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WarmingUP Ph.D. Webinar

Model Predictive Control-based Building Thermal Inertia Exploitation Strategy in District Heating/Cooling Networks

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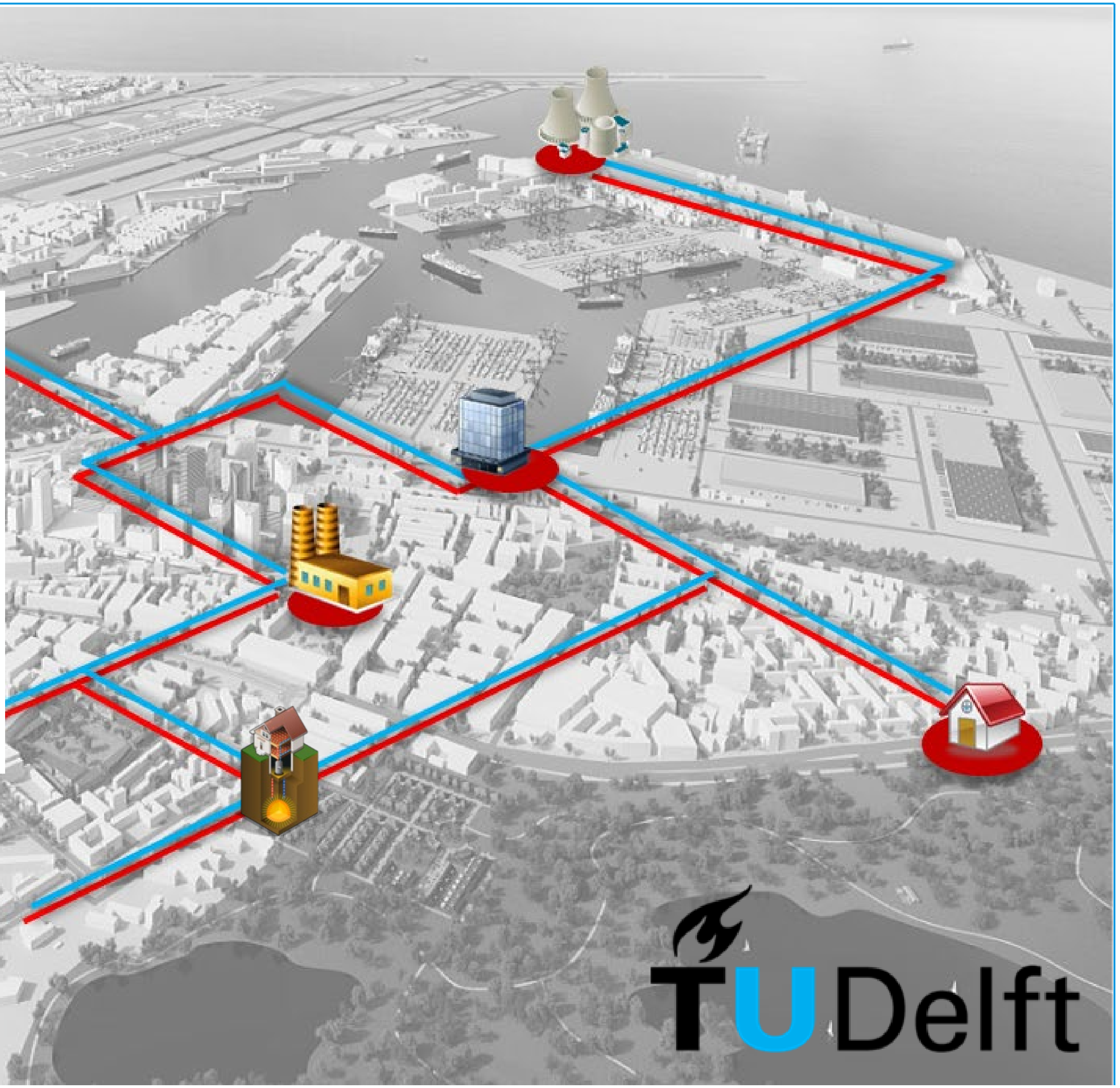
Tuesday, 7 March 2023



Energy Storage in District Heating Grid

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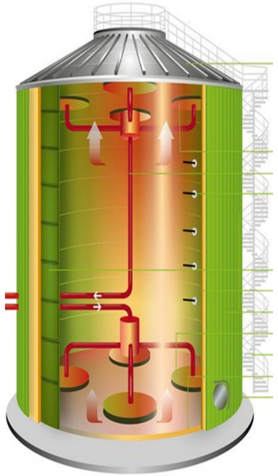
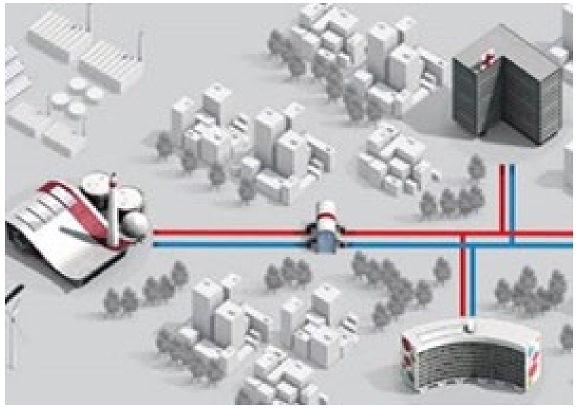
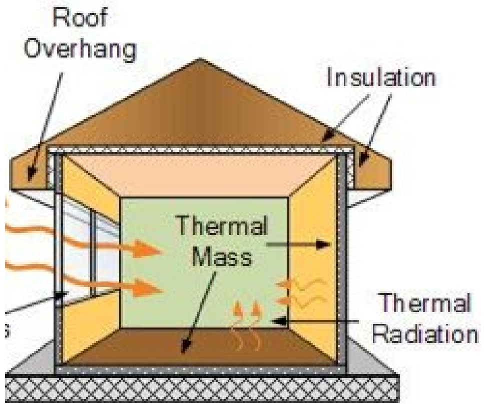


