CPS: Methods for Network-Enabled Embedded Monitoring & Control for High-Performance-Buildings

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Introduction and problem statement

Background

- Buildings account for 40% of total U.S. energy use, 70% of electricity, 38% CO2 emissions.
- HVAC and lighting consumes up to 50% of total energy used in a typical building
- According to Department of Energy estimates,

> Better monitoring and control can deliver up to 50% improvement in HVAC energy usage

Challenges

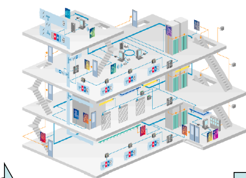
- A building is a complex cyber-physical system: Physical system comprises of uncertain and time--varying dynamic processes (e.g., temperature, occupancy) with multiple spatial and temporal scales; Cyber system comprises of thousands of sensors and actuators in large commercial building
- Every building is unique: cost considerations rules out custom solutions for control, communication, and computation algorithms
- Constraints: Sensing and actuation limitations, bandwidth limitation, computation platforms, deployment and maintenance costs
- Building dynamics and equipment properties change with time: need for adaptation

Research goals

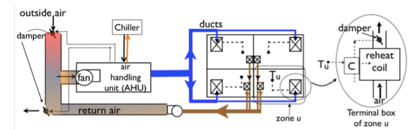
- Develop *methods for the operation and design* of the building cyber physical system
- Methods for operation: distributed estimation and control algorithms which will be used to estimate processes such as occupant and temperature distributions, and control HVAC systems
- Methods for design : set of methodologies for automated design of the network of embedded devices to perform communication and computation for estimation and control.

Technical approach

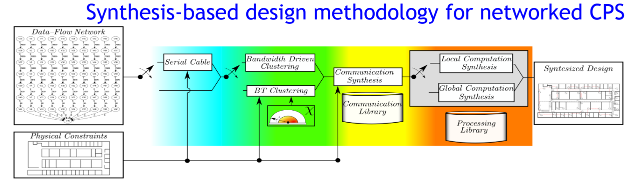
- Prediction and learning-based control of physical and cyber-systems
- Online learning algorithms to adapt to slow variations in the physical system
- Synthesis-based design methodology for networked cyber-physical system



Control, communication computations



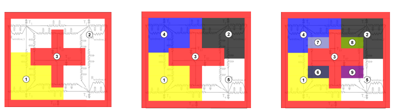
Synthesis-based design methodology for networked CPS

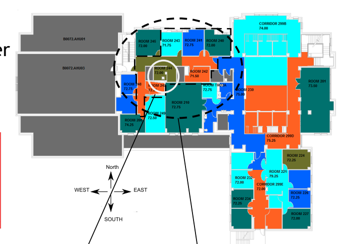


- Input: application task specification, constraints, technology libraries
- Design steps: task clustering, communication and computation synthesis
- Output: optimal execution platform architectures for given application and physical constraints

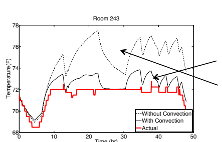
Thermal model identification and order-reduction

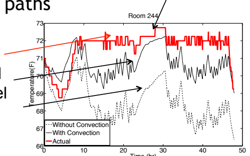
- Structure preserving non-linear model reduction
  - A large number of zones aggregated to a smaller number of zones
  - Incorporates non-linearities due to moisture

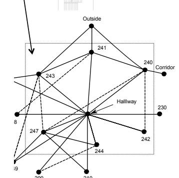




- Closed loop identification of convection paths

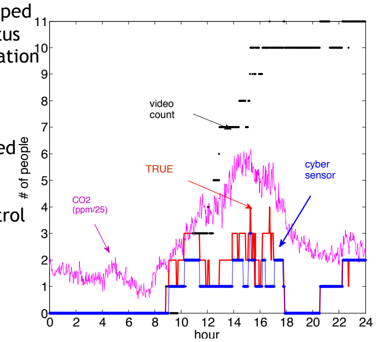






Occupancy measurement and prediction

- Measurement of occupancy
  - "Flow based" sensors accumulate error due to integration
  - Novel cyber sensor developed
    --- computer idle/active status
    --- eliminates error accumulation
- Occupancy modeling
  - statistical models developed
  - Graphical models
    - On-line adaptation
- Integration with building control
  - test-bed development



Test-bed development

- Test-bed : Pugh Hall @UF
  - > server with a BACnet stack
  - > Parallel to BAS
  - > all actuators can be commanded at high frequency
  - > High frequency data collection
- Integration of various new sensors ongoing

(*) K. Deng, P. Barooah, P. G. Mehta, and S. P. Meyn. *Building Thermal Model Reduction via Aggregation of States*. American Control Conf. July 2010

(**) Siddharth Mehta, Chenda Liao, Prabir Barooah, Identification of multi-zone building thermal interaction model from data, IEEE CDC, December, 2011

[o] S. Goyal and P. Barooah, *A lumped model for simulating thermal and IAQ dynamics in multi-zone buildings*, Tech Report, University of Florida, 2010