Innovations in Green Building Design

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Yale University
4+ million buildings sorted by:

- size (floor area, number of floors)
- occupancy (number of employees and time)
- function
- location
- age
- construction type
- energy sources
- energy end-use
- energy efficient features
buildings reporting energy efficient features used more energy per capita than buildings not reporting these features.

Findings were consistent for every building type and size, and for every energy efficient feature from economizer cycles to occupancy sensors.

Findings were also consistent with the 2007, 2005, 2003 and 1999 surveys.
REVIEW OF DOE RESEARCH BY THE NATIONAL RESEARCH COUNCIL

$2$ billion spent on building energy efficiency research since inception of DOE auditors could only identify three programs in which energy savings could be proven:

- advanced refrigerators
- electronic ballasts
- low-e glass
Buildings are becoming larger in square meters per capita and per function

Ambient environmental systems are volumetric
-- increase in building dimensions increases HVAC by the cube

Lighting systems and materials are planar
-- increase in building dimensions increases these by the square
-- if ceiling height is increased, then lighting increases by the cube
Electricity loads in buildings have increased.

- More electrical equipment
  - computers and digital equipment
  - appliances
- More electrical lighting
  - light levels are higher, more area is lit
- More use of space cooling
  - air conditioning increasing at double digit rates in Europe
Primary energy for cooling is increasing at a faster rate than heating.

- Most building strategies are intended to reduce heating.
- An increase in electrical equipment increases cooling requirements.
- Urban Heat Island multiplies local heat load.
- Distributing energy generation to buildings increases local heat load.
WHY HAVE WE BEEN ABLE TO TACKLE THE MAJOR PROBLEMS?
1. ASSUMPTIONS

Buildings are units of property, they are not energy systems
Fig. 127.—Nonuniform or “roller-coaster” lighting result when units are spaced too far apart for their mounting height.
The major energy consuming systems are designed for the building, not its occupants.
A well-designed house should have an HVAC system properly sized to its demands. Equipment sizing ensures a comfortable environment and provides opportunities to recapture some of the expense of constructing an efficient building envelope. Rules of thumb for equipment sizing do not work in modern homes and should not be used.

The Air Conditioning Contractors of America (ACCA) has published simple but effective methods for determining loads and sizing ductwork and heating and cooling equipment. *Manual J* tells you how to calculate heating and cooling loads. *Manual D* tells you...
3. **TOOLS**

Energy analysis is based on conservative volumes which treats the building as a bounded energy system served by homogeneous environmental systems.
HOW DO WE MOVE FORWARD?
Dis-integrate systems at the individual building

Integrate systems as the appropriate phenomenological scales
national/regional

SOURCE

SUPRA-BUILDING

CONSUMER

SUB-BUILDING

component
Utility Market Dynamics

- dynamic load management
- consumption analytics
  - metrics
    - standards, codes
    - benchmarking
  - performance
  - priorities
    - funding
    - research
    - policy
  - equipment efficiency
  - system design
  - building design

- performance
- benchmarking
- standards, codes
Dynamic Properties

Load Analysis & Disaggregation

Chart showing electricity use (kWh) from 2 October to 10 October.
Electricity use breakdown Rosenkranz Hall
From Tue Sep 6 00:00:00 2011 to Tue Sep 13 00:00:00 2011
MULTI-PART METRIC

1. Occupant Determined Loads (per capita)
   a) Occupant behavior
   b) Occupant determined equipment (computers, plug loads, …)

2. Technology Determined Loads (per item/system energy conversion)
   a) Individual equipment efficiency
   b) Operational efficiency of systems (HVAC, lighting, hot water)

3. Building Determined Loads (per area normalized per capita)
   a) Lighting design
   b) Interior climate design

4. Envelope Determined Loads (surface area normalized by climatic conditions)
   a) Climatic source and sink
   b) Daylight utilization
## RESEARCH AREAS

<table>
<thead>
<tr>
<th>Exergy matching</th>
<th>Sink/source management</th>
<th>Building environments</th>
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<tbody>
<tr>
<td>waste heat recovery</td>
<td>surroundings—load shedding</td>
<td>mean radiant temperature thermal environment</td>
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| water heating | discrete—direct control of heat transfer | field of view lighting—*discrete lighting*
| *electrical infrastructure* | thermal inertia | functional zoning |

## POSSIBLE COLLABORATORS

<table>
<thead>
<tr>
<th>Mechanical engineering</th>
<th>Electrical engineering</th>
<th>Mechanical engineering</th>
<th>Physical geography</th>
<th>Neurobiology</th>
<th>Visual Psychology</th>
<th>MIT Media Lab</th>
<th>Public Health</th>
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- Climate model for building design—in progress
- Advanced technologies and materials in lighting—in progress
Figure 4.31: a. Typical Urban Canyon and b. Idealized Urban Canyon

**a. H/W = 1.0**

**b. H/W = 0.5**
Radiative Surface Material Properties

- **Incoming Solar Radiation**
- **Absorptance (α)**
- **Reflectance (ρ)**
- **Emittance (ε)**

<table>
<thead>
<tr>
<th>High</th>
<th>Low</th>
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<tbody>
<tr>
<td><strong>EMITTANCE</strong></td>
<td><strong>0.10</strong></td>
</tr>
<tr>
<td><strong>REFLECTANCE</strong></td>
<td><strong>0.90</strong></td>
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<tr>
<td><strong>Outgoing Radiative Heat Flux</strong></td>
<td><strong>LOW</strong></td>
</tr>
<tr>
<td><strong>Surface Temperature Difference</strong></td>
<td><strong>HIGH</strong></td>
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Naree Phinyawatana Doctoral Research
Adriana Lira Doctoral and Post-doctoral Research
textured wall
reflectance: R=0.1, G=0.3, B=0.6
material: insulator

- reflected light rich in blues (product of diffuse reflection)
- incident light rich in blues
- focal point

reflected light rich in blues but enhanced in reds (product of specular reflection)
specularity is applied to the part of the texture that redirects the reflected rays towards the focal point (the other part of the texture always reflects diffusely)

reflected light rich in blues (product of diffuse reflection)

material: metal

reflected light rich in blues (product of diffuse reflection)

reflected light rich in blues; reds are not enhanced (product of specular reflection)
specularity is applied to the part of the texture that redirects the reflected rays towards the focal point (the other part of the texture always reflects diffusely)
Emirates Hotel Tower, Dubai

Nasser Abulhassan Doctoral Research
wall panel, option 1  
wall panel, option 2  
wall panel, option 3
physical phenomena
heat transfer, mass transfer

inducement of phenomenological behaviors
buoyancy, stratification, (… )-phoresis

human physiology
thermo-regulation, neuro-biology

human perception
zero-crossing, somatic sensations