Thermal Energy Storage Tank

Network Thermal Inertia*





Building Thermal Inertia*

Characteristic of each Thermal Storage

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	TES Tank	Building Thermal Inertia	Network Thermal
Mechanism			
Installation			
Involved Party			
Required Information			

Building Thermal Inertia Exploitation

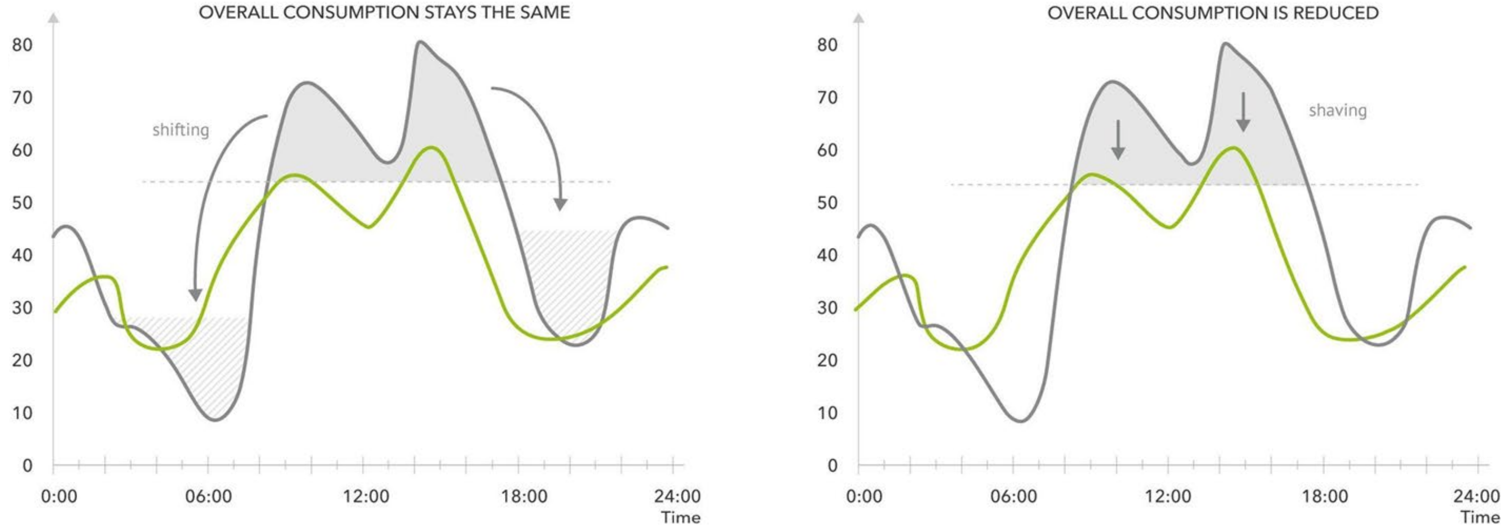
Mechanism

Utilization of building structure as short-term thermal energy storage.

Energy charging: supply additional energy above the exact demand.

Energy discharge: supply less energy below the exact demand.

