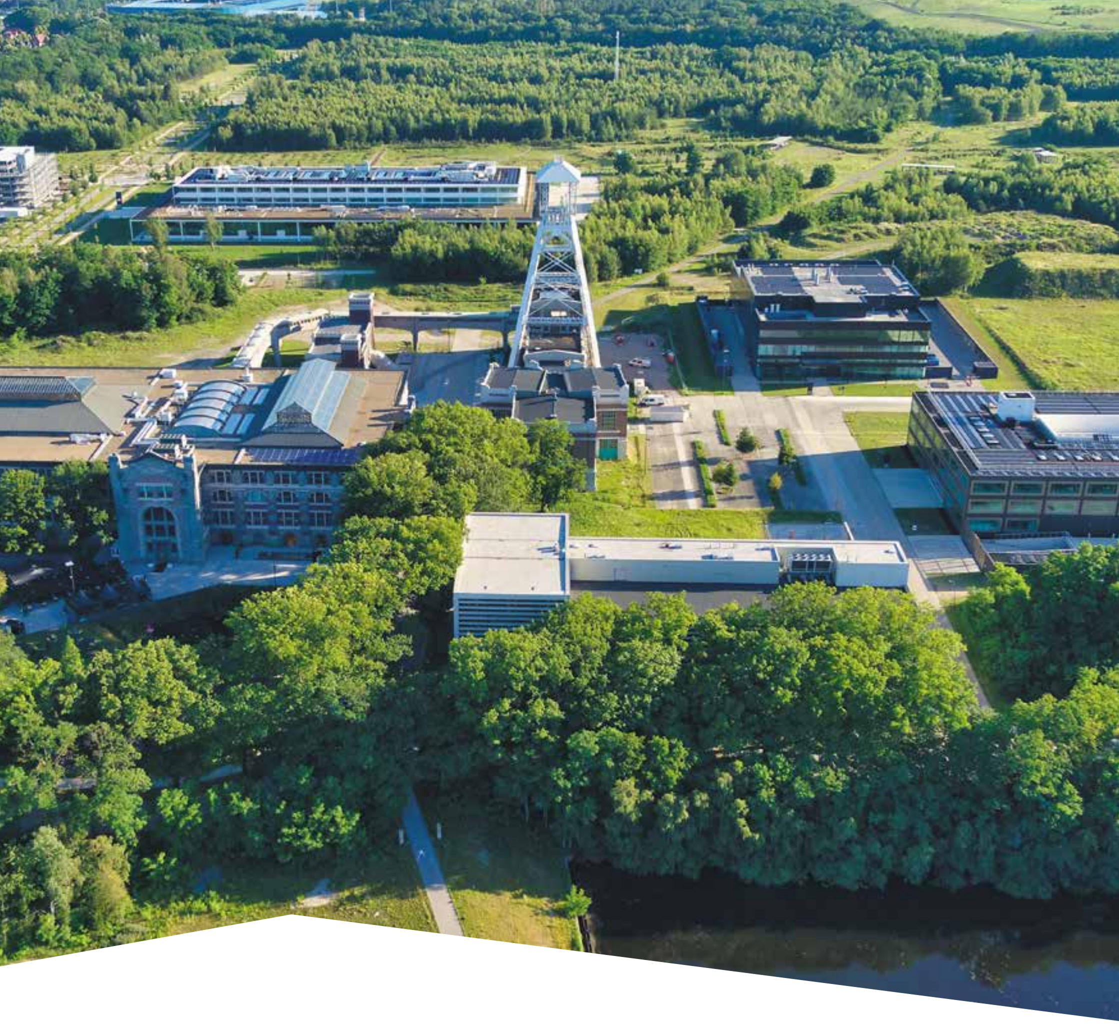

The 19th International Symposium on District Heating and Cooling

Thor Central, Genk – 7-10 September 2025

Programme

vito

Energy Ville

IEA DHC

EnergyVille/VITO is proud to organise the 19th International Symposium on District Heating and Cooling of IEA DHC from 7 to 10 September in Genk, Belgium.

Together with experts, scholars, industry practitioners and policy researchers from all over the world, we will explore the development opportunities and issues in the district heating and cooling (DHC) industry, share innovative research results, and promote international technical exchanges to achieve green, efficient and smart development of the global DHC industry.

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Welcome messages

It is my great pleasure to welcome you to the 19th International Symposium on District Heating and Cooling, organised under the framework of the IEA Technology Collaboration Programme on District Heating and Cooling (IEA DHC). We are delighted to see this long-standing tradition continue here in Belgium, hosted by EnergyVille and VITO, institutions with meaningful contributions to research and innovation in the energy transition.

This year's symposium has attracted participants and contributions from every corner of the world. Such diversity of perspectives and expertise demonstrates once again how vital international collaboration is in addressing the technological, economic and societal challenges facing the district heating and cooling sector today. Together, we continue to build a DHC community that advances knowledge, shares best practices and drives the vision for a sustainable future.

I trust that this unique setting, combined with an engaging programme and the dedication of our local hosts, will offer all of you a stimulating environment for discussion and exchange. May this symposium inspire you to strengthen existing partnerships, forge new connections and help shape the future of district heating and cooling for the benefit of communities worldwide.

I wish you a rewarding and fruitful symposium.

Robin Wilthshire
Chair IEA DHC

A very warm welcome to Belgium for the 19th International Symposium on District Heating and Cooling. We are proud to host this respected event here in Genk, at Thor Park — a place that embodies both heritage and innovation, ready to be discovered during the various activities throughout the programme.

Over the next few days, you will experience a rich and varied programme: inspiring keynote speakers from different parts of the world will share real insight into developments across continents, helping us understand what is happening elsewhere and how we can build on each other's progress. The diverse contributions include sessions on digitalisation, thermal source networks, sustainability, user engagement, geothermal solutions, cost-optimal design, modelling and data handling. We are also pleased that the DHC+ Student Awards will shine a spotlight on exceptional bachelor's, master's and PhD research; an inspiring initiative by the DHC+ Platform, one of our valued sponsors.

Our sincere thanks go to IEA DHC for the trust and collaboration that enable us to strengthen this global DHC community together. And a heartfelt thank you goes to all our sponsors and partners for making this possible. May these days bring you valuable knowledge, new connections and fresh ideas to help shape the vision for district heating and cooling worldwide.

Enjoy your time here and make the most of what our symposium has to offer.

Ann Wouters

Research Program Manager Digital Solutions for Energy Systems at EnergyVille/VITO

Dirk Vanhoudt

Research Roadmap Responsible Digitalisation of District Heating and Cooling Systems at EnergyVille/VITO

PLATTFORM
GRÜNE FERNWÄRME

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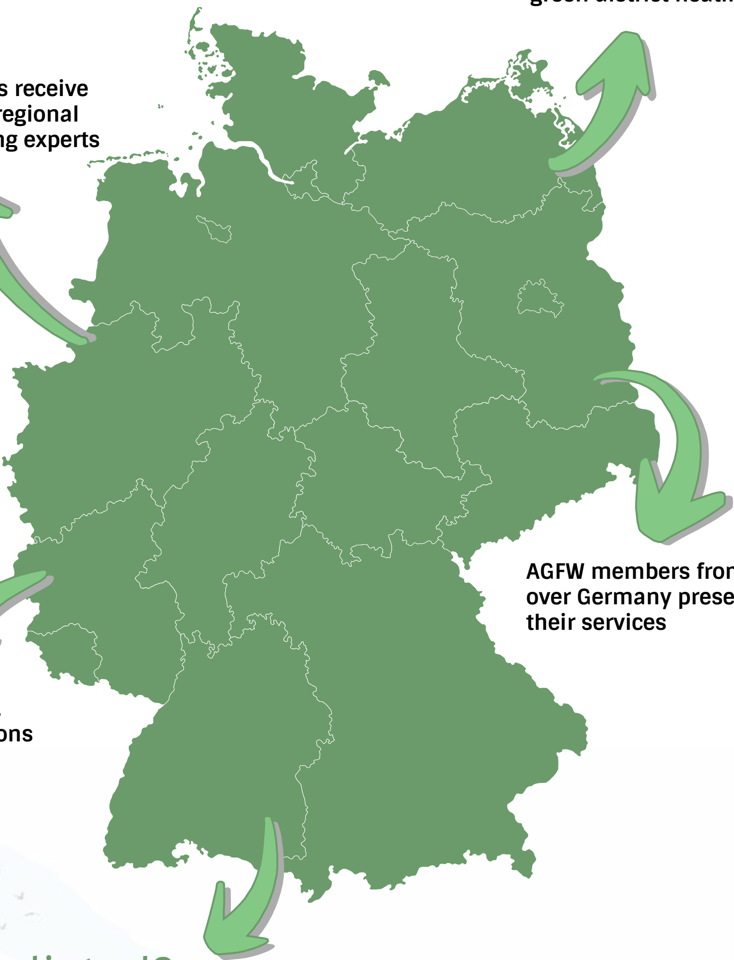
DH Product Directory

Industry directory for green district heating

Municipalities receive guidance on regional district heating experts



AGFW members from all over Germany present their services

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Overview

Conference history: The 19th International Symposium on District Heating and Cooling, September 2025 at EnergyVille, Belgium

The International Symposium on District Heating and Cooling is a global biannual research conference focused on District Heating and Cooling (DHC) research. The first edition took place in Lund, Sweden back in 1987 and was initiated by the board of a Nordic District Heating Research Programme established in 1985.

Until 2004, the Nordic countries took turns when it came to the organisation of the Symposium. By then, the number of participants had grown significantly, with an ever-increasing number of delegates from other countries within and far beyond Europe. That is why, in 2006, for the first time, the Symposium took place outside of the Nordic countries.

Over the years, the biannual symposium has developed into one of the most reputed events worldwide for communication on academic research in the field of DHC. From 2016 onwards, the Symposium has been managed under the wings of the IEA Technology Collaboration Programme on District Heating & Cooling. That same year, in 2016, the Symposium became truly global when its 15th edition was organised in Asia for the very first time.

And now, in September 2025, EnergyVille/VITO brings the Symposium to Belgium.

Overview of all editions

- 1987: Lund, Sweden
- 1989: Reykjavik, Iceland
- 1991: Copenhagen, Denmark
- 1993: Trondheim, Norway
- 1995: Helsinki, Finland
- 1997: Reykjavik, Iceland
- 1999: Lund, Sweden
- 2002: Trondheim, Norway
- 2004: Helsinki, Finland
- 2006: Hannover, Germany

2008: Reykjavik, Iceland
2010: Tallinn, Estonia
2012: Copenhagen, Denmark
2014: Stockholm, Sweden
2016: Seoul, South Korea
2018: Hamburg, Germany
2021: Nottingham, United Kingdom
2023: Beijing, China
2025: Genk, Belgium

Organisation

Organised by

Hosted by

Supported by

DHC+ Student Awards
by **DHC+ Platform**

VITO, one of Europe's leading research centres with 1,300 employees, turns scientific insights into groundbreaking technological innovations, AI solutions, and policy advice. We do so with a single objective: to help the world thrive for at least 1,000 more years.

As a science-to-technology partner, we support companies, governments, and society in their sustainability transition. With our multidisciplinary approach and unique lab, scale-up, and testing infrastructure, we create practical technological innovations. We accelerate progress towards a regenerative economy that reinforces planetary boundaries (prioritising electrification and circularity), smart climate solutions for resilient and secure ecosystems, and a healthy living environment harmonising humans, industry, agriculture, and nature.

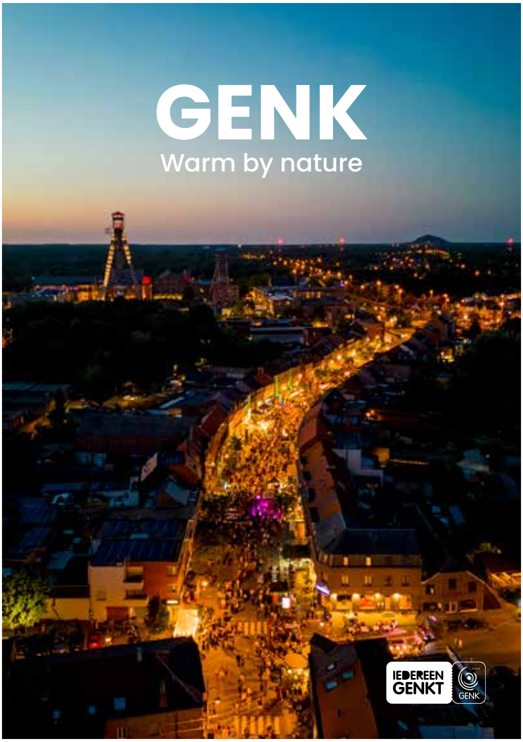
Our staff collaborate in multidisciplinary expertise teams across more than 40 research domains, utilising our unique laboratory and data infrastructure, as well as our extensive network of stakeholders. Through positive transition thinking and comprehensive techno-economic analysis, we deliver systemic solutions that are effective not only on paper but also in the complex realities of everyday life.

At VITO, we harness the power of science, engineering, digitalisation, and collaboration to implement sustainable solutions globally, enabling the continued integration of well-being and prosperity.

VITO is one of the founding partners of EnergyVille, a collaboration with the Belgian research partners KU Leuven, imec and UHasselt in the fields of sustainable energy and intelligent energy systems. EnergyVille develops technology and knowledge to support public and private stakeholders in the transition to an energy efficient, decarbonised and sustainable urban environment. The unique complementarity of the research partners allows EnergyVille to integrate the energy system value chain in its entirety – ranging from materials and components to the level of entire energy systems, business models and strategies. Its activities are clustered in eight interdisciplinary domains: solar energy, battery storage, power electronics, power-to-molecules, thermal systems, electrical networks, energy for buildings & districts, and energy strategies & markets.

With approximately 700 researchers and state-of-the-art research facilities, EnergyVille is a top European innovation hub in the energy field. It bundles research, development and training under one roof and collaborates closely with local, regional, national and international partners from industry as well as public authorities.

IEA DHC is an international funding and collaboration programme for research on district heating and cooling. Since it began in 1983, the IEA DHC has operated under the supervision of the International Energy Agency (IEA), bringing countries together to research, innovate and grow DHC. Countries that participate in the IEA DHC research programme leverage their resources to conduct research that they may not be able to accomplish on their own through international collaboration. The result is that participants gain leading-edge knowledge and insights that can improve energy performance, increase resilience, and reduce greenhouse gas (GHG) emissions, effectively helping to mitigate the impacts of climate change. As of today, the IEA DHC includes participants from Austria, Belgium, Canada, China, Denmark, Estonia, Finland, France, Germany, Italy, Ireland, Korea, Norway, Sweden, the Netherlands, the United Kingdom, and the United States of America.



Scientific Committee

Michael Ahern, Ever-Green Energy, United States
Prof. Markus Blesl, University of Stuttgart, Germany
Prof. Maarten Blommaert, EnergyVille/KU Leuven, Belgium
Stef Boesten, Rijksdienst voor Ondernemend Nederland, the Netherlands
Raymond Boulter, National Resources Canada, Canada
Casey Collins, Duke University, United States
Dr. Alice Dénarié, Politecnico di Milano, Italy
Prof. Elisa Guelpa, Politecnico di Torino, Italy
Dr. Aleksandr Hlebnikov, Tallinn University of Technology, Estonia
Prof. Stefan Holler, HAWK University of Applied Sciences and Arts, Germany
Prof. Anton Ianakiev, Nottingham Trent University, United Kingdom
Peter Kahoe, Sustainable Energy Authority of Ireland, Ireland
Dr. Hanne Paulina Kauko, Sintef, Norway
Håkan Knutsson, SweHeat and Cooling, Sweden
Prof. Risto Kosonen, Aalto University, Finland
Dr. Lukas Kranzl, Technical University Vienna, Austria
Prof. Bruno Lacarrière, IMT Atlantique, France
Prof. Henrik Lund, Aalborg University, Denmark
Prof. Natasa Nord, NTNU, Norway
Dr. Miika Rama, VTT Technical Research Centre of Finland, Finland
Dr. Étienne Saloux, National Resources Canada, Canada
Dr. Ralf-Roman Schmidt, Austrian Institute for Technology, Austria
Prof. Sylvain Serra, University of Pau, France
Prof. Eva Thorin, Mälardalen University, Sweden
Prof. Michele Tunzi, Danish Technical University, Denmark
Dirk Vanhoudt, EnergyVille/VITO, Belgium
Prof. Anna Volkova, Tallinn University of Technology, Estonia
Prof. Haichao Wang, Dalian University of Technology, China
Dr. Robin Wiltshire, BRE, United Kingdom
Prof. Jianjun Xia, Tsinghua University, China

Local organising committee

Ann Wouters:	Research Program Manager Digital Solutions for Energy Systems at EnergyVille/VITO
Dirk Vanhoudt:	Research Roadmap Responsible Digitalisation of District Heating and Cooling Systems at EnergyVille/VITO
Erik De Schutter:	Business Developer Thermal Energy Systems at EnergyVille/VITO
Adinda Vandereyken:	Event organiser at EnergyVille
Nathalie Belmans:	Event organiser at EnergyVille/KU Leuven

Transportation to the venue

Every day a bus of 'Jacobs' will bring you from the train station of Genk (in the centre) to the venue (Thor Central) and back.

The bus will leave at 08.15 each conference day at the trainstation.

Symposium Programme

7 September

19.00-20.30: Welcome reception at M-Hotel (Albert Remansstraat 1, Genk)

8 September

09.00-17.30: Thor Central (Thor Park 8000, Genk)

- Welcome
- Keynote speeches
- Parallel sessions
- Special sessions
- Poster sessions

19.00 - 23.00: Conference dinner at Barenzaal in C-MINE, an industrial heritage site turned cultural hotspot (Evence Coppéelaan 91, Genk). A bus will bring you back to the train station of Genk (in the center) after the diner.

9 September

09.00-17.00: Thor Central (Thor Park 8000, Genk)

- Parallel Sessions
- Special Sessions
- Poster Sessions
- DHC+ Student Award + Best Paper Awards

17.00 - 18.00: Closing reception at Thor Terrazza (Thor Park 8000, Genk)

19.00 - 21.00: Beer tasting at BRAUW (Molenstraat 37/1, Genk)

10 September

08.30-16.00: Technical Tours

- Genk: Visit the Open Thor Living Lab and enjoy a walk with a ranger in the National Park
- Mol - Antwerp: Visit the geothermal site and the heating network in Antwerp
- Genk: Discover C-Mine and visit the Open Thor Living Lab

Programme at a glance

Session	Room	Title
Session 1	Auditorium	Digitalisation of DHC: optimal control 1
Session 2	Grûm 9	Sustainabilty of DHC and user engagement
Session 3	Trueno 8	Cost optimal design strategies 1
Session 4	Auditorium	Thermal source networks
Session 5	Grûm 9	Modelling and data handling
Session 6	Trueno 8	Planning of DHC networks 1
Session 7	Auditorium	Cost optimal design strategies 2
Session 8	Grûm 9	Planning of DHC networks 2
Session 9	Trueno 8	Efficiency improvements, modernisation and RES integration 1
Session 10	Auditorium	Digitalisation of DHC: optimal control 2
Session 11	Grûm 9	Efficiency improvements, modernisation and RES integration 2
Session 12	Trueno 8	Geothermal DHC
Session 13	Auditorium	DHC+ Student Award presentations
Session 14	Grûm 9	Digitalisation of DHC: fault detection and diagnosis
Session 15	Trueno 8	Technological advances for new and existing networks

Sunday 7 September

19.00-20.30: Opening reception + registration

Monday 8 September

Registration					Poster installation **Foyer**	09.00
Opening ceremony/welcome						09.30
Coffee break						10.30
Keynote speeches					Poster presentations **Foyer**	11.00
Lunch						12.30
Session 1 **Auditorium**	Session 2 **Grûm 9**	Session 3 **Trueno 8**	Special Session TS8 **Sun**	Special Session TS5 **Wind**		14.00
Coffee break						15.30
Session 4 **Auditorium**	Session 5 **Grûm 9**	Session 6 **Trueno 8**	Special Session TS6 **Sun**	Special Session TS9 **Wind**		16.00
End						17.30
Conference dinner						19.00

Tuesday 9 September

Session 7 **Auditorium**	Session 8 **Grûm 9**	Session 9 **Trueno 8**	Special Session design **Sun**	Special Session DENSE **Wind**	Poster presentations **Foyer**	09.00
Coffee break						10.30
Session 10 **Auditorium**	Session 11 **Grûm 9**	Session 12 (geo) **Trueno 8**	Special Session CH&C **Sun**	Special Session DENSE **Wind**		11.00
Lunch						12.30
DHC+ Student Award presentations **Auditorium**	Session 14 **Grûm 9**	Session 15 **Trueno 8**	Geothermal workshop **Sun**			14.00
Coffee break						15.30
Awards and closing session						16.00
Closing reception @ Thor Terazza						17.00
Optional: Brewery visit BRAUW						19.00

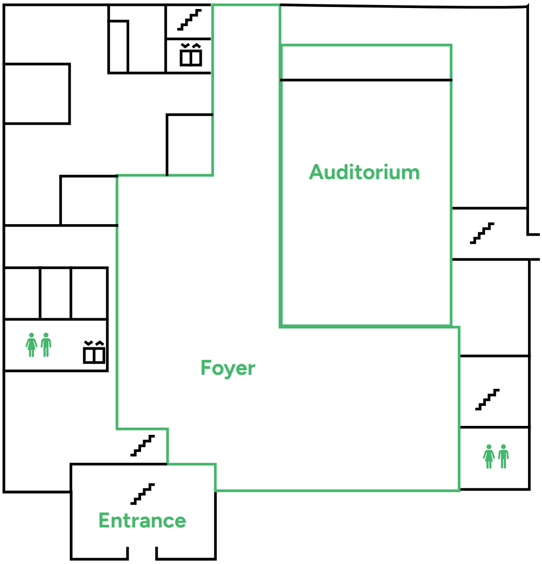
Wednesday 10 September

08.30-16.00: **Site visits**

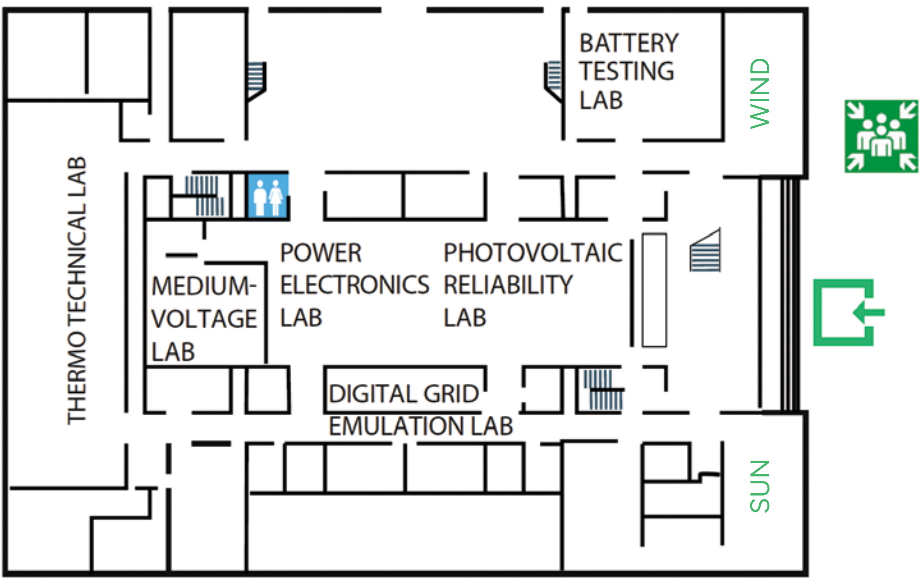
- Open Thor Living Lab and walk with a ranger
- Geothermal site and heating network
- C-Mine and Open Thor Living Lab

Symposium floor plan

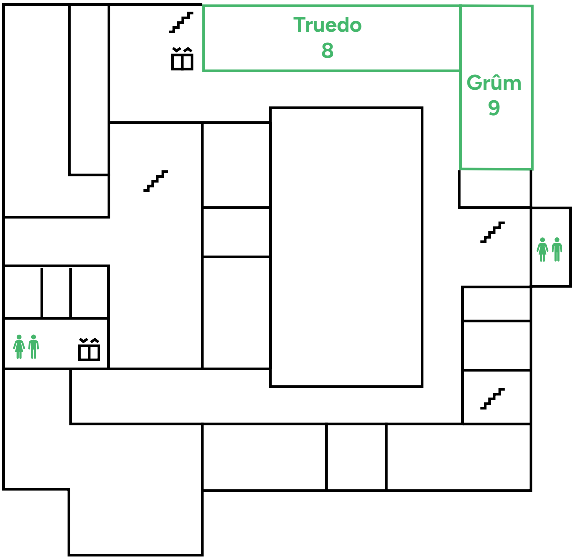
Thor Central: Ground floor



EnergyVille: Ground floor



Thor Central: Second floor



EnergyVille: First floor

Keynote speeches

We're especially proud to present a strong line-up of keynote speakers, representing Europe, Asia, and North America. Together, these leading voices in the global DHC community will offer a unique global perspective on DHC innovations, challenges, and realisations across continents:

- Europe - Robin Wiltshire (IEA DHC and Heatmatters Ltd)
- Asia - Jianjun Xia (Tsinghua University)
- North-America - Michael Ahern (Ever-Green Energy LLC) and David Woodson (University of Washington)

Robin Wiltshire (IEA DHC and Heatmatters Ltd)

Dr. Wiltshire has 30 years of experience in the energy sector and now divides his time between working on heat networks and teaching, striving to integrate his experience into the curriculum for the next generation. Dr. Wiltshire is currently Chair of the IEA Technology Collaboration Programme on District Heating and Cooling.

