CONGRESS EUROHEAT & POWER Glasgow 2017

38th Euroheat & Power Congress
14-16 May 2017, Glasgow, United Kingdom

Special DHC+ Student Awards 2017 session

Modeling of Combined Heat and Power plants for optimal planning of their production

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The research described in the presentation has been conducted in cooperation with Veolia Warszawa, as part of PhD program.

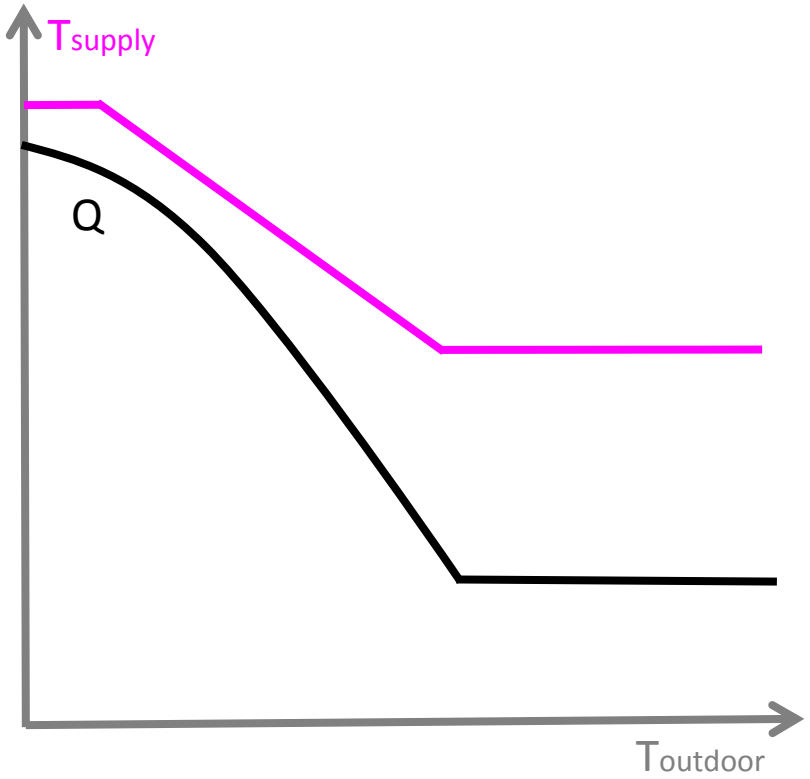
Organised by DHC+ TECHNOLOGY PLATFORM c/o EUROHEAT & POWER

Plan of presentation

- Introduction
- Optimization of CHP plant production with energy storage
- Modeling of the CHP plants
- Case study
- Summary

Introduction

Traditional approach to District Heating



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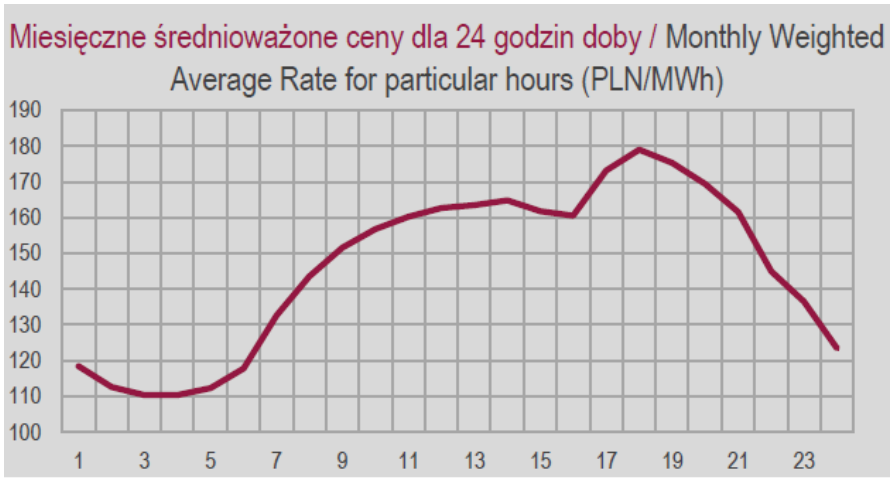
Introduction

