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Water to water heat pump for district heating: modeling for MILP

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Presented by: Stef Boesten

Distributed heat pumps in district heating and cooling systems

- Fifth generation district heating and cooling systems have network fluid temperatures close to ambient (Bünning et al., 2018)
- Potential for large carbon emissions savings (Rogers et al., 2019)
- Combining diversified building profiles thermal profiles can increase energy and exergy efficiency (Zarin Pass et al., 2018)

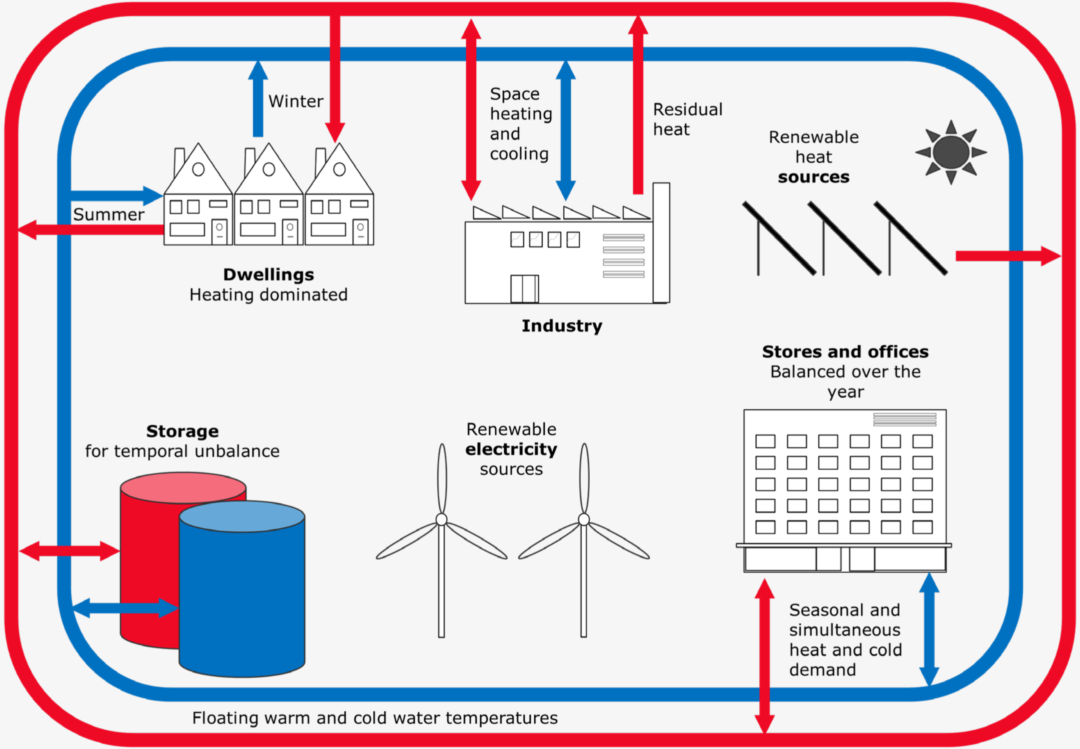

figure: Boesten et al. (2019)

