A Systems Approach to High Performance Buildings

Issues, Scientific Challenges and Recommendations for R&D

ARTIST
Embedded Systems: Industrial Applications
Rome, Italy

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Key Points

- Market pressures on increasing performance for buildings
  - *Energy efficiency: need to go to Net Zero Energy;*
  - *Security: need to improve false-alarm rates dramatically.*

- Current best practices for high-performance buildings
  - *Functional integration for increased efficiency.*

- Barriers for dramatically improved high-performance buildings
  - *Complexity, heterogeneity and emergent behavior of networked systems.*

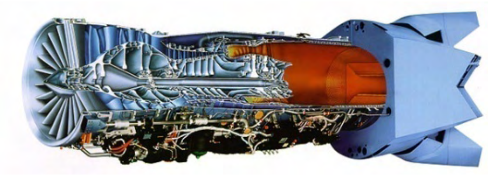
R&D needs in Systems Technology:

1... Design processes that address complexity explicitly;
2... Modeling and analysis that is focused on dynamics;
3... Explicit representation and management of uncertainty;
4... Design methodologies for networked embedded systems;
5... Supply and demand side energy demonstrations.

United Technologies

UTC Power

Carrier



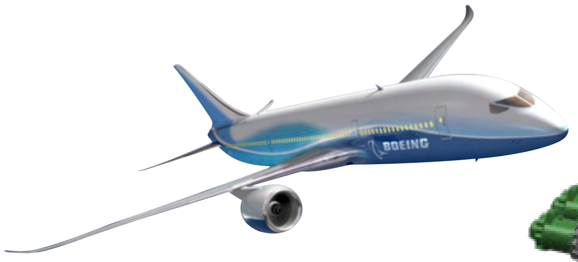
Pratt & Whitney

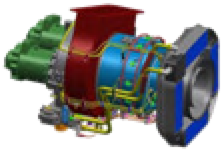
Building Systems

Aerospace Systems

Power Systems

Otis





Hamilton Sundstrand

UTC Fire & Security

Energy, Comfort, Security Needs in Buildings are Evolving

UTC presence in buildings creates opportunities and research challenges

Customer-focused solutions

Enabled by integrated systems

Carbon-neutral buildings by 2030

Buildings must be 4X-5X more energy efficient

Threats becoming more complex

98% false alarms

Building Energy Demand Challenge

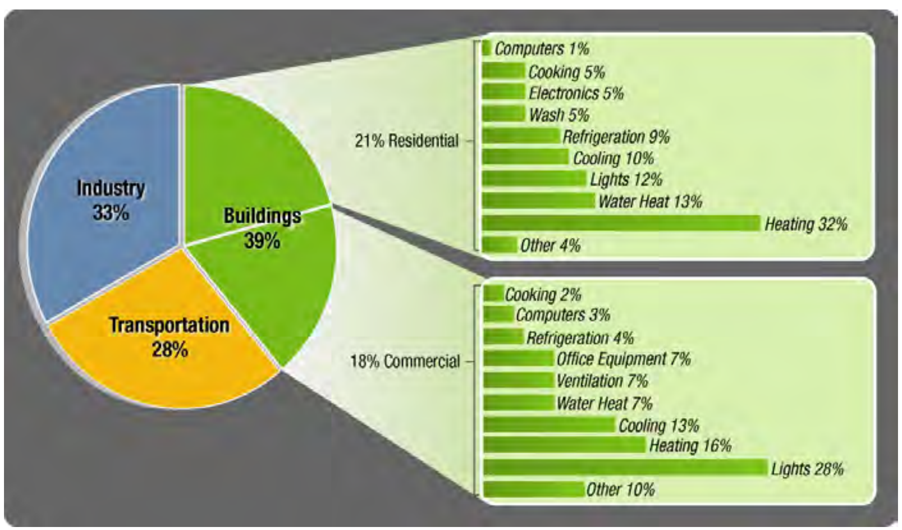
Buildings consume
- 39% of total U.S. energy
- 71% of U.S. electricity
- 54% of U.S. natural gas

Building produce 48% of U.S. Carbon emissions

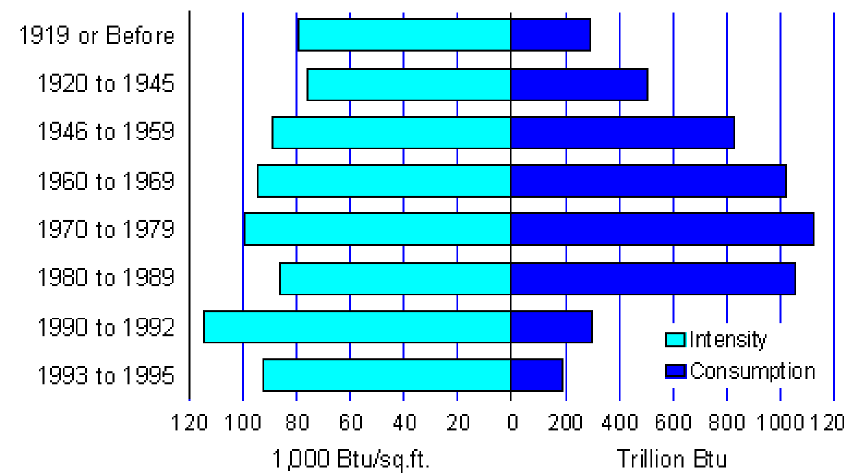
Commercial building annual energy bill: $120 billion

The *only* energy end-use sector showing growth in energy intensity
- 17% growth 1985 - 2000
- 1.7% growth projected through 2025

Energy Breakdown by Sector



Energy Intensity by Year Constructed



Energy Information Administration
1995 Commercial Buildings Energy Consumption Survey