Current situation of district heating



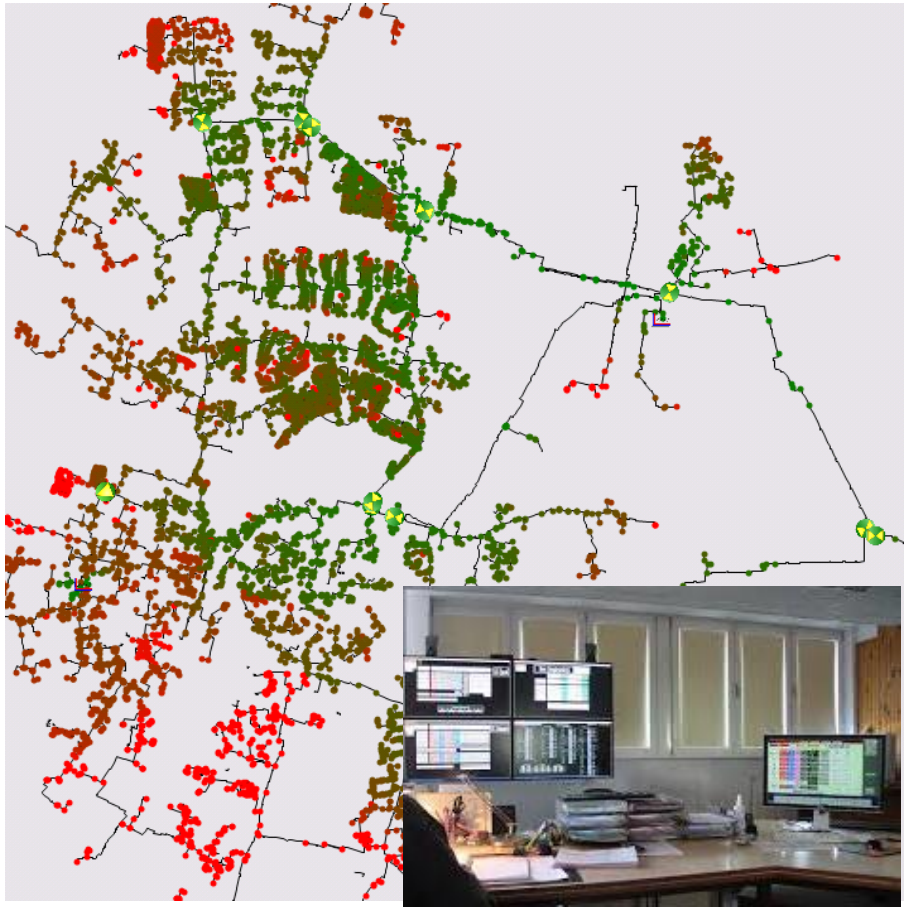
Gas

Biomass

Waste

Coal

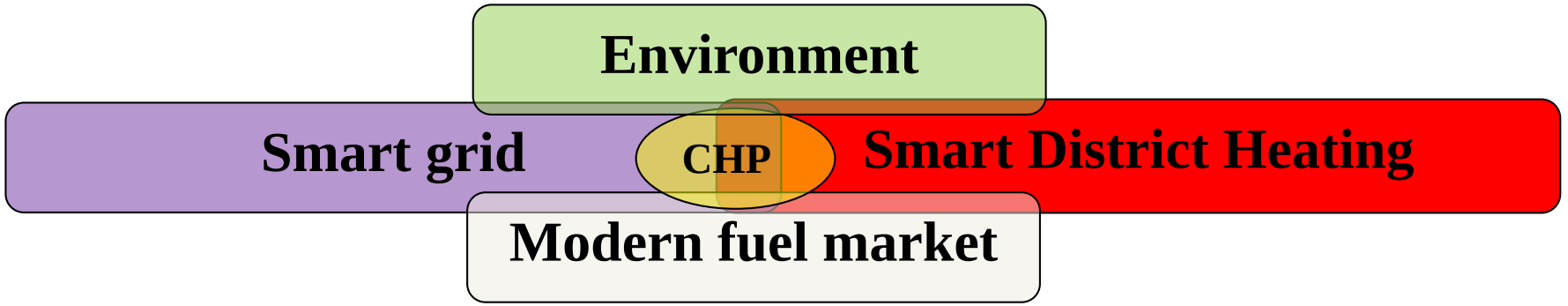
Fuel prices, flue gas emissions, ramp rate of equipment



Introduction

- Conclusion:

  District heating systems, especially the ones supplied from CHP plants, need to adapt to changes in the market and legislation, and especially to improve their **flexibility**

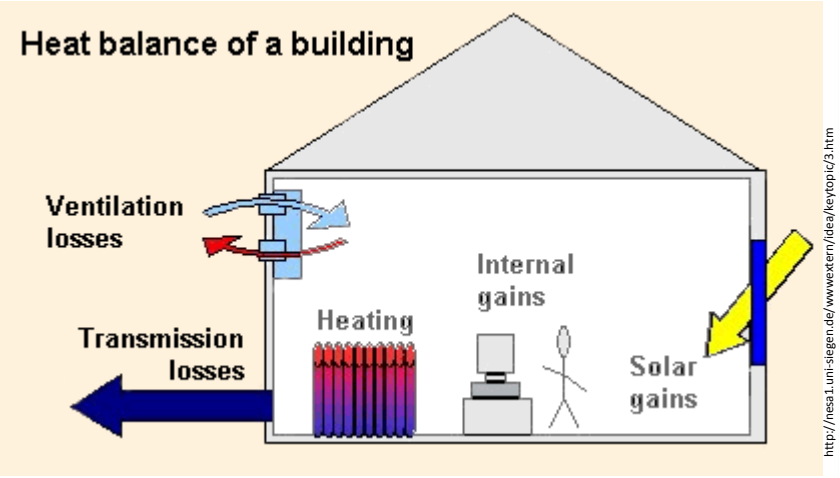


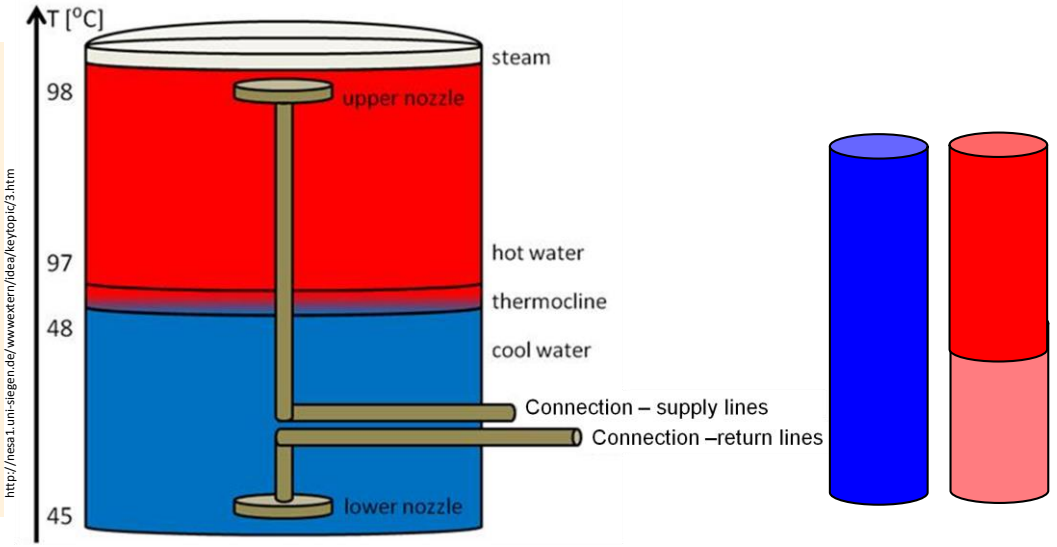
Thermal energy storage in District Heating

Thermal inertia of buildings

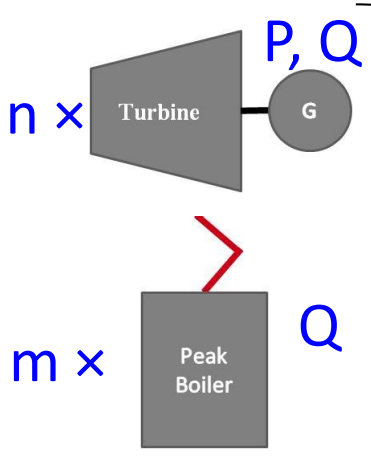
Hot water reservoirs

Thermal inertia of the network (pipes)

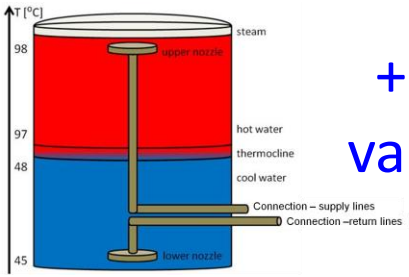




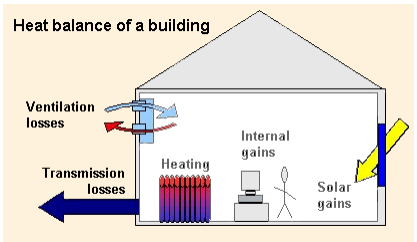
Optimization of production at a CHP plant with energy storage

