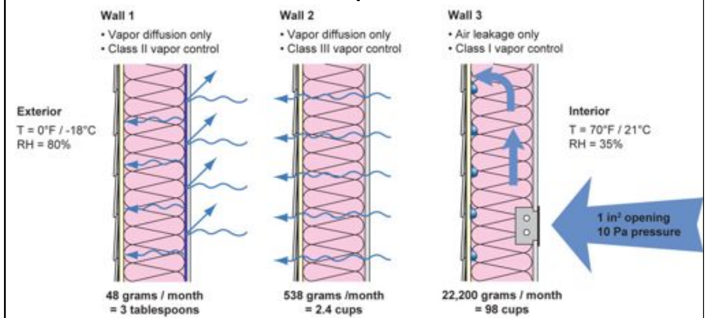
Air moves more vapor than diffusion!



Diffusion is rarely a big deal
Air leakage almost always is!

Calculations for a single stud bay, 8 ft tall, 16" wide

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Air leakage

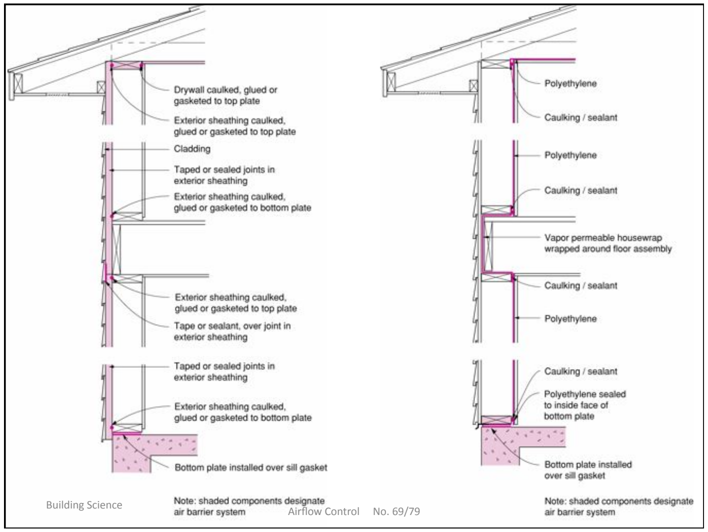
- Hard to save energy with the door open
- Buildings getting tighter, but . . .
  - Many still leak way too much
  - We can't identify the leakers
  - Need to test! Commission!
- Ventilation: Many try to improve air quality by increasing quantity
  - Target good air when and where needed