Sources: Ryan and Nicholls 2004, USGBC, USDOE 2004

Systems of Systems Approach to Energy Efficiency

Creating and Exploiting the Interfaces between Sub-systems

Buildings Design & Energy Analysis

HVAC

Natural Ventilation, Indoor Environment

Windows & Lighting

Networks, Communications

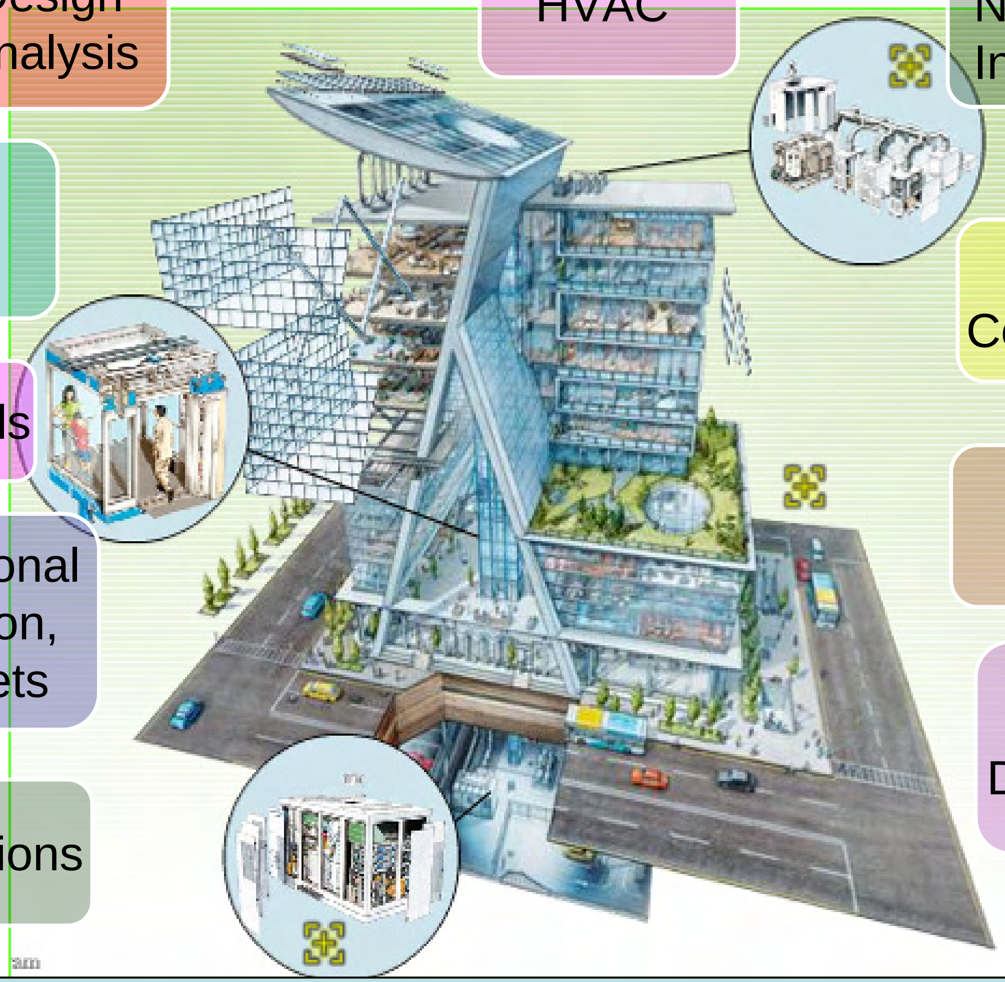
Building Materials

Sensors, Controls

Domestic/International Policies, Regulation, Standards, Markets

Power Delivery & Demand Response

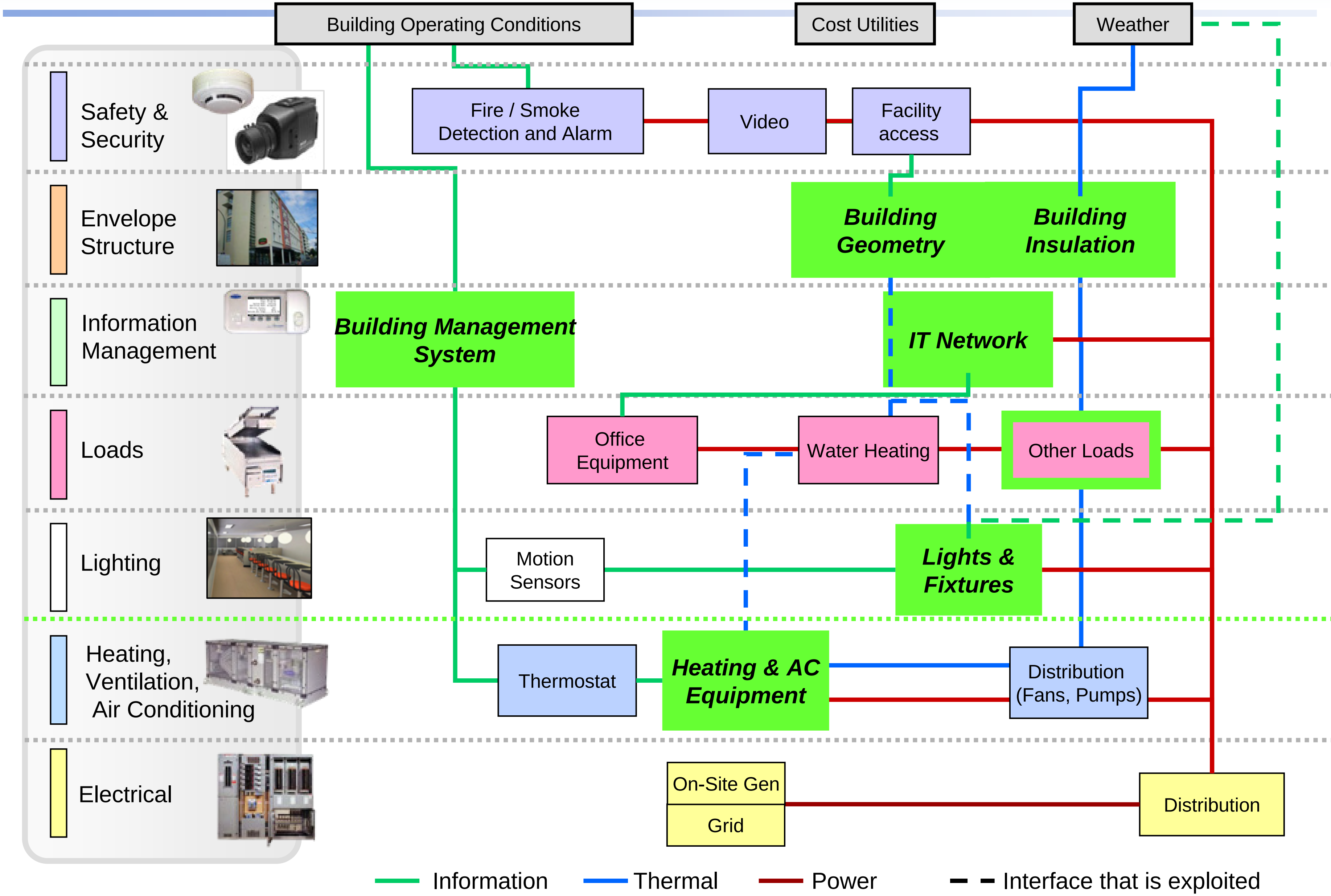
Demonstrations



Integration: ***The Whole is Greater than the Sum of the Parts***

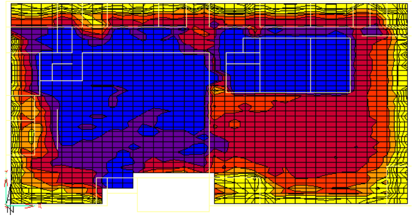
Problems***: Heterogeneity, Complexity, Coordination…***

FULL FACILITY DECOMPOSITION

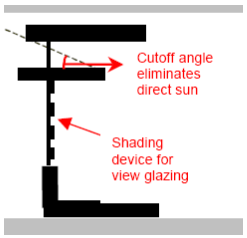


FULL FACILITY INTEGRATION

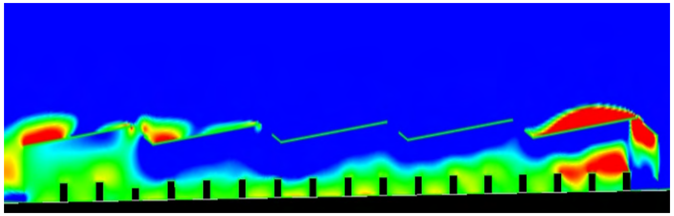
Maximize natural lighting



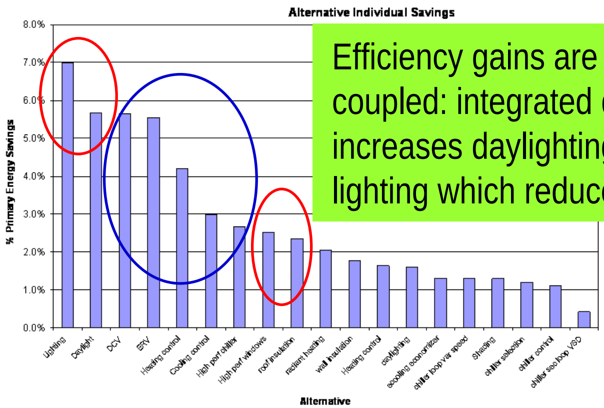
Minimize heat gain (shading)



Exploit natural ventilation

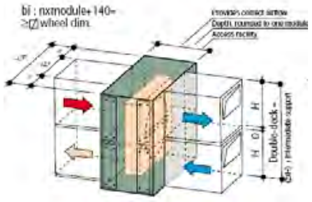


1. **Reduce energy demand early in design**
2. **Select systems to meet demand and optimize**

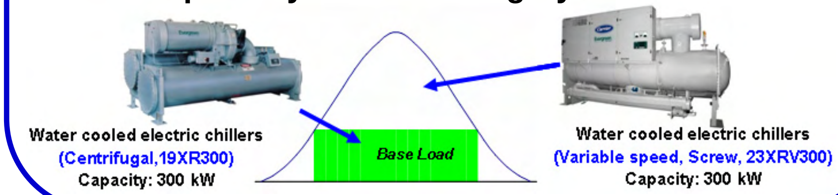


Efficiency gains are not additive but coupled: integrated design of siting increases daylighting which reduces lighting which reduces HVAC load...

