District Energy Management

Optimal Control Strategies of Seasonal Storage Devices

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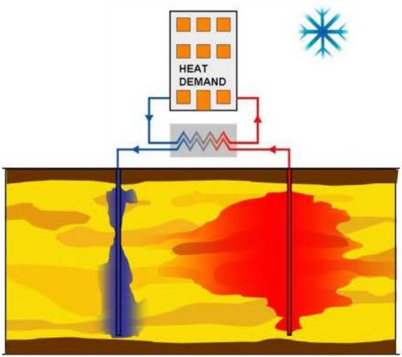
Aquifer Thermal Energy Storage (ATES)

- A large-scale natural subsurface storage for thermal energy
- An innovative method for thermal energy balance in smart grids

Cold season:

- The building requests thermal energy for the heating purpose
- Water is injected into cold well and is taken from warm well
- The stored water contains cold thermal energy for next season



Aquifer Thermal Energy Storage (ATES)

- A large-scale natural subsurface storage for thermal energy
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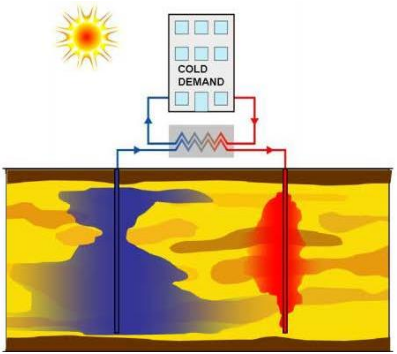
Warm season:

- The building requests thermal energy for the cooling purpose
- Water is injected into warm well and is taken from cold well
- The stored water contains warm thermal energy for next season



Smart Thermal Grids: ATES Systems

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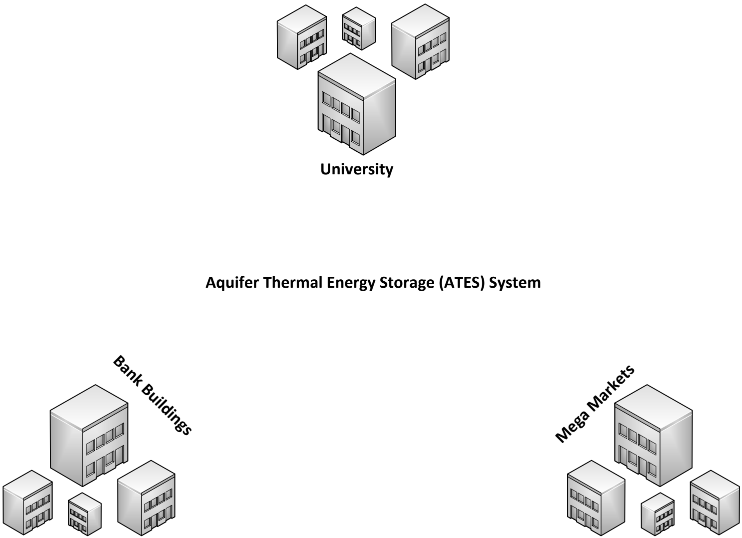

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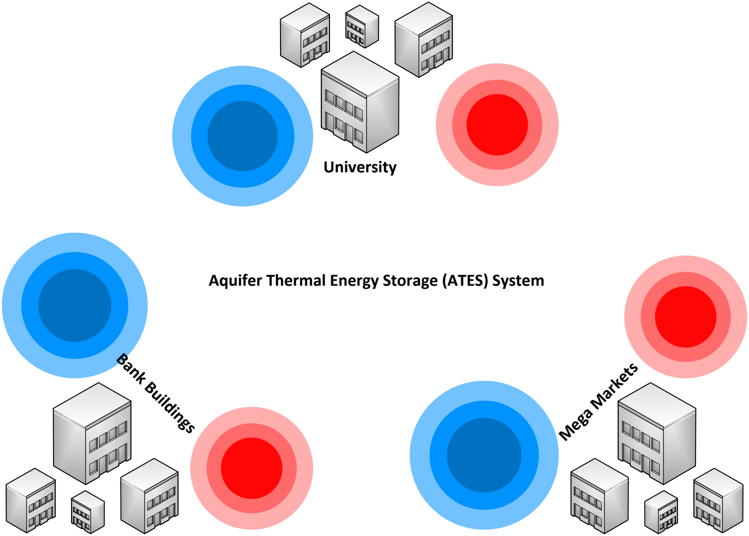

