Improved cogeneration and heat utilization in DH networks

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Project team

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Objective of this project:

- Evaluate and develop approaches that will:
  - *improve the economic feasibility*
  - *the overall efficiency of cogeneration*
- through better utilisation of the generated heat and higher power generation in the CHP plant.

Project's primary focus on small-scale / low heat density DH networks

- CHP plant operated according to heat demand.
- Off-design operation for most periods.
- Low degree of utilisation.

Possible ways of improving the economic feasibility and efficiency of CHP plants

- Increase the power-to-heat ratio (α)
  - process configurations with higher power production efficiencies at part loads
- Long-term thermal storage
  - storage period longer than a week
  - a more constant heat load over the year
  - CHP production feasible for smaller networks

Project divided into 3 tasks

1. Generating load models for heat and electricity
2. Analysing and evaluating long-term storage technologies
3. Developing an optimisation model of DH systems

Load models for heat electricity

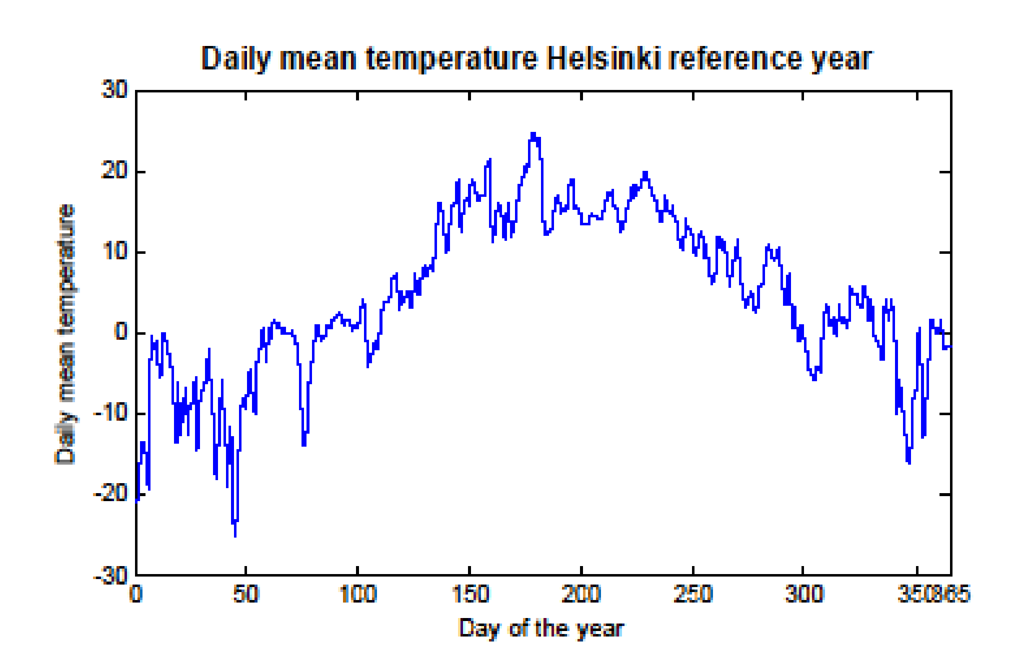
- Important tool for planning of
  - mixed energy distribution systems
  - combined heat and power generation
- Important input parameters for planning
  - maximum heat and electricity load
  - load duration profiles
  - annual heat and electricity demand