Energy Recovery Ventilation

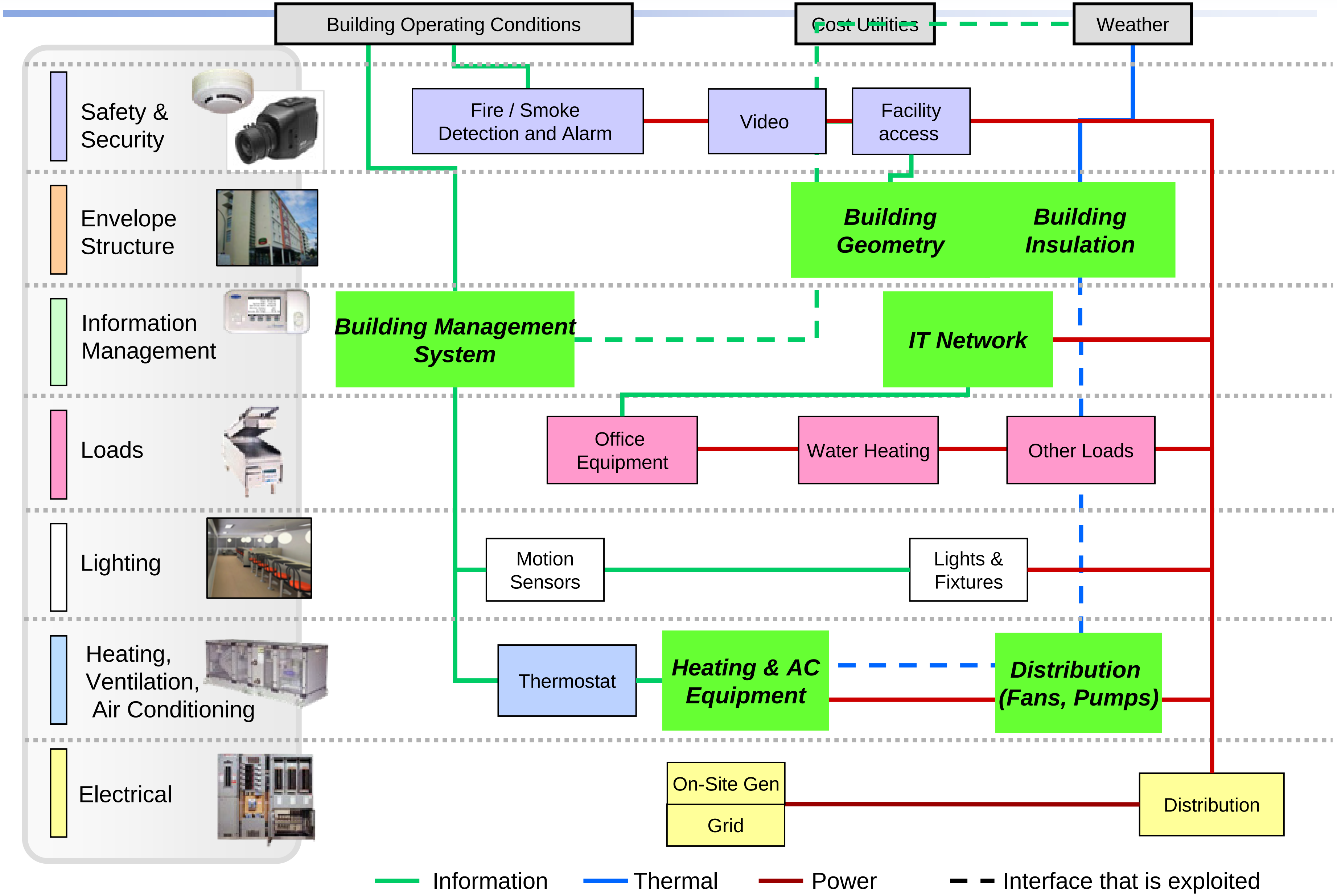


Optimally Sized Cooling Systems

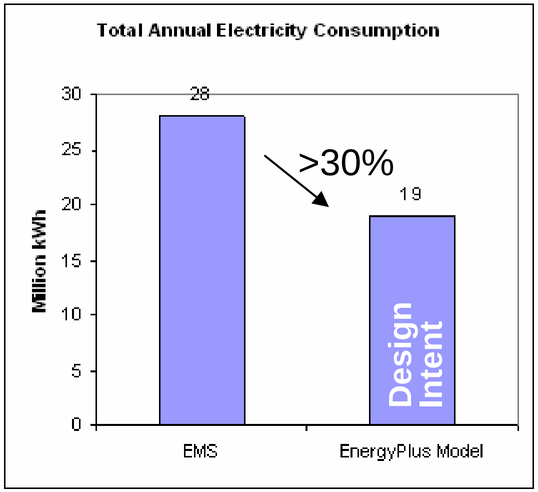


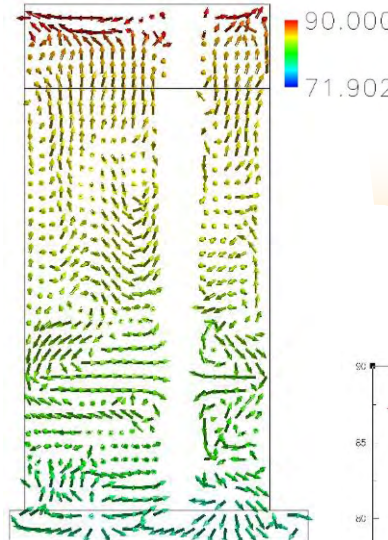
- **25% primary energy footprint reduction at less than 7% incremental cost**
- **Payback 4.2 years total / 2.5 years new items**

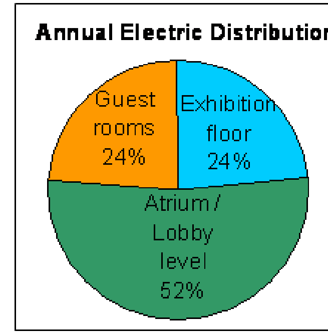
BUILDING SUBSYSTEM DECOMPOSITION



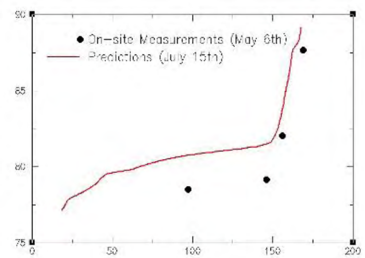
Marriott Hotel Building

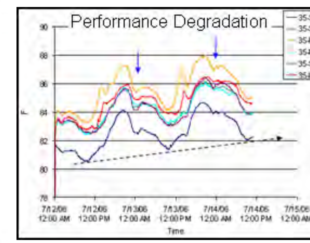


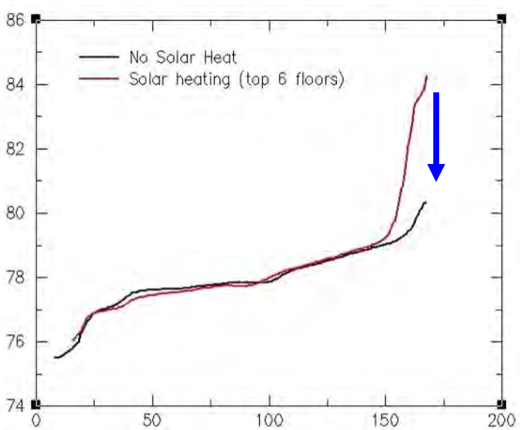


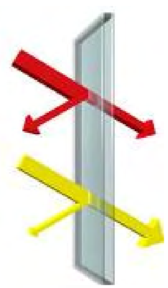


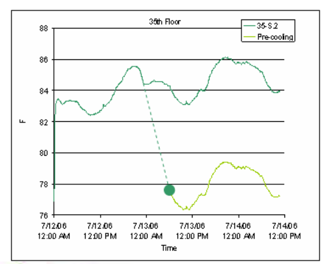
Model prediction

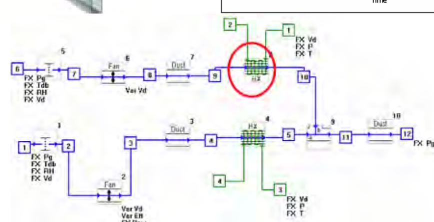










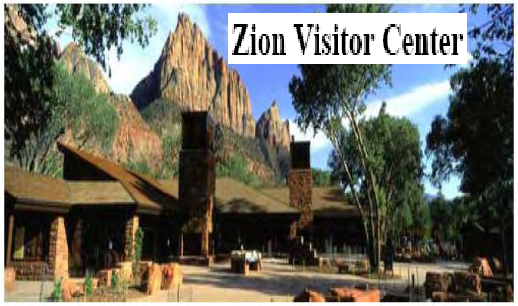


- Manage heat gain
- Optimize control schedule
- Re-size air side equipment

High-Performance Buildings: External Efforts

Design Intent: 66% (ASHRAE 90.1); Measured 44%

Among the low-energy design features used in this building are ground-source heat pumps, an under-floor air distribution system, heat recovery ventilators, an 18.2-kW PV system, daylighting, motion sensors, additional wall and roof insulation, and high-performance windows



Design Intent: 80% (ASHRAE 90.1); Measured 67%

The building design incorporates energy-efficient features such as daylighting, natural ventilation, cooltowers, passive solar heating, solar load control with engineered overhangs, computerized building controls, and an uninterruptible power supply (UPS) system integrated with the 7.2-kW PV system

General Observations

Integrated design of building systems can provide substantial efficiency gains

Actual energy performance lower than predictions

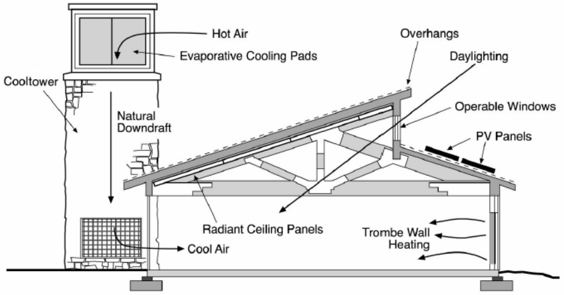


Figure 3-28 Illustration of how the cooltowers work at the Zion Visitor Center

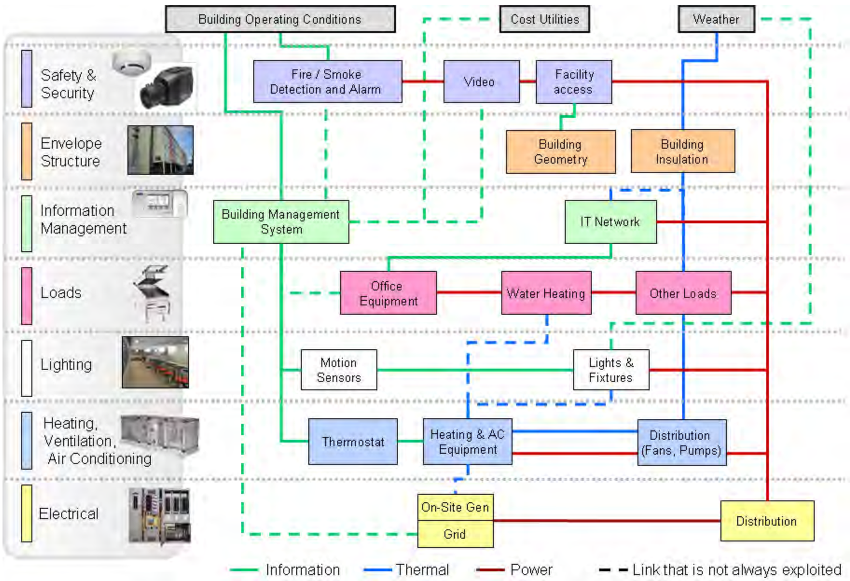
Source: Lessons Learned from Case Studies of Six High-Performance Buildings, P. Torcellini, S. Pless, M. Deru, B. Griffith, N. Long, R. Judkoff, 2006, NREL Technical Report.

