Optimal Energy Management for Building Comfort Service together with ATES Operational Planning

Vahab Rostampour

Delft University of Technology
Deft Center of Systems and Control

User Group Meeting

Tuesday 5th April, 2016

Recapitulate Last UG Meeting

Feedbacks & Comments:

- A comment on building model, e.g. heat transfer between fluid and air
- Using existing building models in literature instead of developing new model
- Contact Prof. Hensen from TU Eindhoven for simulation time issues

Taken Actions:

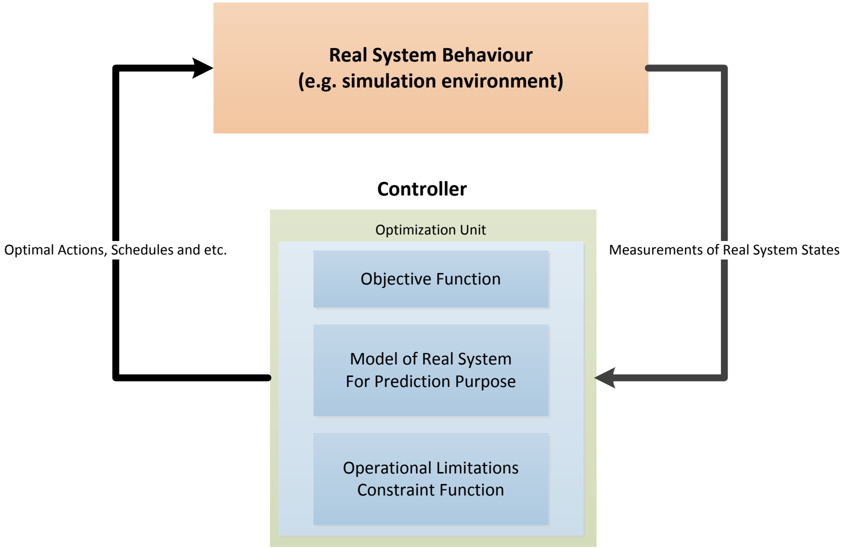
- Preparing a note on the developed building model & describing relations between different variables
- Studying further literature to determine a better building model
- Contacting Prof. Hensen regarding our simulation time problems

Recapitulate Last UG Meeting

Results:

- Developed model has a lumped heat transfer between the fluid and the room air temperature because it is aimed to be used within MPC
- Recommendation for the book 'Building Performance Simulation for design and operation' by Prof. Hensen, et al.
- We distinguished between building simulation model use for assessment (with existing tools/models) and simplified internal model used within MPC
- Internal model used within MPC: it can be a very strongly reduced order model w.r.t prediction horizon and computational complexity
- Building simulation model to assess MPC: obviously include all phenomena and dynamics relevant, e.g. TRNSYS, EnergyPlus, and etc.
- Recommendation for the **'Geotabs Project'** deliverable, documents

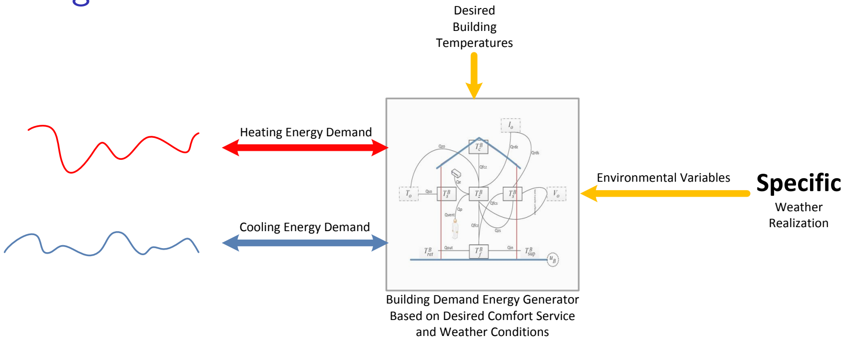
Recapitulate Last UG Meeting



Outline

1. OEM of Building Comfort Service
2. OEM for Smart Thermal Grids
3. Simulation Results & Next Steps
4. Current Research Status

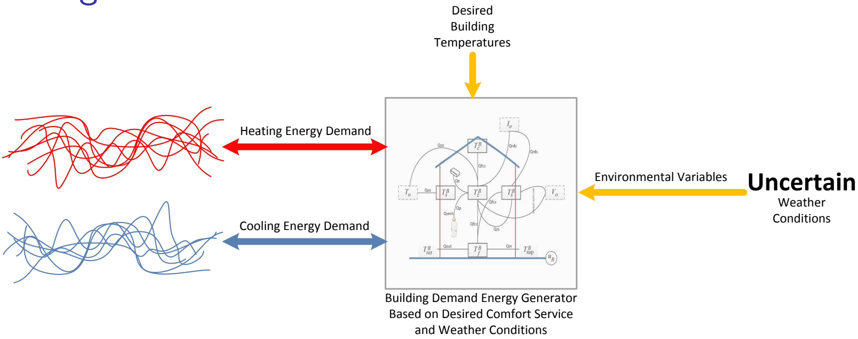
Building Demand Generator



Demand Profile Generator:

- Complete and detailed building dynamical model
- Desired building temperatures (local controller unit)
- In specific weather realization, certain demand profiles are generated