Jianjun Xia (Tsinghua University)

Professor Jianjun Xia is an associate professor at the Building Energy Research Center in the School of Architecture at Tsinghua University. His areas of expertise include energy planning and the utilisation of industrial waste heat for space heating and building energy systems. He is principle (co-)investigator for several 14th and 15th Five-Year National Science and Technology Support Projects, which involve key research into improving the energy efficiency of district heating systems in northern China, the application of industrial surplus heat, and high-performance HVAC equipment. He is the Deputy Director of the Tsinghua Building Energy Research Center, and a member of the Executive Committee, as well as being the Chinese representative for the IEA District Heating and Cooling Technology Collaboration Programme (IEA DHC). He is also the Deputy Director of the Scientific Committee of the China District Heating Association. He is an associate editor of the international journal *Building Simulation*, and is the author or co-author of five books and over 150 scientific papers.

Michael Ahern (Ever-Green Energy LLC)

Michael Ahern has over 30 years of experience in the development, engineering, construction, operation, and management of industrial and energy systems. This includes providing operational oversight for businesses in the industrial and energy sectors, with a specific focus on district systems over the last fifteen years. At Ever-Green, he is responsible for the development and advancement of mission-based campus and community energy and utility systems. He holds a BS in Business Finance from the University of Notre Dame, with a minor in International Business. He is currently a member of the Board of the International District Energy Association (IDEA).

David Woodson (University of Washington)

David Woodson, the Executive Director of Campus Energy, Utilities and Operations at the University of Washington, is leading efforts to upgrade the utility infrastructure and decarbonise the district heating system at the flagship Seattle campus, making energy systems more resilient. Having previously held a similar role at the University of British Columbia (UBC), he is now enjoying the opportunity to apply the lessons he learned there at the University of Washington. He is a UW alumnus (Aerospace and Astronautics, 1991) and holds an MBA from UBC (2006). He is currently the Chair of the International District Energy Association (IDEA).

Parallel sessions

8 September

Session	Author and Title
Session 1 - Digitalisation of DHC: optimal control 1	**Session Chair: Dietrich Schmidt, Fraunhofer IEE, Germany** Numerical analysis of a nonlinear model predictive control for substations in Low-temperature district heating from a German living lab project *Rahul Mohandasan Karuvingal, RWTH Aachen University, Germany* Optimising integration of high-temperature underground thermal energy storage in district heating systems via co-simulation and control *Tijs Van Oevelen, EnergyVille/VITO, Belgium* A bi-level strategy for optimal control of heat distribution in meshed district heating networks including multiple production units *Mohamed Tahar Mabrouk, IMT Atlantique, France* Digital twin modelling to optimise district heating inlet temperature control *Pascal Sander, University of Bremen, Germany*
Session 2 - Sustainabilty of DHC and user engagement	**Session Chair: Jianjun Xia, Tsinghua University, China** New method for welding steel district heating and cooling pipes *Erik Tønjum, Snapwelder AS, the Netherlands* Environmental advantages and recycling potential of temporarily flowable backfill as bedding material for district heating pipes *Florian Spirkl, Ostbayerische Technische Hochschule Regensburg, Germany* Field tests and retrofit attempts on the operational electricity consumption of Chinese district heating network *Menghan Wan, Tsinghua University, China* Evaluating the potential of gamification in district heating systems: Insights from stakeholder and user surveys on motivational tariffs and behaviour change *Nermina Abdurahmanovic, Fraunhofer IEE, Germany*
Session 3 - Cost optimal design strategies 1	**Session Chair: Maarten Blommaert, KU Leuven/EnergyVille, Belgium** Optimising DH supply for positive energy districts *Nirav Patel, TU Wien, Austria* Optimising a multi-vector energy community with geothermal-powered district heating *Natalia Kozlowska, University of Liège, Belgium* Impact of demand simultaneity on optimal district heating network design *Amedeo Ceruti, Technical University of Munich, Germany* Decarbonisation of the Linz district heating system - determining the cost-minimising generation portfolio through optimisation and the role of seasonal thermal storages *Ralf-Roman Schmidt, AIT Austrian Institute for Technology, Austria*

Session 4 - Thermal source networks	**Session Chair: Raymond Boulter, National Resources Canada, Canada** Decarbonisation existing urban fabric through 5th generation district heating and cooling *Arthur Ackermans, Ingenium nv, Belgium* Performance of a prototype substation for 5th generation district heating and cooling networks *Gianni Martinazzoli, A2A Calore e Servizi & Università degli Studi di Brescia, Italy* A 5th generation district heating and cooling network (5GDHC) driven by shallow geothermal, economic analysis and geohydrological modelling for comparison with an individual system *Hoes, Hans, Terra Energy, Belgium* CollecThor: Technical realisation of a low temperature thermal network *Gert Moermans, EnergyVille/VITO, Belgium*
Session 5 - Modelling and data handling	**Session Chair: Stefan Holler, HAWK University of Applied Sciences and Arts, Germany** Integrating high-temperature ATES into district heating networks: FMI-based co-simulation with modelica and FEFLOW *Max Ohagen, Technical University Darmstadt, Germany* Generation of large DH system models using open-source data and tools: an exemplary workflow *André Xhonneux, Forchungszentrum Jülich, Germany* Modelling with the 223P ontology and adaptation for optimised DHC operation *Steffen Wallner, Fraunhofer IOSB, Germany* Optimising thermal energy storage models: enhancing accuracy through Variable layer calibration *Jonas Cleiren, University of Antwerp, Belgium*
Session 6 - Planning of DHC networks 1	**Session Chair: Urban Persson, Högskolan i Halmstad, Sweden** Presentation of the Italian atlas of potential district heating networks to recover industrial waste heat *Alice Dénarié, Politecnico di Milano, Italy* Economic evaluation of a heat highway between existing district heating networks *Katharina Rusch, Energieinstitut an der JKU Linz, Austria* Feasibility assessment tool for district heating and cooling (FAST DHC): A simple decision support tool for the techno-economic evaluation of DHC networks *Henrique Lagoeiro, London South Bank University, United Kingdom* Modelling innovative financing mechanisms for sustainable district heating development *Luis Sánchez García, Högskolan i Halmstad, Sweden*

9 September

Session 7 - Cost optimal design strategies 2	**Session Chair: Ingo Weidlich, HafenCity Universität Hamburg, Germany** Synergies between district cooling expansion and carbon-neutral district heating *Gerhard Totschnig, AIT Austrian Institute for Technology, Austria* Hydraulic integration of large-scale seasonal thermal energy storage with heat pumps in district heating systems *Abdulrahman Dahash, AIT Austrian Institute of Technology, Austria* Graph Preprocessing for MILP-Based District Heating Network Design *Jerry Lambert, Technical University of Munich, Germany* Multi-scenario design optimization of district heating networks with thermal-hydraulic validation *Yacine Gaoua, CEA, France*
Session 8 - Planning of DHC networks 2	**Session Chair: Anna Volkova. Tallinn University of Technology, Estonia** Achieving efficient district heating targets in a Croatian network: heat source mapping and techno-economic scenarios analysis *Daniele Anania, Eurac Research, Italy* Review of Tools and Methods to identify excess heat potentials in district heating *Rasmus Magni Johannsen, Aalborg University, Denmark* Innovative financing mechanisms for sustainable district heating development *Daniel Møller Sneum, Energy Modelling Lab/Lund University, Denmark/Sweden* Transitioning from high-temperature to low-temperature district heating: the evolution of the energy master plan at UZ Leuven Campus Gasthuisberg *Joris Dedecker, Ingenium nv, Belgium*
Session 9 - Efficiency improvements, modernisation and RES integration 1	**Session Chair: Jan Eric Thorsen, Danfoss A/S, Denmark** Natural circulation and other measures to ensure heating supply to buildings connected to district heating in the event of electrical grid blackout *Merilin Nurme, Tallinn University of Technology, Estonia* Optimising low-grade waste heat recovery for district heating: a case study of a steel plant in China *Zanyu Yang, Tsinghua University, China* Integration of decentralised renewable energy sources into DHC systems: technical challenges and experimental solutions *Mohd Basit Wani, Tallinn University of Technology, Estonia* Deterministic optimisation of district heating network retrofit to reduce supply temperature *Anne-Geneviève Lemelle, CEA, France*

Session 10 - Digitalisation of DHC: optimal control 2	**Session Chair: Alice Dénarié, Politecnico di Milano, Italy** Demand side management for peak shaving in district heating systems using model predictive control at substation level *Antoine Piguet, CEA, France* Demonstration of peak shaving through combined demand response and supply temperature control *Tijs Van Oevelen, EnergyVille/VITO, Belgium* Data-Driven cooling demand forecasting for district cooling operation *Hjörleifur Guðbjörn Bergsteinsson, Danfoss, Denmark* Using machine learning to optimise district heating operations *Dietrich Schmidt, Fraunhofer IEE, Germany*
Session 11 - Efficiency improvements, modernisation and RES integration 2	**Session Chair: Ivan Verhaert, Antwerp University, Belgium** Hydraulic and thermal effects of different building refurbishment strategies in district heating networks *Dmitry Romanov, HAWK University of Applied Sciences and Arts, Germany* Improved district heating return temperatures by cascading concepts *Jan Eric Thorsen, Danfoss, Denmark* Mitigating the hidden cost of electrifying heat: A case study using solar and thermal storage to achieve a zero-emission campus while minimising electric grid demand impact *Raymond Boulter, National Resources Canada, Canada* Innovative methodology for profiling foam density: Non-destructive x-ray microscopy (XRM) approach *Pakdad Langroudi, HafenCity Universität Hamburg, Germany*
Session 12 - Geothermal DHC	**Session Chair: Phil Vardon, TU Delft, the Netherlands** Status of the VITO deep geothermal project in Mol – Donk (northern Belgium) *Ben Laenen, VITO, Belgium* Enhancing waste heat integration into district heating through geothermal storage and heat pumps: risk and techno-economic assessment *Amir M. Jodeiri, Eurac Research, Italy* Design of closed-loop geothermal single wells for heating applications *Justin Pogacnik, VITO, Belgium* Borehole heat exchanger field layout optimisation for sustainable district heating and cooling networks *Kai Droste, RWTH Aachen University, Germany*

Session 13 - Student Award Winners	**Session Chair: DHC+** Performance of a prototype substation for 5th generation district heating and cooling networks *Gianni Martinazzoli, Universita degli Studi di Brescia, Italy* Data-driven approach for diagnosing inefficiencies and optimizing district heating networks *Sajedeh Roustaei, Politecnico di Milano, Italy* Systematic Assessment of Scientific Case Studies on Optimization Measures – A Value-Added Approach for District Heating Operators? *Anna Vannahme, TU Munich & Ingolstadt University of Applied Sciences, Germany*
Session 14 - Digitalisation of DHC: fault detection and diagnosis	**Session Chair: Michele Tunzi, Danish Technical University, Denmark** Exploiting synergies of data-driven and model-based approaches for leakage localisation in district heating networks: application of improved approaches *Dennis Pierl, University of Bremen, Germany* From time series to images: Exploring convolutional and vision transformers for fault detection in district heating *Jonne van Dreven, Blekinge Institute of Technology/VITO, Sweden/Belgium* Data-driven fault detection and diagnosis in district heating substations and the impact of return temperature reduction *Vera Alieva, Technical University of Dresden, Germany* Automatic fault detection in DHC systems using hybrid modelling *Pieter Jan Houben, University of Antwerp, Belgium*
Session 15 - Technological advances for new and existing networks	**Session Chair: Ralf-Roman Schmidt, Austrian Institute of Technology, Austria** TFSB as bedding material in district heating pipe construction - scientifically proven long-term experience *Bernd Wagner, AGFW, Germany* Data pre-process methods enhancing HCA measurement usability *Qinjiang Yang, Technical University of Denmark, Denmark* Experimental investigation on the thermal conductivity of alternative bedding materials for district heating networks *Stefan Dollhopf, HafenCity University Hamburg, Germany* Optimising the next generation of district heating and cooling systems while ensuring reliable domestic hot water supply *Mohammad-Reza Kolahi, University of Geneva, Switzerland*

Poster presentations: 8 and 9 September

Heuristic pipe sizing algorithm for 5th generation district heating and cooling networks

Marco Wirtz, nPro Energy GmbH, Germany

Analysis of peak load reduction with configuration of district heating controllers and a newly developed optimisation box

Ina Herrmann, University of Applied Sciences Hamburg, Germany

Data center waste heat utilisation: Analysis and modeling of liquid-cooled servers

Maximilian Stahlhut, Chemnitz University of Technology, Germany

Pyrolysis-plant potentials for DHC in Germany

Christian Timo Johannes Wolff, Fraunhofer ISE, Germany

Measurement-based control strategies for thermal comfort and regulation in low-temperature district heating networks

Mazarine Roquet, Université de Liège, Belgium

Perspectives of end users of district heat in Antwerp

Isaura Bonneux, University of Antwerp, Belgium

Implementation of a Low-Temperature Thermal Source Network Pilot System for Community Energy Independence

Hyeong-Jin Choi, GS E&C Institute, South Korea

Proposal for a method to simultaneously maximise the economic and environmental values of a district heating and cooling system for an electricity market

Kohei Tomita, Waseda University, Japan

Thermal monitoring of concrete ducts – concept presentation

Nils Zimmerling, Chemnitz University of Technology, Germany

Integral heating and cooling optimisation of district heating networks

Femke Janssen, TNO, the Netherlands

Making district heating flexible: Study of flexibility options with different control strategies

Luca Vittorio Valentini, University of Innsbruck, Austria

Evaluating laboratory operations for simulating multi-storey radiator heating systems

Qinjiang Yang, Technical University of Denmark, Denmark

Operational Analysis of a 4GDHC System in an Energy-Self-Sufficient Smart Village in Busan, South Korea

Min-Hwi Kim, Renewable Energy System Laboratory, South Korea

Lowering return temperatures to district heating networks by a cascade concept with integrated heat pump

Sandra Julia Forndran, University of Innsbruck, Austria

Differentiable predictive control for indoor air temperature control in buildings

Arash Farnam, Ghent University, Belgium

Digital control systems for district heating substations: A simulation study on peak load reductions

Dennis Lottis, Fraunhofer IEE, Germany

A comparison between district heating and heat pumps investment and operational cost for district energy efficiency measures

Mohsen Sharifi, EnergyVille/VITO, Belgium

Development and Demonstration of a Smart Interactive Thermal Energy Balanced Network for Distributed Next-Generation District Heating and Cooling Systems

Yong Kim, Apt-neuroscience Inc., South Korea

Dynamic flow temperature optimisation increases energy-efficiency in a district heating network

Jochen K. Illerhaus, Karlsruher Institute of Technology, Germany

Integration of a closed-loop geothermal system in a district heating network: Impact of eccentricity of the inner pipe to the flow and heat transfer.

Johan Van Bael, VITO, Belgium

Decarbonising peak heat load in district heating: Current practices and future renewable strategies

Magdalena Pflügl, Energieinstitut an der JKU Linz, Austria

Measuring district heating network effect on district cooling network losses in an urban environment

Tanel Kirs, Talinn Technical University, Estonia

A comparative techno-economic assessment of seasonal thermal energy storage for decarbonised district heating networks

Delaram Bayat, KTH Royal Institute of Technology, Sweden

Geothermal district heating networks in Iceland – challenges and future strategies at Veitur Utility

Heimir Tryggvason, Reykjavik Energy, Iceland

Large-scale solar thermal systems in district heating networks: A review of German projects regarding dimensioning, temperatures and stagnation times

Bert Schiebler, Institut für Solarernergieforschung GmbH (ISFH), Germany

Toward a Reference Model for Thermal Energy–Balanced EMS: Review of 5GDHC and Korean Implications

Jeong-woon You, Korea EMS Association, South Korea

Session 1: Digitalisation of DHC: optimal control 1

8 September: 14.00-15.30 - Auditorium

Session Chair: Dietrich Schmidt, Fraunhofer IEE, Germany

Numerical analysis of a nonlinear model predictive control for substations in low-temperature district heating from a German living lab project

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The transition to renewable energy sources necessitates innovative decarbonization strategies for district heating systems, with a focus on reducing fossil fuel usage. Low-temperature district heating (LTDH) technology offers a method to reduce energy consumption and enable integration of renewable energy resources. However, this transition increases system complexity. It requires the development of advanced monitoring and control strategies to optimize network performance by minimizing pump power, maintaining supply temperature consistency, achieving hydraulic balancing and reduce demand fluctuations to improve overall energy efficiency. Substation control is particularly challenging because it is essential to optimize network performance on grid side and ensure user comfort with minimum energy consumption on building side. To address these challenges, this study investigates nonlinear Model Predictive Control (MPC) for substations and compares it with a rule-based control.

We examine a planned LTDH network in a German living lab, featuring a two-pipe system with a 43°C grid supply temperature. The network includes a supply station equipped with a centralized pump using water as the heat transport medium and sewage water heat pump technology as the energy source. The network connects four multifamily buildings with an estimated annual heat demand of 755 MWh. Each building substation has a heat exchanger as the core component, designed for a 14K temperature differential and estimated peak loads. Flow regulation on the grid side is achieved through a motorized control valve. On the building side, each substation is equipped with a storage tank and a circulation pump, integrated to support the building's heating infrastructure. Every apartment is outfitted with floor heating systems and has an electric boiler to boost the temperature to 60°C for the domestic hot water systems.

Using the modelica based simulation framework we develop the substation models with a rule-based control strategy based on the secondary side storage tank. These models are validated using real-time data collected from the substations. Further advancing our approach, we develop a nonlinear MPC strategy for substation control. Comparative numerical analyses demonstrate that nonlinear MPC outperforms rule-based control, particularly in optimizing fluid flow and temperature regulation. The results highlight nonlinear MPC's potential to enhance operational efficiency in LTDH systems by reduction in the pump energy consumption, improvement in thermal stability and smoothing load fluctuations by forecasting demands.

The findings of this study emphasize the advantages of advanced control techniques, such as nonlinear MPC, in LTDH substations and their significance in improving overall energy efficiency.

Optimising integration of high-temperature underground thermal energy storage in district heating systems via co-simulation and control

Tijs Van Oevelen, Dirk Vanhoudt, Juliano Camargo, Philip J. Vardon, Martin Bloemendal, Ergin Kükrer, Max Ohagen, Mattias Krusemark, Tien Hung Pham, Willem Hagemann, Franziska Krenzlin, Till Spengler
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The Horizon Europe funded PUSH-IT project aims to showcase the full-scale applications of high-temperature heat storage (up to 90°C) in geothermal reservoirs at six different sites with various societal, heat network and geological conditions relevant across Europe. PUSH-IT will implement, develop, and test the ability of three different technologies (mine, borehole and aquifer thermal energy storage) to store and recover heat. In addition to key developments needed for these novel high-temperature storage technologies, their integration and operation in the district heating (DH) systems is a challenge, requiring novel approaches for simulation and control.

Hence, a key task in PUSH-IT is to optimise the operation of the district heating (DH) systems with integrated storages via supervisory control. A smart DH network controller is being developed and will be demonstrated, which will be able to adjust the heat demand of the network using demand side management to adapt to the real-time conditions of the geothermal reservoir and the heat production units. The controller will perform coordinated management of the supply from multiple heat sources. Furthermore, the smart DH network controller will be able to minimise the supply and return temperature of the network, and as such minimise the heat losses in the network and maximise the capacity of the geothermal wells by increasing the difference between extraction and injection temperatures. The control system will manage the thermal energy flows on both short- and long-term horizons. For this purpose, the controller will benefit from predictions from data-driven models of the buildings, network, geothermal storage and heat production facilities.

Another key goal of PUSH-IT is to assess the performance of underground thermal energy storage (UTES) systems and their integration into DH networks. A co-simulation platform enables coupled modelling of both systems, with UTES modelled using the finite element method and DH networks simulated via multiphysics simulation software. Data exchange occurs through specific communication interfaces, facilitating structured model interaction while accounting for communication variability. This co-simulation approach allows for accurate performance assessment, system optimisation and large-scale scenario analysis. Additionally, it supports the development of reduced-order models for the controller algorithms.

In this presentation, an overview will be given about the status of the PUSH-IT project, and in particular the development of the co-simulation environment and the controller. The intention is to test the first algorithms in the winter of 2025-2026, and this presentation will focus on these first algorithms.

A bi-level strategy for optimal control of heat distribution in meshed district heating networks including multiple production units

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District Heating Networks (DHN) are known to favour the integration of renewable and waste heat sources. Hence, modern DHNs are based on distributed production with low environmental impacts. However, DHNs have high thermal inertia and long response delays, making their control challenging, especially in the presence of distributed generation units.

In this work, an optimal model-based control strategy is proposed. It allows a reduction of energy production while keeping an acceptable quality of service (QoS). It consists of solving an optimization problem on a rolling horizon window to calculate optimal mass flow rates in the network's pipes and optimal supply temperatures at the generation units. The optimization problem is split into two nested sub-problems. The first one is an optimal energy dispatch problem based on predefined production costs. It calculates the mass flow rates thanks to an iterative linear optimization process. The second sub-problem is a non-linear optimization that uses a dynamic distribution system model to calculate QoS indicators (surplus and deficit of energy at each substation). It alters the dispatch given by the first sub-problem and calculates optimal supply temperatures at the generation units. The non-linear problem is solved using a gradient-free optimization algorithm.

The control strategy is tested on a 26-node DHN and compared to a control strategy based on a predefined production merit order. The results show that the occurrence of surplus or deficit using the proposed control strategy is higher but with substantially lower amplitudes and durations, which leads to a higher QoS. In addition, the proposed control strategy allows for substantial energy savings by reducing the supply temperature when possible without affecting the QoS.

Digital twin modelling to optimise district heating inlet temperature control

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As a key application of Industry 4.0, the digital twin (DT) offers significant potential to enhance safety and optimise the performance of physical systems. In this context, the DT serves as the foundation for assessing pipe ageing and energy efficiency, in terms of heat losses and pump performance, in relation to inlet temperature, enabling optimal dynamic control. However, to ensure reliability, deviations between the physical network and its digital representation must be minimised.

This research evaluates a district heating network by comparing measured data with simulation results of its DT, represented as a thermo-hydraulic model. The model includes a stationary hydraulic calculation and a dynamic temperature simulation to account for time delays caused by flow transit. With approximately 190 km of pipelines and over 900 customers, this district heating network serves as a valuable test case for evaluating the performance and accuracy of the DT. Although the simulation accounts for temperature, pressure, and mass flow, this study primarily examines supply and return temperature dynamics. Accurate modelling of the temperature spread—capturing the temporal distribution of supply and return temperatures—is crucial for understanding heat loss and its impact on downstream network behaviour. Additionally, precise temperature cycles support a more reliable fatigue analysis of the network. To achieve this, the study uses high-resolution data from 18 temperature sensors, comparing empirical measurements with the results of the DT's thermo-hydraulic model.

Preliminary results show a strong correlation, with simulated temperature distributions closely matching measured data, confirming the accuracy of the model in predicting heat loss. For a winter month, the mean absolute error of 12 key temperature sensors in the supply network is 1.16 K. This confirms the DT's capability to accurately model network behaviour, in particular temperature spread and heat loss. For a full validation, the data will be analysed over a full year.

Validation of these results is a critical step in optimising inlet temperature control. The DT continuously monitors network conditions and provides insight to adjust temperature settings to ensure energy efficiency and system reliability. By simulating different network conditions and predicting the impact of dynamic inlet temperature, the DT enables proactive adjustments to mitigate issues like pipe ageing and heat loss. Evaluating the control strategies not only improves network performance, but also supports the development of advanced, automated control approaches, such as Model Predictive Control (MPC) and neural networks, driving ongoing improvements in district heating systems' performance and sustainability.

Session 2: Sustainabilty of DHC and user engagement

8 September: 14.00-15.30 - Grûm 9

Session Chair: Jianjun Xia, Tsinghua University, China

New method for welding steel district heating and cooling pipes

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Today all steel pipes used for DHC are welded in the traditional way.

According to major welding organization there is a lack of more than 300.000 welders in Europe and more than 350.000 welders in the US. These numbers are increasing every year. The UK has lost 25% of their welders in the last 5 years due to ageing/retirement. This is expected to continue at high speed due to a high everage age of todays welders. Recruitment of welders is at an all-time low and this is considered the largest challenge in the welding industry today.

To ramp up district heating from today's 13-14% of total space heating towards the targeted 50% (in the Ålborg University report of Nov 2023), will require access to thousands of new welders across Europe. They don't exist and this can become the largest bottleneck. This is already acknowledged by Vital Energi, one of the largest developers in the UK:

https://www.heatnic.uk/case-studies/bridging-the-welding-skills-gap-to-ensure-the-uk-can-meet-its-net-zero-targets/

Snapwelder has developed a new way of welding steel pipes, which does not require specialized welders. By using a thermite welding, pipes can be welded in a few minutes by personnel taking a two-days training course. This does not only solve the problem with lack of welders, but it also reduces the time of installation of steel piping significantly and thereby reduces the total cost of installing new networks. Today's work-intensive welding is a cost driver for DHC networks.

Other advantages by using thermite welding is no use of gas and electricity at installation, much lower physical wear of the welders compared to traditional welding, less blocking time of streets and areas in the installation period.

Today teh welding companies recruit lots of their welders from more distant areas of the globe as local workers do not want this unconfortable and phycically damaging work. This import of workers from poor countries is a kind of social dumping whickj is not sustainable. By changing to thermite welding with very low phycical wear local workers can be employed in a high degree.

