# ENERGY EFFICIENCY: CHALLENGES


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Cadence Design Systems

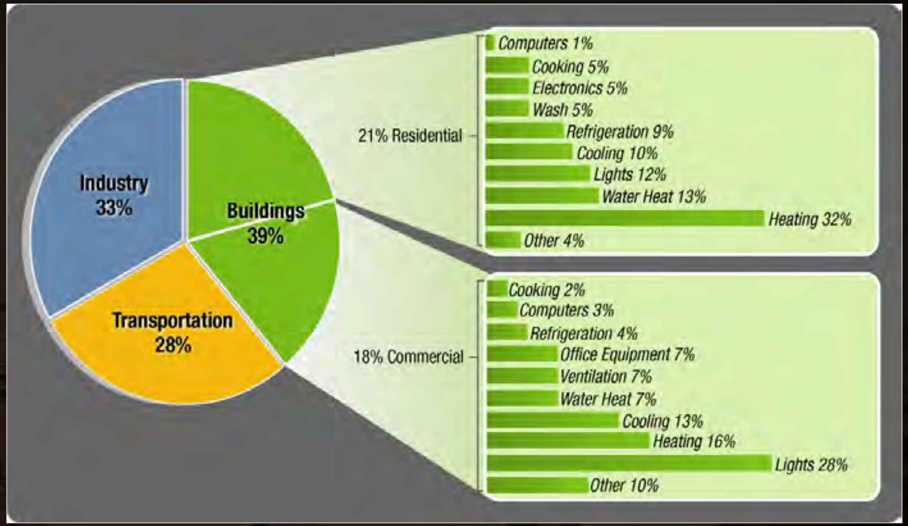

# Outline

- Buildings and Energy consumption
- The Grand Challenge Approach to Energy Efficiency
- ICT technology for Energy Efficiency
- Buildings and Smart Grid
- Building operating system
- Conclusions

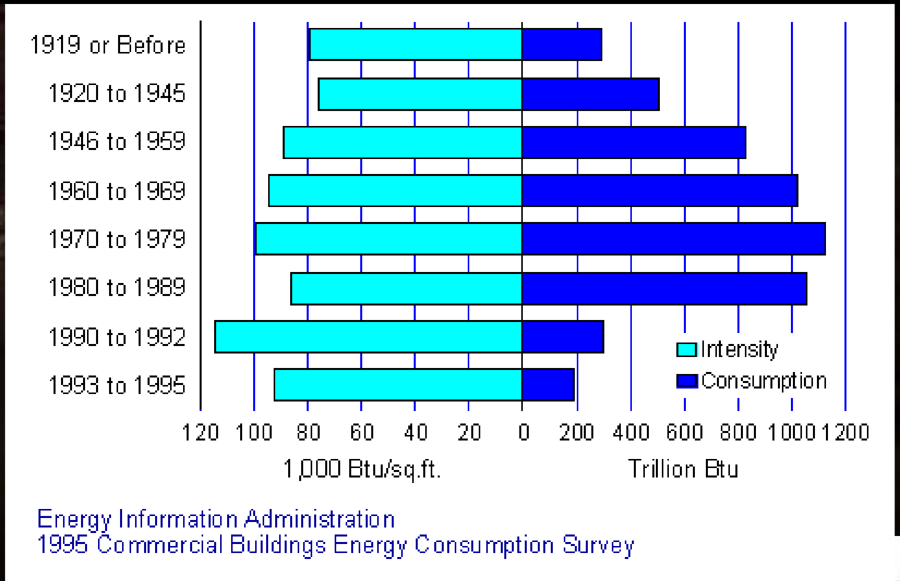
# Building Energy Demand Challenge

- 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**



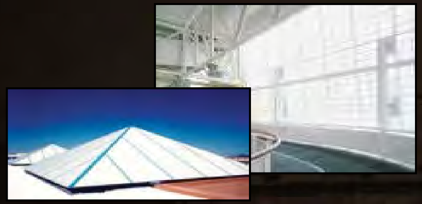

Sources: Ryan and Nicholls 2004, USGBC, USDOE 2004

# UTC Green Building ...Otis Elevator TEDA Center

## 25% Energy Reduction: Systems Engineering & Available Technology

**“one of a kind” new building with existing technology**

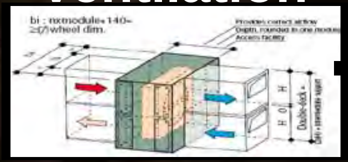
### Daylighting



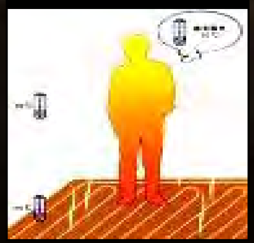

### High Performance Equipment

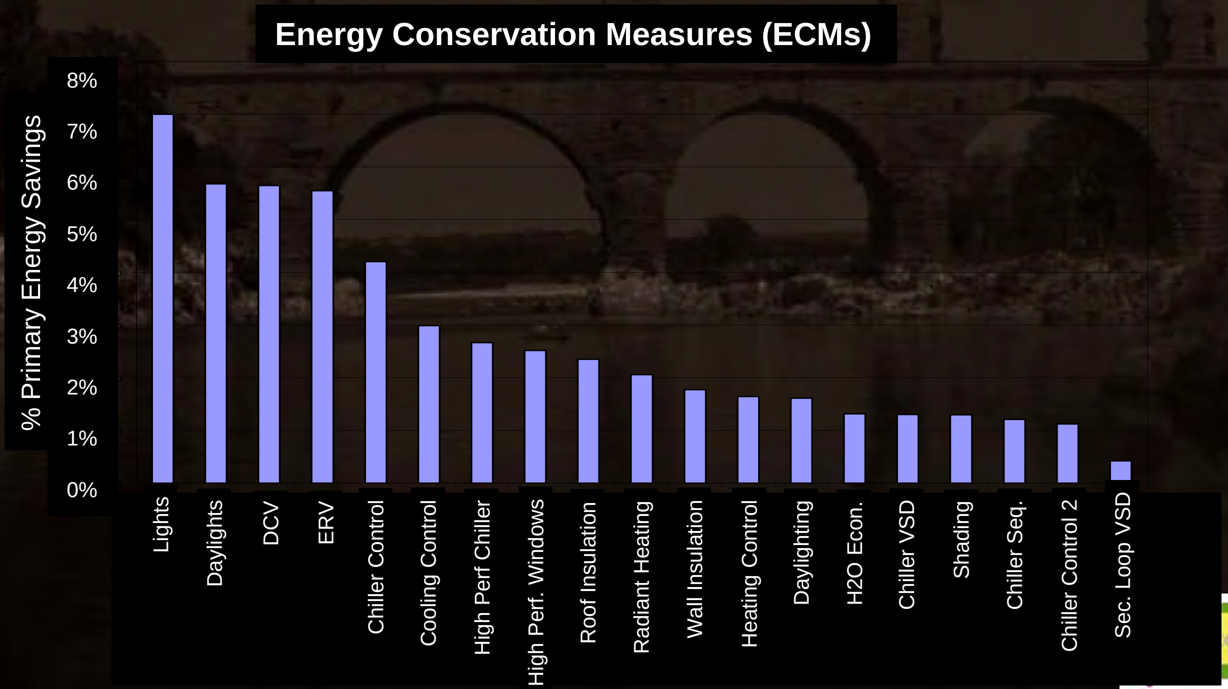
### Shading

### Energy Recovery Ventilation

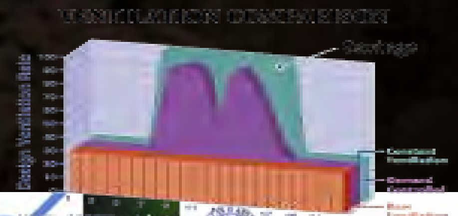


### Radiant Heating






### Demand Controlled Ventilation



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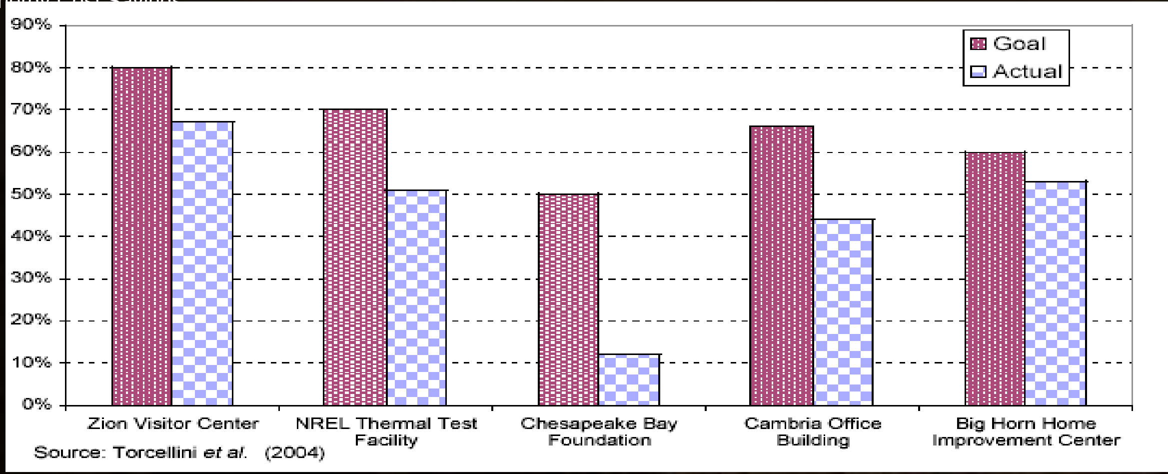
# Gaps in ***Operation*** of Retrofitted Buildings

