Building Energy Efficiency Research

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• Affiliated Faculty, Woods Institute for the Environment
• Affiliated Faculty, Emmett Interdisciplinary Program in Environment and Resources (E-IPER)
• Advisory Professor, School of Economics and Management, Tongji University, Shanghai
• Visiting Professor, School of the Built Environment, University of Salford, UK
How to best balance demand and supply of energy?
Why are we only measuring safety, cost, and schedule performance during construction and then expect a high-value, energy-efficient building?

$, energy, CO₂, human costs, etc.

1. Business Operations Cost
2. Facility Maintenance Cost
3. Building Operations Cost
4. Value from Facility
5. Design-Construction Costs
Can we call this engineering?

- Predicted energy consumption does not match actual consumption (findings from buildings where owners really cared about energy performance)
Three-pronged research approach

• Top-down
  – Characterizing buildings according to their energy use

• Bottom-up
  – Understanding building use, operation, and energy consumption to enable
    • Better (re)design, construction, renovation, and operation
    • Smart, automated adjustments in energy use

• Learning from the best
  – Case studies with progressive building owners and operators
Main Areas of Research

• Metrics
• Design methods
• Comparing predicted vs. actual performance
• Characterizing energy consumption

• Differences in 2011 compared to 10 years ago
  – Much more awareness
  – Much more computing power
  – Much more data

• What’s still lacking
  – Engineering methods for reliable predictions
  – Project management methods that deliver energy efficient buildings
  – Clearly established cost and value metrics
  – Quickly institutionalizing innovations from demonstration projects
On a m2 basis the “blue” building performs poorly, i.e., it uses about 50% more energy than the green building.

Which building operator should get a Christmas bonus?
Which building operator gets a Christmas bonus?

On a transaction per m2 basis the “green” building performs poorly, i.e., it uses about 80% more energy than the green building.
Where to intervene to reduce energy consumption? (with Mauricio Toledo)

Stanford SH  260 buildings  
12,000 students  
4.5 million sqf

How hard is to achieve further savings?
### 4D Benchmark conceptualization

<table>
<thead>
<tr>
<th>Utility Type</th>
<th>TEMPORAL AGGREGATION</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MO</td>
</tr>
<tr>
<td>ABS</td>
<td>MO_ABS</td>
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<tr>
<td></td>
<td>Monthly consumption</td>
</tr>
<tr>
<td>STU</td>
<td>MO_STU</td>
</tr>
<tr>
<td></td>
<td>Consumption per student</td>
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<tr>
<td>SQF</td>
<td>MO_SQF</td>
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<tr>
<td></td>
<td>Consumption per square foot</td>
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<tr>
<td>HIG</td>
<td>MO_HIG</td>
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<tr>
<td></td>
<td>Highlighting of bldgs exceeding operational req.</td>
</tr>
</tbody>
</table>

### Consumption Type

- SQF ➔
- STU ➔
- ABS ➔
Industry Case Studies (with Benjamin Welle)
Next Steps....

Application of Artificial Intelligence (Knowledge-Based Systems) and Distributed Computing to Daylighting MDO
Comparing predicted and actual performance

Space level
- Room temperature predicted

System level
- Cooling Load predicted

Component level
- Fan speed predicted

relate
aggregate
compare

Value
- Room temperature observed

Cost
- Cooling Load observed

Intervention
- Fan speed observed

Data from Global Ecology Building

Predicted

Observed
Energy performance of Y2E2

Source: Arup’s Calibrated Y2E2 model report

- Actual operation is close to design baseline model (code)
- Actual operation is far away from original design goal
- Calibrated models show about 50% improvement compared to calibrated baseline
Energy simulation input

Building geometry

HVAC system

Weather

Simulation control parameters

Internal loads

15,000 input objects

Results
Valve position and flow rate correlate - System works mostly during occupied hours

Hot water loop temperature ~ 150 °F VS. 180 °F
Energy Performance Comparison Methodology (work by Tobias Maile)

Step 1: Preparation
- Create or update energy model
- Establish component hierarchy
- Set up data collection

Step 2: Matching
- Update input
- Simulated data
- Simulation approximations
- Measured data
- Measurement assumptions
- Create data pairs via hierarchy

Step 3: Evaluation
- Detect differences
- Identify performance problems
- Estimate impact
- Improve building operation
- Feedback to HVAC design

Legend
- Performance data
- Tasks
- Approximations
- Assumptions
- Feedback

Actual building

Key Contributions
Santa Clara County Jail – Energy Efficiency Retrofit (in collaboration with LBNL)

1. Geometry model is complete
2. HVAC model in complete
3. Currently: testing and debugging of EnergyPlus model
Night Purge Simulation for Y2E2
(with Erin Hult and Gianluca Iaccarino)
Characterizing energy consumption

Daily Energy Demand in Kw

Retail Store

High School
Case: Adobe Systems in San Jose
(with Robert Graebert, CEE, Randy Knox, Adobe)

- 3 towers with 915,000 sq.ft. office space
- 16-18 floors high, 7-15 years old
- 2300 employees
ENERGY STAR Score Trending Up for All Towers

Data center calculation different
All Towers LEED EB Platinum Certified

Highest LEED EB Score ever

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<thead>
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<th>Year</th>
<th>Almaden</th>
<th>East</th>
<th>West</th>
<th>Platinum 2006</th>
<th>Maximum 2006</th>
<th>Maximum 2009</th>
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</table>
50% of Projects with < 2 Year Payback

Mean for Payback: 0.5 years (Meter), 4.6 years (Simple Payback), 4.7 years (Simulation)
Over $1,000,000 Annual Savings from Projects with < 1 Year Payback

- < 0.1
- < 1
- < 2
- < 10
- >= 10
- n/a

Annual Savings vs. Payback Years

<table>
<thead>
<tr>
<th>Annual Savings</th>
<th>Payback Years</th>
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</thead>
<tbody>
<tr>
<td>$900,000</td>
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<tr>
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<td>&lt; 1</td>
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<td>&lt; 2</td>
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<tr>
<td>$500,000</td>
<td>&gt;= 10</td>
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<tr>
<td>$400,000</td>
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</table>

Legend:
- Enabling Projects
- Simulation
- Simple Payback Calculation
- Meter
Source of savings (how investments were selected and justified)

- Simple Payback Calculation, $1,529,315
- Meter, $534,370
- Simulation, $307,954
- Enabling Projects, $220,929
Drivers For Projects:

- **Operations Management**: projects proposed by the operations team independently of available incentives.

- **Third Party Incentives**: projects pursued to collect monetary incentives. The reduced cost allowed for larger projects.

- **New Technologies**: projects driven by new technologies. Positive side effect is recognition as a leader in adopting new technologies.

- **Corporate**: projects implemented due to the corporate culture established by management.

- **LEED EB driven**: projects with the primary goal to influence the LEED EB score.

- **Regulation**: none of the Adobe Systems projects were initiated due to regulatory requirements.