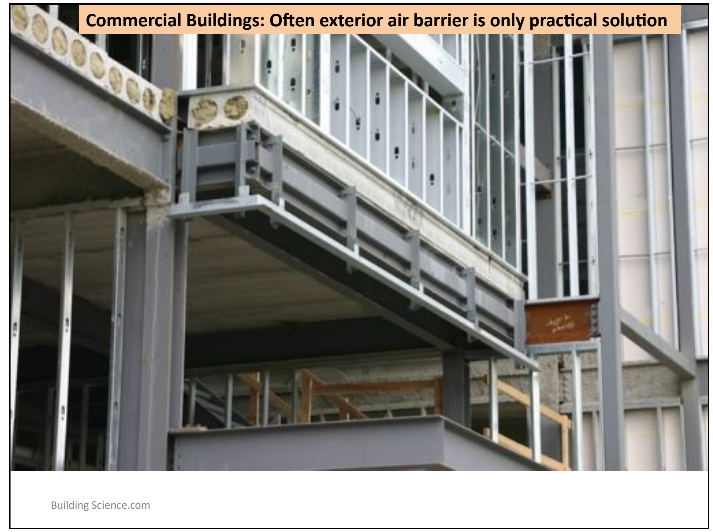
67/175 11/20/10

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

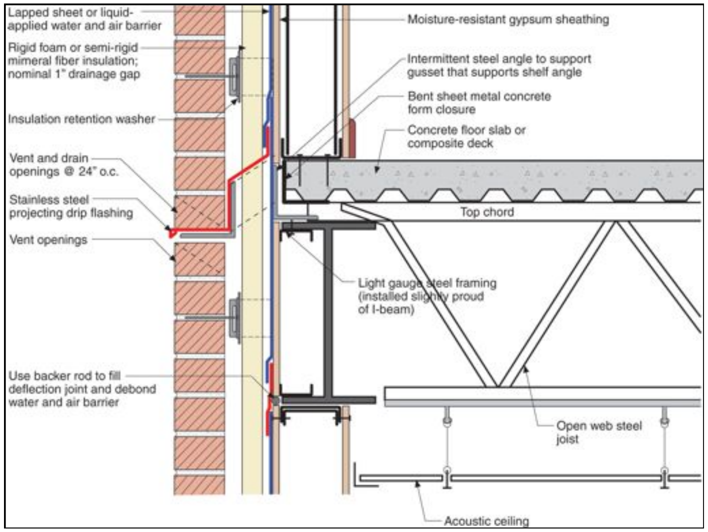
68/175 11/20/10

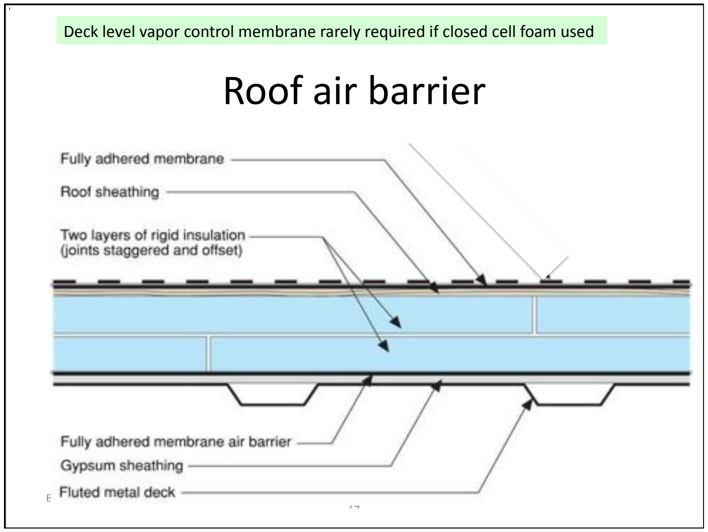

Drywall caulked, glued or gasketed to top plate
Exterior sheathing caulked, glued or gasketed to top plate
Cladding
Taped or sealed joints in exterior sheathing
Exterior sheathing caulked, glued or gasketed to bottom plate
Exterior sheathing caulked, glued or gasketed to top plate
Tape or sealant, over joint in exterior sheathing
Taped or sealed joints in exterior sheathing
Exterior sheathing caulked, glued or gasketed to bottom plate
Bottom plate installed over sill gasket
Note: shaded components designate air barrier system
Polyethylene
Caulking / sealant
Polyethylene
Caulking / sealant
Vapor permeable housewrap wrapped around floor assembly
Caulking / sealant
Polyethylene
Caulking / sealant
Polyethylene sealed to inside face of bottom plate
Bottom plate installed over sill gasket
Note: shaded components designate air barrier system
Building Science
Airflow Control No. 69/79

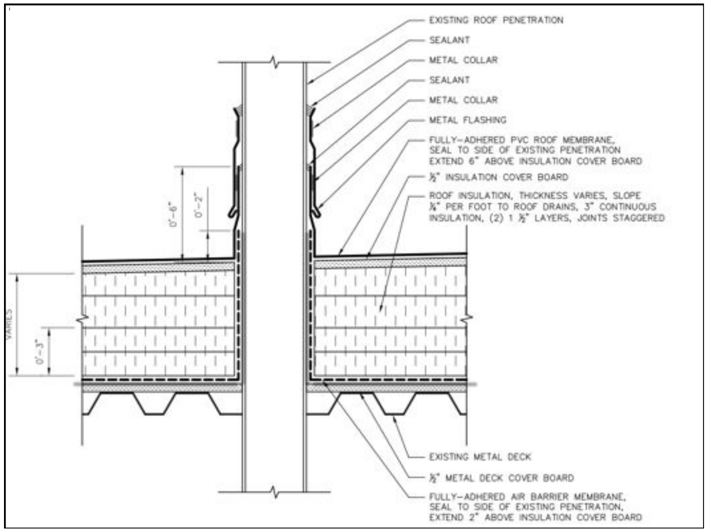

Commercial Buildings: Often exterior air barrier is only practical solution
Building Science.com

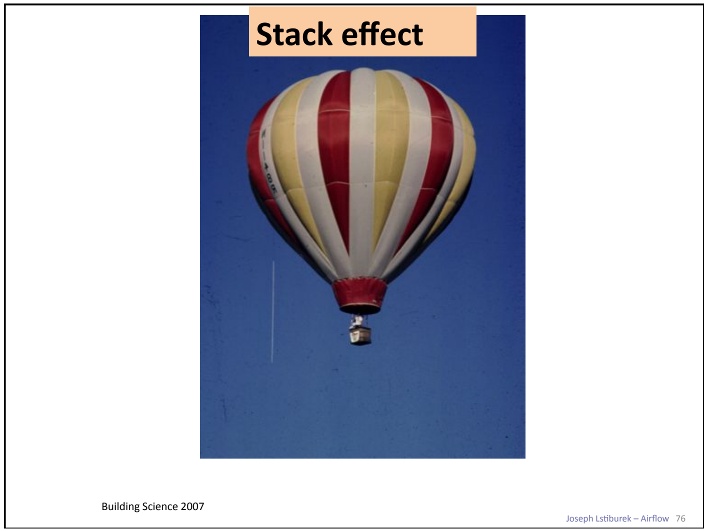

Poly combines air *and* vapour control
-Must be sealed and supported to be air barrier
-Cover most area and you have vapor control
Building Science.com
Airflow Control 71

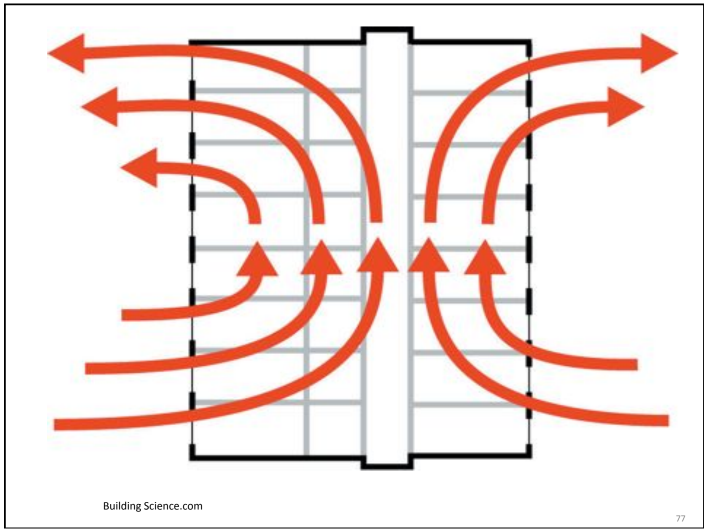

Rigid Exterior Air Barrier
Building Science.com
72

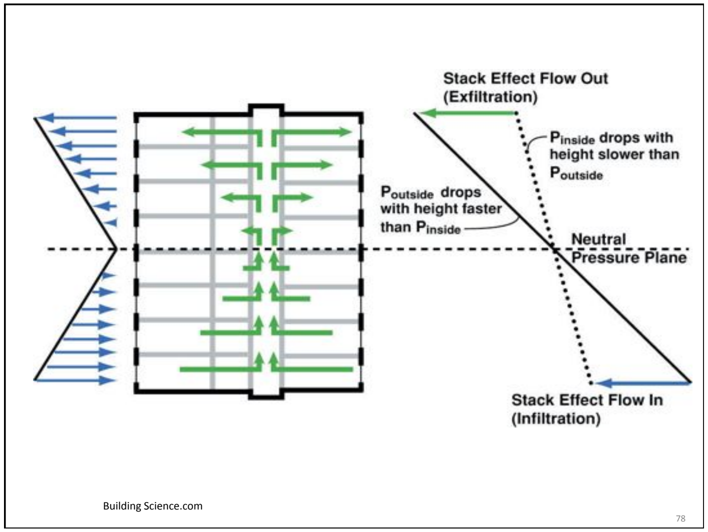

Lapped sheet or liquid-applied water and air barrier
Rigid foam or semi-rigid mineral fiber insulation; nominal 1" drainage gap
Insulation retention washer
Vent and drain openings @ 24" o.c.
Stainless steel projecting drip flashing
Vent openings
Use backer rod to fill deflection joint and debond water and air barrier
Moisture-resistant gypsum sheathing
Intermittent steel angle to support gusset that supports shelf angle
Bent sheet metal concrete form closure
Concrete floor slab or composite deck
Top chord
Light gauge steel framing (installed slightly proud of I-beam)
Open web steel joist
Acoustic ceiling