**Gaps between predicted & actual performance**

Models over-predict gains by ~20-30%

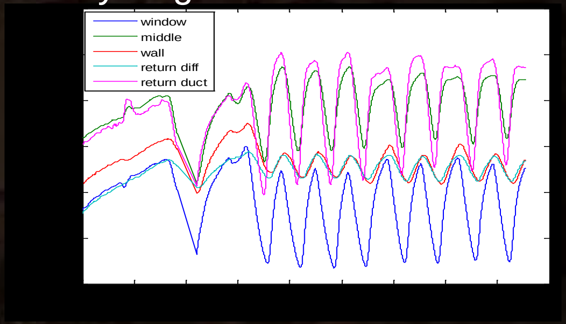
Energy Cost Savings




**Operational faults waste ~20% energy**

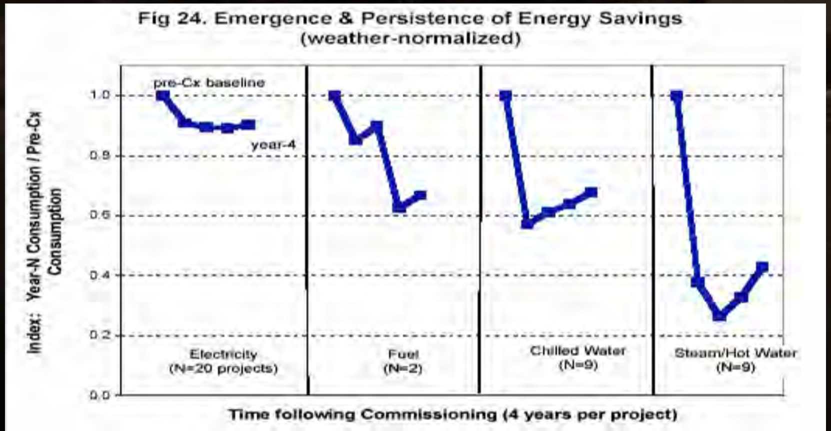
- HVAC – air distribution
- Operations and control

Cycling Controls




Broken Equipment

**Commissioning Gains Quickly Erode**




Façade Damage

*Many of these faults are invisible.*

Source: “The Cost Effectiveness of Commercial Buildings Commissioning,” LBNL, 2005.

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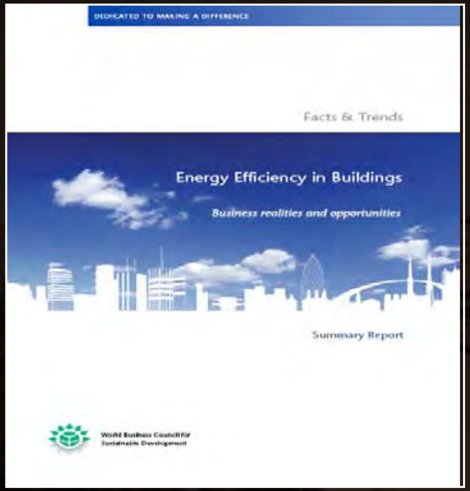
# WBCSD: Addressing Industry Fragmentation & Behavior





Professional and Trade Responsibilities (Functional Gaps)

Building Delivery Process (Management Discontinuities)

Operational Islands (Ineffective coordination, Poor communication)

## Fragmentation

What types of participants/ influencers in the building industry are the biggest barriers to building more sustainable buildings?


## Behavior

Why are more green/ sustainable buildings not built?


Source: WBCSD EEB Quantitative Research (graph); WBCSD EEB Qualitative Research

# Systems of Systems Approach to Energy Efficiency

## Consider Buildings as Composition of Subsystems

Buildings Design Energy and Economic Analysis

Windows and Lighting

HVAC

Domestic/International Policies, Regulation, Standards, Markets

Demonstrations, Benchmarking, Operations and Maintenance

Natural Ventilation, Indoor Environment

Networks, Communications, Performance Database

Sensors, Controls, Performance Metrics

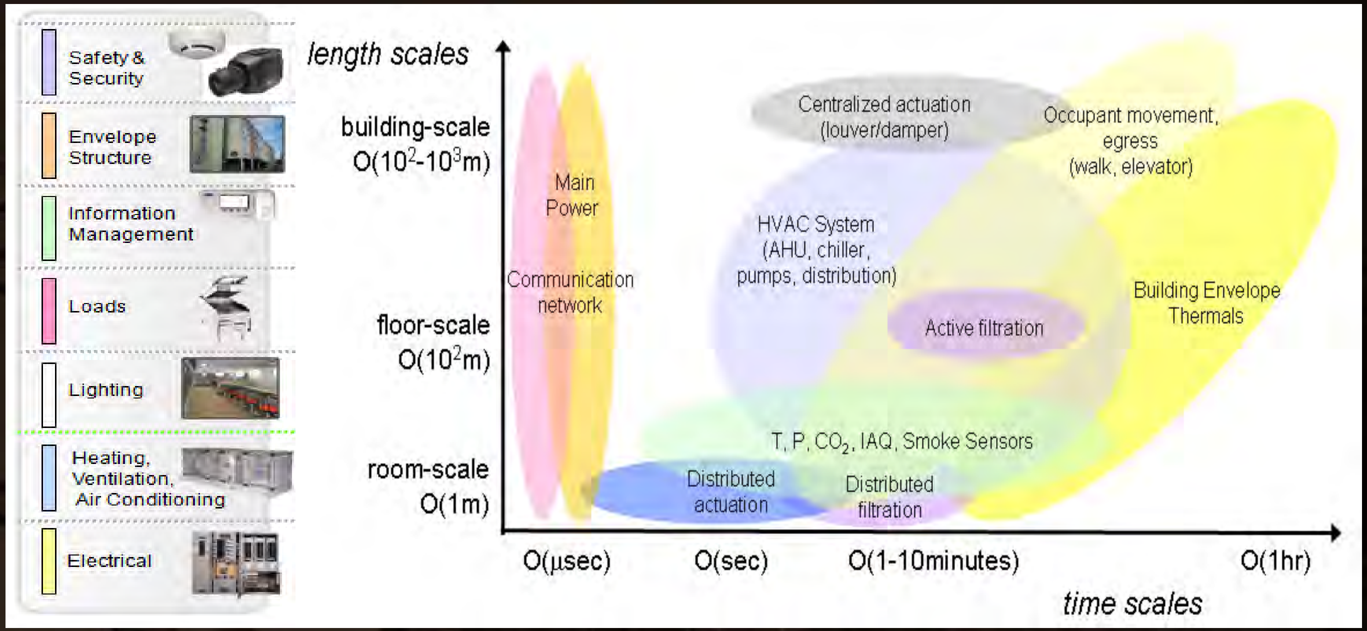
Power Delivery and Demand Response

Building Materials, Misc. Equipment

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

# Building Systems Integration Challenges
## Complex* interconnections among building components

- HETEROGENEITY
  - Components do not necessarily have mathematically similar structures and may involve different scales in time or space
- SIZE
  - The number of components may be large/enormous
- DISTRIBUTED NETWORKED SYSTEMS
  - 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
- FRAGMENTED MARKET
  - Long and complex value chain
  - Difficult to articulate how to attack the problem from an industrial point of view




* 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.