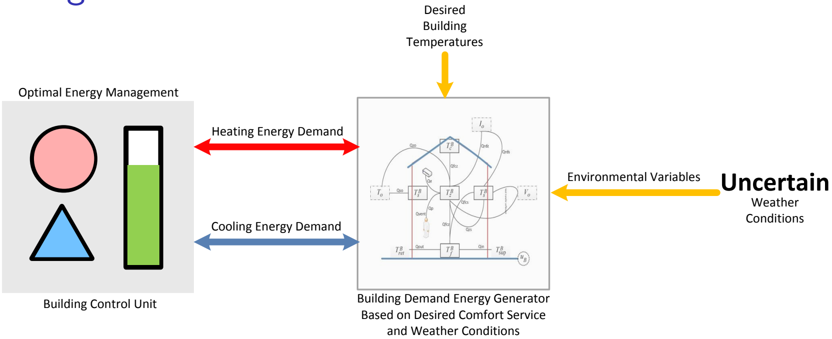
Building Demand Generator



Demand Profile Generator:

- Complete and detailed building dynamical model
- Desired building temperature (local controller unit)
- In uncertain weather conditions, uncertain demand profiles are generated

Building Comfort Service

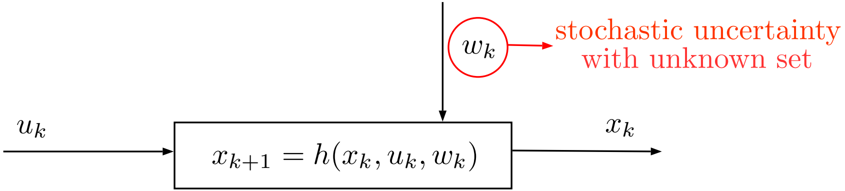


Building Control Unit:

- Main components: Boiler, HP, HE, micro-CHP, Buffer Storage
- **ON/OFF status** together with **production schedule** as decisions
- Thermal **energy balance** for dynamical systems

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

Optimal Control Strategies

Finite horizon predictive control problem:

$$\min_{(u_k, y_k)_{k=0}^{M}} \quad J(x_k, u_k) := \sum_{k=0}^{M} x_k^\top Q x_k + \sum_{k=0}^{M-1} u_k^\top R u_k \,, \; Q \succeq 0 \,, \; R \succ 0$$

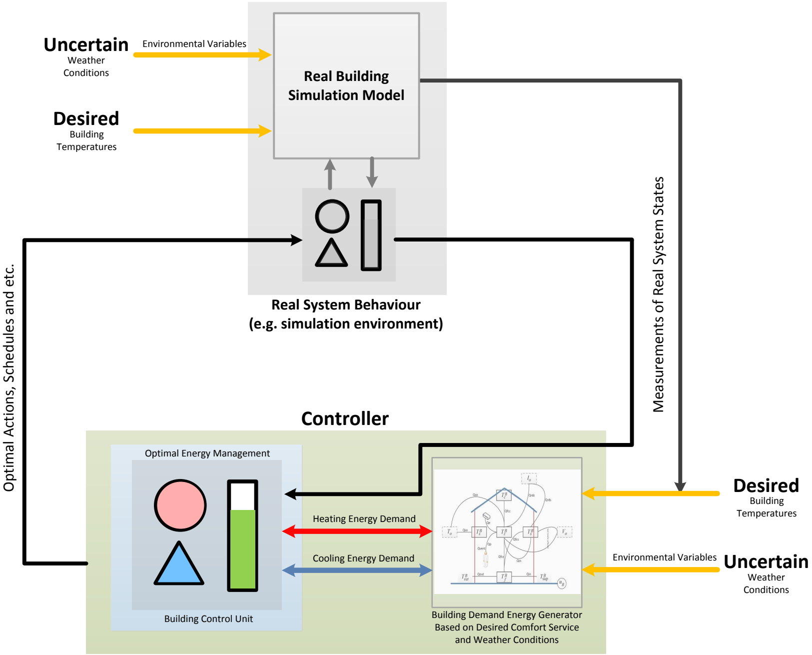
$$\text{subject to:} \quad f_k(x_k, u_k, y_k) \leq 0 \,, \; y_k \in \{0, 1\} \,, \; k = 0, 1, \cdots, M$$

Objective function: $J(x_k, u_k)$ consists of the following parts:

- Tracking building comfort profile
- Minimizing building operational cost

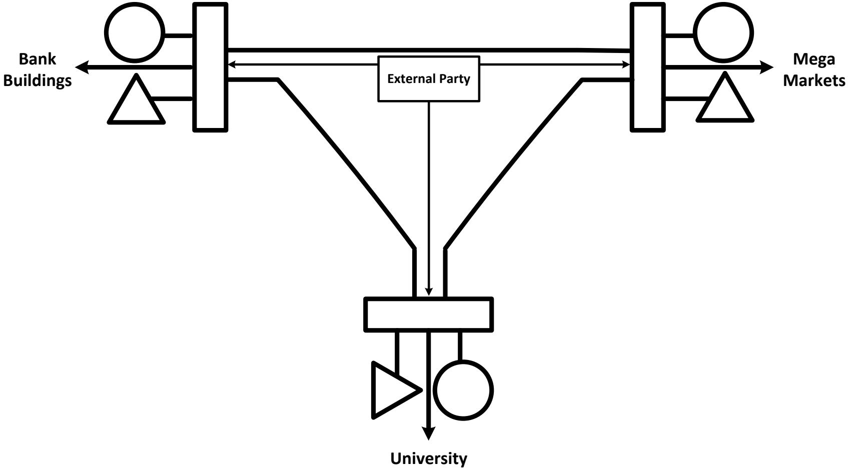
Additional parts of objective function for the future studies:

- Reducing carbon emission gas
- Planning ATES operations

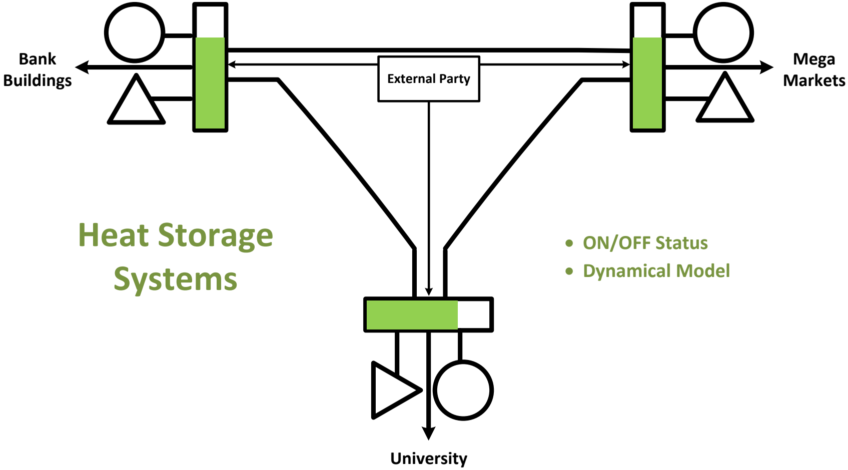

Uncertain
Weather
Conditions
Environmental Variables
Desired
Building
Temperatures
Real Building
Simulation Model
Real System Behaviour
(e.g. simulation environment)
Optimal Actions, Schedules and etc.
Measurements of Real System States
Controller
Optimal Energy Management
Building Control Unit
Heating Energy Demand
Cooling Energy Demand
Building Demand Energy Generator
Based on Desired Comfort Service
and Weather Conditions
Desired
Building
Temperatures
Environmental Variables
Uncertain
Weather
Conditions

Outline

Smart Thermal Grids: Conceptual Representation

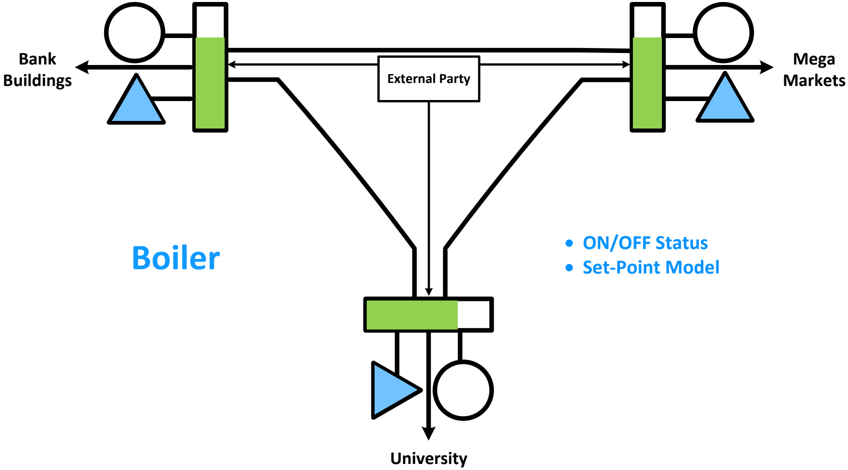


Smart Thermal Grids: Conceptual Representation

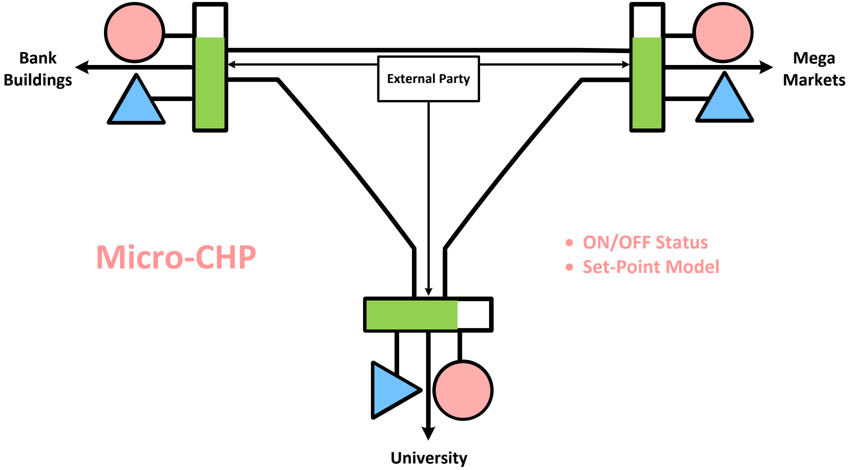


- ON/OFF Status
- Dynamical Model

Smart Thermal Grids: Conceptual Representation



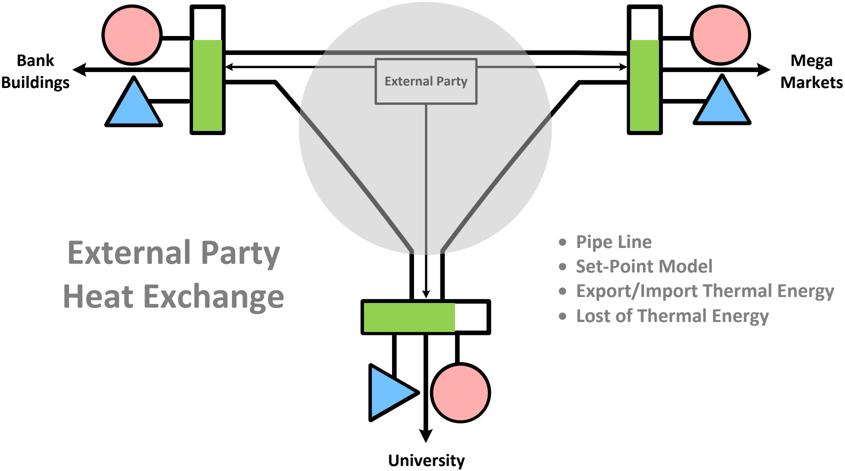
Smart Thermal Grids: Conceptual Representation