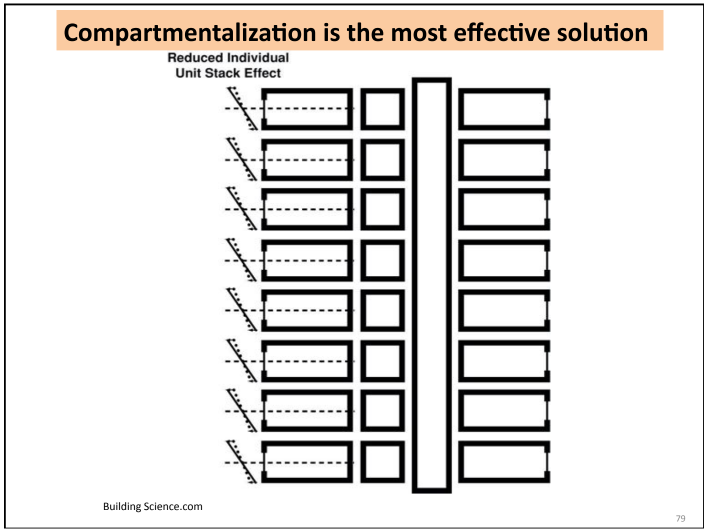

Deck level vapor control membrane rarely required if closed cell foam used
Roof air barrier
Fully adhered membrane
Roof sheathing
Two layers of rigid insulation (joints staggered and offset)
Fully adhered membrane air barrier
Gypsum sheathing
Fluted metal deck

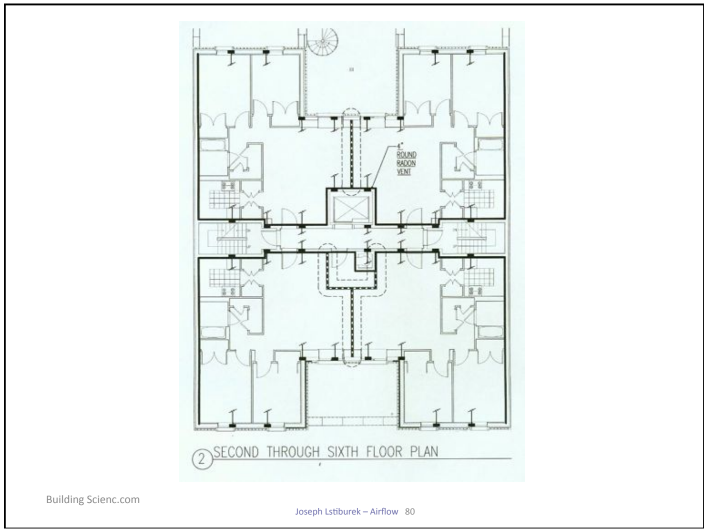

EXISTING ROOF PENETRATION
SEALANT
METAL COLLAR
SEALANT
METAL COLLAR
METAL FLASHING
FULLY-ADHERED PVC ROOF MEMBRANE, SEAL TO SIDE OF EXISTING PENETRATION EXTEND 6" ABOVE INSULATION COVER BOARD
½" INSULATION COVER BOARD
ROOF INSULATION, THICKNESS VARIES, SLOPE ¼" PER FOOT TO ROOF DRAINS, 3" CONTINUOUS INSULATION, (2) 1 ½" LAYERS, JOINTS STAGGERED
EXISTING METAL DECK
½" METAL DECK COVER BOARD
FULLY-ADHERED AIR BARRIER MEMBRANE, SEAL TO SIDE OF EXISTING PENETRATION, EXTEND 2" ABOVE INSULATION COVER BOARD


Stack effect
Building Science 2007
Joseph Lstiburek – Airflow 76


Building Science.com
77

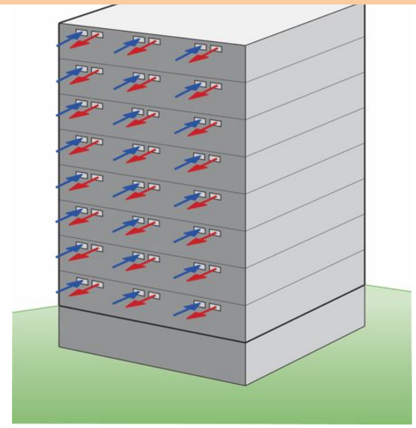

Stack Effect Flow Out
(Exfiltration)
Pinside drops with height slower than Poutside
Poutside drops with height faster than Pinside
Neutral Pressure Plane
Stack Effect Flow In
(Infiltration)
Building Science.com
78


Compartmentalization is the most effective solution
Reduced Individual
Unit Stack Effect
Building Science.com
79