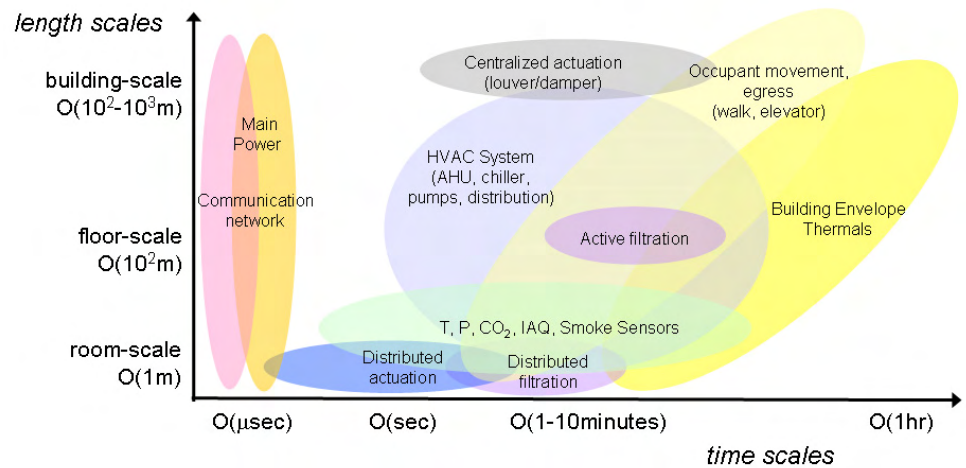
Failure Modes Arising from Detrimental Sub-system Interactions

- Changes made to envelope to improve structural integrity diminished integrity of thermal envelope (e.g. “retainer wall acting as a fin”)
- Adverse system effects due to coupling of modified sub-systems:
  - changes in orientation and increase in amount of glass on façade (affects solar heat gain)
  - indoor spaces relocated relative to cooling plant (affects distribution system energy) while simultaneously reducing plant size
  - improper thermal bridging of window frames and adjoining walls resulted in heat loss, adversely impacting heating energy
  - Trombe walls for passive heating add to cooling loads in summer requiring façade design (e.g. overhang) to provide shade
- Lack of visibility of equipment status/operation and large uncertainty in loads (e.g. plug, occupancy, leaks), leading to excess energy use

Building Systems Integration Challenge

Complex interconnections among building components*





- Components do not necessarily have mathematically similar structures and may involve different scales in time or space;
- The number of components may be large/enormous
- Components can be connected in a variety of ways, most often nonlinearly and/or via a network. Local and system wide phenomena may depend on each other in complicated ways
- Overall system behavior can be difficult to predict from the behavior of individual components. Overall system behavior may evolve along qualitatively different pathways that may display great sensitivity to small perturbations at any stage

* D.L. Brown, J. Bell, D. Estep, W. Gropp, B. Hendrickson, S. Keller-McNulty, D. Keyes, J. T. Oden and L. Petzold, Appled Mathematics at the U.S. Department of Energy: Past, Present and a View to the Future, DOE Report, LLNL-TR-401536, May 2008.

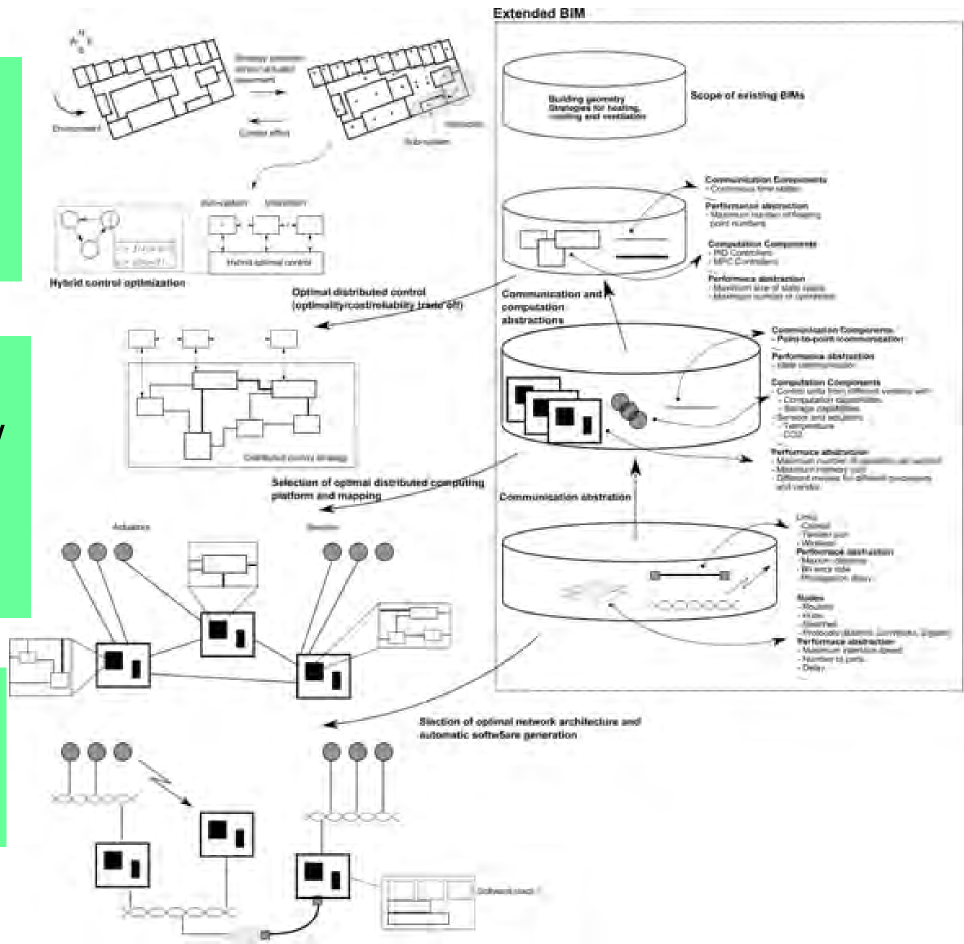
** "Leadership under challenge: Information technology R&D in a competitive world", PCAST report, Aug. 2007.

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*



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

Needs for Basic Science and Measurement for High Performance Buildings

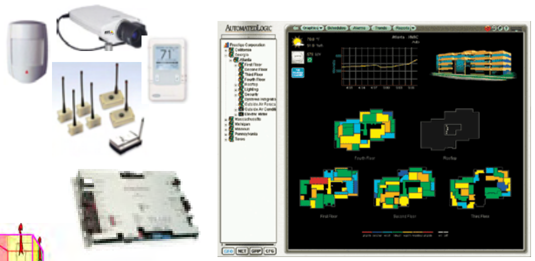
Energy Savings in Commercial Buildings

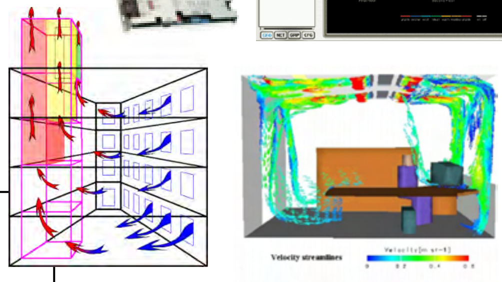
45-80% Demand Reduction

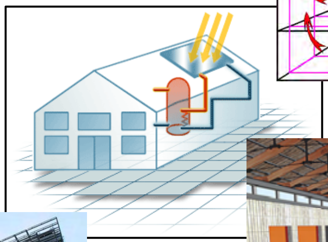
Energy Efficiency Gains

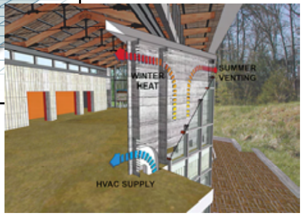
5-20% ↓	**Information Systems & Networks** *Occupancy, utility rate, weather…*
10-15% ↓	**Comfort & Ventilation Systems** *Ventilation, air movement…*
10-15% ↓	**Thermal Systems** *Thermal recovery, storage…*
20-30% ↓	**Green Buildings** *Architecture, envelope…*

Baseline Footprint (ASHRAE 90.1)