Micro-CHP

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

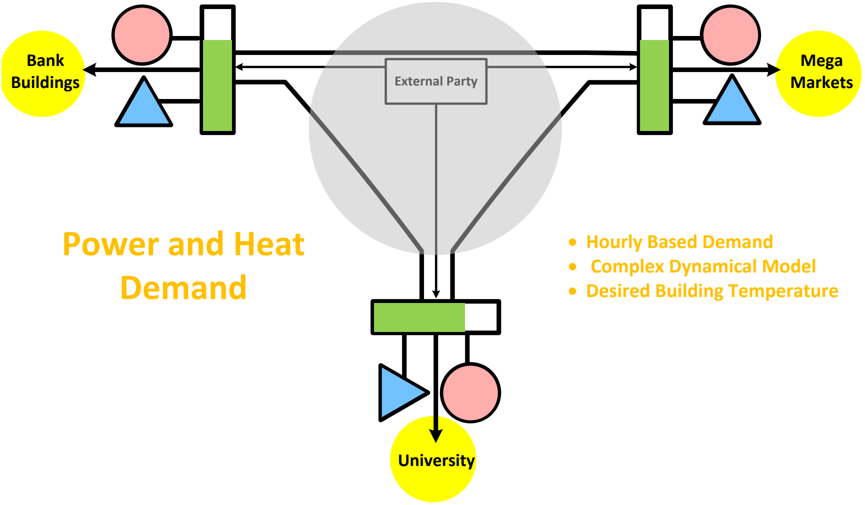
Smart Thermal Grids: Conceptual Representation



External Party
Heat Exchange

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

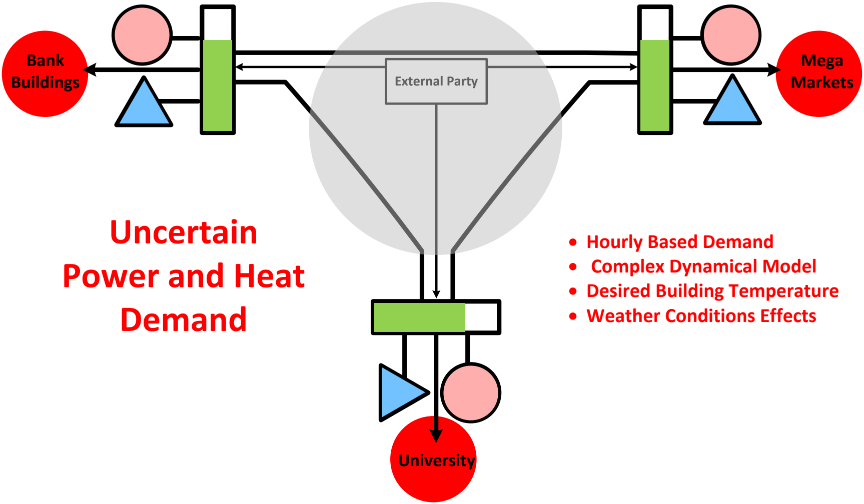
Smart Thermal Grids: Conceptual Representation



Power and Heat Demand

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

Smart Thermal Grids: Conceptual Representation



Uncertain
Power and Heat
Demand

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

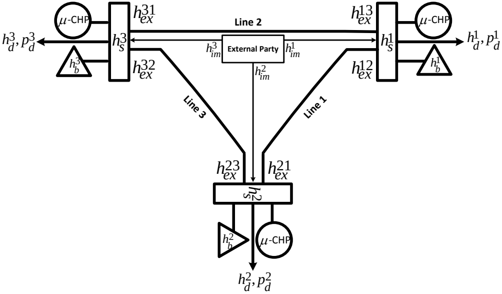
Outline

Three Agents Case Study

Simulation Study Settings:

- Day-ahead control problem
- Economical cost function
- Operational constraints
- Uncertain energy demand
- Unit commitment problem
- Production scheduling problem

households, greenhouses
smart thermal grid example



Mixed-Integer Chance-Constrained Linear Optimization Problem

Developed Unified Framework

Resulting optimization problem in each sampling time:

$$\min_{(u_k, y_k)_{k=0}^{M}} \quad J(x_k, u_k)$$

$$\text{subject to:} \quad f_k(x_k, u_k, y_k) \leq 0\,,\; y_k \in \{0,1\}\,,\; k = 0, 1, \cdots, M$$

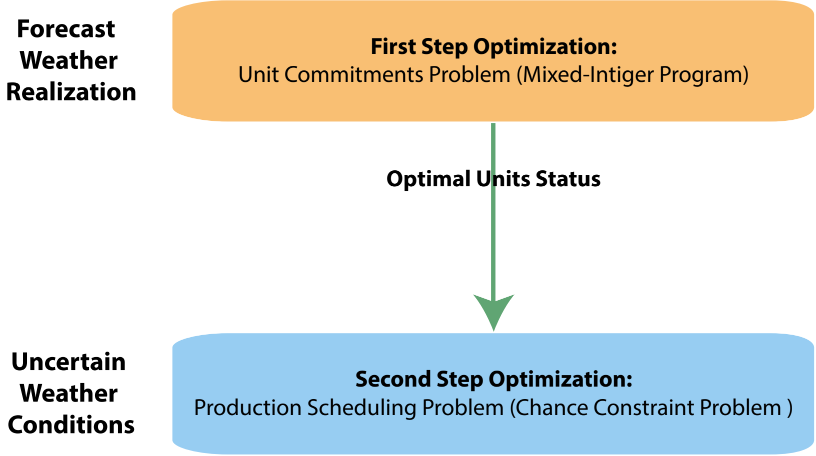
$$\mathbb{P}\{x_k \in \mathcal{X}\} \geq 1 - \varepsilon \quad \Rightarrow \textbf{chance constraints}$$

where $\varepsilon \in (0, 1)$ is defined as the desired level of constraints violation