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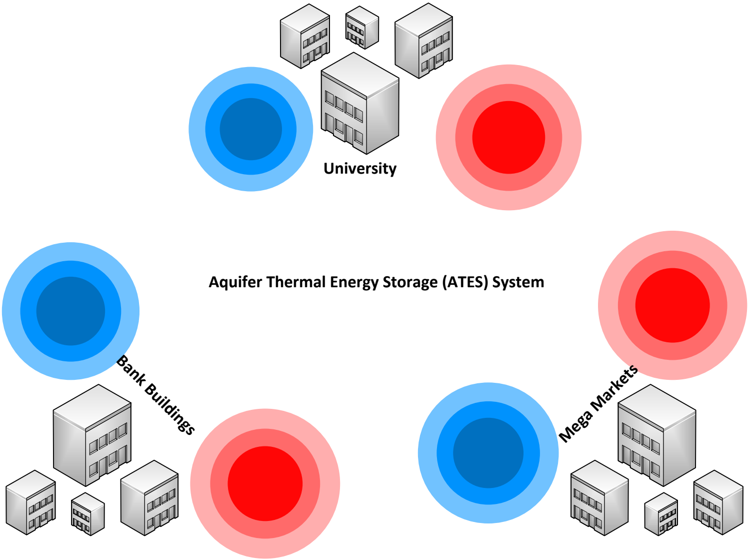

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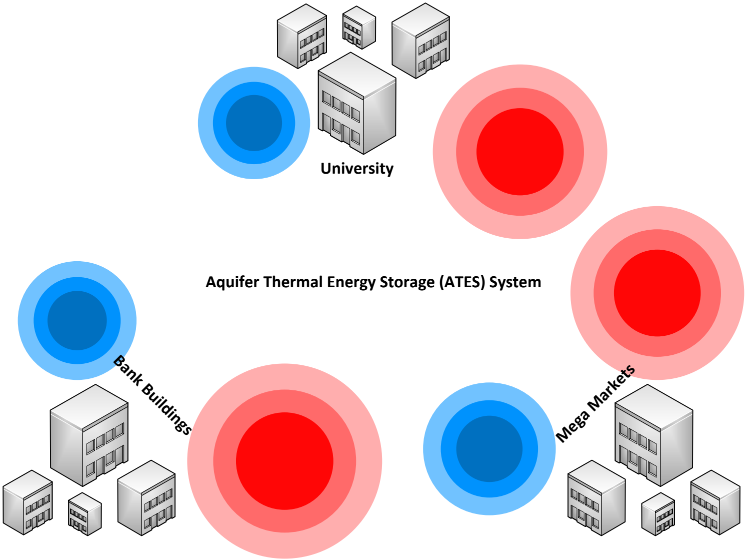

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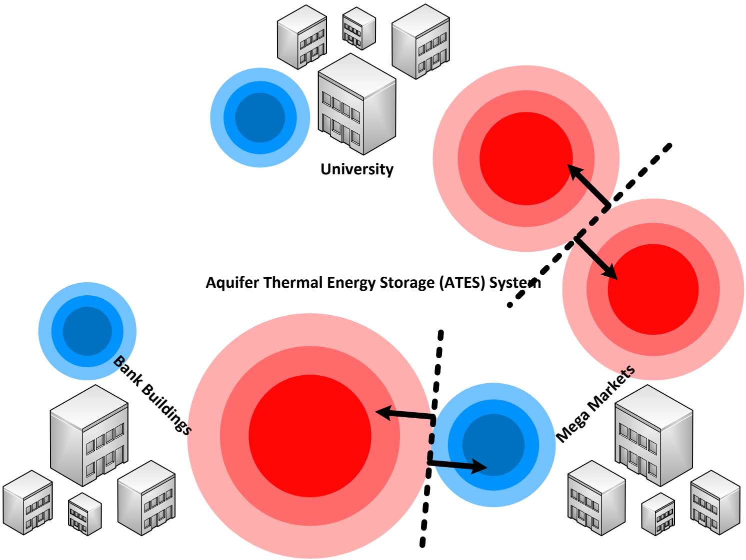
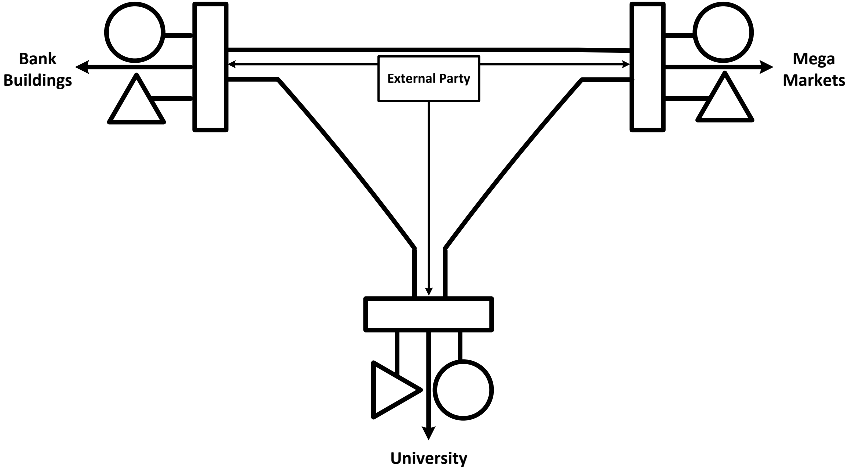
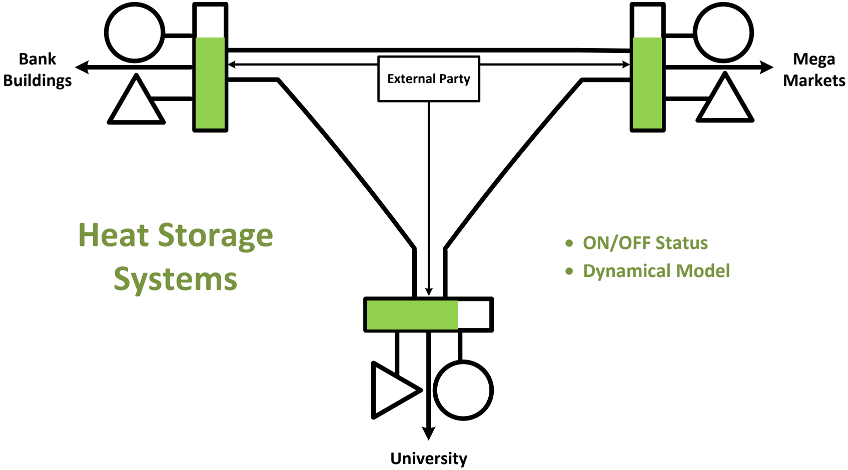