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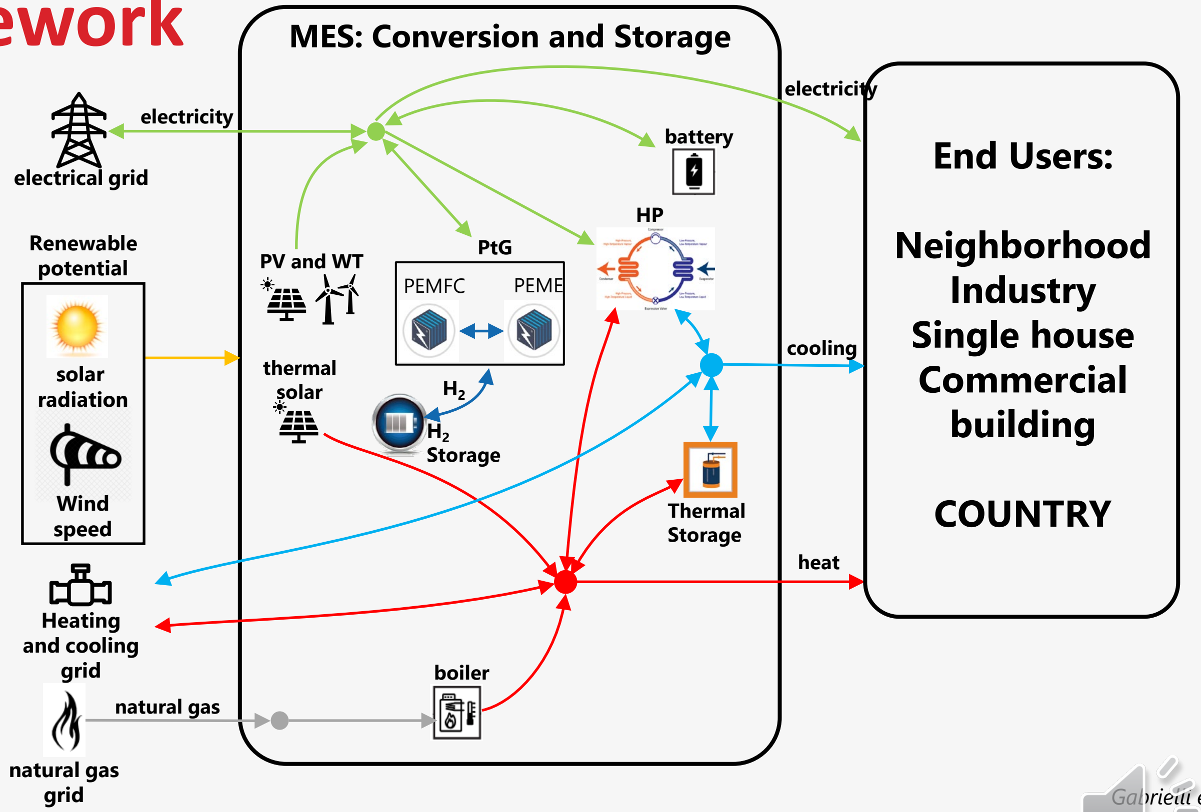
Research question

- What is the **potential costs and emissions savings** of bi-directional, two-pipe, fifth generation district heating and cooling networks, applied in an urban area?

Modeling framework

- Mixed integer linear programming (MILP)
- Optimization of multi-energy systems (MES)
- Energyhub approach



Gabrielli et al.
Appl. Energy 2018 (219) & Appl. Energy 2018 (221)

Modeling framework

$$\min_{\boldsymbol{x},\boldsymbol{y}} \left(\boldsymbol{c}^{\boldsymbol{T}}\boldsymbol{x} + \boldsymbol{d}^{\boldsymbol{T}}\boldsymbol{y}\right)$$

subject to

$$\boldsymbol{A}\boldsymbol{x} + \boldsymbol{B}\boldsymbol{y} = \boldsymbol{b}$$

$$\boldsymbol{x} \geq \boldsymbol{0} \in \mathbb{R}^{\boldsymbol{N}}, \boldsymbol{y} \in \mathbb{N}^{\boldsymbol{M}}$$

Input Data

- Weather conditions
- Energy demands
- Energy prices
- Carbon rates
- Technology cost and performance

Gabrielli et al. Appl. Energy 2018 (219) & Appl. Energy 2018 (221)

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Input Data

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Decision var.