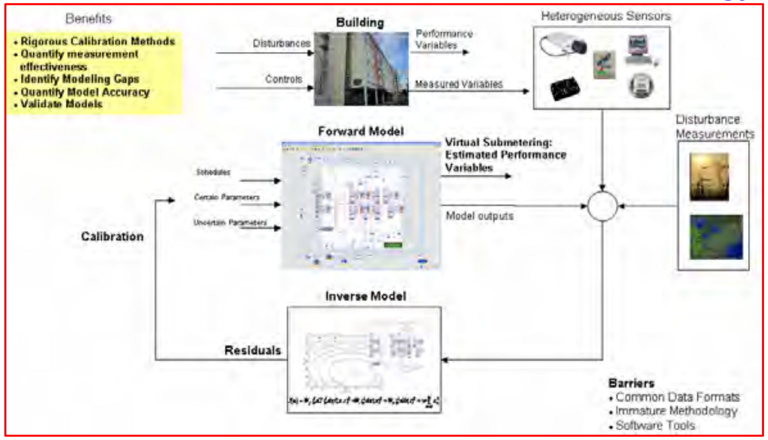
Technology Risk & Readiness

- Reduce risk/enhance maturity
- Make solutions scalable & robust
- Drive commercial adoption

DOE Seed Projects Kicked Off: Oct. 2008

Technology Maturation and Demonstration at University of California - Merced

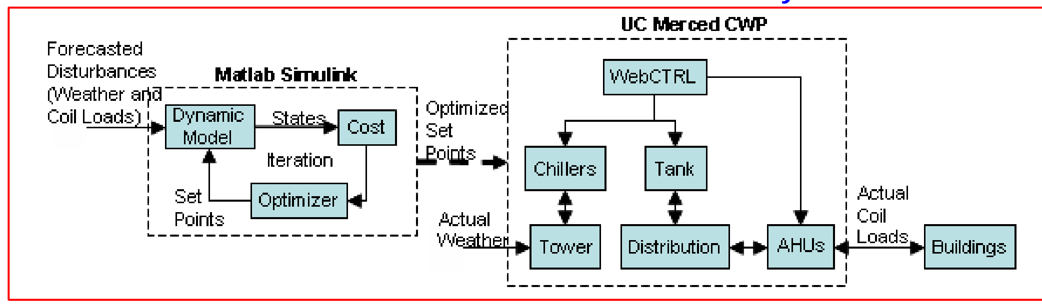
Real-time Visualization of Model-based Energy Performance



U.S. Department of Energy
Energy Efficiency and Renewable Energy

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

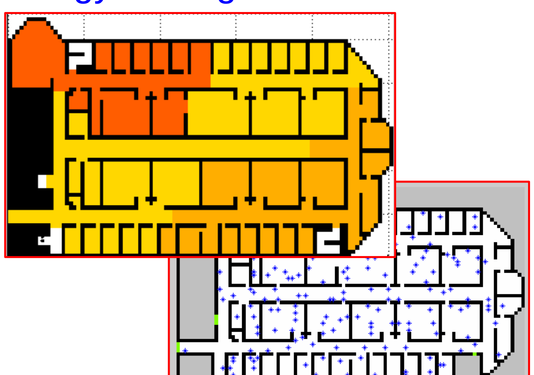
Model Predictive Control of HVAC systems



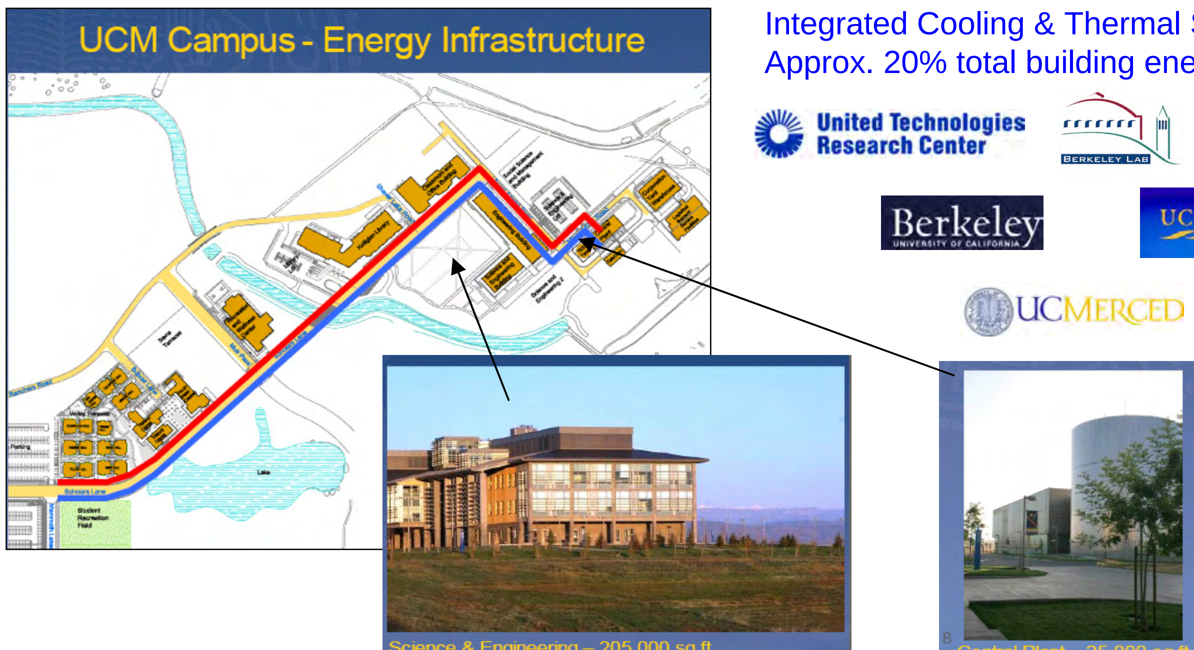
Integrated Cooling & Thermal Storage
Approx. 20% total building energy ↓

United Technologies Research Center
Berkeley Lab
Berkeley University of California
UCSB
UC Merced

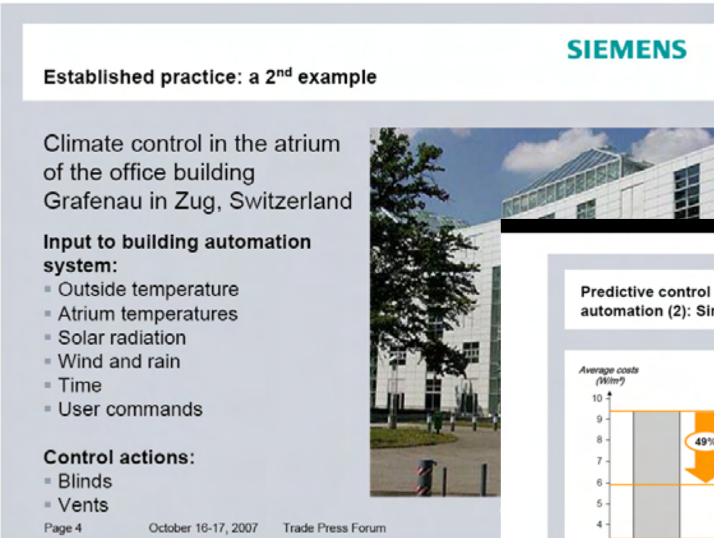
Occupancy-based energy management

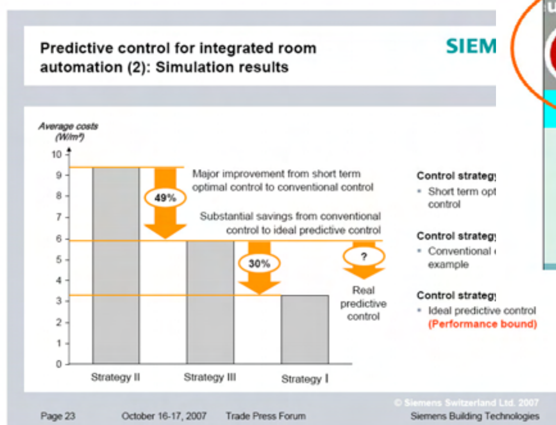


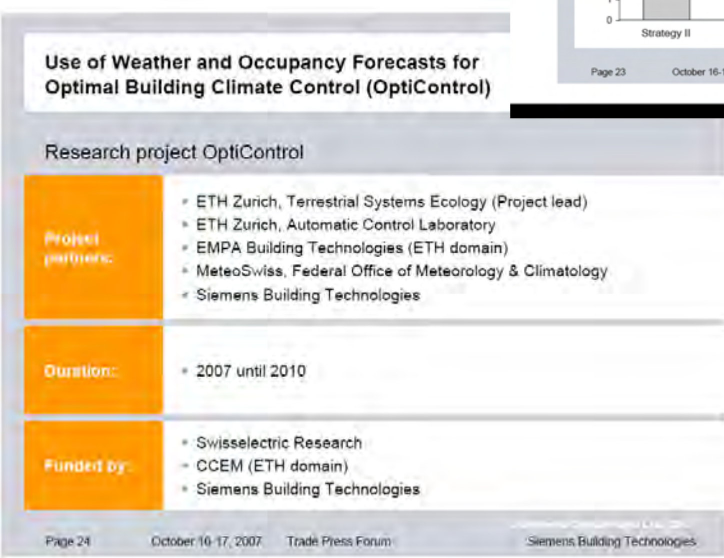
Integrated Security & HVAC Systems
Approx. 20% HVAC system energy ↓