# Building Systems Integration Challenges

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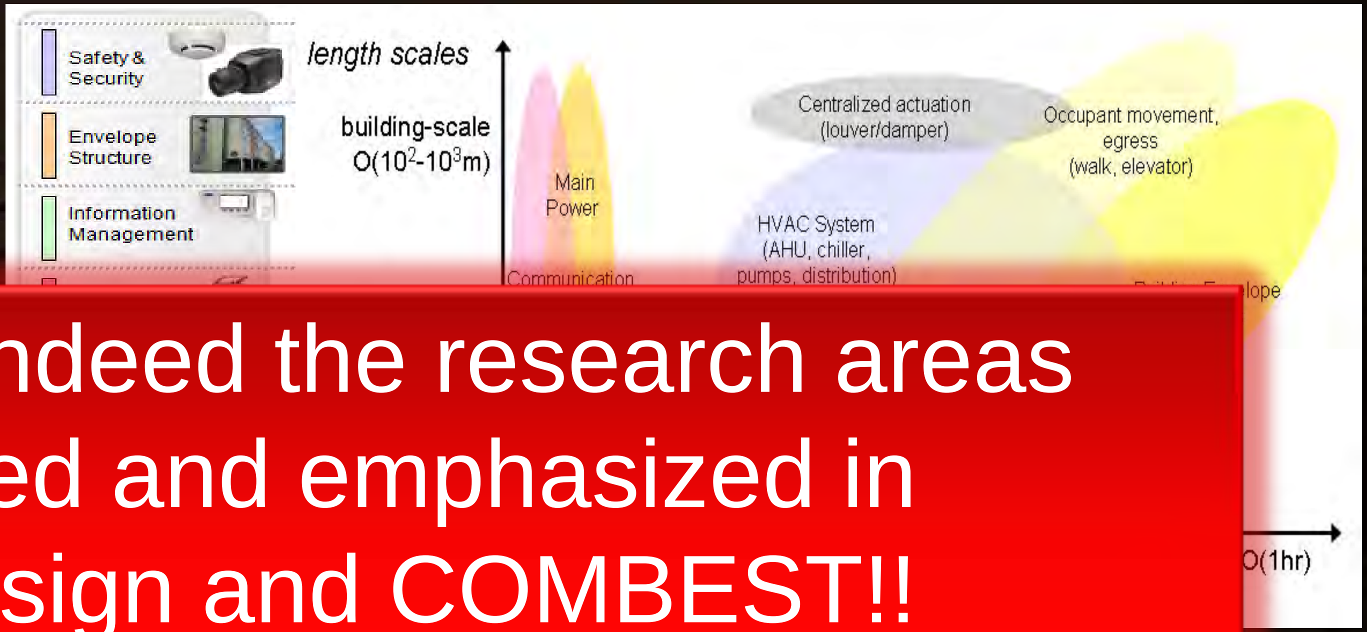


Keyes, J.
Past,

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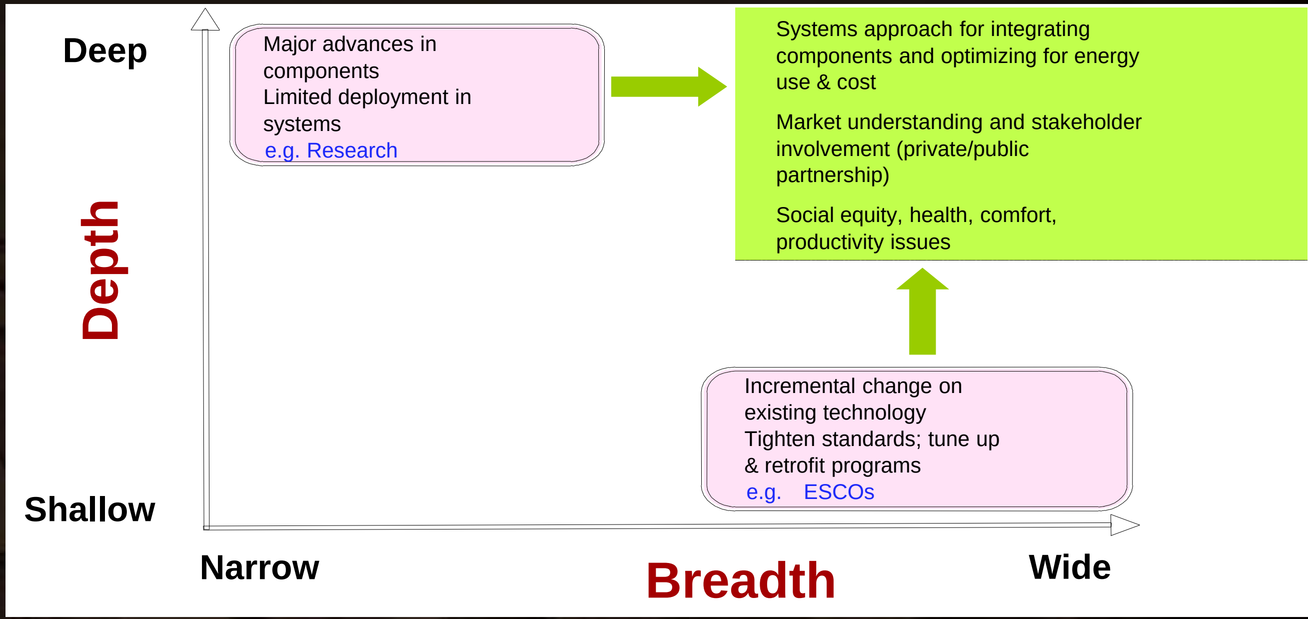
  - Difficult to articulate how to attack the problem from an industrial point of view

These are indeed the research areas supported and emphasized in ArtistDesign and COMBEST!!
CORE of the Energy Efficiency Challenges

# Key Summary Points

- Buildings are energy intensive
- Energy consumption must decrease by 50% in all retrofits and 90% in all new buildings by 2030
  - Urgent problem
  - New construction
  - Retrofits
- Gaps in design processes
  - Modeling tools, design processes, methods to achieve the 80% universally
- Gaps in operations
  - Controls, diagnostics, robustness, “how buildings really operate”, data assimilation
- Neither has been a focus of R&D to date
  - DOE has invested in incremental improvements of existing tools, methods and process
- Barriers in policy, economics and behavior




- Incremental and component level research programs are unlikely to “solve” the problem, i.e. produce the changes in energy use needed.
- Problem too large to be attacked by a single entity

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# World-wide Landscape:
# Energy Collaborative Research

Researchers at U.S. universities, led by Berkeley, **Stanford University** and the **Massachusetts Institute of Technology**, are targeting the $2 billion in energy research funds contained in the House recovery bill. The research dollars will produce jobs, reduce U.S. dependence on foreign oil and stem the production of greenhouse gases, according to the **Association of American Universities**, a group of 62 schools that conduct research.

Obama's New Energy for America Plan, as explained on the White House Web site, calls for creating five million jobs by spending **$150 billion**, over 10 years, "to catalyze private efforts to build a clean energy future."

Two major energy initiatives were launched in 2007: the Energy Biosciences Institute (EBI), a partnership of UC Berkeley, Berkeley Lab, and the University of Illinois, funded by BP with $500 million over ten years; and the Joint BioEnergy Institute (JBEI), a partnership of three national labs and three research universities in the San Francisco Bay Area, funded by the U.S. Department of Energy with $125 million over five years.

# Example of Grand Challenges-Use Inspired Research

- ARPA-E is a bold concept that will provide access to the funding needed to bring the next generation of energy technologies to fruition. Specifically ARPA-E aims to:
    - Enhance our economic security by identifying technologies with the potential to reduce energy imports from foreign sources; reduce energy-related greenhouse gas emissions; and improve efficiency across the energy spectrum.
    - Ensure we remain a technological leader in developing and deploying advanced energy technologies.
- ARPA-E will uniquely focus on high risk, high payoff concepts - technologies promising true energy transformations.
- ARPA-E director: Arun Majumdar, UC Berkeley and LNBL

Barack Obama and Steven Chu addresses

# Outcome & Milestone Roadmap

3 Years (2011)

- >50% reduction in energy consumption at the end of 3 years demonstrated in a “deep” retrofit with 10 year internal payback
- Develop methodology for scale-up with energy, health, comfort, and safety in mind
- Curriculum development tie-ins for training personnel
- Product communication protocols

5 years (2013)

- >70% reduction in energy consumption demonstrated in a “deep” retrofit with 20 year payback (projected mature cost)
- >80% reduction in energy consumption demonstrated in a new building with cost of conserved carbon below onsite new clean generation
- Demonstrate fully automated self-tuning continuous energy minimization at test facility with designed comfort and indoor air quality
- Demonstrate moderate scale up
- Develop regional market transformation programs for buildings industry

