HighEFF

FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

Thermal storage and model predictive control for improved utilization of industrial waste heat in district heating

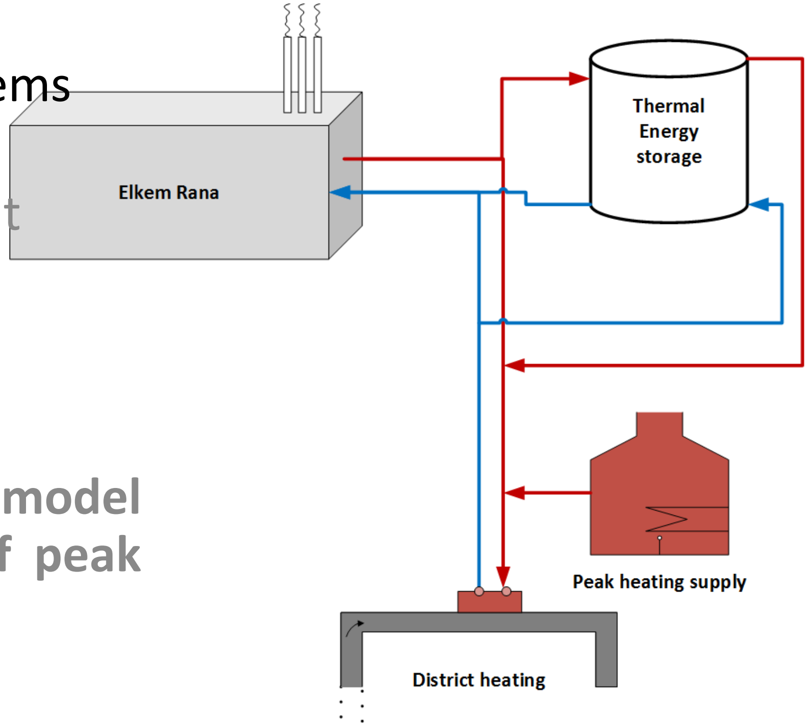
Hanne Kauko, Brage Rugstad Knudsen and Terje Sund-Olsen

SINTEF Energy Research / Mo Fjernvarme

4th International Conference on Smart Energy Systems and 4th Generation District Heating, Aalborg 13-14 November 2018

Motivation

- Industrial surplus heat has high potential for utilization in DH
  - Total amount of heat available often larger than the demand, but peak heating required due to temporal mismatch in availability / demand
- Thermal energy storage (TES) widely applied in DH systems utilizing heat sources with predictable output
  - More challenging in a system utilizing a surplus heat source with fluctuating output
- Goal for the study
  - **Analyze the potential of TES in combination with model predictive control (MPC) to minimize the use of peak heating at Mo Fjernvarme**



FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

HighEFF

FME – Forskningssenter for miljøvennlig energi

Norges forskningsråd

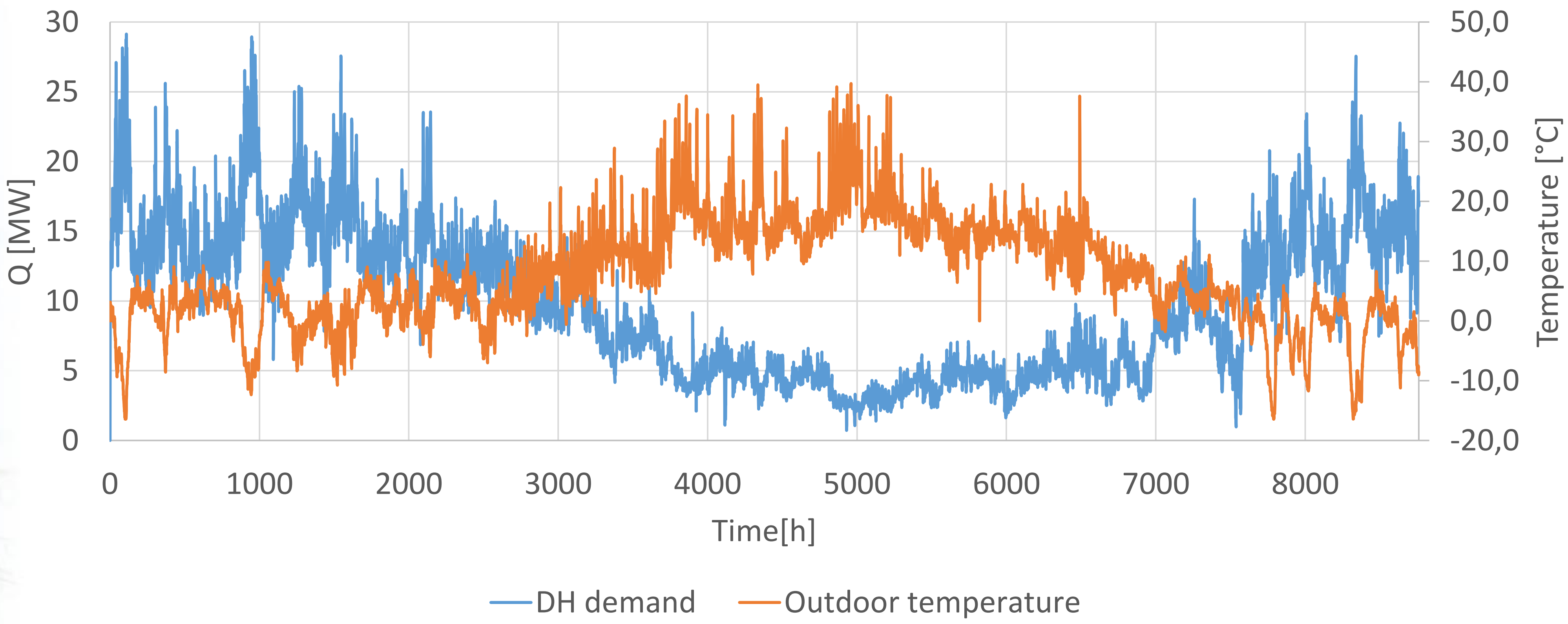
Case study description

District heating in Mo i Rana

DH production in Mo i Rana

- Mo Fjernvarme: Utilizing surplus heat from Mo Industry Park for DH
  - Heat source: off-gases from FeSi production plant
- Amount of waste heat available exceeds the demand
  - Large fluctuations in availability
  - Peak boilers: CO-gas, electricity, oil