We would like to present this new welding technology at the Symposium, as we consider this the only sustainable way of welding new steel DHC piping networks.

Environmental advantages and recycling potential of temporarily flowable backfill as bedding material for district heating pipes

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District heating networks are a key to a successful transformation towards climate neutrality. Typically, District Heating Pipes (DHP) are embedded in coarse sand with specific grain size distributions and soil-mechanical properties. An alternative to this are the temporarily flowable backfill materials (TFB). These are a mixture of aggregate, binder (e.g. cement), water and, if necessary, additional supplements, e.g. bentonite. TFB can be mixed-on-site or mixed-in-plant, depending on the boundary conditions. Where possible, the excavated soil is used as aggregate. This paper will look at possible environmental advantages as part of a life cycle assessment, especially regarding the carbon footprint, if TFB is used in place of typical sand bedding. A total of 7 environmental impact factors are compared as part of a case study. As there are a multitude of variables with widely ranging impact for the calculation of the environmental impact, an additional sensitivity study was performed, to determine key parameters for the carbon footprint. In a multitude of cases; it can be shown that TFB has a smaller carbon footprint compared to sand bedding, as the number of transports can be greatly reduced and the TFB doesn't need to be compacted. These factors predominate the need of cement, which is negatively connoted regarding the environmental impact.

If the excavated soil is not eligible as an aggregate for TFB, an alternative base component is necessary. Typically, mixed-in-plant-produced TFB uses sand, as the properties of TFB based on recycling materials has hardly been investigated. In order to conserve natural resources and at the same time recycle construction waste, investigations were carried out into the production and strength behavior of TFB made from different construction materials. The main goal was to mix TFB which is easily re-excavated, as per German guideline H ZFSV. This was achieved with every recycling material, but with varying amount of cement necessary. As part of a long-term study, a delayed increase in strength depending on the source material could be shown. This is due to pozzolanic reactions.

Both studies were carried out as part of a research project funded by the Federal Ministry for Economic Affairs and Climate Action.

Field tests and retrofit attempts on the operational electricity consumption of Chinese district heating network

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District heating (DH) contributed to a large amount of energy consumption while producing significant carbon emissions. Supportive policies have been introduced by the government and scholars' endeavor on a variety of research to facilitate the decarbonization of district heating systems (DHSs). However, researches on heat networks seldom address the actual operation and power consumption of district heating networks (DHNs). This study adopted the DHNs as the object of investigation, uncovering its operational data and conducting an energy-saving diagnosis and transformation.

In this study, the overall analysis of electricity consumption of 70 DHNs in China was conducted through a statistical approach. The influence of macro factors on electricity consumption was evaluated, including outdoor climate, user indoor temperature, network heat consumption and water replenishment indices. Field tests on DHNs with high power consumption were conducted, focusing on key operational parameters such as temperature, pressure, and flow rate to identify operational inefficiencies and potential areas for improvement. The search implemented retrofitting attempts to address identified issues and assessed the impact on power consumption through a comparative analysis of before and after renovation.

Based on data analysis of over 70 DHNs in China, this study identified significant regional variations in energy consumption, with Ningxia exhibiting the highest (1.955kWh/m^2) and Beijing the lowest (0.999kWh/m^2) power consumption. The power consumption is directly proportional to the heat consumption index, with the average value of the heat consumption index recorded at 0.37 GJ/m^2. The average value of the water consumption index is noted as 30.76 kg/m^2, and the average indoor heating temperature is documented at 20.83°C. Field tests revealed key technical issues including system resistance, hydraulic imbalance, inefficient pump selection, and inadequate monitoring. Retrofitting measures such as heat exchanger cleaning, desilting, hydraulic balancing, and pump replacement resulted in average energy savings of 52% across the networks tested, demonstrating the potential for substantial improvements in heating network efficiency. Optimizing pump selection is a critical and essential strategy for reducing power consumption.

This research offers a systematic analysis of energy consumption patterns and operational challenges in Chinese heating networks compared to existing studies. By quantitatively evaluating the impact of retrofit measures, this study provides valuable insights and benchmarks for improving energy efficiency in the heating area.

Evaluating the potential of gamification in district heating systems: Insights from stakeholder and user surveys on motivational tariffs and behaviour change

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Technical solutions alone cannot fully optimize district heating systems (DHS), as the behaviour of end-users plays an important role in the system's efficiency and performance. Therefore, emphasizing strategies to actively engage customers and fostering collaboration with consumers are essential to reach the full potential of DHS. One approach to achieving this is the use of gamification. While gamification has proven effective in various domains, its application within the context of DHS remains underexplored, requiring further investigation into its potential impact.

Building on our prior research on gamification in district heating systems (DHS) [1], this paper presents the findings of an empirical study investigating the perspectives of both energy providers and end-users on gamified approaches and motivational tariffs. The study examines the potential of these methods to enhance user engagement, foster behaviour change, and improve energy efficiency within DHS. Surveys were conducted with two key groups: energy companies, both those utilizing motivational tariffs and those that do not, and end-users to investigate their interest and receptiveness to such methods.

The paper outlines the survey design and methodology, highlighting its focus on understanding barriers, opportunities, and preferences for motivating tariffs and gamification solutions within DHS. It examines key aspects such as the willingness of companies to adopt motivational tariffs, end-user receptiveness to interactive and incentive-driven energy-saving mechanisms, and potential synergies between the two groups.

This research aims to provide a comprehensive overview of the practical factors influencing the adoption of motivating tariffs and gamified approaches in DHS. It seeks to identify common themes, challenges, and opportunities that can guide the development of innovative solutions for energy efficiency and behaviour change. The paper contributes to advancing the discourse on gamification in energy systems by offering preliminary insights and setting the stage for future research and implementation.

It offers insights for stakeholders seeking to use gamification as a tool for advancing energy efficiency, reducing costs, and fostering sustainable behaviour change, but also enables customers to understand the significance and advantages of these strategies.

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Session 3: Cost optimal design strategies 1

8 September: : 14.00-15.30 - Trueno 8

Session Chair: Maarten Blommaert, KU Leuven/EnergyVille, Belgium

Optimizing DH supply for positive energy districts

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Motivation and Central Question: PEDs are urban areas designed to achieve net-zero energy import and net-zero carbon emissions annually while working toward a surplus of locally produced renewable energy. PEDs aim to maximize energy efficiency, integrate local renewable energy, and enhance energy flexibility to adapt to dynamic demand and supply conditions. DH systems offer a scalable and efficient solution for meeting these objectives. However, existing DH networks often rely on fossil fuels, making them unsuitable for PEDs. This study is motivated by the need to transition traditional DH systems to align with PED goals.

Research Question: What are the cost-optimal supply portfolios for decarbonized DH systems in PEDs, and how do they contribute to achieving energy efficiency, renewable integration, and energy flexibility?

Methodology: This study customizes and extends the Hotmaps DH supply model to align with PED objectives. Key modifications include incorporating sector coupling with the electricity sector, enabling a more integrated approach to balancing heating and electricity demands. The methodology adopts a scenario-based approach to evaluate various supply strategies, integrating technologies and resources that enhance sustainability and flexibility. Each scenario evaluates cost-minimal investment portfolios, supply dispatch optimization, and the integration of renewable energy and excess heat potential. PED-specific constraints, including net energy positivity and carbon neutrality, are incorporated. Synthesized case studies represent varying local conditions, such as resource availability and demand profiles.

Results: The study will provide detailed insights into the optimal design and operation of DH systems for PEDs:

1. Optimal Supply Portfolios: Scenarios reveal cost-efficient combinations of technologies, such as heat pumps, biomass CHP, and thermal energy

storage, that meet PED goals.

2. Economic and Grid-Impact Analysis: Study shows how DH in PEDs can interact with and benefit surrounding energy systems. Key areas include: 1) Evaluating the economic impact of optimized DH networks on the electricity grid. 2) Quantifying grid-related benefits of technologies like heat pumps and thermal storage during high or low renewable energy availability.

Conclusion: This research demonstrates the feasibility of transitioning DH systems to align with PED objectives. By customizing and extending the Hotmaps DH Supply model, the study identifies cost-optimal supply portfolios that decarbonize DH networks. The findings emphasize the critical role of technologies like heat pumps and thermal storage in supporting grid integration, reducing emissions, and ensuring economic viability. The insights gained can provide valuable recommendations for urban planners and policymakers, offering a pathway for implementing scalable and sustainable DH systems in PEDs.

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Optimizing a multi-vector energy community with geothermal-powered district heating

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The building sector plays a critical role in achieving the goal of a climate-neutral economy by 2050. Decarbonizing the heating and cooling sector remains one of the primary challenges in the transition to a sustainable energy future, with district heating and cooling networks serving as a key solution. Moreover, the concept of energy communities has gained importance. These groups of interconnected buildings focus on locally generating, consuming, and sharing renewable energy, ensuring efficient resource use. This paper investigates multi-vector energy communities, with particular emphasis on the thermal energy dimension and the integration of geothermal energy within these systems. A research gap has been identified regarding the optimal balance between centralized and decentralized heat production, accounting for temperature levels within the energy system and equitable thermal energy distribution among energy community members from a building-scale perspective. Within these communities, locally produced electricity can also be shared among members. The study leverages shallow geothermal energy in a closed-loop system to power a low-temperature district heating network, modelled to account for heat losses and distance-based household connections. Seasonal regeneration of the ground during summer, potentially driven by space cooling demands, is also considered to enhance system efficiency. The analysis seeks to determine the optimal energy configuration, considering factors such as borehole field size, geothermal resource availability, geothermal system efficiency, temperature levels within the energy system, and ground limitations due to heat extraction. Several constraints will impact household energy systems, and different supply temperatures will be analysed. The case study includes households with their respective heat (space heating and domestic hot water), cooling and electricity demand, and geothermal characteristics. An optimization approach is applied, considering both building-scale and district-scale perspectives. The Renewable Energy Hub Optimizer (REHO), a decision-support tool, is utilized to optimize the design and operation of energy communities [1]. Future work will explore thermal energy sharing and the integration of geothermal energy storage to further enhance system performance.

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Impact of demand simultaneity on optimal district heating network design

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District heating networks (DHNs) are a promising technology for a renewable supply of heating in urban environments [1]. To achieve a cost-effective energy supply to consumers, careful design and planning of the networks is needed due to high upfront capital needs, complex thermo-hydraulic systems, and weather-dependent energy sources [2], [3]. Optimization is a promising tool for the design of DHNs [4]. A vast body of literature has been published on the application of mixed-integer (e.g. [6]), nonlinear (e.g. [7], [8]) and heuristic algorithms (e.g. [9]) for district heating network topology and piping design, including the integration of RES and storage (SSRN [10], [11]). The objective function of the optimization algorithms varies, but a pre-defined heating demand is always present.

Predicting heating demands is a challenging task and is inherently uncertain [12], [13]. This stochasticity is not included in deterministic algorithms but it enables economies of scale, because of reduced installed power needs due to not simultaneous peak demands, a phenomenon known as simultaneity effect [14]. Further effects that enable economies of scale when aggregating demands include concurrency effects and diversity of heating demand. Stochastic optimization methods can be applied to include stochastic parameters into the decision-making process. Stochastic Programming is an established method of stochastic optimization and has been applied to district heating networks, including price, and demand uncertainty [15], [16]. However, no authors have systematically studied the effects of concurrency on DHN optimization outcomes to date. We include concurrency effects into a novel stochastic district heating design optimization via a two-stage stochastic programming approach ("sp" model). The formulation is compared to two scenarios: an optimization model without concurrency effects ("peak" model, [6]), and an ex-post calculation of the concurrency effects ("ex-post peak" model). We find that concurrency greatly impacts the total costs due to large reductions in the installed thermal capacity of the pipes. The value of the stochastic solution is calculated to assess the benefits of the "sp" model. However, the benefits of "sp" in simple networks of a full stochastic optimization compared to "ex-post peak" are limited. The solving times of "sp" model increase rapidly compared to "ex-post peak". The application of decomposition methods such as Dantzig-Wolfe [17] could significantly decrease solving times by exploiting the matrix structure of the two-stage problem. Further research should investigate the robustness of the results under various demand scenarios.

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Decarbonisation of the Linz district heating system - determining the cost-minimising generation portfolio through optimisation and the role of seasonal thermal storages

Ralf-Roman SCHMIDT, Gerhard TOTSCHNIG, Demet SUNA, Christian SCHEINECKER, Fabian LEIMGRUBER, Philipp ORTMANN

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With a heat generation of 1,187 GWh, 58% of LINZ AG's district heating (DH) comes from gas-fired combined heat and power (CHP), 12.6% from biomass and 29.4% from waste incineration. Linz AG aims at reducing the fossil generation to zero by 2040, with interim targets of 60% and 80% renewable share in 2030 and 2035 respectively.

Methodology: For determining the cost-minimising DH generation portfolio, a comprehensive analysis of the technically and economically relevant variants has been done, using an optimisation-based approach. Therefore, initially important framework conditions were defined, including energy price scenarios, assumptions regarding the availability of renewable fuels and the development of the DH demand. Furthermore, key technology options were evaluated, including seasonal thermal storages and industrial waste heat. Furthermore, the DH system was modelled and parameterised, including a model validation. Finally, different decarbonisation paths were considered using an optimizer. Its aim was to minimise the total costs (net present value) for the years 2030, 2035 and 2040. Within the scenarios, the optimiser decides to invest in renewable technology options and storage in order to achieve the interim targets set, while taking into account operational constrains and restrictions such as the maximum amount of biogenic fuels.

Results and conclusions: For all scenarios and assumptions considered, the decarbonised DH generation mix in 2040 is made up of approx. 1/3 waste incineration (which is assumed to be climate-neutral via Carbon Capture and Storage in 2040); 1/3 power-to-heat (electric boilers, large heat pump) and / or waste heat (if available) and 1/3 renewable fuels (biomass / wood, biomethane), especially in winter. In scenarios with medium to high energy prices, storages are increasingly economical, up to a seasonal thermal storage, which can have a size of up to 1 million m3. In general, large investments in heat generation, storage and, if available, waste heat utilisation are required. Together with lower revenues from CHP electricity generation the heat generation costs turn out to be higher than in business-as-usual scenarios without decarbonisation. Industrial waste heat has the potential to make a significant contribution to decarbonisation. Depending on the purchase prices, its utilisation can also bring economic advantages over alternatives.

However, there is a high degree of uncertainty due to potentially changing political and economic conditions, so that regular adjustments to the strategy are required.

Session 4: Thermal source networks

8 September: 16.00-17.30 - Auditorium

Session Chair: Raymond Boulter, National Resources Canada, Canada

Decarbonization existing urban fabric through 5th generation district heating and cooling

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5th Generation District Heating and Cooling (5GDHC) systems provide key benefits, such as the use of low-temperature renewable resources, bidirectional operation, decentralized energy distribution, and the potential for energy sharing. While 5GDHC seems a promising solution for greenfield developments, its implementation in existing urban environments can present considerable challenges. These challenges include the limited availability of renewable energy sources in dense cityscapes, high heating demands from existing buildings, and the complex boundary conditions set by various stakeholders. This raises a question: how do we tackle these challenges to enable decarbonization of the existing urban fabric through 5GDHC?

This paper explores this question through four case studies that represent diverse urban contexts in Belgium where a 5GDHC network was implemented or explored:

1. University Hospital of Leuven: A highly dense, energy-intensive site with stringent operational reliability requirements.
2. Bijlokesite, Ghent: A dense, energy-intensive site with high historical value and limited renewable energy potential.
3. Watersportbaan, Ghent: A low-density, energy-intensive site with abundant renewable energy sources.
4. Cinquantenaire, Brussels: An energy-intensive, historically significant site in the dense city center of Brussels, facing additional challenges related to building renovation phasing.

Each of these sites currently relies heavily on fossil-based heat production, and the implementation of a 5GDHC network aims to transition them to fossil-free, low-temperature heating and cooling systems. As will be discussed in this paper, no single solution fits all situations. The unique characteristics of each case require tailored approaches to overcome the barriers posed by the existing building stock, financial constraints, and boundary conditions.

A key finding in our experience is that phasing the implementation of 5GDHC networks and the adaptation to the existing building stock is critical. Incremental steps, with long-term goals in mind, are essential for overcoming financial and technical challenges. This paper argues that while the path to decarbonizing existing urban areas using 5GDHC is complex, it holds considerable potential if approached strategically and with flexibility. Additionally, this paper provides insights into the practical application of 5GDHC systems in diverse urban contexts, offering valuable experience and advice for future projects aimed at decarbonizing existing building patrimonium.

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Performance of a prototype substation for 5th generation district heating and cooling networks

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In recent years, the district heating (DH) sector has seen the development of an unconventional type of network called, 5th generation district heating and cooling (5GDHC), which is characterised by the sharing of heat at neutral temperatures [1] and the thermal decoupling of buildings connected to the network through the installation of decentralised heat pumps. The heat pumps, replacing the heat exchangers installed in the substations of conventional DH networks, enable to cover both the heating and cooling demand of end users, even at the same time, and to use low-temperature heat sources, natural or from waste heat [2, 3, 4].

The other feature of this kind of network is the decentralised pumping system that operates to satisfy the flow required by the heat pump. However, the low temperature differences between the supply and return lines of the network result in higher flow rate values than in conventional DH [5]. These characteristics lead to an increase in substation complexity in 5GDHC networks compared to substations of conventional DH networks. Furthermore, the features of the 5GDHC are well described in the literature with techno-economic evaluations or comparisons between 4th and 5th generation DH [6,7] with numerical simulations but a detailed description of the substation, its performance and energy consumptions there is missing.

The aim of this work is to present a 100 kW prototype substation for 5GDHC networks that supplies an inhabitant building with a heating and cooling demand, and which is equipped with measuring instruments to monitor its operating conditions. After the design and realisation of the prototype, tests were performed in a heating and cooling configuration for one and a half years to assess the proper operation of the prototype and its performance. Two types of tests were performed: on-design and off-design tests to characterise the prototype under different working conditions. The tests showed energy consumptions and their distribution between the main components of the substation: heat pump, pumping system and auxiliaries. Moreover, the COP of the heat pump and the EER, when the heat pump works as chiller, were derived as well as the overall COP (G-COP), obtained by considering thermal losses, consumptions by auxiliaries and pumping system.

Test results show that the COP of the heat pump under on-design conditions is between 3.3 and 4.2, while the EER is between 4.3 and 4.7. G-COP is between 2.6 and 3.1. COP under off-design results between 2.7 and 6.8.

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A 5th generation district heating and cooling network (5GDHC) driven by shallow geothermal, economic analysis and geohydrological modelling for comparison with an individual system

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Shallow geothermal installations are often developed individually in Belgium, each one will work out its own installation. This goes well when the installations stay away from each other. The success of the technology creates greater density where systems will increasingly affect each other negatively. Especially in an urban context, this becomes an inextricable tangle. On top of that, different types of systems are active, both smaller closed and larger open systems are applied according to project size and specific needs. The approach described above is detrimental to the pursuit of further sustainability of the building stock as it will quickly lead to saturation of the available space. In addition, sub-optimal implantation of source systems will lead to reduced efficiency and poor profitability. Based on a concrete example case, it will be shown that it makes sense to go for a collective approach, in combination with a 5th GDHC. The impact was investigated by subsurface modelling and additional economic analysis. The hydrogeological modelling is performed using FeFlow 8.1, a 3D finite-element software. Both open loop systems (ATES, Aquifer Thermal Energy Storage) and closed loop systems (BTES, Borehole Thermal Energy Storage) are modelled in this study. The thermal and hydraulic impact of the different systems on each other and the environment is investigated. The results show that when shallow geothermal systems are operating close to each other, there is a risk of mutual impact. Open loop systems can have both thermal and hydraulic impact on nearby systems, while closed loop systems can only thermally impact their surroundings significantly. The impact radius of closed loop systems is usually much smaller compared to the impact radius of open loop systems. The economics of a project improve by combining geothermal systems. There is an economy of scale and thermal energy can be better exchanged when different building types are coupled with each other. The use of a fifth-generation network with uninsulated pipes optimally contributes to favourable economics.

CollecThor: technical realisation of a low temperature thermal network

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The CollecThor project in Thor Park Genk, Belgium, represents a pioneering advancement in sustainable energy infrastructure. As one of Belgium's inaugural fifth-generation district heating and cooling networks, CollecThor is designed to optimize the exchange and storage of thermal energy among connected buildings, enhancing energy efficiency and sustainability.

Unlike traditional district heating systems that operate at high temperatures and rely on centralized heat sources, CollecThor employs a low-temperature thermal network that facilitates bidirectional energy flows. This configuration enables buildings to function as both energy producers and consumers, allowing surplus heat from one structure to be utilized by another. The system's foundation is built upon shallow geothermal energy, utilizing an Aquifer Thermal Energy Storage (ATES) system. This approach involves storing thermal energy in underground aquifers at depths exceeding 65 meters, providing a natural and efficient means of energy storage and retrieval.

The initial phase of CollecThor's implementation includes connecting existing buildings within Thor Park—such as Thor Central, IncubaThor, and EnergyVille 1 and 2—as well as eight additional plots designated for future development. The network's modular design allows for straightforward expansion, facilitating the integration of new buildings and technologies as the park evolves. By maximizing the exchange of residual heat and cold between these structures, the system significantly reduces the need for additional energy input, thereby decreasing overall carbon emissions.

A key technological component of CollecThor is its intelligent control system, which manages the distribution and storage of thermal energy throughout the network. This system ensures that energy is allocated efficiently based on real-time demand and supply conditions, further enhancing the network's performance. Additionally, the integration of advanced monitoring and data analytics tools allows for continuous optimization and provides valuable insights for future developments in district heating technology.

CollecThor's innovative approach aligns with broader sustainability goals by reducing reliance on fossil fuels and promoting the use of renewable energy sources. By serving as a testing ground for cutting-edge thermal energy technologies, the project not only contributes to the decarbonization of the built environment in Genk but also offers a scalable model that can be adapted to other regions seeking to implement sustainable district heating solutions.

In summary, CollecThor exemplifies a forward-thinking application of fifth-generation district heating technology, leveraging shallow geothermal energy, intelligent control systems, and modular design to create a sustainable and efficient thermal network. Its implementation demonstrates the potential of collaborative innovation in advancing energy transition initiatives.

Session 5: Modelling and data handling

8 September: 16.00-17.30 - Grûm 9

Session Chair: Stefan Holler, HAWK University of Applied Sciences & Arts, Germany

Integrating high-temperature ATES into district heating networks: FMI-based co-simulation with modelica and FEFLOW

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Shifting surplus heat from summer to winter is crucial for optimizing modern district heating (DH) networks, particularly as the share of must-run renewable energy sources—such as geothermal wells—continues to expand and required reductions in CO_2 intensity of energy increases. High-temperature Aquifer Thermal Energy Storage (HT-ATES) provides a promising solution to address this seasonal mismatch, yet practical integration into DH networks requires careful consideration of geological and operational factors.

In this work, we introduce a novel co-simulation framework that couples Modelica/Dymola with the groundwater and heat transport software FEFLOW. Our approach leverages the Functional Mock-up Interface (FMI) to combine system-level DH modeling - using open-source libraries such as Buildings and DisHeatLib - with detailed subsurface simulations. Two specialized FEFLOW interfaces were developed: a C++ plugin for three-dimensional reservoir simulations and a Python plugin to handle coupled 2D axisymmetric models.

As a proof of concept, we apply these methods to the planned HT-ATES at TU Delft, where surplus geothermal energy is stored for later use in the DH network serving both the university and part of the city of Delft. To evaluate our framework, we devised four scenarios: (1) a reference system using a 1D ATES model from the Buildings library of Modelica/Dymola, (2) a system coupling two separate 2D FEFLOW axisymmetric models, one for each hot and cold wells, with the Modelica/Dymola model of the DH network, (3) a system coupling with a 3D FEFLOW model, with the Modelica/Dymola model of the DH network, and (4) a standalone FEFLOW simulation with predefined boundary conditions.

We compare each scenario's recovery efficiency, computational performance, and sensitivity to groundwater flow and heterogeneous geology. The results highlight how co-simulation can enhance the accuracy of HT-ATES predictions and provide valuable insights for optimizing system design and operation. This study underscores the advantages of bridging system-level and high-fidelity models, setting the stage for future research on economic feasibility, environmental impacts, and long-term sustainability of HT-ATES in DH networks.

Generation of large DH system models using open-source data and tools: An exemplary workflow

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Adapting existing district heating (DH) systems towards an efficient and climate-neutral heat supply to buildings is a major challenge. The fast evaluation of various measures in DH systems to improve sustainability and operation efficiency is made even more difficult by the fact that detailed information on existing DH systems, e.g. on the supplied buildings or historical measurement data, is generally not publicly available.

Combining available data on DH system into so-called DH models to obtain a digital representation of a DH system is one way of analysing opportunities to decarbonise existing DH systems. Such DH models can be used in optimisation or simulation approaches to identify different measures to improve operational efficiency or to integrate sustainable heat sources.

In this work, we present a comprehensive workflow for DH model generation using publicly available data and open-source tools. In this DH model generation workflow, the three main types of DH components, the heat supply, the pipe network and the supplied buildings, are enriched with different sources of information or with estimated values calculated by tools when no data is available. A detailed example of a DH model generation is presented using various open-source datasets, including the general network topology provided by the DH operator, geo-referenced data of buildings close to the DH network, DH connection rates and survey data on the year of construction of buildings. In addition, open-source tools, such as a network graph management tool or a demand profile generator, are used to create a detailed and comprehensive DH model.