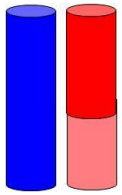


10÷20 variables

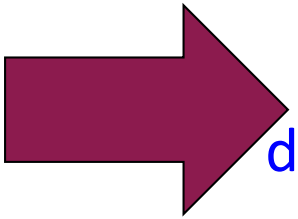


+ 5÷10 variables





× 72h

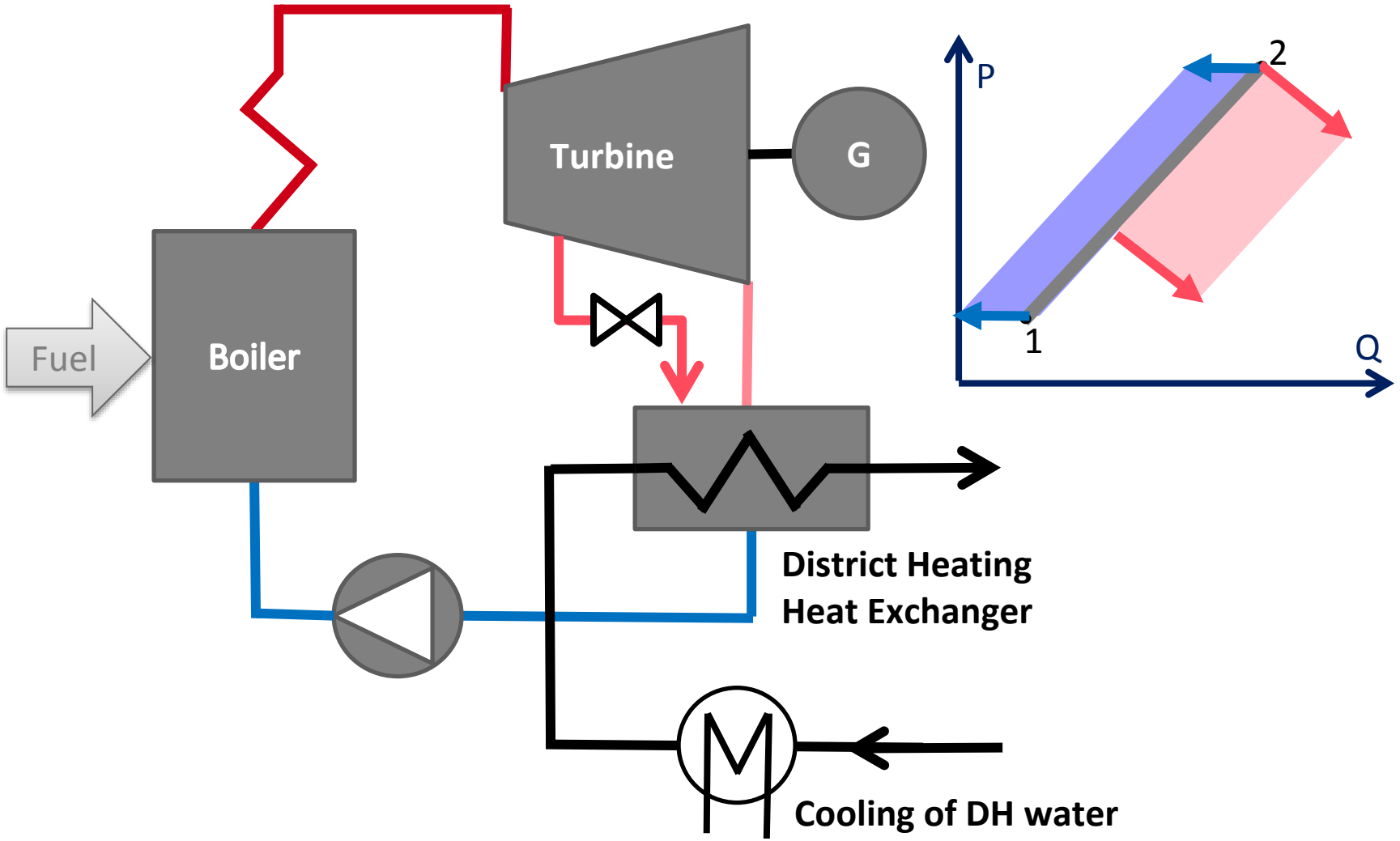


1000÷2000 decision variables

Need for simple and fast models for simulation of CHP plant behavior

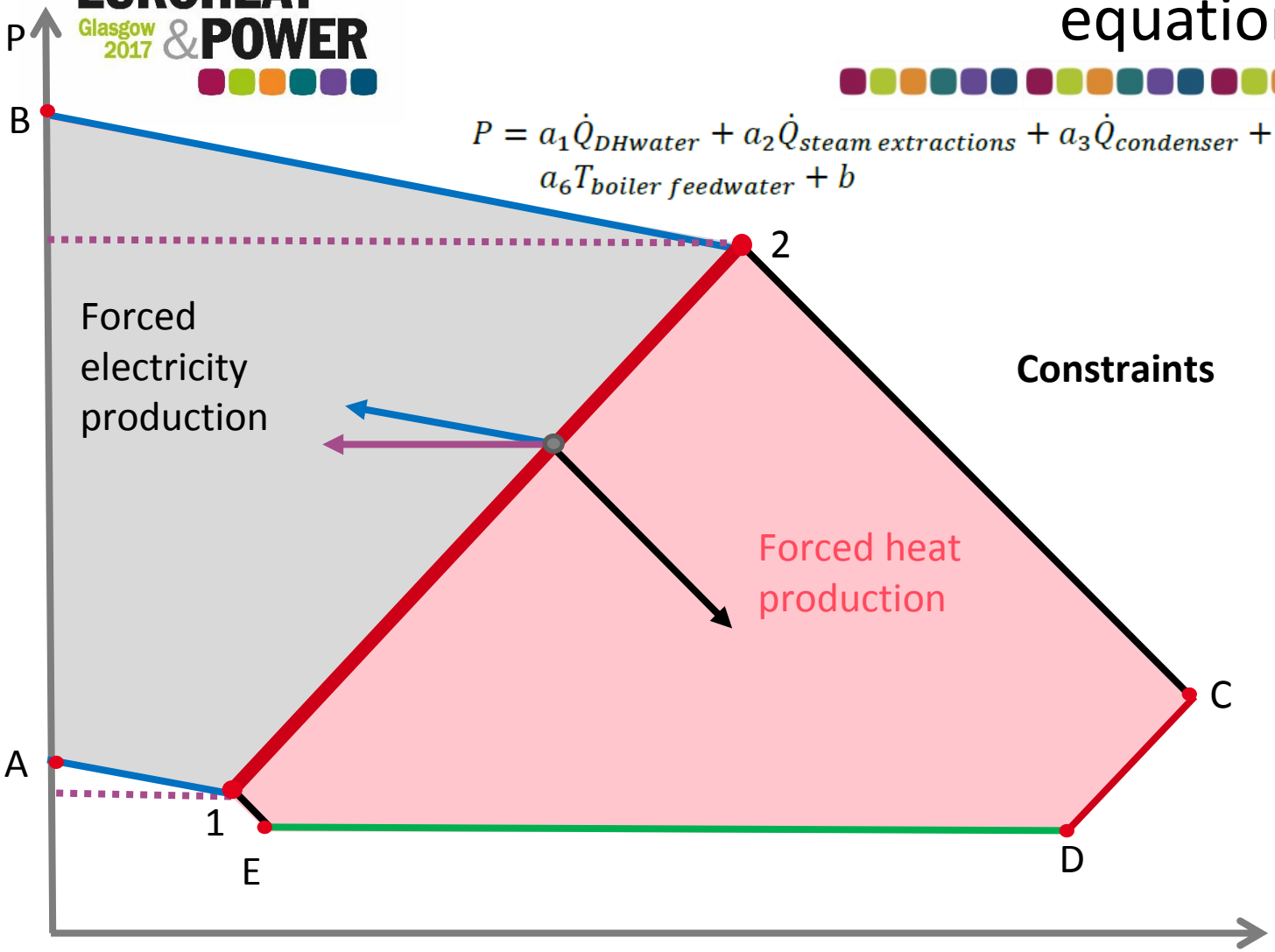
Time available for calculation: 5 ÷ 30 min