2016 2018 2030

NOW 2011 2013

7.5 years (2016)

- Tens to Hundred deep retrofit with >50% reduction in energy consumption with market averaged payback
- Tens of new buildings with 90% reduction in energy consumption with market averaged payback

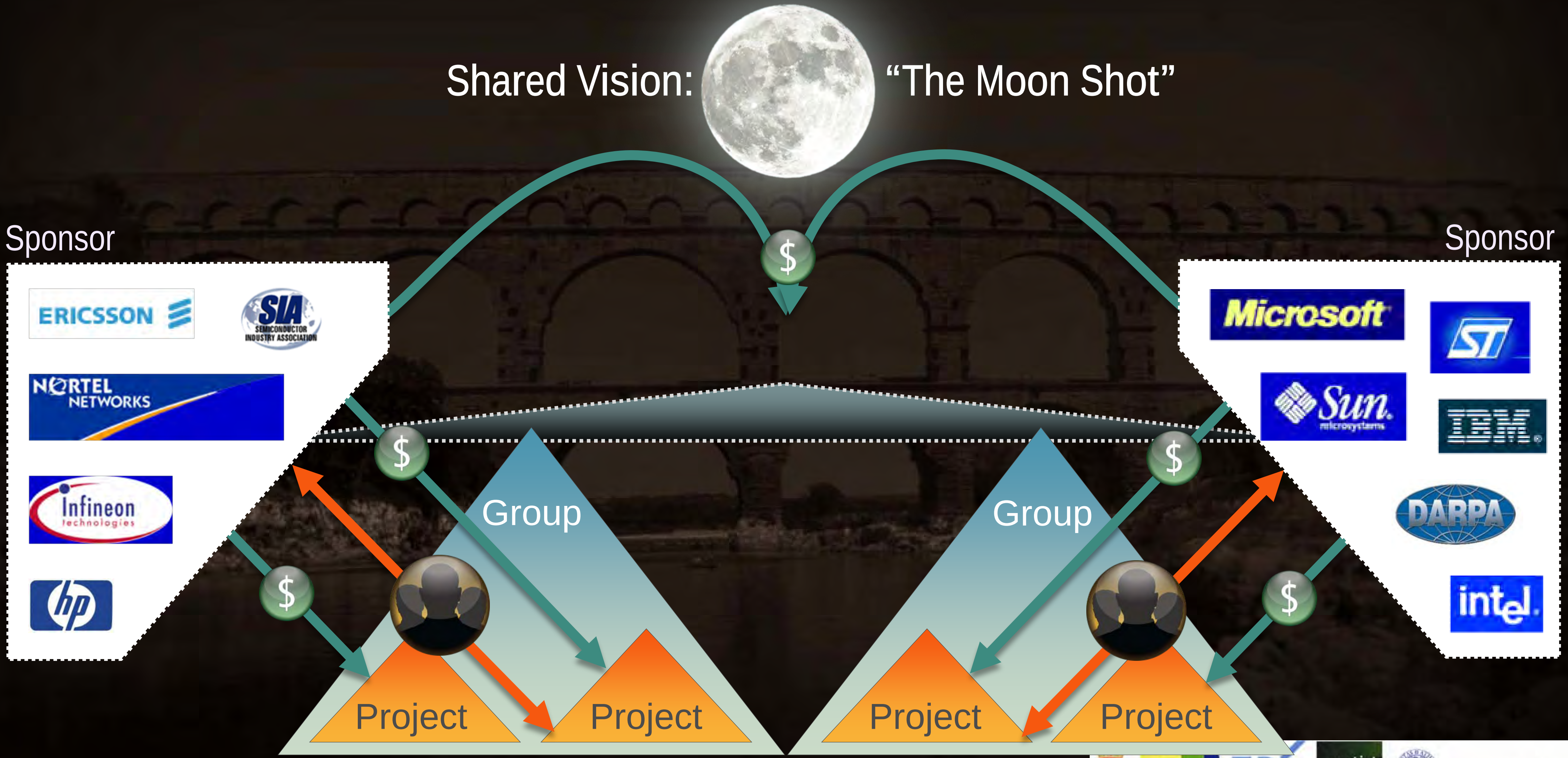
10 years (2018)

- Tens of thousands of buildings being deep-retrofitted (>50% reduction) annually [payback time]
  - Deploying fully automated self-tuning continuous energy minimization and indoor environment optimizing in retrofits and new buildings
  - Multiple service companies offering deep-retrofit capabilities with financing, remote monitoring, and performance guarantees
- Scale up for new buildings design and construction towards zero net energy and designed indoor environment and security with ~10-15 year payback time
- Several dozen hardware and software products available from private sector enabled with BOP protocols, and plug-and-play capability

CPUC Goals

All new commercial buildings in CA will be zero net energy

# Organizing for High-Impact R&D



# The “Moon Shot” Approach

- Use an overarching, long-range goal to organize and loosely direct the research
- Usually application-driven
- Organize the effort as a loose confederation of tightly-knit sub-projects
- Even if you don’t reach the moon, lots of good results will be produced

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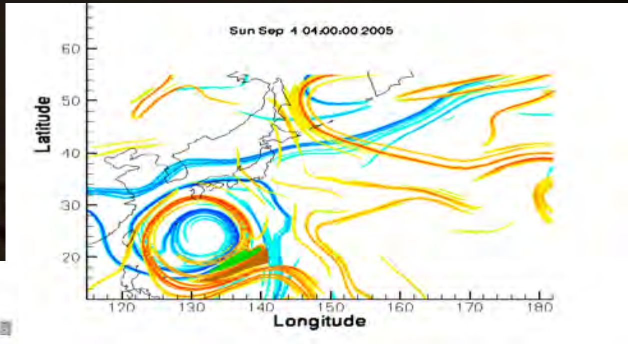
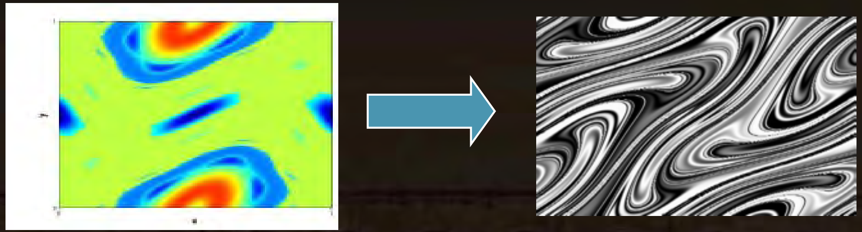
# Enabling Technology

**LBNL, UTRC, UC Santa Barbara, UC Berkeley, Stanford, UIUC**

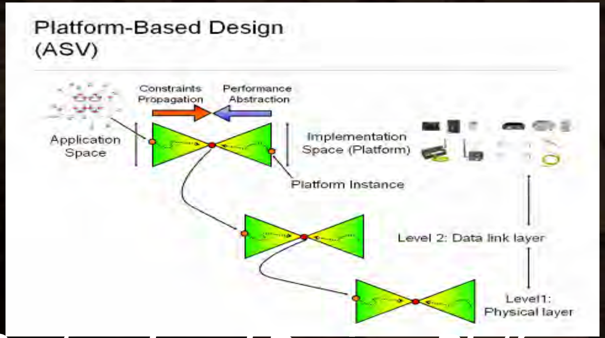
*Numerical Methods for Analysis of Mixing*



