Energy Efficient Buildings
A Systems Approach
R&D Directions

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Key Points

• Energy efficient buildings. **Achieving >50% over current standards (ASHRAE 90.1) is possible**; proof points occur for all sizes and climates; buildings designed using climate responsive design principles.

• Market conditions – currently **driven** by labeling and **increasingly by regulatory pressures** (carbon cost not sufficient to drive market: findings through UTC led WBCSD study).

• What is hard? **Delivery process handoffs are a problem** and are where there is a loss of potential for energy savings in design, construction and operation.

• What are R&D areas?
  • Address Productivity – **need design tools** (configuration exploration, specification of equipment and controls, automated implementation) – for automation on all parts of delivery chain.
  • Address Risk. Need calibrated models (experimental facilities) **and ability to calculate, track and manipulate uncertainty (DFSS).**
  • Address Operations – need to understand sensing requirements, **failure modes** and FDIA.
Outline

Energy Efficient Buildings

Market Conditions

What is hard?

R&D
Office Building Primary Energy Intensities

- **US Average**
- **Japan Average**
- **Germany Average**
- **WestEnd Duo**
- **Debitel**
- **Deutsche Post**
- **DS-Plan**

**Primary Energy Intensity (kWh/m²):**

- **Internal Loads**
- **Internal Loads (est)**
- **HVAC + Lighting** (breakout not available)
- **Lighting**
- **Ventilation**
- **Space Cooling**
- **Space Heating**

United Technologies Research Center
HIGHLY EFFICIENT BUILDINGS EXIST

Energy Retrofit
10-30% Reduction

Very Low Energy
>50% Reduction

Cityfront Sheraton
Chicago IL
1.2M ft², 300 kWhr/m²
5753 HDD, 3391 CDD
VS chiller, VFD fans, VFD pumps
Condensing boilers & DHW

Tulane Lavin Bernie
New Orleans LA
150K ft², 150 kWhr/m²
1513 HDD, 6910 CDD
Porous Radiant Ceiling, Humidity Control
Zoning, Efficient Lighting, Shading

Bonn Germany
1M ft², 75 kWhr/m²
6331 HDD, 1820 CDD
No fans or Ducts
Slab cooling
Façade preheat
Night cool

• Different types of equipment for space conditioning & ventilation
• Increasing design integration of subsystems & control

LEED Design
20-50% Reduction
Outline

Energy Efficient Buildings

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What is hard?

R&D
UTC SUSTAINABILITY ROADMAP

**Operations**
- UTC establishes first set of EH&S goals (1991)
- Otis opens TEDA facility, the world’s first green elevator factory, in China (2007)
- Pratt & Whitney breaks ground on an engine overhaul facility, targeted to meet LEED platinum standards, in Shanghai (2007)
- UTC launches 2010 EH&S goals, which include absolute metrics and a new goal on greenhouse gas emissions (2007)

**Products**
- Carrier introduces Evergreen® chiller (1996)
- Otis launches the Gen2™ elevator system (2000)
- UTC launches the PureComfort® cooling, heating and power system (2003)
- Pratt & Whitney launches EcoPower® engine wash (2004)
- UTC launches the PureCycle® geothermal power system (2007)
- UTC Power introduces 400 kW PureCell® system (2008)
- Pratt & Whitney flight tests PurePower™ PW1000G engine with Geared Turbofan technology (2008)

**Advocacy**
- U.S. Green Building Council (1993)
- Pew Center on Global Climate Change (1998)
- Dow Jones Sustainability Index (1999-2009)
- Global 100 Most Sustainable Corporations in the World. (2005-2009)

**Energy use**
(1997-2008)

**Water use**
(1997-2008)
UTC Sustainable Product Launches

Otis Elevator

UTC Power

2007 recipient

Purecycle® Geothermal Power System

UTC Power

Combined Heat Power (CHP) system

Pratt & Whitney

Geared Turbofan™ Engine
WBCSD EEB PROJECT

A world where buildings consume zero net energy

Energy efficiency first
From the business voice
Launch and lead sector transformation
Contribution to “sustainable” buildings
Communicate openly with markets
ECONOMIC ASSESSMENT – US ONLY

*reflects scale up of buildings contribution to IEA Blue Map scenario, 2050
RECOMMENDATIONS

Create and enforce building energy efficiency codes and labeling standards
   Extend current codes and tighten over time
   Display energy performance labels
   Conduct energy inspections and audits

