Low-Energy Commercial and Multi-Unit Residential Buildings

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Outline

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

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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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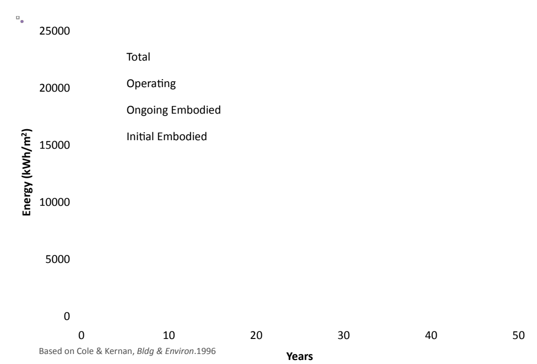
Office Example



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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UNIVERSITY OF BATH

INVENTORY OF CARBON & ENERGY (ICE) Version 2.0

Summary Tables

Prof. Geoff Hammond & Craig Jones

January 2011

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.

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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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What is this energy thing?

How to confuse people with facts and numbers

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Operational Energy Consumption

- Energy consumption during operation is the big problem
- When you have reduced this by 80%, start to worry about embodied energy / pollution
- LEED is not a reliable means of energy reduction
- **Need to use real numbers to measure**

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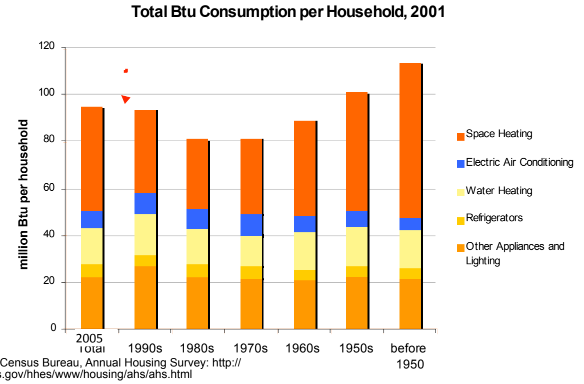
Old & New Houses Energy Use



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

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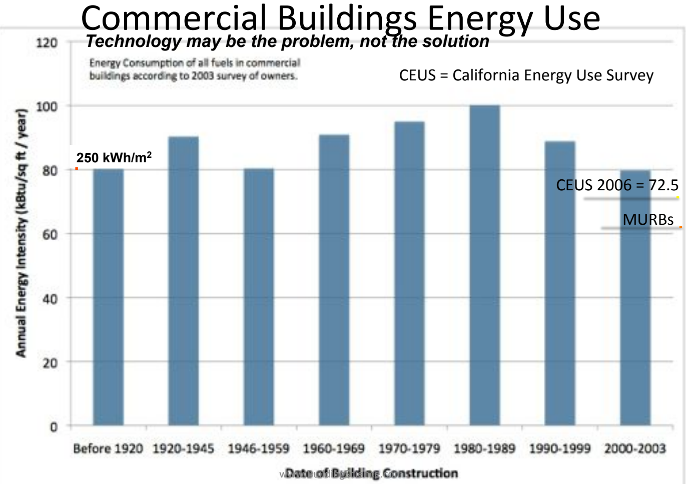
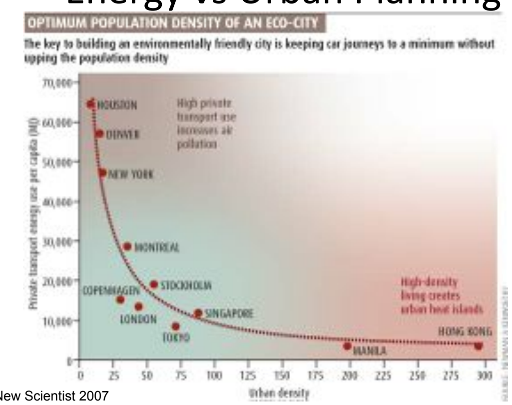
Commercial Buildings Energy Use



Energy vs Urban Planning



Source: New Scientist 2007

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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