Objective



Building Thermal Inertia Exploitation

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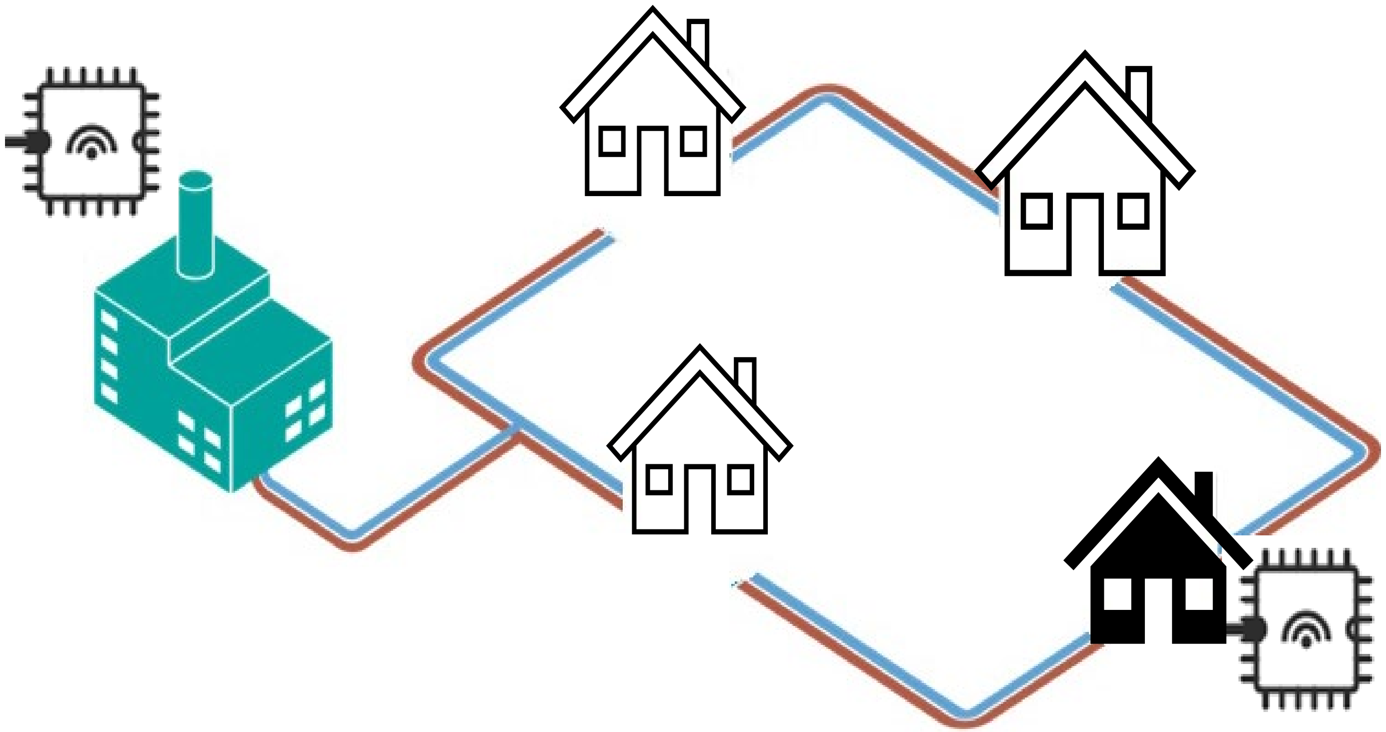
District Heating Grid-Building Interaction

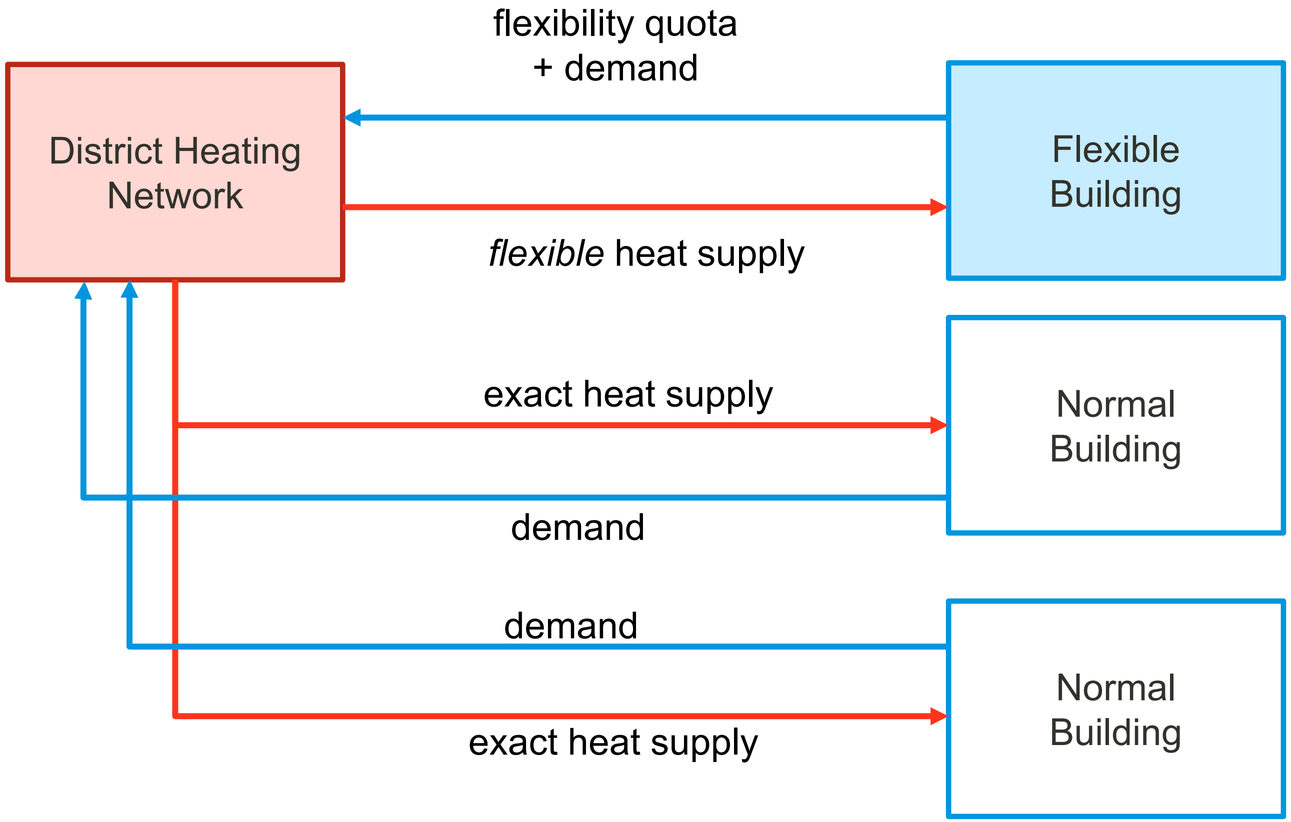
1. *Heat generation scheduling*
2. Pressure & Temperature Control