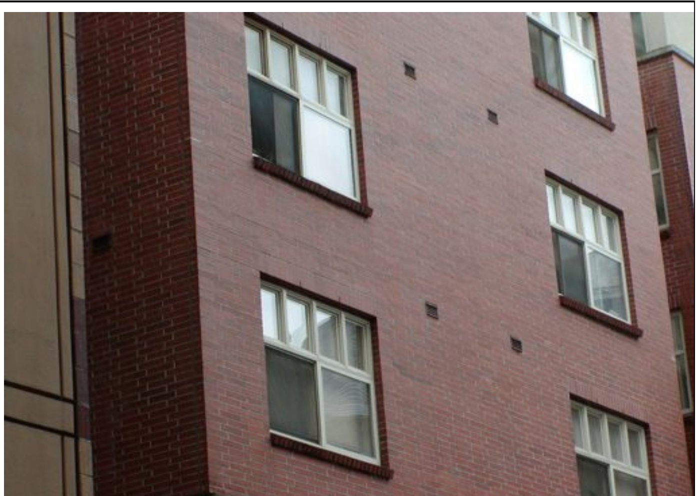

SECOND THROUGH SIXTH FLOOR PLAN
Building Scienc.com
Joseph Lstiburek – Airflow 80

Building Science.com

Individual air supply/exhaust per tenant

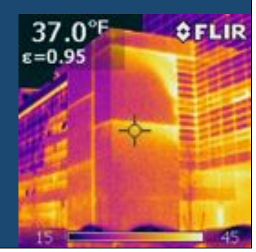


Building Science



Building Science

Thermal Control



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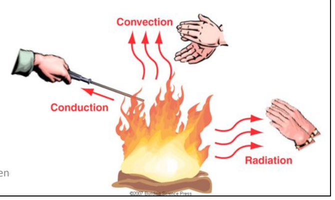
Thermal Control

- Insulation
  - Slows heat flow in and out
- Windows
  - Slow heat flow in and out
  - Control solar gain : allow or reject?
- "cool" roofs
  - Reduce solar gain
- Radiant barriers



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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

How much Insulation

- Heat Flow = $\dfrac{\text{Area} * (T_{inside} - T_{outside})}{\text{R-value}}$
- Double R-value, halve heat flow. Always.
- Optimum depends on
  - Cost of energy over life of building
  - Cost of adding more insulation
  - Savings in mechanical equipment, controls

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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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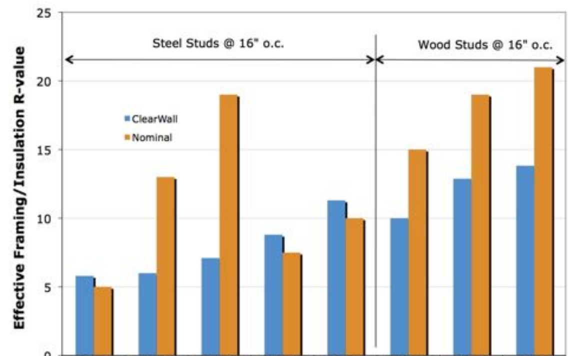
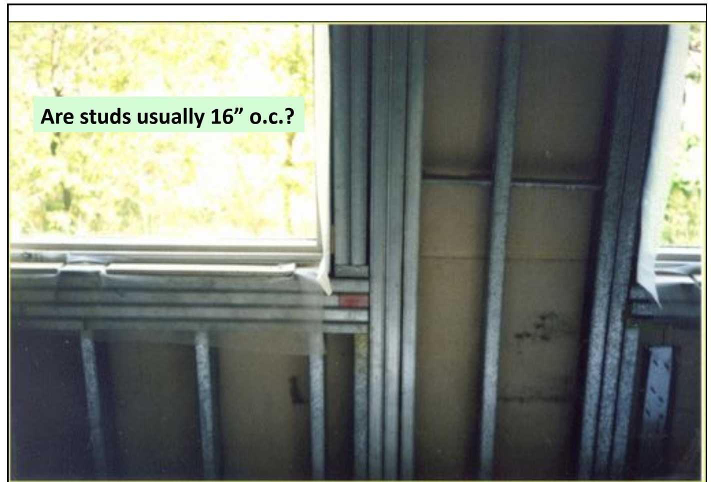
Best-case R-values for stud walls



	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 A9.2B. ci denotes a layer of continous insulation with no framing penetrations