Beware 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)
  - But.. 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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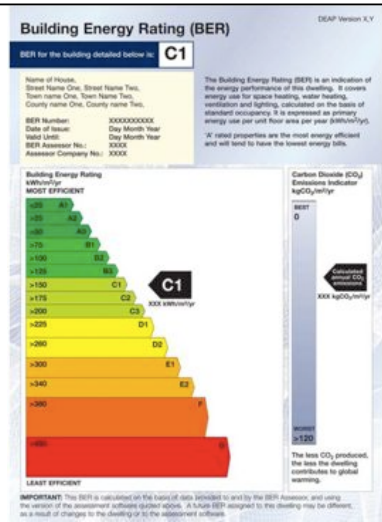
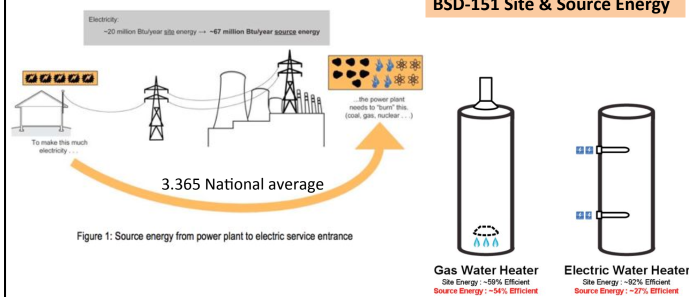


Electricity is Dirty

- Site vs Source (or Primary)

BSD-151 Site & Source Energy



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- to 8% 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)
WECC 1.11 lb CO_2 / kWh

Fossil Fuel GHG Emissions

- Assuming combustion @ 100% efficiency
- Nat gas
  - 117 pds CO_2 / MMBtu = 0.40 lb /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

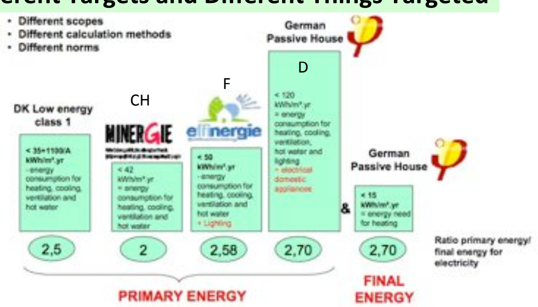
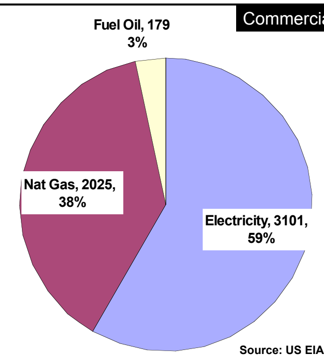


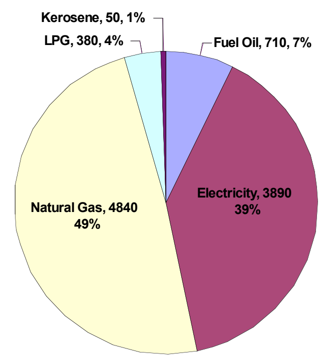
Figure 3. Comparison of the Danish low energy class 1, the Swiss energy calculation method (Minergie), French energy calculation methods (Effinergie), with the two energy frames as defined in the Passive House standard (total energy consumption and heating consumption per year). Source: Pascal Eveillard,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