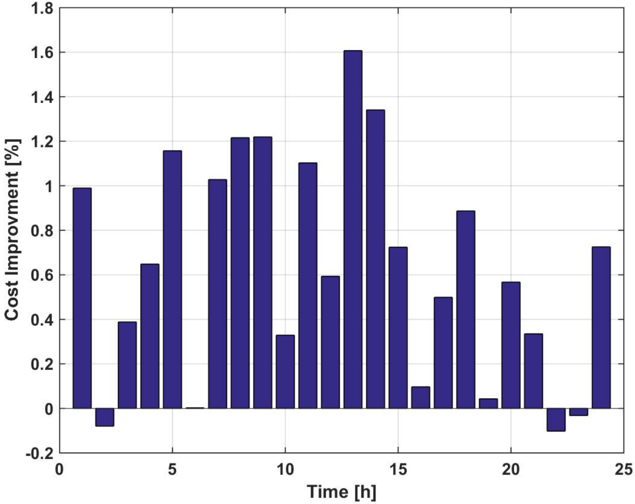
Optimal Solution in Theoretical Probability Sense:

- robustness features of constraints in a relaxed probabilistic setting based on randomization of the constraints
- extracting at random some instances of the uncertainty, and then finding the optimal solution of a problem

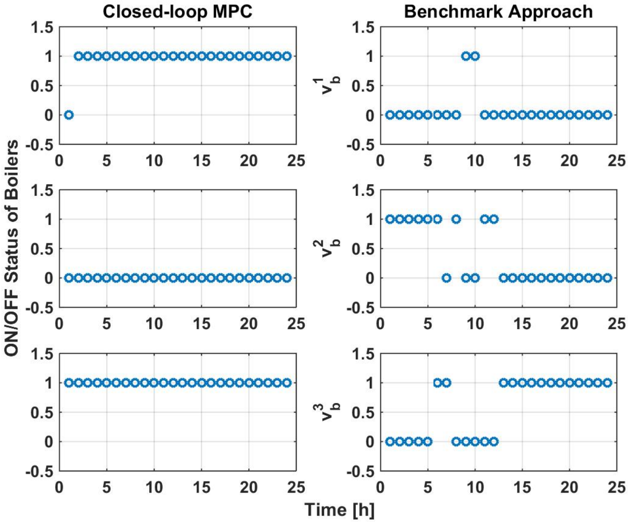
Comparison: Benchmark Approach



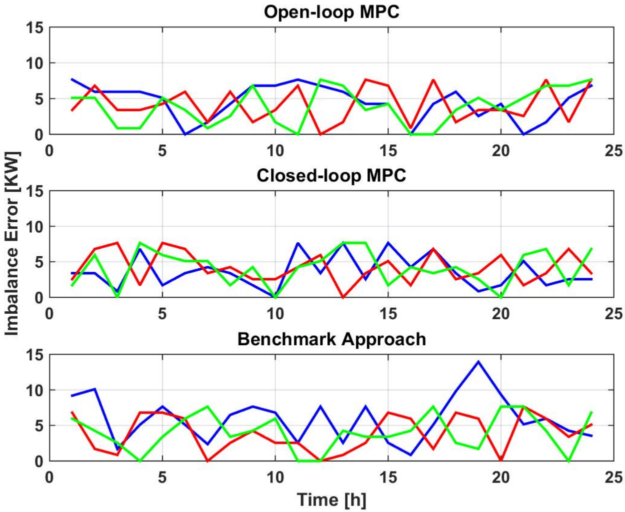
Simulation Results: Relative Cost Improvement



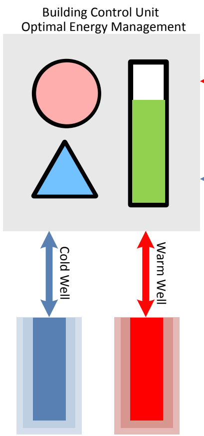
Simulation Results: ON/OFF Status of Boilers