Smart Thermal Grids: Conceptual Framework



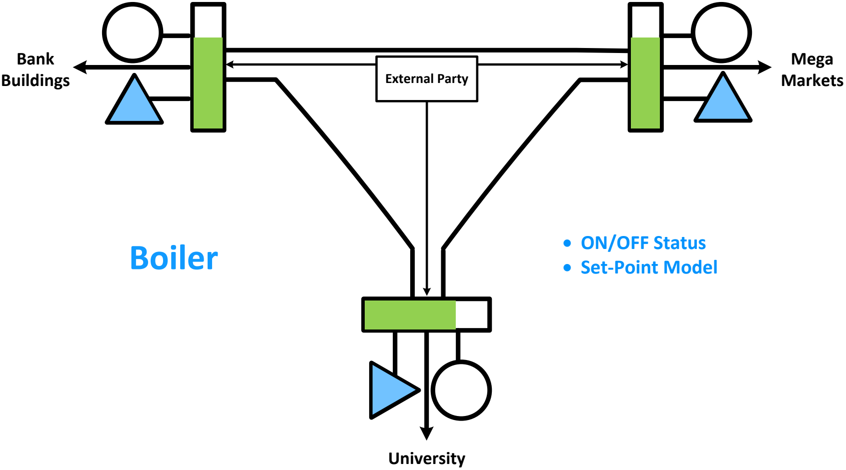
Smart Thermal Grids: Conceptual Framework



Heat Storage Systems

- **ON/OFF Status**
- **Dynamical Model**

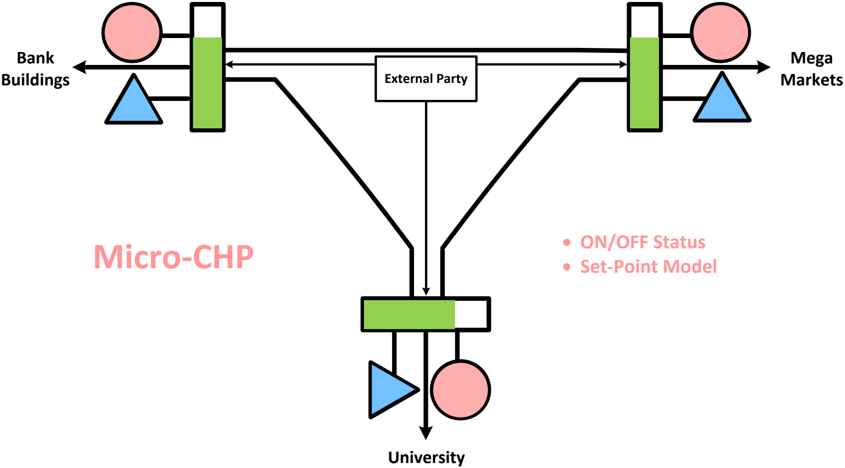
Smart Thermal Grids: Conceptual Framework



