CEEMS – Cyber Enabled Energy Management of Structures

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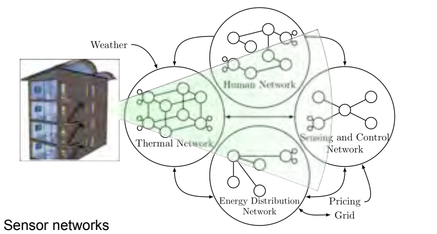
Structures as Cyber-Physical Systems



- Sensor networks
  - power flow, temperature, relative humidity, carbon monoxide and carbon dioxide.
- Actuation systems
  - cooling and heating systems, air flow, building access.
- Multiple physical domains
  - thermal dynamics, power flow, people flow
- Control systems
  - Thermal management, air quality management, energy management

Challenges and Opportunities

- Challenges
  - Increased Complexity:
    - New forms of on-site energy production and storage are expected
    - Sensor networks with a richer set of sensors are possible
  - Continuous Commissioning: Adaptation needed as building ages and uses change
    - United States Green Building Council suggests that a quarter of new buildings with LEED certification do not save as much energy as designs predicted - New York Times, “Some Buildings Not Living Up to Green Label”, August 31, 2009.
  - Multiple Objectives: Minimize energy use, emissions, cost
  - Activity Recognition: User behavior is a key element

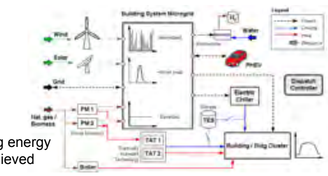
Thrust Areas

Application Specific
- Simulation and Optimization for Buildings and Integrated Energy Systems
- Cyber Enabled Building Energy Management Systems
- Activity Recognition

Application Inspired
- Interconnected Dynamic Systems - Identification
- Interconnected Dynamic Systems - Decision and Control

Simulation and Optimization

Objective:
- Develop methods for **simulation** and **design** of highly integrated, dynamic, building energy systems



Expected Outcomes:
- Quantify amount of building energy consumption reduction achieved
- Design methods for matching building TER, dispatch decisions, demand side management, system ‘right’ sizing, etc. under various objectives (min. cost, max. efficiency, min. carbon,…)
- Establish which multi-objective design optimization methods are most effective for building/building cluster energy system applications
- Establish performance metrics for optimization

Example Results:
- Multi-objective MILP optimization.
- Example result for optimization: Wind-PV-FC-Batt in Office Bldg:
  - Purchase of fuel cell generation show strong dependence on utility demand charges. Results highly sensitive to difference in natural gas and grid-electricity pricing

Energy Management Systems

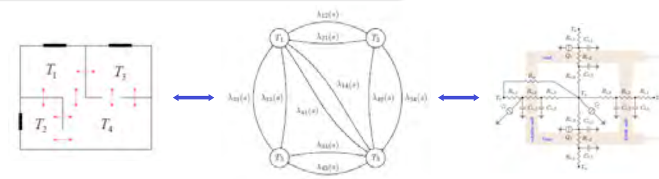
Objective:
- Cyber-enabled dispatch of energy in a building using multi-agent systems

Expected Outcomes:
- Topologies and methods for agent based building energy management
- Coordination and control for intelligent energy management
- Interface with utilities/service providers

Example Results:
- Cyber-enabled building energy management system (CEBEMS) approach
  - Distributed agent-based control
- Enabling technologies include:
  - Smart meters and inverters
  - Communication backbone in building
  - local on-site generation sources
- Optimization of agent behavior
  - Baseline simulation
  - Agent behavior optimization using MOLP

Interconnected Dynamic Systems

Unified Dynamic Graph Approach:
- Integrator nodes with rational interconnection weights
  - Nodes represent energy storage
  - Interconnections represent physical elements
  - Generalization of consensus network



Control

Objective:
- Develop or adapt analysis and design tools for interconnected dynamic systems typified by buildings

Expected Outcomes:
- Stability, controllability and observability analysis based on interconnection structure
- Control design for efficient dispatch of energy for control of temperature profiles in a building

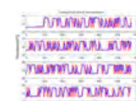
Example Results:
- Necessary conditions for stability and controllability based on graph interconnection structure

Identification

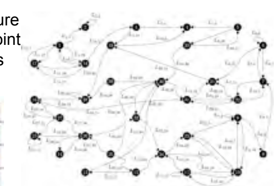
Objective:
- Exploit structure in system identification of interconnected dynamic systems

Expected Outcomes:
- Experimental design for building identification.
- Network models for dynamic behavior of buildings and related systems relevant to efficient energy operation.
- Methods for exploiting sparsity in system identification.

Given:
Zone temperature data with set-point perturbations



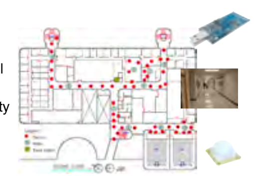
Find: Topology



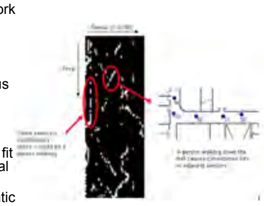
Activity Recognition

Objective:
- Develop new methods to represent and recognize activities of groups of people from low-level sensor network data

Expected Outcomes:
- System will discover activity models from observations, and amount of supervised training will be minimal
- Calculate of the probability density function for *n* people being in a room R at time Δt in the future



Example Results:
- Simple, low level sensor network data
  - Low cost sensors are more likely to be deployed
  - By using simple, anonymous sensors, we avoid privacy concerns
- Hierarchical approach
  - Hidden Markov models are fit to the data over small spatial and temporal scales
  - A probabilistic latent semantic analysis approach is used to characterize activities over larger scales



Outreach

- Summer 2010 and 2011: Presented Energy Efficiency Module as part of Summer Workshop at CSM for GK-12 teachers
  - 30 participants each year
- Presentation on energy storage and transfer in buildings,with hands-on experiments to measure latent vs. sensible energy, and the R-value of materials