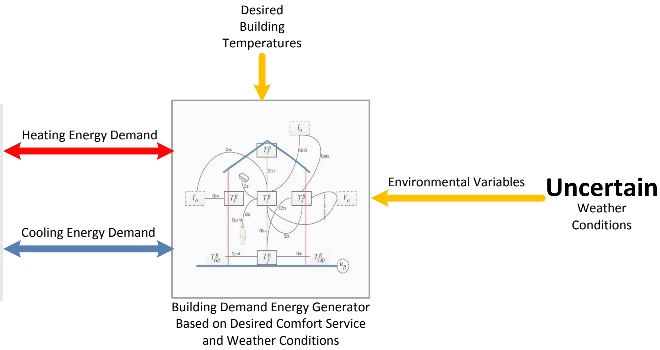


Simulation Results: Imbalance Error Trajectories



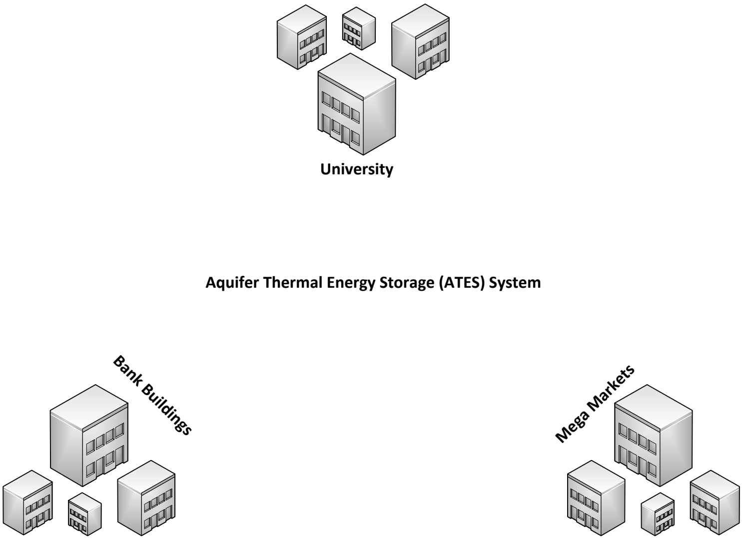
Next Steps: ATES Systems





- **Incorporate ATES System**
- **Interaction between components**
- **Different operational time scale**
- **Additional degrees of freedom**

Next Steps: ATES Systems Smart Grids



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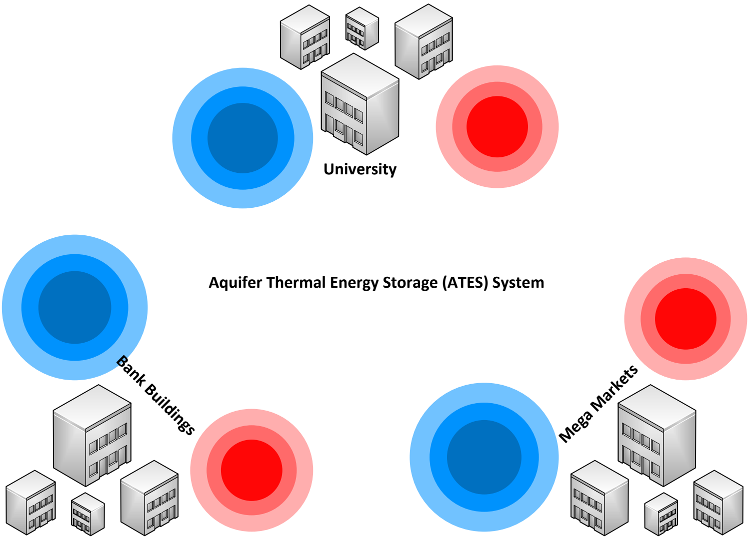

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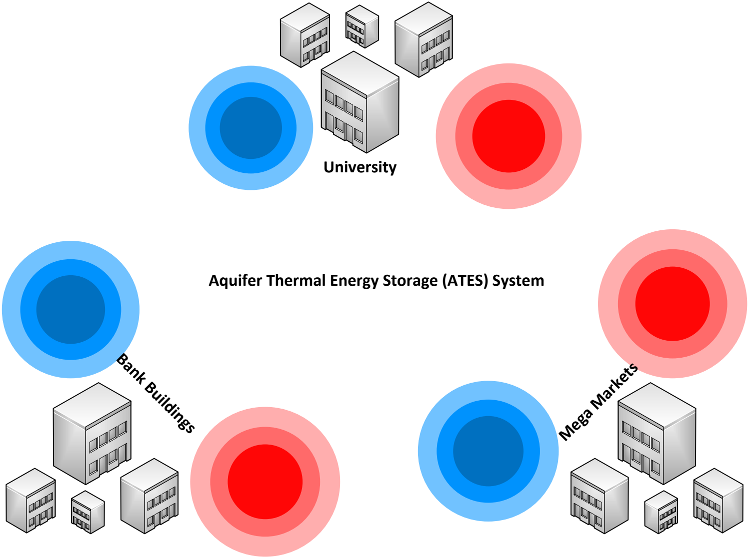

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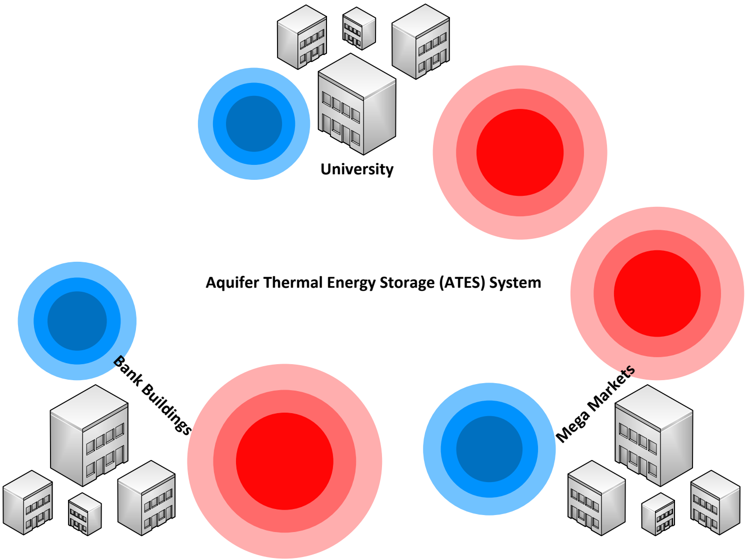