Commercial



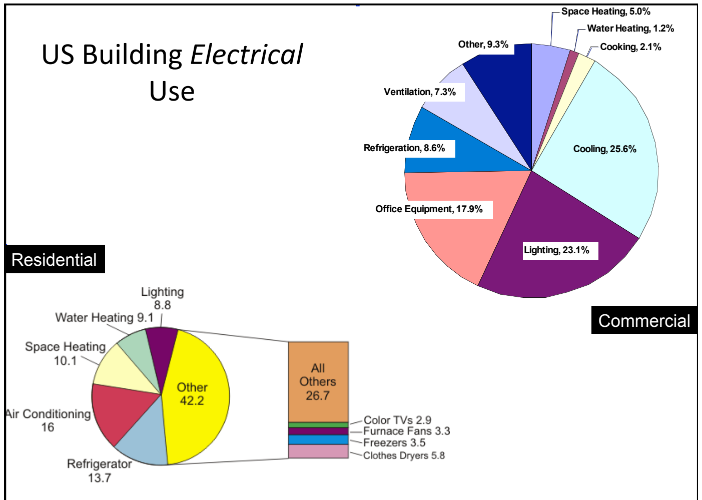


Residential

Source: US EIA

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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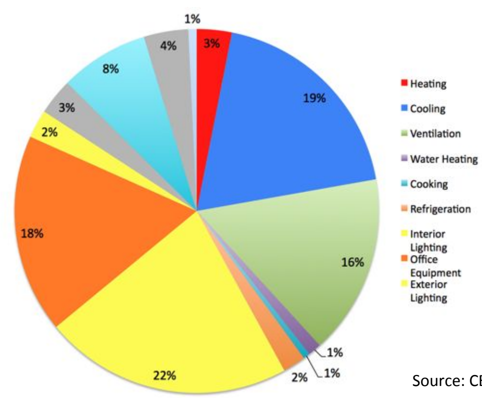
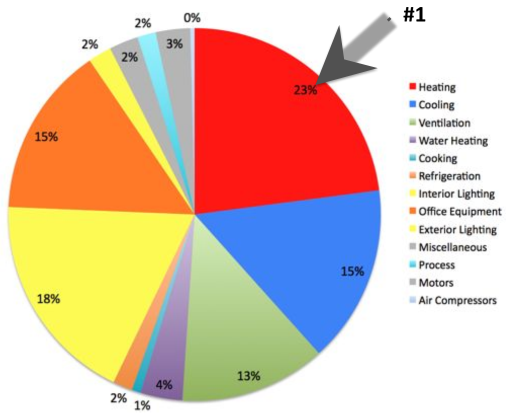
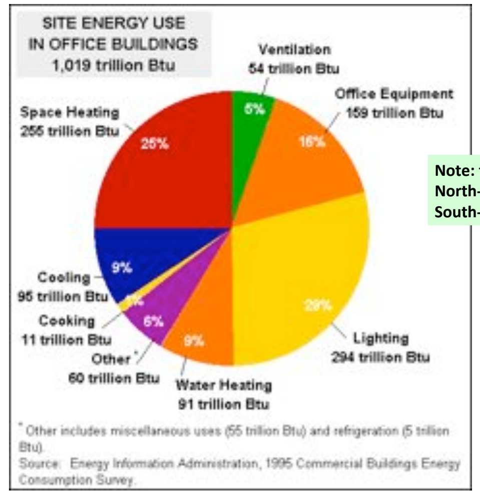
California Large Office Electric



