Sponsored by: NSF Grants CNS-1446582 & CNS-1446478

THE OHIO STATE UNIVERSITY

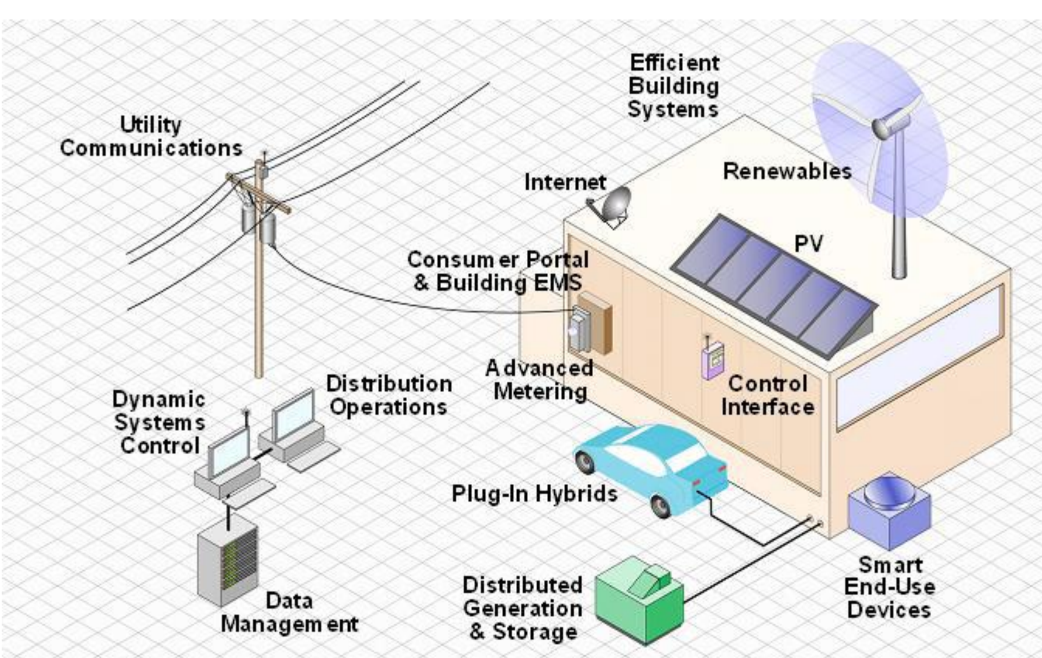
Virginia Tech

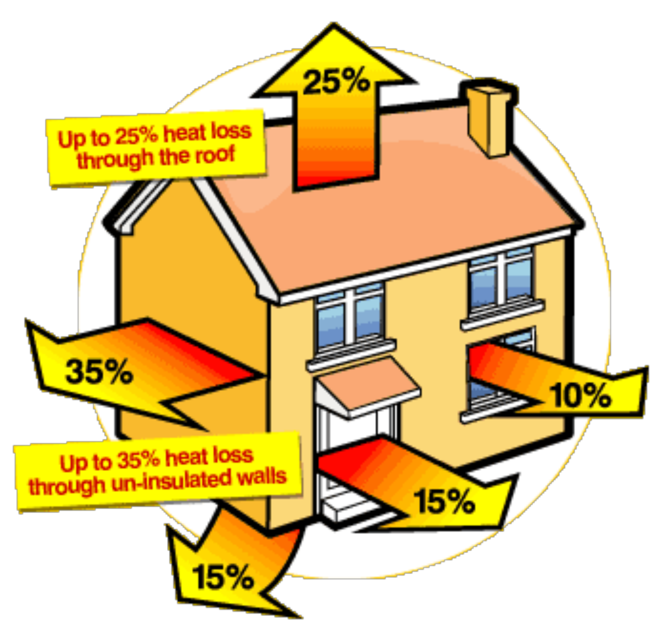
Cognitive Green Building: A Holistic Cyber-Physical Analytic Paradigm for Energy Sustainability

Ness Shroff (OSU), Qian Chen (OSU), Thomas Hou (VT), Wenjing Lou (VT)