Demonstration of load modelling

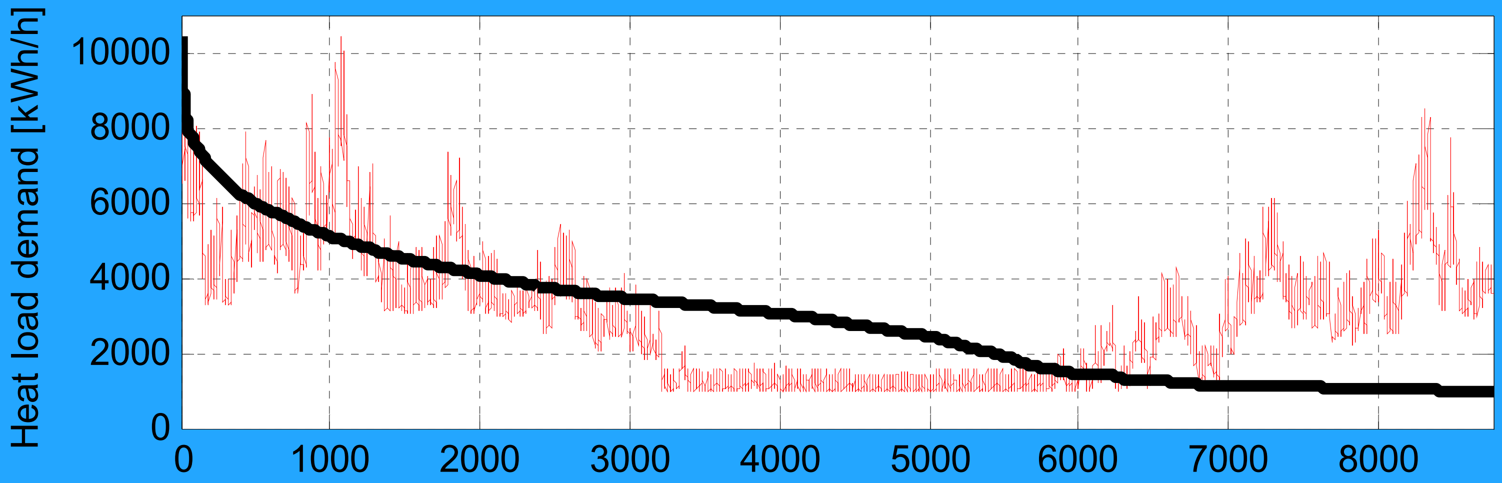
A case study for aggregated load modelling

Description of planning area:

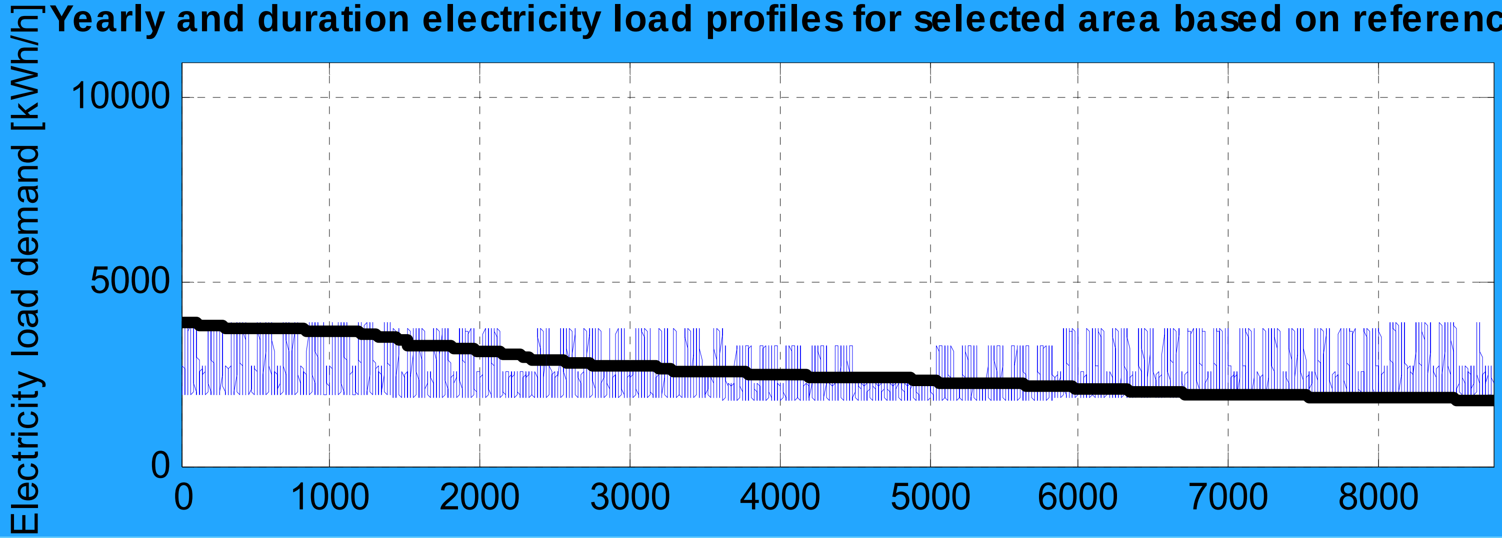
- Number of buildings within each building category or archetype.
- Available area for each building.
- Construction year for each building.
- Major retrofitting, if any, for each building.
- Type of heating within each building: hydronic heating system or electricity distribution system only.
- Future development, if any, within the system boundaries.



