Case Studies

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Flexibility by implementation of heat pumps in multi-vector energy systems and thermal networks

Demo No.:	**Location/City:**	**Country:**
D-001	Utrecht	The Netherlands

Project name (short and full title): Flexibilization of the electricity grid by means of AI optimization of heating networks, heat pumps and CCGTs

Quotation:

Schedule of the demo project (research study): 2024	**Year of realisation:**

Leader organisation (owner, constructor, solution developer, research inst., etc.):
Flex Technologies B.V.

Participating organisations – demonstration project part (involved other organisations):
TU Delft, Vattenfall

Budget of the demo (invest/monitoring etc.):

Summary of the project:
The future energy system will lead to the coupling of various energy carriers (electrons, molecules and heat) to guarantee a more flexible, reliable and higher-quality system. The coupling between electrons and heat currently takes place on a smaller scale. Larger-scale coupling between heat networks and electricity networks cannot be effectively realized at the moment due to a lack of optimization solutions that make heat production more flexible. For most heating networks in the Netherlands, the heat demand is therefore leading in the production plan, regardless of the conditions on the electricity market. This while heat production and a heat network, due to its thermal mass and reasonable predictability in demand and demand peaks, has a high flexibility potential.

This project will develop a continuously operating grid simulator and optimization model for heat networks and production units including STEGs/AVIs/CHPs and heat pumps, in which the energetic buffer capacity of heat networks is used to maximize the yields on the electricity market minus the production costs of the heat

Expected results:

- A grid simulator that can simulate the heat and fluid dynamics in a district heating network, including various kinds of heat sources, water pipes and heat exchangers, as well as electricity generation of coupled heat-electricity sources.

- An optimization model that can optimize the scheduling of the above-mentioned heat and electricity sources in real time.

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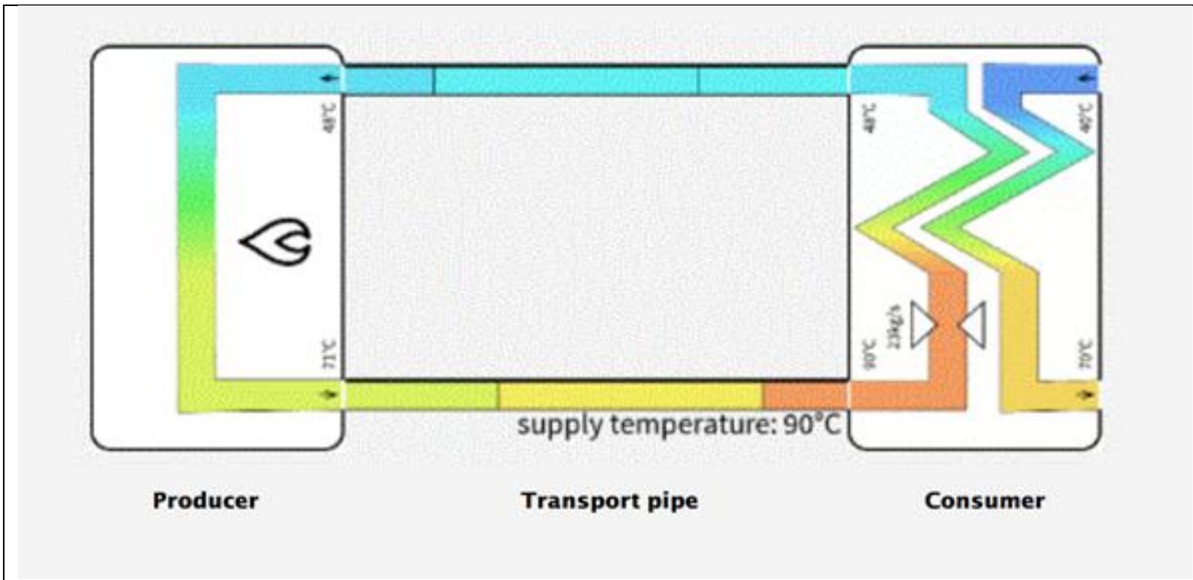
Published articles (paper, article etc.):		
• Stepanovic, Ksenija, et al. "Unlocking the flexibility of district heating pipeline energy storage with reinforcement learning." Energies 15.9 (2022): 3290. • Wu, Jichen, et al. "GridPenguin: A District Heating Network Simulator." Conference Proceedings New Energy for Industry 2022. 2022.		
Contact information: Rob Everhardt, Flex Technologies B.V., +31647635648, rob@flextechnologies.ai		
Country: The Netherlands	**Participating Organisation:** Flex Technologies	**Contact/name:** Rob Everhardt



Homepage address: http://flextechnologies.ai

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Project classes:

RD&D status

Large-scale demonstration (results based on measurements)	Small-scale demonstration	Lab scale (results based on measurements)	Design study (results based on simulation)
☐	☐	☒	☒

Type of heat pump

Decentralized HP (cold district heating)	Centralized HP with a district heating system
☒	☒
Heating	Cooling
☒	☐