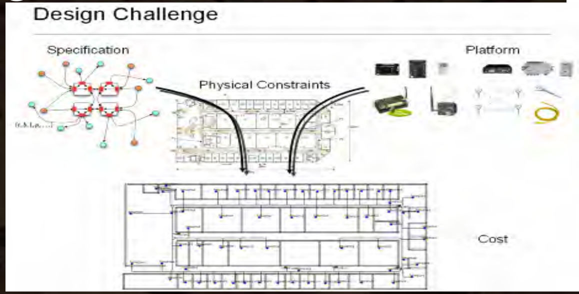

Safe and Immune Buildings



*Control of Mixing*



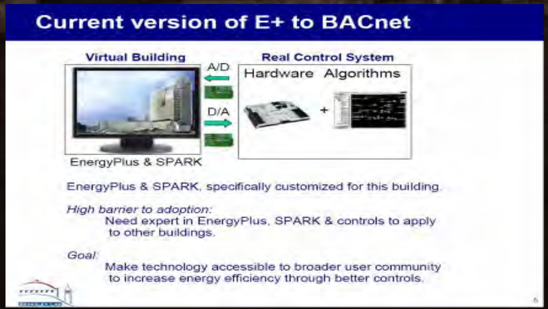

*System Level Design: Platform Based Design*




*Building Network Synthesis: Platform Based Design*

Net Zero Energy Buildings


Wireless Enabled Visibility of Energy Use




*Control Oriented Modeling and Design*

Energy Efficient Retrofits of Existing Buildings

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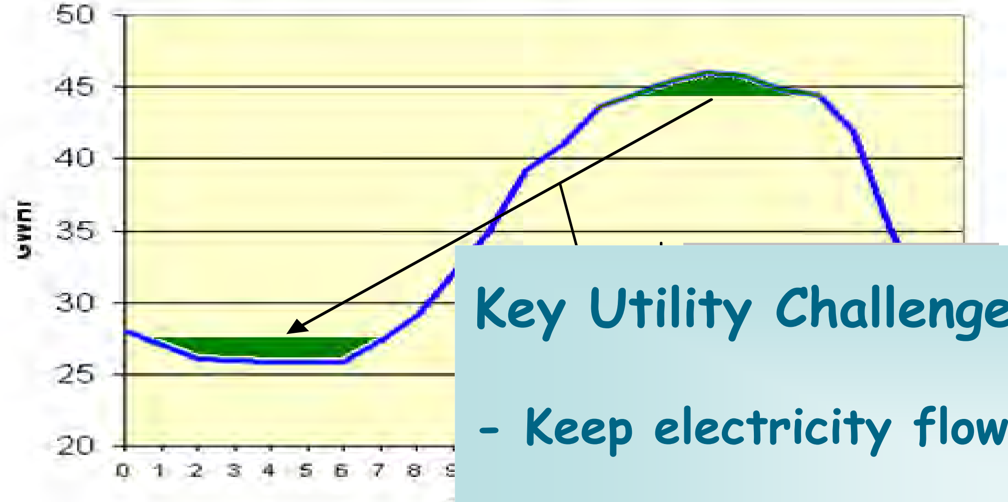
# Business Week: October 7th , 2009!

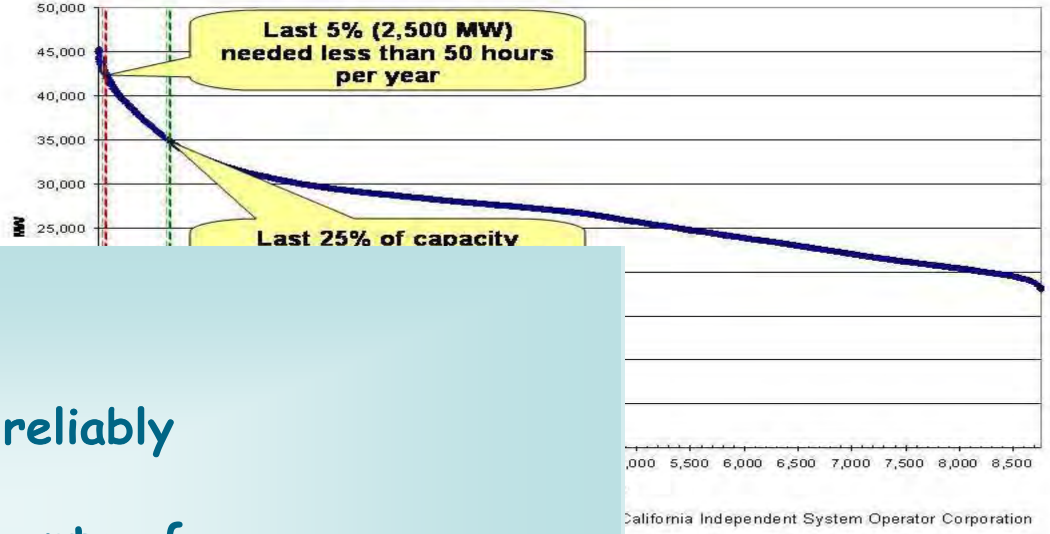
- Food producer Cargill is taking a carving knife to its electricity bills. At a plant in Springdale, Ark., where the company handles about 50,000 turkeys a day, electricity bills run more than $2 million a year. But **Cargill** thinks it can cleave $680,000 from the total by using its own generators on high-demand days. The secret behind this money-saving plan lies in what's known as the **smart grid**—a wholesale revamp of the system that distributes energy to homes and businesses around the country. Government bodies and utility providers are in the early stages of this multibillion-dollar upgrade to transform the existing grid into **a two-way network where power and information flow in both directions between the utility and the customer,** not just from the provider to the user.
- The Electric Power Research Institute, a nonprofit research and design group, estimates that it will **cost $165 billion, or roughly $8 billion a year for 20 years**, to create the smart grid. The market for the gear needed to overhaul smart-grid communications alone may reach **$20 billion a year in five years**, Cisco estimates. Other technology companies developing smart-grid software and hardware include IBM, Oracle, Google, and Siemens.

# Challenges for the 21st Century Utility

Peak Load is 2x greater than off-peak…



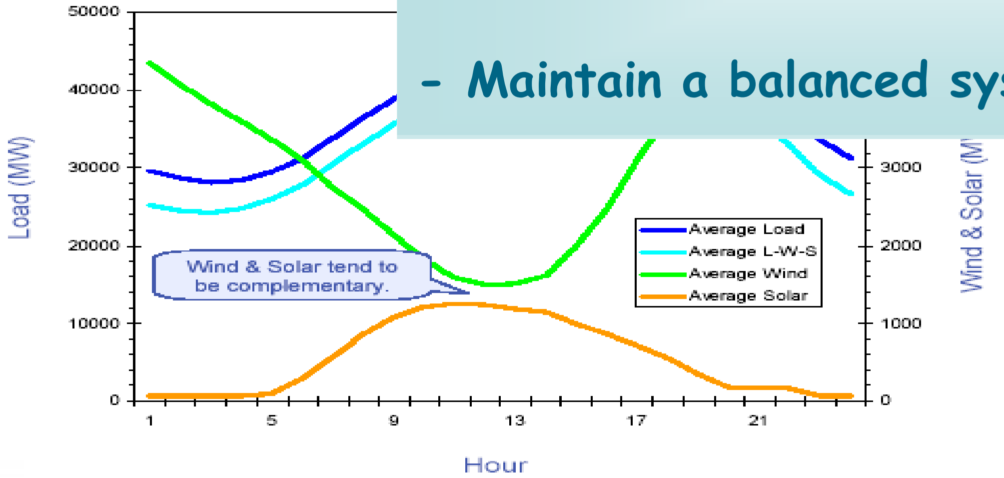

…leading to significant unutilized capacity

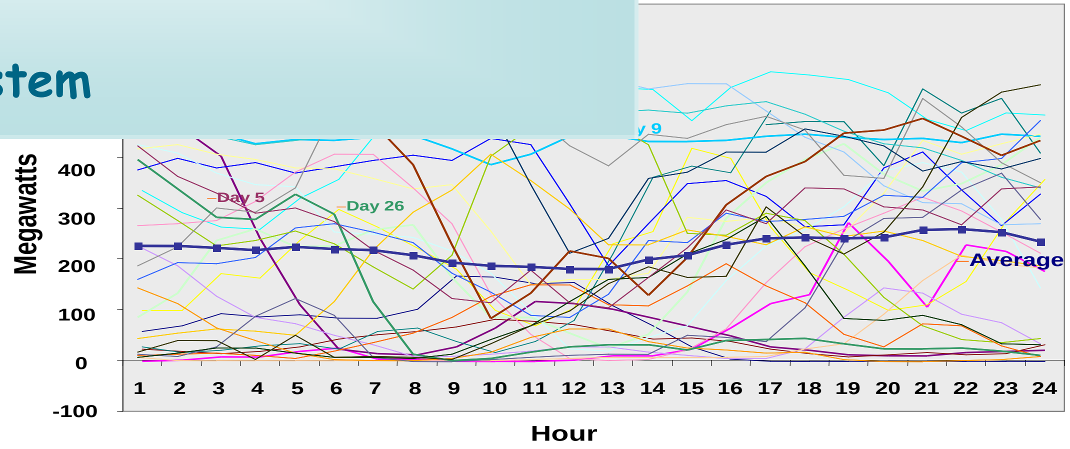



## Key Utility Challenges:

- Keep electricity flowing reliably
- Integrate increasing amounts of distributed and intermittent resources
- Maintain a balanced system

