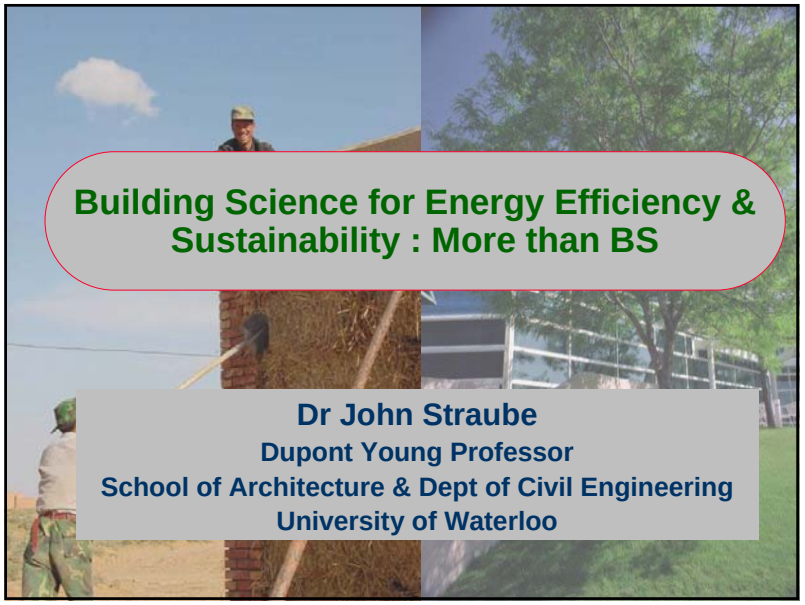


Building Science for Energy Efficiency & Sustainability : More than BS

Dr John Straube
Dupont Young Professor
School of Architecture & Dept of Civil Engineering
University of Waterloo

Energy

Energy
therefore
the Building Enclosure

- Building Science can be the solution not the problem

Outline

- Buildings, Energy and the Environment
  - Do we have a problem?
- How can designers reduce this impact
  - Are we doing our job?
- Strategies
  - Broad brush
- Techniques and examples
  - A review of some approaches / technologies

Buildings

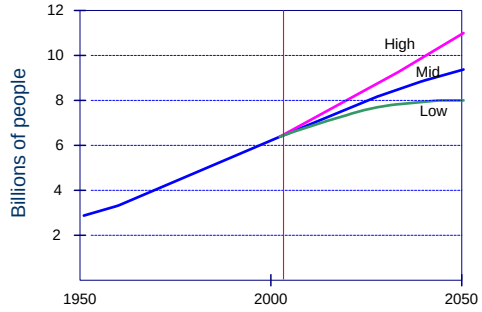
- Buildings are part of the environment
- Consume resources
  - materials *and* energy
- Pollute, displace (and provide) habitats
- A "durable good"
  - Running shoe (1 yr), car (10 yr), bldg (100yr?)
- Hence -- more careful long-term design
  - (e.g. societal involvement is justified)

Ecological Footprint

- term developed by Wackernagel & Rees
- Measure resource use and pollution "absorption" capacity in land area
- Compare available "productive" land to land area required
- Summary (1999)
  - Avg world citizen: 2.3 ha
  - Available land: 1.9 ha/person
  - Canada: 6.9 USA 9.6 ha
  - Bangladesh: 0.6 ha

Population Growth

- Slowing, but another 50%



Consumption Growth

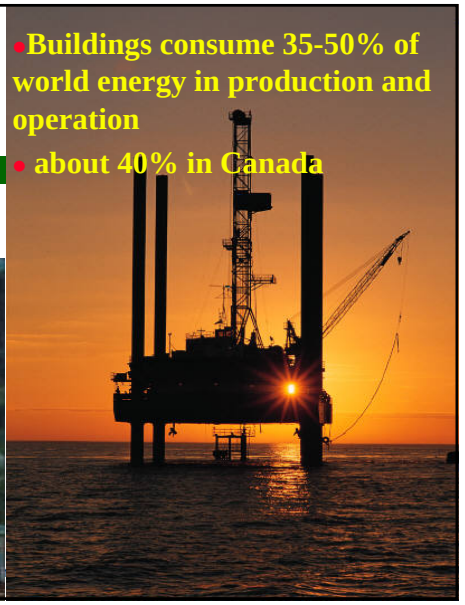
- Increasing "affluence" means increased consumption
  - e.g., Chinese GDP growing by 6-10%/yr
  - bigger houses, more appliances
  - replace labor with materials/energy
- American house
  - 1950: 400 sf/person
    - 1600 sf/house (4 people)
  - 2000: 750 sf/person or
    - 2400 sf/house (3.2 people)