Heat source of HP: Geothermal probes, CHP, heat pump, boiler

Power supply for HP (electricity grid, PV, wind turbine etc.): electricity grid

Buildings

New buildings	Existing buildings	Mix of new and existing buildings
☒	☒	☐
Residential	Non-residential	Mixed use
☒	☒	☒

Energy storage

Battery storage		Thermal energy storage	
Centralized	Decentralized	Centralized	Decentralized
☐	☐	☒	☐

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Control for the flexible heat pump operation

Heat driven control[1]	Predictive control[2]	Rule based control[3]
☐	☒	☐

1. General description of the project

The "Flex-Heat" district heating optimization project focuses on improving the efficiency and flexibility of existing district heating systems. It aims to optimize heat and electricity production, integrate renewable energy sources, and reduce energy waste. Using the "GridPenguin" simulator, the project evaluates various optimization methods to create a benchmark for performance comparison. The project involves a collaborative effort of researchers, engineers, and experts, and it addresses challenges related to environment and modeling uncertainties. By dynamically controlling heat and electricity production, the system adapts to fluctuating electricity prices, RES availability, and heat demand predictions. The project's goal is to achieve a more sustainable district heating system, contributing to the energy transition and reducing dependency on fossil fuels.

2. Building and system description of the project

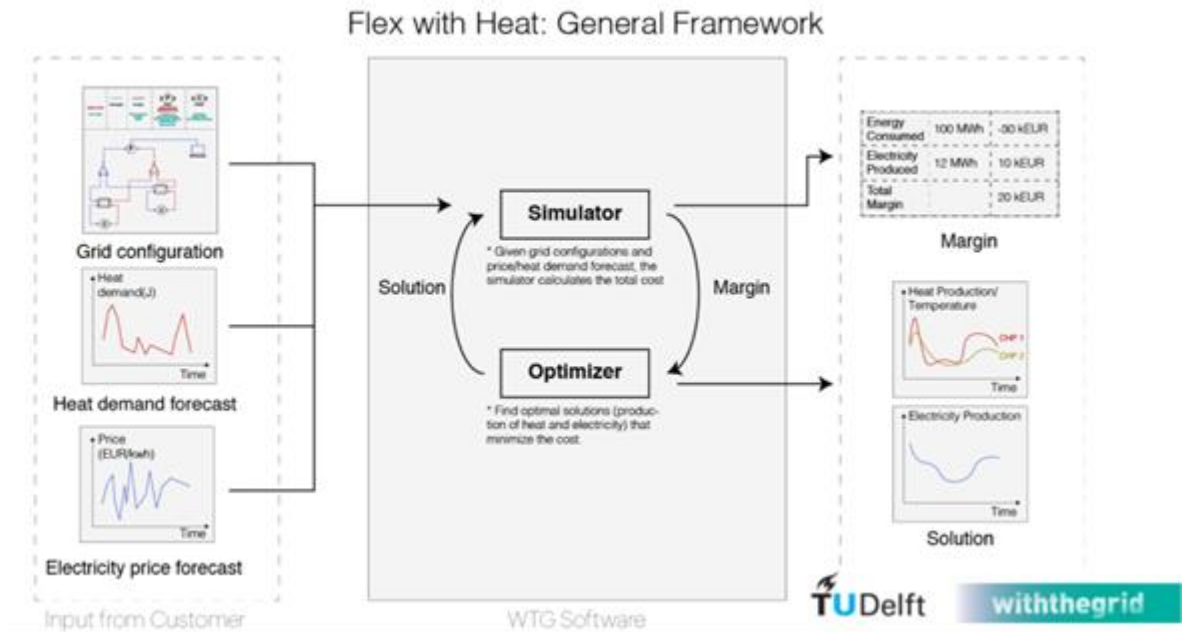

Figure 1 General description of the workflow of our proposed software

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3. Energy supply – scheme of the heat supply system:

The heat supply system is a vital component in providing heating and hot water to buildings. It comprises heat generation sources like CHP units, boilers, and renewable energy systems. The heat is transported through insulated pipelines to end-users, where heat exchange units facilitate its distribution.

For existing district heating systems, transformation strategies focus on optimizing efficiency and sustainability. Coupling heat and electricity production in CHP units allows better utilization of renewables and profit gain through electricity trading. Integrating pipeline energy storage provides flexibility without additional investments in storage tanks, optimizing load balancing and reducing energy waste.

Advanced optimization algorithms and machine learning enable dynamic control of heat and electricity production, adapting to real-time heat demand and renewable energy availability. This optimization enhances overall system efficiency and reduces environmental impact.

Through strategic integration of renewables, energy storage, and advanced control methods, the heat supply system can be transformed into a more efficient, flexible, and sustainable network, contributing to a greener energy future.

4. Flexibility – scheme and control strategy of the system:

The flexibility scheme and control strategy of the "Flex-Heat" district heating optimization project are essential for efficiently harnessing the potential of the district heating system. A well-designed flexibility scheme and control strategy enable the system to dynamically respond to changing energy demand, fluctuating electricity prices, and renewable energy availability.

Data collection is a crucial aspect of the flexibility scheme. The project leverages data from two primary sources: the Wanda software and real grids from the energy company Vattenfall. Wanda provides valuable and accurate simulation data on heat physics and hydraulics. Real grid data from Vattenfall offers insights into the actual details of the district heating system.