The climate and total DH demand in 2017



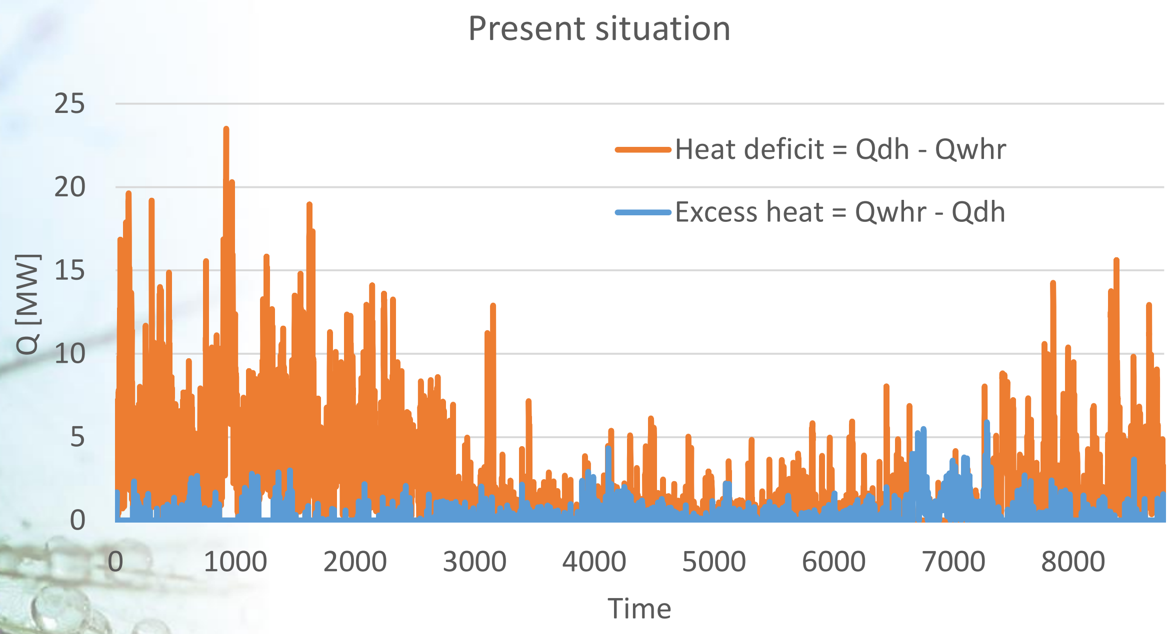
Total DH demand: **84 GWh**

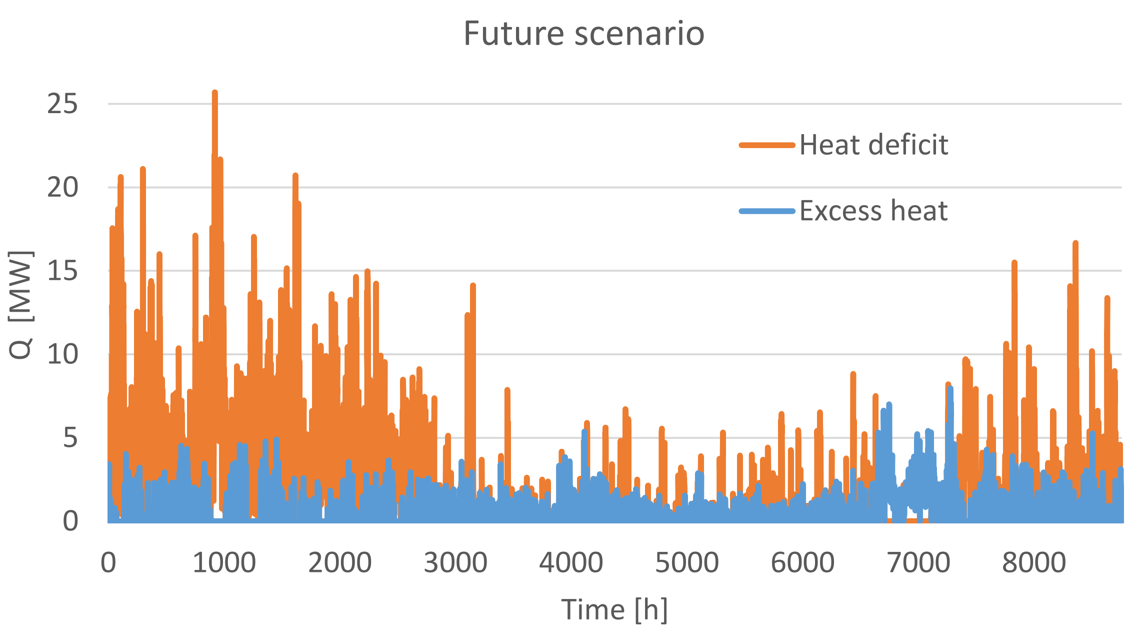
Total peak heating demand: **18 GWh**

→ **21 %** of the total production / **94 %** of the heat production costs

→ 2017 was not a representative year!

Potential for TES?





Could TES be used to recover some of the rejected heat, to reduce use of peak heating?

- Future scenario
  - 20 % increase in surplus heat production
  - 10 % increase in the demand

	Current	Future
Total excess heat [GWh]	1.4	3.4
Total heat deficit [GWh]	19.1	16.1

FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

Methodology

Modelling approach

- Dynamic modelling using Dymola / Modelica
  - MPC implemented with jModelica
  - iPopt med Casasdi applied to solve dynamic optimal control problems

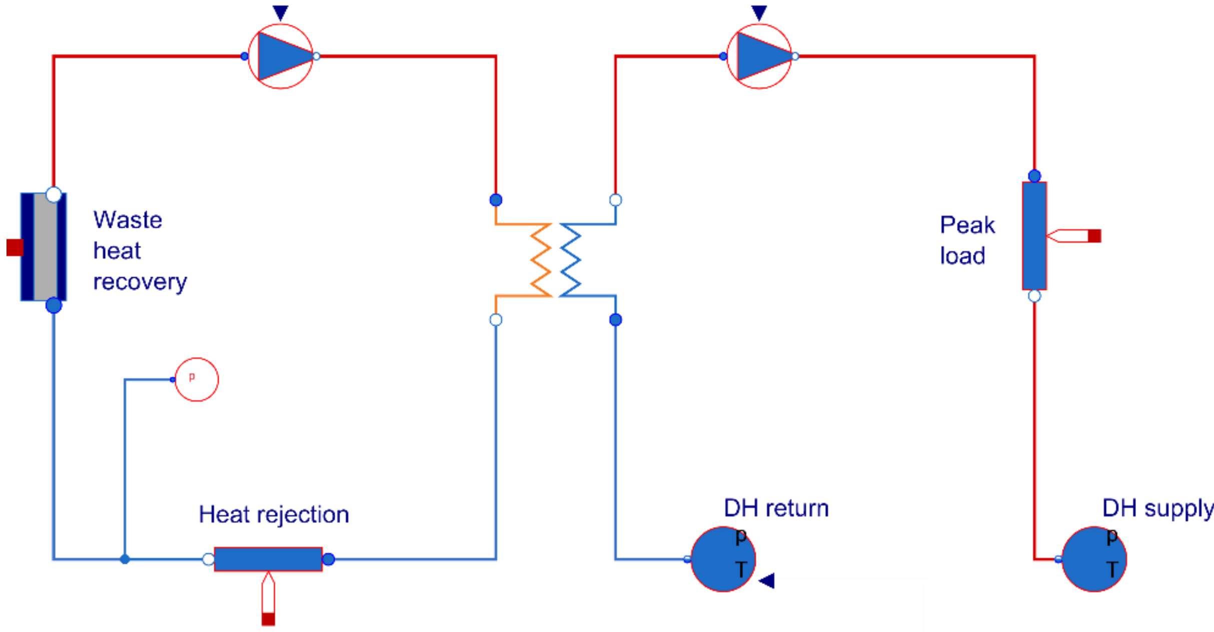
- Measurement data for heat demand and production for 2017

- **3 scenarios** evaluated for **December 2017**:
  1. Baseline – future scenario with no TES
  2. With TES, "normal" control strategy
  3. With TES + MPC

