FROM DEVICE TO SYSTEM EFFICIENCY:
Examples from Buildings

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Alternative Population and GDP/P Scenarios

- Population (billions)
- GNP/capita

Years:
- 2000
- 2025
- 2050
- 2075
- 2100

Population (billions):
- 2000
- 3000
- 4000
- 5000
- 6000
- 7000
- 8000
- 9000
- 10000
- 11000
- 12000

GNP/capita (USD):
- 0
- 5000
- 10000
- 15000
- 20000
- 25000
- 30000
- 35000
- 40000

(a)
Medium Population, 1.6% per year growth of GDP per capita, 450 ppmv peak

[Graph showing the relationship between the rate of energy intensity decline and required carbon-free power. The x-axis represents the rate of energy intensity decline (%/yr) ranging from 0.0 to 3.0, while the y-axis represents required carbon-free power (TW) ranging from 0 to 100. The graph includes lines for 2025, 2050, 2075, and 2100, indicating the required carbon-free power for each year under the given population and GDP growth assumptions.]
Low Population, Declining Rate of Growth in GDP per capita, 450 ppmv peak
C-Free Power (TW) required to stabilize at 450 ppmv CO2 for various rates of reduction in energy intensity, medium population and high GDP/P growth.
Factor by which energy intensity decreases (relative to 2000) for various annual rates of decrease starting in 2000.
Energy and the New Reality: Facing up to Climatic Change

• Island Press (Washington), Spring 2005
• 160,000 words
• 225 figures+photos
• 130 tables
• 13 mathematical boxes
A Primer on Energy-Efficient Building Design and Retrofits

- Proposal to Island Press, Summer 2004 release
- 110,000 words
- 105 figures
- 60 Tables
- 15 mathematical boxes
Electricity Use in OECD Countries

- Industry: 36%
- Residential: 26%
- Commercial: 23%
- Power Plant: 6%
- Agriculture: 1%
- Transport: 1%
- Distribution: 7%
- Industry: 36%
Natural Gas

- Residential: 26%
- Industry: 29%
- Commercial: 12%
- Electricity Generation: 21%
- District Heating: 10%
- Other: 2%
Primary Energy

Industry: 32%
Transport: 27%
Residential: 21%
Commercial: 14%
Agriculture: 2%
Non-energy: 3%
Other: 1%

Residential Energy Use, USA

- Space Heating: 35%
- Space Cooling: 8%
- Water Heating: 14%
- Refrigerators/Freezers: 9%
- Lighting: 6%
- Cooking: 3%
- Clothes Dryers: 3%
- TVs: 4%
- Furnace Fans: 2%
- Miscellaneous: 16%
- Furnace Fans: 2%
- TVs: 4%
- Clothes Dryers: 3%
- Cooking: 3%
- Lighting: 6%
- Refrigerators/Freezers: 9%
- Water Heating: 14%
- Miscellaneous: 16%
Commercial Sector Energy Use, USA

- Lighting: 25%
- Miscellaneous: 32%
- Space heating: 13%
- Space cooling: 7%
- Water heating: 6%
- Office equipment: 9%
- Refrigeration: 4%
- Ventilation: 4%
Commercial Sector Electricity Use, Toronto

- Lighting: 47%
- Ventilation: 20%
- Heating: 11%
- Cooling: 7%
- Hot Water: 3%
- Other: 4%
- Plug Load: 8%
Electricity Use, 16-story New York Office Building

- Lighting: 41%
- Fans: 18%
- Cooling: 12%
- Cooling tower: 2%
- Elevator: 4%
- Hot Water: 1%
- Pumps: 3%
- Office Equipment: 18%
- Heating: 1%
Electricity Use, Generic Hong Kong Office Building

- Lighting: 29%
- Chillers: 41%
- HVAC Auxiliaries: 13%
- Office Equipment: 16%
- Heating: 1%
Envelope Heat Loss

- Single-Glazed (R1, $U=5.7 \text{ W m}^{-2} \text{ K}^{-1}$)
- Double-Glazed (R2, $U=2.8 \text{ W m}^{-2} \text{ K}^{-1}$)
- Double-Glazed, Argon-filled, low-e (R4, $U=1.4 \text{ W m}^{-2} \text{ K}^{-1}$)
- Triple-Glazed, Argon-filled, low-e (R5.7, $U=1.0 \text{ W m}^{-2} \text{ K}^{-1}$)
- OBD, Walls (R12, $U=0.47 \text{ W m}^{-2} \text{ K}^{-1}$)
- NBC, Walls (R20, $U=0.28 \text{ W m}^{-2} \text{ K}^{-1}$)
- NBC, Roof (R32, $U=0.18 \text{ W m}^{-2} \text{ K}^{-1}$)
- Advanced House: Walls (R40), Roof (R60)
Effective R-values with Dynamic Insulation

![Graph showing the relationship between R-value and thickness of insulation for different air velocities (V=0.5 m/hr, V=1.0 m/hr, V=1.5 m/hr). The graph includes a line labeled "Actual." ]
Temperatures in Advanced House