Yearly and duration heat load profiles for selected area based on reference year



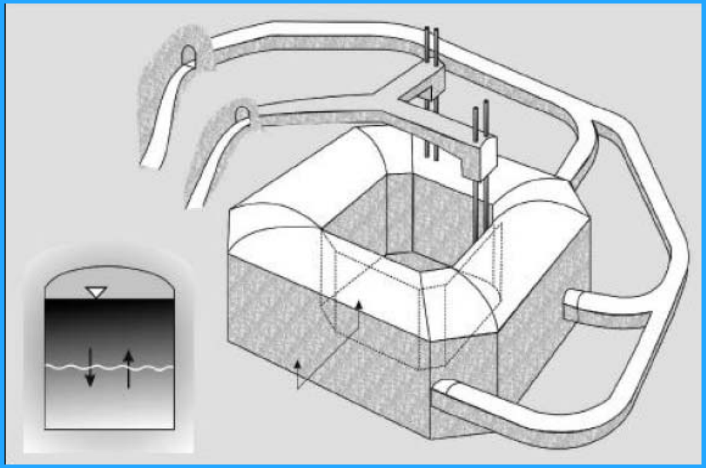
Yearly and duration electricity load profiles for selected area based on reference year



Long-term storage technologies

- Short-term thermal storage (less than 60 000 m^3)
  - steel tanks only proven technology for CHP
    - pressurised / non-pressurised
- Long-term thermal storage (greater than 100 000 m^3)
  - rock cavern storage
    - technology used for storing oil and petroleum products
  - borehole storage
    - open or closed system

Examples of storage constructions

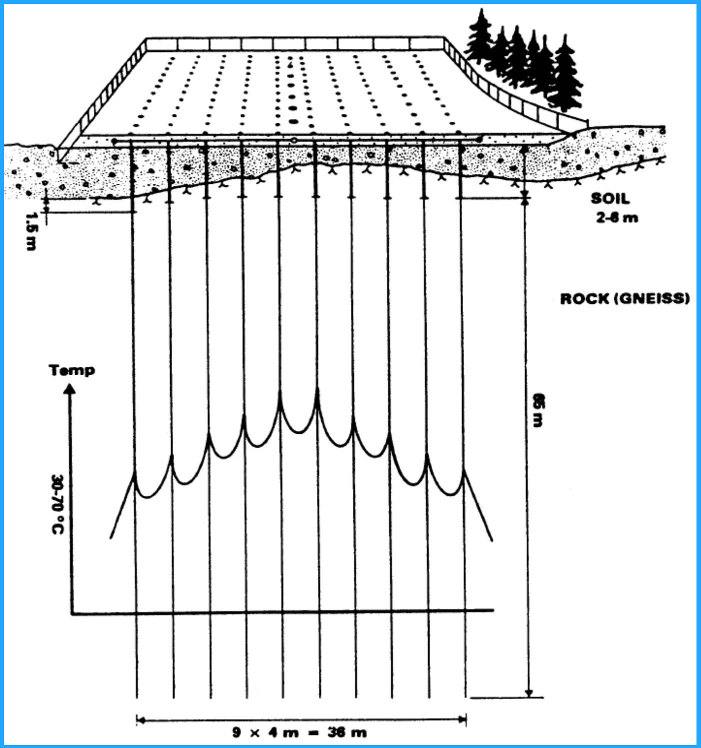


Rock cavern storage:

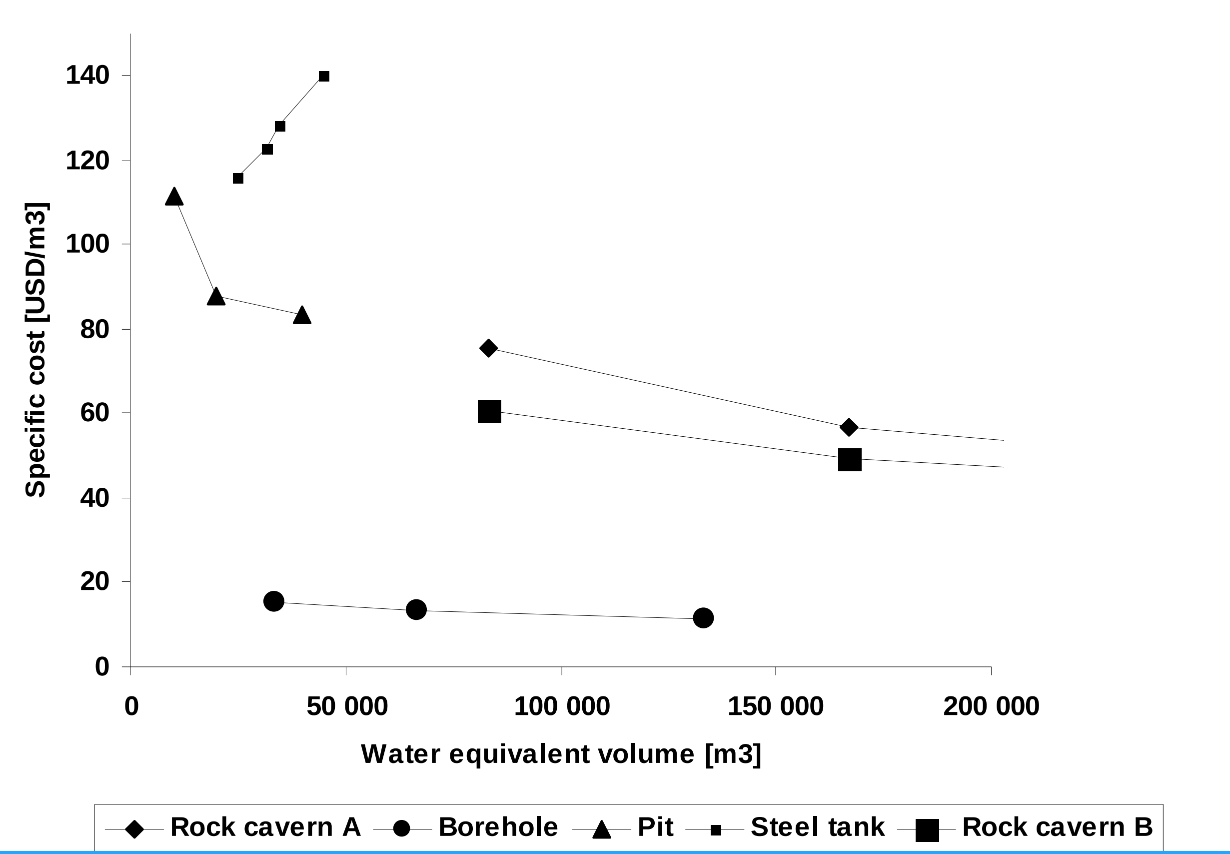
- Lyckebo outside Uppsala (Sweden)
- built in 1982
- a toroid with rock pillar in the centre

Borehole storage:

- Luleå (Sweden)
- built 1982



Specific costs for storages as a function of water equivalent volume



Some conclusions

- Heat storage application in CHP system (waste incineration plant)
  - best economy peak load demand is supplied by oil: 200 000 m3 rock cavern
  - good economy of long-term heat storage independent of the size of the storage for a system with a biomass-fired CHP as base load and biomass boiler for peak load
  - economy of heat storage depends on power price
- Heat storage in a local DH network outside a main network with a CHP system
  - heat generation from heat only oil and electric boilers can be replaced if long-term heat storage are used
  - but the economy for application of rock cavern is uncertain but the use of borehole seems to be interesting

Multi-period MINLP model for optimising CHP plants in DH networks with long term thermal storage

$$\max f(\mathbf{x},\mathbf{y}) \text{ subject to } \begin{cases} h_i(\mathbf{x},\mathbf{y}) = 0 & i \in \{1,2,\ldots,k\} \\ g_i(\mathbf{x},\mathbf{y}) \leq 0 & i \in \{1,2,\ldots,l\} \\ \mathbf{x} \in X \subseteq \mathcal{R}^n, \mathbf{y} \in Y \subset \mathcal{Z}^m & \end{cases}$$

Objective function:

•Power and DH incomes – Fuel Costs – Investment Costs

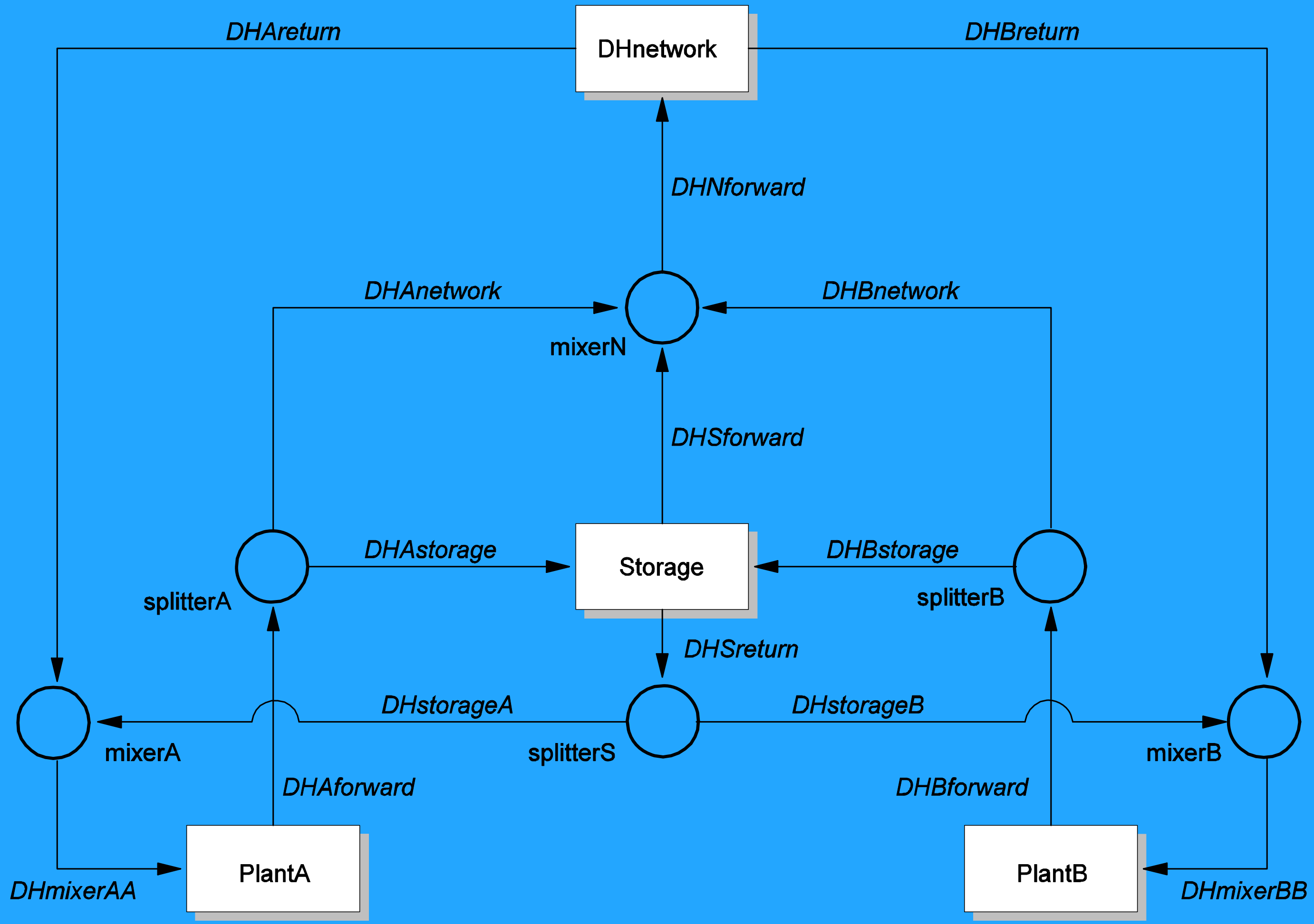
Constraints:

•Mass and Energy Balances

•Feasibility constraints (temperatures, mass flow, etc)

•Regression models (CHP plants power generation, forward temperature)

DH network (example) topology



Optimisation model analysis

Model size:

	78 periods	*26 periods*
Equations	5900	2000
Variables	8200	2700

Model properties:

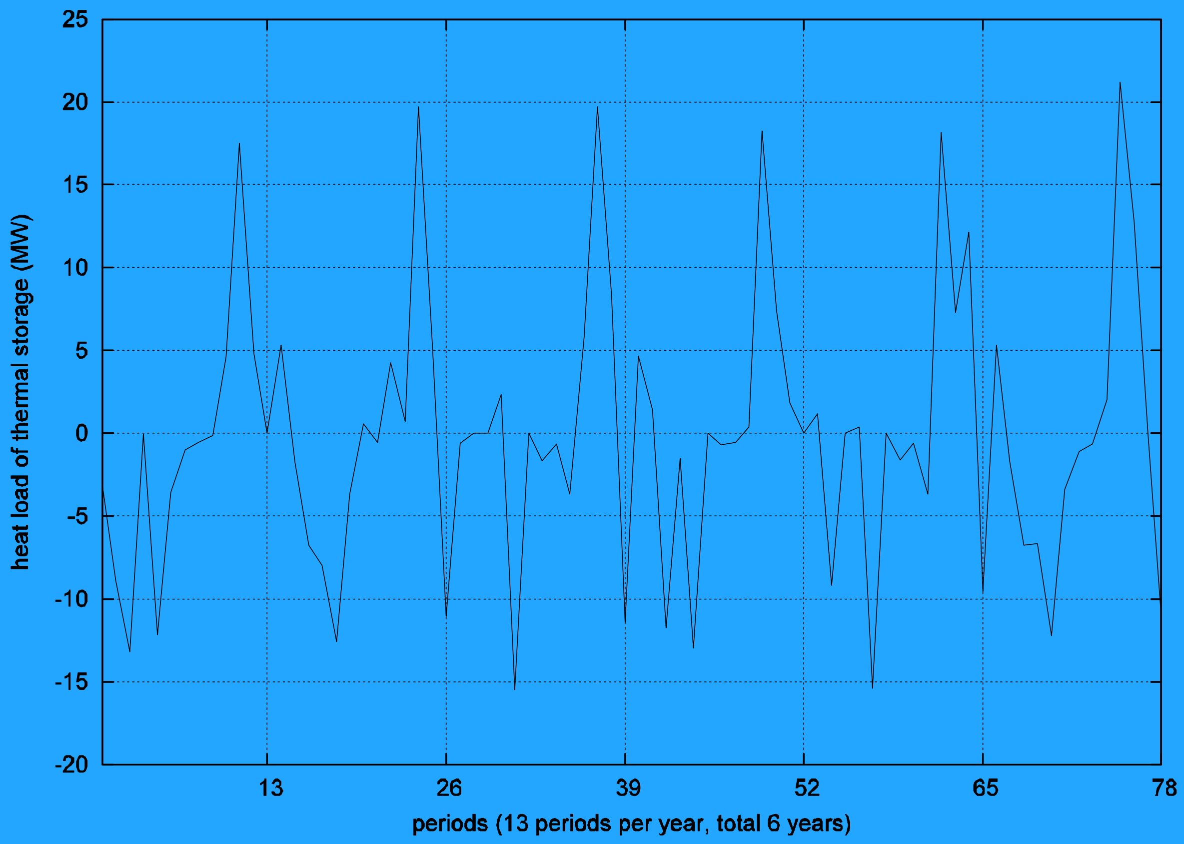
-mixed integer (binary decision variables)

-nonlinear

-nonconvex (energy balance, regression models)

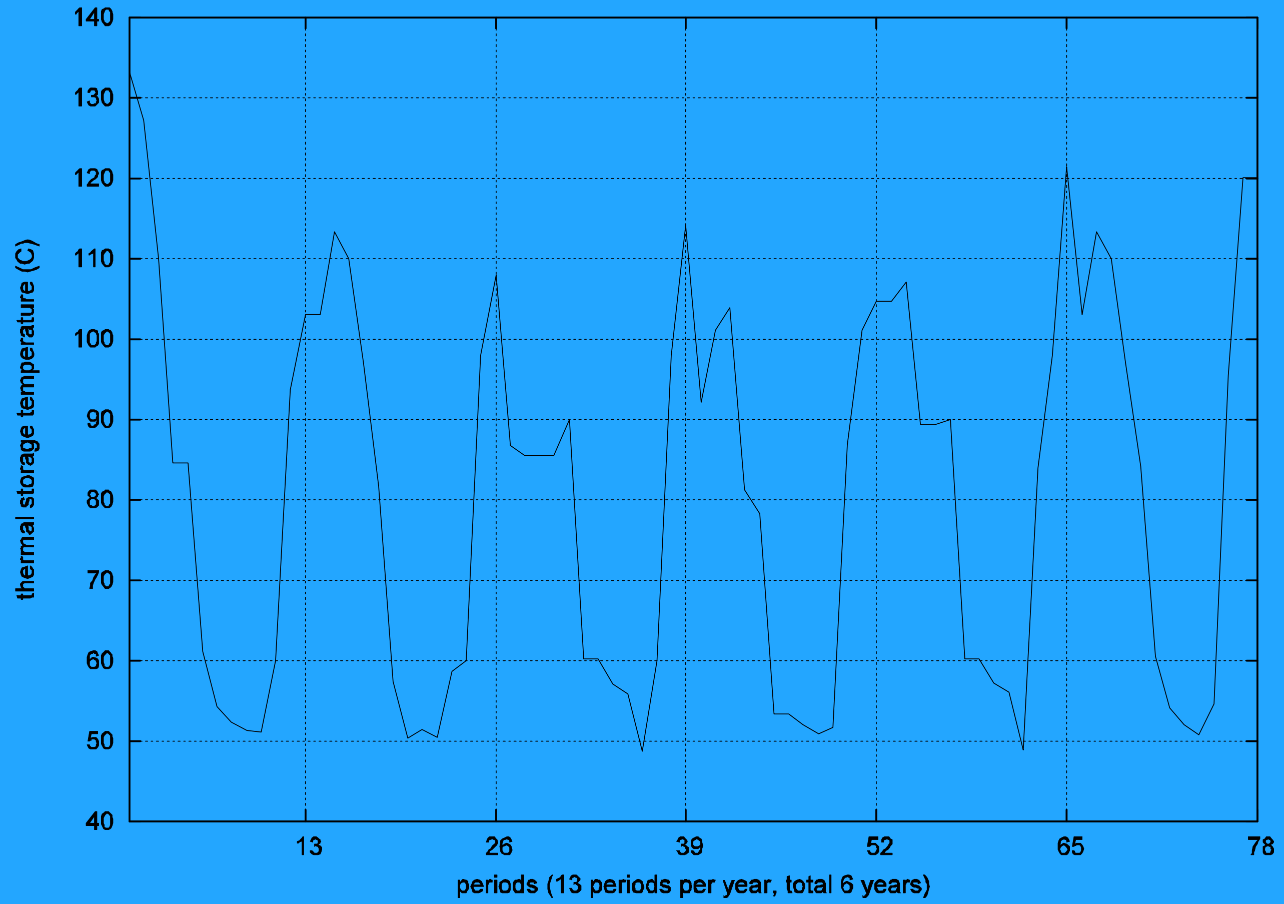
Example of results (1/2)