- Tech. selection and size
- Scheduling (on/off)
- Operation: conversion/storage
- Import/Export

Gabrielli et al.
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Modeling framework

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subject to

$$\boxed{\begin{array}{l} \boldsymbol{Ax} + \boldsymbol{By} = \boldsymbol{b} \\ \\ \boldsymbol{x} \geq \boldsymbol{0} \in \mathbb{R}^{\boldsymbol{N}}, \boldsymbol{y} \in \mathbb{N}^{\boldsymbol{M}} \end{array}}$$

Input Data

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Constraints

- Technology behavior
- Energy balances

Gabrielli et al.
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Modeling framework

$$\min_{x,y} \boxed{\left(c^T x + d^T y\right)}$$

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Input Data	Decision var.	Constraints	Objective funct.
• Weather conditions • Energy demands • Energy prices • Carbon rates • Technology cost and performance	• Tech. selection and size • Scheduling (on/off) • Operation: conversion/storage • Import/Export	• Technology behavior • Energy balances	• Total annual cost • Total annual emissions ε-constraint method

Gabrielli et al.
Appl. Energy 2018 (219) & Appl. Energy 2018 (221)

Heat pump model

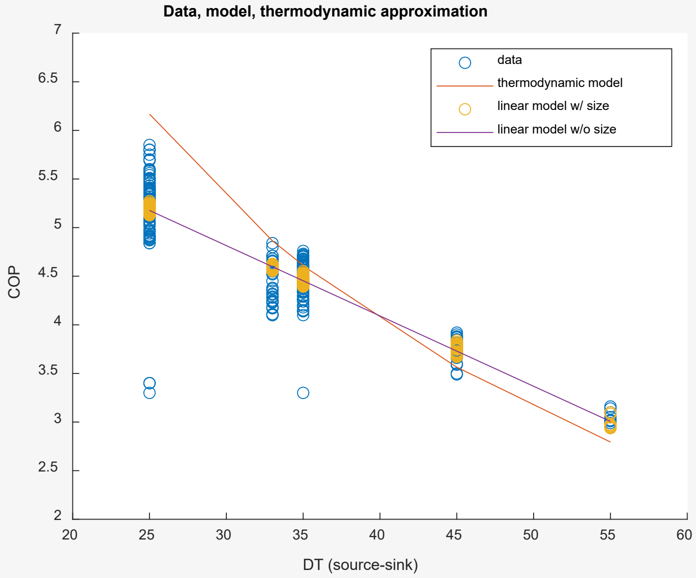
- Data collection:
  - Manufacturer datasheets
  - brine-water and water-water heat pumps
  - 100 kW < Heating output < 1600 kW
- Heat pumps included:
  - Trane RTWF series
  - Trane RTWD series
  - Viessman Vitocal series
  - Trane RTSF series
  - Trane CGWN series
- 114 models, 262 datapoints

Performance

- $COP = a_0 + a_1 * (T_{sink} - T_{source}) + \cancel{a_2 * S}$
  - S heat pump design size

- $P_t = COP \ * F_t$
  - $\alpha S * x_t \ \leq F_t \leq \beta S * x_t$
  - F_t electricity input
  - x_t heat pump on/off status

- However, $S * F_t$ not allowed in MILP formulation, both design variables
- MSE 0.0976 → 0.0990



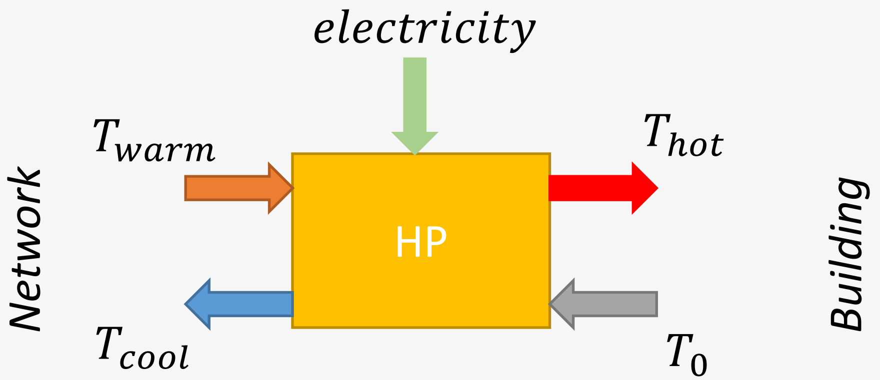
Thermodynamic model: Olympios et al. (2020)