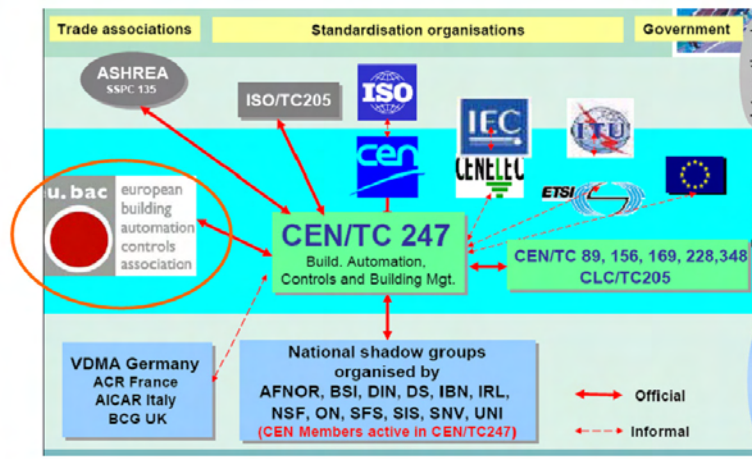
European Movement on Energy Efficiency







NORMS & REGULATIONS INTERACTIONS



EU.BAC CERTIFICATION

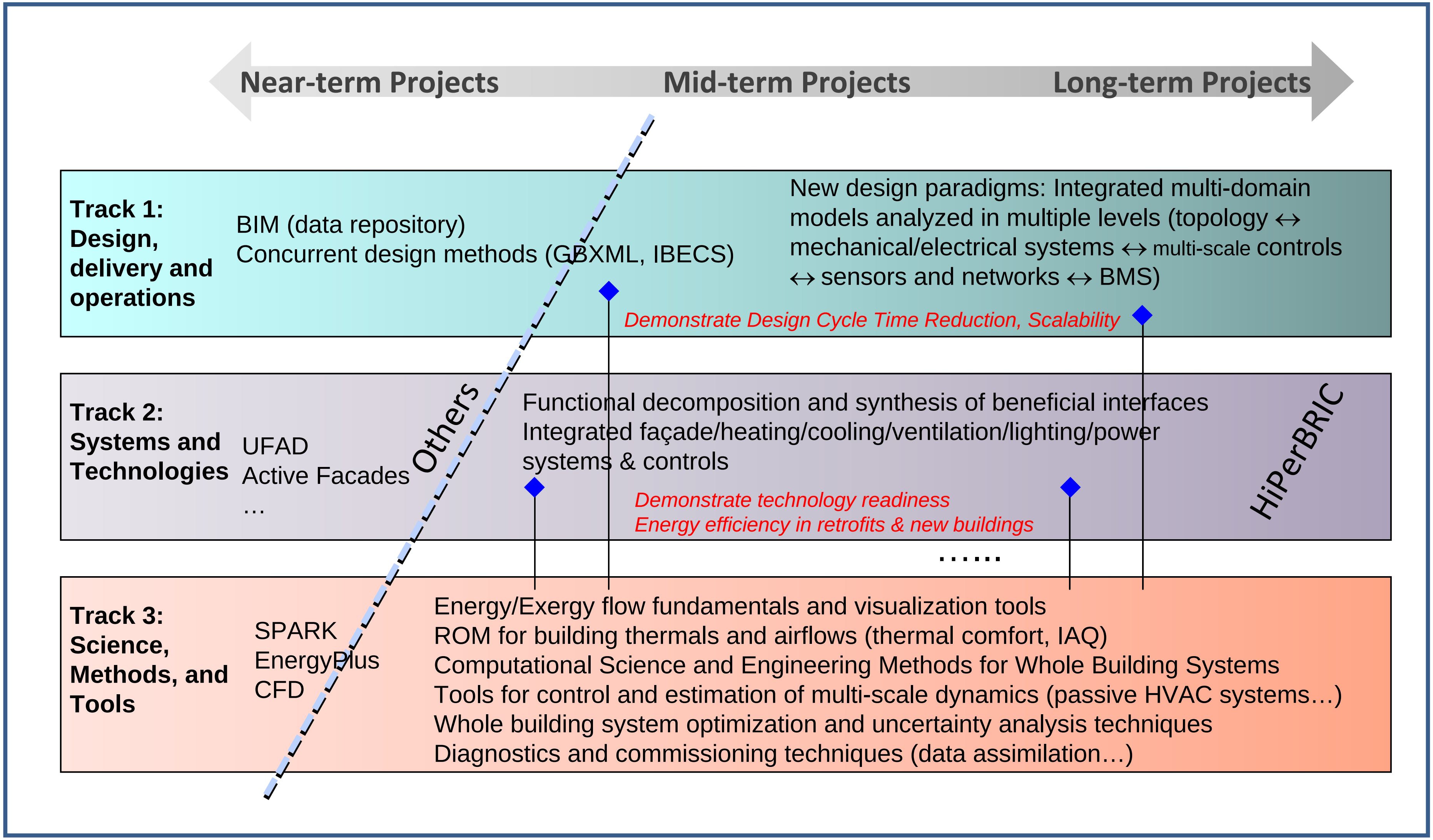
- REQUIREMENTS :
  - PRODUCT :
    - Compliance test vs EN15500
    - Compliance test with eu.bac certification specific tests
  - MANUFACTURING PROCESS :
    - Existence Quality Management System and Quality Plan
    - Inspection of manufacturing site

CSTB le futur en construction

Industry-university partnerships; standards and model based certification

Sources
Carrier-EMEA 2008
ETH Energy Symposium 2008

Proposed R&D Investments and Program Tracks



Maturation of Methods, Tools & Technologies

Strategic Research and Development Plan

SEEDLINGS
$0.5 M PROJECTS

FOCUSED RESEARCH PROJECTS
$5 M PROJECTS

LARGE-SCALE TECHNOLOGY DEMONSTRATIONS
$5 - $50 M PROJECTS

NOW 6 MO.	PHASE I 1 YEAR	PHASE II 1 YEAR	PHASE III 2 YEARS	FIELDL DEPLOYMENTPHASE 5 YEARS	2018

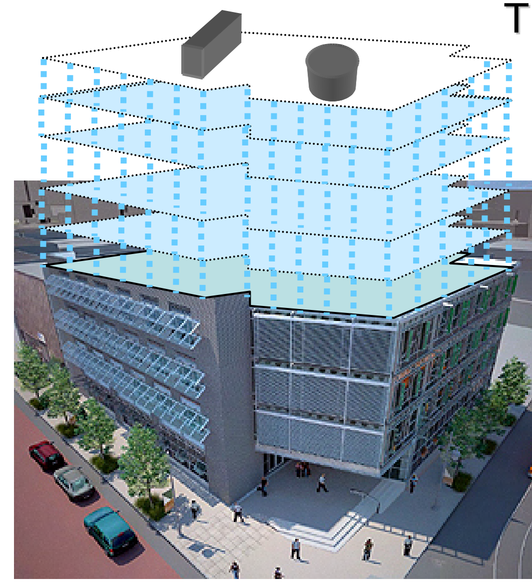
1. Data assimilation & fault diagnostics
2. Dynamic comfort modeling & optimization
3. Model predictive control
4. Design flows for networks & controls
5. Energy modeling infrastructure
6. ...
7. ...
8. ...

Workshops

1. Monitoring, Prognostics & Commissioning
2. Building Operating Platform
3. Integrated Design Methodology & Tools

VIRTUAL SCALE-UP

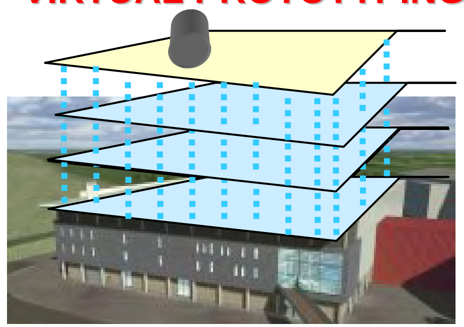
TRL9



CONCEPT FEASIBILITY

TRL4

VIRTUAL PROTOTYPING



TRL6

SUB-SCALE FACILITY

MEDIUM-SCALE NATIONAL RESEARCH FACILITY

FULL-SCALE DEMONSTRATION

1. ZERO NET ENERGY BUILDING

2. 50% EFFICIENT RETROFIT BUILDING

Backup

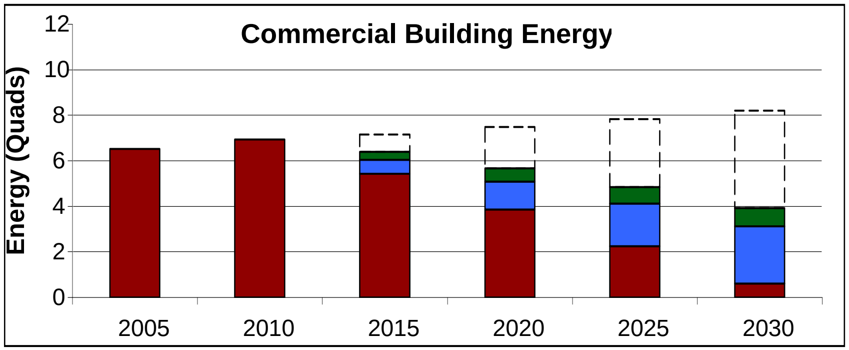
HiPerBRIC Vision

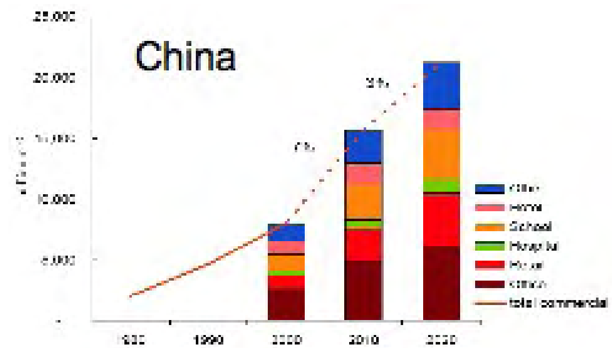
Enable transformation of U.S. Commercial buildings sector in 20 years, starting NOW

