Opportunities and Challenges in Broad Scale Deployment of Advanced Building Control Solutions

Sonja Glavaski
United Technologies Research Center
June 26, 2012
UTRC Team

Satish Narayanan, Sorin Bengea, Yiqing Lin, Russell Taylor, Shui Yuan, Draguna Vrabie
United Technologies

Business units

Otis

Pratt & Whitney

Sikorsky

Hamilton Sundstrand

UTC Climate, Controls & Security

UTC Power
Investing In Technical Excellence

Strategic themes...

- Renewable energy
  - PureCycle®
    - Geothermal power plant

- Revolutionary aircraft systems
  - X2 technology

- Advanced propulsion & power
  - PurePower®
    - PW1000G

- Enterprise security & safety
  - Intelligent security and fire detection systems

- Integrated high-performance building systems
  - Increase occupant comfort, safety, and security, while reducing energy usage and operating costs

Capabilities & expertise...

- Physical Sciences
- Systems
- Thermal & Fluid Sciences

United Technologies Research Center
Department Capabilities

Physical Sciences...
- Chemical engineering
- High temperature materials
- Materials analysis
- Applied mechanics

Systems...
- Cyber physical systems
- Control & modeling
- Embedded intelligence
- Decision support
- Power electronics

Thermal & Fluid Sciences...
- Acoustics
- Combustion
- Applied fluid dynamics
- Thermal management
Outline

- Building Energy Demand Challenge
- Role of Optimal & Adaptive Control in Reducing Building Energy Use
- Demonstrated Benefits of Model-Based Building System Control: Field Experience (High Performance Test Beds)
- Opportunities & Challenges in Broad-Scale Adoption of Advanced Control Solutions
Key Points

- Increasing energy efficiency in buildings is the fastest and most effective mean to meeting global energy demand

- Reducing energy use in buildings can be accomplished by integration of information and coordination of functions at supervisory level and managing heating, cooling, ventilation and other building functions on demand

- Broad-scale adoption of optimal control solutions is hindered by their current lack of robustness, and level of “field engineering” required

- Integrated tool-chains for automated generation of control algorithms and analysis tools for verification and validation of the algorithms are needed
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
Robust Building Operation Needs: Optimizing and Sustaining Energy Performance

- Buildings are subject to environmental disturbances
- Building energy performance is strongly tied to dynamical uncertainties (occupancy, weather) that are often ignored, leading to sub-optimal performance
- Existing building automation systems do not make component level energy consumption visible and they do not isolate sources of inefficiency
Role of Optimal Control in Reducing Building Energy Use

**Cost Driver:** Direct digital controls (DDC) specification and installation

- **Specification**
- **Installation**
- **Startup**
- **Commissioning**
- **Building occupation**

### BAS Cost Drivers

- **DDC Control:** 12%
- **Project Mgmt & Installation:** 18%
- **Engineering & Commissioning:** 50%
- **Other Material & Warranty:** 20%

### Sequences of operation

- General Products
- Execution

### Points list

- Single zone with economizer, VAV, CHW cooling and VFD

---

**United Technologies Research Center**

Test Bed 1
- Building Performance Monitoring & Controls (DOE)
- Whole Building Diagnostics & Controls (DoD)
- Energy Micro-grids (DoD)

Test Bed 2
- Integrated Building Energy & Safety (Tsinghua-UTC Institute)

Cities:
- Berkeley
- East Hartford
- Cork
- Shanghai

Institutes:
- Integrated Energy & Security Systems
Test Bed 1: Full-scale Optimal Control System Demonstration at UC Merced

District scale performance optimization by supervisory control

Team members: UC Berkeley; LBNL; UC Merced

- LEED Gold Central Plant (ALC and Carrier equipment)
- Coordinate chillers, pumps, cooling tower using thermal storage, weather and building load information
- 5% system efficiency gain demonstrated (2009-2010)
Test Bed 1: Supervisory Optimal Control Approach

Steady state equipment, semi-empirical dynamic load and dynamic thermal storage models integrated for off-line optimal control law generation and set point optimization

**GOAL:** minimize energy costs by planning chilled water plant operations over 24 hour horizon

**MODEL-BASED CONTROL DESIGN**

- **MODEL** components responsible for chilled water generation, storage, distribution, and consumption

- **CALIBRATE** model parameters using manufacturer data and measured historical data and **VALIDATE** calibrated models against historical campus data (within 5-10% energy)

- **OPTIMIZE** chilled water plant run time and set-points by coordinating chilled water generation, storage, and consumption over prediction horizon
Lessons learned

- Challenges for optimal loading of chillers
  - Impact of weather and load uncertainties on critical optimization variables
  - Constrained actuation due to unknown health status of the equipment and safety margins
  - 2 chiller configuration constraint results in lower efficiency than 1 chiller configuration
  - Equipment level controllers (PID) needed re-tuning to enable new set-point tracking
Test Bed 2: Building-scale Control Demonstration at CERL

Optimization based supervisory control to reduce HVAC system energy use

Team members: UC Berkeley; ORNL; ACE CERL

- Estimate and predict loads (weather, occupancy)
- Data-driven and reduced-order steady-state models of equipment (coils, fans) and dynamic models of loads (occupancy, zone temperature dynamics)
- Vary hot/cold deck heating/cooling air temperature set points, zone & Outdoor Air ratio airflow rates
Test Bed 2: Integrated Building Control System Performance

Average energy savings at HVAC system level ➙ System/plant set point optimization

Occupant temperature & CO₂ constraints met
Advanced Building Controls Deployment: Opportunities

Current State

- Heterogeneous models (combination of steady state look up tables, switching behavior, static nonlinear performance maps, dynamic behavior) not amenable to on-line optimization
- High cost (manual/labor intensive) and complexity of controls specification/design, configuration, installation and commissioning
- Solutions not always optimal and subject to system/equipment degradation and building usage changes

Desired State

- Hybrid models with guaranteed performance and tools for rapid model calibration and validation (Startup)
- Tool-chain that will automatically extract optimization problem formulation from simulation models (Commissioning)
- Tools for automatic Validation & Verification of control system under various load & weather scenarios (Installation)
Challenges

- Development of accurate disturbance models (loads, weather) used for prediction
- Robustness of optimal solution and convergence time of large-scale, non-linear hybrid systems, for wide range of disturbances
- Formulating optimization problem (in a standard format to be used by solvers) automatically and accurately from simulation models