Sustainable and Energy Efficient Urban and Built Infrastructure Development: Opportunities and Challenges in Systems Engineering

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KEY POINTS

- Energy use in buildings matter
  - Efficiency offers the best means to substantial reduction in energy use
  - External drivers defining the market – building energy performance labeling, auditing and reporting

- Highly energy efficient buildings exist
  - 50-70% energy use reduction in buildings is feasible with existing technologies
  - Systems approach to design and operations is key
  - Barriers to market adoption are speed and quality of design and associated costs
  - Systems engineering challenges exist in all phases of building delivery

- System design and delivery methodologies can drive and persist aggressive energy use reduction
  - Integrated design methods and engineering tools
  - Methodologies for extensive validation and verification of system implementations
UNITED TECHNOLOGIES

United Technologies

Otis
Pratt & Whitney
Hamilton Sundstrand
Sikorsky
UTC Fire & Security
Carrier

$52.9B

building systems

aerospace systems

power solutions

Otis
UTC Fire & Security
Carrier
UTC Power
Pratt & Whitney
Sikorsky
Hamilton Sundstrand
The Energy Demand Problem in the Built Infrastructure...
Urbanization and Energy Demand

The future is urban.

Global population (billion)

- In rural areas
- In urban areas

Source: UN

The bulk of the increase in global energy-related CO2 emissions is expected to come from cities, their share rising from 71% in 2006 to 76% in 2030 as a result of urbanization.

In China alone…
1 billion people will live in cities by 2030
40 billion square meters of office space will be built in 5 million buildings. 50,000 of these buildings could be skyscrapers (the equivalent of 10 New York Citys).

In the U.S., half the buildings needed by 2030 do not exist.

Sources: Ryan and Nicholls 2004, USGBC, USDOE 2004
Building Energy Use Matters

IEA Estimates of Emissions Abatement by Source/Sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>2050 BAU</th>
<th>2050 Blue MAP</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generation</td>
<td>--</td>
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<td>18.2</td>
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<tr>
<td>Industry</td>
<td>23.2</td>
<td>5.2</td>
<td>9.1</td>
</tr>
<tr>
<td>Buildings</td>
<td>20.1</td>
<td>3.1</td>
<td>8.2</td>
</tr>
<tr>
<td>Transport</td>
<td>18</td>
<td>5.5</td>
<td>12.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>62</strong></td>
<td><strong>14</strong></td>
<td><strong>48</strong></td>
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</tbody>
</table>

Buildings consume precious resources:
- 39% of total U.S. energy, similar worldwide
- 71% of electricity & 54% of natural gas in U.S.

Building produce 48% of U.S. Carbon emissions and nearly 40% worldwide

75% reduction in Building Sector Energy Use Required

Sources: Ryan and Nicholls 2004, USGBC, USDOE 2004, IEA Energy Technology Perspective 2008
What Will It Take
and
Is It Feasible?
WBCSD: Energy Efficiency in Buildings Project

Four year project motivated by increasing global energy crisis

Must transform the way buildings are designed, constructed and operated

Global market perception study revealed market failures

See [www.wbcsd.org](http://www.wbcsd.org) for more information
Complexity in Building Delivery Practices

**Need:**
- Tools to integrate process & communities
- Tools to integrate building design and operations
- Align incentives

Building Energy Economic Policies

*Economic policies on whole-building energy-intensity are effective*

World Business Council for Sustainable Development
Energy Efficiency in Buildings Project

(Analysis is an example result for single family residences.)
Economic Assessment – US Only

Energy use reductions economically viable

- **Auto Safety Regulations**
  - 2% First Cost Premium

- **Required Building Efficiency Investments**
  - 3% Total Cost Premium
  - 13% First Cost Premium

- **Building Fire Safety Regulations**
  - 5% First Cost Premium

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

*CO2 Emission Reductions*

- Incremental Investment to Achieve Reduction

- **Incremental Investment, $B**
  - $0
  - $25
  - $50
  - $75
  - $100
  - $125
  - $150
  - $175
  - $200

- **< 5 year payback**
- **<10 year payback**
- **> 10 year payback**
Market and Regulatory Landscape
Changing… Necessitating A Systems Approach
Rapidly Evolving Landscape

U.S. Market Attributes
- LEED Performance: Make Energy Use Visible
- Certified buildings must recertify at least once every 5 years to maintain LEED-EB status” (2009)
- LEED-NC requires measured performance (2010)

EU Market Attributes
- Energy Use Monitoring : Make Energy Use Visible
  - EU Buildings Directive (EPBD) 2002
  - Building Energy Performance Requirements in Germany Tightened by 30% (2009)
- EU-wide regulation for energy compliance
  - All New Buildings to be Net-Zero by 2018 (EU legislation)

China Market Attributes
- Energy Conservation Regulations 2007
- Poor adherence driving reporting requirements
Whole Building Energy Performance Ratings
Integrated Design Process Key to Improving Whole Building Energy Performance