Scenario 1: Baseline scenario

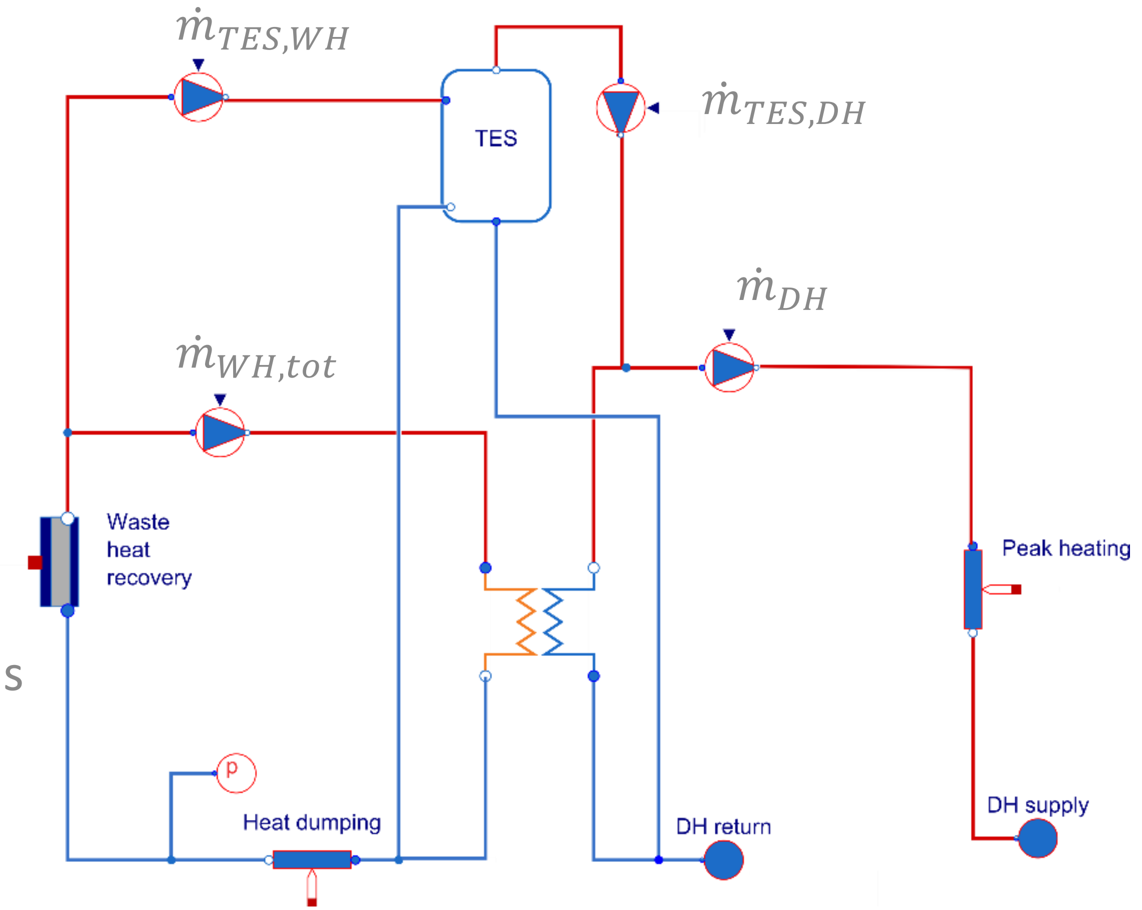
- **Objective**: Dimension component models and validate the model towards measurement data

- Simplifications
  - Water as the working fluid everywhere
  - The DH grid modeled as an open loop with supply & return temperatures and mass flow based on data



Scenario 2: TES and regular control strategy

- Control strategy:
  - Charge when excess heat available:
    $$\dot{m}_{TES,WH} = max\left(0, \frac{\dot{Q}_{WH} - \dot{Q}_{DH}}{\dot{Q}_{WH}} \dot{m}_{WH,tot}\right)$$
  - Discharge when there is a heat deficit:
    $$\dot{m}_{TES,DH} = max\left(0, \frac{\dot{Q}_{DH} - \dot{Q}_{WH}}{\dot{Q}_{DH}} \dot{m}_{DH}\right)$$
  - Temperature at the top of the tank needs to be at the level of the supply temperature
  - Try to keep the tank temperature at the bottom below 105 °C (max. supply temperature level)



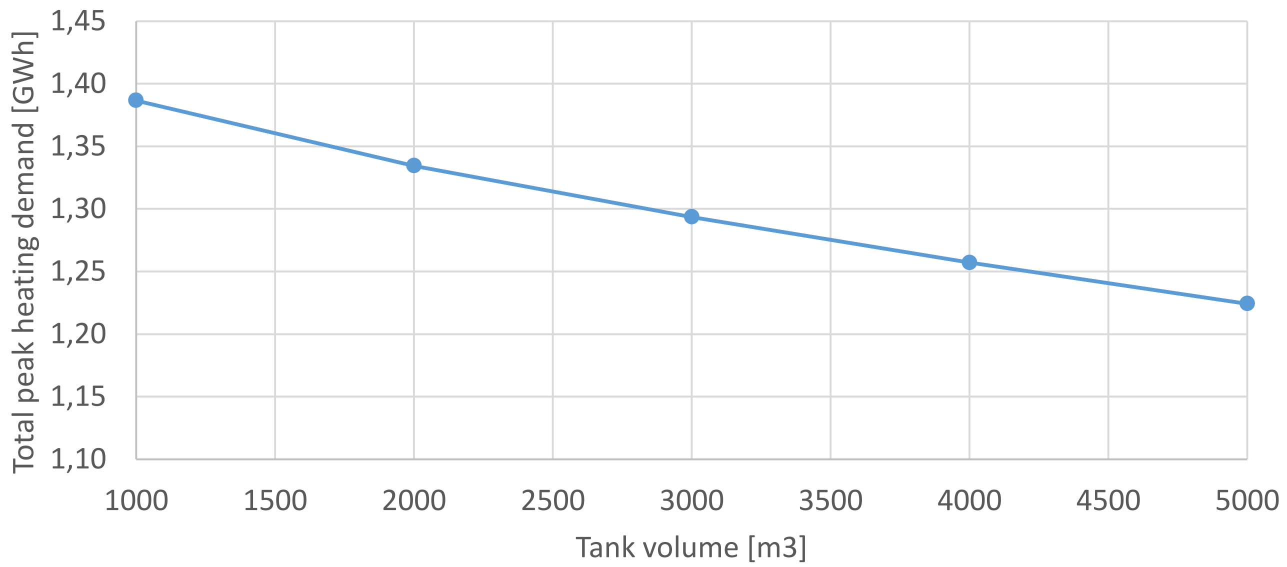
FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