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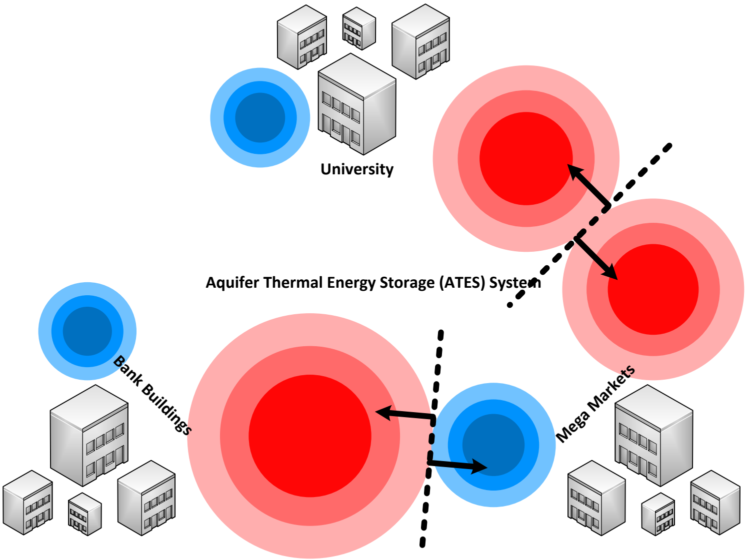


Next Steps: Price Based Negotiation Algorithm

$$\sum_{i=1}^{N} \min_{(u_k^i, y_k^i)_{k=0}^{M}} \quad J_i(x_k^i, u_k^i)$$

local constraints

$$\text{subject to:} \quad f_k^i(x_k^i, u_k^i, y_k^i) \le 0\,, \quad y_k^i \in \{0,1\}\,,\ k = 0, 1, \cdots, M$$

$$r_k^i + r_k^j \le \bar{r}_{(i,j)}\,, \qquad r_k^i := g(x_k^i, u_k^i, y_k^i)\,,\ \forall\, i, j \in N_{-i}$$

coupling constrains

Centralized Framework:

- Local constraints: limitation of operations
- Thermal capacity radius: r_k^i for each agent i
- Coupling constraints: limitation of ATES capacity
- Total distance between agents: $\bar{r}_{(i,j)}$ for neighboring agents i, j

Next Steps: Price Based Negotiation Algorithm

$$\min_{(u_k^i, y_k^i)_{k=0}^M} \quad J_i(x_k^i, u_k^i) + p_{(i,j)} r_k^i$$

coordination price

$$\text{subject to:} \quad f_k^i(x_k^i, u_k^i, y_k^i) \leq 0\,, \quad y_k^i \in \{0, 1\}\,,\ k = 0, 1, \cdots, M$$

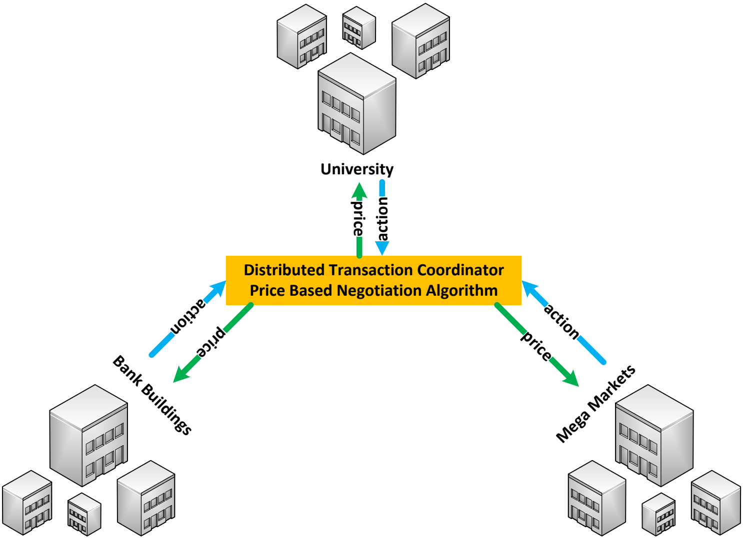
$$r_k^i := g(x_k^i, u_k^i, y_k^i)$$

local problems

Distributed Transaction Coordinator:

- Local problems: completely decoupled framework for all agents
- Driven under the influence of the coordination price: $p_{(i,j)}$
- Coordinator task: **updating price** w.r.t local actions

Next Steps: Price Based Negotiation Algorithm



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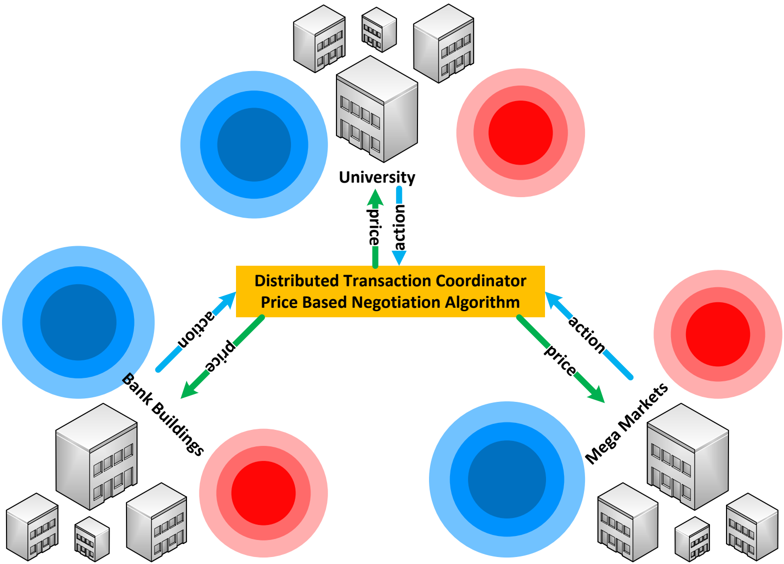