1. Building Thermal Model Estimation
2. *Supply Deviation Quota **

Building Thermal Inertia Exploitation

District Heating Grid-Building Interaction



Building Thermal Model Estimation

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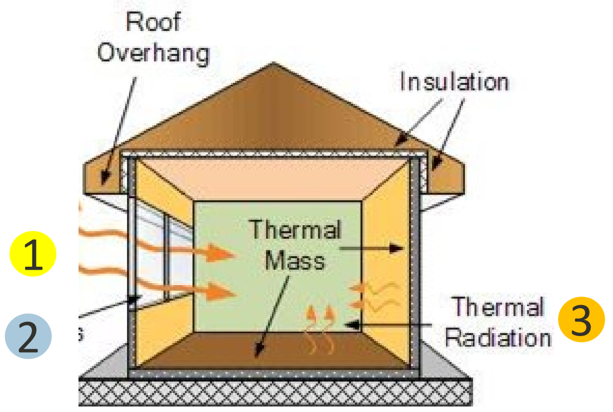

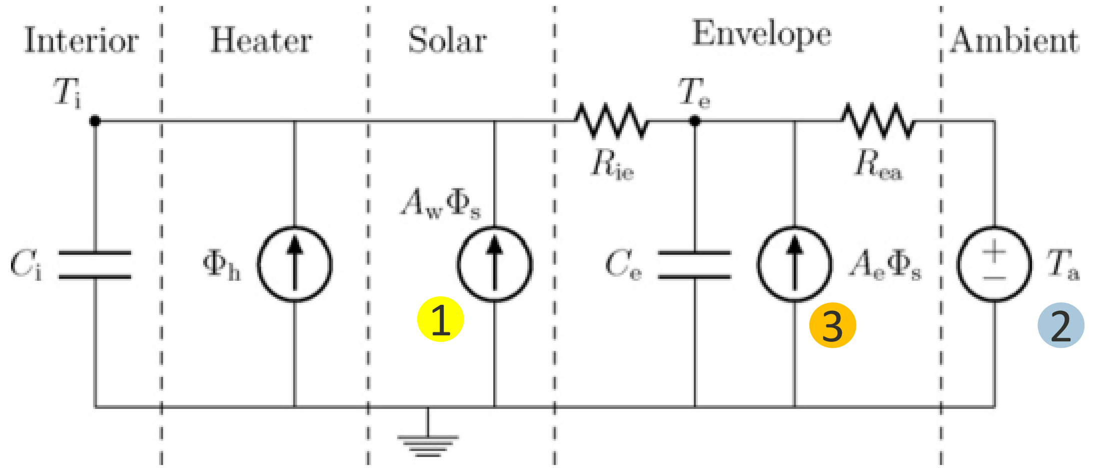

State-space Model

$$\dot{\mathbf{T}}(t) = \underbrace{\begin{bmatrix} -\frac{1}{R_i C_i} - \frac{1}{R_e C_i} & \frac{1}{R_e C_i} \\ \frac{1}{R_e C_e} & -\frac{1}{R_e C_e} \end{bmatrix}}_{\mathbf{A}_c} \mathbf{T}(t) + \underbrace{\begin{bmatrix} \frac{1}{R_i C_i} & \frac{A_i f_s}{R_i} & \frac{\eta_h}{C_i} \\ 0 & 0 & 0 \end{bmatrix}}_{\mathbf{B}_c} \begin{bmatrix} T_a(t) \\ \Phi_s(t) \\ \Phi_h(t) \end{bmatrix}$$

$$\mathbf{y}(t) = \underbrace{\begin{bmatrix} 1 & 0 \end{bmatrix}}_{\mathbf{C}_c} \mathbf{T}(t)$$

Differential Equation

$$C_i \dot{T}_i = \frac{1}{R_i}(T_a - T_i) + \frac{1}{R_e}(T_e - T_i) + A_z f_s \Phi_s + \eta_h \Phi_h$$

$$C_e \dot{T}_e = \frac{1}{R_e}(T_i - T_e) + \frac{1}{R_i}(T_a - T_e)$$

Estimation Process

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1. Dataset: Input data ($\begin{bmatrix} T_a & \Phi_s & \Phi_h \end{bmatrix}$), Output/observation data (T_i)