John Straube

www.BalancedSolutions.com

Resource Depletion: Energy

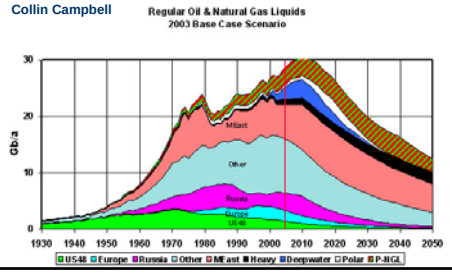
- Buildings consume 35-50% of world energy in production and operation
- about 40% in Canada



Oil & Gas Depletion

- *Cheap* oil and gas is almost gone
- Huge new energy services required for developing world
- Lots of coal, tar sands … but we can't burn it

Collin Campbell



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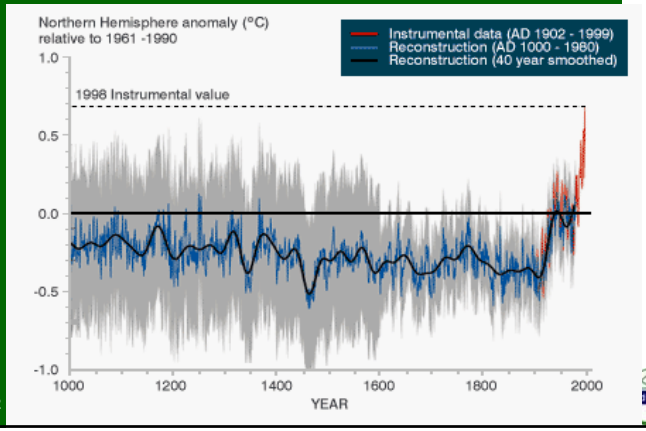
BBC

Climate Change: it could just be a blip, or ….



Buildings, Energy, Pollution

- Buildings consume *68%* of all electricity
- Canada Building construction and renovation
  - $60 Billion per year
  - 8% of GDP
- Operation of US buildings
  - Purchased energy costs $300 Billion in US
  - 560 million tons of CO_2 per year
  - 36% of US total and 9% of global CO_2 production
  - 49% of US total SO_2

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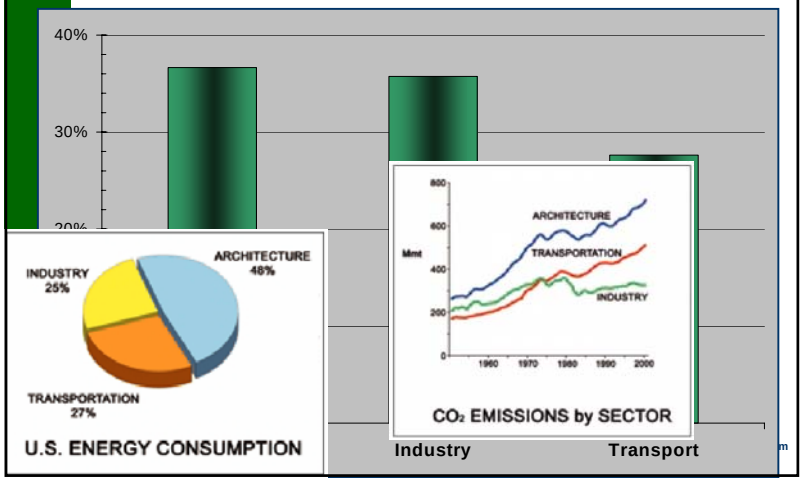
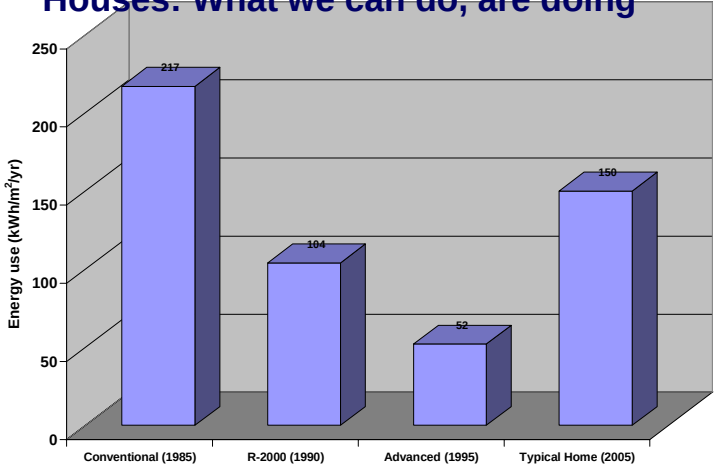
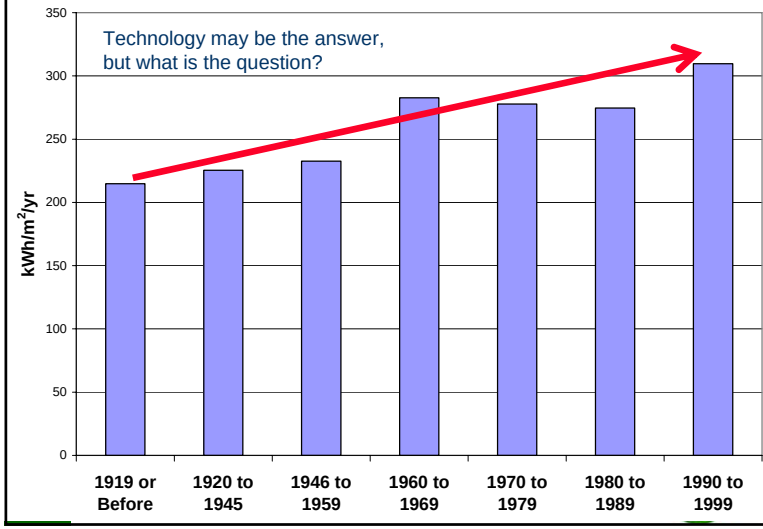
Building Share: Operational Energy