The combination of many extensive open-source datasets and the addition of estimated values results in plausible DH system representations that can be used, for example, to analyse the utilisation of heat source potentials in the vicinity of the existing DH system. Future work will focus on validating these generated DH models with real data and also expanding the variety of open-source datasets and tools used.

Modelling with the 223P ontology and adaptation for optimised DHC operation

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District heating and cooling networks (DHCs) are the key to decarbonizing the heating sector. Consequently, they will be expanded or newly planned in the coming years. A crucial aspect of transforming to emission-free DHCs is the digitalization of these systems. With ongoing digitalization, a new set of tools becomes available to optimize DHC operations, such as identifying the most problematic consumer substations, predictive maintenance, optimized heat production, evaluation of potential extensions, and sector coupling. A possible future use case application is the cross-domain usage of data via data spaces like Gaia-X [1]. Additionally, according to the German HKVO (Heizkostenverordnung), consumption data acquisition systems must be remotely readable by January 1, 2026 [2], which allows further optimizations of the DHC operation.

Due to the absence of a single standardizing data model for DHC data, many network operators develop their own data models for their DHCs, either alone or in collaboration with companies. To leverage the potential of digitalization and apply advanced optimization strategies, expensive customer-specific interfaces often need to be created, making it difficult or sometimes economically impossible to integrate new digital services or software vendors. To fully realize the benefits of digitalization, a standard for data, interfaces and semantics is necessary, allowing software distributors to easily adapt their software to various systems. It is preferable to extend an established standard like an ontology out of the building system or energy system domain to the DHC domain.

This paper presents a comparison of different standards for detailed modeling of distribution infrastructure and the adaption of the 223P ontology [3] for DHC, guidelines of the usage and two case studies. The case studies originate form the SimKiMop (Fkz. 03EN3074A) and TrafoWärmeNetze (Fkz. 03EN3093B) research projects. In the SimKiMop project, data-driven models are trained using DHC simulations to reduce computing time for optimal operation of distributed heat generators. Conversely, the TrafoWärmenetze project emphasizes cost-optimized transformation planning for heating networks, evaluating expansion options for existing networks, and investigating the cost-optimized exchange of generation units for emission-free generators. In both projects, mapping the network topology in the form of a graph, with certain attributes of the heat generation units, is essential.

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Optimizing thermal energy storage models: Enhancing accuracy through variable layer calibration

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Due to the growing need to mitigate climate change and enhance energy efficiency, the utilization of heat pumps has become increasingly popular. The efficiency of these heat pumps is highly dependent on temperature, especially when integrated with Thermal Energy Storages (TES) to improve energy efficiency. Precise modeling of internal temperature distributions within TES is crucial for optimal real-time operation and predictive control, as control optimization is highly sensitive to prediction inaccuracies. Therefore, developing precise TES models is necessary to fully maximize their optimization potential and ensure reliable and efficient heating solutions in real-world applications.

Numerous validated one-dimensional (1D) TES models with constant volume layers exist; however, their primary focus has been on validating outgoing temperatures while often neglecting the measured temperatures inside the storage tank, which are critical for controlling the heat pump. In large installations, sensor modeling presents challenges where the exact location is not known, and offsets and delays can occur due to environmental influences and sensor construction. These sensors, often situated inside metal sockets surrounded by air or conductivity gel, can have significant temperature measurement offsets and delays, impacting the activation and efficiency of the heat pump.

This research presents a novel approach that builds on the suggestion of Zinsmeister et al. to apply variable layer sizes to improve the accuracy of the model at the connections. The approach involves calibrating the different layer sizes and locations to increase accuracy at the most critical points, such as connections and sensor locations inside the TES, while reducing the number of layers in less critical areas to improve computational efficiency.

The primary objective is to enhance the accuracy of TES models, facilitating reliable control optimization while attempting to reduce computational burden where possible. By intelligently dimensioning the layers according to connection positions and sensor locations, the research aims to achieve high accuracy with potentially fewer layers, thereby minimizing computational load. The Tunable Variable Layer Size TES model is applied to multiple cases and compared to the commonly used Constant Layer Size TES model. The outcome is a refined TES model that enhances predictive control, resulting in more efficient energy use, cost savings, and reliable system performance, addressing both the accuracy of outlet temperatures and the critical internal temperatures measured by sensors.

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Session 6: Planning of DHC networks 1

8 September: 16.00-17.30 - Trueno 8

Session Chair: Urban Persson, Högskolan i Halmstad, Sweden

Presentation of the Italian atlas of potential district heating networks to recover industrial waste heat

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This work presents the Italian Atlas of waste heat sources for District Heating, an online tool that has been developed jointly by Politecnico di Milano and RSE to highlight the significant untapped potential of industrial waste heat recovery for DH.

The web tool has a double feature. The first is the Atlas itself, containing heat demand and industrial heat sources mapping. Most importantly, the map shows possible heat recovery projects characterized by quantity of recovered heat, served demand, network layout and cost of the initiative. These are obtained through an optimization algorithm aiming at matching heat demand with heat sources through DH networks at minimal costs, in competition with other individual heating sources. The second feature is the possibility for the users to use customize the analyses of a single DH project through the Detailed evaluation tool: this is a calculation tool, based on the algorithm used for the Atlas construction, that allows a potential user to recalculate the feasibility of a heat recovery project through DH in a geographical area, limited by a chosen radius, modifying the initial input data and adding different costs, hypothesis and financial aspects. The results of the model's application include the total amount of waste heat [MWh] recovered from the industrial source in the DH, the optimal network topology [km] and its capital cost [€], and the LCOE [€/MWh] of the sold heat.

The results show that out of more than 800 industries mapped from ETS register, the waste heat availability amounts to 36.1 TWh/year, out of which 11.6 TWh/year from low temperature heat residues needing heat pumps and 24.5 TWh/year of high temperature waste heat directly connectible to DH systems. The heat demand of multifamily and tertiary buildings technically connectable to DH is estimated to be 100.3 TWh/year.

The matching algorithm's outcomes suggest an overall amount of 17.8 TWh/year of economically sustainable industrial heat recovery via DH projects (7.38 TWh/year recovered from LT industrial processes and 10.44 TWh/year from HT processes).

The Atlas aim is to show the big potential of these projects through visual, immediate and easy to understand figures, so to promote a faster implementation of these initiatives toward industries, DH operators and local administrations. Being also user oriented, the tool allows customized calculations and sensitivity analysis aimed at different scenarios investigations.

Economic evaluation of a heat highway between existing district heating networks

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District heating is a key component of regionally anchored, renewable, and efficient energy systems. This study assesses the economic feasibility of establishing a "Heat Highway" through a Supra-Regional District Heating Network (SR-DHN) [1] between Linz and Wels, Austria, 30 km apart. SR-DHNs connect existing district heating networks, enhancing supply security, reducing outage risks, and optimizing sustainable and cost-effective energy use.

Using the transparent Heat Merit Order model [2], this study examines the economic and environmental benefits of connecting the two existing district heating networks. Based on mostly publicly available data, the optimization potential enabled by an SR-DHN is calculated ex-post for the period from January 2018 to December 2021. The SR-DHN spans two locations with ten units: both cities rely on Waste-to-Energy combined heat and power (WtE CHP) units for base load, supplemented by Biomass CHP, Gas CHP units in Linz, and in each location a Gas boiler (HOB) for peak demand and backup. The Heat Merit Order model ranks units hourly by their marginal heat generation costs ascendingly, determining which are most economical to operate. Less cost-efficient units generate less heat and are replaced by cheaper alternatives. Annual savings are derived by comparing simulated costs of the SR-DHN with the separate local district heating networks. The annual cost savings, taking into account assumptions and restrictions, also serve as a basis for assessing whether the savings justify an investment in the connecting pipeline (CAPEX of the pipeline). Importantly, the simulation always results in optimization, meaning savings are never negative. In the worst case, the simulation would not use the SRDHN and operate the local systems as before. It is therefore clear that the savings must first justify the construction and operation of the line and that no simple statement on the economic viability of the line can be derived from the result.

The results show that the heat substitution follows a seasonal pattern: in winter, plants primarily serve their local networks, leaving little excess heat for transfer. In summer, both WtE units meet local demand. The greatest impact occurs in transitional seasons (spring and autumn), when Wels' WtE unit supplies heat to Linz, replacing Gas CHP units. This integration reduces variable heat generation costs by an average of 16.3% annually and lowers CO_2 emissions by approximately 15% per year.

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Feasibility assessment tool for district heating and cooling (FAST DHC): a simple decision support tool for the techno-economic evaluation of DHC networks

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The Feasibility Assessment Tool for District Heating and Cooling (FAST DHC) project, funded through the IEA DHC Annex XIV, aims to develop and demonstrate a simple, freely available, web-based decision support tool for the techno-economic performance evaluation of 4th generation district heating

(4GDH) and thermal source networks (TSNs), whilst also enabling their comparison to individual heating and cooling (H&C) solutions. The TSN concept is in its early stage of development and there is a lack of understanding of its relative merits against traditional DHC concepts, i.e. how do 4G and TSN systems compare and what are their competitive advantages to individual H&C systems. The FAST DHC tool will enable users (e.g. local authorities, designers and energy planners) to perform early-stage feasibility studies and easily compare the potential benefits of the latest DHC typologies, providing greater clarity on how/where each system may be best applied. The aim of the tool is to assist the development of the DHC sector by equipping users with a reliable initial estimate of proper system setup, therefore maximising benefits to DHC developers, operators and end users. This paper introduces the FAST DHC tool, describing its design and functionalities, and provides the results from case studies where the FAST DHC tool has been compared to other commercial tools for the techno-economic modelling of DHC systems.

Modelling innovative financing mechanisms for sustainable district heating development

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In the ongoing climatic- and security of energy supply crisis, a radical transformation of the heating supply is required. In urban areas, a cost-effective solution from a societal perspective is usually a combination of district heating and individual heating solutions. However, the potential for district heating expansion is highly dependent on the financial framework conditions, which are seldom studied. This study aims to address this gap by assessing the consequences of various financial conditions on the competition between district heating and individual heat pumps using the city of Bilbao, Spain, as a case study. This analysis is conducted as a two-step process. First, a comprehensive GIS dataset is used for mapping heat demands in high spatial resolution. Through this mapping, the city has been divided into clusters, enabling estimation of construction costs of developing a district heating network. In the second step, this information has been incorporated into an energy system model by utilizing the TIMES energy systems framework,. This modelling identifies the minimum cost trajectory for the decarbonisation of the

heat supply by centralized and individual heating technologies under different financial assumptions. As part of the wider study Annex XIV Project 03 (The FinDH project), this presentation shares the modelling methodology to conduct the analyses of financial framework impacts on the deployment of DH.

Session 7: Cost optimal design strategies 2

9 September: 09.00-10.30 - Auditorium

Session Chair: Ingo Weidlich, HafenCity Universität Hamburg, Germany

Synergies between district cooling expansion and carbon-neutral district heating

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Motivation and central question

This presentation is based on the results of a commissioned study carried out for an Austrian district heating and cooling producer. As part of a study, economic options for the expansion of the district cooling supply were examined. It was also important to examine possible synergies with district heating. One objective in district heating is to achieve a 60% or 100% renewable share in district heating generation by 2030 or 2040 respectively. This required a comprehensive investigation of the technically and economically interesting variants of a future generation portfolio.

Relevant questions regarding the expansion of district cooling were:

- Does it make sense to use absorption chillers driven by waste heat from industry and waste incineration for cooling in summer?

- As a certain cooling load is also expected in winter: Is it economical to use heat pumps to utilize the waste heat from the cooling systems in winter for district heating? Especially as the district heating needs to be decarbonized.

- Is it economical to use district cooling storage? What are the advantages?

Results and conclusions

Methodological approach

An investment planning and operation optimization model for district heating and district cooling was created to plan the expansion of district cooling. In this model, possible synergies between district heating and district cooling are shown in an overall optimization model. A large number of framework conditions and scenarios were examined.

Considered technologies: direct river cooling; compression chillers; absorption chillers; heat pumps; cold storage

Results and conclusions

In the scenarios investigated, “free” waste heat from industry and waste incineration was available in summer. However an absorption chiller using this “free” heat, was not economical due to limited operation hours. For the absorption chiller, the capacity of the cooling towers would also have to be increased. This increases to the costs of absorption cooling considerably. In all scenarios, it was economical to use the waste heat from the cooling systems in winter to provide district heat with the help of a heat pump. The district cooling storage system was also economical in all scenarios. The district cooling storage system allows the compression chillers to be used when electricity is cheap and helps to cover peak loads. For the realization of mixed district cooling generation, it is essential whether there is enough space available for the different heat flows and cooling systems.

Hydraulic integration of large-scale seasonal thermal energy storage with heat pumps in district heating systems

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Large-scale seasonal thermal energy storage (sTES) coupled with heat pumps (HPs) plays a pivotal role in the decarbonization of district heating (DH) systems by facilitating a higher share of renewable energy, enhancing operational flexibility, and enabling sector coupling (Tosatto et al., 2023). However, the optimal planning and integration of HPs with sTES remain a key challenge due to complex interactions between system components and varying operational conditions (Dahash et al., 2021).

This study presents a comprehensive numerical investigation into the optimal hydraulic integration of HPs with sTES using validated numerical models implemented in the simulation environment Modelica/Dymola. A systematic parametric analysis is conducted, exploring a wide range of design and operational parameters that influence the overall performance of the sTES-HP system.

These parameters include sTES type, storage volume, insulation, charging and discharging port configurations, number of sTES units, operating temperature ranges, cascading strategies for both sTES and HP units, and other critical factors.

To thoroughly assess the system's performance, multiple key performance indicators (KPIs) are employed, covering both technical and environmental aspects. The evaluation considers energy, ground temperature variations, and CO_2 emissions, providing a holistic assessment of the sustainability and efficiency of different integration strategies.

The findings of this study offer valuable insights into the planning, design and operation of sTES-HP systems, supporting the development of more efficient and sustainable DH networks.

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Graph Preprocessing for MILP-Based District Heating Network Design

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District heating systems play a crucial role in enabling a socially accepted and economically viable transition towards a renewable energy system. They offer numerous advantages over a building-specific heat supply, including increased efficiency, reduced emissions, and better integration of renewable heat sources. Although mixed-integer linear programming algorithms for district heating planning are the subject of ongoing research, their ability to optimize network design for large-scale districts and consider multiple design periods is still limited. A promising strategy to enhance scalability is to reduce the number of decision variables before optimization. Therefore, this work explores several preprocessing techniques to reduce model complexity, such as removing unused network segments and algorithmically determining flow directions before the optimization.

Based on various example networks, it can be shown that preprocessing significantly decreases the number of model variables without restricting the feasible solution space. Afterwards, the optimization times for preprocessed and non-preprocessed networks using both commercial and open-source solvers were evaluated to determine the overall effectiveness of the proposed preprocessing methods.

Multi-scenario design optimization of district heating networks with thermal-hydraulic validation

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District heating networks are essential components of energy transition strategies, ensuring efficient and sustainable thermal energy distribution. However, designing and expanding these networks in complex urban environments pose significant challenges. Traditional approaches for network design often rely on empirical decisions or simplify the problem to reduce complexity, neglecting detailed physical models or operational constraints. These simplifications include ignoring optional connections for prospective users, omitting project phasing, considering a single scenario and heat source, and failing to validate the thermal-hydraulic feasibility of the design.

To address these limitations, an advanced design tool was developed with the Grenoble District Heating Company (CCIAG). This tool integrates graph theory algorithms, mathematical optimization models, and thermal-hydraulic simulations to enable the optimal design of district heating networks. Starting from road and building maps, prospective energy data, and production scenarios, the tool identifies optimal connection points for prospective users, reduces the road map to limit the solution space and accelerate optimization computations, and formulates and solves the network design optimization problem to determine the optimal layout, including pipeline lengths and diameters, connected heat plants, and substations.

The tool incorporates strategic and operational constraints, such as maximum flow velocities, thermal transport losses, and penalties for crossing specific infrastructures like bridges and tramways. It offers flexibility in optimization criteria, including minimizing CAPEX by optimizing routes and connections, or maximizing energy density by increasing energy transported per unit network length. Once the layout is determined, the tool allows partial redesign, enforcing redundancy through network meshing to ensure supply security.

A key feature of the tool is its ability to interface with a network-level thermal-hydraulic simulator to validate operational assumptions made during optimization. Through an iterative process, the tool ensures that heat demand in each scenario, precisely accounting for thermal losses, realistic hydraulic configurations and realistic heat exchanger operation at the substation level.

The proposed approach has been validated through simulations on real-world cases, demonstrating its relevance, operational efficiency, and notable performance improvements compared to commercial alternatives. This automated district heating network design tool has proven effective in optimizing performance and reducing costs. Future developments will focus on reducing computation times by improving the solution space reduction methods and industrializing the tool for broader deployment by CCIAG.

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Cooling, Sep 2023, Beijing, China.

Session 8: Planning of DHC networks 2

9 September: 09.00-10.30 - Grûm 9

Session Chair: Anna Volkova. Tallinn University of Technology, Estonia

Achieving efficient district heating targets in a Croatian network: heat source mapping and techno-economic scenarios analysis

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In the city of Vukovar, Croatia, a small district heating (DH) network is in operation, with a production of about 13 GWh/y and a length of 5.5 km. The system is operated with variable supply temperatures (up to 95 °C in winter, down to 65 °C in summer). The main production plant consists of three gas boilers. In 2019, a first step towards decarbonising the system was undertaken with the installation of a solar thermal field (flat-plate collectors, total aperture area 850 m²). The solar field contributed about 3% of the total heat production in 2022. To comply with the European definition of efficient DH, the share of renewable energy sources (RES) and waste heat (WH) in the system must be significantly increased. This study explores the possibilities to decarbonise this system by mapping and assessing possible RES and WH opportunities that could be integrated into the network. An aggregate simulation model, developed in python and based on hourly energy balance calculations, is employed to analyse decarbonisation scenarios in detail. The model accounts for thermal losses, calibrated using real operational data, and allows for the comparison of different dispatch strategies for prioritising heat sources. The considered solutions include low-temperature WH from supermarkets, the expansion of the solar field, and the addition of a heat pump (HP) utilising the nearby Danube river as a heat source. For the solar field, the model has been specifically calibrated using available monitoring data to ensure accurate performance representation. Furthermore, a parametric analysis is conducted to evaluate the optimal size of a potential thermal storage unit, aimed at enhancing system flexibility and efficiency. Scenarios are examined from both technical and economic perspectives. Under the considered conditions, the river HP is expected

to play a major role, thanks to its easily scalable size. At the same time, a careful balance between HP sizing and operation periods is required in order to achieve both the desired RES share and an acceptable levelized cost of heat (LCoH). Simulations show the feasibility of reaching a 50 % RES share (related to the 2035 efficient DH requirements) roughly tripling the solar field size, installing a < 1.5 MW HP and adding a 5 MWh thermal storage. Even excluding operation during the coldest month (achieving a seasonal COP > 3) and prioritising solar field, the HP can operate for > 4000 h/y, yielding a LCoH compatible with current heat tariffs.

References

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Review of tools and methods to identify excess heat potentials in district heating

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Utilizing excess heat for district heating has been shown to be relevant as part of the decarbonization of energy system, as this integration allows for a more efficient use of energy. Excess heat for district heating can come from a range of different sources, such as industrial processes, datacenters and Power-to-X. The potential for excess heat varies depending on local conditions, and therefore a range of different methods and tools have been developed and used for a range of studies on different geographical scales. To identify tendencies in these methods and tools for identifying excess heat potentials, a review of methods and tools is presented. The review only includes peer-reviewed publications indexed in Scopus that have afterwards been sorted and categorized by the authors. A total of 196 publications are included in the review, dating from 1988 to 2024. The different publications are categorized based on different aspects, such as the source of the excess heat included, year of publication, the scale of the study, and the principal method used, so that general tendencies can be identified. Using statistical data for the identified relevant papers, as well as discussing selected individual papers methods, the review finds that there is an increasing number of publications within this field, and that there historically has been a nearly sole focus on industrial processes, whereas new types of excess heat sources, such as datacenters and

Power-to-X facilities, are receiving more and more attention within research. Most of the studies have employed types of energy system analyses to identify potentials for excess heat, with a smaller part utilizing Geographical Information Systems. Likewise, the study also shows that most studies are from authors located in Europe and China, with a majority of papers also analyzing potentials in Europe and China.

Innovative financing mechanisms for sustainable district heating development

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Since the late 19th century, district heating (DH) has been deployed at a commercial scale. Globally, DH covers 9% of final heating needs in buildings and industry (IEA, 2024), while Europe is at 13% market share (Mathiesen et al., 2023). By 2050, Europe has the potential to reach 25-48% market share of DH (Billerbeck et al., 2024; Mathiesen et al., 2023). Averaging over the last century, the deployment growth of DH was around 1%-point/decade. Reaching 2050-potentials means accelerating this growth to 1%-point per year or every second year. Until 2045/50 up to 2 trillion Euros would be needed for a Europe-wide rollout of DH. This is a tremendous task for the DH community. And a tremendous opportunity for funding providers. Both may benefit from getting to know each other better. Our study bridges the investor- and DH communities by analysing and interpreting financial frameworks for DH.

Building on an extensive literature review (200+ pieces of peer-reviewed and grey literature) and interviews with 31 experts, we identify financial frameworks and data (e.g. internal rate of return-requirements and costs of capital). The impacts of these financial frameworks are analysed for a high-resolution city-case in the TIMES model. A series of analyses are conducted to determine impacts of financial frameworks on investor- and policy-relevant aspects. Including CO2 emissions, fuel mix, system cost, cost of capital thresholds and internal rate of return.

Preliminary results indicate that brownfield (i.e. already-existing) DH fits well within the infrastructure asset class: a stable, low-returns, long-term investment. Exceptions to this rule shows that lacking regulation and uncertain end-user base means that DH is considered a riskier investment in UK than in Denmark. Greenfield DH (new DH systems) tends to be considered riskier and may face higher costs of capital initially. This may pose challenges to reaching the deployment-potentials of 25-48% market share.

Derisking, broadly divided into design- and operation phases, is key to attracting funding and reduce costs of capital. The design-phase can be derisked economically by delegating risk to public entities through e.g. blended finance (Popovic et al., 2024) or by access to low-cost capital like the Danish special purpose credit. Regulatorily, derisking can be enforced through zoning or phase-out of competing heat sources. The operation phase corresponds to the less risky brownfield-systems. Here, derisking can focus on managing the more "classical" operational expenditures and revenues, e.g. long-term contracts, diversification and externally through stable and long-term regulation.

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Transitioning from high-temperature to low-temperature district heating: the evolution of the energy master plan at UZ Leuven Campus Gasthuisberg

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The University Hospital Campus in Leuven (UZ Leuven Campus Gasthuisberg), the largest hospital and research site in Belgium, is undergoing a transition from a high-temperature district heating system to fossil-free, low-temperature and energy-efficient heating and cooling infrastructure.

Historical Context

In 1975 the campus was equipped with a second-generation district heating network operating at 180 °C (superheated water, 42 MW, ca. 6,3 km pipe length) for campus-wide heating and local steam production. This high-temperature network ensured reliable heating for the entire campus.

Energy Masterplan

In 2007, UZ Leuven, in collaboration with engineering firms Ingenium and Deerns, developed an initial energy master plan to modernize the existing heating and cooling infrastructure and to enlarge the infrastructure to serve the planned campus expansion. This original master plan focused on introducing ground water heat pumps (ATES), combined with a campus-wide fifth-generation thermal grid to connect each building cluster to the ATES-system (realization in progress). Peak heat production would still be supplied by the campus district heating network. The plan aimed a step-by-step reduction of the temperature of the district heating network, achieving a temperature of 110 °C today.

Evolving energy policies and the need for decarbonization necessitated a reassessment of these principles. An updated master plan study in 2021-2023 by UZ Leuven and Ingenium investigated different fossil-free scenarios, both with centralized and decentralized heat and cold production options. This resulted in a new Energy Master Plan, based on building renovation, the further roll-out of the fifth-generation thermal grid, more heat pumps and a step-by-step conversion of the campus district heating grid and other existing energy infrastructure to fossil-free low-temperature systems.

Lessons learned and view from the energy system designer

An energy master plan is not a static document. During the almost 20 years of energy master planning, step-by-step realization and many more years before complete realization, the Energy Master Plan encountered changing insights, technical and practical issues, complex and constantly changing building energy legislation and many more. This process has provided us with valuable lessons and insights that can facilitate the process of converting other high-temperature (campus) district heating systems.

Session 9: Efficiency improvements, modernisation and RES integration 1

9 September: 09.00-10.30 - Trueno 8

Session Chair: Jan Eric Thorsen, Danfoss A/S, Denmark

Natural circulation and other measures to ensure heating supply to buildings connected to district heating in the event of electrical grid blackout

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Due to the increasing frequency of power outages as a result of severe weather conditions and the synchronization of the Baltic countries electricity frequency with continental Europe, the focus has been on ensuring the security of energy supply. Most of the vital functions of modern society rely on the availability of electricity, including the heating systems of buildings. Security of supply is especially important for residential buildings. Approximately 70% of apartment buildings in Estonia use district heating (DH), in the Nordics it exceeds 80%. EU energy efficiency and energy efficiency of buildings directives stipulate that share of renewable energy sources in the energy mix should increase and that the EU should use more of DH where possible. Given the geopolitical shifts and the stochastic nature of renewables, this topic is highly relevant therefore investigating DH and heating substation behavior during a power outage.