2. State-space Model Parameterization

$$\theta_1 = \frac{1}{R_\mathrm{e} C_\mathrm{i}},\ \theta_2 = \frac{1}{R_\mathrm{i} C_\mathrm{i}},\ \theta_3 = \frac{1}{R_\mathrm{e} C_\mathrm{e}},\ \theta_4 = \frac{1}{R_\mathrm{i} C_\mathrm{i}},\ \theta_5 = \frac{A_\mathrm{i} f_\mathrm{s}}{R_\mathrm{i}},\ \theta_6 = \frac{\eta_\mathrm{h}}{C_\mathrm{i}}$$

3. Parameter Estimation

$$\hat{\theta} = \arg\max_{\theta} \sum_{k=1}^{N_d} (y_{k+1}(\theta) - y_k(\theta))$$

$$\dot{\mathbf{T}}(t) = \underbrace{\begin{bmatrix} -\frac{1}{R_\mathrm{i} C_\mathrm{i}} - \frac{1}{R_\mathrm{e} C_\mathrm{i}} & \frac{1}{R_\mathrm{e} C_\mathrm{i}} \\ \frac{1}{R_\mathrm{e} C_\mathrm{e}} & -\frac{1}{R_\mathrm{e} C_\mathrm{e}} \end{bmatrix}}_{\mathbf{A}_\mathrm{c}} \mathbf{T}(t) + \underbrace{\begin{bmatrix} \frac{1}{R_\mathrm{i} C_\mathrm{i}} & \frac{A_\mathrm{i} f_\mathrm{s}}{R_\mathrm{i}} & \frac{\eta_\mathrm{h}}{C_\mathrm{i}} \\ 0 & 0 & 0 \end{bmatrix}}_{\mathbf{B}_\mathrm{c}} \begin{bmatrix} T_\mathrm{a}(t) \\ \Phi_\mathrm{s}(t) \\ \Phi_\mathrm{h}(t) \end{bmatrix}$$

$$\mathbf{y}(t) = \underbrace{\begin{bmatrix} 1 & 0 \end{bmatrix}}_{\mathbf{C}_\mathrm{c}} \mathbf{T}(t)$$

Building Thermal Flexibility Calculation

Decision: **Heat supply deviation interval** for *next few hours*.

Objective: Minimize energy price paid that must be paid by the customer.

energy price

incentive

$$\max_{\alpha} \sum_{k=0}^{H-1} p(k)h(k) - i_x(k)h_x(k)$$

deviation

ambient temp.
solar radiance

District Heating Control

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Decision: Heat generation scheduling

Objective: Minimize generation price / emission / network temperature

generation cost

$$\min_{h_g} \quad \sum_{k=0}^{H-1} p_e(k)h_g(k)$$

$$s.t. \quad h_g \leq H_{g,\max}$$

heat source capacity

$$\text{network thermal model}$$

$$\text{network fluid dynamical model}$$

Simulation Settings

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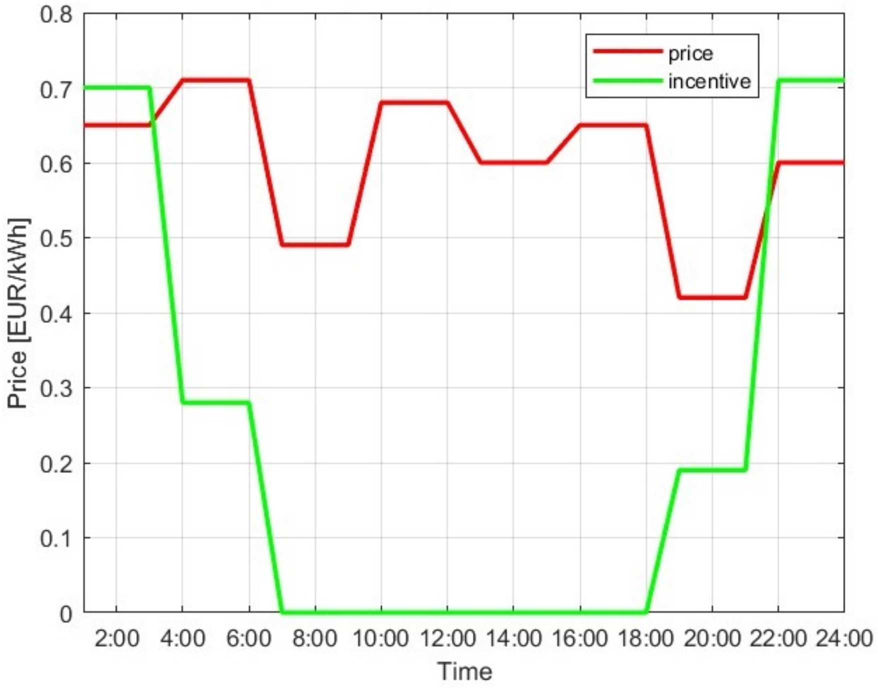
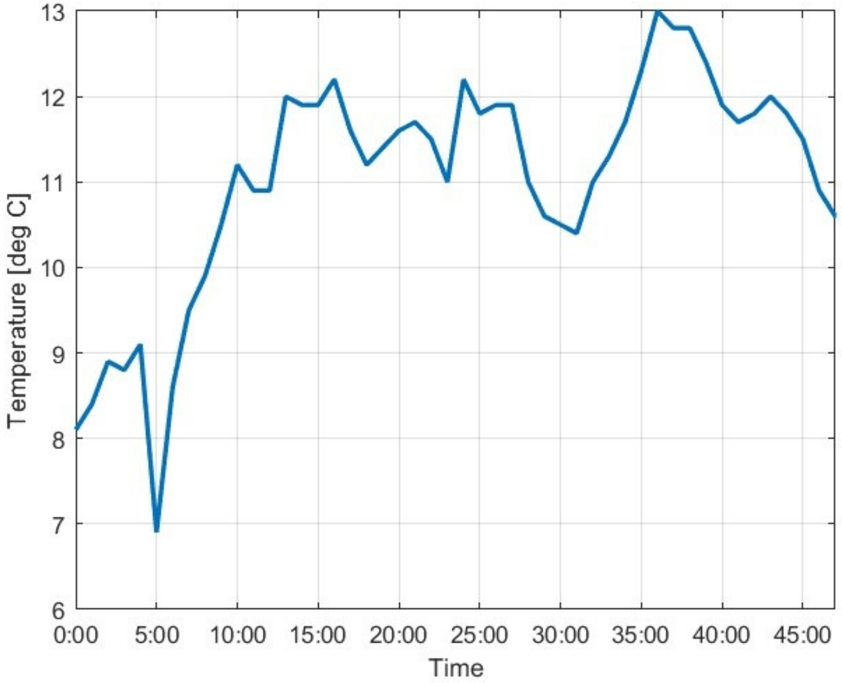
Building Data Source: Purdue Building Dataset
Input: (annual ambient temperature, solar radiance, heat consumption)
Output: zone/room temperature data