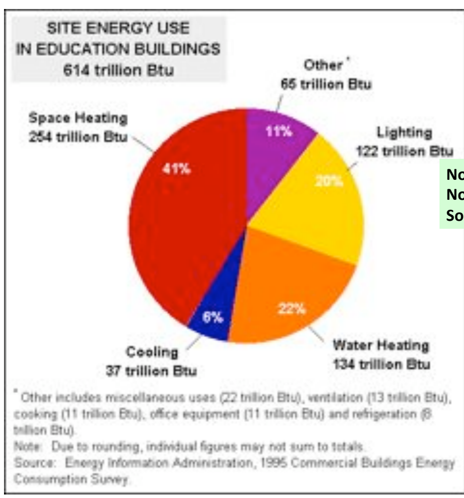
Source: CEUS 2006

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

NATIONAL NREL National Renewable Energy Laboratory

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

Innovation for Our Energy Future

Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector

B. Griffith, N. Long, P. Torcellini, and R. Judkoff
National Renewable Energy Laboratory

D. Crawley and J. Ryan
U.S. Department of Energy

Technical Report
NREL/TP-550-41957
December 2007

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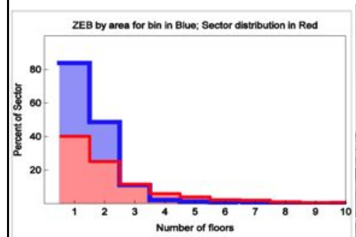
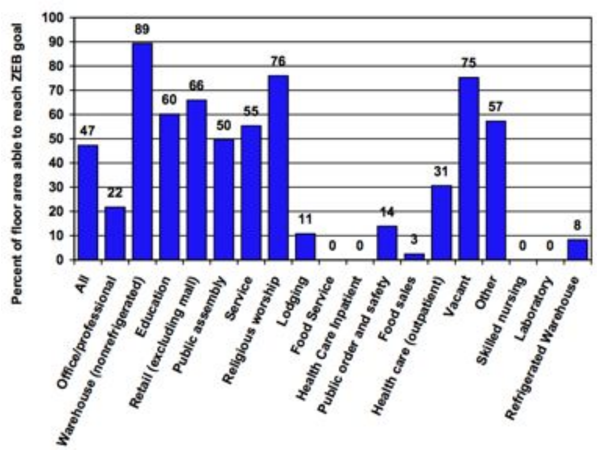
NetZero

- NZE is not likely a desirable goal for all bldgs
- Someone needs to pay for the 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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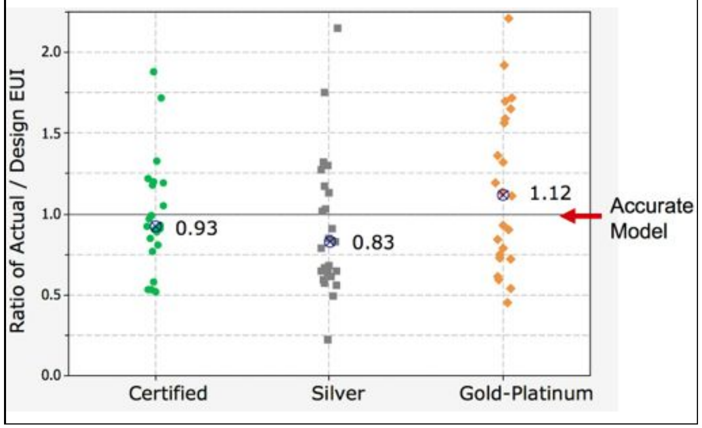
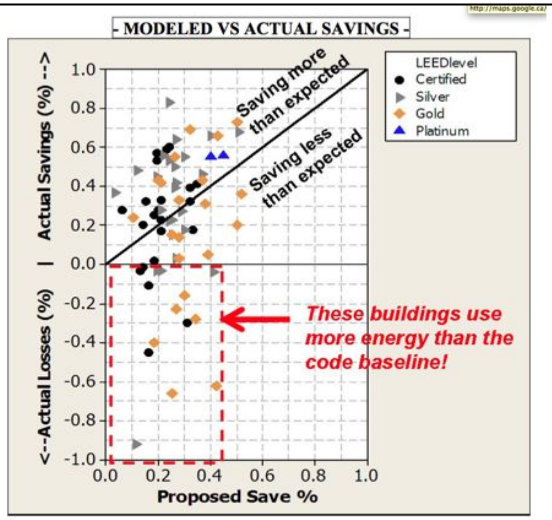
Modeling Critical



LEED buildings from New Buildings Institute Study



LEED buildings from New Buildings Institute Study

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

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.

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

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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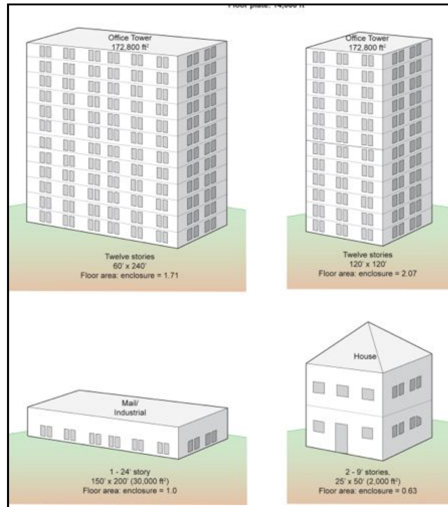


Size Matters

- Enclosure surface area to floo

e ratio, the more
sign & climate impact

Form & Massing

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

VS.