In the event of a blackout, the regulations stipulate that the cogeneration plants are switched to "island mode", minimizing heat and electricity production while maintaining the functionality of DH circulation pumps. In these certain cases a positive amount of energy usage is required from consumers connected to district heating in order to maintain the vitality of the DH operation system.

Considering the research conducted in Sweden it is evident that turning a power failure natural circulation is going to take place in the DH customers' buildings due to the temperature difference and the heat consumption might be withheld. The present study demonstrates that even though the circulation pumps in the heating substation will be stopped whenever the electricity supply halts, circulation in radiator systems will still transfer significant amounts of heat throughout the building. The circulation will occur when water density differences are evoked by temperature variations in the system. Heat will be passed from DH water to the heating substations heat exchanger if the valves are fully open. Several physical experiments have been performed with heating simulating an electrical grid blackout event. The results reflect on pre-set hypotheses depending on the welfare of the building's heating system.

Additionally, the research examines the options for continuing the heat supply after a power outage and analyzes the function of heat substation in that matter. A set of recommendations are compiled to provide advice amongst DH utilities and owners of customer buildings in Baltic countries.

Optimizing low-grade waste heat recovery for district heating: A case study of a steel plant in China

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The steel industry accounts for more than 10% of global energy consumption and is a key area for energy conservation and emission reduction. China's steel industry is mainly concentrated in the northern regions, where utilizing low-grade waste heat for heating nearby areas is one of the important strategies to improve energy efficiency and reduce dependence on traditional fossil fuels. However, in the actual process of waste heat utilization, there are issues such as insufficient utilization, low efficiency, and difficulties in implementing solutions. It is urgent to improve these issues in order to promote the development of industrial energy conservation and clean heating.

This study focuses on a steel plant in Changzhi, Shanxi Province, China, with an annual production capacity of 3 Mt. Based on extensive field measurements and data analysis, the steel plant's waste heat characteristics and local heating requirements are thoroughly evaluated. Furthermore, to address the existing issues of incomplete utilization and low efficiency in the current waste heat utilization, a new phased waste heat utilization scheme is proposed, which includes: (1) replacing steam-heated water with slag flushing water for heating; (2) substituting steam with slag flushing water for heating; and (3) utilizing low-grade waste heat from flue gases and cooling water for district heating in nearby areas.

The analysis estimates a total waste heat capacity of approximately 328.78 MW, distributed among exhaust steam (50%), cooling water (30%), and flue gases (20%). The phased scheme incorporates technologies such as plate heat exchangers, absorption heat pumps, and electric heat pumps, delivering significant economic advantages. Each phase achieves costs below 2.82 USD /GJ, with phase 1 being the most cost-effective at 1.69 USD /GJ, significantly lower than the 8.7 USD /GJ for conventional gas heating.

This study addresses critical challenges in industrial waste heat recovery, offering practical solutions to enhance energy efficiency and support the sustainable development of district heating systems.

Integration of decentralized renewable energy sources into DHC systems: Technical challenges and experimental solutions

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District heating and cooling (DHC) systems have been widely established to provide a cohesive structure for integrating different types of renewable energy sources (RES). Integrating RES with conventional heat generation technologies presents significant technical and operational challenges. There is a need to study how can we overcome challenges confronted by such integration, including the technical difficulties associated with the exploitation of individual RES.

With the transition to next-generation district heating (DH) systems, it is crucial to understand their adaptability to future designs and standards. Individual integration of RESs may lead to new challenges related to variable flow rates, return temperature fluctuations, pump control, heat exchanger efficiency, local storage integration, peak load management, and hydraulic balancing of the building circuit with the DH network. The goal of this work is to review how experimental investigations can address these challenges to successfully integrate decentralized energy sources (solar thermal, geothermal, etc.) into DH systems. This paper systematically reviews the impact of key operational parameters (e.g., inlet water temperature, pressure drop, flow rates, supply temperatures) and environmental parameters (e.g., solar irradiance, ambient temperature, wind speed) on system performance. The focus is particularly on the experimental studies that have successfully replicated phenomena difficult to capture in generic simulation models, such as internal control strategies of commercial components, delayed and inaccurate implementation of set points, and the behavior of the thermohydraulic system.

A specialized research laboratory is currently under development to study the impact of both operational and environmental parameters on the thermal output of building-integrated solar thermal systems. The proposed experimental setup includes three types of solar thermal collectors, two thermal energy storage tanks, a heat pump, a district heating emulation unit, and a control system. The main purpose is to investigate how bidirectional heat transfer stations, heat generators, consumption, and storage can be connected in different ways. These distinct connections have different influences on the district heating network operation that require more analysis and understanding.

This study demonstrates the importance of experimental research in transforming district heating and cooling systems. The laboratory structure is presented to foster collaboration with other researchers.

Deterministic optimisation of district heating network retrofit to reduce supply temperature

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District heating networks are essential to decarbonize heating as long as they use low-carbon energy sources. On many existing networks, this entails operating with lower temperatures. Reducing the operation temperature of a district heating network involves the retrofit of several assets. In the literature, many studies deal with buildings retrofit, others with substations resizing; however, few tackle the distribution part. Indeed, a reduction in temperature results in an overall increase in mass flow rates and thus velocities, exceeding the recommended limit in certain pipes.

Many solutions are possible, including distributed storage which can locally reduce the mass flow rate in pipes by shifting heat demand peaks to off-peak time. As many different sizing, localisations and operation schemes are feasible for those storages, an optimisation approach is required to define the most appropriate configuration. This distributed storage optimization approach, however, necessitates a holistic view of the networks, which is highly challenging due to: (i) the large number of variables required to describe the topology, (ii) the complexity of modelling non-linear phenomena, and (iii) the need to account for dynamic behavior.

Meta-heuristics are generally used to address these problems. The quality of the optimum found with meta-heuristics depends on the quantity of explored configurations and are often time-consuming. Deterministic approaches seem to be a yet unexplored reasonable alternative in spite of the complexity of the equations. Few deterministic optimisations of district heating network consider the topology, thermo-hydraulic variables and a dynamic resolution. Furthermore, among them, some do not consider storages, others reduce time horizon to several stationary states, and the last ones resort to linear formulation through exploiting concurrent simulation outputs.

This work proposes an optimisation method for the retrofit of district heating networks including the topology, thermo-hydraulic variables and a resolution over several chronological time steps. The study case is an existing district heating network facing bottlenecks in pipes due to the supply temperature reduction. The solution considered is the integration of distributed storages. The explored strategy is based on dynamic non-linear optimization.

Session 10: Digitalisation of DHC: optimal control 2

9 September: 11.00-12.30 - Auditorium

Session Chair: Alice Dénarié, Politecnico di Milano, Italy

Demand side management for peak shaving in district heating systems using model predictive control at substation level

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Global heat demand at the level of District Heating (DH) systems is typically characterized by peak load periods in the morning and the evening. This causes the starting-up of peak production plants, which are generally the most costly both economically and environmentally. It would then be beneficial for DH-network operators to be able to shift demand from peak to off-peak periods. However, they face challenges in managing space-heating demand, as they lack direct control over heating circuits. They can only adjust heat power at substations, where space-heating and Domestic Hot Water (DHW) demands are aggregated. Furthermore, operators lack access to indoor temperature data, as most buildings are not equipped with connected thermometers.

This paper presents a methodology based on Model Predictive Control (MPC) to enforce a load reduction plan at substation level, while minimizing thermal discomfort for inhabitants. The associated work is part of a partnership between CEA and CCIAG, the operator of the Grenoble DH-network in France. The MPC regulates the thermal load supplied to the substation to maintain an acceptable indoor temperature during nominal phases, and constrains heat power below nominal values during load reduction phases. Post-loading phases mitigate heat power overshoot when returning to the nominal phase, and pre-loading phases allow slight overheating to reduce peak demand further.

The MPC strategy is built upon a R1C2 building model, which captures the two key forms of thermal inertia: that of the indoor air and the heating circuit. It is calibrated using only power and temperature data from substations. The

R1C2 model is used in simulation to compute the initial states using observed exterior temperature, solar irradiance, and actual heat power. It is also used within a Mixed Integer Linear Programming (MILP) model, either to find the maximum load reduction level, or to compute heat power setpoints that minimize indoor temperature deviation from a target value, using weather forecasts as input.

The methodology is validated through offline simulations on three buildings in Grenoble, constructed in 1915, 1970 and 2012, over four daily scenarios and a full heating season. Real systems are emulated using a R5C5 simulation model, calibrated with historical indoor temperature data. Results show that the MPC effectively maintains indoor comfort while achieving notable peak load reduction. However, further work is needed to ensure reliable and robust DHW demand management during load reduction phases, addressing potential disaggregation errors.

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Demonstration of peak shaving through combined demand response and supply temperature control

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District heating networks intrinsically have a lot of thermal energy flexibility contained within the building stock and the distribution network. This flexibility can be activated through demand response and supply temperature control respectively. This flexibility potential is therefore a valuable resource for coordinating the supply and demand of energy, within and beyond the thermal energy sector. It can be used for e.g. peak shaving, maximizing integration of renewable and waste heat sources, and reduction of distribution temperatures. In general, smart flexibility management can lead to increased sustainability and reduced cost for the operation of the energy system.

In this work, a supervisory control system for optimizing the operational performance of district heating systems has been developed. It is aimed towards real-time high-level prediction and coordination of the flexibility assets across the thermal distribution chain based on thermal-hydraulic modeling. Recently, an improved version of this supervisory control system has been tested in an isolated branch of the district heating network of Brescia, Italy. In this test, the objective was to reduce heat load peaks by a combination of building demand response and network supply temperature control. In this conference contribution, the control methodology, testing approach and evaluated test results will be presented.

Data-Driven cooling demand forecasting for district cooling operation

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The global adoption of district cooling is increasing rapidly and extending beyond traditionally hot climates due to rising temperatures, urbanisation and the environmental benefits of central cooling. Cooling currently consumes around 20% of global electricity consumption, a figure that is forecast to increase significantly. Efficient operation of district cooling depends on accurate demand forecasting, which is crucial for both operational optimisation and long-term strategic planning.

At an operational level, accurate short-term forecasting (from hour up-to 14 days ahead) enables efficient management of cooling systems. For example, operators can dynamically adjust the number of active chillers and optimise supply temperatures to precisely match fluctuating demand, minimising energy waste and operating costs while ensuring reliable service. Real-time adjustments based on accurate predictions reduce peak energy consumption and improve the overall efficiency of the system. Reliable long-term demand forecasts (months) are also essential for long-term planning in order to make informed decisions about infrastructure development, capacity expansion and resource allocation. Accurate long-term forecasts enableutilities to negotiate favourable long-term electricity contracts, mitigate price volatility and secure a cost-effective energy supply. Forecasting is also critical for planning preventive maintenance, minimizing downtime,and ensuring continued reliable operation. Forecasting future demand enables proactive planning and investment, reducing the risk of capacity shortages and ensuring the long-term sustainability of the system.

%Significant investments in district cooling are evident in regions like the UAE, Saudi Arabia, and Asia. Sweden, with Europe's largest market share and steady growth since the 2000s, exemplifies the long-term viability of this technology. However, the need for sophisticated forecasting methodologies remains a key challenge.

This paper presents a novel online short-term forecasting method for cooling demand. Its core contribution is identifying the key variables impacting cooling demand, thereby improving the accuracy of forecasting models}. The proposed approach includes real-time updates so that the model can dynamically adapt to changing conditions and improve accuracy over time. Both physical (e.g., ambient temperature, humidity) and social (e.g., occupancy rates, behavioral patterns) factors are analyzed to determine their influence on cooling demand, which are then used as inputs. The accuracy of the method will be demonstrated through its application to a real-world district cooling system.

Using machine learning to optimise district heating operations

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The energy transition requires a comprehensive conversion of our energy systems, particularly in the area of heat supply. District heating is a key technology for this. To ensure that heating networks continue to operate efficiently and in an environmentally friendly manner in the future, they must be modernized and optimized. The ongoing project ML4FW aims to use machine learning (ML) to improve the operation of district heating systems by optimizing the control parameters in substations. By lowering system temperatures, but above all the return temperatures, energy losses can be reduced, making the heat supply more sustainable overall. In the project, a ML-Ops pipeline is being developed to optimize the operation of substations in district heating systems. The pipeline collects real-time measurement data from the buildings' control systems, which is provided via the infrastructure of a housing association involved in the project and stored in a central database. Based on this data, an optimization framework automatically calculates the best control parameters for the substation. Integrated anomaly detection monitors the system and adjusts the model if necessary to react to changing conditions. The optimized parameters are then fed back to the control systems and applied directly during operation. This dynamic adjustment improves energy efficiency, reduces losses and lowers operating costs. The project will be tested in practice in five residential buildings during the winter period 2024/2025. These field tests offer the opportunity to validate the ML-supported optimizations under real conditions. The primary aim of the project is to demonstrate the applicability and effectiveness of ML methods for the automatic and continuous adaptation of control parameters to changing operating conditions in real district heating substations. Calculations show that optimizing just a few house substations in a district heating network can lead to significant cost savings by lowering the return temperatures. In addition, a more efficient return temperature improves the transport capacity of the networks and creates space for new connections without having to reinforce the network. By improving the efficiency of the heating networks, the project not only reduces operating costs, but also contributes to achieving climate targets by reducing energy consumption and CO_2 emissions. Since in most cases the installed house stations are supplied and installed with standard settings for the control parameters, adjusting a small number of control parameters can have a significant effect on the entire district heating system.

Session 11: Efficiency improvements, modernisation and RES integration 2

9 September: 11.00-12.30 - Grûm 9

Session Chair: Ivan Verhaert, Antwerp University, Belgium

Hydraulic and thermal effects of different building refurbishment strategies in district heating networks

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In line with Göttingen's climate plan, a collaborative initiative was launched in 2022 by local research institutions to develop sustainable heating solutions for the north campus of Göttingen University. This initiative focuses on transforming the existing district heating network by integrating renewable energy and waste heat into it, as well as storing thermal energy underground. A key aspect of the transformation is refurbishment of campus buildings. The primary challenge addressed in this work is, therefore, determining the priority order for refurbishing these buildings from hydraulic and thermal perspectives of the district heating network.

The investigation utilizes a hydraulic model, which requires network topology data and building heating demands. By applying continuity and momentum equations in matrix format, and using the optimization tool "Gurobi," the model outputs the pressure at each node and mass flow rate for every branch. Similarly, a thermal model, sharing input requirements with the hydraulic model and focusing on specific matrix equations, provides data on node temperatures and supplied heat power, using "Matlab" for computations.

This study examines various refurbishment scenarios on the Göttingen north campus: renovating the farthest buildings from the Combined Heat and Power (CHP) plant, those nearest to it, the most energy-consuming buildings, and refurbishing all buildings. The findings indicate that, hydraulically, prioritizing the farthest buildings from the CHP plant yields the greatest benefit. Refurbishing all buildings without prioritization is the second-best option for hydraulic benefits but may be less practical. From a thermal perspective, different strategies show similar outcomes.

This research may help energy planners and key stakeholders to make informed decisions regarding effective refurbishment strategies for campus infrastructure.

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Improved district heating return temperatures by cascading concepts

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As the focus on the performance of district heating (DH) systems intensifies, this study explores three cascaded substation concepts to assess their potential for reducing the DH return temperature at the building level substation.

A lower DH return temperature is crucial for lowering the DH flow temperature to optimal levels, thereby enhancing system efficiency, which is a key feature of 4th generation DH.

Within the ARV project (https://greendeal-arv.eu), DH substation concepts have been evaluated, including parallel, two-stage, aftercooling, and mid-cooling configurations, with the parallel concept serving as the baseline for comparison.

The analysis, based on annual simulations, covers generalized parameter combinations to demonstrate the potential for DH return temperature reduction across the different substation concepts in comparison to the baseline. Additionally, the impact of various climate profiles is explored, represented by the cities of Copenhagen, Helsinki, Paris, and Rome.

The aftercooling and mid-cooling concepts have a reduction potential in annual

DH return temperatures by 4-9°C for 4th generation DH operations, compared to the parallel system.

References

Related work:
https://www.sciencedirect.com/science/article/pii/S036054422400522X

Mitigating the hidden cost of electrifying heat: A case study using solar and thermal storage to achieve a zero-emission campus while minimizing electric grid demand impact

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This study investigates the feasibility of achieving carbon neutrality in campus heating through integration of on site PV or solar thermal and thermal storage systems. Using a simulation case study based on a real federally owned campus in Ontario, Canada, various scenarios were explored to assess their potential to meet Canadian 2050 net-zero emission targets while minimizing electrical demand. Results indicate that multiple scenarios employing a combination of PV, solar thermal, BTES, and PTES on a district energy system were capable of achieving carbon neutrality. However, variations in annual consumption, peak demand, and land use highlight the importance of considering trade-offs of multiple metrics in evaluating the feasibility of net-zero emission campuses.

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Innovative methodology for profiling foam density: non-destructive X-ray microscopy (XRM) approach

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Pre-insulated bonded (PIB) pipes are widely used in district heating systems, relying on rigid polyurethane foam (RPF) for thermal insulation and structural support. Various studies have highlighted that the foam layer critically impacts pipe performance and durability. To meet industry standards, manufacturers are required to maintain a minimum foam density of 55 kg/m³ as specified by EN 253. However, the pressures during the foaming process result in non-uniform density distribution across the pipe's cross-section, varying from the interface with the steel medium pipe to the high-density polyethylene casing layer. This study introduces a novel, non-destructive methodology utilizing nanoscale X-ray Microscopy (XRM) to precisely map RPF density distributions. Traditional methods, such as liquid displacement and cut-and-weigh techniques, often suffer from inaccuracies and challenges related to sample preparation. In contrast, the proposed XRM approach provides high-resolution imaging, revealing significant density gradients and heterogeneities not detectable with conventional methods.

Four XRM data acquisition techniques were evaluated—3D rotational, single-shot 2D, and 2D stacking—focusing on their time efficiency and accuracy. While the 3D approach offered superior resolution, it was computationally intensive. Data augmentation and calibration enhanced the performance of 2D methods, achieving comparable accuracy with reduced acquisition times. Validation against traditional techniques confirmed XRM's superior precision and its ability to capture density variations caused by the foaming process. This methodology enables improved characterization of RPF in PIBs, offering insights into degradation mechanisms and aiding quality assurance. The findings have broader implications for advancing material research and industrial applications of composite foams. Future work will focus on refining algorithms and expanding the technique's application to other materials and contexts

Session 12: Geothermal DHC

9 September: 11.00-12.30 - Trueno 8

Session Chair: Phil Vardon, TU Delft, the Netherlands

Status of the VITO deep geothermal project in Mol – Donk (northern Belgium)

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In October 2023 VITO invited experts to discuss future scenarios for VITO's geothermal facilities in Mol. VITO launched the development of the facilities end 2009 on the assumption that deep geothermal energy can make an important contribution to the energy transition. To verify whether this assumption is correct, the project aims to provide information and data on:

- The geothermal potential of the Lower Carboniferous Limestone Group [1],
- The technical and economic feasibility of deep geothermal energy,
- The technical and non-technical challenges for the development of deep geothermal energy,
- The social and ecological potential of deep geothermal energy in the Flemish energy system.

From the start, it was VITO's intention to use the geothermal facilities to supply heat to the district heating network that is serving the research campus of SCK. CEN – VITO and a nearby residential area, as well as to new developments in Mol and Dessel.

Over the years, the project generated important data on e.g., the Lower Carboniferous reservoir, the chemical composition and NORM-content of the formation fluid, the environmental impact of deep geothermal and the viability of geothermal heat delivery and co-generation [2,3,4]. However, VITO did not yet succeed in running the plant at its design capacity. The main question about the plant's operability is the seismic activity during the extraction of geothermal heat. Since the start of heat production in December 2019, two felt earthquakes were recorded [5]. These two seismic events resulted in a red-light situation according to the traffic light safety procedures and requested for long-term suspension of the operations and an in-depth analysis of the situation.

Based on the current understanding and after consultation with multiple partners VITO identified actions to reduce this seismic risk. In November 2023, VITO's board of directors gave permission to adjust the installation and to implement a predictive traffic light protocol with a view to new production tests in winter 2024 - 2025. In addition, the results of a 3D seismic survey are anticipated to better understand the geothermal reservoir's structure and the origin of the seismic activity.

It remains VITO's ambition to use the geothermal facilities in Mol as a test site to investigate effective integration of deep geothermal in next-generation district heating networks and to convert the knowledge and experiences gained into tangible value propositions for all stakeholders. Central to this ambition is stable heat delivery in a way that is acceptable for the stakeholders.

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Enhancing waste heat integration into district heating through geothermal storage and heat pumps: risk and techno-economic assessment

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The decarbonization of district heating (DH) systems requires innovative solutions to integrate renewable energy sources and low-grade waste heat (WH). However, low-grade sources present challenges such as temperature mismatches, fluctuating availability, seasonal demand variations, as well as economic and regulatory barriers. This study investigates (i) a hybrid configuration combining geothermal energy storage with heat pump (HP) substations to enhance WH utilization in existing DH networks and (ii) general risks associated with this type of system, including techno-economic aspects (e.g., uncertainties in ground conditions and future electricity prices) as well as regulatory aspects (e.g., possible changes in waste heat classification and supporting policies).

The chosen configuration is analyzed through a simplified techno-economic modeling framework developed in Python. The framework enables parametric evaluation of system efficiency, heat losses, HP performance, and levelized cost of heat (LCoH), while providing rapid scenario analyses for DH planners, utilities, and investors. An open-source borehole model is adapted to simulate the geothermal component, exploring various depth conditions. Hybrid HP configurations are modeled with approximate COP functions, capturing temperature-dependent performance impacts.

A risk analysis is also carried out. A likelihood/gravity approach is adopted for selected risks. The aforementioned techno-economic model is used to assess the economic impact of the most significant uncertainties (e.g., ground temperature), with a preliminary risk level analysis. Risk management strategies are also discussed (e.g., including safety margins in cost estimates or sharing risks among multiple stakeholders).

The model is applied to the Bolzano district heating system, an Italian network with a yearly heat production of approximately 130 GWh and supply temperatures ranging from 65°C to 100°C. The study considers examples of industrial waste heat at different temperature levels, demonstrating how ground storage improves WH utilization and affects overall costs.

References

This work is part of the InteGradeDH project, funded under Annex XIV of IEA-DHC.

Design of closed-loop geothermal single wells for heating applications

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Geothermal energy is a well-established solution for covering the heating demand in industrial and district heating applications. Among these, geothermal closed-loop single wells (GCLSW) stand out as a versatile and low-risk option, as they can be deployed in a broad range of underground settings and have low risk to induced seismicity. While GCLSW systems generally yield lower energy output compared to the most common open-loop geothermal systems (such as the geothermal doublets), the latter are only viable in subsurface environments with sufficient permeability and rock continuity—conditions that are not always met. When open-loop systems are not feasible or overdesigned for the energy demand, GCLSW becomes an option that must be considered and properly designed. Key input parameters include the energy demand, the well geometry (horizontal – vertical well), the rock thermal properties, and the temperature gradient. Together these parameters determine the optimal design specifications of the system: total well length, circulating flow rates, and injection temperatures. This paper presents a methodology that look for optimizing the cumulative coefficient of performance (COP) of the system to determine the optimal design parameters for an existing well in Mol, Belgium. The methodology leverages numerical tools for simulating the coupled heat transfer between the rocks and the wells and consider the gross produced heat, pumping energy, and energy demand for computing the COP. The approach aims to enhance the accuracy of performance predictions and optimize system configuration for diverse well geometries in a heterogeneous geological setting.

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Borehole heat exchanger field layout optimization for sustainable district heating and cooling networks

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The European Union has committed to achieving greenhouse gas neutrality by 2050 [1], and Germany has declared its intention to reach this goal by 2045 [2]. To achieve greenhouse gas neutrality, processes that utilize fossil fuels need to be drastically reduced. Heating and cooling constitute the largest energy consumption sector in Germany, accounting for about 50% of final energy consumption [3]. Currently, about 80% of district heating and cooling (DHC) supply comes from fossil sources [4].

Geothermal energy, a low-carbon technology, is crucial for accelerating the energy transition in the building sector and reducing the carbon footprint of DHC. One method of harnessing geothermal energy is through shallow geothermal probes. The efficient design of borehole heat exchanger (BHE) fields, which involves optimizing the positioning and number of probes, is critical for maximizing heat transfer. However, the design guidelines in Germany's VDI 4640 standards are limited to rectangular BHE layouts with a maximum capacity of 30 kW and up to five probes. For DHC applications, which require significantly higher capacities, these guidelines fall short. Furthermore, real-world projects often involve irregular polygonal areas, necessitating customized designs to ensure efficient and cost-effective heat extraction.

Aiming to enhance existing methods for rectangular BHE fields, we utilize statistical optimization to optimize the design of BHE fields for irregular polygonal areas within reasonable computation times. Our study combines analytical g-function methods based on a simplified resistance-capacity model with particle swarm optimization. This approach utilizes three key inputs: geometry, hourly-resolution heating/cooling demands, and thermal response test data.

The method optimized BHE arrangements beneath artificial lakes connected to a 4th-generation district heating network, where the lakes enable thermal regeneration of the BHEs. Results demonstrate that the polygonal area requires 374 probes spaced 6.87 m apart to meet specified demands. For comparison, a regression model based on VDI standards extrapolated values for larger borehole fields under the same demands, resulting in 396 probes using conventional design practices. This represents a 5.6% reduction in probes compared to VDI standards. Since the cost and time required to construct large-scale BHE fields are nearly proportional to the number of probes, this method also reduces both construction time and expenses.