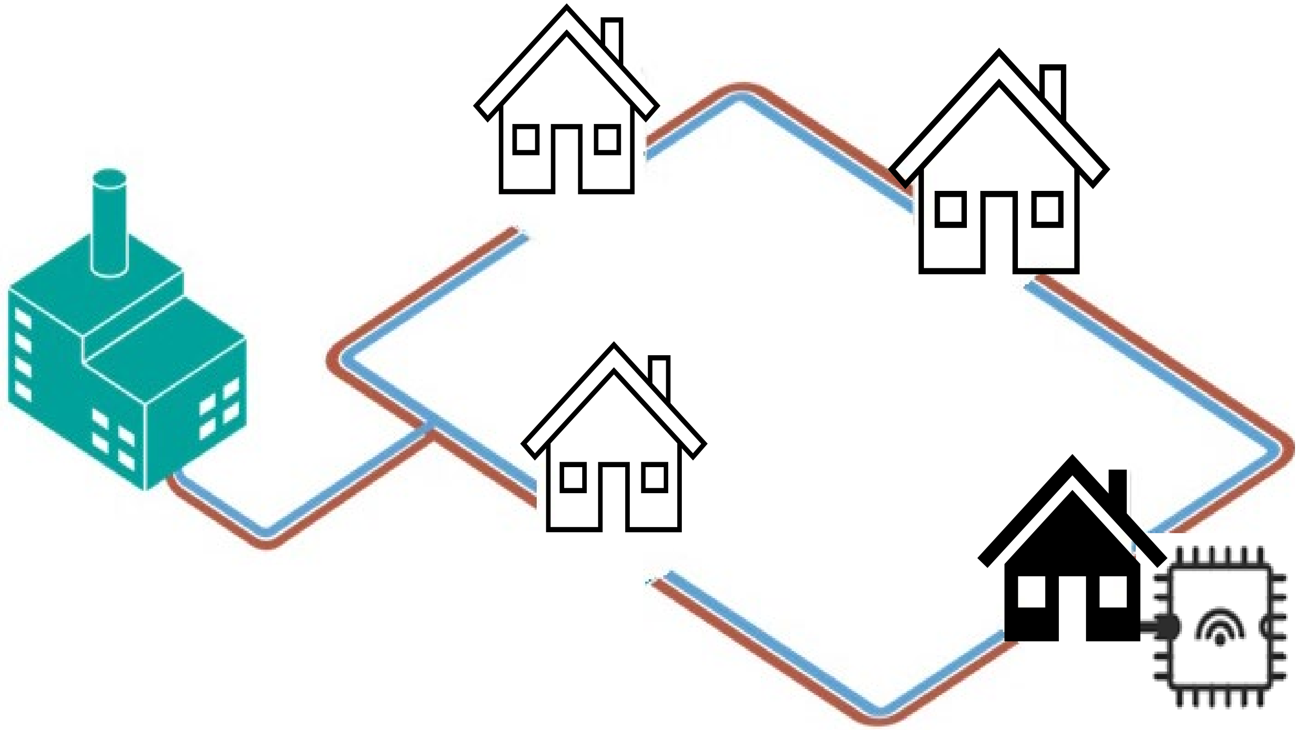




Simulation Settings

No Building: 1 Flexible building + 3 normal buildings

Heat Sources: Heat Pump



Simulation Results