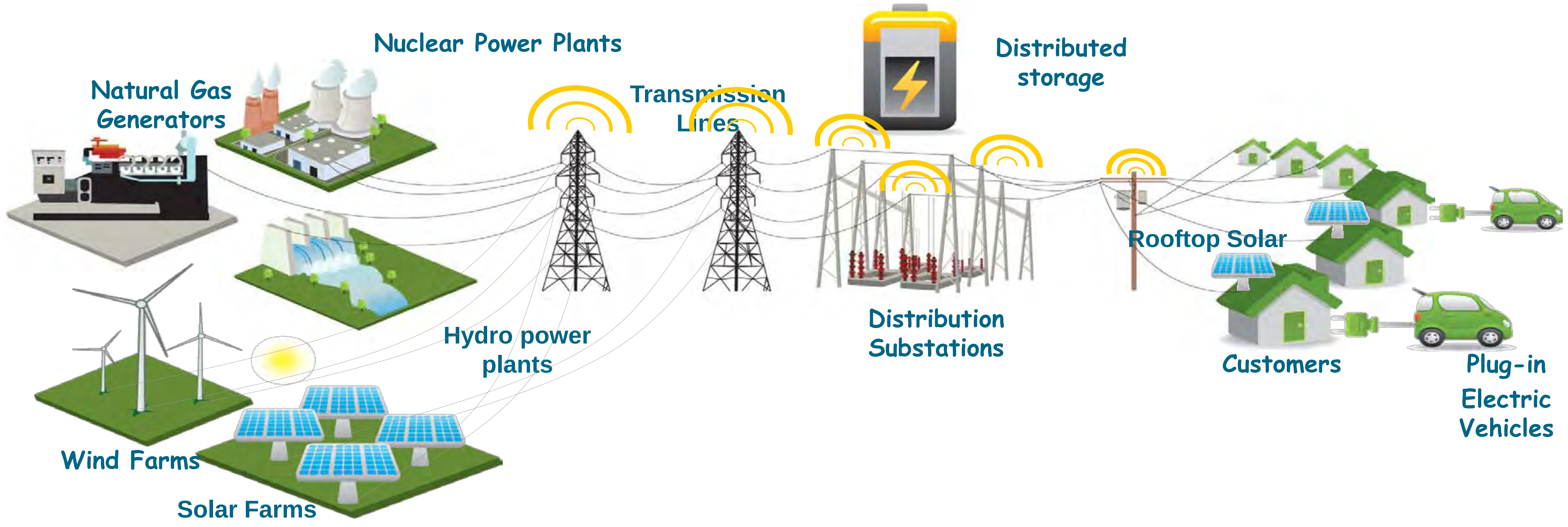
Wind and solar are non



# Large-scale Renewables and Distributed Resources Impact Supply and Demand Unpredictably…

## … Driving the Need for a Smarter Grid



# A Smart Grid

*Smart*

**Overlay with an "Intelligent" Infrastructure**

- Pervasive sensing and measurement devices
- Pervasive control devices
- Advanced data communications
- Computing and information management

Power Plants

Transmission Networks

Substations

Distribution Networks

Consumers

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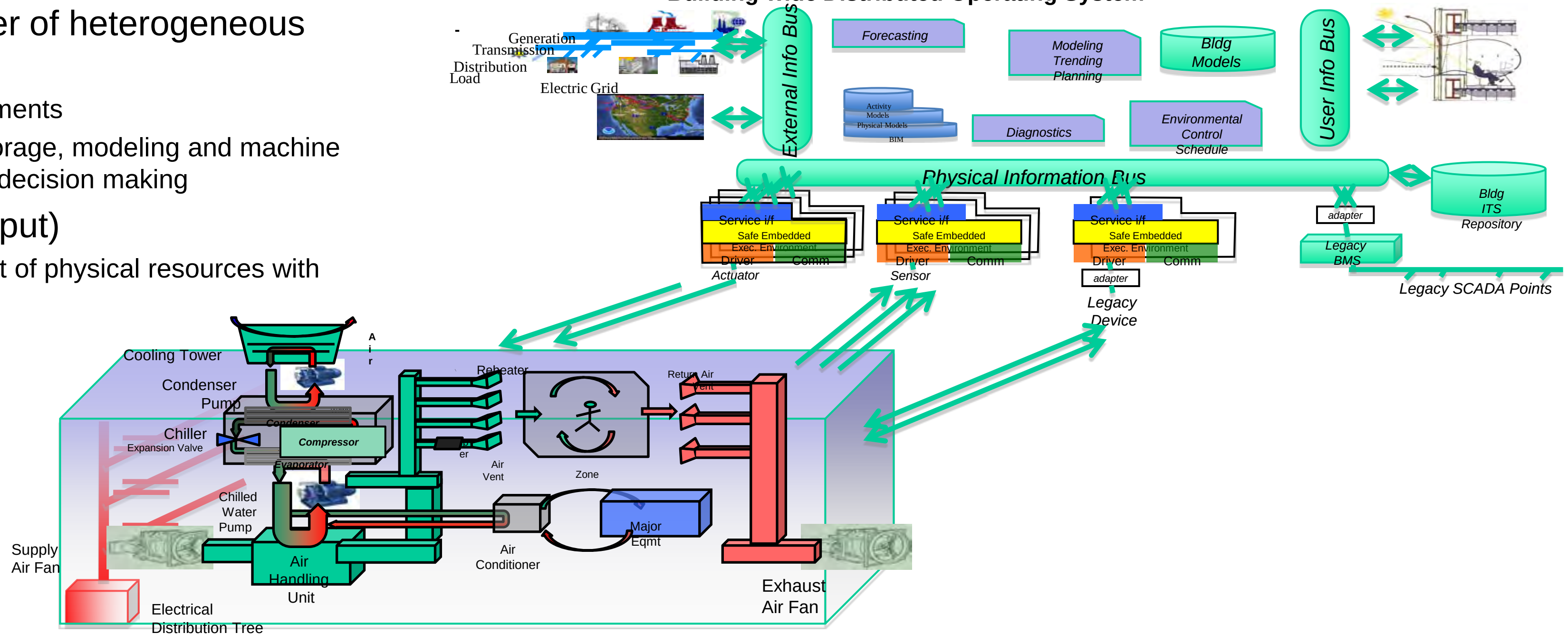
# Towards a Building-wide Integrated Operating System

- ❖Model-driven
  - ❖First principle, physics-based
  - ❖Data-driven, feature-based
- ❖Integration of large number of heterogeneous sensors and actuators
  - ❖Sensor, Information-rich environments
  - ❖Discovery, tasking, collection, storage, modeling and machine learning, visualization, on/offline decision making
- ❖Policy expression (user input)
  - ❖Interpretation and management of physical resources with respect to high-level policies
- ❖Security and privacy
  - ❖Fault-detection
  - ❖Isolation
  - ❖Recovery