11-10-24

E. Gratia, A. De Herde / Energy and Buildings 35 (2003) 473–491

Shape and Orientation: Heating Energy for cool climate, small building

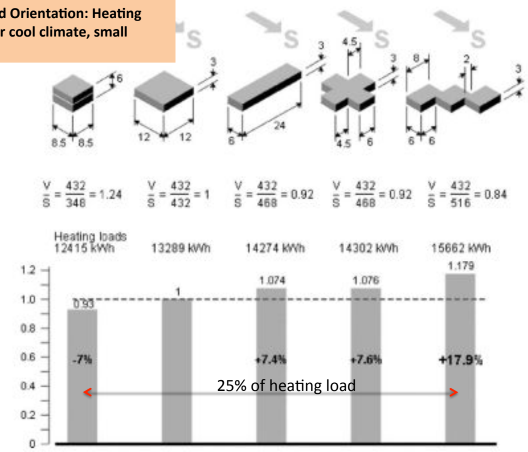


Fig. 4. Impact of the building shape on the heating loads.

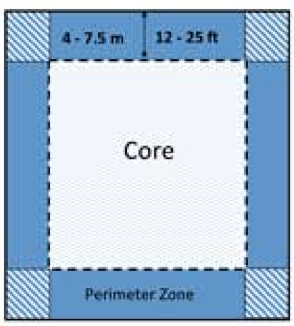
Building Shape

- Alphabet Soup
  - H I A B E

Large Buildings

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

Core / Perimeter



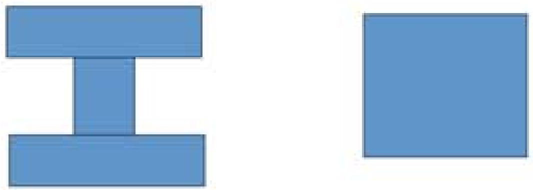
- Perimeter Zone
  - performance dominated by climate and enclosure
- Core Zone
  - dominated by interior use. Climate/enclosure almost irrelevant
- In most occupancies, core needs ***cooling and lighting all year long, all day***

Define "perimeter"

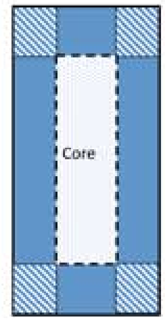
- Maximum distance about 25 ft/ 7.5 m
  - Classrooms often 25-30 ft, open plan office
- Minimum often set by walls/partitions of exterior offices
  - Cellular offices often 15 ft/ 4.5m deep

Expanded Plans

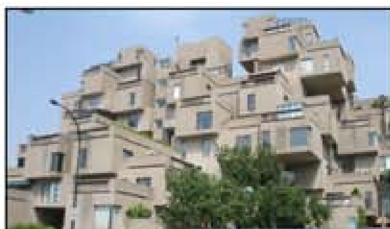
- Better daylight, easier ventilation but more enclosure heat loss and gain and air leaks



Skin Dominated Building



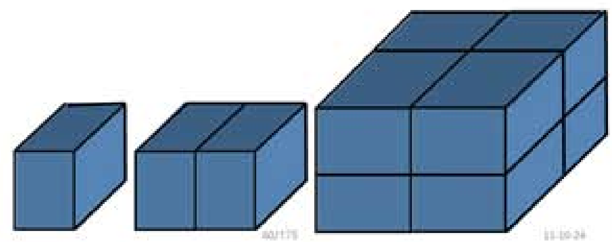
- Perimeter Zone over most of floor area
- Excellent daylighting and cross ventilation opportunities
- Termed "Skin Dominated"
- ***Demands good building enclosure***