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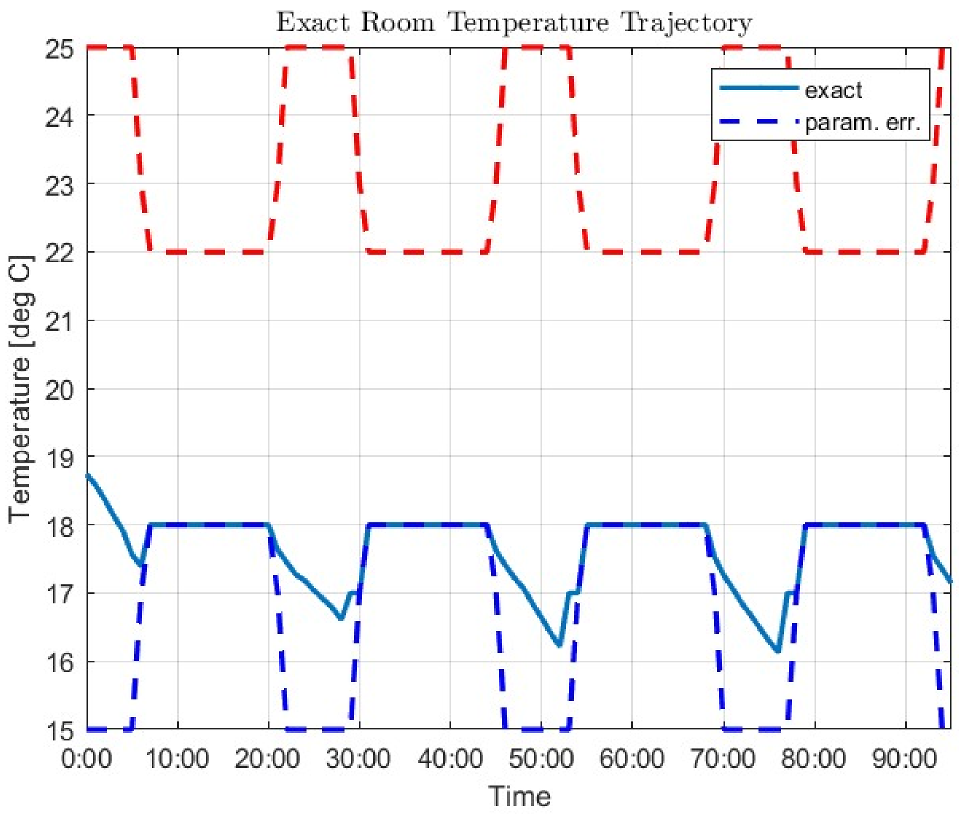
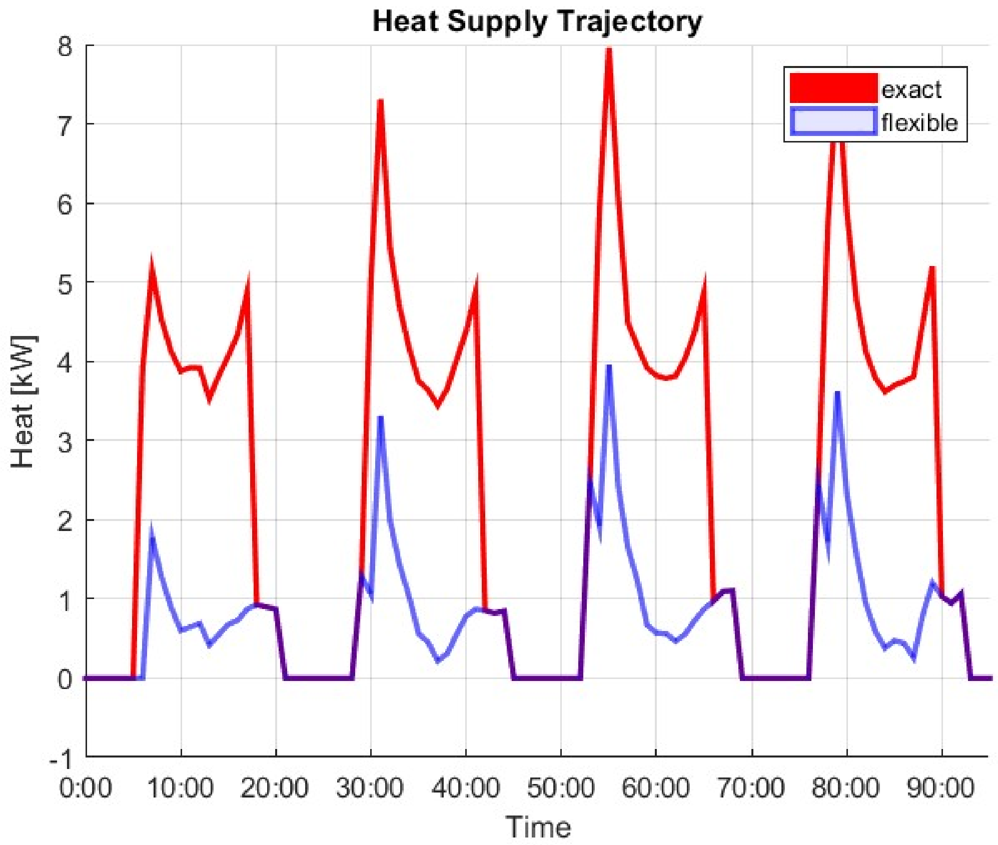
1. High Capacity Heat Source