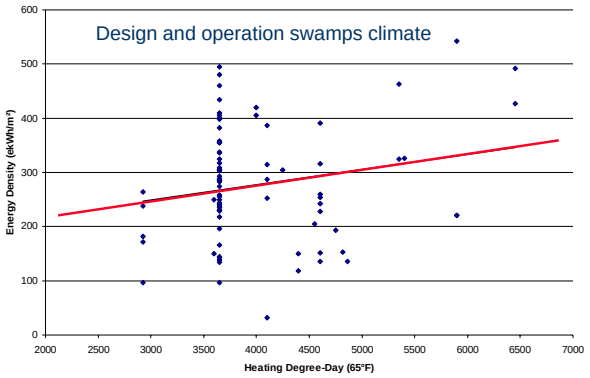
Houses: What we can do, are doing



Yr 2000 Commercial Building Energy Use



MURBS:Vancouver vs Edmonton



Learning to Count

- Many so-called "Green" buildings use a lot of energy and materials
- Average Canadian office 420 kWh/m^2/yr (in 1998)
- BC Telus(www.advancedbuildings.org)
  - Uses about 400 kWh/m^2/yr
- Foster's Leipzig Double façade
  - 450 kWh/m^2/yr

"Green" Buildings

- Recognize buildings have an impact
- *Minimize or eliminate*:
  - non-renewable resource use
  - non-renewable energy consumption
  - damage to the local and global ecology
  - production of waste and pollutants
- Buildings and Built Environment shape activity that consumes and pollutes

Goal

- If we must build, build greener buildings
- Eventually,
  - Buildings that use no net energy, enhance ecology, clean air and water
  - sustainable buildings in a sustainable community
- Future
  - Renewable / bio-materials
  - Building systems that allow reuse/recycling
- *"Within one generation, nations can achieve a ten-fold increase in the efficiency with which they use energy, resources and other materials"*

1997 Carnoules Statement to Government and Business Leaders

"Good" Buildings Are . . .

- Fu
  - r
- He
  - f
- Du
  - s
- Ad
  - f
- En
  - i
- Non-polluting
  - in operation and production

e occupants

resh air

ime

d easily

•Green Buildings are just one part of Good Buildings

•Must consider all aspects of the whole system

What should we do?

- *"Use energy & material more effectively both in production & operation of buildings while polluting & damaging ecology as little as possible"*
- Follow this over the whole life-cycle
- Can we?
  - Easy to reduce energy by 30% at no cost
  - Easy to cut waste and consumption by more
  - Major changes we can reduce by factors of up to 10!
  - BUT, requires change/commitment at concept stage

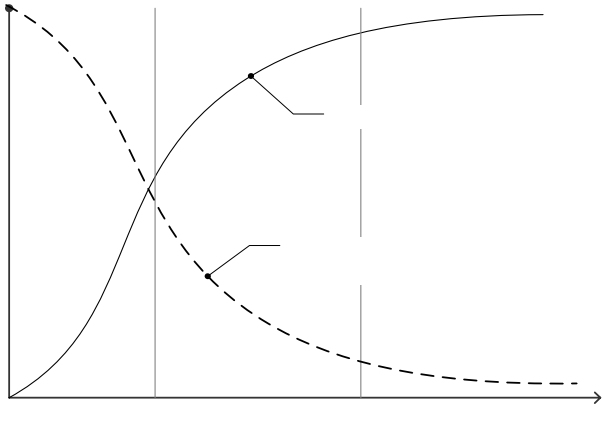
How can we do it?