- Roof: -10 °C
- Concrete floors: 16.5 °C
- Living spaces: 20 °C
- Heat Pump: 22 °C
- Temperatures in the airstream
- Low temperature floor heating
- Taps: 60 °C
- Individual hot water tanks: 40 °C
- Main preheat tank: 45 °C
- DHW: 45 °C
Solar-Air Collectors

System type 1

System type 2

System type 3

System type 4

System type 5

System type 6
Cooling loads in a Los Angeles Office Building

- Lighting: 28%
- Fans: 13%
- Windows: 21%
- Walls: 3%
- Fresh Air: 10%
- Roof: 8%
- Office Equipment: 5%
- People: 12%
Cooling Loads, Generic Hong Kong Office Building

- Fresh Air: 20%
- Lighting: 18%
- Fans: 10%
- People: 27%
- Office Equipment: 13%
- Windows: 8%
- Walls: 4%
- Roof: 0%
Air-Flow Windows

- **Outdoor-Outdoor**
  - summer cooling

- **Outdoor-Indoor**
  - winter heating

- **Window, Wall, Perforated Wall**

- **Indoor-Indoor**
  - winter heating

- **Window**

- **Indoor-Outdoor**
  - summer ventilation
Passive Ventilation
Pump or Fan Energy Use

%Peak Flow

%Peak Power

- Fans
- Pumps
- Throttle Valve
- Inlet Vane
- Outlet Damper
- VSDs
- Cubic Law
Solar-Powered Desiccant Dehumidification with Displacement Ventilation and Chilled-Ceiling Cooling
Light Shelves

Increased uniformity of daylight level
Shading from high summer sun

Fixed Light Shelf

Adjustable Light Shelf
Light Pipes
Light-guiding Shades
Laser-cut Panels

Venetian Blind

Deflected light 80%

LCP
Electrochromatic Windows

![Graph showing the transmission of light through electrochromic windows in two states: Fully Bleached State and Coloured State. The x-axis represents wavelength (μm), and the y-axis represents transmission (%).]
Heat Pump Performance

(a) $n_c=0.65$

Condenser Temperature:
- 30°C
- 50°C
- 70°C
- 90°C

(b) $n_c=0.65$

Condenser Temperature:
- -10°C
- -5°C
- 0°C
- 5°C
- 10°C

Evaporator Temperature (°C)

Heating COP

Cooling COP
European Office Retrofit Project

Country: DN SW DE NW UK CH CH

Savings: 76 39 77 46 51 52 60

Energy Use (kWh/m²/yr)

- Electric
- Thermal
Apartment Retrofit Example: > 75% Savings in Primary Energy

Table 14.1 Example of energy savings from retrofitting an apartment block in Switzerland. Given is energy use in units of MJ/m² per year. Source: Humm (2000).

<table>
<thead>
<tr>
<th></th>
<th>Prior to retrofitting</th>
<th>After retrofitting</th>
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</thead>
<tbody>
<tr>
<td>Conductive heat loss</td>
<td>473</td>
<td>216</td>
</tr>
<tr>
<td>Ventilation heat lossa</td>
<td>119</td>
<td>76b</td>
</tr>
<tr>
<td>Internal heat gain</td>
<td>114</td>
<td>108</td>
</tr>
<tr>
<td>Net heating requirement</td>
<td>478</td>
<td>184</td>
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<tr>
<td>Hot water requirement</td>
<td>108</td>
<td>100</td>
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<tr>
<td><strong>Energy for space and hot water heating</strong></td>
<td><strong>586</strong></td>
<td><strong>284</strong></td>
</tr>
<tr>
<td>Heating efficiency</td>
<td>0.85</td>
<td>3.2</td>
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<tr>
<td>Electricity demand</td>
<td></td>
<td></td>
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<tr>
<td>Heat pump</td>
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<td>89</td>
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<tr>
<td>Mechanical air circulation</td>
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<td>6</td>
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<tr>
<td>Photovoltaic system (gain)</td>
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<td>8</td>
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<tr>
<td>Secondary energy demand</td>
<td>690</td>
<td>87</td>
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<tr>
<td><strong>Primary energy demand</strong></td>
<td><strong>863</strong></td>
<td><strong>193</strong></td>
</tr>
</tbody>
</table>
Design Process

Level 1:

Level 2:

Level 3:

Summary:

- Much of the energy needs in buildings (lighting, ventilation, cooling, heating) can be achieved passively using solar energy and/or radiant techniques.
- Buildings thus become the collectors and transformers of renewable energy.
- Much of the remaining energy needs can be greatly reduced by putting together mechanical systems in a more intelligent fashion.
- Device efficiencies tell us next to nothing about system efficiencies.
- Improved design process alone can achieve savings of 50% in new buildings compared to common practice.
- An integrated process combined with best (but currently available technologies) gives demonstrated savings of 75-90% in new buildings.
- Retrofits that include solar features can often achieve savings of 40-75% in existing buildings.