Boiler

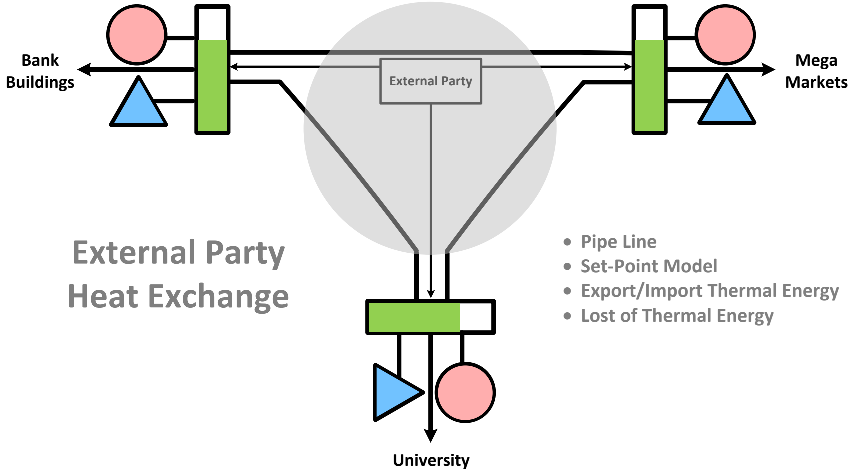
- **ON/OFF Status**
- **Set-Point Model**

Smart Thermal Grids: Conceptual Framework



- ON/OFF Status
- Set-Point Model

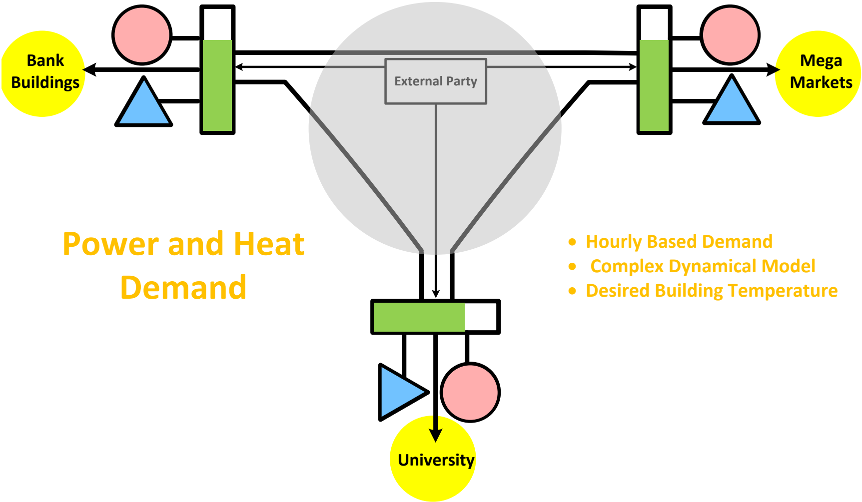
Smart Thermal Grids: Conceptual Framework



External Party Heat Exchange

- Pipe Line
- Set-Point Model
- Export/Import Thermal Energy
- Lost of Thermal Energy

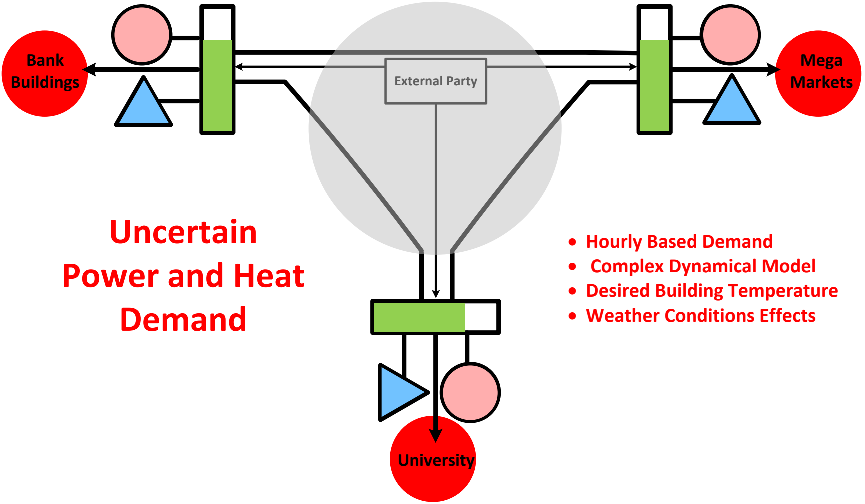
Smart Thermal Grids: Conceptual Framework



