Buildings Systems
Grand Challenges to Increase Energy Efficiency

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Vision

We need to do more transformational research at DOE ... including **computer design tools** for commercial and residential buildings that enable **reductions in energy consumption of up to 80 percent with investments that will pay for themselves in less than 10 years**

Dr. Steven Chu, House Science Committee Testimony, March 17, 2009

We will nurture a **system integration approach to building design, aided by computer tools with embedded energy analysis**. It was the system integration of the automobile engine, transmission, brakes and battery that enabled Toyota to create the Prius. With computer control of ignition timing and fuel mix, today’s automobile engines operate at 20 percent higher efficiency. With computer monitoring and continuous, real-time control of HVAC systems, lighting, and shading, far more spectacular efficiencies can be realized in buildings. There is a growing realization that we should be able to build **buildings that will decrease energy use by 80 percent with investments that will pay for themselves in less than 15 years**. Buildings consume 40 percent of the energy in the U.S., so that energy efficient buildings can decrease our carbon emissions by one third.

Secretary Chu, Caltech Commencement, June 12, 2009
KEY POINTS

- Buildings matter for energy use; highly energy efficient buildings exist;
- Valid economic returns exist but external forces – labeling, auditing and reporting – will be needed to drive transition
- A systems approach is necessary to obtain deep – and persistent - energy benefits
- Systems design and delivery methodologies are driving aggressive energy use reduction in aerospace applications
  1. Rigorous requirements capture & analysis
  2. Architectural tradeoffs and selection using extensive computational modeling
  3. Extensive validation & verification

  **Building science and technology lags this demonstrated performance**

- A national research agenda for buildings must focus on
  1. Building systems science
  2. Novel building components driven by system level bottlenecks
**EEB PHASE 2 – MODEL ANALYSIS**

**US economic assessment**

- **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

![Graph showing CO2 Emission Reductions and Incremental Investment to Achieve Reduction](graph.png)

- **CO2 Emission Reductions**
- **Incremental Investment to Achieve Reduction**

*Reflects scale-up of buildings contribution to IEA Blue Map scenario, 2050*
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
HIGHLY 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

**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

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

**Very Low Energy**
>50% Reduction

Different types of equipment for space conditioning and ventilation
Increasing design integration of subsystems and control
High Performance Buildings: Reality

Cambria Office Building
**Design Intent:** 66% (ASHRAE 90.1); Measured 44%

KfW Building, Frankfurt, GERMANY
**Design Intent:** 100kWH/m2/yr

Actual energy performance substantially lower than design predictions due to detrimental sub-system interactions

“As designed” energy performance accomplished after substantial system tuning

Building Subsystem Interactions: “One Size fits All” Implies Inefficiency
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Thermodynamics + Information Technology (computation & communication) + Algorithms

Lots of Thermodynamics... Lots of Connectivity...

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**Diagram Notes:**
- Building Operating Conditions
- Cost Utilities
- Weather
- Safe & Secure
- Environmental Structure
- Information Management
- Heating, Ventilation, Air Conditioning
- Lighting, Lights & Fixtures
- Envelope, Building Insulation
- Building Operating Conditions
- Safety & Security
- Information Technology (computation & communication)
- Algorithms
- Thermodynamics
- Lots of Connectivity...

**Energy Consumption Diagram:**
- Energy consumption for a typical office vs. the Deutsche Post building.
- Comparison of energy consumption for different categories: Conditioning, Ventilation, Lighting, Heating.
- Data from Measurements 2003.
A building system is defined to be the composition of different functioning subsystems or components with precisely designed interfaces, controlled to operate robustly, and always meeting performance within known bounds under changing environmental conditions and use.
Boeing's newest airplanes, the 787 Dreamliner and the 747-8, highlight the company's commitment to environmentally progressive design innovation. Incorporating four innovative technologies—new engines, increased use of lightweight composite materials, high-efficiency systems applications, and modern aerodynamics—the 787 is designed for the environment with an impressive 20 percent improvement in fuel use and an equivalent reduction in CO₂ emissions compared to today's similarly-sized airplanes. The 747-8 offers a 16 percent improvement in fuel use and CO₂ emissions over the 747-400.
Aerospace Systems: Lessons Learned

Efficiency improvements derived through exploitation of system interactions

Requirements capture & rigorous analysis

Architecture trade studies & evaluation

Use of computational tools (modeling of architectures, evaluation of robustness, generation of test vectors)

Validation & verification
Building System Integration Challenges

Bottlenecks in design & operation

Quantification of key parameters and subsystems and tolerances for energy savings

Efficient exploration of system configurations for guaranteed performance

Rigorous system and component requirement specification to ensure proper handoffs in delivery chain

Capture multiscale dynamics in computationally feasible manner for operation

Detect component faults from system level information

Robust supervisory control design
Today’s Agenda

Investable areas for building science - systems

Requirements tracking and analysis tools

Multi-scale, multi-physics modeling and simulation with uncertainty analysis

Cost effective, autonomous, networked…controls

Model based validation and verification of building systems and controls

Software, software toolchains and software methodologies for design and operation

Tools to assist in transparent auditing and regulation of building energy performance
Today’s Agenda

Investable areas for building science - components

- Active, flexible controllable building envelope technologies
- Climate appropriate passive ventilation capabilities
- Fast acting thermal storage
- Long duration thermal storage
- Independent, fast-acting humidity control
- High efficiency, low GWP HVAC materials and / or new configurations
ADVANCED COMPUTATION FOR BUILDING SCIENCE

Model reduction methods

Optimization methods

Sensitivity analysis tools

Methods to compute invariant dynamics
AWARE, INTERACTIVE, RECONFIGURABLE BUILDINGS

Advanced sensing → Embedded control/diagnostics → Automated commissioning ⇒ Persistent energy efficiency
Finally – Realize Impact

- **Concept & Design**
  - A & E Firms

- **Build**
  - Contractors

- **Operations & Maintenance**
  - Property Managers & Operations Staff

**Low Energy**
- Unaware
- Savings Potential
- Beneficial: scalability
- Miss
- Beneficial: robustness
- Loss

**Current State**
- Benefit: productivity