**Building-wide Distributed Operating System**

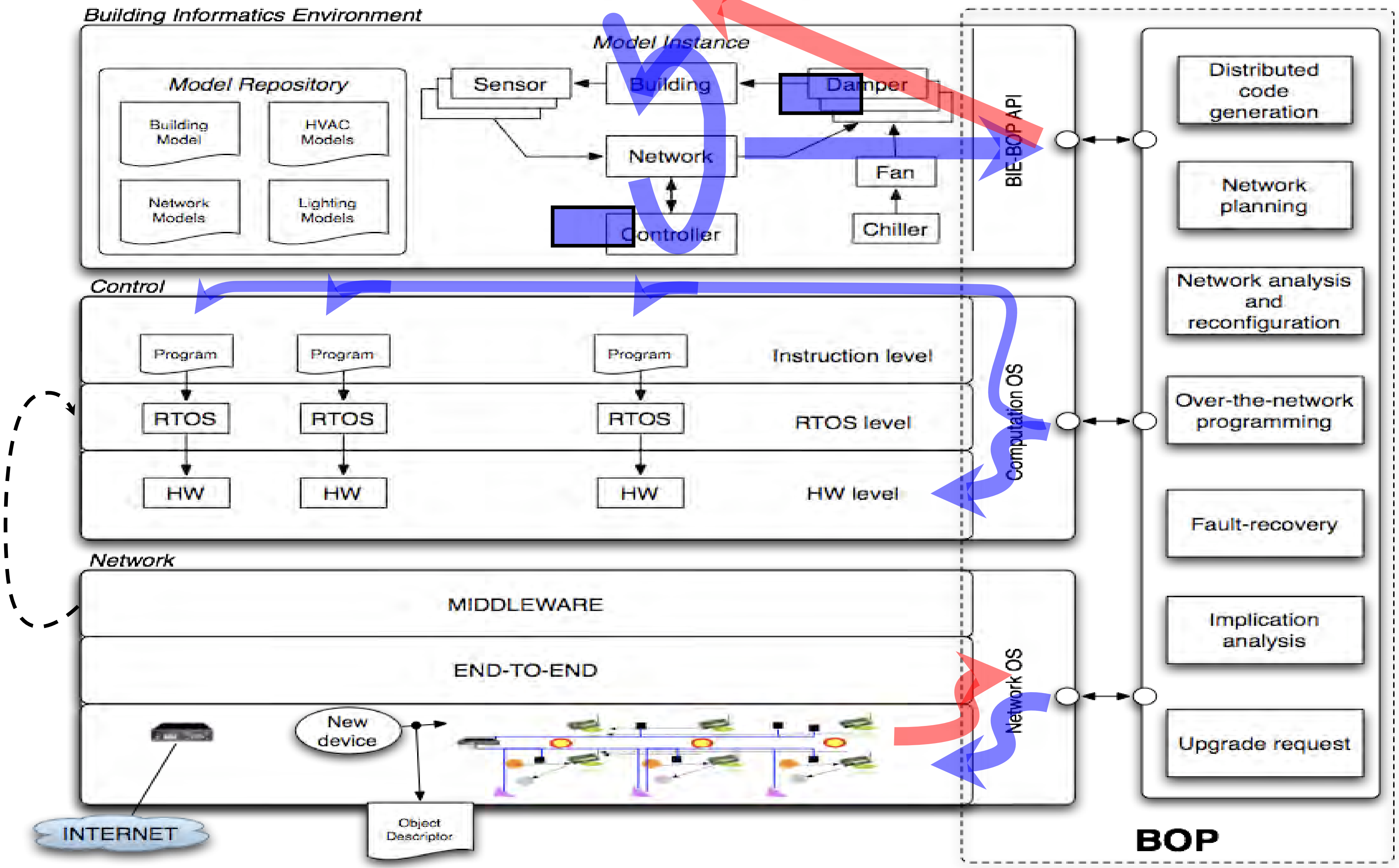



**Building Environmental Manufacturing Infrastructure**

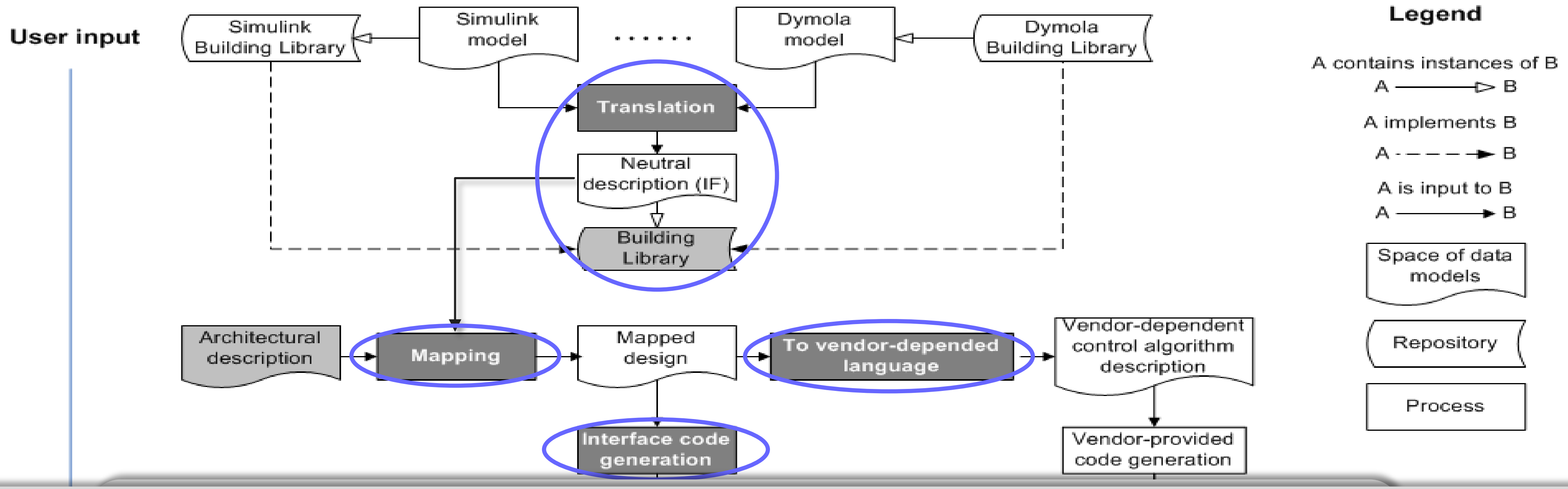
- ❖Static, model-driven commissioning
- ❖Building Management Systems (BMS)
- ❖Set-point driven control scheme
  - ❖Temperature, pressure, flow rates, motor speeds, louver positions
- ❖Set-points maintained at control points
- ❖Forgoes closed-loop feedback and dynamic modeling
  - ❖Building viewed as fixed structure

- ❖Individual building as part of larger Grid network
  - ❖IPSes inside building
  - ❖External negotiation for power through IPS
- ❖BIOS/IPS integration
  - ❖Management of user policies and IPS policies
  - ❖Load shifting/shedding working in concert with grid

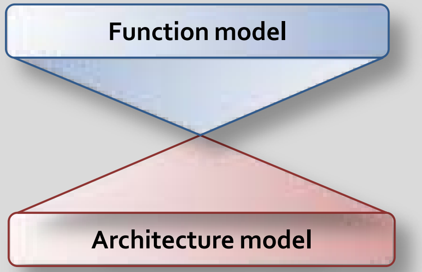
# Building Operating Platform



# Software Synthesis Flow




## *Mapping and Communication Interface*




**Objective**

- Minimize life-cycle cost

**Constraints**

- End-to-End latency constraints
- Utilization constraints

**Variables**

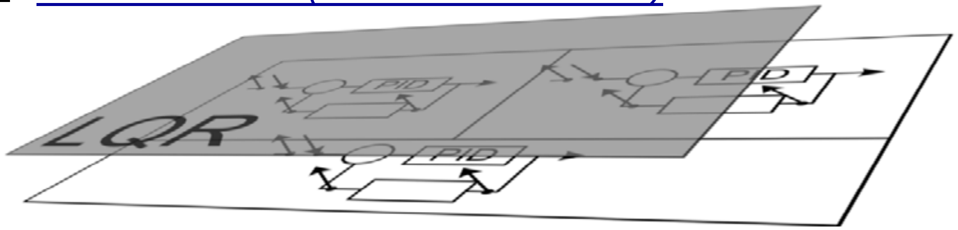
- Allocation of tasks to processing units
- Allocation of messages
- Assignment of priorities to tasks and messages
- Assignment of periods to tasks

To maintain behavior when distributing the system

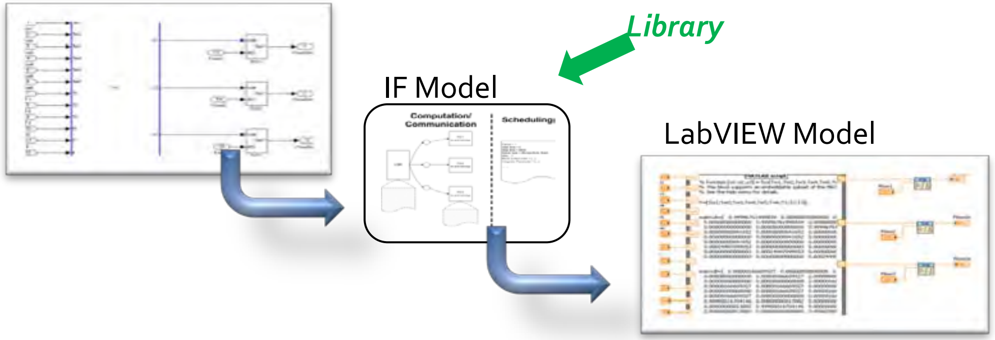
- Stream equivalence:
  Communication between tasks guarantee no loss of data, so that values of the data are kept the same as the original system.
  - Protocols to guarantee stream equivalence on LTTA *[Benveniste et.al, "Loosely Time-Triggered Architectures based on Commnication-by-Sampling", 2007]*
  - Application example: historical data storage.
- Real-time data:
  - Also guarantee the timeliness of data.
  - Add latency constraints according to time assumption in the functional model and resolve them.
  - Application example: real-time control systems such as HVAC and lighting control.