Scenario 2: TES and regular control
Dimensioning of the tank

Selected tank size: 3000 m^3

- 7 % reduction in total peak heating demand for December
- Total heat capacity: 175 MWh, corresponding to ca. 50 % of the average daily DH demand in December
- Storage discharge capacity: 8 MW at a mass flow rate of 40 kg/s
  - Approximately 50 % of max. peak heating supply

Tank volume [m^3]	Reduction in peak heating demand (%)
1000	0.5 %
2000	4.3 %
3000	7.2 %
4000	9.8 %
5000	12.2 %

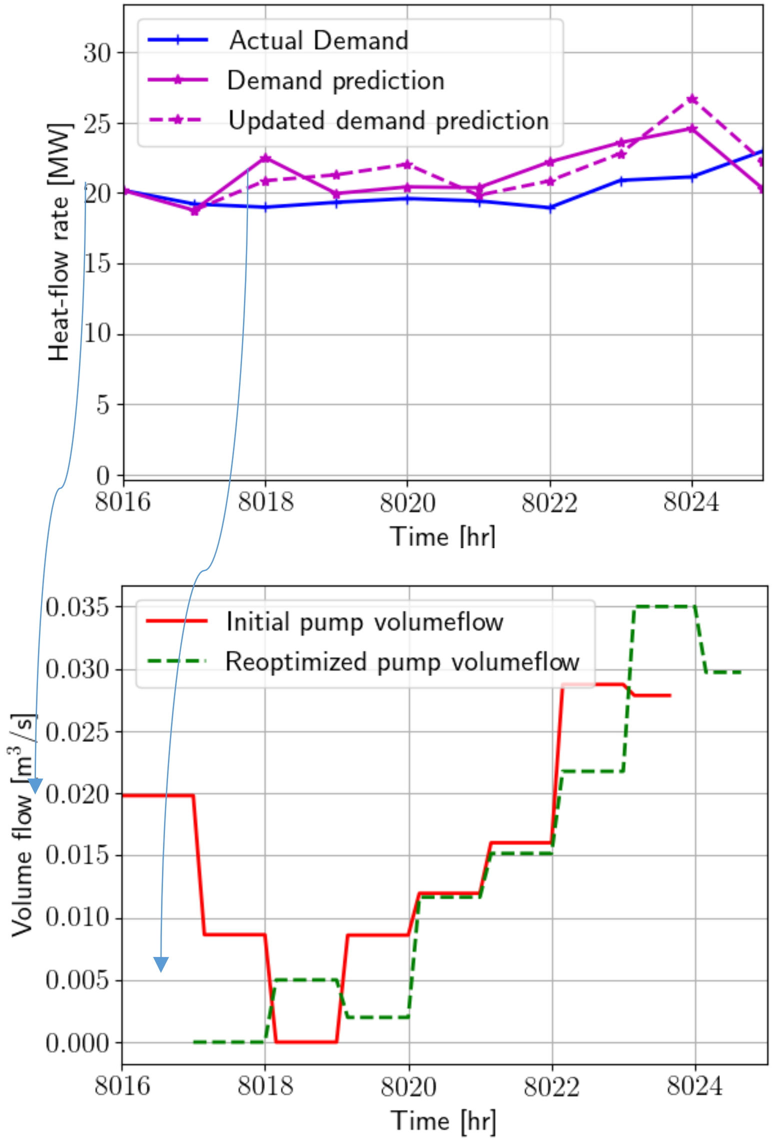


HighEFF

FME FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

Scenario 3: TES and model predictive control

- Multivariable control of pumps, peak heating and heat rejection.
- Exploit predicted heat demand to optimally control TES in/outflow and minimize peak heating.
- Natural way of handling constraints (satisfaction of demand, pumpflows, max. TES temperature)
- Feedback introduced by re-optimizing control inputs on a receding horizon.