[1] *formulation based on: Gabrielli et al. Appl. Energy 2018 (219)*

Operation

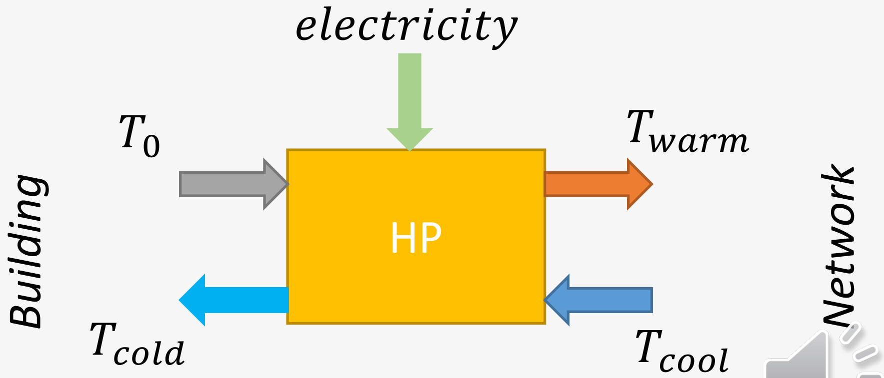
- Heating operation

$$COP = f(T_{hot} - T_{warm})$$



- Cooling operation

$$COP = f(T_{warm} - T_0)$$



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Energy balance

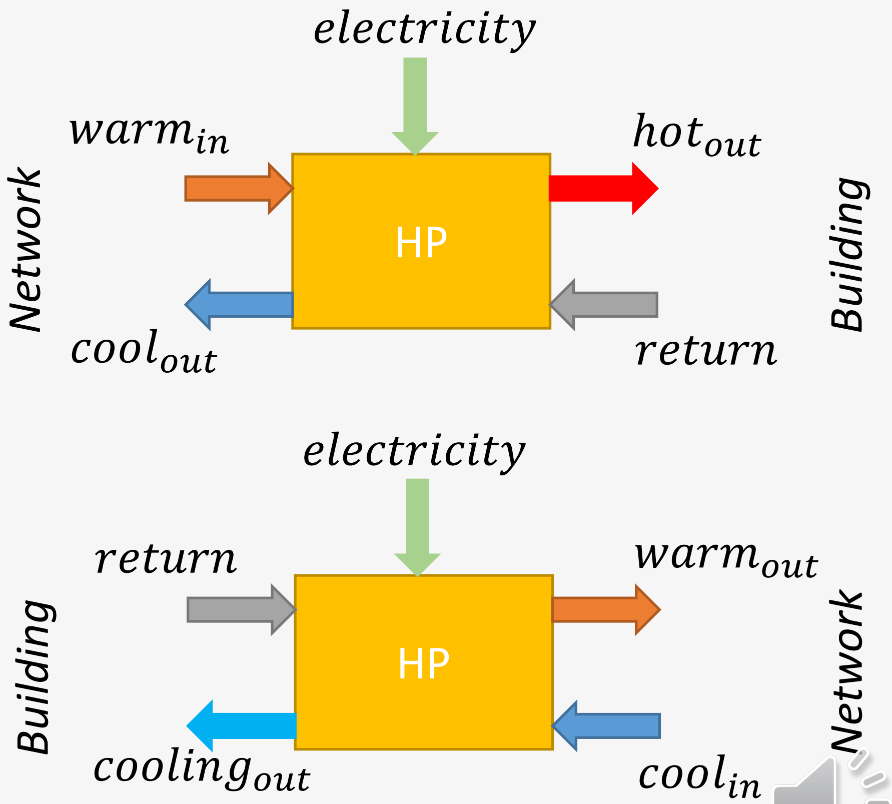
$$\frac{P_{cooling}}{P_{heat}} = \frac{T_0 - T_{cool}}{T_{warm} - T_0}$$