Simulation Results

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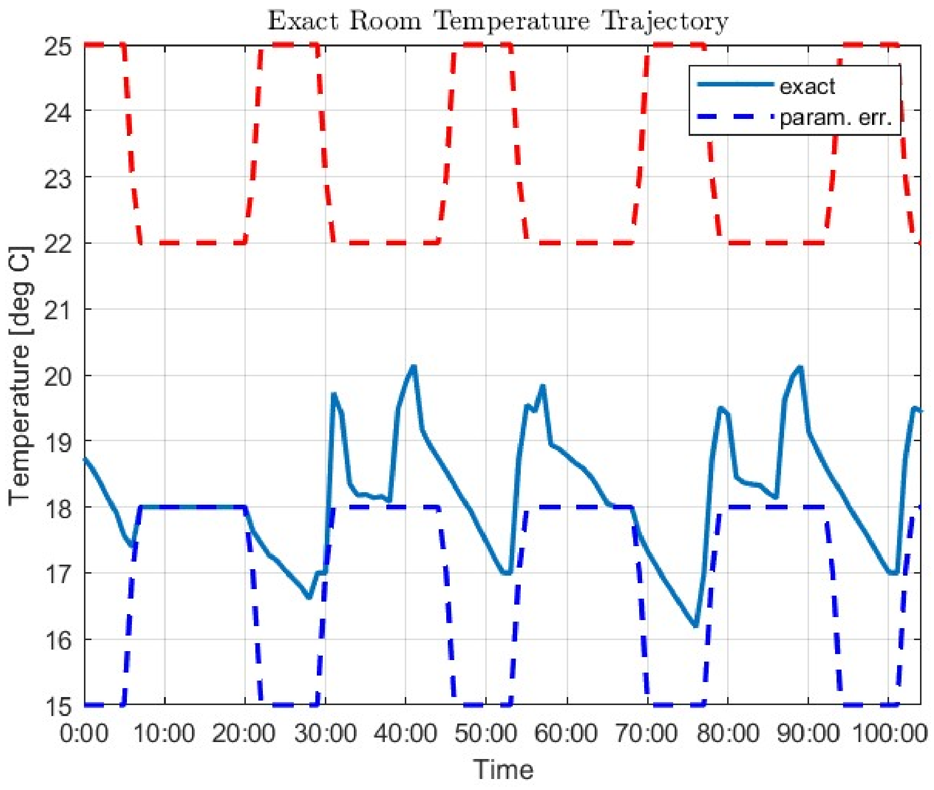
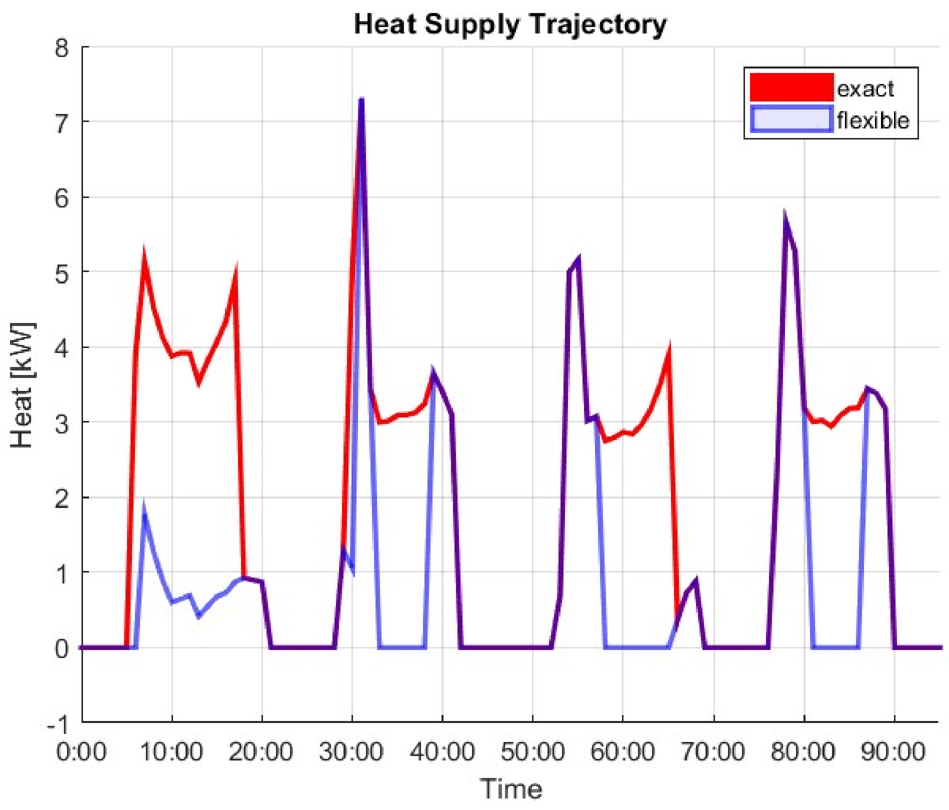
2. Low Capacity Heat Source





Intermediate Conclusion

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1. Flexible building as a “heat storage”
2. Comfort Constraints Satisfaction

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Thank you for Your Attention!

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TU Delft