Back-pressure turbines



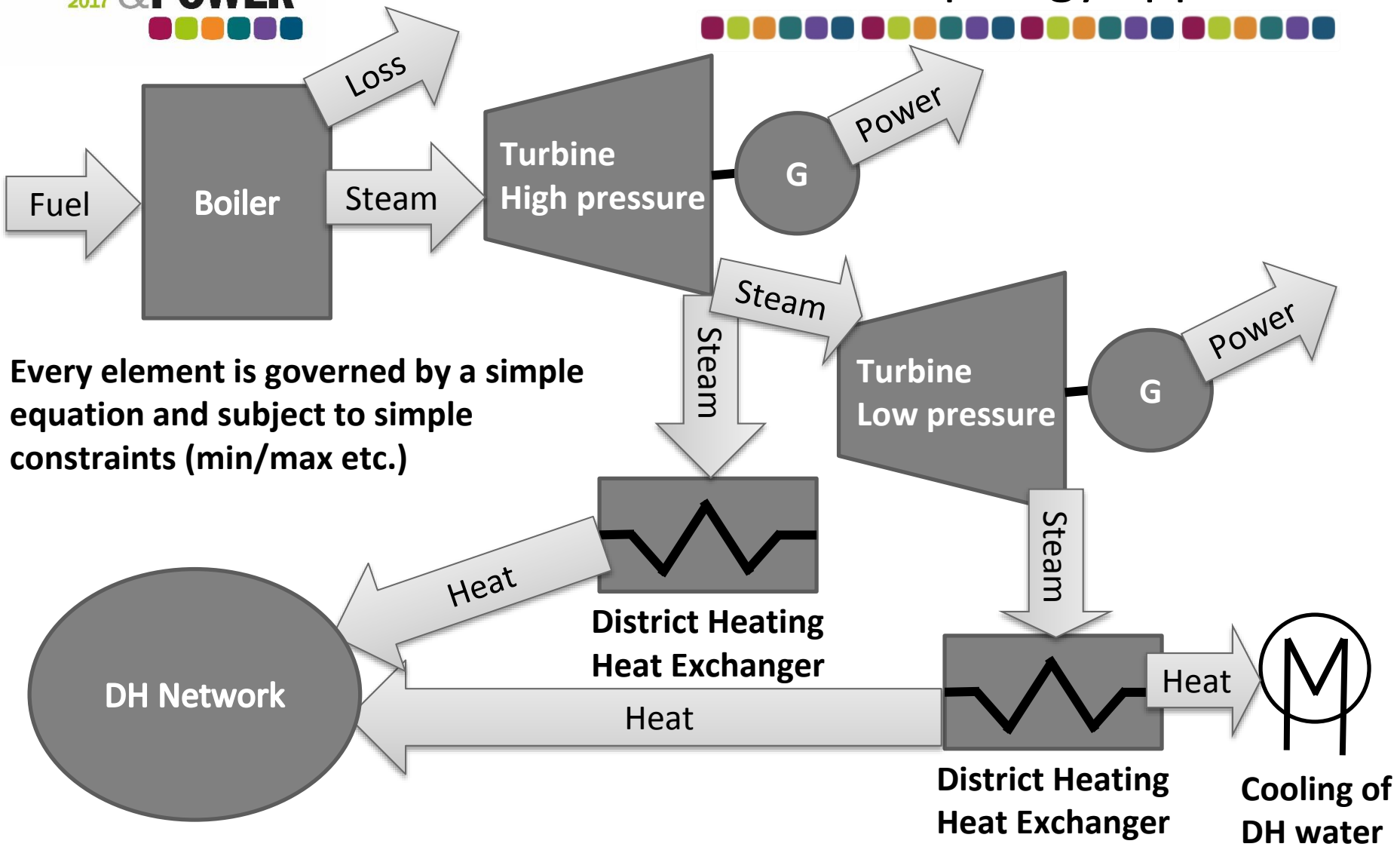
Modeling CHP production units: equation approach

$$P = a_1\dot{Q}_{DHwater} + a_2\dot{Q}_{steam\ extractions} + a_3\dot{Q}_{condenser} + a_4T_{supply} + a_5T_{return} + a_6T_{boiler\ feedwater} + b$$