Optimal usage of the long-term thermal storage



Example of results (2/2)

Temperature profile of the long-term thermal storage

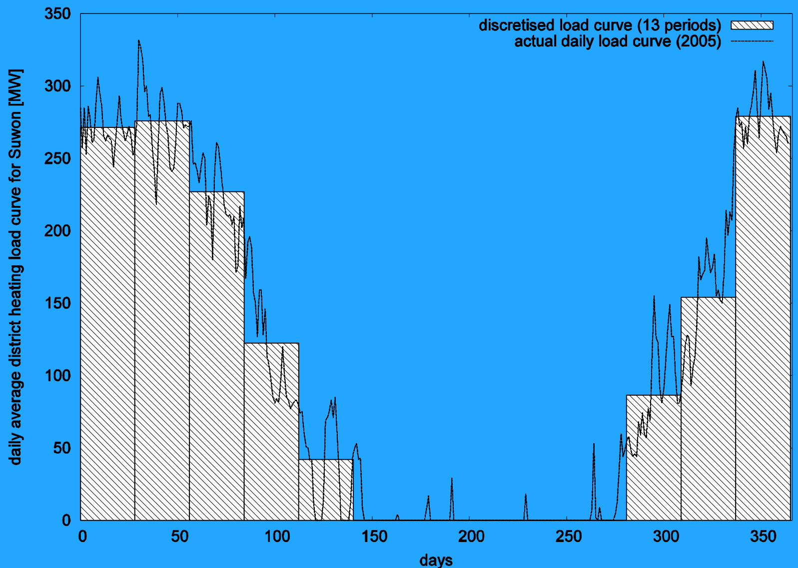


Application to an existing DH network

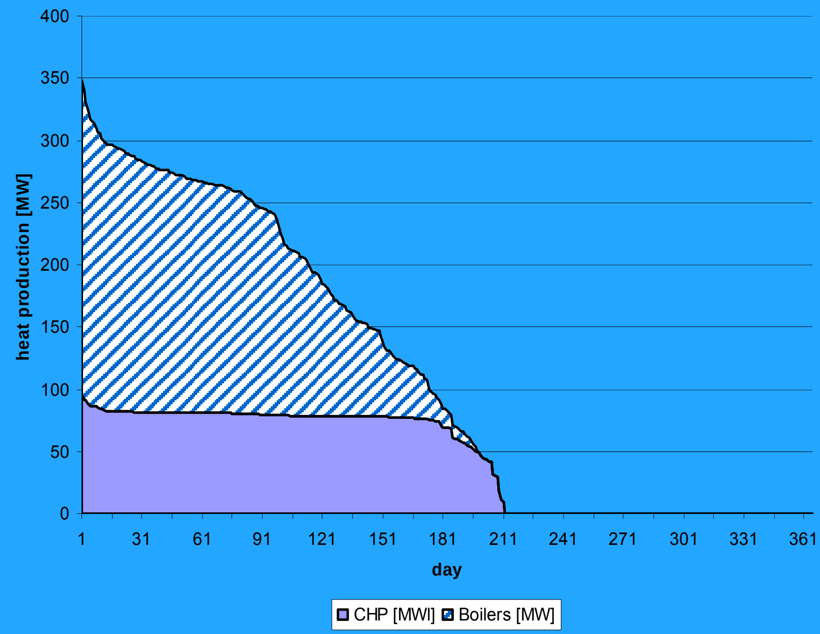
Suwon area DH network (Korea):