1. Accept challenge
   - First must acknowledge we have a problem
2. Set real Performance benchmarks
   - provide designers with targets, measure and enforce them!
3. Learn the techniques and strategies
   - Many, many are available
   - May require changes in architecture for easy gains
4. Start in concept stage
5. Systems approach / integrated design
6. Measure / model performance
   - If we don't measure, we can't direct and improve

How to do it

- System integration
  - "Professional specialization" disease
  - Sub-system optimization
  - Non-optimal whole system design
- Real benefits come as a system
  - Good windows = no perimeter heat/ cool
  - Airtight + good insulation can mean no furnace
  - shade and solar windows save AC costs, fans, and ducts
  - Reduced power = renewable energy economical

Performance vs Cost & Time



How to do it

- We already know how!
  - E.g. Compact fluorescents (1/5 as much)
  - E.g. Highly insulating windows (1/3 as much)
  - E.g. Better enclosure insulation / airtightness (1/2)
  - E.g. Efficient HVAC and office equipment (1/2)

Role of Building Science

- Predicting & Quantifying performance
  - New materials and system performance
  - Energy consumption / pollution
  - Building mechanical systems
  - Material quantities
  - Indoor Air quality
- Quality control
  - Air tightness
  - Thermal bridges

Strategies

- At concept stage
  - How will building be shaped, oriented
- Define real targets and track them
  - E.g. material quantities, energy use, VOC
- Involve consultants early and iteratively
  - Energy analysis? Day lighting studies?
- Assess major decisions in green terms
  - Curtainwall or punched windows
  - Metal roof or asphalt, carpet or concrete

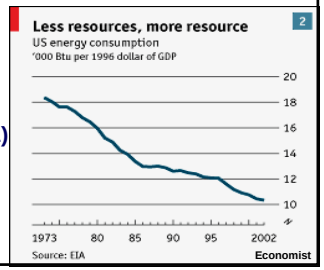
Cost o

Trade-offs

- Italian Marble foyer or condensing boiler?
  - Too easy
- Green Roof or 2” of EXPS
  - Pretty easy
- Heat recovery ventilator or insulated sheathing or superwindows?
  - depends

Energy & Efficiency

- People want services not energy
  - Warm home, not gas
  - Light, not electricity
- Hence, efficiency allow us to have our cake and east it
- Energy reductions after ’73 / ’79
- California brownouts(2001)
  - 12% cut in 6 months simply by citizen action



The Zero-sum Myth

- Myth: “*It is not economical to save energy and reduce pollution*”
- Fact: Median threshold for EE decisions
  - 1.9 yr payback / 71% after-tax ROI (Dept of Energy)
- Pollution inspection & control = expensive
- Saving energy is not expensive
  - Can often be CHEAPER!
  - e.g. Dupont, Lockheed, Shell, Suncor
  - Building Science Corp (www.buildingscience.com)

“I can’t afford to”

- Often “can’t” means “don’t want to”
- E.g., choice of exterior enclosure
  - R20 exterior wall = $15-40 / sq ft
  - R2 curtainwall = $40-70 /sq ft
- Finishes
  - Granite tiles in front lobby
  - vs Polished concrete or ceramic tiles
- Often *cheaper* not more expensive
- Building scientist can quantify

Technology to reduce energy+pollution

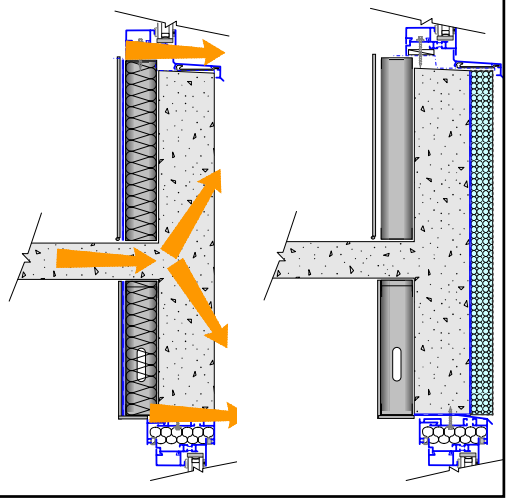
- Reduce heat loss and gain
  - Insulation
  - Avoid thermal bridges
  - Use good windows
  - Airtight
- Avoid energy use
  - Efficient appliances and elevators
  - Collect from sun
  - Use daylighting
- Then, generate renewable energy

John Straube

Poor Glass & thermal bridges = Brown?

- Low-E?