Research Motivation

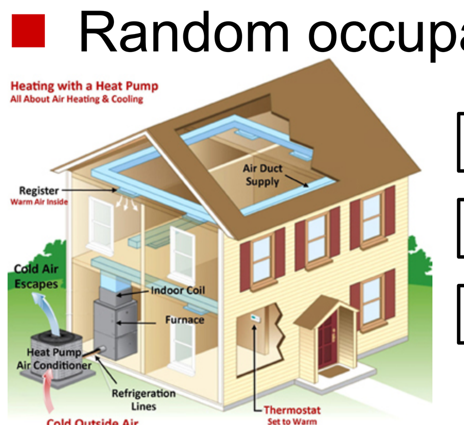
- Future buildings are highly-engineered systems integrating **cyber** (sensing, communication, computation, & control) and **physical** (active/passive civil infrastructures) subsystems
- Buildings are **inefficient**: Use 39% of energy, consume 70% of electricity, and account for 39% of CO_2 emissions
- Current green building designs are simply organized around a set of energy consumption benchmarks (e.g., LEED) **without taking a holistic CPS** viewpoint.

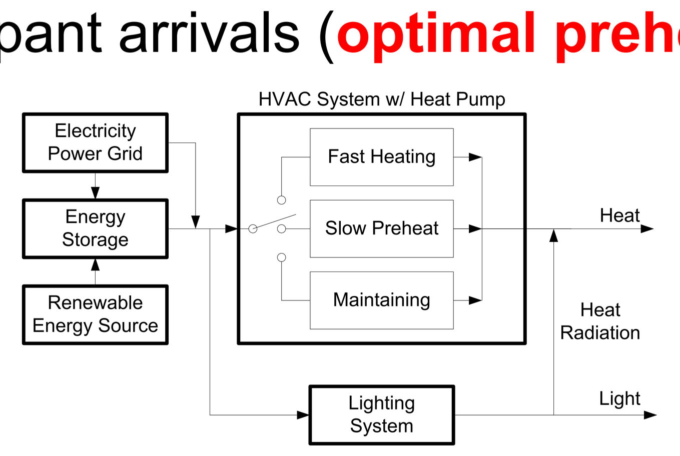


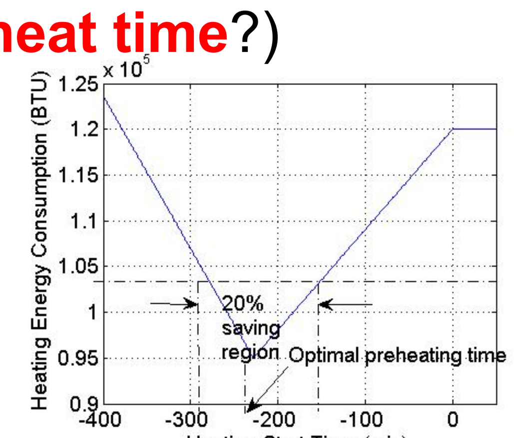


Building Energy Elasticity: A Motivating Example

- **Simulation Study**: A building with heat pump in heating mode:
  - Slow preheat (most efficient, but slow), Fast heating (least efficient, but fast), and maintaining
  - Random occupant arrivals (**optimal preheat time**?)