# Case Study - Hierarchical Room Temperature Control

## *Function model (two-level controller)*




## *IF Translation*




**Comparison of Simulink model and LabVIEW model**

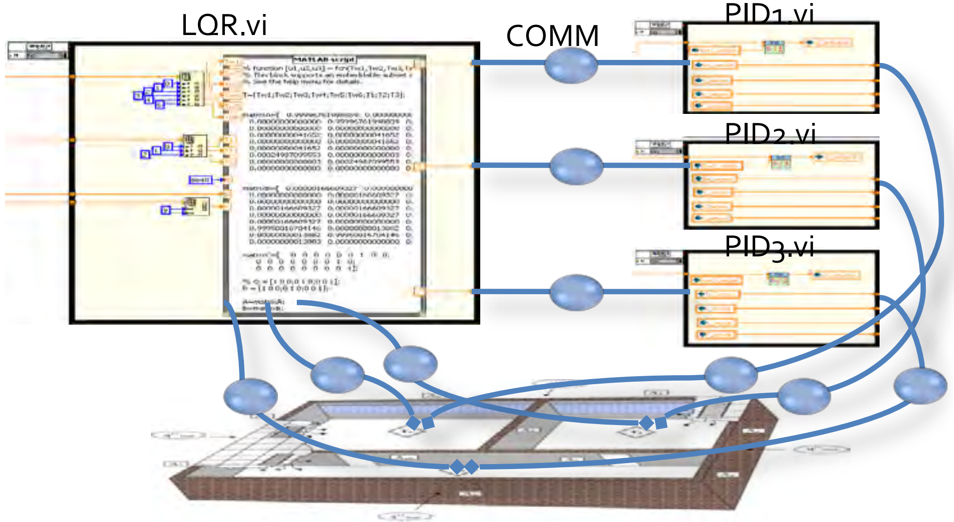
| Room Temp | Room1 | Room2 | Room3 |
|---|---|---|---|
| Average Difference | 0.304% | 0.304% | 0.419% |
| Maximum Difference | 4.36% | 4.36% | 4.63% |

| Cumulative Air Flow | Room1 | Room2 | Room3 |
|---|---|---|---|
| Difference | 1.38% | 1.38% | 1.53% |

- Part of the simulation differences come from PIDs
- Used a lower abstraction level for more precision, and reduced the difference by 10 times compared to the higher level translated model.

## *Mapping & Communication Interface*

- Use communication protocols proposed in *[Benveniste et.al, "Loosely Time-Triggered Architectures based on Commnication-by-Sampling", 2007]*
- Simulate the distributed model in LabVIEW
  - PEs with local clocks (different periods and offsets are set)
  - Communication modeling: 1. abstract latency annotation, 2. specific protocol (currently use TCP/IP).




**Comparison of centralized model and distributed model**

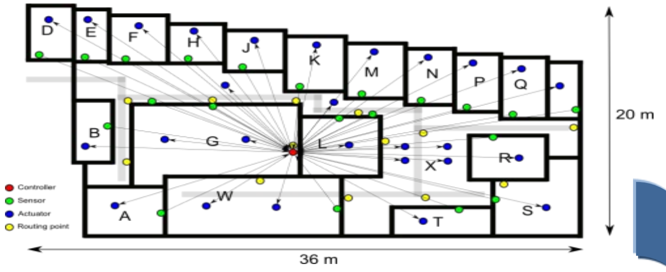
| Room Temp | Room1 | Room2 | Room3 |
|---|---|---|---|
| Average Difference | $9.81*10^{-3}$% | $8.72*10^{-3}$% | 0.0103% |
| Maximum Difference | 0.801% | 0.771% | 0.726% |

| Cumulative Air Flow | Room1 | Room2 | Room3 |
|---|---|---|---|
| Difference of Total Mass Flow | 0.0601% | 0.0556% | $9.52*10^{-3}$% |

# Communication Synthesis

*Building upon the COSI framework*

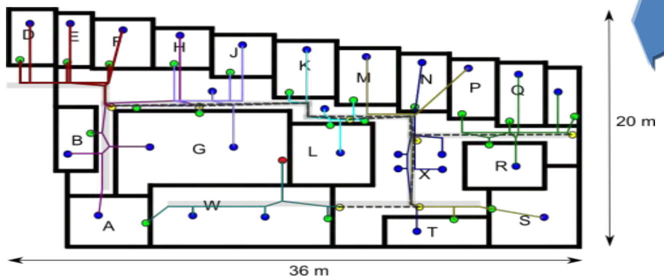
COSI Synthesis (DOP Center example)




Sensor to controller
-Latency: 0.3 s
-Message length: 8 bits
-Period :1 s

Controller to actuators
-Latency: 0.4 s
-Message length:16 bits
-Period:1 s

Network library
-Field bus 78kb/s (ARCNET)
-Field bus 2.5Mb/s (ARCNET)
-Constraints: topology, degree, length
-Two level hierarchical network



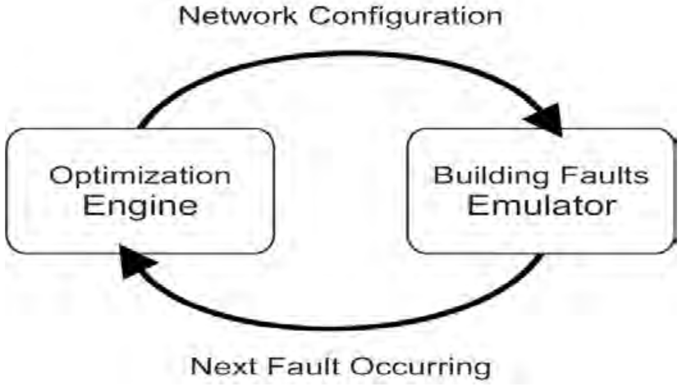

8 Networks (2.5Mb/s) plus a
high speed, second level network
-Estimated cost $21385
-Bus load: 96kb/s(min), 237kb/s(max),
139kb/s(avg), Networks are distance
and degree limited, not bandwidth limited

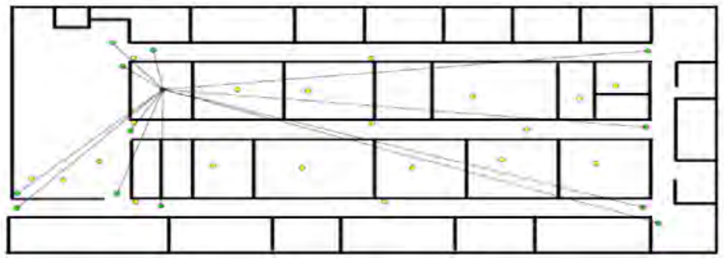
## Further development

- Added wireless models (Zigbee)
- Design flow and optimization for node placement and optimal routing
- Added scheduling of flows in beacon-enabled Zigbee networks
- Dynamic reconfiguration (started)

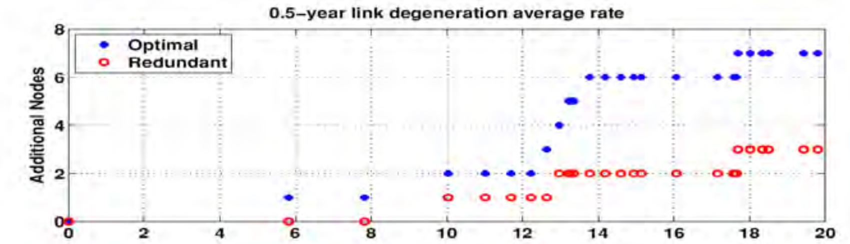
## Required effort

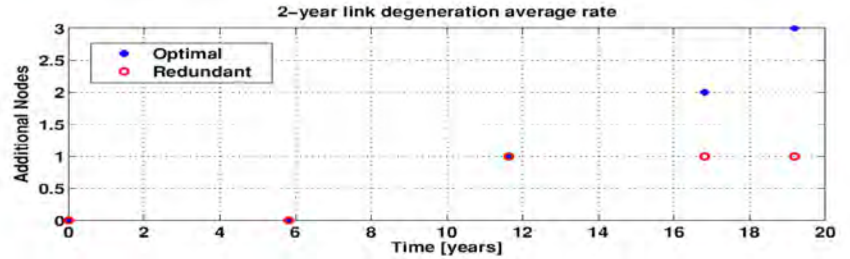
Development of NOS, diagnostics, reconfiguration



- Zigbee network
- Exponentially distributed link failures
- Node failure based on battery life
- Optimal re-routing



# Conclusions

- Energy Efficiency great challenge
- Substantial funding is available
- Lack of business clarity about go-to-market and approaches
- Concerted effort towards end-goal (moon shot not rocket science)
- Technology in ICT available to address energy efficiency
- Need system approach
- Opportunity to pull together separate communities