The control strategy revolves around optimizing the heat and electricity production to achieve maximum efficiency and flexibility while meeting heat demand requirements. The integration of pipeline energy storage plays a central role in decoupling heat and electricity production from CHP units.

Using various machine learning tools, the system estimates the dynamics of the district heating network through interactions with the simulation environment. This RL-based control strategy adapts to real-time changes in energy demand and availability of renewable energy sources. It takes into account the uncertainties from Wanda data and real grid data to make informed decisions on heat and electricity production.

The control strategy operates in day-ahead and intraday (real-time) markets. In the day-ahead market, production facilities are scheduled to operate during each hour of the following day, considering heat demand predictions and electricity prices. In the intraday market, participants continuously trade electricity with delivery on the same day, allowing the system to adjust electricity production based on real-time market conditions.The overall goal of the control strategy is to achieve moderate profit gains impacted by environmental stochasticity while maintaining stability, feasibility, and adaptability. By utilizing the flexibility scheme and implementing the RL-based control strategy, the "Flex-Heat" district heating optimization project aims to transform district heating systems into more efficient, sustainable, and resilient energy networks for a greener energy future.

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5. Description of the business model with a flexible HP-operation

The business model with a flexible heat operation leverages the energy-saving potential and cost-saving opportunities within district heating systems. By optimizing heat production and operation, the model can achieve energy savings and reduce operating costs. This flexible approach enables the heat pump to adjust its operation based on fluctuating electricity prices and renewable energy availability, leading to increased utilization of low-cost electricity and renewable sources, resulting in substantial cost savings for consumers and improved overall system efficiency.

6. Results of the project

The findings from the "Flex-Heat" district heating optimization project indicate that the potential for incorporating the electricity market within the district heat system is limited. Despite implementing the machine-learning-based control strategy and exploring pipeline energy storage, the project revealed minimal opportunities for significant integration of the electricity market.

The study identified challenges related to the system's complexity, environmental uncertainties, and modeling limitations, which constrained the feasibility of real-time electricity trading and heat-electricity decoupling. As a result, the anticipated energy savings and cost reductions were not as substantial as initially anticipated.

While the project did not achieve significant advancements in electricity market integration, it provided valuable insights into the district heating system's limitations and the need for more comprehensive approaches to enhance flexibility and sustainability.

The project's results contribute to a better understanding of district heating optimization and serve as a foundation for future research and innovations in energy-efficient heating systems.

7. Challenges / socio economical barriers and opportunities

The "Flex-Heat" district heating optimization project faced challenges due to the complexity of the district heating system (DHS). Unlike traditional approaches, the focus was on data-driven machine learning algorithms for optimization. However, the project encountered a unique challenge - the small difference in cost and profit between different strategies. The algorithm could only achieve less than a 5% increase in profit or cost reduction compared to simple strategies. This limitation was attributed to the intricate nature of the DHS, environmental uncertainties, and modeling constraints.

While the results showed modest improvements, the project provided valuable insights into district heating optimization. It highlighted the need for a multi-faceted approach, combining mathematical optimization, data-driven algorithms, and real-time control strategies. Collaboration between researchers and industry stakeholders is essential to unlock the full potential of district heating systems for increased efficiency and sustainability.

Although the immediate impact on electricity market integration was limited, the knowledge gained serves as a foundation for future research in developing more sophisticated optimization methods. As the energy landscape evolves, continued advancements in optimization techniques will play a vital role in shaping a greener and more sustainable energy future.

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8. Additional information: Flexibility options

Contents: district heat pump

Share of heat sources (in %)	1. Heat source: 2. Heat source: 3. Heat source:	%
Share of power supply (power grid, PV-units at site, wind turbine at site etc.)	1. Power supply: 2. Power supply: 3. Power supply:	%
System boundary by calculation of the SPF		
Seasonal performance factor in design and measured (SPF)		
COP of Heat Pump at the design condition (point in °C or traverse as function in °C), independent of site boundaries		
COP incl. all peripheral devices at source and sink side		
Location of heat pump (e.g. heating centre (centralized heating installation), using existing infrastructure etc.)		

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Contents: district heating network

Land area for buildings served by heat distribution network		m²
Total heated floor area in buildings connected		m²
Trench length for heat distribution network		m
Heating capacity		kW
Heat annually supplied into the heat distribution network		MWh/a
Heat annually delivered from the heat distribution network		MWh/a
Annual average supply temperature in the heat distribution network		°C
Annual average return temperature in the heat distribution network		°C
Heat generation based on renewable sources		MWh/a
Share of renewable sources		%

Contents: description of energy storage system

Energy storage type:	Distribution grid heat storage tanks
Storage size (capacity):	
Term of flexibility:	Distribution grid: typically a few hours
Storage temperature (thermal energy storage)	Distribution grid: 70 - 140 °C

Contents: indicators for flexible heat pump operations

Cost (potential cost saving)	**<5%**	
Thermal level (losses of thermal comfort)	**~10%**	
Load matching factors (load supply & load cover factors)		