Aquifer Thermal Energy Storage (ATES) Network
Distributed Energy Storage in Smart Grid

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Outline

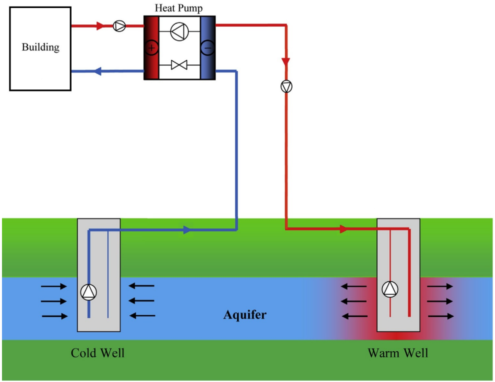
1. Problem Statement
2. Proposed Modeling
3. Concluding Remarks

Outline

Schematic of the problem

Warm season:

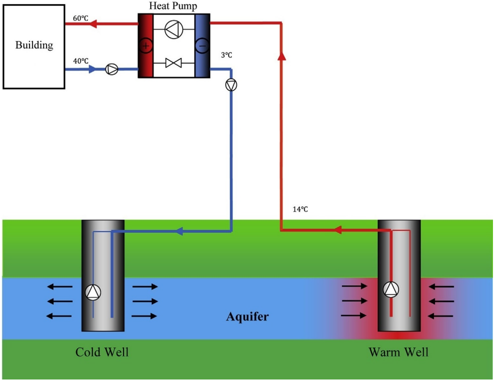
- The cooling is required for the building.
- The cold water is taken from cold well.
- The warm water is injected to the warm well.



Schematic of the problem

Cold season:

- The heating is required for the building.
- The warm water is taken from warm well.
- The cold water is injected to the cold well.



Questions?

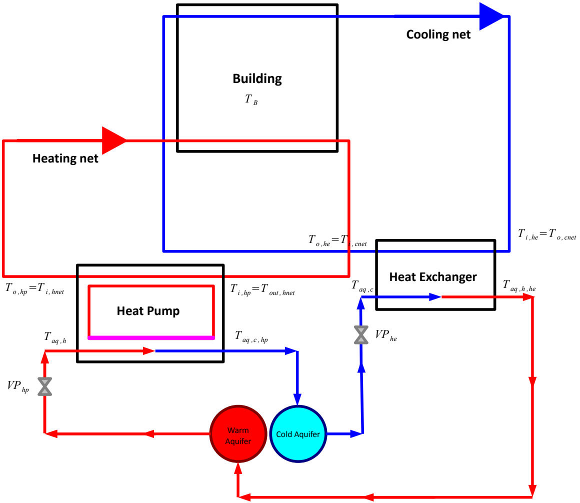
- How to model the building?
- How to model the heat pump?
- How to model the thermal energy storage (aquifer)?
- Importantly, How detailed has to be the modeling parts?
- In which cycle (yearly-season), the problem has to be considered?
- How to have the combination of the heating and cooling for a yearly study?

Outline

The heating and cooling systems

Proposed framework:

- Yearly cycle
- Cooling network works with heat exchanger
- Heating system works with heat pump
- regulation of building temperature



Basis definitions

- **State variables:** temperatures of the all components.
- **Free variables:**
  - valves position (flow rates)
  - stored thermal energy, heating and cooling energy
- **Objective:**
  - tracking desired temperature for the building
  - energy management of the building
- **Constraints:**
  - balance of the extraction and injection of the energy amount of aquifer
  - simultaneous running of the heating and cooling system

Building model

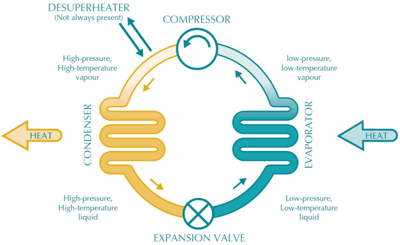
- Building temperature changes: $C_B \dot{T}_B = Q_{heating} + Q_{hw,b} + Q_{gain} - Q_{loss}$
- Heat water temperature changes: $C_{hw} \dot{T_{hw}} = Q_h - Q_{hw,b}$

where

- $Q_{heating}$: the amount of heating power
- Q_{gain}: the amount of heating power is obtained via lighting, occupancy (number of people) and etc.
- Q_{loss}: the amount of lost of thermal power to the environment: $Q_{loss} = UA_{ba} * (T_B - T_{amb})$
- $Q_{hw,b}$: the thermal power from heating network into the building: $Q_{hw,b} = UA_{hw,b} * (T_{hw} - T_B)$
- Q_h: the produced thermal power from heat pump.

Heat pump model

- Thermal power from heat pump into heating net: $Q_h = COP * (Q_h - Q_s)$
- COP: coefficient of performance of heat pump. quadratic approximation: $a_0 + a_1 \Delta \bar{T} + a_2 \Delta \bar{T}^2$ where $\Delta \bar{T} = \frac{T_{in} + T_{out}}{2} - T_{amb}$



- $Q_h = \rho_w c_{pw} \phi_{hnet} * (T_{out,hp} - T_{in_h p})$
- $Q_s = \rho_w c_{pw} VP_{hp} \phi_{hp} * (T_{aq,h} - T_{aq,c,hp})$

Aquifer Thermal Energy Storage model

The easiest model is an autoregressive exogenous model **ARX(1,1)**:

- Warm well model: $Q_{aq,h}(t+1) = \eta_{h,t} Q_{aq,h}(t) + S_h(t)$
- Cold well model: $Q_{aq,c}(t+1) = \eta_{c,t} Q_{aq,c}(t) + S_c(t)$

- $S_h(t)$ and $S_c(t)$ are positive in case if we inject, negative if we extract thermal energy from wells.
- Limitation of the capacities and rate of charge and discharge energy.

How to capture the neighboring effects: we can add the following part into their dynamics: $\sum_{j \in N_i} A_{ij} Q_{ij}^{aq}$

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Conclusions

- Considering a dynamical building model
- Formulating a static model of heat pump in the building thermal system
- An energy-based ATES system model

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