Incentivize energy-efficient investments
   Establish tax incentives, subsidies and creative financial models to lower first-cost hurdles

Encourage integrated design approaches and innovations
   Improve contractual terms to promote integrated design teams
   Incentivize integrated team formation

Fund energy savings technology development programs
   Accelerate rates of efficiency improvement for energy technologies
   Improve building control systems to fully exploit energy saving opportunities

Develop workforce capacity for energy saving
   Create and prioritize training and vocational programs
   Develop “system integrator” profession

Mobilize for an energy-aware culture
   Promote behavior change and improve understanding across the sector
   Businesses and governments lead by acting on their building portfolios
Outline

Energy Efficient Buildings

Market Conditions

What is hard?

R&D
Combined Cooling, Heating & Power

PureComfort™ Integrated Energy Solutions

Traditional Central Power Plant

- Coal Oil Natural gas
- Waste heat
- 67%
- Electricity

Combined Cooling, Heating and Power (CCHP)

- Natural gas
- 100%
- Waste heat
- 20%
- 80%
- Electricity Hot water Chilled water
Actual energy performance lower than predictions

**Failure Modes Arising from Detrimental Sub-system Interactions**

- Changes made to envelope to improve structural integrity diminished integrity of thermal envelope
- Adverse system effects due to coupling of modified sub-systems:
  - changes in orientation and increased glass on façade affects solar heat gain
  - indoor spaces relocated relative to cooling plant affects distribution system energy
- Lack of visibility of equipment status/operation, large uncertainty in loads leads to excess energy use

ENERGY IMPACT IN DESIGN-BUILD PROCESS

Concept & Design
- A & E Firms
- Specialty Engineering Firms
- CAD Software Vendors
- BIM Software Vendors
- Analysis Software Vendors

Build
- Contractors
- Equipment Vendors
- Control System Vendors
- IT Infrastructure Vendors

Operations & Maintenance
- Property Managers & Operations Staff
- Monitoring and Maintenance Companies
- Maintenance Software Vendors

NZEB

Current ASHRAE 90.1

Inadequate concept exploration
“We are slaves to our commissions”

Unapproachable Analysis Tools
“Protractors vs. daylighting simulation”

Design intent costed out
“Value Engineering”

As-built variances from spec
“Can’t do it that way”

Poor operation
“Too complicated, I shut it off”

Maintenance
“Broken economizer”

Unaware 50%

Miss 30%

Loss 20%
Outline

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Market Conditions

What is hard?

R&D
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<thead>
<tr>
<th>Barriers</th>
<th>Enablers</th>
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<tr>
<td>Lack of process and tools for system analysis and design</td>
<td>Computational science, physics-based modeling, methodology, tools and training for Integrated design</td>
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<td>Lack of a demonstration capability for technology maturation</td>
<td>Full scale demonstrations facilities and concentration of talent</td>
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<tr>
<td>Lack of tools for on-going auditing, commissioning &amp; operations</td>
<td>Methodology, tools and training for building operations (e.g. computational/IT/controls advances)</td>
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<tr>
<td>Lack of a long reach and broad scope in technology and business model exploration</td>
<td>Pre-competitive collaboration among industry, national labs and universities</td>
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Basic Science To Enable Energy Savings

**Architecture & Envelope Optimization:** Whole building simulation, uncertainty analysis, and definition of abstraction layers

**Mechanical Systems Specifications & Supervisory Control:** Multi-scale (zone-room) modeling, computation and hybrid system optimization

**Rapid and Robust Implementation:** Network design and data assimilation

**Needs for Basic Science and Measurement for Energy Efficient Buildings**

**Requirements & Architecture Exploration:** BIM and Tool Chains for Integrated Mechanical and Control Design

**Integrated Design:** Decentralized Control Design & Analysis for Robust Operation

**Implementation:** IT enabling continuous commissioning and occupancy and plug load estimation for detailed energy management
DOE Projects: Merced Campus
Technology Maturation and Demonstration at University of California - Merced

Real-time Visualization of Model-based Energy Performance

Integrated Energy Information Systems
Approx. 20% total building energy ↓

Occupancy-based energy management

Integrated Security & HVAC Systems
Approx. 20% HVAC system energy ↓

Model Predictive Control of HVAC systems

Forecasted Disturbances (Weather and Coil Loads) → Matlab Simulink → Optimized Set Points

Integrated Cooling & Thermal Storage
Approx. 20% total building energy ↓