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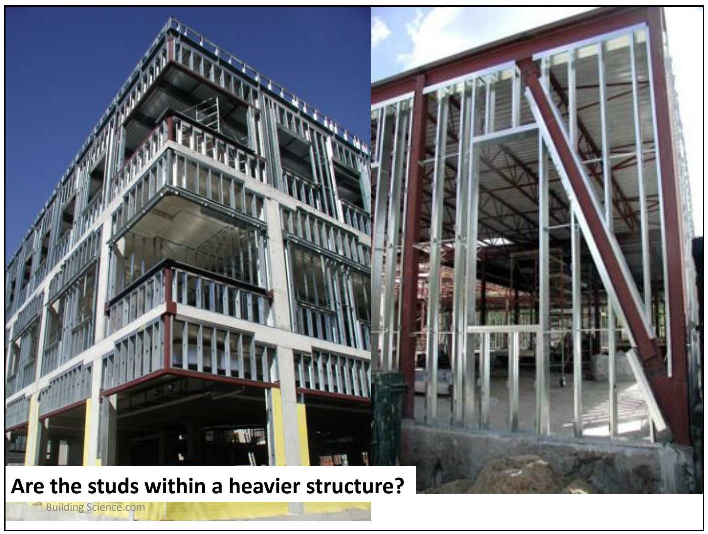
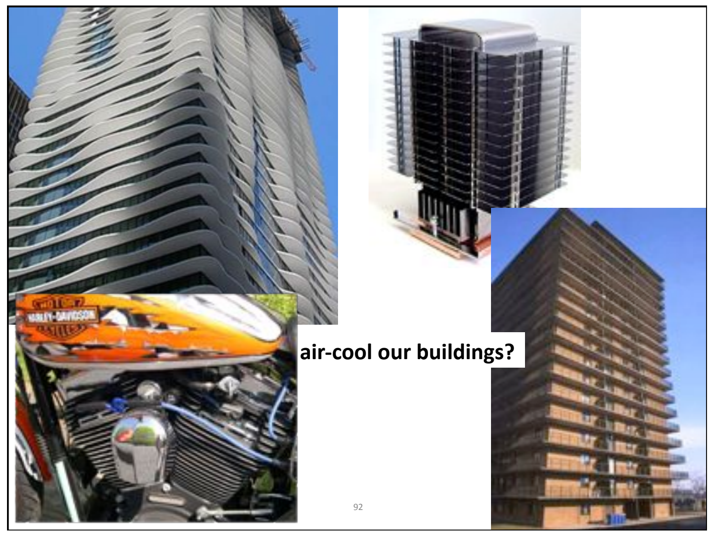
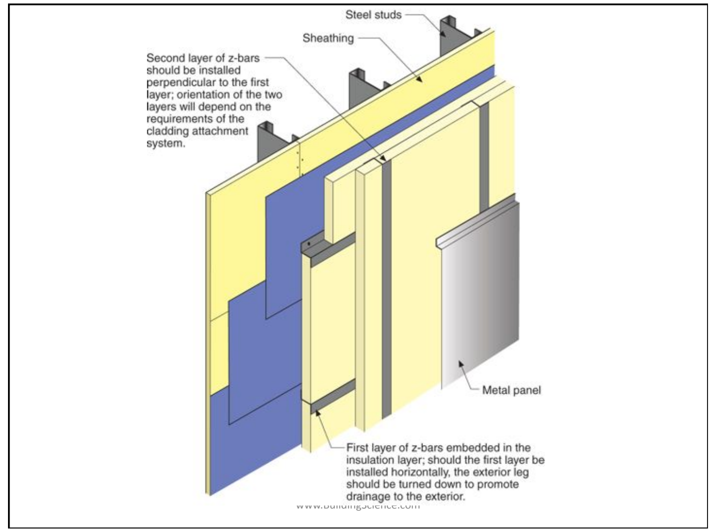
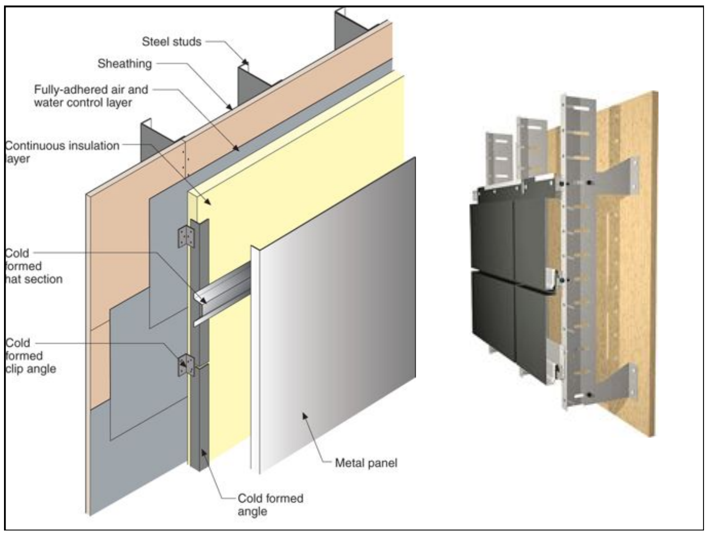


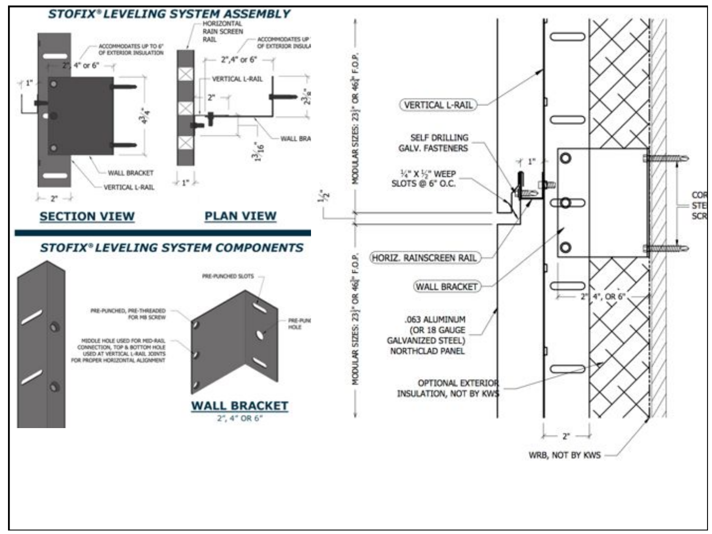


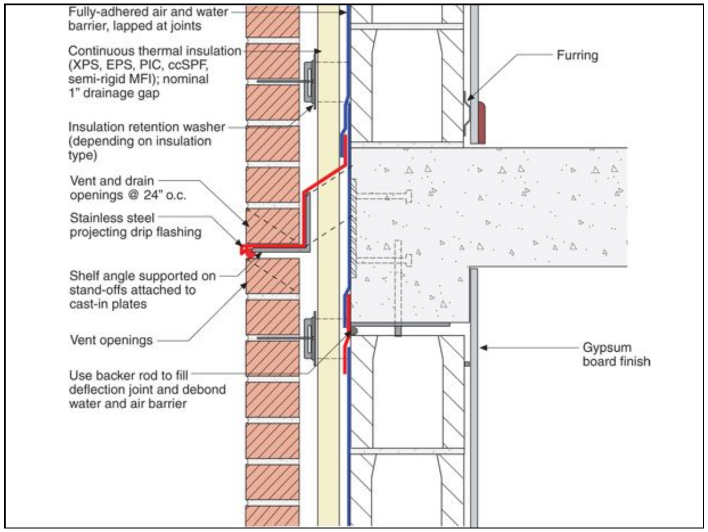
Thermal Bridge Examples

- Balconies, etc
- Exposed slab edges









Windows

- Our most expensive thermal bridges
- Aluminum is 4-5 times as conductive as aluminum
- Difficult to buy commercial aluminum windows / curtainwall over R3.
- Allow solar heat in
  - Useful in cold weather
  - Requires cooling in summer