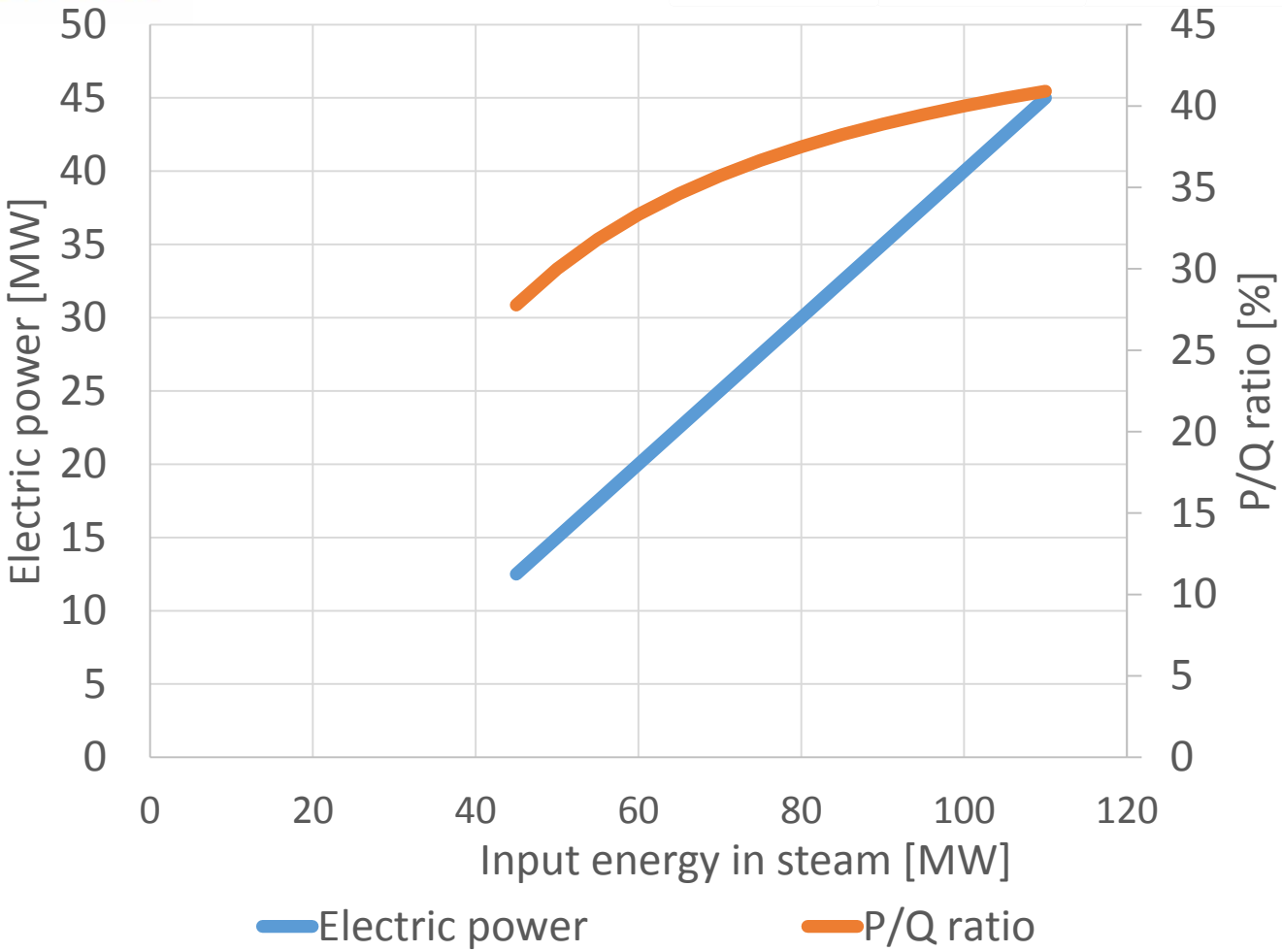


$$\dot{Q}_f = a_1\dot{Q}_{heat\ exchangers} + a_2\dot{Q}_{steam\ extractions} + a_3\dot{Q}_{condenser} + a_4T_{supply} + a_5T_{return} + a_6T_{boiler\ feedwater} + b$$