Power and Heat Demand

- Hourly Based Demand
- Complex Dynamical Model
- Desired Building Temperature

Smart Thermal Grids: Conceptual Framework

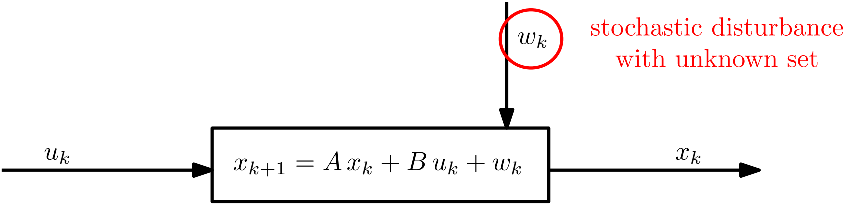


Uncertain Power and Heat Demand

- Hourly Based Demand
- Complex Dynamical Model
- Desired Building Temperature
- Weather Conditions Effects

Mathematical Model

Define x_k to be the imbalance error between demand and production level. This yields the following dynamical model for imbalance error:



Our objective: design a state feedback control policy that minimizes the energy consumption of buildings, while keeping room temperatures between comfortable limits, despite *uncertain weather conditions*, and subject to the operational constraints

Stochastic Optimization Problems

Optimization problems under uncertainty:

- **Robust Programs:** provide a guaranteed level of performance for all admissible values of the uncertain parameters equally likely:

$$\begin{cases} \min_{x} & c(x) \\ \text{s.t.} & g(x,\delta) \leq 0, \quad \forall \delta \in \Delta \\ & x \in \mathcal{X} \end{cases} \qquad \textbf{(RPs)}$$

  - Tractability issue occurs in many control problems
  - Very conservative since all uncertainty realizations are treated equally

Stochastic Optimization Problems

Optimization problems under uncertainty:

- **Chance Constrained Programs:** the relaxed version of RPs that allow constraint violation with a low probability $\varepsilon \in [0, 1]$:

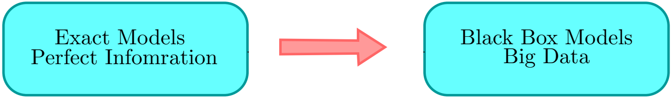
$$\begin{cases} \min\limits_{x} & c(x) \\ \text{s.t.} & \mathbb{P}\left[g(x,\delta) \leq 0\right] \geq 1 - \varepsilon \\ & x \in \mathcal{X} \end{cases} \qquad \textbf{(CPs)}$$

  - Accessibility of the probability distribution $\mathbb{P}$
  - Intractable optimization problem and in general nonconvex
  - Probability associated with the chance constraints can be hard to compute since it requires a multi-dimensional integral

Stochastic Optimization Problems

Optimization problems under uncertainty:

- **Big Data Programs:** We see a definite transition from a classical exact model to a data driven approach in the age of big data:



- How we deal with optimization and or control problems to reflect this transition?
  - We do not know the model information exactly: $\mathbb{P}$, $g(\cdot)$
  - Only a finite amount of data is available $\{\, g_k(\cdot) \,|\, k = 1, 2, \cdots, N \,\}$
- How much information is really required to make meaningful estimates or informed decisions?

Stochastic Optimization Problems

Optimization problems under uncertainty:

- **Scenario Programs:** Computationally tractable approximations of CPs in which only finitely many uncertainty scenarios are considered:

$$\begin{cases} \min_{x} & c(x) \\ \text{s.t.} & g(x, \delta_i) \leq 0, \quad \forall i \in \{1, \cdots, N\} \\ & x \in \mathcal{X} \end{cases} \qquad \textbf{(SPs)}$$

  - δ_i, for $i = 1, \cdots, N$, are N independent and identically distributed scenarios drawn according to the probability measure $\mathbb{P}$
  - Based on generating a large number N of stochastic scenarios, thus may lead to a very conservative solution
  - E.g., convex problem $N > 10^3$, and nonconvex problem $N > 10^4$

Conclusions

Remarks:

- Centralized control problem formulation for a **SmartThermal Grid**
- **Affine Uncertainty Feedback Policy** with chance constraint formulation
- **Convex Reformulation** of the proposed stochastic constrained control

Next Steps:

- Developing a **Real Demand Profile Generator** by using a detailed building dynamical model
- Incorporating **Aquifer Thermal Energy Storage System (ATES)** in the developed framework

Thank you! Questions?

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