Skin dominated

Grouping buildings

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



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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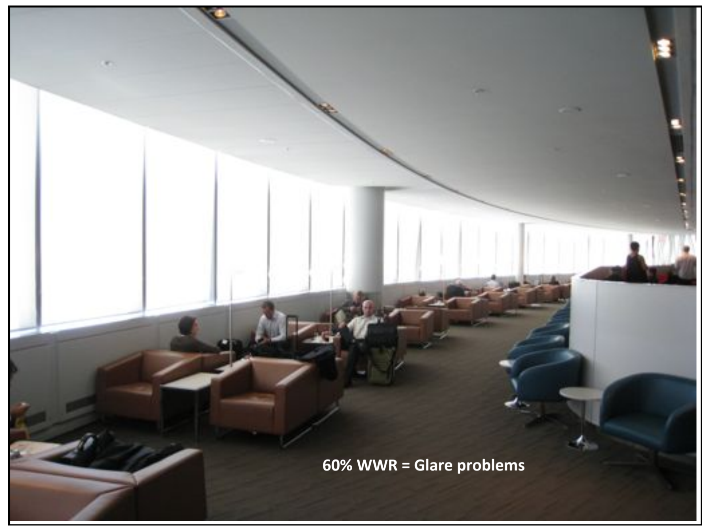
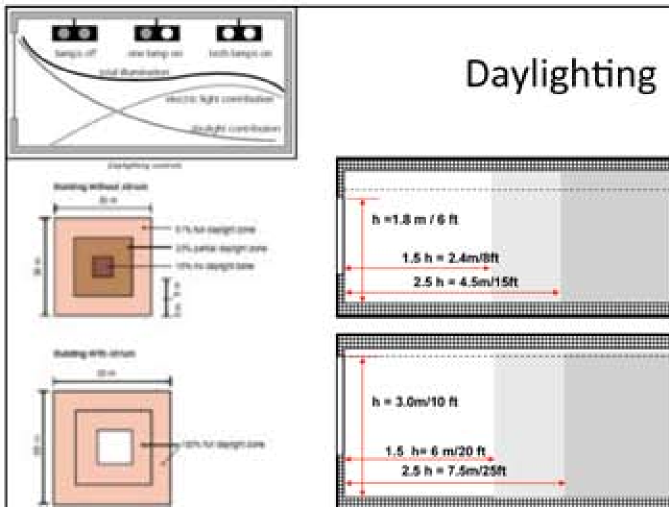


Daylight Penetration

- 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

Daylighting



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

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

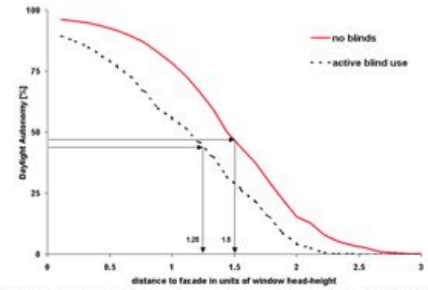
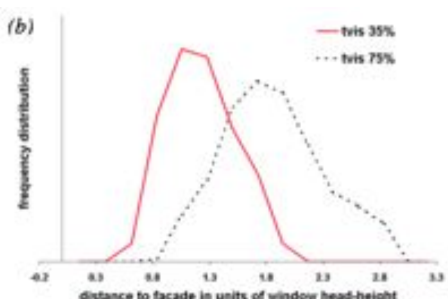


Figure 2: Daylight autonomy distributions for a rectangular room located in New York City facing South. The facade is fully glazed above work plane height and features a solar protective glazing with a visual transmittance of 35% . The minimum illuminance level in the office is 500lux and office hours 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.

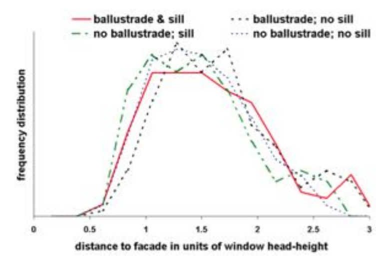


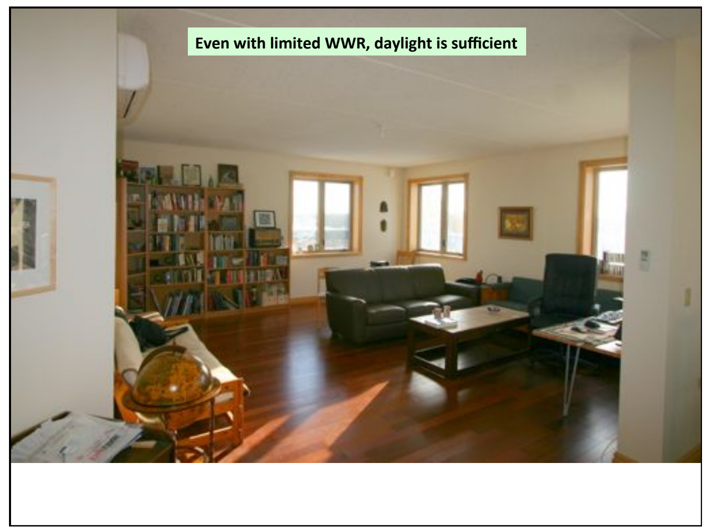
Figure 6: Frequency distributions of predicted daylit zone depths with blinds for varying facade