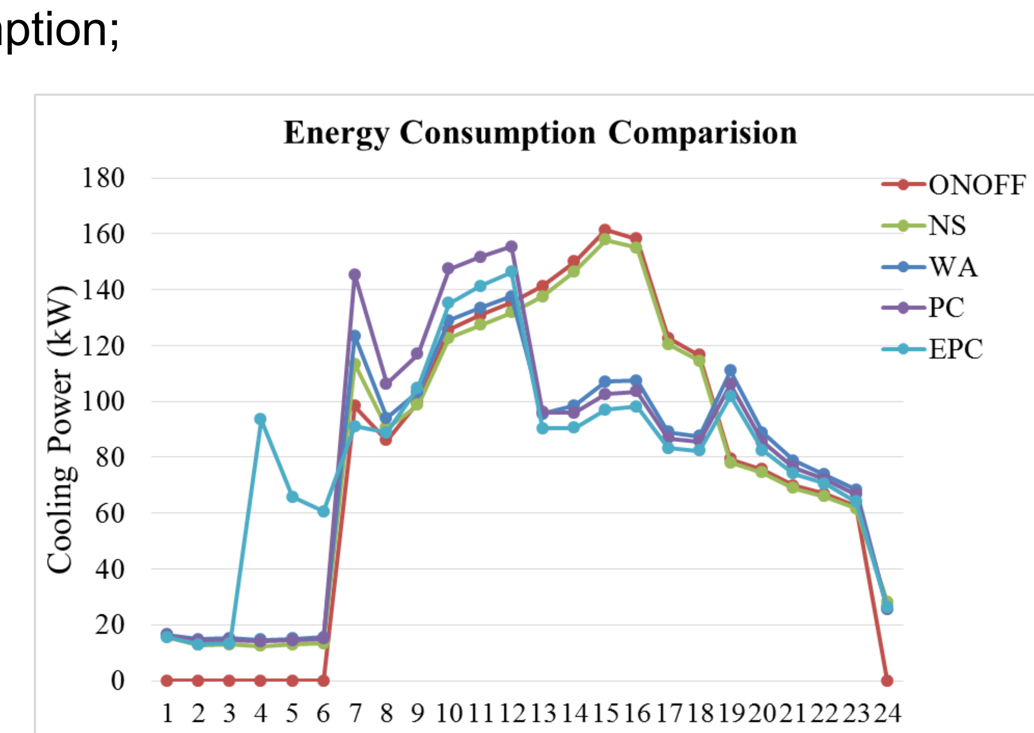




Observation: 54% energy saving under optimal preheat strategy; At least 20% saving as long as in 1-hour window containing optimal preheat time

Precooling Strategies Studies

- **Research Tasks**:
  - Compare 10 HVAC scheduling strategies on minimizing peak load, total energy consumption, and total energy cost based on simulations
  - Develop analytical optimization formulations based on R-C thermal transfer models for optimal precooling scheduling
  - Develop low-complexity algorithms to solve the formulated precooling problem with strong performance guarantee
- **Main Results:**
  - Choosing 25°C as night-setback temperature results in near optimal cooling energy consumption;
  - All the demand limiting (DL) strategies help reduce the peak load and the Load Weight-Averaging method performs the best.
  - The Extended Precooling (EPC) strategy combined with DL further reduces the peak load during the on-peak hours.



Our Approach

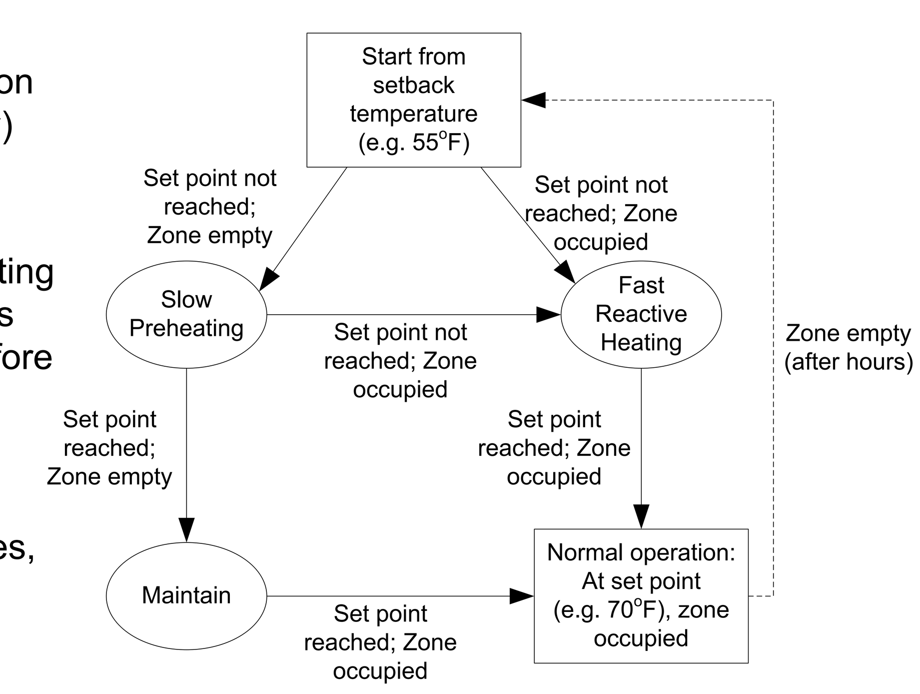
- Consider complex interactions between systems of systems, provide high degree of security, agility, and robustness:
  - **Intra-Building Integrated Energy Management**: Develop *cognitive* control schemes to adapt to: i) demand elasticity, ii) human comfort zones, and (iii) ambient environments
  - **Managing Multi-Building Interactions**: Ensure that not only are the energy costs minimized, but also *no instabilities* caused in the power grid due to myopic actions.
  - **Coping with Anomalous Conditions**: Building energy management under both physical (extreme weathers) and cyber (e.g., malicious cyber-attacks).