heating

$$P_{hot,out} = P_{warm,in} + P_{cool,out} + F_t$$

cooling

$$P_{cooling,out} = P_{cool,in} + P_{warm,in} - F_t$$



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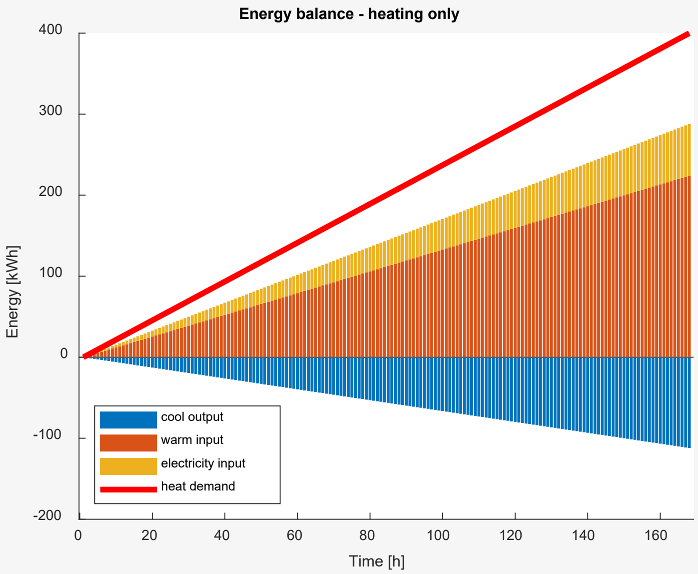
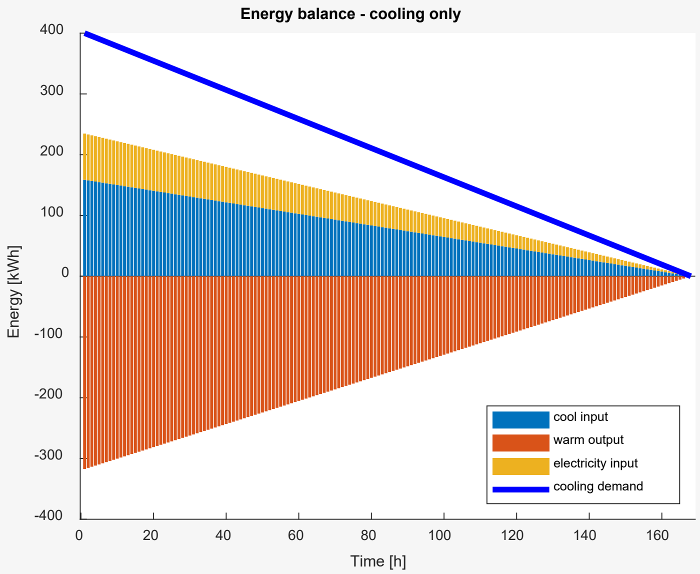
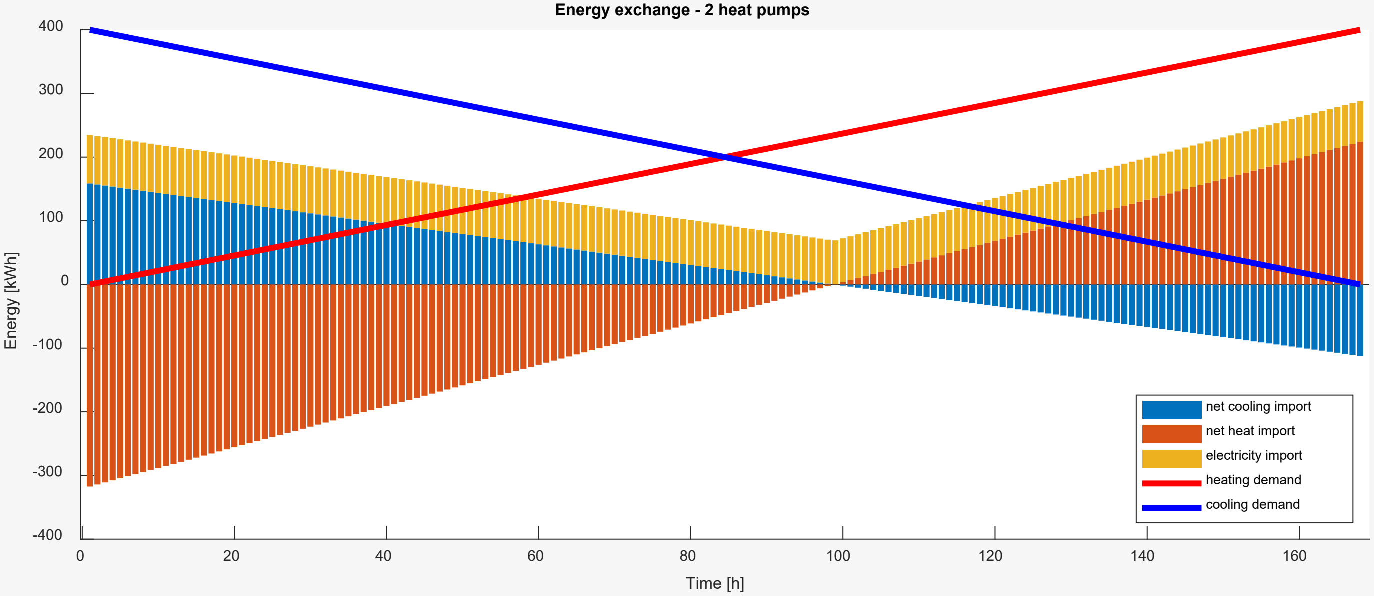
Example operation – energy balance