"Out of the box"



“Green” technologies

- Natural ventilation – beware humidity
- Efficient lighting - not LED
- Super windows
- Flyash and silica fume concrete
- ICF walls (concrete and insulation)
- SIPS (OSB and foam)
- Ground source heat pumps – but electric

“Green” technologies

- High efficiency boilers and chillers
  - Distribution!! Avoid air heating / cooling
- Radiant heating/cooling + DOAS
- Exterior, controlled sun blinds
- Recycled materials – steel Wood Plastic
- Efficient appliances, computers, printers
  - Ultra-efficient = off

Beware

- All glass Double Facades and DBZ – not!
  - Redefine the problem
- Access Flooring
  - Not needed for displacement ventilation
  - Use radiant/ hydronic for real comfort
- Strawbale and adobe
  - If all else is good: count

Saving Energy, Resources, $

- Proper Concepts
  - Orientation, shape, massing, etc.
- Fewer materials and simpler buildings
  - Fewer, simpler finishes and materials
- Reduce loads!
  - Save operating costs and
  - Reduce need for heating and cooling
- Improve equipment choice & efficiency
  - pumps, fans, chillers, lights, elevators
  - costs more, but smaller equip required
  - hour-by-hour computer modeling almost mandatory

Choose strategy based on orientation, climate, building

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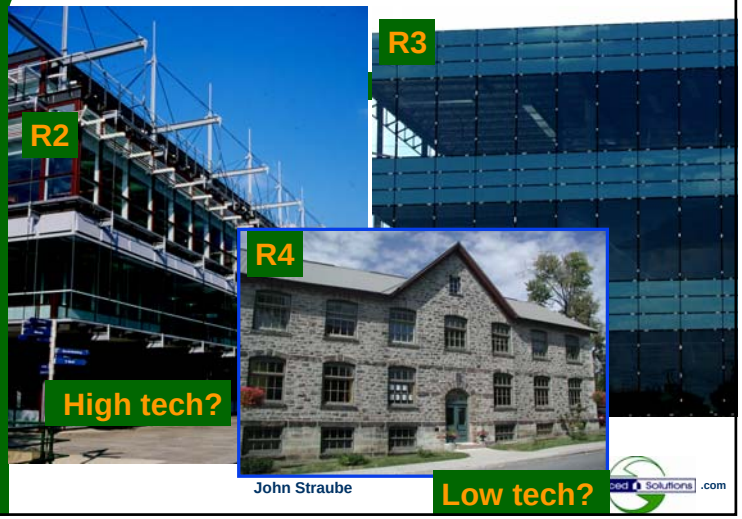
Windows, Insulated Enclosures



John Straube

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Windows, Insulated Enclosures

- Getting better . . .

John Straube

How to reduce need for energy?

- Use efficient or no lighting
  - use daylighting and occupancy controls
- Use top quality building enclosure
  - minimize heat loss/gain (more comfort)
  - stop air leakage (no condensation)
  - control solar heat and light, i.e. spectrally selective
- Use efficient equipment
  - printers, computers, fans, pumps, faxes, etc.
- *Sun is biggest and easiest load to control*
  - use it for heating, avoid it to reduce cooling

John Straube

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The System Cascade: Office Bldg

- E.g., reduce window solar heat gain so …
- cooling is reduced, so …
- chiller, fans, and ducts are reduced, so …
- smaller plenum space floor to floor and reduced square footage
- **so you save capital and energy!**
- Now repeat for lighting, equipment, ventilation loads. *Individual* cost benefit may not be positive, but system benefit is!

"Spin off" Benefits

- Better HVAC (e.g., 100% fresh air) = better IAQ
- Daylighting and better indoor air quality (IAQ) increases productivity, sales, morale
- Less noise and drafts from over-taxed cooling systems
- More tolerant to power failures
- Passive energy (PV, wind, solar) is diffuse, so lower loads = economic viability

Change resource use

- Renewable materials *sustainably* produced
  - Certified timber (low energy required)
- Recyclable materials with *low energy* use
  - Reuse wood and steel
  - Recycled steel uses about 70% of energy
- Both must not generate dangerous pollutants during their life cycle

Examples of Renewable Material

- Wood
  - Harvest sustainably
  - Improve fibre use
- Bamboo
  - Grows quickly, quite strong
- Other fibres
  - Hemp, cotton, flax, grass, straw, etc.
- Soil, earth, rock
  - intensive mining problems
- Natural polymers (e.g., starch)