- 99 000 households, 140 commercial and public buildings
- CHP plant (82 MW_t, 43 MW_e)

Heat load in the Suwon area for 2005



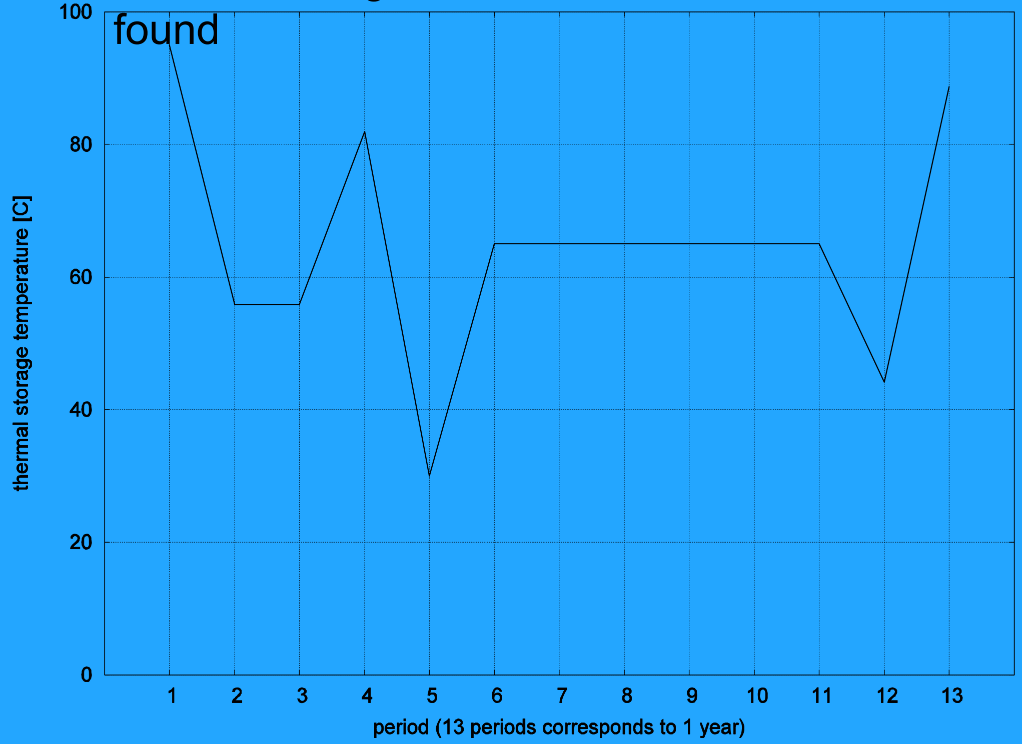
Duration curve for the heat supply in the Suwon area for 2005



Results from the Suwon study

- Best solution found (with storage)
  - annual profit of ~22.9 million USD
- Best solution found (without storage)
  - annual profit of ~18.1 million USD
- Value of the long-term thermal storage 4.8 million USD/a.
- Rock cavern type storage with an estimated price of about 20 USD/m^3 or about 6.0 million USD in total

Annual temperature profile for the long-term thermal storage for Suwon for the best solution found



Final results and conclusions

Objective of the project:

"*evaluate and develop approaches that will improve the economic feasibility and the thermal efficiency of cogeneration through better utilisation of the produced heat and higher power generation in the CHP plant*".

Three main results

- Evaluation of long-term storage technology and applications
- Two approaches (or tools)
    - A load model for estimation of simultaneous heat and electricity demand in buildings for a specified planning area
    - Multi-period MINLP model for optimising structural changes and the operation of CHP plants in DH network with long-term storages