In conclusion the optimization algorithm determines the optimal number and arrangement of BHEs in irregular polygonal areas within reasonable computation times, enhancing construction efficiency and supporting the development of BHE fields.

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Session 13: DHC+ Student Award presentations

9 September: 14.00-15.30 - Auditorium

Session Chair: DHC+

The DHC+ Student Awards will shine a spotlight on exceptional research by bachelor's, master's and PhD students in the field — an inspiring initiative by the DHC+ Platform, one of our valued sponsors.

Performance of a prototype substation for 5th generation district heating and cooling networks

Gianni Martinazzoli
Universita degli Studi di Brescia, Italy

Data-driven approach for diagnosing inefficiencies and optimizing district heating networks

Sajedeh Roustaei
Politecnico di Milano, Italy

Systematic assessment of scientific case studies on optimization measures – A value-added approach for district heating operators?

Anna Vannahme
TU Munich & Ingolstadt University of Applied Sciences, Germany

Session 14: Digitalisation of DHC: fault detection and diagnosis

9 September: 14.00-15.30 - Grûm 9

Session Chair: Michele Tunzi, Danish Technical University, Denmark

Exploiting synergies of data-driven and model-based approaches for leakage localization in district heating networks: Application of improved approaches

Dennis Pierl, Julia Koltermann, Kai Vahldiek, Bernd Rüger, Kai Michels, Andreas Nürnberger, Frank Klawonn

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Leakage detection and localisation in District Heating Networks (DHNs) remains critical to maintain operational reliability and minimise economic and energy losses. Three different data-driven and model-based approaches have been proposed to solve this problem and delivered promising results [1]: an approach for detecting and evaluating leakage-induced pressure waves (PWS), a numerical-analytical approach based on a district heating network model (MBSE) and a purely data-driven approach (ML). All these approaches rely on current measurement data from the network, i.e. pressure, flow rate and temperature. These approaches have been continuously improved ever since. The MBSE approach, which was previously based on a purely hydraulic DHN model, has been extended to include the thermal model equations, which allows better consideration of the available temperature measurement data. This temperature measurement data is also used by the ML approach in order to estimate the resulting potential for improvement with better preselections. These approaches are applied to the same historical measurement data of real DHN leakage events used in a previous study to evaluate the performance enhancements. First, the approaches are evaluated independently to quantify their individual improvements. Subsequently, as previously demonstrated, their interoperability is examined to exploit potential synergies to narrow down their search space and effectively locate leakages. The results are compared to the baseline established in the aforementioned paper, highlighting the impact of the methodological extensions on the overall leakage localisation performance. By combining the refined individual results of the three approaches, this study not

only emphasises the respective strengths of each method, but also underlines the importance of combining their capabilities to achieve a robust and efficient leakage localisation framework for DHNs.

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From time series to images: exploring convolutional and vision transformers for fault detection in district heating

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Efficient and accurate fault detection and diagnosis (FDD) in district heating (DH) systems is vital for ensuring reliability and reducing operational costs and energy losses. In recent years, notable progress in research on FDD in DH systems has been propelled by data-driven methodologies and the availability of sensor data. However, significant challenges remain, such as lacking large, high-quality labelled datasets. Without sufficiently annotated data that spans diverse operating conditions and fault types, developing and validating robust FDD models with broad applicability becomes challenging. Consequently, efforts to standardise and collect extensive high-resolution labelled data are crucial for advancing the field and delivering reliable fault detection solutions in DH systems. While advanced approaches such as machine learning have shown promise in capturing the complex interactions among system components and identifying subtle fault patterns, traditional methods rely on manually defined thresholds or domain-specific feature engineering. In this work, we introduce a transfer learning approach that transforms time series sensor data, such as supply temperature, return temperature, and the difference between the two measurements (Delta T), into two-dimensional visual representations. This transformation enables us to exploit existing large pre-trained convolutional and vision transformer-based models (ResNet, GoogleNet, MobileNet, AlexNet, DenseNet, and ViTs), which excel at hierarchical feature extraction from images. Consequently, transfer learning reduces the need for large datasets. We validate our approach on real-world DH substation data containing faults such as sensor issues, high heat curves, oversized valves, and large secondary leakages. Preliminary results show we can achieve high fault detection accuracy with the models demonstrating robustness to noise and class imbalances while requiring minimal training time. These findings suggest that converting time series data into visual images or shapes can effectively leverage the strengths of large-scale pre-trained deep learning models in an industrial setting. The proposed method could be generalised to various fault detection scenarios and other domains requiring time-series analysis.

Data-driven fault detection and diagnosis in district heating substations and the impact of return temperature reduction

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The efficient operation of district heating substations plays a crucial role for optimizing energy use, reducing carbon emissions and ensuring economic benefits for both utility companies and consumers. This study presents a fault detection and diagnosis (FDD) approach for substations in a German district heating network using automated analysis and visualisation of smart meter data from the primary side of substation through a Python-based evaluation tool. The tool integrates geospatial representation of substations and visualises key performance indicators such as return temperature, hydraulic capacity utilization, and temperature difference. Moreover, the tool also has the option of filtering according to certain metadata information, such as connected load and building type. The filtering can be expanded as required to identify inefficient substations of a certain type.

In order to systematically identify inefficient behaviour of a substation, four recurring patterns have been defined, each associated with potential root causes. These include high return temperatures and both high and low hydraulic capacity utilization, continuous flow rate outside of heating periods, and hydraulic instability. Possible causes such as defective control valves, incorrect controller settings and oversized heat exchangers or control valves are analysed for each fault type. The prioritisation of fault troubleshooting is supported by scatterplot-based segmentation of substations identified as inefficient, considering parameters such as return temperature and connected load. Furthermore, substations with high hydraulic capacity utilization but high temperature differences are identified as hydraulic critical, requiring careful examination before a supply temperature reduction is carried out to avoid undersupply.

A key focus is optimisation potential of reducing return temperatures, which brings considerable benefits for both utility companies and consumers. Lower return temperatures help to reduce energy requirements of circulation pumps, enable allocation of additional hydraulic capacities for integrating potential new customers, increase the efficiency of renewable heat generations (e.g., heat pumps) and minimise thermal losses. The analysis quantifies the impact of eliminating identified faults and shows the potential for improving the overall efficiency of the district heating network. By addressing these faults, consumers can also avoid unnecessary heat consumption in summer, improve regulatory response times, and enhance overall operational security.

Through a combination of automated diagnostics, geospatial visualization, and statistical analysis, this paper underscores the value of data-driven analysis in modern district heating systems. By implementing these methodologies, utility companies can proactively address inefficient substation behaviour, improve operational reliability, and support the transition to more sustainable district heating networks.

Automatic fault detection in DHC systems using hybrid modelling

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Buildings account for 40% of global energy consumption, with 36% attributed to their heating, ventilation, and air-conditioning (HVAC) systems. In district heating (DH) networks, inefficient building-level thermal management can lead to increased peak loads, higher return temperatures, and overall inefficiencies in heat distribution. These inefficiencies are caused by suboptimal control on the one hand and undetected faults or degeneration of components on the other hand. Therefore, optimizing the connected building heating systems is not only crucial for reducing energy consumption but also for improving the performance and sustainability of DH networks.

In order to employ state-of-the-art control methods like model predictive control (MPC) or reinforcement learning (RL), an accurate simulation model is necessary. However, current practice is to use physics-informed (PI) models, which do not take into account the specific conditions in which a system is operating. Moreover, components in the system will start to degenerate, causing their behaviour to diverge from their simulated behaviour. This gap between simulation and reality is called the sim-to-real gap. To correct the simulation for this gap, a methodology is used where the PI model is composed with data-driven (DD) models on the level of the components. This way, the original structure of the PI model, and therefore also its explainability, is maintained.

State-of-the-art research in automatic fault detection in building heating systems employs DD methods to create models that can detect when a component is behaving differently. The main issue for these methods is that labelled data on faulty building heating systems is scarce. Moreover, it is hard to generalize these models, such that they can be universally employed.

That is why this paper proposes a methodology for automatic fault detection in building heating systems based on the architecture of the DD models that correct the PI model to match the current behaviour of the system. Using these DD models, latent space representations of the components can be created and compared, which enable automatic fault detection without the need of a labelled dataset.

Session 15: Technological advances for new and existing networks

9 September: 14.00-15.30 - Trueno 8

Session Chair: Ralf-Roman Schmidt, Austrian Institute of Technology, Austria

TFSB as bedding material in district heating pipe construction - Scientifically proven long-term experience

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Temporary Flowable, Self-Compacting Backfill Materials (TFSB) consist of base material (soil/excavated material and/or soil building material), water and additives (hydraulic and/or layered silicate). They are free-flowing after mixing and are installed without additional compaction in accordance with the technology. For pipe construction, this results in potential for reducing costs, construction time and the conservation of resources compared to the conventional bedding of district heating pipes in sand in accordance with EN 13941: Part 1 and EN 13941: Part 2. Increasing requirements of the circular economy have an impact on the use of sand as backfill material and the handling of trench excavation material and require innovative backfill construction materials.

While TFSB are already used extensively for other pipe- and line-bound infrastructures such as sewer pipes, water pipes or power lines, the bedding material is still a niche application in district heating pipe construction despite the good level of technical research specific to district heating. The reasons for this are of a practical nature. They include the lack of implementation of calculation approaches in static calculation software applications and, above all, the lack of scientifically proven long-term experience in district heating pipe construction using TFSB, especially with regard to axial pipe bedding and re-excavation capability.

In the national research project "FW-ZFSV 4.0", which was completed in July 2024, the authors worked intensively on removing existing obstacles, also together with DH utilities. A key element of the project was extensive research on TFSB-embedded district heating pipes with tests and material tests on a research test section after eight years of operation, development of quality assurance measures suitable for construction sites, using direct and indirect test methods, laboratory tests on TFSB-mixtures, in particular based on recycled materials as base material, and the implementation and validation of IT-supported calculation models based on measurement results from the research test section.

The project results show that district heating pipes can safely be embedded in TFSB in the long term using suitable district heating-specific TFSB-mixtures as well as professional planning and quality assurance in civil engineering and pipe construction. Based on field and laboratory tests on the TFSB research test section, the project results on planning, quality assurance in the construction process and resource conservation are presented. The contents of this article provide an important basis for DH utilities to exploit the potential of TFSB in district heating pipe construction.

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https://www.agfw.de/zfsv

Data pre-process methods enhancing HCA measurement usability

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Heat cost allocators (HCAs) are devices mounted on radiators to distribute the heating consumption among flats and secure fair billing of each user in buildings connected to district heating networks or with central heating systems. In recent years, HCA data has also been utilized for building heating system analysis, fault detection, diagnosis, and optimization. However, certain inherent characteristics of HCAs may limit the effectiveness of directly using HCA data for analysis, such as data truncation and the amount of recorded data points over time. This highlights the importance of pre-processing HCA data before conducting analysis.

This study was conducted in a fully digitized laboratory simulating a multi-story building's radiator heating system with 40 radiators. Each radiator was equipped with a flow meter, temperature sensor, energy meter, and HCA. Data was collected under various operating conditions, including different supply temperatures and flow rates.

The research explores methods to improve the quality and usability of HCA data for analysis. Several aspects were considered: First, an uncertainty analysis of HCA measurements was conducted based on the accuracy of temperature sensors to understand the device's inherent uncertainty. Second, HCA data is often truncated (e.g., recorded as integers), which can impact dynamic analysis. Since the truncation error exhibits statistical properties, Bayesian inference can be applied to estimate the missing decimal values. Third, for radiators with low heat output, HCAs may record sparse data over certain periods. In such cases, probabilistic interpolation methods, such as Gaussian process regression, can be used to estimate missing values. Finally, several representative radiators and HCAs were selected to evaluate the effectiveness of these pre-processing techniques. The after-processed HCA data will be used to estimate the energy consumption and return temperatures for these radiators and be validated by the temperature, flow, and energy meters.

Experimental investigation on the thermal conductivity of alternative bedding materials for district heating networks

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The specific heat losses [W/m] of buried bonded pipes in district heating systems depend on multiple factors, including pipe insulation, operational and soil temperatures, as well as the thermal properties of the surrounding subsoil [1–3]. While European standards define thermal conductivity coefficients for soil under dry, medium-dry, and wet conditions [4], they do not consider variations in soil composition due to the standardized use of natural sands and sand-gravel mixtures as bedding and backfill materials.

However, factors such as regional regulations (e.g., Germany's Substitute Building Materials Ordinance) [5], resource scarcity [6], and the growing adoption of low-temperature networks drive interest in alternative materials [7]. Recycled materials from construction and demolition waste, such as crushed concrete, offer a promising solution aligned with resource conservation and circular economy principles. Yet, their compatibility with existing standards remains a critical concern. Therefore, it is important to improve the knowledge of these materials and evaluate the thermal properties to understand their potential impact on the thermal efficiency of district heating systems.

This paper provides a comprehensive review of current knowledge on the thermal conductivity of common bedding materials and its impact on the specific heat losses and gives a perspective on alternative bedding materials made from construction and demolition waste. Thermal conductivity measurements are conducted according to ASTM standard D 5334-14 [8] with the thermal needle probe procedure. As the thermal conductivity of soils is highly dependent on the water saturation [9, 10] the materials are tested from a fully saturated to a dry state. Selected unbound recycled materials, including recycled concrete, mixed minerals, and brick minerals, as well as natural sands are examined under compacted conditions to simulate real trench environments. Additionally, a classification approach is developed to determine parameters analogous to saturation levels as defined in EN 13941 [4].

The results confirm that the method according to the ASTM standard D 5334-14 [8] standard and the measurement equipment used are suitable for determining the thermal conductivity of bedding materials for district heating pipes in respect to their water content. The tested alternative materials exhibit significantly lower thermal conductivity than sand, leading to reduced specific heat losses in district heating networks. These findings highlight the potential of recycled materials to improve the thermal efficiency of district heating networks while supporting circular economy goals.

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Optimizing the next generation of district heating and cooling systems while ensuring reliable domestic hot water supply

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The transition to low-temperature bidirectional district heating and cooling (DHC) networks offers a promising pathway toward energy-efficient and decarbonized urban heating and cooling. However, supplying domestic hot water (DHW) within these systems remains a challenge due to its higher temperature requirements, which often lead to exergy destruction and reduced system efficiency. This paper investigates optimal strategies for designing and operating bidirectional district network systems that minimize exergy destruction and losses while ensuring a resilient domestic hot water supply that balances efficiency, flexibility, and resilience.

A key aspect of this study is the dynamic control of supply and return temperatures to satisfy multiple heat demands while maintaining a low-carbon, low-temperature network. By optimizing temperature levels, heat exchange processes, and system configurations, the study aims to enhance both energy and exergy efficiency and improve the overall sustainability of thermal networks. The paper further explores the impact of peak electricity grid loads on district network performance, considering the interaction between electrical and thermal sectors.

Furthermore, worst-case scenarios, including extreme weather conditions, are analyzed to assess their impact on network performance. Simulation results demonstrate how these conditions affect temperature management and energy efficiency, highlighting essential design considerations for maintaining domestic hot water supply without excessive energy consumption or exergy losses.

The findings contribute to the ongoing development of next-generation low-carbon district heating and cooling systems by proposing optimized operational strategies that ensure the sustainable, resilient, and exergy-efficient district heating and cooling networks. By incorporating dynamic temperature control mechanisms and thermal energy storage, this study highlights pathways to achieving a low-temperature, thermodynamically efficient, and decarbonized DHC infrastructure while reliably meeting DHW heat demand requirements.

Heuristic pipe sizing algorithm for 5th generation district heating and cooling networks

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The transition towards low-carbon and energy-efficient heating and cooling solutions has spurred the development of Fifth Generation District Heating and Cooling (5GDHC) networks, which leverage low-temperature distribution, decentralized heat pumps, and geothermal borehole fields to provide both heating and cooling from a single, highly flexible infrastructure. While 5GDHC systems promise substantial efficiency gains and emissions reductions, their implementation requires careful network sizing and configuration to ensure cost-effectiveness, reliability, and adaptability to varying load conditions. This work presents a novel heuristic pipe sizing algorithm designed for the unique characteristics of passive 5GDHC networks, where each building is equipped with a decentralized heat pump and the circulation pumping is integrated within these heat pumps rather than centralized. The algorithm is based on a tailored optimization heuristic that integrates demand estimation, hydraulic calculations, and thermal balancing of the distribution network and ground-source field. It accounts for building-specific load profiles, spatial layouts, and interconnections among substations, ensuring that the resulting network configurations minimize lifecycle costs, pressure losses, and excessive thermal imbalances in the geothermal boreholes. Our approach has been implemented into a comprehensive 5GDHC design tool that assists engineers and planners in identifying network topologies, pipe dimensions, and borehole field parameters under various operating conditions. We will present the underlying methodology and demonstrate its capabilities through a real-world use case, highlighting the algorithm's ability to support design decision-making and adapt to changing urban energy needs. By providing a flexible, transparent, and computationally efficient sizing solution, our work contributes to accelerating the adoption and optimization of next-generation district heating and cooling systems.

Analysis of peak load reduction with configuration of district heating controllers and a newly developed optimization box

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The reduction of peak loads is one of the main tasks to enable the increase of sustainable heat generation in district heating systems (DHS). In German DHS, most of the controlling devices control the heat consumption with a simple heat curve that defines the set point flow temperature due to the current ambient temperature. In cases of short-term temperature drops (e.g., because of thunderstorms), a parallel opening of various affected control valves to adjust the flow temperature accumulates a peak load in the district heating grid. Many installed controllers already have configuration options to avoid these actions, e.g., by averaging the ambient temperature. If activated, abrupt changes in ambient temperature do not have a direct impact on the set point flow temperature and stored heat in the building mass is used. The set point flow temperature is adjusted slowly to avoid an impulsive opening of the valve. However, these settings are not activated in many cases.

Thanks to a developed test rig, a research group of the Competence Centre for Renewable Energy and Energy Efficiency (CC4E) at the University of Applied Sciences Hamburg can determine the ability of peak load reduction with controllers of different manufacturers. The test rig consists of four DH control units, which can be tested in a Hardware-in-the-loop-test environment. A detailed simulation of DHS and high-quality temperature simulators ensure realistic surrounding circumstances for the controller. A high-frequency measurement of controller output signals enables exact analysis of flow temperature controlling strategies. Furthermore, thanks to RC-building models, the simulation tool can be used to evaluate the impact of peak shaving on the indoor temperature of affected buildings.

Additionally, an optimization box for reducing peak loads has been developed. It is installed between ambient temperature sensor and controller and optimizes the ambient temperature measured by the controller in cases of specific weather events like an abrupt temperature drop. The events are detected due to measurement of ambient temperature and ambient pressure.

Executed studies show that controller-integrated peak shaving mechanisms have a decreasing effect on peak heat consumption. In the investigated case, an ambient temperature time series with a steep temperature drop has been analyzed with and without configured peak shaving setting. Moreover, it has been shown that the usage of the optimization box can lower the peak demand if used in combination with controllers without any peak shaving configuration options.

Data center waste heat utilization: Analysis and modelling of liquid-cooled servers

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In Europe, data centers currently account for approximately 2% of total electricity consumption. In Germany alone, the energy demand for data centers exceeded 2000 MW in 2020, with further growth anticipated. The heat generated during operation must be continuously dissipated via cooling systems. Direct liquid cooling is an efficient method where the cooling medium, usually water, is fed directly to the IT components, and the heat is absorbed through cold plates. Compared to cooling with air, this allows higher cooling temperatures due to better heat transfer. The maximum cooling temperature depends largely on the specific IT system and can vary between 45 °C and 70 °C. Liquid-cooled data centers therefore offer various possibilities for waste heat recovery, such as integration into district heating networks. However, increasing the cooling temperature impacts the power consumption of servers, heat transfer to the coolant, and may also affect IT system performance.

To quantify these effects, a comprehensive analysis based on benchmark tests was conducted on ten liquid-cooled servers under varying cooling temperatures and IT loads as part of the KETEC research project (subproject 11). The results show that IT performance was unaffected at coolant inlet temperatures between 25 °C and 50 °C. However, increasing the average cooling temperature from 30 °C to 50 °C resulted in an 8.5% rise in power consumption. Heat transfer to the liquid coolant was reduced by 14.6% due to heat losses. Based on these experimental results, a simulation model was developed and implemented in TRNSYS. This model enables the prediction of the behavior of direct liquid-cooled servers and the assessment of various applications for waste heat utilization. Building on this model, a more advanced simulation model was created in TRNSYS to analyze the integration of data center waste heat into district heating systems. This enhanced model examines how different cooling temperatures affect the data center's electricity consumption, energy requirements for the cooling system, and energy consumption of heat pumps used for waste heat recovery. The simulation provides a detailed assessment of how data center cooling conditions influence waste heat integration into district heating networks.

Pyrolysis-plant potentials for DHC in Germany

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An essential step in the fight against climate change is the reduction of greenhouse gases in the atmosphere. To achieve this, the heat supply must transition to carbon-free heat generation. In this district heating networks seem to be a promising solution. DHNs will therefore be increasingly expanded or newly planned in the future. In addition, existing networks are being decarbonized by new generation plants based on renewable energies or waste heat utilization. Also negative emission technologies (NET) like biomass pyrolysis will increase in dissemination. Besides producing heat and electricity, it serves as sink for CO_2. Due to the use of biomass it competes with other biomass-based energy producers and the production of biogenic fuels.

This paper examines the pyrolysis-plant potential for two distinct scenarios concerning district heating networks (DHN) in Germany. The first scenario reflects the current state, which features approximately 4000 existing DHNs with 124 TWh heating energy per year [1]. The second scenario is based on the future scenario of AGFW with 189 TWh [1] . This results in around 12000 generic DHN in Germany.

Due to a lack of comprehensive data, the DHNs will be generated in a generic manner, and the base loads will be computed using standardized load profiles. In the subsequent phase of the analysis, a comprehensive examination of the local waste biomass potentials in proximity to the identified district heating networks (DHNs) will be conducted. This assessment will facilitate the calculation of optimal sizes for biomass pyrolysis facilities, ensuring that they are effectively matched to the available waste biomass resources. By employing a systematic approach, the integration of pyrolysis technology within the DHC framework can be enhanced, thereby maximizing resource utilization and contributing to sustainable energy solutions.

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Measurement-based control strategies for thermal comfort and regulation in low-temperature district heating networks

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Low-temperature district heating networks represent a key pathway for decarbonising urban heating by enabling the integration of zero-carbon energy sources, including renewables and waste heat. These networks support energy-efficient heat delivery, large-scale seasonal storage (e.g. geothermal) and improved performance of heat pumps, solar panels and combined heat and power systems. Despite these benefits, significant challenges remain, such as designing networks to minimise heat losses and pumping energy consumption while reliably meeting heat demand. Ensuring compatibility of temperature levels with existing buildings, which are often designed for high temperature heat sources, is also a major concern.

This study investigates measurement-based control strategies to ensure thermal comfort under both design and operational conditions. Specifically, it evaluates the use of simple return temperature control strategies based on measured data, adjusting pump speeds in response to the return temperature of the most critical consumer. The aim is to investigate strategies that replicate practical approaches used in the implementation of district heating networks. By coupling dynamic models of key system components - including thermal storage, networks, pumps, control and building envelopes - the study provides a complete picture of the system dynamics that the control system has to deal with.

The novelty of this approach lies in the integration of system dynamics with the resulting indoor temperatures of the connected buildings, providing a comprehensive strategy to optimise both thermal comfort and operational efficiency, while addressing the challenges posed by the existing building infrastructure, its specific requirements and occupancy. Field measurements from two existing buildings and their associated thermal networks validate the proposed models and methods.

Perspectives of end users of district heat in Antwerp

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Exploring the perspectives of key stakeholders and end users within the district heating and cooling (DHC) industry is crucial for the successful implementation and expansion of DHC systems. While DHC offers a promising solution for reducing carbon footprints and optimizing energy use in urban areas, its adoption is complex and relies on a diverse group of actors, each with distinct interests, concerns, and long-term goals. This study presents results from interviews with possible end users to better understand the views of these key players.

The focus of this research is on Antwerp, the second-largest city in Belgium, which, despite its potential, has relatively low implementation rates for DHC systems. This study examines the motivations, concerns, and expectations of residents. Interviews were conducted with potential end users to assess their awareness of DHC systems, their perceived benefits and drawbacks, and the role of social networks in shaping their decisions.

While DHC is typically promoted for its energy efficiency and cost savings, this study shifts attention to the social factors influencing adoption. It explores how trust in local energy providers, community influence, and a shared sense of sustainability commitment affect end-user decisions. The findings reveal that although many end users can see how there might be environmental and financial advantages of DHC, uncertainties about costs, long-term reliability, and the availability of clear information often act as barriers.

By highlighting the views of end users, this study underscores the need for more transparent communication, targeted outreach, and community-based initiatives to encourage DHC participation. Integrating both economic and social considerations into policy and planning could lead to greater acceptance and a more inclusive energy transition. The results of these interviews can be used to develop surveys and discrete choice experiments to find more quantitative evidence of the points raised by the interviewed end users.