Renewable Energy

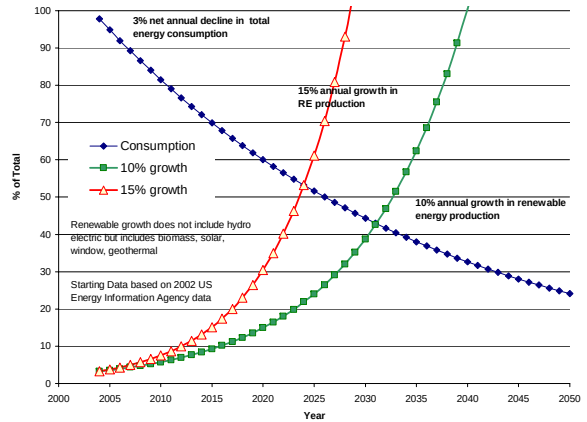
- Energy from renewable sources tend to be very diffuse
- become economical with hyper efficient buildings
- Generation at point of use saves distribution
- Central generation allows load leveling
- If plentiful, energy-saving is less important

Examples of Renewable Energy

- Biomass (including wood stoves)
  - Particulate pollution, production intensity
- Photovoltaics
  - Embodied energy and pollution
- Fuel cells?
  - Where is the hydrogen coming from?
- Wind power
  - Ecosystem disruption
- Hydroelectric
  - Habitat destruction / disruption
- Conservation and Efficiency
  - "negawatts", embodied energy required?

All these choices have problems

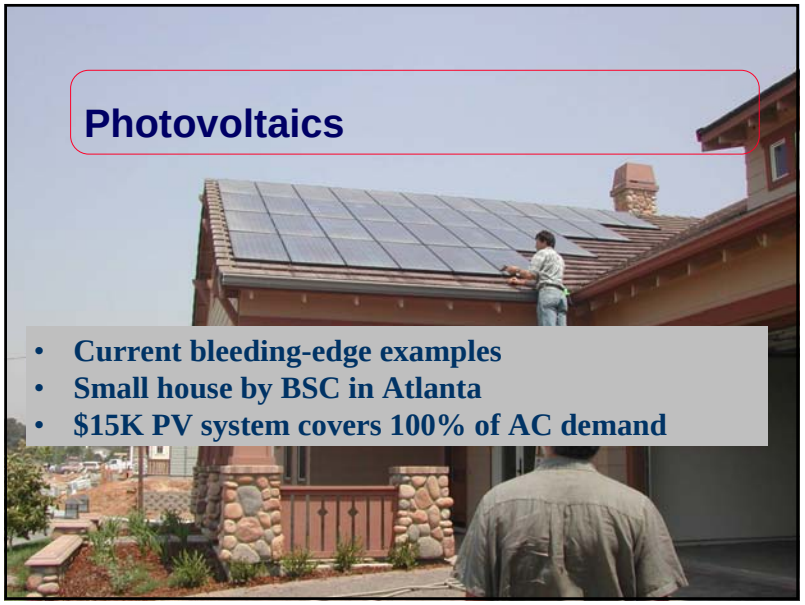
Efficiency + renewable



Photovoltaics

- Generate electricity from sun
- Peak utility loads now coincide with peak sun
- Utility system efficiency is around 32%
- PV system efficiency around 10% and rising
- Cost per watt is dropping (approx 25cents/kWh)
- Key to effectiveness is reducing demand

Photovoltaics



- Current bleeding-edge examples
- Small house by BSC in Atlanta
- $15K PV system covers 100% of AC demand

Fuel Cells

- Around 35-40% efficient (55-80% theoretical)
- No fundamental moving parts
- Scalable
- Require source of hydrogen
  - No easy pure renewable sources
  - Many sources are inefficient
  - Methane and methanol (but can be burned directly)
- Unlikely to "save" us, but can displace some sources

Wind Energy

- Used for at least a millennium
- Depends on site and climate
- Highly sensitive to scale
  - Large much cheaper
- Highly sensitive to windspeed
  - Energy α V^3
- Intermittent, alas
- Europe growing at >20%

Biomass

- Stored solar energy
  - Provides habitat during collection
- As simple as a wood stove
  - Beware Particulate pollution
- Methane production
  - Land fills
  - Human waste
  - Intentional bio-mass
- Ethanol production
  - High density energy from waste, not corn!