Modeling CHP production units: topology approach



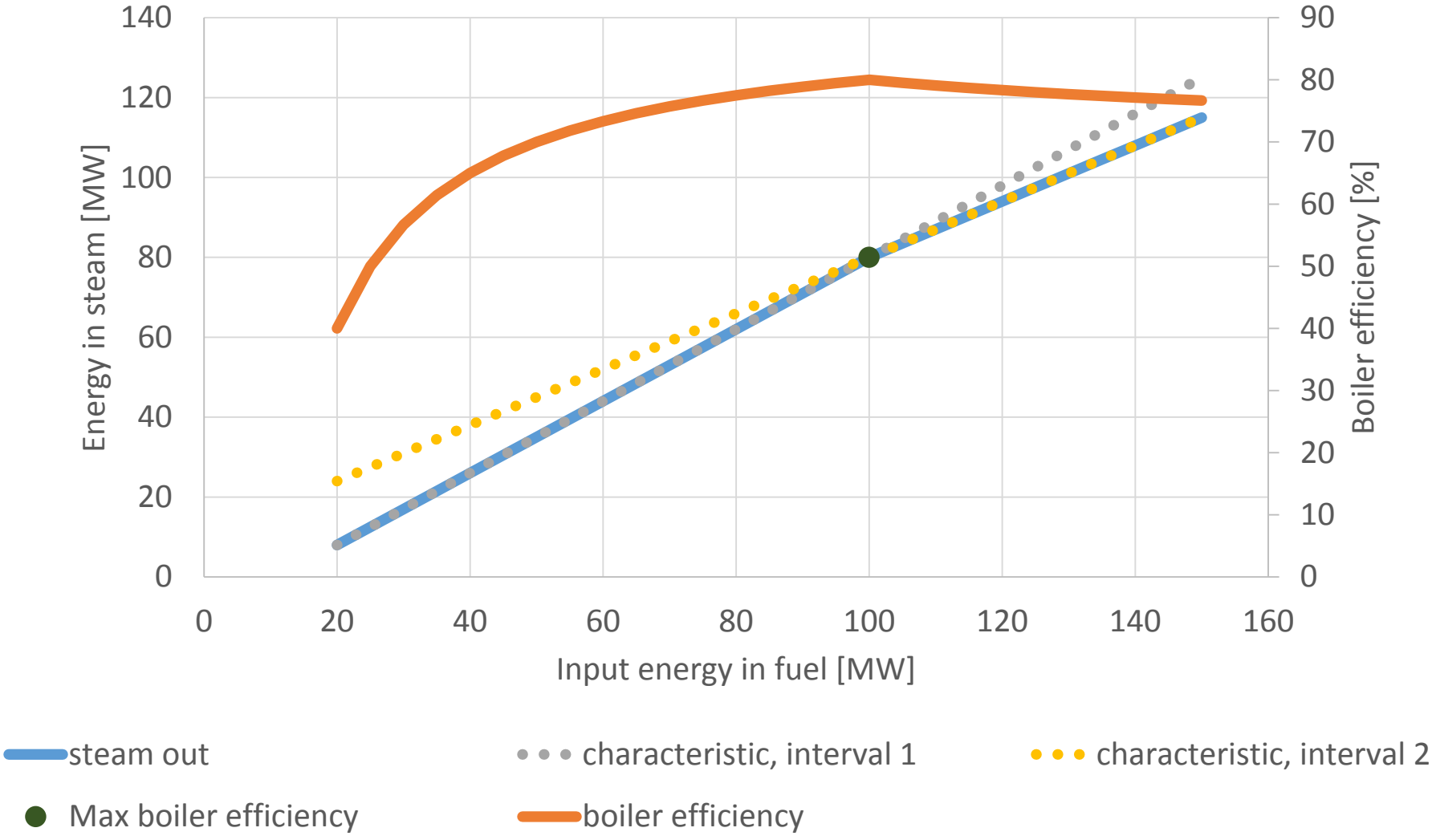
Topology approach: Turbines



$$P_{electric} = a\dot{Q}_{steam\ in} + b;$$

$$\dot{Q}_{steam\ out} = \dot{Q}_{steam\ in} - P_{electric}$$

Topology approach: Boilers



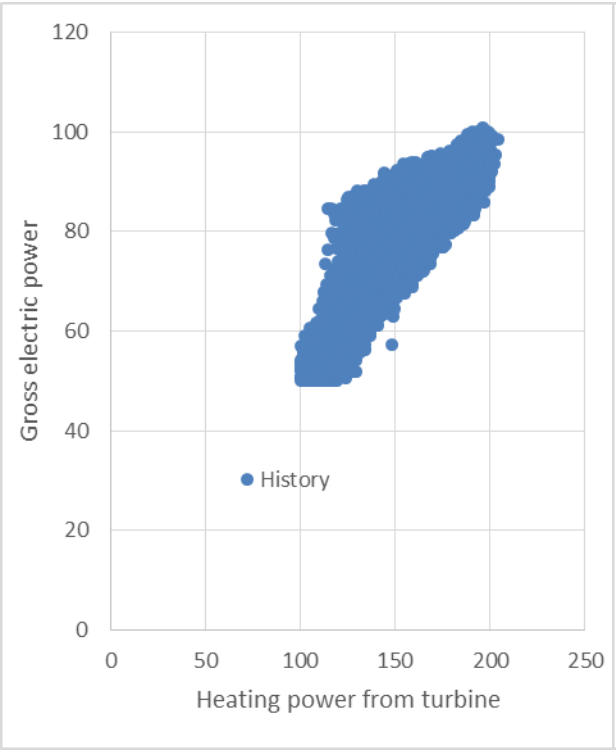
Advantages & Disdvantages

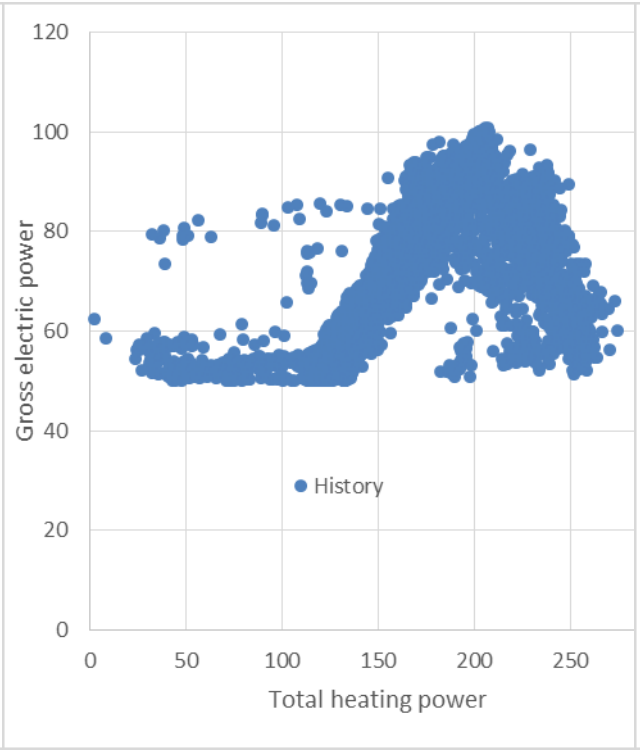
	Topology approach	Equation approach
+	Comprehensive method of creating the model	Full control over the equations
+	Low risk of errors, easy to find errors	No unnecessary equations included
+	High replicability, clear and understandable model structure	Possibility to model every kind of complicated constraint
−	Actual set of equations is not visible	Model has to be created manually
−	Unnecessary equations exist in the model	High risk of errors
−	Not all rules and constraints can be modeled	Low replicability, hard to understand the model

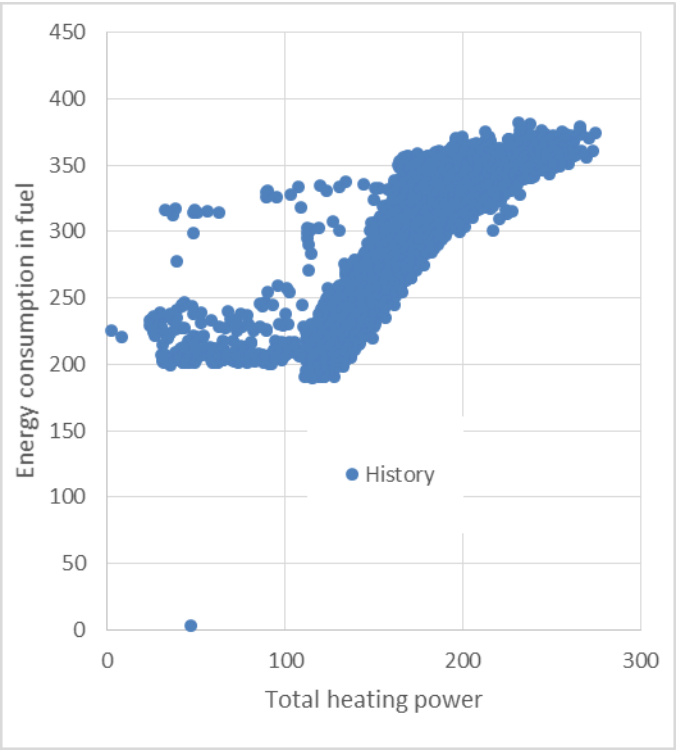
Mixed Approach: Topology Approach + special equations when necessary