Implementation of a low-temperature thermal source network pilot system for community energy independence

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In order to achieve carbon neutrality in buildings and communities, the 5th Generation District Heating and Cooling (5GDHC) system, which operates at geothermal temperature levels, has emerged as an innovative solution that surpasses the capabilities of existing 4th Generation District Heating Systems (typically operating at approximately 60°C). The present study puts forward the adoption of 5GDHC systems as a strategic approach to achieving energy self-sufficiency at the district level, whilst also evaluating the design and operational energy savings potential of a pilot system implementation. The pilot site selected for this study is the Gachon University campus, where dormitories and an AI engineering building have been designated as target facilities for the 5GDHC pilot system design. The design process incorporated a comprehensive evaluation of the energy supply range of the 5GDHC system within the building, and simulations were conducted to analyze energy savings during operation. For the purpose of this study, nPro software was utilized, which was specifically developed for 5GDHC system analysis. Utilizing this instrument, the research team conducted an evaluation of the efficiency enhancements of heat pumps employed for cooling, heating, and domestic hot water supply, in addition to electrical consumption patterns. The energy-saving performance of the 5GDHC system was quantified by comparing it with traditional systems, such as air-source heat pumps and gas boilers. Moreover, the study proposed integrating solar photovoltaic panels into the building's roof to evaluate the potential for improving annual energy self-sufficiency. Furthermore, the impact of the proposed system on maximizing the utilization of locally generated renewable energy by increasing the proportion of electricity consumed from renewable sources was investigated. The findings indicate that the 5GDHC system has a substantial impact on

enhancing energy efficiency, fostering annual energy self-sufficiency at the regional level, and expeditiously augmenting self-consumption rates through the utilization of renewable energy sources.

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Proposal for a method to simultaneously maximize the economic and environmental values of a district heating and cooling system for an electricity market

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District heating and cooling system (DHC), which is responsible for supplying heat, cold, and electricity to the region, often have a combined heat and power system (CHP) that has the ability to generate electricity as well as generate heat and cold because of the perspective of improving energy efficiency. Hence, they have high potential as a distributed energy source that can contribute to the stabilization of the power system by utilizing CHP not only for the local demand but also for the entire power system. However, many DHCs are only used for the region. On the other hand, in recent years, the spread of renewable energy sources with fluctuating output, such as solar and wind power, has destabilized the power system. With the aim of further promoting the use of renewable energy through the procurement of power sources that contribute to the stabilization of the power system and promoting free competition in the power industry, the establishment of electricity markets that procure power sources from various providers is being completed or considered in countries around the world. In Japan, in addition to the traditional wholesale electricity market, the balancing market was newly established in 2021, which trade adjustment power delta-kW and kWh.

In our previous study, we proposed an operational method that would enable DHC to simultaneously supply electricity to the balancing market in Japan while fulfilling its responsibility for local heat, cold, and electricity supply, as well as a method for evaluating its economic efficiency.

On the other hand, even though one of the reasons for establishing electricity markets was to promote the spread of renewable energy ultimately, many electricity markets around the world only evaluate the economic value of power sources. Therefore, to encourage decarbonization across the electricity industry as a whole in the future, it is essential to take environmental value into account. Still, there is no established method for evaluating it.

In this study, we first propose a method for evaluating both the economic value composed of operation cost (delta-kW and kWh cost) as well as environmental values composed of CO2 emission from fuel and grid power consumption, on the premise that DHC will simultaneously supply electricity to the balancing market while fulfilling its responsibility for local heat, cold, and electricity. Finally, based on the valuation method, we propose a method for determining an operation that maximizes the total of economic and environmental values.

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Thermal monitoring of concrete ducts – concept presentation

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District heating allows for a reliable and cost-efficient supply. Furthermore, the networks allow the integration of renewable heat sources, which then can be distributed to the connected consumers. Eventually, this is the key to achieving environmental policies [1]. These networks differ substantially regarding the used piping, including thermal insulation and covering, installation, and topology. Today, the use of preinsulated bonded pipe systems laid in the ground is preferred. However, a significant proportion of transmission pipelines in Germany consists of pipes laid in non-accessible concrete ducts.

Data, which describes the condition of the whole pipeline system in detail and locally resolved, is the basis for innovative maintenance strategies (e.g. model-based assessment). For preinsulated pipes, for instance, through extensive research projects methods to estimate the remaining service life have been developed [2]. In contrast, the level of knowledge in the field of pipes in concrete ducts is relatively low. Through metrological monitoring, only the detection of leakage, for example, was possible [3]. There are no insights available, that heretofore causes of slow processes (e.g. moisture penetration) based on measurements or a scientific theory were investigated.

The contribution describes a concept for thermal monitoring of DH pipes laid in concrete ducts. The commissioning is planned for 2025. Two pipeline routes will be investigated with two monitoring systems in each case. A monitoring system contains multiple sensors (e.g. temperature, heat flux, humidity, flow rate) at different locations (e.g. on pipe, inside thermal insulation, on surfaces of concrete ducts, and in the ground). The recording of the weather is carried out by a weather station (e.g. air temperature / humidity, pressure, wind speed / direction, solar radiation intensity, precipitation intensity).

Many states and processes (e.g. substantial change in thermal insulation) are not directly measurable or comprehensively determinable. Here, numerical models or evaluation methods must be developed and used. All the works stated above are located in the joint project SAM-FW (Sustainable Asset Management Fernwärme).

Furthermore, the article explains the planned data processing, which also is necessary for innovative maintenance. Here the authors can refer to concepts, which have been developed during the Research Platform Refrigeration and Energy Technology (KETEC).

A measuring instrument undertakes the actual measurement. This instrument will be coupled with an edge-device. There, later a decentralized evaluation of measured data can proceed (e.g. filtering, aggregating), which informs the operator. In the authors' view, procedures taking the operators' needs into account must be developed.

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Integral heating and cooling optimization of district heating networks

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The need for cooling will increase towards 2050 as the global temperature is predicted to rise. At the same time the number of district heating networks (DHN) is increasing as countries are transitioning to more sustainable sources for heating. Future designs of DHNs should account for these developments and thus include options for combined heating and cooling in the decision making.

An open-source Mixed Integer Linear Problem framework is developed for design and operational optimization of energy systems; Multi Energy Systems Integral Design and Operation (MESIDO). MESIDO enables an integral optimization which includes sizing of assets, determining source and storage allocation and sizing of transport pipes. This is achieved by minimizing the Total Cost of Ownership of the system while ensuring the technical feasibility. This work focuses on the inclusion of cooling demand and cooling assets, to allow for the design and operational optimization of 5th Generation District Heating and Cooling Networks (5GDHC).

5GDHC networks operate at lower temperatures and have the ability to use sustainable energy and/or lower heat grade sources like aquathermal energy or residual heat from datacentres. Combining such sources with Low Temperature Aquifer Thermal Energy Storage (LT-ATES), at temperatures up to 25°C for cold and heat storage, can improve the business case significantly. This is, in combination with the potential predominant use of heat pumps instead of gas boilers to cater for potential heating peaks or heat upgrading. When the latter occurs in winter, both hot and cold water is produced simultaneously. The warm water from the aquathermal source or LT-ATES, is then upgraded for heating purposes and the cold water can cater for cooling demands (for example datacentres) or potentially be stored in the LT-ATES. However, during summer the LT-ATES can be charged with heat originating from the aquathermal source when there is an imbalance between the seasonal cooling and heating demand. Furthermore, the operation of the heat pumps is also considered due to fluctuating price profiles or limiting electricity grid capacities which is linked to potential cost savings or sizing of such assets and network feasibility.

A combined heating and cooling network could be economically beneficial over a separate DHN and individual cooling solutions depending on several factors. These include factors like the heating and cooling demands of a specific area and the availability of low temperature energy sources in lieu of high temperature renewable heat sources.

Making district heating flexible: Study of flexibility options with different control strategies

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In pursuit of a substantial reduction of greenhouse gas emissions in the atmosphere, the European Union aims for full decarbonization of district heating by 2050. The task is particularly challenging due to the intermittent nature of renewable primary energy sources and the non-dispatchability of waste heat. The goal of this study is to evaluate and compare the combined effect of the activation of different flexibility options to optimize the integration of high share of renewable and waste heat in third and fourth generation district heating networks. These options include the use of: demand-side flexibility, thermal storage in dedicated devices and the network itself as a storage. Demand flexibility for residential users can come from the use of a decentralized thermal storage tank or from using the thermal inertia of the floor heating system or the (well insulated) building itself.

The mentioned different flexibility types are going to be tested under a range of boundary conditions with the goal of identifying the best control strategies to maximize the share of renewable and waste heat in the DH energy mix. Other key performance indicators (KPIs) as levelized cost of heat production, overall CO_2 emissions, network's transmission efficiency, peak shaving of heat power, electric grid friendly use of surplus electricity from renewable electricity sources by sector coupling with heat pumps are going to be considered for comparison and evaluation.

The evaluation of flexibility options has to be done with a matrix of a discrete number of input parameters for what concerns: plants' technology used, plants' size and share, consumption profile, thermal storage size, control strategy adopted. The analysis is going to be performed in a district heating simulation tool where a digital twin of a real existing network is modeled. The tool calculates pressure and temperature in network's nodes and volume flows in pipes. All different control strategies are going to be tested while guaranteeing reliability of service for customers, which includes the check of minimum supply temperature and minimum pressure differences at nodes.

The authors wish to quantify, with the defined KPIs, the performance of the mentioned flexibility options. The authors are willing to investigate not only the separate effect of flexibility options, but also a combination of them by defining more complex control strategies.

Evaluating laboratory operations for simulating multi-storey radiator heating systems

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In the transition towards the low-temperature district heating (LTDH) system, the demand plays a crucial role. The heating installations in buildings directly determine the return temperature in the district heating (DH) network and influence how low the supply temperature can be. Moreover, faults or suboptimal operations can substantially compromise the overall system efficiency. This study investigates how radiator systems impact heat distribution, indoor temperatures, and interactions with heat generation, with a focus on hydraulic balancing, supply/return temperature strategies, and fault detection.

We conducted laboratory experiments using a four-floor radiator system simulating eight residential units (40 radiators of mixed types across the north/south wall). The setup replicates real-world district heating demand patterns and is fully digitalized with electronic thermostat radiator valves (TRVs), heat cost allocators (HCAs), and different meters for temperature, flow, and pressure measurements.

Two supply temperature strategies were compared under moderate outdoor conditions (5-10°C): a constant low-temperature mode (55°C) and a high-temperature weather compensated mode (60-65°C). In another comparison test, two radiator distribution modes were analyzed: a fully active system with all radiators in operation versus a partially active system (35% radiators turned off, closer real-world occupant behavior). Under these settings, we focus on how different operating modes affect parameters such as the supply and return water temperature difference, room temperature, and some key radiators' performance (toilet towel heaters, radiators with inherent errors).

Operational analysis of a 4GDHC system in an energy-self-sufficient smart village in Busan, South Korea

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The building sector accounts for roughly one-third of global energy consumption and CO_2 emissions. Decarbonizing building heating and cooling is therefore a critical priority. Heat pumps, particularly air-source (ASHP) and ground-source (GSHP) systems, have emerged as key technologies for low-carbon buildings—especially when powered by renewable electricity. Modern low-temperature district heating and cooling (DHC) networks are also recognized as essential for decarbonizing urban building energy, by improving efficiency and enabling integration of renewable and waste heat sources. However, standalone heat pumps face performance limitations (e.g. in cold climates or when loads are imbalanced), which highlights the need for integrated thermal networks that enable energy sharing.

Fourth-generation DHC (4GDHC) networks operate at supply temperatures of around 40–70 °C, significantly cutting distribution losses and narrowing the gap between supply and end-use temperatures. Lower network temperatures also facilitate the use of multiple heat sources and improve heat pump COPs, while allowing load sharing among buildings. This study presents an empirical analysis of a real 4GDHC system in the Busan Eco Delta City Smart Village, South Korea. The pilot site has 56 households and community facilities, using a low-temperature ambient water loop with geothermal and water-source heat pumps, plus on-site solar PV generation. Three years of operational data were analyzed. The network supplied approximately 1,507,720 kWh of heating and cooling per year while consuming about 531,036 kWh of electricity, for an average COP of ~2.84. Notably, an estimated 20–30% of heat was lost in the thermal storage and 15–25% in the distribution network. Efficiency varied seasonally, with the COP dropping in winter due to higher heating loads and colder source temperatures. In terms of energy self-sufficiency, the Smart Village demonstrated strong performance as a near net-zero energy community. When comparing solar PV generation to the five major end uses (excluding plug loads), the energy self-sufficiency rate reached 124.4%. Including plug loads reduced the rate to 77.4%, and when community office buildings were added, the overall rate declined to 46.3%. Accounting for electric vehicle (EV) charging loads brought the total self-sufficiency down slightly further to 45.6%.

Overall, the 4GDHC system demonstrated promising performance but also revealed areas for improvement. Minimizing thermal losses (for example, through better insulation of storage tanks and pipes) and refining control strategies for seasonal operation could further boost efficiency, particularly under peak winter conditions. This real-world demonstration underscores the value of full-scale pilot projects: insights from the Busan Smart Village can inform future designs and operational strategies to enhance efficiency and maximize the decarbonization potential of next-generation low-temperature DHC networks.

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Lowering return temperatures to district heating networks by a cascade concept with integrated heat pump

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Currently Austria has a share of 17% of DH systems of the overall heat supply with significant growing development potential [1]. Therefore, it is important, that these systems work efficiently. This means in particular, to aim for low return temperatures from customers, because this does not only decrease thermal losses, but also reduces electricity consumption of feeding pumps and allows higher supply capacities.

In a case study, the technical room of a multi-family building was modelled in the simulation software Polysun [2]. For the building, there are measurement data of heat and flow meters for one year available. These data are used to define load profiles for space heating (SH) and domestic hot water (DHW) consumption as well as for calibrating the model in terms of DH consumption. This model is then used to evaluate the optimization potential of a cascade concept with an integrated heat pump. The original system provides the supply of SH and DHW preparation in parallel, which means that the high return temperatures from DHW preparation due to the coverage of circulation losses leads to overall high return temperatures. In a cascade concept, DHW and SH are supplied in series with the same flow rate. In times with higher DHW demand than SH demand a bypass pump in the SH loop covers the missing flow. This means that while this concept is efficient in winter, there are still high return temperatures to be expected in summer.

In the original system, 90% of the energy is transmitted with return temperatures to DH above 50°C, 30% even with return temperatures above 55°C. With the cascade variant, half of the DH energy is transmitted with return temperatures below 40°C, but 12% of the energy is still transmitted with return temperatures above 50°C.

Therefore, for further improvement a heat pump is integrated to cover the circulation losses in the DHW system during periods of low or no SH demand. Several external heat sources for this heat pump, like outdoor or inlet air or the building mass itself but also internal heat sources like the buffer or DHW tank, are investigated. The integration of a heat pump in the DHW circulation line could further reduce this amount of 12% of energy transmitted with return temperatures above 50°C to almost zero. In the simulations, this approach has shown to be a very efficient method for reducing the return temperature from consumer side.

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Differentiable predictive control for indoor air temperature control in buildings

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District heating and cooling (DHC) systems play a crucial role in the transition toward sustainable and energy-efficient urban environments. With the increasing demand for low-carbon energy solutions, DHC systems provide a centralized approach to efficiently distribute thermal energy while integrating renewable energy sources, waste heat recovery, and advanced control strategies to enhance overall system performance. One of the key challenges in managing DHC networks is the optimal control of indoor air temperature in buildings, ensuring both occupant comfort and energy efficiency. Traditional Model Predictive Control (MPC) methods have been widely used for this purpose due to their ability to handle system constraints and optimize energy consumption over a prediction horizon. However, MPC is often computationally expensive, making real-time implementation in large-scale building networks challenging.

In this paper, we propose a learning-based control strategy using Differentiable

Predictive Control (DPC) to regulate indoor air temperature while reducing the computational burden associated with conventional MPC approaches. DPC leverages the differentiability of optimization problems to enable end-to-end learning of control policies that approximate optimal solutions while significantly reducing real-time computation. By embedding a differentiable optimization layer into the control policy, DPC allows for efficient gradient-based updates, enabling fast adaptation to changing environmental conditions and system dynamics. This approach eliminates the need for real-time optimization at every control step while maintaining high control performance.

The proposed DPC method is evaluated in a simulated indoor temperature regulation scenario under varying thermal loads and disturbances. Results demonstrate that DPC achieves comparable performance to MPC in terms of maintaining thermal comfort and minimizing energy consumption, while significantly reducing computational demands. This reduction in computational complexity makes DPC a promising candidate for real-time control in large-scale building energy management systems integrated with DHC networks. Furthermore, the learning-based nature of DPC allows it to adapt to changing building dynamics and external conditions, making it a robust and scalable solution for sustainable temperature control in smart buildings.

Digital control systems for district heating substations: A simulation study on peak load reductions

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District heating plays an important role in the implementation of the heat transition. In this context, the project "EnEff:Wärme: UrbanTurn" (FKZ: 03EN3029) focuses on the development of innovative approaches to transform district heating supply. The overarching goal is to identify technical solutions for the transformation of district heating systems, propose new design criteria, and develop innovative approaches for operation and control. To address the associated challenges and objectives, "technology sets" have been derived, which represent a combination of identified research questions and methodologies for answering them. These methodologies include both simulation and experimental investigations. One of the technology sets presented in this work analyses the impact of digitized substations and their control system on a district heating network.

Practical experience indicates that most substations are operated with default factory settings and that after installation, no adjustment of the control parameters to the specific local situation is made. This is seen as a source of simultaneity patterns in the resulting daily heat demand profiles, particularly reflected in the morning peak loads. Since peak load boilers based on fossil fuels are primarily used to meet these peaks, the study investigates how the digitization of the control of substations can contribute to reducing peak loads.

In this work, a simulation model is created that represents a part of a district heating network, including pipelines, heat exchangers, control valves, differential pressure valves, controller, as well as the heating systems in the connected buildings in detail. With this model a quantification of the influences of easily implementable software-based measures, on the morning peak at the primary generator and on secondary-side comfort is conducted. The measures examined include, for example, a minimal temporal shift of the night setbacks or the software-based change rate limitation of the input signals for the controllers. These are therefore measures that can presumably be easily retrofitted to substations that are already installed but digitally connected. Preliminary results show that these software-based measures can achieve significant reductions in peak loads without incurring substantial comfort losses.

A comparison between district heating and heat pumps investment and operational cost for district energy efficiency measures

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The decarbonization of urban heating systems requires strategic investments in energy efficiency measures and sustainable heating technologies. This study compares the investment and operational costs of district heating (DH) and heat pumps (HP) following optimal district energy efficiency measures. The analysis is based on a case study in Sint-Niklaas, Belgium, where buildings are first clustered according to their characteristics to identify optimal renovation strategies, considering both individual and collective decarbonization targets. The study follows a two-step approach. First, optimal renovation measures are determined for different building clusters based on fabric improvements and energy resource upgrades to minimize heat demand. Once the optimal level of fabric renovation is reached, the investment and operational costs of DH and HP are compared, considering capital expenditures (CAPEX), operational expenditures (OPEX), energy prices, and system efficiency. The results provide insights into the cost-effectiveness of DH and HP solutions within a district-wide decarbonization framework. This research offers valuable guidance for policymakers, urban planners, and stakeholders, facilitating informed decision-making for the transition to sustainable district energy systems in Belgium and beyond.

Dynamic flow temperature optimization increases energy-efficiency in a district heating network

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Reducing heat losses in district heating networks (DHNs) enhances operational efficiency and lowers environmental impact. Heat losses in DHNs depend on the temperature difference between the network fluid and the ambient environment. Thus, reducing flow temperature reduces these losses [lund18]. Traditionally, producer outlet flow temperature is stabilized at a given set point using a low-level controller. This set point is determined by a static correlation with other process parameters, commonly referred to as the heating curve. Frequently, heating curves consider only the ambient temperature as a determinant.

This work examines two strategies for reducing the flow temperature by generating producer flow temperature set points: (1) applying a numerically derived near-optimal static heating curve that minimizes energy by interpolating between optimal operating points, and (2) following a time-dependent trajectory of flow temperature set points found numerically for given demand and ambient temperature profiles. Strategy (2) is paired with two demand profiles: The first approximates demand as proportional to ambient temperature, and therefore considers no additional information beyond the time evolution of what is also available to strategy (1), the static heating curve. The second assumes perfect knowledge of a realistic demand profile and represents a best-case scenario.

Both strategies (1) and (2) leverage a static hydraulic model for the steady-state flow distribution and a dynamic thermal model as described in [rose23]. A low-level closed-loop controller sets the producer flow temperature according to either of the strategies and completes the model. A case study examines a tree-structured, single-producer DHN, a variation of which has previously been studied in [macha22]. Simulations for evaluation are performed using a higher-fidelity differential equation solver while the optimizations rely on a basic finite-difference approximation.

Our results demonstrate that strategy (2), the dynamic trajectory, achieves greater energy savings than strategy (1), the static heating curve, for both demand profiles. The highest savings are observed under realistic demand conditions.

In conclusion, dynamic producer flow temperature trajectory planning over a closed-loop system model could reduce heat losses regardless of demand prediction accuracy. Since only producer flow temperature is used as an input and a low-grade demand prediction suffices to produce results, the approach may be deployable in existing networks.

The methods have no apparent theoretical limitations for application to more complex network structures. Future research could explore their scalability and effectiveness across diverse DHN configurations.

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Integration of a closed-loop geothermal system in a district heating network: Impact of eccentricity of the inner pipe to the flow and heat transfer

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Efficient heat production and distribution of renewable energy is a challenge to our society. Geothermal energy in district heating networks has the potential to reduce CO2 emissions and enable the transition to a low-carbon districts. Hydrothermal resources in sedimentary basins (open-loop systems) are present in multiple European countries, but have the challenge of finding thermal reservoirs that have porosity and permeability suitable for economic production. Environmental-leakage-, corrosion- and radioactive salt deposition challenges are associated with the fluids circulating in the process. Fracturing of the rock formations implies an environmental risk for groundwater pollution and seismicity. These issues have in the past reduced the social acceptance for geothermal developments.

Closed-loop geothermal system, in contrast, operates without a need for hydraulic, thermal or chemical stimulation, which can help avoid the risk of induced seismicity. It is also more predictable since it does not rely on permeability of the reservoir. Different configurations of deep closed-loop systems have been analysed in terms of their energy and economic performance .

This paper is focussing on one of the closed-loop concepts, namely on the DualPipe technology (concentric pipe in pipe system), recently developed for petroleum well applications and now applied in geothermal applications. The technology allows for both vertical but also horizontal drilling for added reach and improved heat extraction at medium depths.

Although the concept seems logic, there are practical limitations. One of the challenges is to have the inner pipe centred around the outer pipe especially in the horizontal sections. Support structures along the length of the concentric pipe are options, but makes the manufacturing and the commissioning of concentric pipes expensive and the overall concept time consuming and costly.

Currently, the impact of eccentricity (inner pipe positioned eccentric to the outer pipe) has not been studied. In this paper, the effect of eccentricity of the inner pipe to the outer pipe on the thermal and hydraulic performance is analysed. The study was conducted using the incompressible flow solver available within the SU2-Suite.

Results show that the heat transfer characteristics of the pipe in pipe concept were reduced substantially in the extreme case (the inner pipe touching the outer pipe) having an effect on the opex of the closed system and the optimal integration in the district heating network.

Additionally, alternative solutions to increase the heat-transfer performance of the pipes in pipe concept are proposed.

Decarbonizing peak heat load in district heating: Current practices and future renewable strategies

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Despite the increasing integration of renewable energy sources, district heating (DH) networks are still heavily dependent on fossil fuels. Many DH networks already use climate-neutral alternatives for heat generation including geothermal and solar thermal energy, biomass, heat pumps, waste heat and waste incineration, mainly to meet base load demand. A major challenge for most DH networks is de-fossilizing peak heat loads to achieve complete decarbonization. The IEA-DHC Annex XIV project RE-PEAK investigates how peak heat loads in DH systems can be met using renewable energy sources.

As part of this project, a survey was conducted among DH network operators and DH experts, such as researchers or consultants. The survey explored definitions of peak heat load, current peak heat load technologies and future climate-neutral strategies. It also examined technical and economic factors associated with different approaches for covering peak heat load in DH systems in net-zero energy systems.

The survey results show that there is no uniform definition of peak heat load. Some define it as the maximum heat demand in a defined period, while others refer to a percentage of capacity. Fossil fuel boilers are currently most commonly used for peak heat load provision, followed by thermal energy storage and biomass boilers. About half of the surveyed DH network operators have developed a net-zero strategy, although the term strategy can be interpreted broadly. The preferred technologies for covering peak loads in a net-zero DH system include thermal energy storage, electric boilers, heat pumps, and renewables like biomass and green gas. Technical factors such as reliability and technology readiness are seen as advantages, while high investment and operating costs are considered as barriers to the adoption of these technologies The survey also shows a preference for boilers over combined heat and power plants as well as for electric boilers over heat pumps, for meeting peak heat loads in net-zero DH systems due to lower investment costs and greater flexibility.

In conclusion, while fossil fuels are the primary source for covering peak heat loads in district heating networks, many DH network operators are actively planning their transition towards full defossilization. Efficient and renewable solutions like thermal energy storage, electric boilers, heat pumps, green gas and biomass boilers are seen as the most promising options for the future. However, economic barriers and infrastructure challenges need to be addressed to successfully transition to net-zero DH systems and achieve full decarbonization.