Example operation – energy exchange



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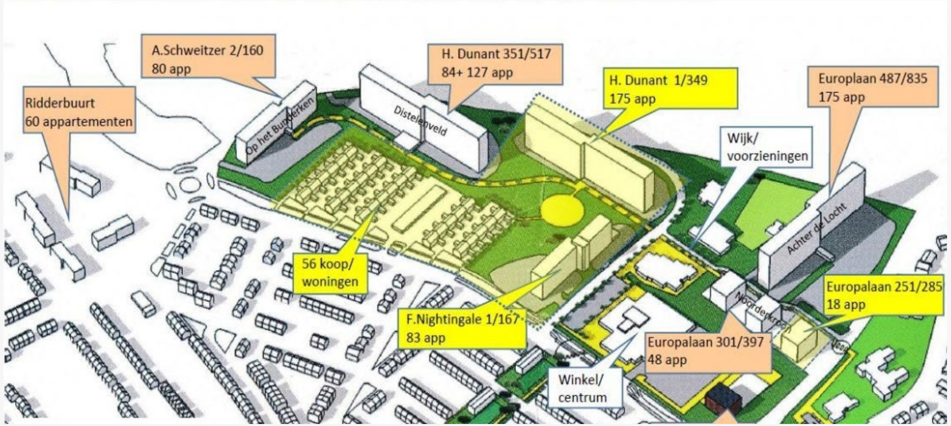
Case study

- Post-war Dutch residential neighborhood
  - 781 post-war apartments and row houses
  - 49 new apartments
  - 5000 m^2 supermarket and utilities: 8 TJ cooling demand
- Technology options
  - Connection to ULT backbone (28 °C/14 °C)
  - Heat pump, cold and hot thermal storage at each node
  - Two-pipe network in neighborhood



Summary

- We presented a networked heat pump model for MILP
  - Operating at
    - 100 kW < P < 1600 kW
    - 25 K < ΔT < 55 K
  - Some variance in dataset remains unexplained
- Heat pump model operates in energy hub
  - Simultaneous heating and cooling with cross-consumption
- Future work
  - Implementation in real case study

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