Case study

- Historical measurements from 1 year, hour by hour





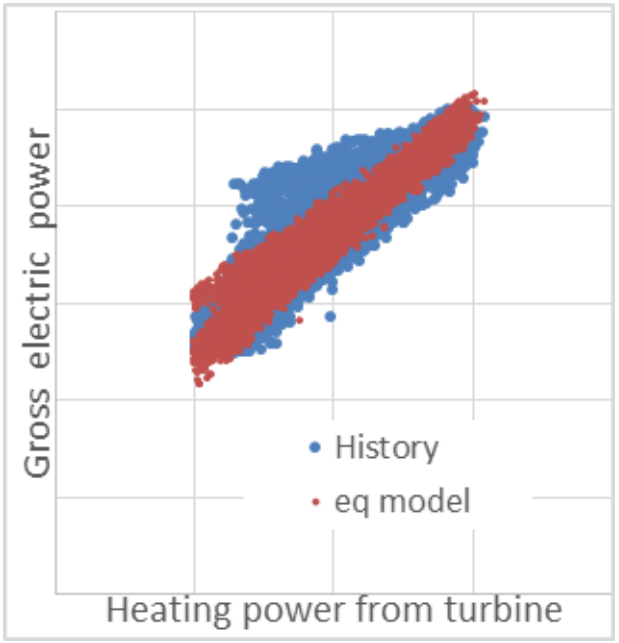


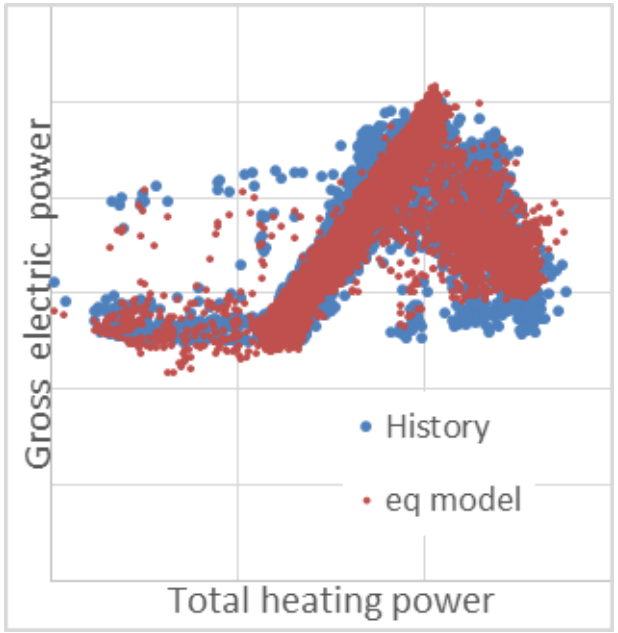
- Modeling with 3 methods and comparing results

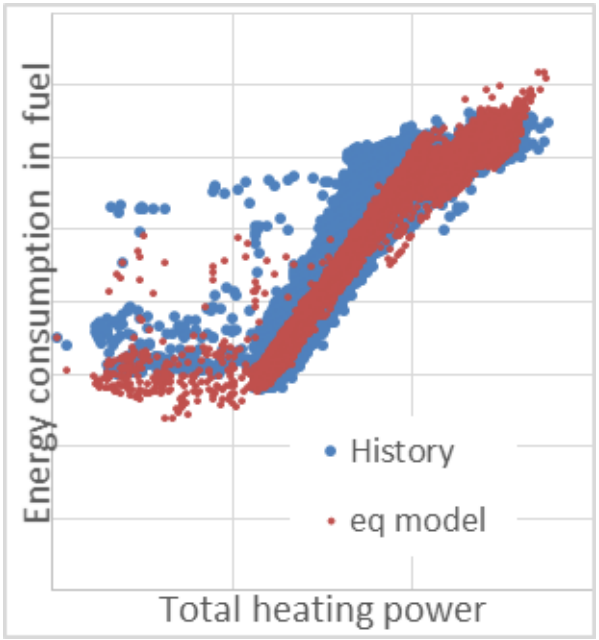
Case study

- Equation approach

$$P, Q_f = a_1 \dot{Q}_{DHwater} + a_2 \dot{Q}_{steam\ extractions} + a_4 T_{supply} + a_5 T_{return} + a_6 T_{boiler\ feedwater} + b$$







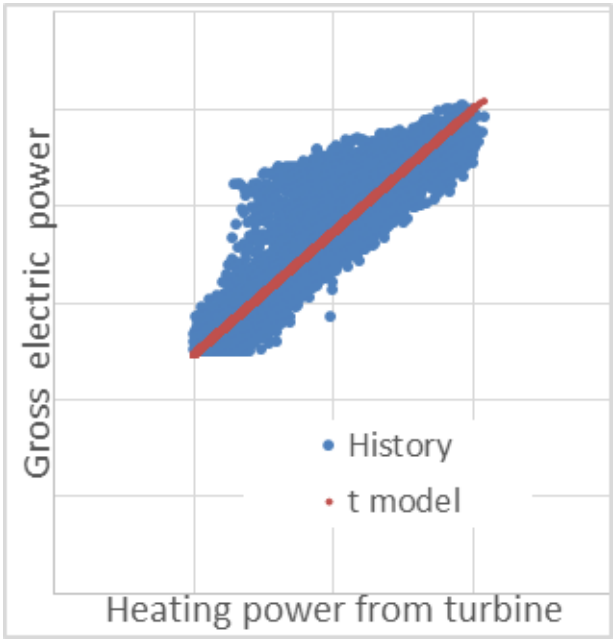
- Mean Absolute Percentage Error:

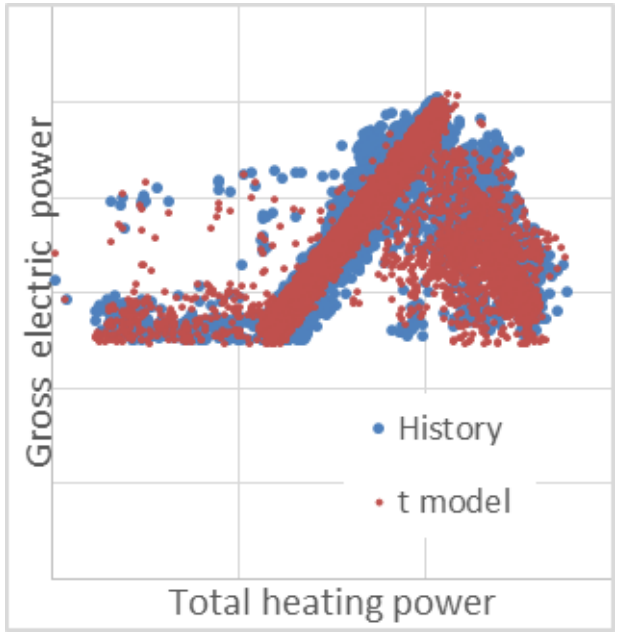
  3.79% (Electric power); 4.04% (Energy in fuel)