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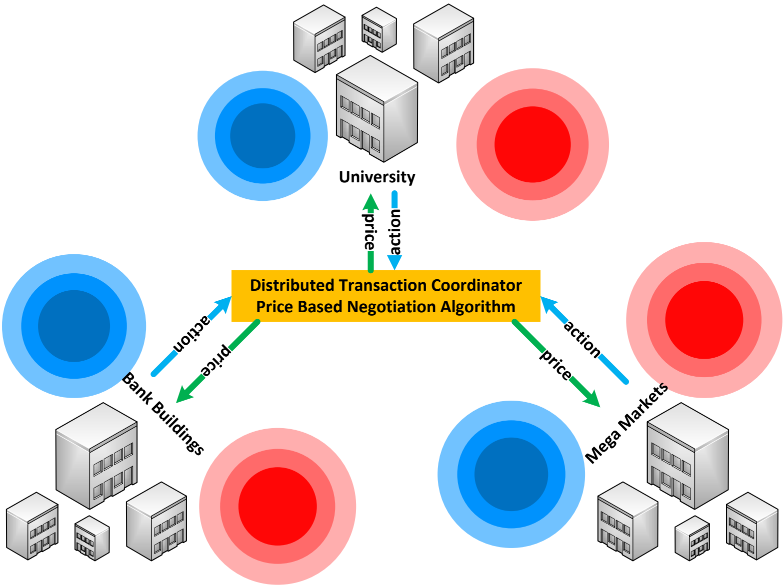

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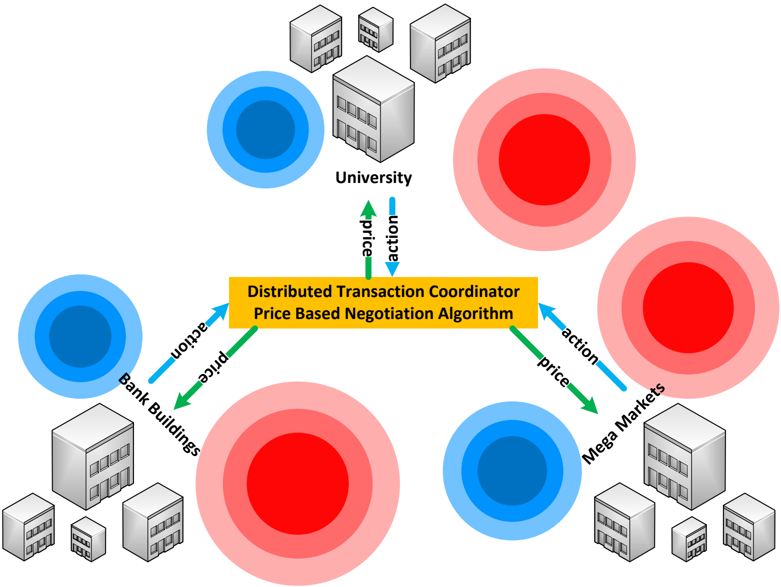

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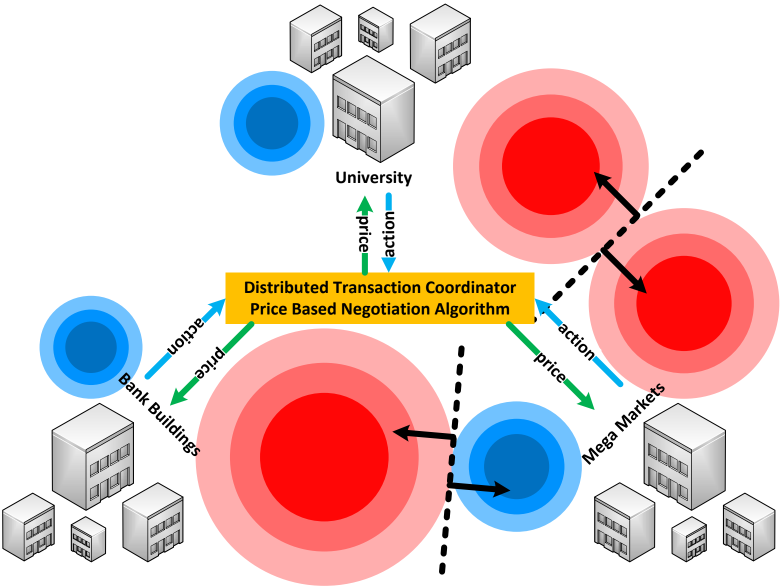

Outline

Current Research Status

Achievements:

- Robust Randomized MPC for Energy Management in Smart Thermal Grids
  Accepted for European Control Conference 2016
- Building and Aquifer Thermal Energy Storage Model in Smart Grids
  Accepted for European Geothermal Congress 2016
- Novel Probabilistic FDI Threshold Design for Uncertain Nonlinear Systems
  Submitted for Conference on Decision and Control 2016
- Chance Constrained MPC for Stochastic Discrete Event Nonlinear Systems
  Under Revision for Conference on Systems, Man, and Cybernetics 2016

Current Research Status

Under Progress:

- Dual Scenario Program for Chance Constrained Optimization Problems
- On the Road Between Convex and Nonconvex Scenario Program for Chance Constrained Optimization Problems
- Stochastic Distributed MPC for Chance Constrained Linear Systems

Master Students Thesis:

- Stochastic Distributed Coordination in Smart Thermal Grids
  Wicak Ananduta (Expected Graduation August 2016)
- Distributed Stochastic Production Scheduling in Smart Grids
  Ole ter Haar (Expected Graduation February 2017)

Thank You!
Questions?

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TUDelft NWO