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Measuring district heating network effect on district cooling network losses in an urban environment

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District heating and cooling (DHC) has been widely implemented as an efficient solution for regulating indoor climates across different types of buildings. Over the years, DHC has evolved through multiple generations, becoming more sustainable and environmentally friendly. Advancements in production technology and network optimization have further improved its efficiency, reducing wasted energy. DHC networks, like production systems, have continuously advanced to minimize thermal losses. In urban areas, where space is limited and multiple communication networks exist, DHC pipes are often installed close to one another. This proximity between hot and cold pipes can influence thermal losses, yet many existing DHC network modeling software overlook this factor. Understanding the impact of pipe placement on thermal efficiency is essential for optimizing DHC systems and further improving their sustainability. To address this issue, this paper presents a ground temperature measurement experiment where DHC pipes are installed next to each other. The study measures seasonal variations in DHC network temperatures, outdoor temperatures and ground temperatures. Measured data about thermal losses can be compared to modelled data. By analyzing these factors, the research aims to quantify the effect of pipe placement on network losses and provide insights into improving DHC system efficiency. The results of this study will contribute to the development of more accurate DHC network models that account for the influence of adjacent hot and cold pipes. This knowledge can help optimize pipe placement strategies and enhance the overall efficiency of district heating and cooling systems. As cities continue to expand and prioritize sustainable energy solutions, improving the performance of DHC networks will be crucial for achieving carbon neutrality and reducing energy consumption.

A comparative techno-economic assessment of seasonal thermal energy storage for decarbonized district heating networks

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A transition toward decarbonizing the heating and cooling sector is crucial for achieving a carbon-neutral economy [1]. However, in most European countries, 50% of the overall energy is used in domestic heating and hot water production [2], with 67% of this energy provided by fossil fuels, resulting in 35% of total CO2 emissions [3, 4]. According to IEA, despite the increase in renewable energy usage, only 11% of global heat demand was met by renewable sources in 2019, mainly resulting from seasonal and daily mismatches between solar heat generation and demand. Unlike electricity storage, heat storage offers a more cost-effective solution for balancing and enhancing network flexibility [5, 6]. Therefore, seasonal thermal energy storage systems (STES) are considered crucial for facilitating the integration of renewable energy sources into the energy network, as well as the utilization of industrial waste heat and cooling as primary energy sources for district heating and cooling (DHCN) networks [7]. However, high initial costs, (hydro-)geological limitations, and heat losses are the main challenges in implementing STES [8]. To address these challenges, this study conducts a comparative technical and economic feasibility assessment of integrating seasonal thermal energy storage systems into the existing district heating and cooling network. The analysis focuses on identifying and comparing key economic and technical performance indicators to determine the most favorable implementation strategies. Specifically, the study compares the techno-economic viability for high temperature solar collectors and underground STES (pit, aquifer, and boreholes TES) integration in DHN characterized by different load profiles and architectures. Benchmarking of such alternatives against business as usual systems are included also considering different foreseeable carbon taxes. Therefore, this study aims to offer practical recommendations to policymakers, energy planners, and industry professionals to facilitate the transition toward sustainable district heating and cooling systems.

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Development and demonstration of a smart interactive thermal energy balanced network for distributed next-generation district heating and cooling systems

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As the distributed energy market rapidly expands in South Korea, there is a growing demand for regional energy efficiency technologies that leverage the identification and integration of localized energy resources at the demand site level. In response to these evolving market trends, this study aims to develop and demonstrate efficiency enhancement technologies for next-generation distributed district heating and cooling (DHC) systems.

The core technology, termed the "Smart Interactive Thermal Energy Balanced Network", is designed for communities consisting of multiple buildings with heterogeneous heating and cooling demand profiles. The system comprises an energy hub equipped with heat pumps, demand-side buildings, and a low-temperature thermal network optimized for renewable and unused heat energy utilization. It enables: (1) bidirectional thermal exchange among buildings for demand balancing; (2) centralized balancing of residual loads and network-wide temperature control via the energy hub; (3) improved building energy efficiency and system-wide coefficient of performance (COP); and (4) flexible integration of diverse unused energy sources.

For demonstration, the system has been deployed in a community consisting of three functionally distinct buildings—an office facility, a dormitory, and a data center. Over 5,000 cumulative hours of operation, it aims to supply more than 300 RT of thermal load while achieving key performance targets: a levelized cost of heat (LCOH) of 95 KRW/kWh, carbon emission reductions exceeding 50%, an energy self-consumption rate of up to 70% based on renewable and unused thermal sources, and a more than 40% reduction in annual energy use per unit area.

Based on the validated outcomes of this demonstration, the project seeks to develop scalable business models—such as distributed DHC services, Energy Distribution and Control Operator (EDCO) operations, thermal grid planning, and consulting services—for application in both domestic and global markets.

Acknowledgements

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Geothermal district heating networks in Iceland – challenges and future strategies at veitur utility

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Veitur utilities operates the largest geothermal district heating networks in Iceland, supplying heat to the capital region through a combination of low-temperature geothermal fields and groundwater heated in high temperature geothermal power plants. This unique system presents both opportunities and operational challenges related to resource management, efficiency, and long-term sustainability.

One of the primary challenges is the integration of water sources with incompatible chemical compositions. The use of both low-temperature geothermal water and heated groundwater from power plants requires careful management to prevent scaling and deposition in pipelines, heat exchangers, and consumer installations. Additionally, maintaining system balance between supply and demand, particularly during peak load periods, remains a critical operational concern.

To address these challenges, Veitur has been actively developing future strategies for resource optimization and network expansion. A key component of this strategy is the exploration of new low-temperature geothermal fields to increase supply capacity while reducing reliance on high-enthalpy sources. Furthermore, research is underway to assess the feasibility of blending different geothermal water sources to create a unified network, potentially reducing infrastructure complexity and improving efficiency.

Veitur is also investing in innovative approaches to enhance heat recovery and energy efficiency. These include the potential use of thermal storage, improved pumping technologies, and advanced monitoring systems to optimize network operations. Future development plans are being guided by comprehensive demand forecasting models that assess the expected growth in heating needs over the next century.

In this paper, an overview will be provided of the operational and strategic challenges facing Veitur's geothermal district heating system, discuss ongoing projects aimed at improving resource management, and highlight the company's long-term vision for a resilient, efficient, and sustainable heating network. By sharing these insights, Veitur aims to contribute to the global discussion on best practices for managing geothermal district heating systems in a changing energy landscape.

Large-scale solar thermal systems in district heating networks: A review of German projects regarding dimensioning, temperatures and stagnation times

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Large-scale solar thermal systems (STS) can play a relevant role to decarbonize the district heating (DH) sector and are becoming more important for achieving climate goals.

Our research project aims to reduce barriers and increase the overall attractiveness of large-scale STS. The approach is based on the use of evacuated tube collectors (ETC) with specially designed heat pipes. Due to their simple hydraulics and inherent ability to selectively limit the maximum system temperature, these collectors offer an untapped potential for innovative and efficient system designs.

An initial part of the project aims to investigate dimensioning standards and existing installations in Germany as basis for the ongoing research. For this purpose, we analyzed 38 concepts from feasibility studies (1) and 31 realized large-scale STS with ETC (2). As a main result from (1) and (2) we found out that around 50 % of all these STS can supply more than 15 % of the annual heat demand. The maximum solar fraction (SF) in (1) is 62 % and 35 % in (2). Generally small DH networks (e.g. bioenergy villages) can easier achieve higher SF, due to the better availability of useable ground areas and the tendency towards lower grid temperatures. The average SF of such realized systems is 22 % (2), so that the biomass boiler can completely shut-down during the summer periods. Thus, many plant operators reported that unpleasant start-stop behavior of the biomass boilers can be completely avoided and fuel as well as emissions can be saved. In contrast to the feasibility studies (1) most realized systems (2) have comparatively small thermal energy storages (TES), which leads to relevant stagnation times in summer. Stagnation results in high collector temperatures (180-270 °C) and evaporation of the heat transfer medium as well as to high thermal loads on the surrounding components. To handle stagnation loads, safety devices and robust components are essential. In the analyzed STS (2) we observed 15 to 40 stagnation events per year (SF: 15-25 %), which shows the relevance of this operation state.

The extended version of the paper comprehensively describes the recent standards of dimensioning large-scale ETC fields for feeding DH networks. Several parameters, e.g. solar fraction, storage volume, grid temperatures and stagnation, will be discussed as a result from our analysis (1) and (2) as well as by a concrete monitored STS (3). Finally, the article will give an outlook to an optimized system concept with intrinsically safe overheating prevention.

Toward a reference model for thermal energy–balanced ems: Review of 5gdhc and Korean implications

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South Koreas district heating infrastructure is primarily based on centralized systems using high-temperature hot water distribution. This structural limitation hinders the integration of low-temperature distributed heat sources and the implementation of demand-responsive control and thermal energy trading. In particular, the existing heat supply infrastructure was designed based on a large-scale, unidirectional thermal supply system. As a result, it lacks the operational flexibility to support distributed heat sources, demand-responsive control strategies, or energy transactions among multiple stakeholders. Moreover, due to the absence of a thermal energy management system (EMS) capable of coordinating real-time supply and demand, energy operations are confined to individual facility control. As a result, there is a growing demand for a next-generation EMS that can integrate and manage multiple energy such as electricity and heat at the district.

This study serves as a preparatory step toward establishing a reference model for implementing a thermal energy–balanced EMS. The objective is to identify the core functions and structural components necessary for next-generation district energy systems. Pilot cases of fifth-generation district heating and cooling (5GDHC) were reviewed to organize key concepts and operational structures, and to assess their applicability to Korean conditions. The case studies were compared and organized with a focus on system architecture, control strategies, and communication interfaces. From this analysis, structural insights were derived to support the future design of a thermal energy–balanced EMS reference model.

Acknowledgements

This research was funded by the Energy Technology Development Program of the Korea Institute of Energy Technology Evaluation and Planning (No. RS-2025-02317972).

IEA DHC Annex TS8: Experimental investigations of DHC systems

8 September: 14.00-15.30 - Sun

Reaching climate targets requires transforming and expanding district heating (DH) networks. The use of variable and multivalent heat sources calls for digitalisation, sector coupling and innovative operating strategies. Laboratory and field experiments—supported by digital applications such as digital twins—enable the investigation and development of realistic DH supply concepts. Compared to simulation-based approaches, these methods offer deeper insights into physical behaviour and support the improvement and validation of software tools and calculation data.

Within this context, the IEA DHC Annex TS8 project promotes experimental research to support the development of advanced DH strategies. It focuses on identifying promising digital technologies, compiling robust design and control methods, and assessing requirements for future DH studies. While several experimental facilities are already in operation—often tailored to specific research tasks—linking selected infrastructures may complement and strengthen ongoing investigations. Literature reviews and targeted surveys help map available lab and field setups, contributing to an informed and integrated research landscape.

This session presents key project results and provides insights into experimental research shaping the future of district heating.

Presentations in this special session:

- Anna Cadenbach (Fraunhofer IEE, Germany): Experimental Investigations of DHC Systems: Innovative Approaches to Optimise District Heating Networks for Sustainable Development
- Oliver Gehrke (Technical University of Denmark (DTU), Denmark): Experimental characterization of pipe heat flow in a District Energy Laboratory
- Chia Qian Tong (Fraunhofer IEE, Germany): Data-Driven Maintenance in District Heating Substations: FMEA-Based Failure Prediction and Efficiency Optimization
- Basit Wani Mohd (TalTech, Estonia): Integration of Decentralized Renewable Energy Sources into DHC Systems: Technical Challenges and Experimental Solutions

IEA DHC annex TS5 & LIFE supportDHC project: Decarbonising DHC with renewables and waste heat: from research to on-site support

8 September: 14.00-15.30 - Wind

The joint IEA DHC Annex TS5 & LIFE SupportDHC Project Special Session will explore the practical transformation of district heating and cooling (DHC) systems through the integration of renewable energy and waste heat. Experts involved in both the project and the expert group will share real-life case studies, insights from research and planning, and methodologies for assessing renewable energy potential using GIS tools. The session will conclude with a panel discussion bridging policy, research, and on-the-ground implementation.

Presentations in this special session:.

- Thomas Pauschinger (AGFW, Germany): Welcome & Introduction. Introduction to the IEA DHC Annex TS5 group and the LIFE SupportDHC project. Background on DHC transformation and practical experiences from Germany
- Ingo Leusbrock (AEE INTEC, Austria): Key insights on planning and implementing DHC transformation processes. Lessons learnt from case studies
- Alice Dénarié (Politecnico di Milano, Italy) Supporting DHC operators: Present experiences from the field. Overview of diverse starting situations among DHC operators. Types of support activities and present experiences in the project
- Urban Persson (Halmstad University, Sweden): RES Potential Assessment. An analytical framework for methodologies. Application of GIS tools to selected SupportDHC operators

Co-funded by the European Union

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- Edmund Widl (AIT, Austria): An Overview of the Networking Potential of DHC Test Facilities
- Jad Al Koussa (EnergyVille/VITO, Belgium): A literature review on ongoing and recently completed research projects involving experimental investigations related to district heating and cooling

IEA DHC annex TS6: Status assessment, ageing, lifetime prediction and asset management of district heating pipes

8 September: 16.00-17.30 - Sun

Existing DH networks are the pillar for the implementation of the European climate targets. A lot of DH pipes in these networks have been built before the 1990s and to ensure the security of supply we need to know their remaining service life as well as targeted maintenance strategies. Requirements for maintenance strategies are meaningful inventory, accurate damage statistics, and comprehensive operating data as well as reliable simulation results from asset management tools. Scarce existing data in combination with the numerous influences on the service life of a DH pipes result great uncertainties in asset management. The IEA DHC Task Shared 6 Project is collecting and gaining research results regarding the forecasting accuracy of the remaining service life of the DH pipes and to improve asset management simulations.

The IEA DHC Annex TS6 Session will summarize previous project results and provide in-depth insights into the remaining service life of prefabricated DH pipes aged in operation.

Presentations in this special session:

- Stefan Hay (AGFW, Germany) The TS6 Project: overall objectives and results gained
- Comparison of different methods for status assessment and service life prediction of pre-fabricated district heating pipes aged in operation:
  - Tillmann Deselaers (AGFW, Germany) – The samples history: locations, loads and operational conditions
  - Nazdaneh Yarahmadi (RISE, Sweden) – Results gained with RISE PipeOpsy
  - Andreas Leuteritz (IPF Dresden, Germany) – Results gained based on current standards and chemical analysis of polyurethane foam
  - Stefan Hay (AGFW, Germany) – Summary and Conclusions
- Ingo Kropp (3S Consult, Germany) Asset Management of DH Pipes: researchers' perspective

- N.N. (DH operator) Asset Management of DH Pipes: practical experiences
- Anna Cadenbach (Fraunhofer IEE, Germany) Creating a Future Perspective for DH networks based on general trends and improved Asset Management Simulation

IEA DHC annex TS9: Digitalisation of district heating and cooling, improving efficiency and performance through data integration

8 September: 16.00-17.30 - Wind

District heating and cooling (DHC) systems have traditionally operated with limited controls which lack detailed insights into supply and utilization structures, hindering optimal heat generation and network operation. Digitalization offers new opportunities for more efficient and sustainable management of DHC systems, enabling better integration of renewable sources, improved network operation, and enhanced end-user experiences. In transitioning to a 100% renewable energy system, digitalizing DHC systems is crucial, as it optimizes generation and network operations, improves heating system control in buildings, and empowers end-consumers.

This session will explore the impact of digitalization on the DHC industry, highlight state-of-the-art technology, and discuss challenges and opportunities for integrating digital processes into DHC systems. By focusing on the potential to enhance the 4th Generation District Heating (4GDH) system, the workshop seeks to empower stakeholders with the knowledge needed for informed decision-making and optimization of DHC performance and data utilization.

Presentations in this special session:

- Dietrich Schmidt (Fraunhofer IEE, Germany) Digitalization of district heating: Enabling technology for transforming heat networks
- Edmund Widl (AIT, Austria) Challenges for data access and data interoperability in DHC
- Qian Wang (KTH, Sweden) Use cases and applications of semantic modelling for DHC and buildings
- Michele Tunzi (DTU, Denmark) Using the flexibility in the network pipes and the buildings to reduce peak loads in a district heating network
- Kristina Lygnerud (LTH, Sweden) & Zheng Grace Ma (SDU, Denmark) How digitalization can impact the business case of DH - online contribution

Design optimization methods for district heating and cooling networks

9 September: 09.00-10.30 - Sun

With an evolution to low and very-low temperature networks, multiple (intermittent) heat producers, and heat storage, the design of heating networks has become increasingly complex. In recent years, several methods have been introduced to automatically design heating networks based on mathematical optimization strategies, including cost-effective network topologies, dimensioning of pipes and producers, and operational parameters. The resulting mathematical optimization problem is complex with discrete variables and intrinsic nonlinear model aspects that often necessitate simplification to linearized programming approaches. More recently, different nonlinear optimization approaches have emerged as alternatives that are able to maintain the nonlinear nature of the flow and heat transfer.

The aim of this special session is to introduce and review the different optimization approaches for design optimization, present state-of-the-art topics in different approaches, and discuss on their virtues and drawbacks.

Presentations in this special session:

- Maarten Blommaert (EnergyVille/KU Leuven, Belgium) Review on Design Optimization Methods for District Heating Networks
- Kobus Van Rooyen (TNO, Netherlands) Integral Heating and Cooling Optimization of District Heating Networks
- Nicolas Vasset (CEA-LITEN, France) Multi-scenario design optimization of district heating networks with thermal-hydraulic validation
- Martin Sollich (EnergyVille/KU Leuven, Belgium) Optimal Placement of Heat Pump Substations in District Heating Networks for Cost-Effective Temperature Reduction

DENSE (Dependable Smart Energy Systems) PhD topic pitches

9 September: 09.00-10.30 & 11.00-12.30 - Wind

This special session is dedicated to the DENSE (Dependable Smart Energy Systems) project, a 4-year Marie Skłodowska-Curie Actions-Doctoral Network (HORIZON-TMA-MSCA-DN) funded within the framework of the HORIZON EUROPE Program. 12 doctoral candidates from the DENSE (Dependable Smart Energy Systems) project will present their progress and goals. They want to reach out to experts within the various relevant fields, creating awareness for the groundbreaking research topics they are exploring and searching for valuable feedback and perhaps collaboration opportunities.

DENSE is addressing individual research projects and training of early-stage researchers in the innovative dependable engineering of Smart Energy Systems (SESs) with the main focus on robustness as well as preventive and corrective actions under uncertainty. Dependability of complex networks, such as SESs, characterizes their ability to deliver services that can justifiably be trusted. Thus, dependability comprises system attributes, such as availability, reliability, safety, integrity and maintainability. A key requirement of dependability is the desire for providing justifiable trust in the system performance. Hence, rigorous systems engineering yielding provable performance guarantees throughout the system's lifetime is already required at the design stage.

Presentations in this special session:

- The 12 doctoral candidates will pitch the progress and the goals of their PhD research

Community-led Heating and Cooling: The Road to the EU's Thermal Democratisation

9 September: 11.00-12.30 - Sun

The goal of this special session is to inform the audience about Community-led Heating and Cooling Networks, including the number of Community-led Heating and Cooling Networks projects (REScoop.eu data), their citizen-led nature, their drivers and barriers, while offering policy recommendations for their replication.

This special session will combine presentations with active audience participation, discussing the barriers that were faced in heating and cooling decarbonisation.

The Target audience for this session are local and regional authorities, potential developers (cooperatives, small utilities, energy communities, etc.) and energy experts

Presentations in this special session:

- Covenant of Mayors: Introduction to local authorities' needs for heating and cooling decarbonisation and municipal heating and cooling planning.
- REScoop.eu: Introduction to energy communities and their Community-led Heating and Cooling initiatives
- ConnectHeat: Presentation of project and results

Geothermal Workshop: Establishing the Future of Geothermal and Underground Thermal Storage Solutions for DHC networks

9 September: 14.00-15.30 - Sun

Join us for an interactive workshop dedicated to advancing geothermal and underground thermal energy storage solutions for district heating and cooling networks.

The session will begin with a round of 2-minute participant pitches to stimulate ideas and highlight ongoing initiatives. This introduction round will be followed by a collaborative working session aimed at outlining the key contents of a strategic white paper. The ambition of the special session is to identify together opportunities and barriers, innovation needs, explore implementation pathways, and ideally match contributors to sections of the paper.

This is a unique opportunity to help drive and support the development of sustainable, low-carbon thermal networks, and contribute to a document that will inform future research and investment agendas in the sector.

Be part of the conversation — and the solution!

Technical tours

Collecting point: Thor Central

To make this 19th edition a perfect blend of knowledge exchange, networking and local discovery, participants can choose one of the following technical visits on Wednesday 10 September (only for those who have registered in advance):

Genk: Explore the Open Thor Living Lab, where innovative energy solutions are developed, tested and demonstrated, and enjoy a guided walk through Thor Park with a ranger.

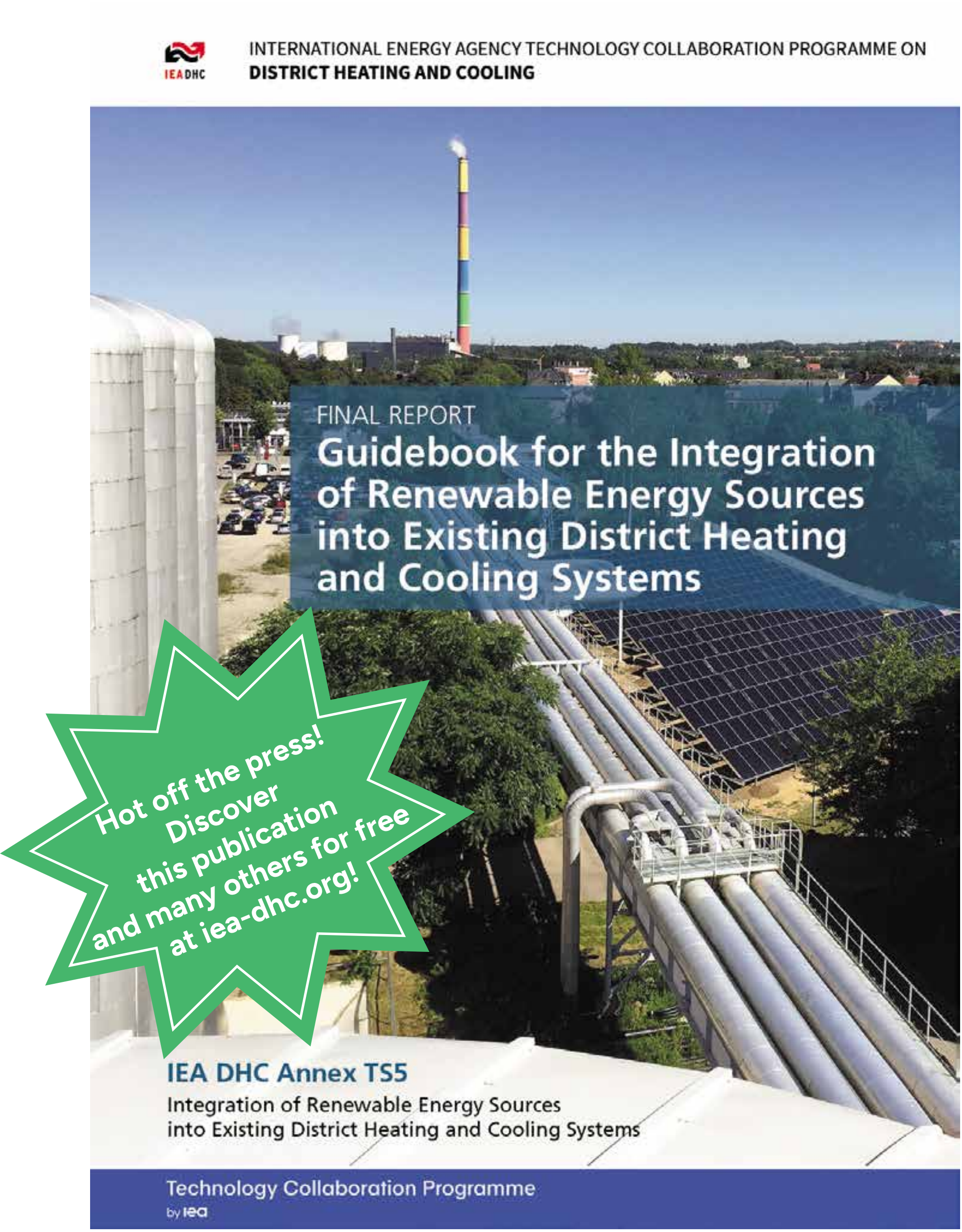
- 08.30-09.00: registration at Thor Central
- 09.00-12.00: Visit Open Thor
- 12.00-13.00: Lunch at Thor Central
- 13.00-15.00: Walk with the ranger in The National Park Hoge Kempen

Mol – Antwerp: Discover the geothermal site in Mol and the district heating network in Antwerp — perfectly connected to Brussels Airport and Brussels South Station for those travelling onwards.

- 08.30-09.00: registration at Thor Central
- 09.00-10.00: Travel to Mol
- 10.00-12.00: Visit to the geothermal central
- 12.00-13.00: Transfer to Antwerp + Lunch in the bus
- 13.00-16.00: Visit to the Fluvius heating network

Genk: Visit C-Mine, a beautifully redeveloped mining site that celebrates industrial heritage, and combine it with a visit to the Open Thor Living Lab.

- 08.30-09.00: registration at Thor Central
- 09.00-12.00: Visit to C-Mine
- 12.00-13.00: Lunch at Thor Central
- 13.00-15.00: Visit Open Thor


INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME ON
DISTRICT HEATING AND COOLING

FINAL REPORT
Guidebook for the Integration of Renewable Energy Sources into Existing District Heating and Cooling Systems

IEA DHC Annex TS5
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