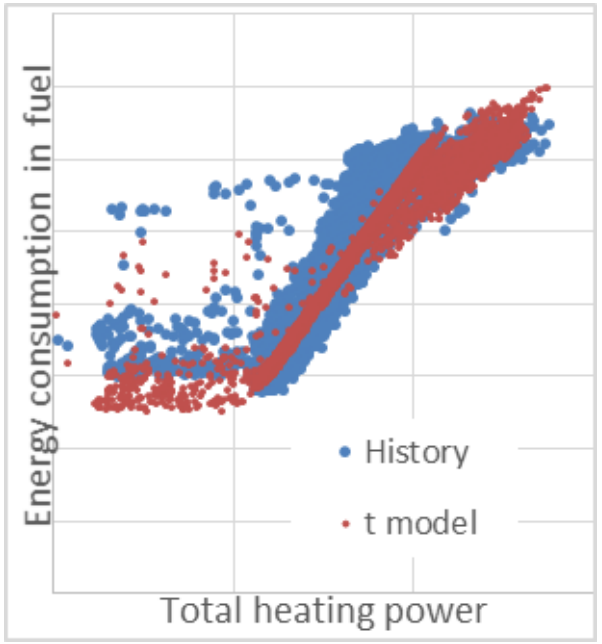
Case study

- Topology approach (1 efficiency interval)

$$P_{electric} = a\dot{Q}_{steam\ in} + b;\ \dot{Q}_{steam} = a\dot{E}_{fuel} + b;$$







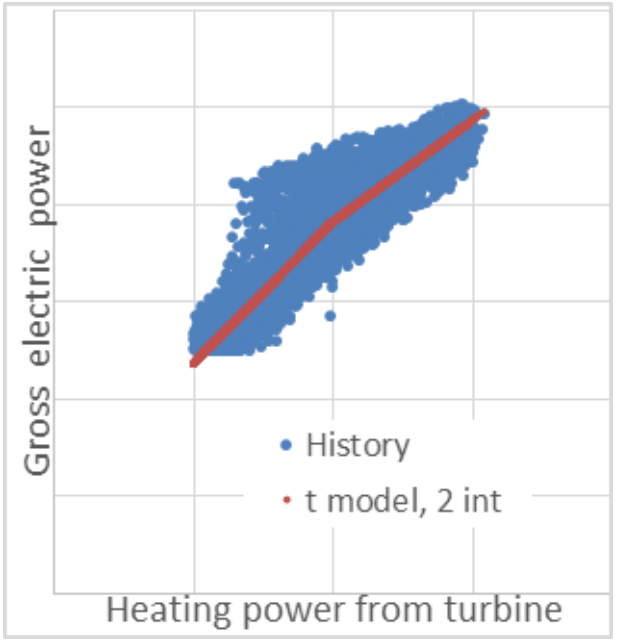
- Mean Absolute Percentage Error:

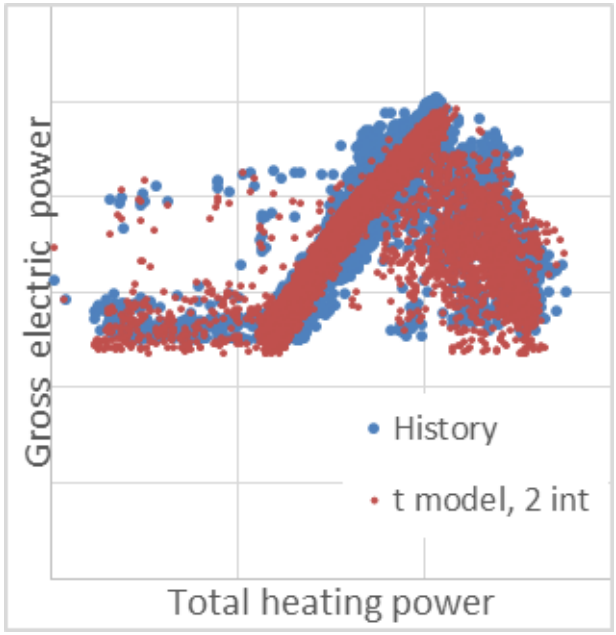
  4.99% (Electric power); 4.67% (Energy in fuel)

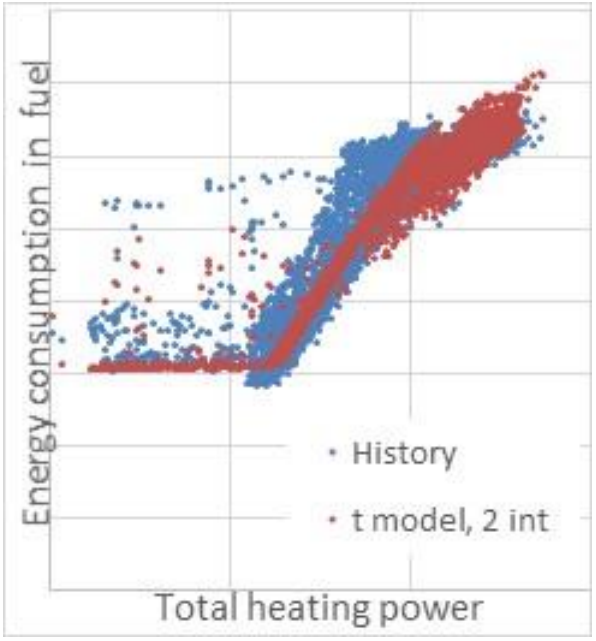
Case study

- Topology approach (2 efficiency intervals)

$$P_{electric} = a\dot{Q}_{steam\ in} + b;\ \dot{Q}_{steam} = a\dot{E}_{fuel} + b;$$







- Mean Absolute Percentage Error:

  4.94% (Electric power); 4.30% (Energy in fuel)

Summary

- Optimization of CHP plant production with energy storage requires simple, preferably linear models of production units
- Two main approaches have been shown
- Equation approach allows for higher accuracy
- Topology approach is more replicable, clear and understandable
- A mixed approach (topology approach with additional equations) can be also used

References

- 1. **Leśko, Michał. *Smart District Heating Concept. Warszawa : Master thesis, 2014.***
- 2. **Słupiński, Mateusz. Metoda analizy złożonego systemu na przykładzie strategii produkcji energii w elektrociepłowni. *PhD thesis.***
- 3. **Sergio Rech, Andrea Toffolo and Andrea Lazzaretto. TSO-STO: A two-step approach to the optimal operation of heat storage systems with variable temperature tanks. *Energy 45 (2012).***
- 4. **Bujalski, Wojciech. *Optymalizacja pracy elektrociepłowni wyposażonej w zasobnik ciepła ("Optimization of the operation of a CHP plant equipped with a heat accumulator"). Warszawa : Oficyna Wydawnicza Politechniki Warszawskiej, 2013.***

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