Hydroelectric

- Stored solar energy
- Large scale disrupts (not necessarily destroys) habitat
- Small scale often less disruptive and can be positive
- Must be aware of full riverine behaviour
- Significant low-head mini- and micro-hydro available

Co- Generation

- Combined heat and power (CHP)
- Generate electricity and use waste heat for process requirements
- Sandy-by generation already required
- Examples
  - Diesel generators
  - Micro turbines
  - Fuel cells
- Large systems achieve over 80% efficiency

Green and healthy

- Green buildings are often healthy
  - Low VOC
- Healthy buildings are not necessarily green
  - Mechanical ventilation
- These are two desirable requirements – they are not intertwined more than any other

Case Studies

A few ideas from real buildings

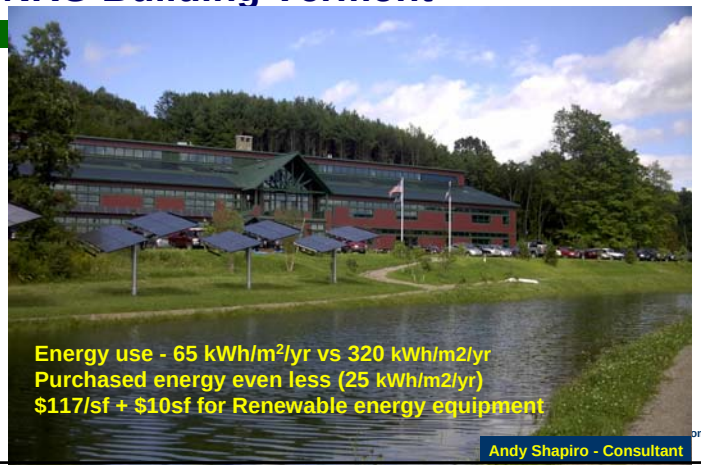
The Future Sustainable Office

- Practical Implementation example:
  - Limits glazing area to less than 50% of exterior
  - High R-value glazing ***system*** -- U < 1.0 W/m²/C (R>5)
  - Employs shading devices or low SHGC (<0.30) glass
  - Dimmable/controlled fluorescent lighting
  - 100% Outdoor supply air with ERV & dehumidification
  - Radiant cooling panels remove sensible heat
  - Optimal thermal mass
  - Embodied energy analysis of alternate designs
    - minimum aluminum, plastics, stainless, steel, etc.
  - Off-gassing budget

The Efficient Commercial Bldg

- Tightly controls solar and internal gain
  - reduce size of chiller and ducts, fans, pumps
- Reduces heat loss with high insulation levels
  - reduce boiler, avoid perimeter heat
- Is very airtight -- but provides plenty of fresh air
  - control air quality
- Controls light levels based on sun / occupancy
  - uses daylighting - saves energy, improves comfort
- Uses heat and enthalpy recovery on fresh air
  - don't throw away what you bought

NRG Building Vermont



Energy use - 65 kWh/m^2/yr vs 320 kWh/m2/yr
Purchased energy even less (25 kWh/m2/yr)
$117/sf + $10sf for Renewable energy equipment

Andy Shapiro - Consultant

Waterloo Apartment/Office

- Urban infill
- Less cost than average Waterloo apt.
- Predicted <100 kWh/y (vs 280 typical)

Rocky Mountain Institute (RMI.org)

- Less than median cost

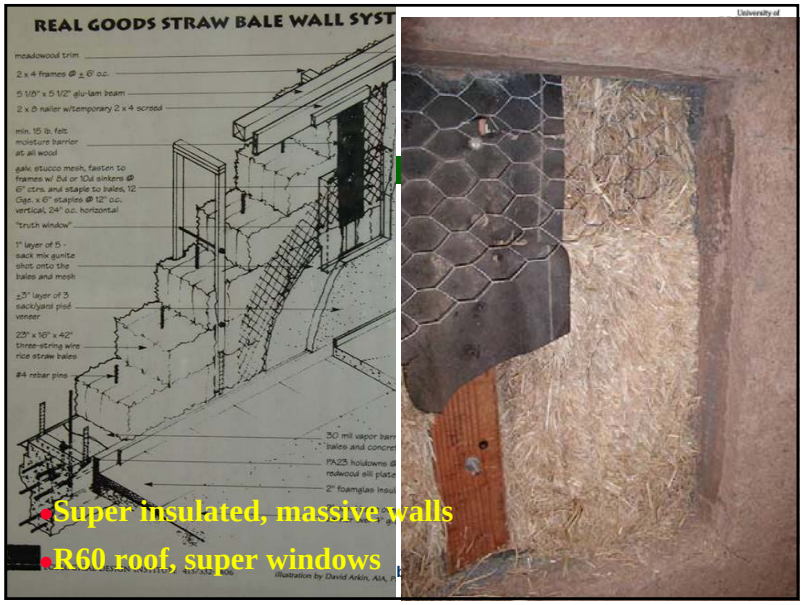
Purchases 99% less heating

- 90% less electricity

Ridge Winery

- Strawbale-earth plaster
- Super-Insulated / Shaded
- Low-energy


Orientation, shape
e.g., Real Goods


REAL GOODS STRAW BALE WALL SYST
Super insulated, massive walls
R60 roof, super windows