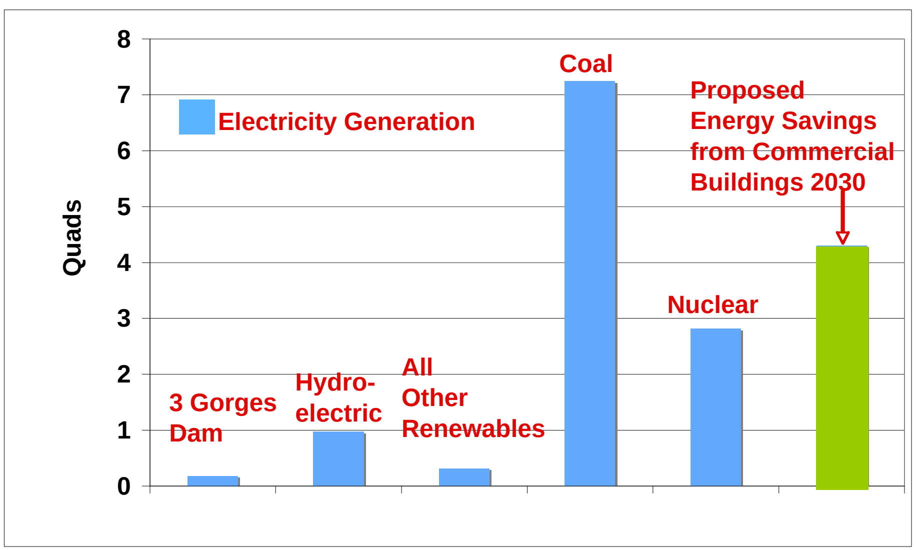
– Save >4 Quads of energy and reduce >400 million tons of CO_2 annually

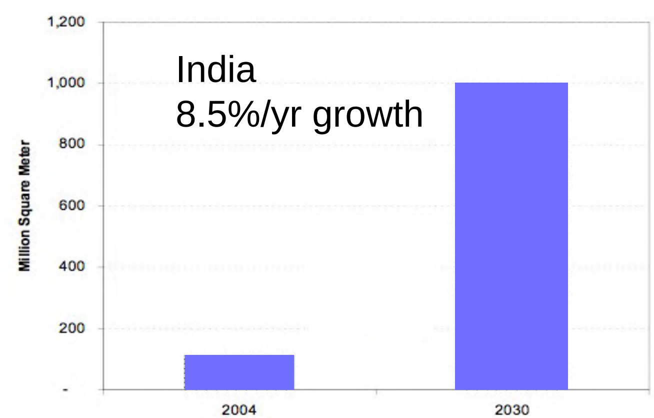
- Reduction in energy consumption: 90% in new buildings; >50% in retrofits

– Enhance health, comfort, safety/security and water usage while gaining energy efficiency









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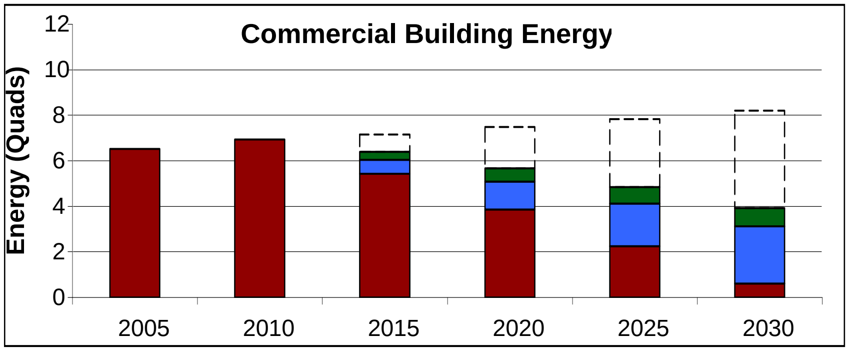
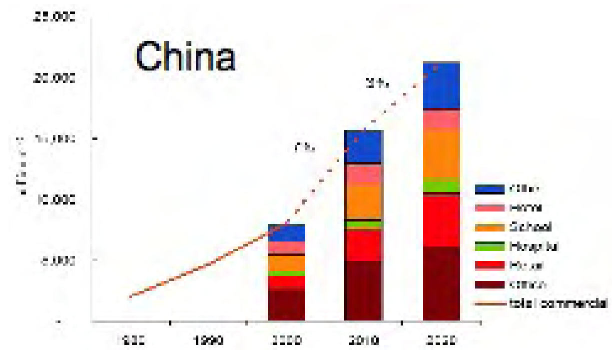
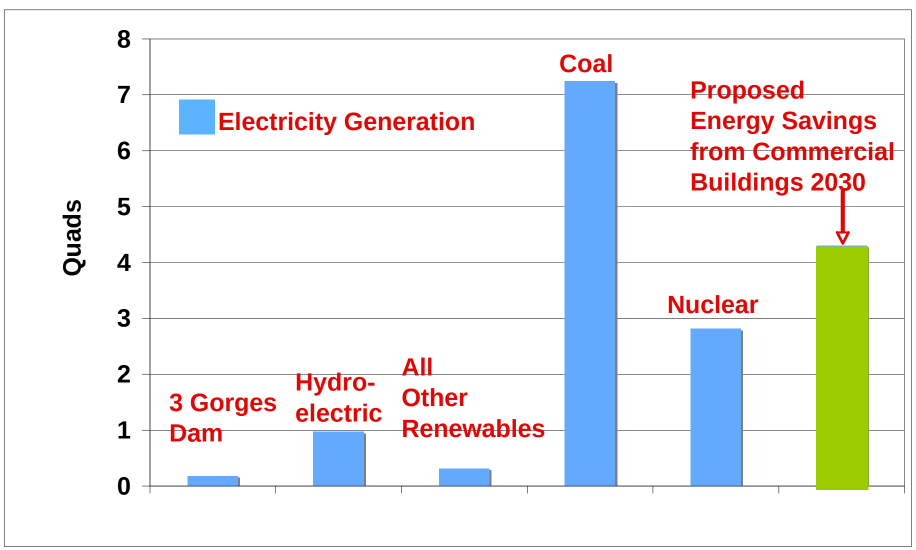
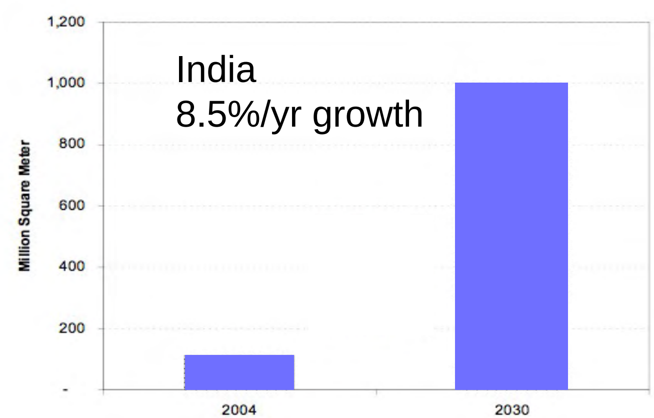