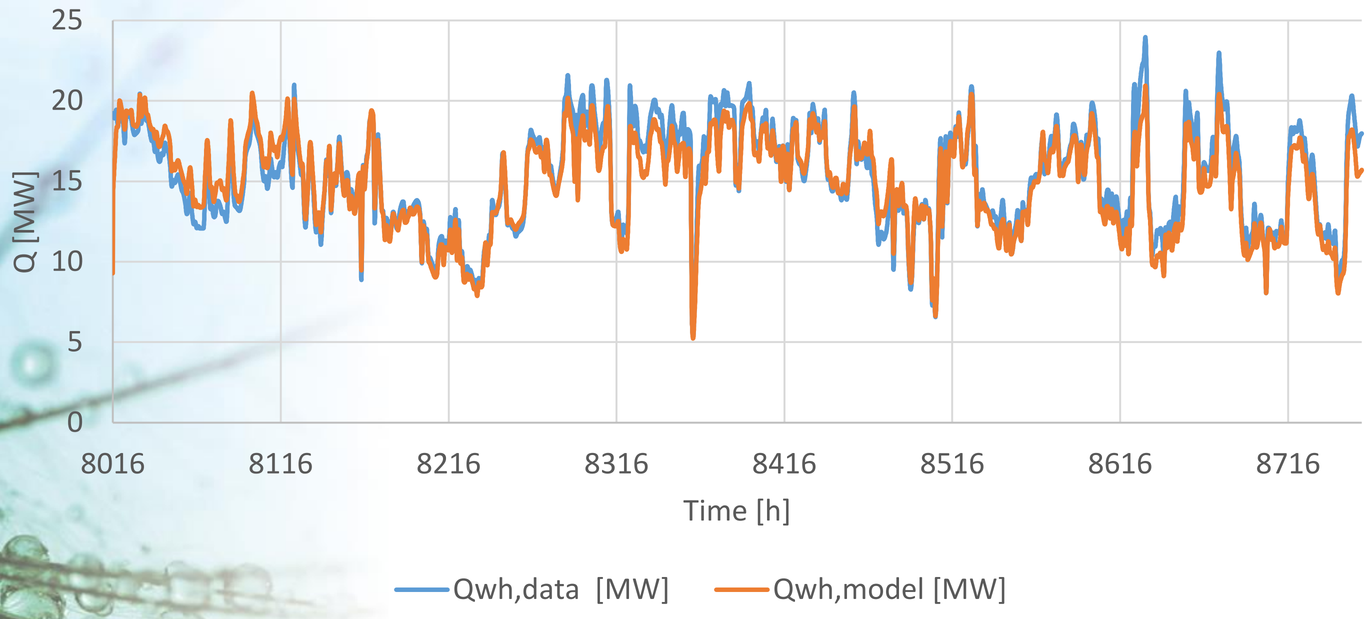
Setup:

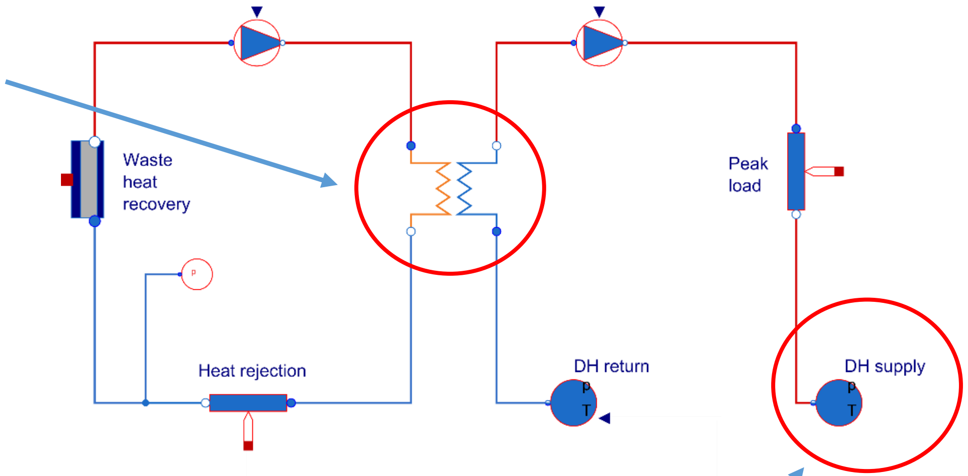
- 12h prediction horizon; reoptimize pump flow velocities and peak heating <u>each hour.</u>
- Demand prediction not implemented - use demand data with added noise to emulate uncertainty in predictions.

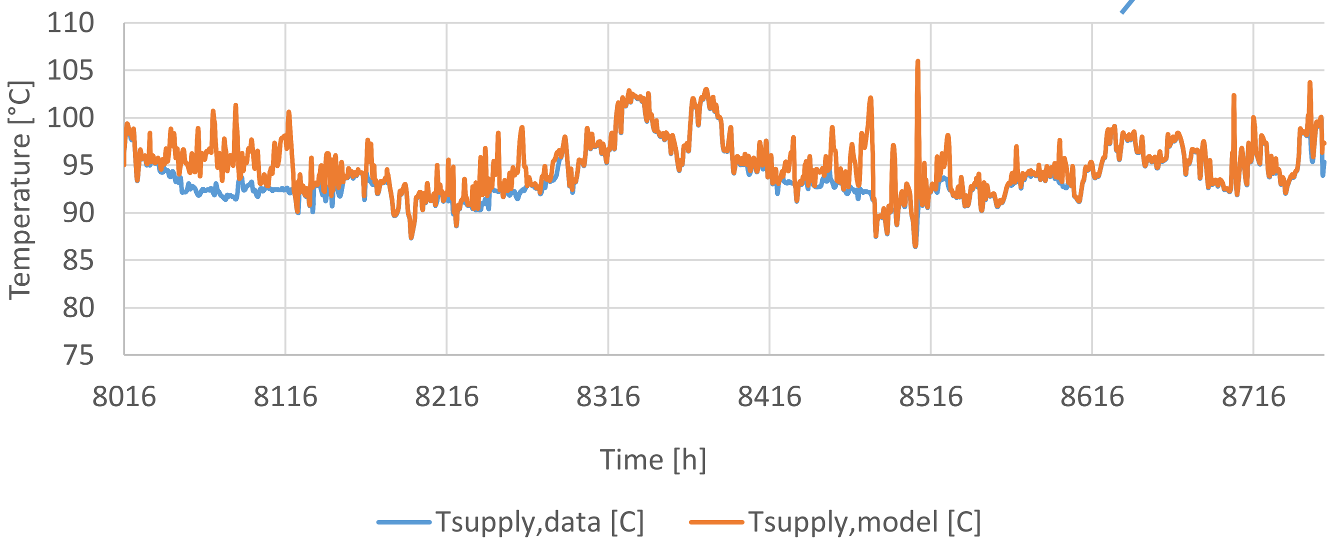
FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