Deciduous shading, water element


REAL GOODS
Daylighting glare control
Solar heating/cooling
Night ventilation

Building Reuse

- Major existing resource
- Great possibilities

be

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Breeze Residence

- Arkin+Tilt Architects, Berkeley
- Low impact solar home of natural materials

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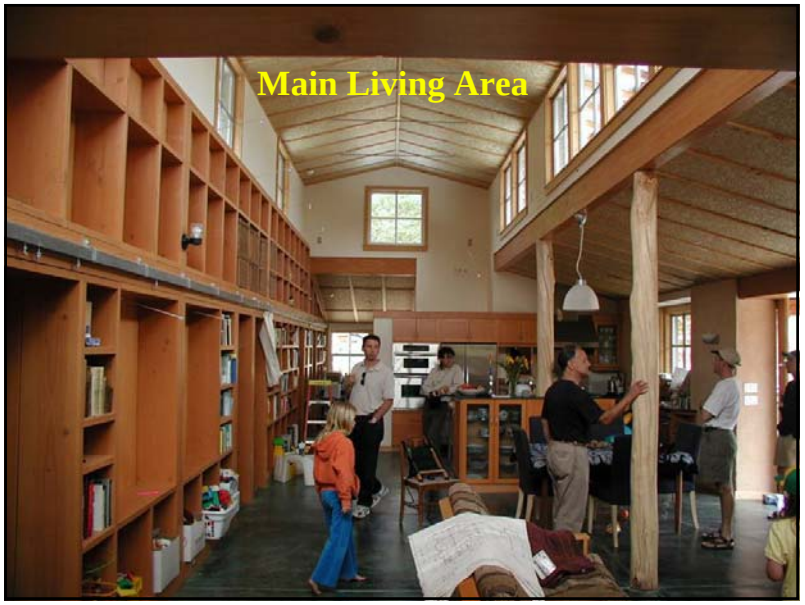
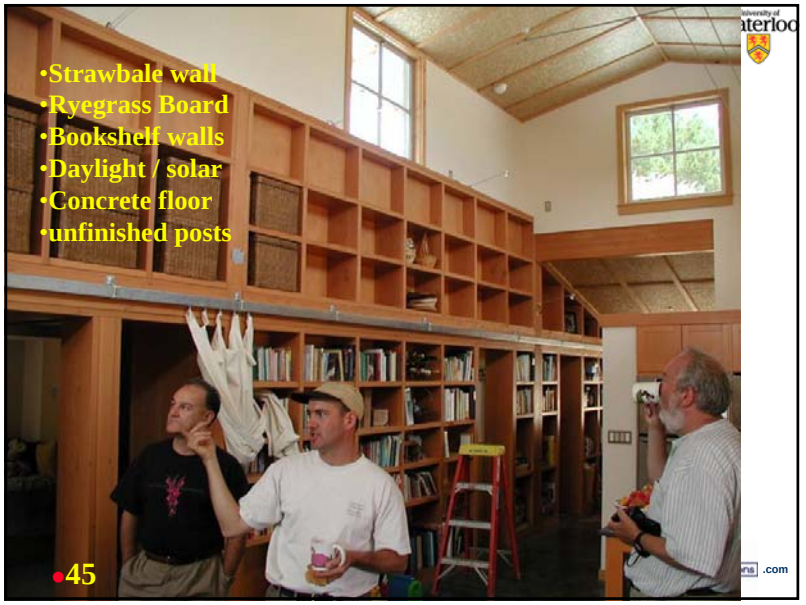
- Locally recycled countertop

- Hardi-plank unpainted roof





Future

- Change will occur slowly and gradually
- Pollution is waste - hence expensive
- Fossil fuels will not run out, but our ability to accept pollution will
- Buildings must be integrated into lifestyle, transportation, ecology
- *Good design, rationally based, can save non-renewable resources, without pollution*

The Future

- Paradigm shift from “least evil” to “as much good”
- Buildings must eventually
  - Produce energy
  - Clean air and water
  - Enhance local ecology
  - Reuse materials, low-damage recycle,

Review - How can we do it?

1. Accept challenge
   - First must acknowledge we have a problem
2. Learn the techniques and strategies
   - Many, many are available
   - May require changes in architecture for easy gains
3. Start in concept stage and work holistically
4. Measure performance
   - If we don't measure, we can't direct and improve

Review-Strategies

- At concept stage
  - How will building be shaped, oriented
- Define real targets and track them
  - E.g. material quantities, energy use, VOC
- Assess major decisions in green terms
  - Curtainwall or punched windows
  - Metal roof or asphalt, carpet or concrete
- Involve consultants early and iteratively
  - Energy analysis? Day lighting studies?

The Beginning