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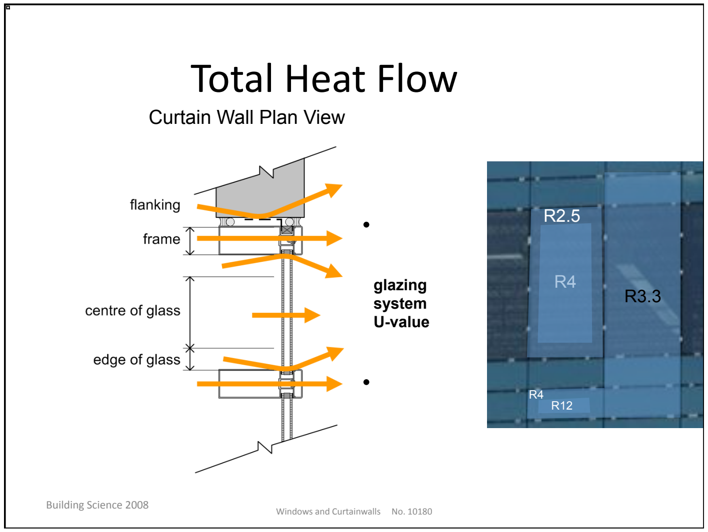
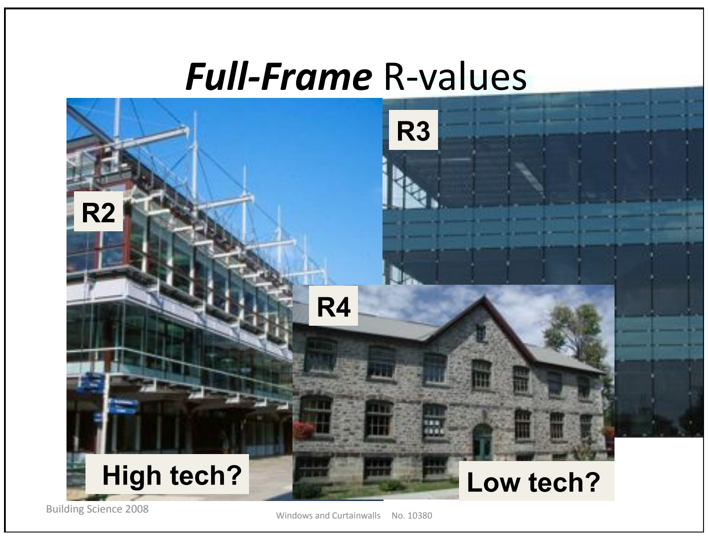
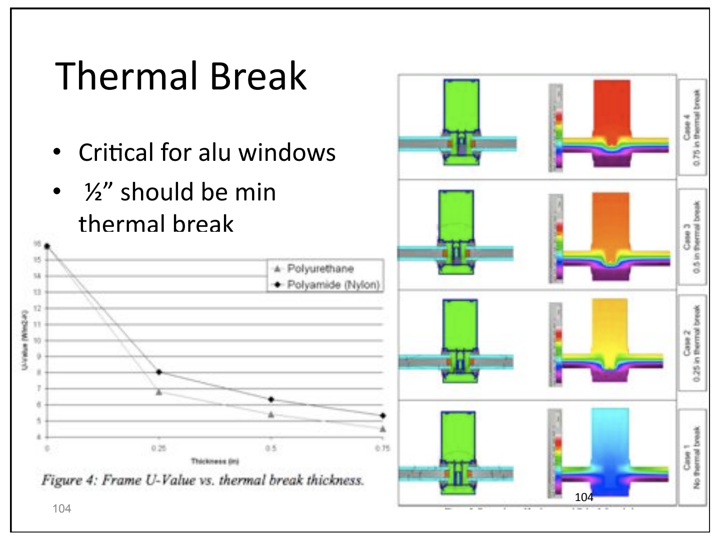
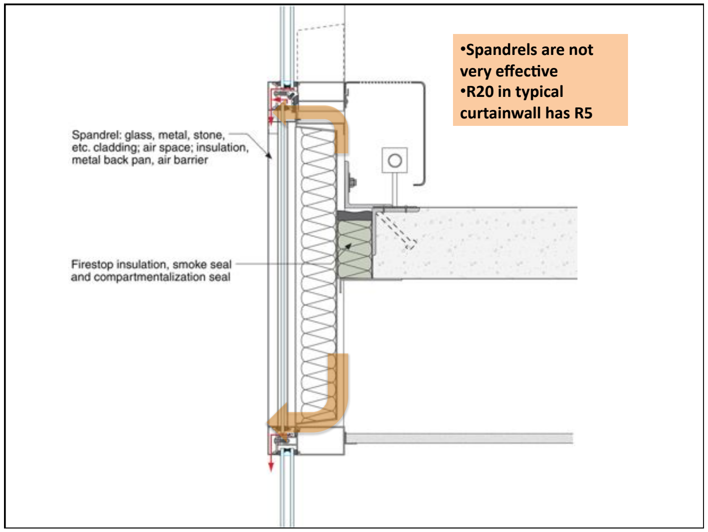

Total Heat Flow
Curtain Wall Plan View
flanking
frame
centre of glass
edge of glass
glazing system U-value
R2.5
R4
R3.3
R4
R12
Building Science 2008
Windows and Curtainwalls No. 10180