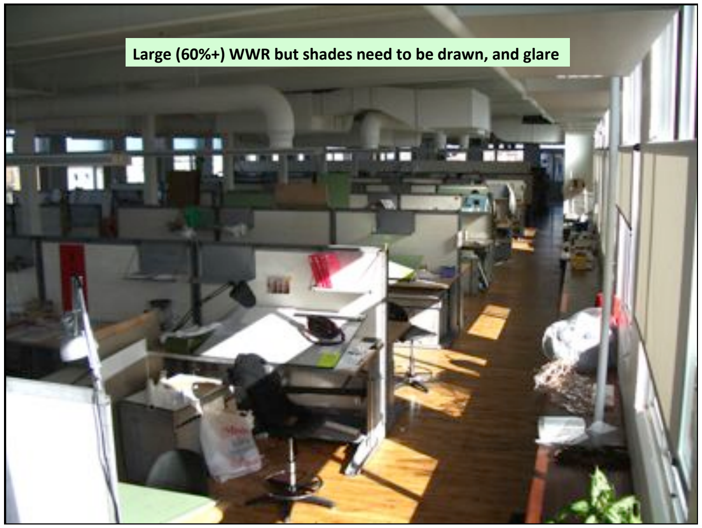
From: C Reinhart, 2005

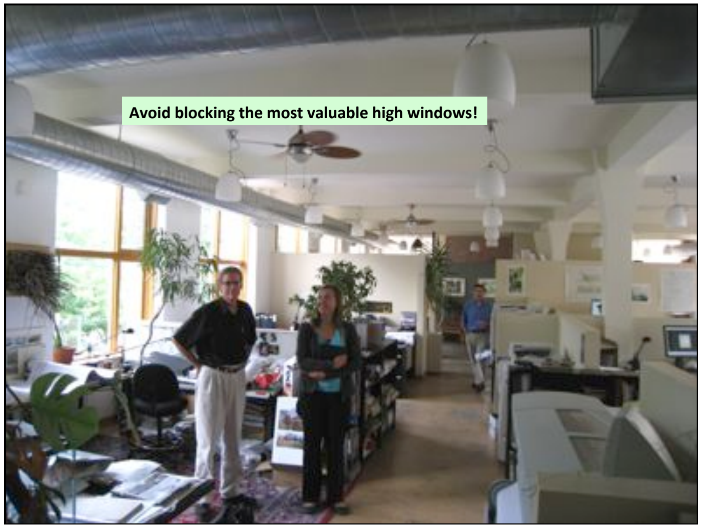

Architecture: Vertical and horizontal shading
Too much glass, so dark tint

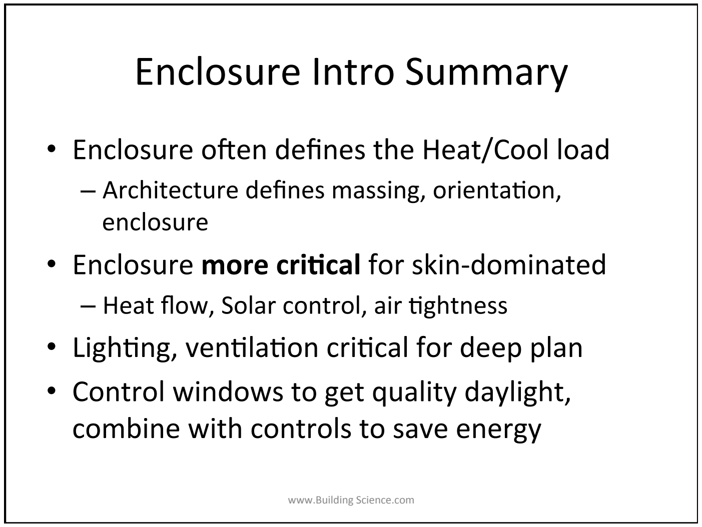

Looks clear
no lighting controls


Diffuse Toplight, reflective interior surfaces can be very effective


Even with limited WWR, daylight is sufficient


Large (60%+) WWR but shades need to be drawn, and glare


Avoid blocking the most valuable high windows!


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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