Impact from earlier use of Integrated Design Process

Linear Design Process

Integrative Design Process

All Hands Meetings
Integrated Design for Energy Efficient Buildings

Reduce energy demand via integrated design of building envelope and systems
Use of integrated design approach and system modeling and simulation
25% primary energy footprint reduction at less than 7% incremental cost
Payback 4.2 years total / 2.5 years new items
Sustainable and Energy Efficient Facilities in UTC

LEED Platinum
44% energy savings

P&W Shanghai Engine Center

LEED Gold
25% energy savings

Otis TEDA facility

LEED-Cl Silver

P&W G Bldg. Renovation

UTC LEED-EB factories
(11 factories worldwide achieving this milestone)

Carrier’s Charlotte (-17%),
Carrier’s Huntington (-31%),

... and 24 additional are registered (2009)
But Integrated Design is Insufficient and the Entire Delivery Process Must Undergo a Transformation...
Energy Efficient Buildings: Reality

Large Variability in Performance Predictions

Performance simulations conducted for peak conditions

As-built specifications differ from design intent, resulting in compromise of energy performance due to detrimental sub-system interactions

Uncertainty in operating environment and loads

Source: M. Frankel (ACEEE, 2008)

Challenges in Delivering Energy Efficiency

- Concept & Design
  - A & E Firms
- Build
  - Contractors
- Operations & Maintenance
  - Property Managers & Operations Staff

1. Low Energy
   - Savings Potential: 100kWh/m²/y
   - Unaware
      - Design Not Scalable
2. Current State
   - Savings Potential: 300kWh/m²/y
   - Miss
      - Systems Not Robust
3. Benefits Do Not Persist

Emergence and Persistence of Energy Savings (normalized)
So, are there proof points for very low energy consumption buildings? What do we know about them?
Highly Energy Efficient Buildings Exist

**Energy Retrofit**
10-30% Reduction

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

**Very Low Energy**
>50% Reduction

Deutsche Post
Bonn Germany
1M ft², 75 kW hr/m²
6331 HDD, 1820 CDD
No fans or ducts, slab cooling, façade preheat, night cool

**LEED Design**
20-50% Reduction

Tulane Lavin Bernie
New Orleans LA
150K ft², 150 kW hr/m²
1513 HDD, 6910 CDD
Porous radiant ceiling, humidity control, zoning, efficient lighting, shading
Case Studies in Germany

- Visits to building sites and design companies in Germany and Switzerland conducted July (2009) to understand the design and delivery of low energy buildings
- The buildings typically targeted energy intensity of 100 kWh/m²/year (excludes plug loads); less than half of typical German energy usage and a third of those in U.S.
- Most buildings have sustained, measured low energy performance

<table>
<thead>
<tr>
<th>KfW Westarcade</th>
<th>KfW Ostarcade</th>
<th>DFS</th>
<th>Westend Duo</th>
<th>Debitel</th>
<th>Theater Haus</th>
<th>Mercedes</th>
<th>DS-Plan</th>
<th>Euweg</th>
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<td>Zurich, Switzerland</td>
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Commercial Office Building Energy Use

- 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
Robust, Low Energy Performance Through “Climate Adaptive” Design

• Standard equipment
• No shading
• Highly sealed envelope

“Climate adaptive design”

• Dynamic Thermal Storage
• Active shading
• Natural ventilation

“One size fits all”
Monitoring and Tuning Necessary to Achieve Energy Performance Targets

KfW East Arcade Building Case Study

- 45%

Tuning the controls for night purge (pre-cooling thermal mass)
Low Energy Building Delivery Process

Concept & Design
- A & E Firms
- Climate Engineering Firm

Build
- Contractors

Operations & Maintenance
- Property Managers & Operations Staff
- Performance Assurance Firm

Specialists
- Climate Engineering Firm
- Performance Assurance Firm

Design principles to optimize thermal interactions

Detailed Control Specification

Energy Interaction Design & Analysis

Quality Assured Installation

Monitoring to Ensure Performance

Post-occupancy performance tuning

Sources: Transsolar, DS-Plan, Fraunhofer Institute for Solar Engr.
Challenges in Delivering Energy Efficiency In The Built Infrastructure

• Integrated design methods, engineering software and tools
  Tools for architectural tradeoffs and selection with modeling and simulation tools that can handle heterogeneity, uncertainty and multi-scale dynamics
  Tools for rigorous requirements capture and tracking
  Uncertainty quantification and risk assessment tools
  Methodologies and tools for automated system failure analysis to establish tolerances critical to achieving and sustaining target energy performance
  Capability to update design models with commissioning and operational data (dynamic Building Information Models)

• Methodologies for validation and verification of system implementations
  Model-based validation and verification of building systems and controls
  Tools to assist in auditing and regulation of building energy performance
Sustainable Development at District – City Scale

- Potential for larger impact and benefit
- More complex decision making
- Larger scope of infrastructure and system alternatives
Thank You...