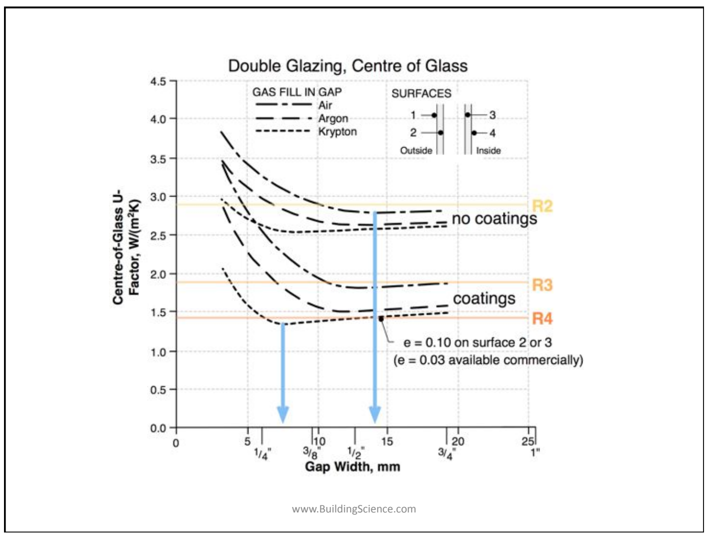

PTB
Building Science

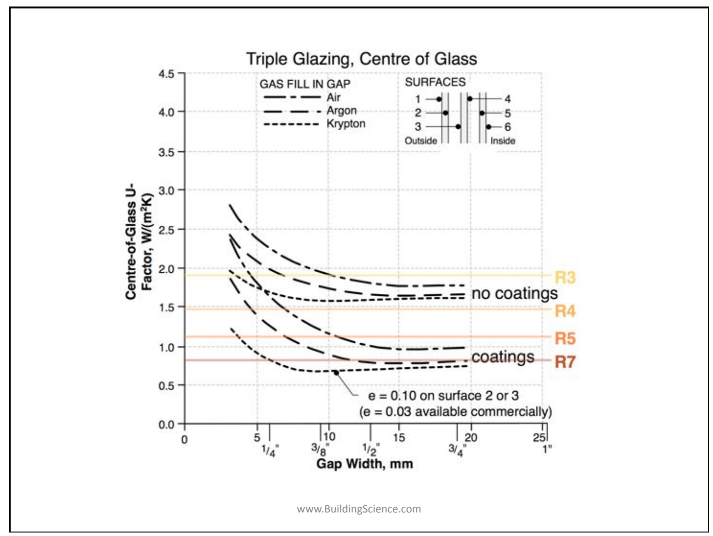

Full-Frame R-values
R3
R2
R4
High tech?
Low tech?
Building Science 2008
Windows and Curtainwalls No. 10380


Thermal Break
Critical for alu windows
½" should be min thermal break
Polyurethane
Polyamide (Nylon)
Figure 4: Frame U-Value vs. thermal break thickness.
104


•Spandrels are not very effective
•R20 in typical curtainwall has R5
Spandrel: glass, metal, stone, etc. cladding; air space; insulation, metal back pan, air barrier
Firestop insulation, smoke seal and compartmentalization seal


High Performance
Getting better . .
R10
Southwall
R7
R6
R24
Kawneer
Visionwall
Building Science 2008
Windows and Curtainwalls No. 10680

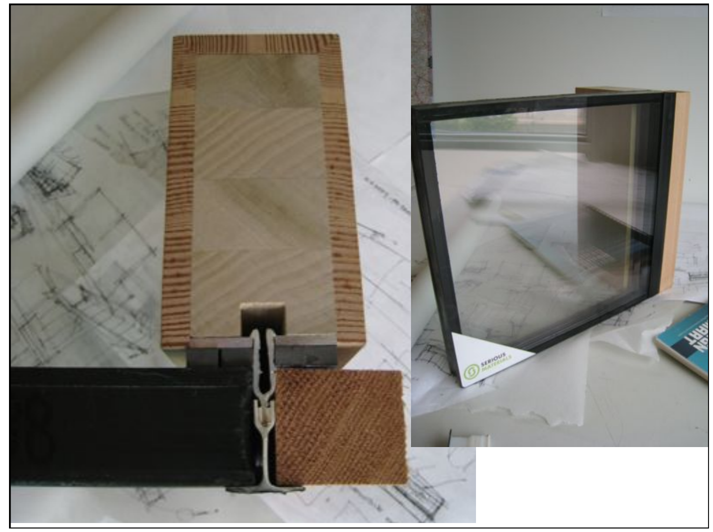

Double Glazing, Centre of Glass
GAS FILL IN GAP
Air
Argon
Krypton
SURFACES
Outside
Inside
Centre-of-Glass U-Factor, W/(m²K)
no coatings
coatings
R2
R3
R4
e = 0.10 on surface 2 or 3
(e = 0.03 available commercially)
Gap Width, mm
www.BuildingScience.com


Triple Glazing, Centre of Glass
GAS FILL IN GAP
Air
Argon
Krypton
SURFACES
Outside
Inside
Centre-of-Glass U-Factor, W/(m²K)
no coatings
coatings
R3
R4
R5
R7
e = 0.10 on surface 2 or 3
(e = 0.03 available commercially)
Gap Width, mm
www.BuildingScience.com

	Center of Glass (COG) Performance*				AlpenGlass+™	
Industry Leading Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.05	20.00	0.29	0.44	Dual Pane, Triple Low Solar Heat Coefficient Film	Xenon
Premium Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.07	14.29	0.24	0.43	Dual Pane, Dual Low Solar Heat Coefficient Film	Krypton
	0.11	9.09	0.51	0.65	Dual Pane, Dual High Solar Heat Coefficient Film	Krypton
High Performance	U-Value	R-Value	SHGC	VT	Glazing	Fill
	0.11	9.09	0.30	0.55	Dual Pane, Single Low Solar Heat Coefficient Film	Krypton
	0.19	5.26	0.60	0.73	Dual Pane, Single High Solar Heat Coefficient Film	Krypton

*Performance numbers are center-of-glass values based on LBNL Window 5.2 software.