Results

Scenario 1: Baseline

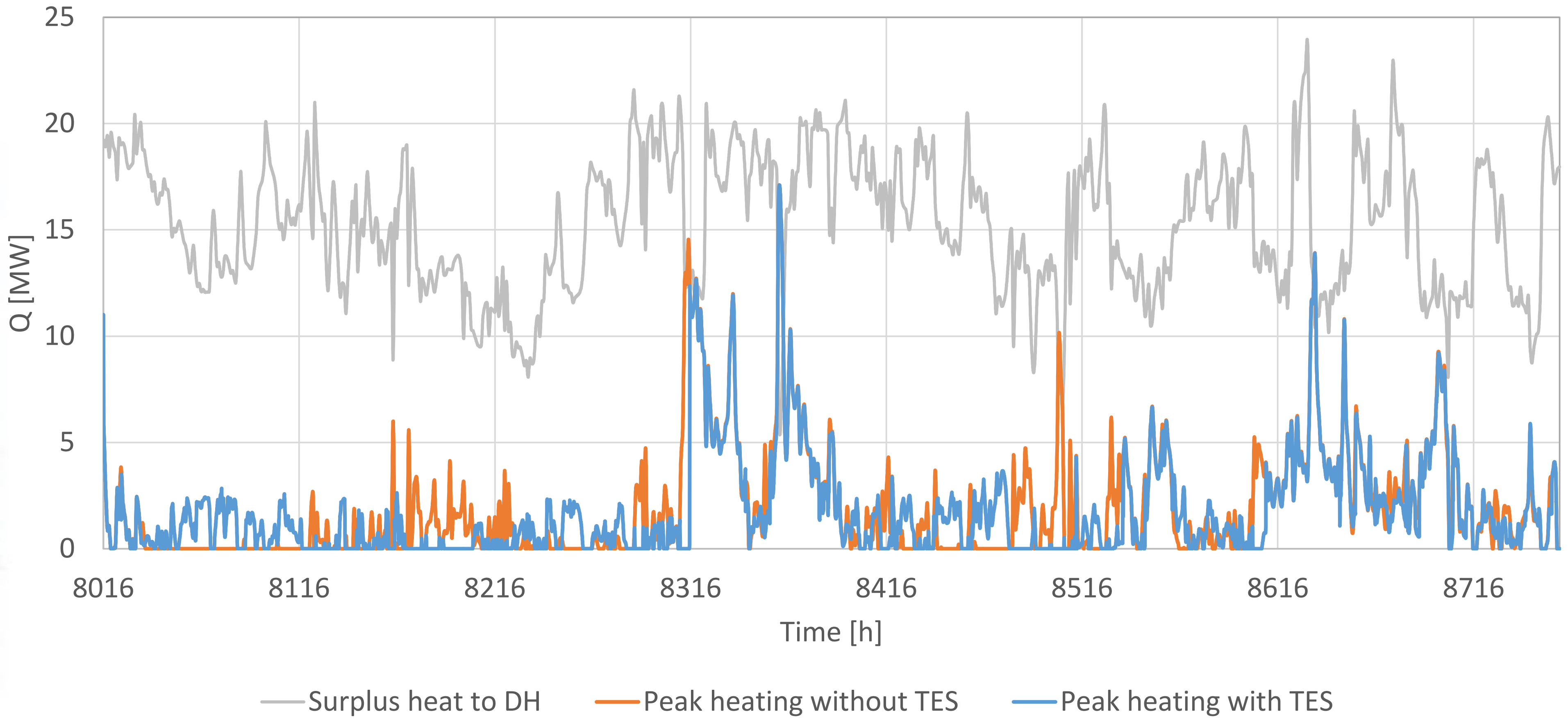




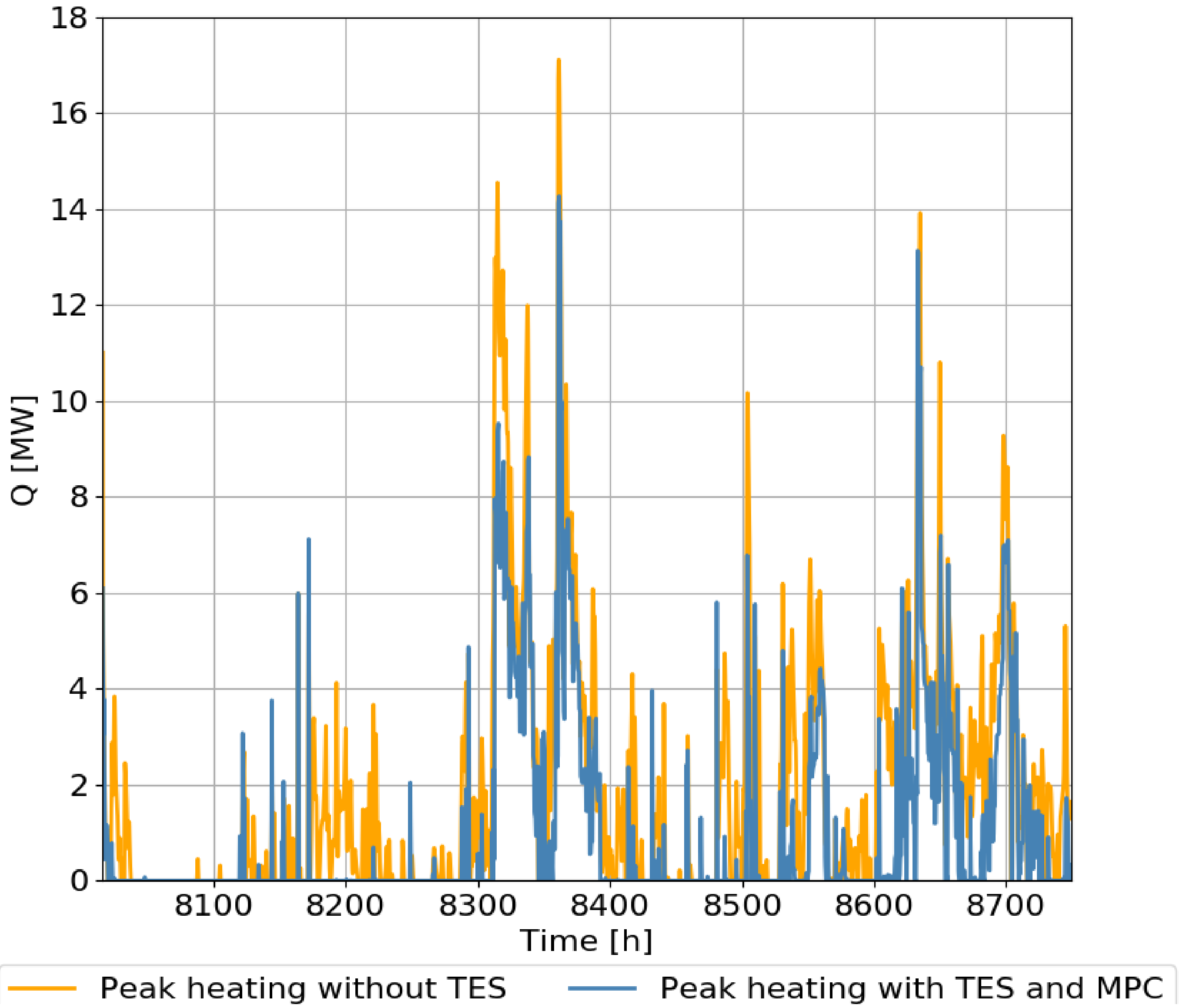


HighEFF
FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

Scenario 2: TES and regular control – results



Scenario 3: TES and MPC



Comparison

	Basecase	With TES	Reduction from basecase (%)	With TES+MPC	Reduction from basecase (%)
Total peak heating [MWh]	1394	1294	7.20 %	707	49.3%
Max peak heating [MW]	17.1	17.1	0.03 %	14.2	17.0%
Total heat dumping [MWh]	1121	1043	6.93 %	549	51.1%

HighEFF
FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

Concluding remarks

- Industrial surplus heat is a low-cost and environmentally friendly heat source for DH
  - Use of peak heating sources increases the costs and environmental impact of the heat production significantly
- TES with regular control strategy appears to have a limited possibility to reduce the use of peak heating sources
  - Only 7 % reduction in peak heating
  - In addition: challenging to control the temperature in the tank
- Combining TES with MPC changes the picture:
  - Leveraging demand predictions and optimizing control inputs is key to utilizing TES and minimizing necessary peak heating!
- Future work
  - Calculating the potential cost reduction and payback time for a TES tank
  - Optimal tank dimension for total cost optimality

FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

HighEFF

FORSKNINGS-
SENTER FOR
MILJØVENNLIG
ENERGI

Norges forskningsråd

Thank you for your attention.

hanne.kauko@sintef.no

This study was partly funded by HighEFF - Centre for an Energy Efficient and Competitive Industry for the Future and partly by KPN LTTG+ - Low-temperature thermal grids with surplus heat utilization.

The authors gratefully acknowledge the financial support from the Research Council of Norway (GA 257632/E20 & 280994/E20) and user partners of HighEFF, in particular Mo Fjernvarme and Mo Industry Park.