National Laboratory-Industry-Academia Partnership

Dr. Michael J. McQuade
Sr. VP, Science & Technology

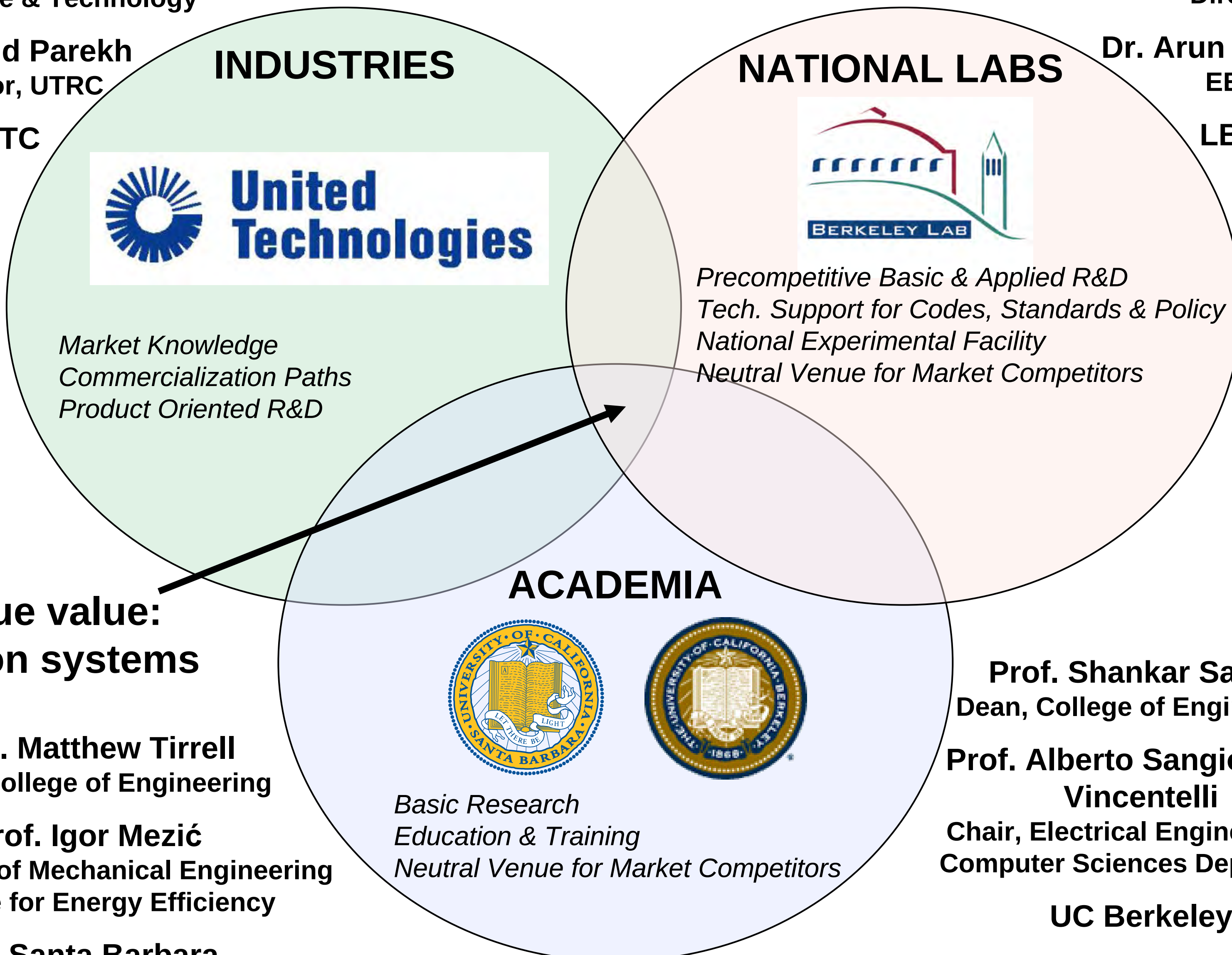
Dr. David Parekh
Director, UTRC

UTC

Dr. Steven Chu
Director

Dr. Arun Majumdar
EETD

LBNL



Unique value: focus on systems

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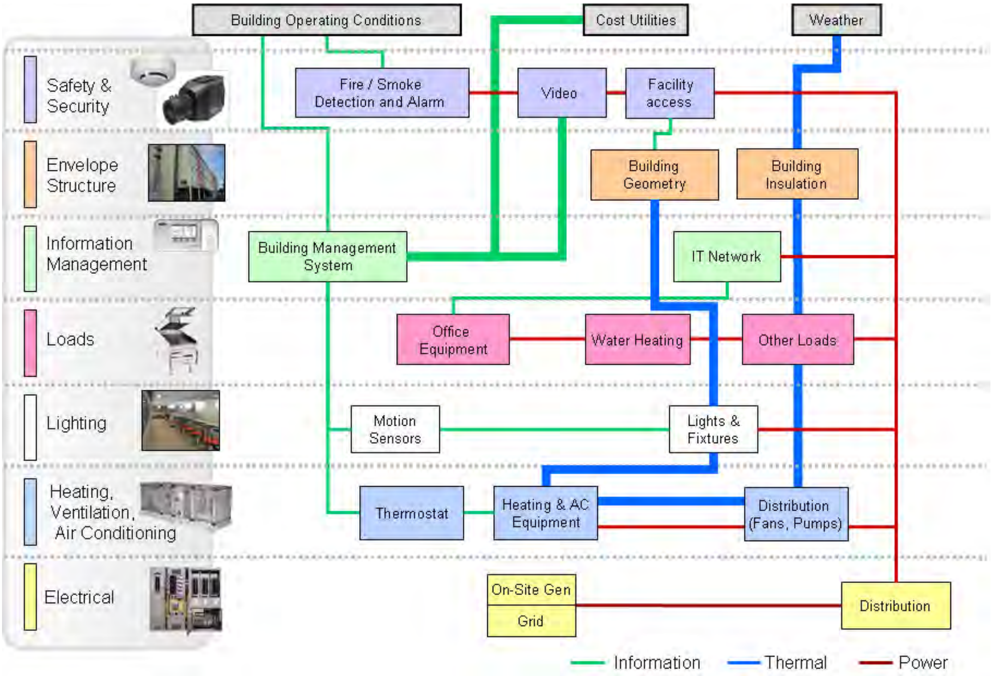
Integration-Enabled High Performance Buildings

Robust engineering and operation of complex interfaces

Integrated Façade, lighting and HVAC



Concept: Utilize building façade to balance artificial and natural lighting, match lighting loads with occupancy and HVAC demand

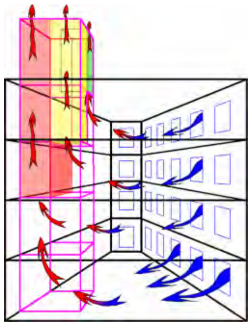
Challenge: Fundamental understanding of lighting, building material properties, and their dynamics relative to indoor/outdoor disturbances (e.g. weather, lighting, occupancy…), co-design of building façade, lighting and HVAC systems, robust control architectures, uncertainty

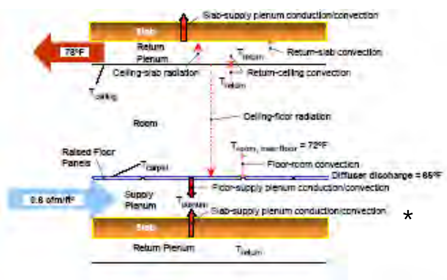
Benefit: >50% reduction in lighting demand while matching HVAC demand

Integration-Enabled High Performance Buildings

Robust engineering and operation of complex interfaces

Integrated Envelope and HVAC Systems
Natural, Passive and Hybrid Ventilation





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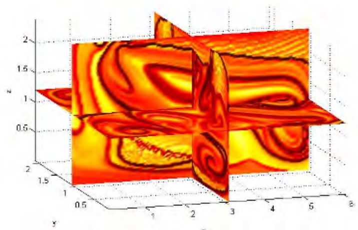

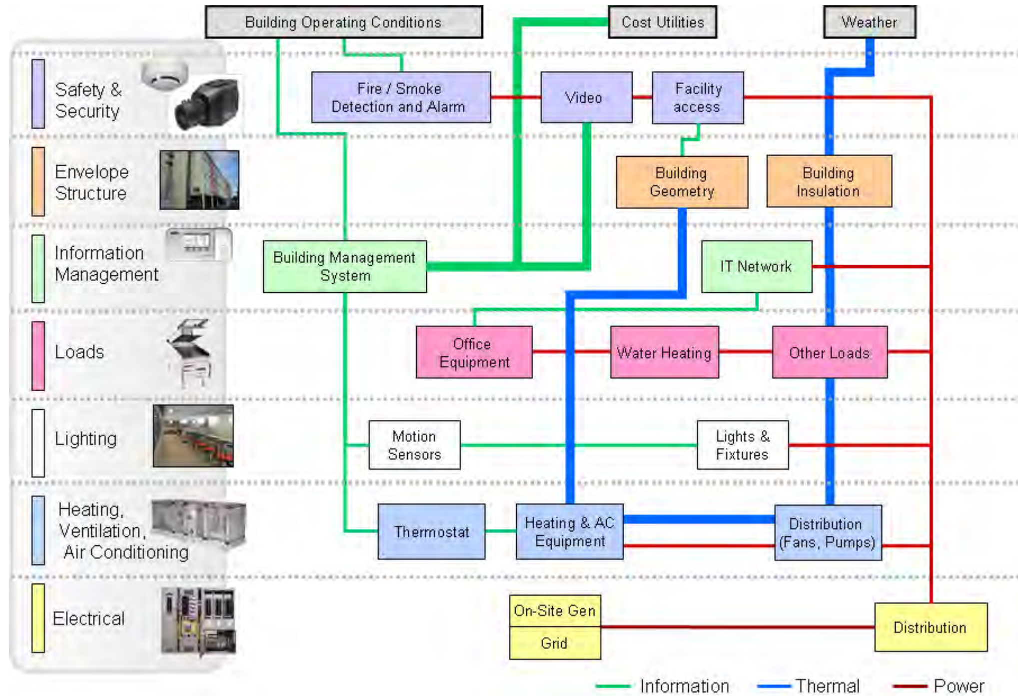

Concept: Hybrid HVAC systems to take advantage of building material for thermal storage, natural ventilation and passive heating/cooling systems to match occupancy demand

Challenge: Fundamental understanding of energy/thermal/air flows and their coupling to dynamics of disturbances such as weather, occupancy, co-design of building HVAC and envelope systems, robust control architectures, uncertainty

Benefit: 30-50% reduction in ventilation energy demand, gains in occupant health/productivity

Designing UFAD Systems: Updated Guidelines August 8, 2006 (F. Bauman, CBE, McCoy UFAD Workshop)