Courtesy of ThermaProof Windows and AlpenGlass+



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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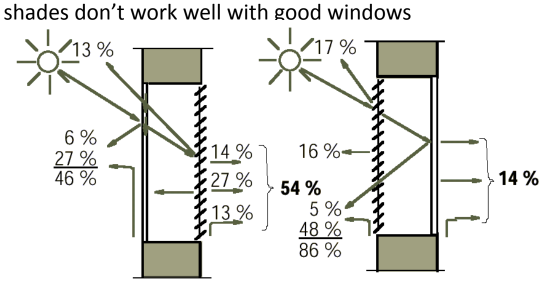
Interior or Exterior Shade

- 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



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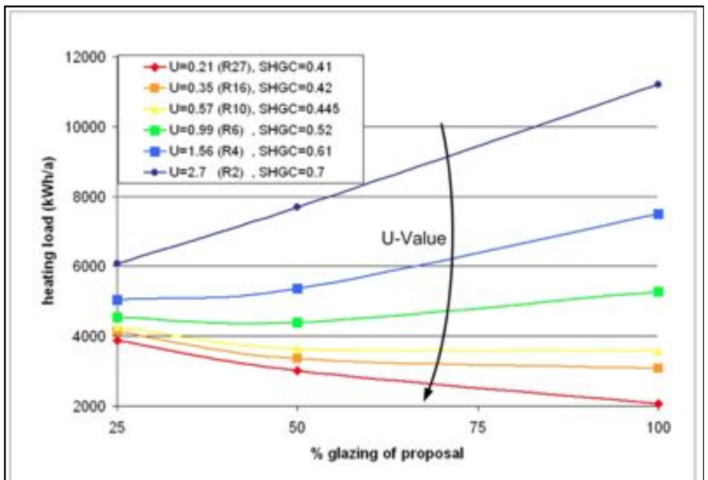


Figure 3.3.1 b): Heating load vs. % glazing of proposal for various windows.

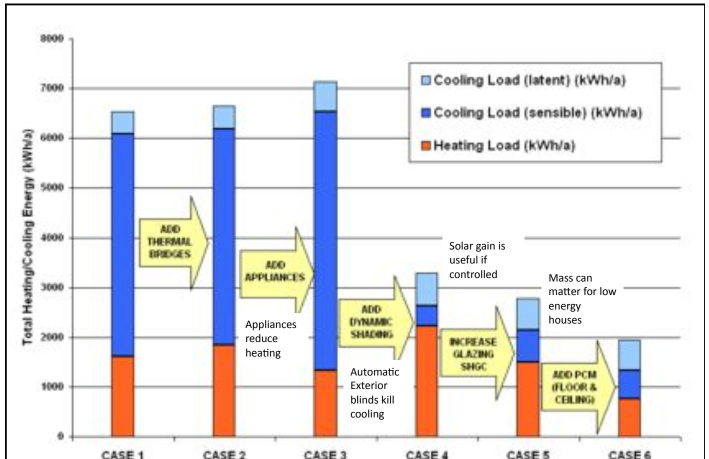
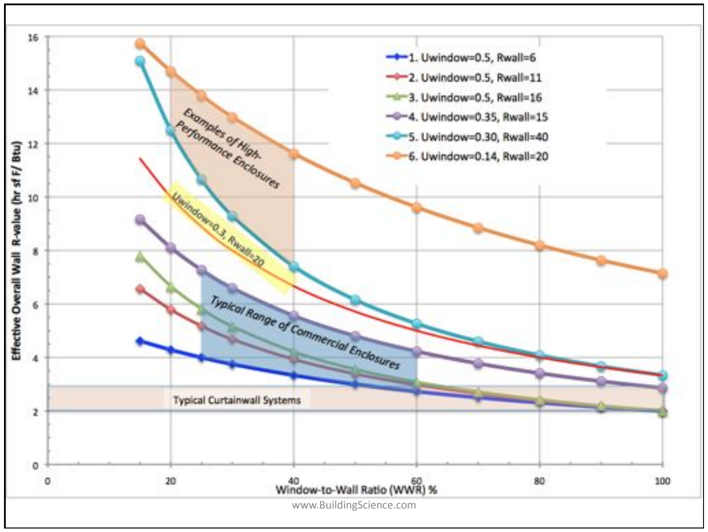
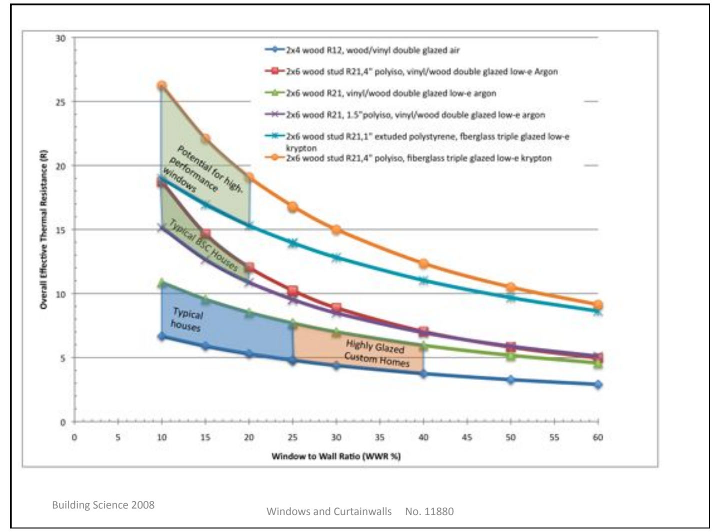


Figure 3.6.1 b: ESP-r simulation results for the refined house model.


1. Uwindow=0.5, Rwall=6
2. Uwindow=0.5, Rwall=11
3. Uwindow=0.5, Rwall=16
4. Uwindow=0.35, Rwall=15
5. Uwindow=0.30, Rwall=40
6. Uwindow=0.14, Rwall=20
Examples of High-Performance Enclosures
Uwindow=0.3, Rwall=20
Typical Range of Commercial Enclosures
Typical Curtainwall Systems
Effective Overall Wall R-value (hr sf F/ Btu)
Window-to-Wall Ratio (WWR) %
www.BuildingScience.com


2x4 wood R12, wood/vinyl double glazed air
2x6 wood stud R21,4" polyiso, vinyl/wood double glazed low-e Argon
2x6 wood R21, vinyl/wood double glazed low-e argon
2x6 wood R21, 1.5"polyiso, vinyl/wood double glazed low-e argon
2x6 wood stud R21,1" extuded polystyrene, fberglass triple glazed low-e krypton
2x6 wood stud R21,4" polyiso, fiberglass triple glazed low-e krypton
Potential for high-performance windows
Typical BSC Houses
Typical houses
Highly Glazed Custom Homes
Overall Effective Thermal Resistance (R)
Window to Wall Ratio (WWR %)
Building Science 2008
Windows and Curtainwalls No. 11880