A unified analytical foundation for green building design that comprehensively manages energy sustainability.

Cognitive Intra-Building Integrated Energy Analytics

HVAC State Transitions

- If occupant arrives earlier than preheat starting time, then HVAC must be turned on immediately and fast heating (most costly) will be used
- If occupant arrives later than preheat starting time, then HVAC starts slow preheating as scheduled. But once occupant arrives before preheating reaches set point (e.g., 70F), HVAC switches to fast heating mode.
- If sufficient time before an occupant arrives, then HVAC goes through slow preheating and then maintaining mode (least cost).



Problem Formulation

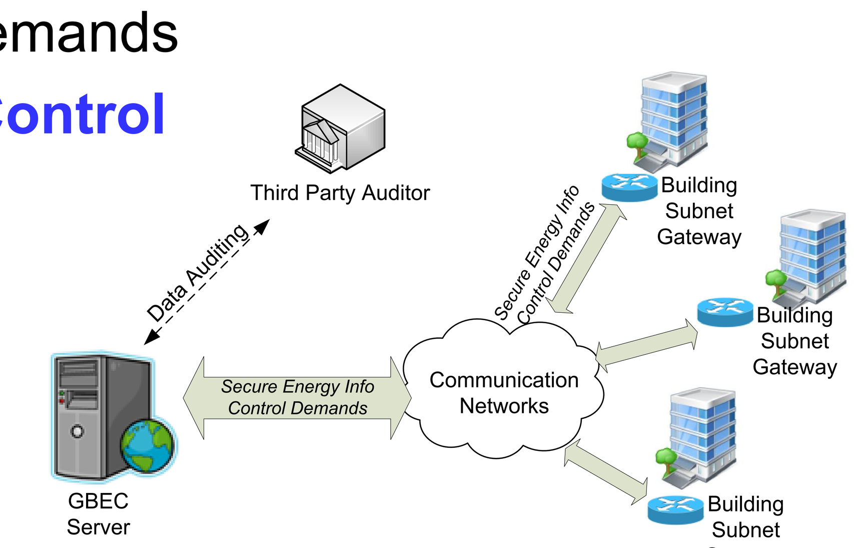
$$\text{ECM:} \min_{s,b(\cdot)} \left\{ \mathbb{E}\left[\bar{C}(s,\eta,\beta,b(\cdot))\right] \middle| \begin{array}{l} \text{HVAC heating modeling constraints in a);} \\ \text{Renewable energy storage dynamics in b).} \end{array} \right\}$$

- **Research Tasks**:
  - Understanding fundamental limits of **elastic** energy saving with **human comfort zone**.
  - Understanding **spatial** impact on building energy control.
  - Exploiting **statistical** information of renewable energy **inelasticity**-based building energy minimization.

Building Energy Analytics for Anomalous Conditions

- **Sustaining Building Energy Supply under Extreme Weather**

  Maximize the lasting days of local energy generation/storage while meeting basic energy demands
- **Cyber-Security for Energy Control**
  - Autonomous **context-aware key management** for building energy sensors
  - **3rd-party** data integrity verification for **cloud-based** energy control server



Selected Recent Publications

- J. Liu, "High-order Momentum: Improving Latency and Convergence for Wireless Network Optimization," in Proc. IEEE INFOCOM, Honolulu, HI, Apr. 2018.
- F. Wu, Y. Sun, L. Chen, J. Xu, K. Srinivasan, and N. B. Shroff, "High Throughput Low Delay Wireless Multicast via Multi-Channel Moving Window Codes," in Proc. IEEE INFOCOM'18, Honolulu, HI, Apr. 2018.
- Q. Chen, "Challenges in Developing Teaching Effectiveness and Scholarship through Service Learning Projects," in Proc. the 54th ASC International Conference, Minneapolis, MN, Apr. 2018.
- H. Shi, J. Liu, and Q. Chen, "HVAC Precooling Optimization for Green Buildings: An RC-network Approach," in Proc. the 9th ACM International Conference on Future Energy Systems (ACM e-Energy), Karlsruhe, Germany, Jun. 2018.