Book of abstracts: 3rd International Conference on Smart Energy Systems and 4th Generation District Heating

National Museum, Copenhagen, 12-13 September 2017

Lund, Henrik; Mathiesen, Brian Vad

3RD INTERNATIONAL CONFERENCE ON SMART ENERGY SYSTEMS AND 4TH GENERATION DISTRICT HEATING

BOOK OF ABSTRACTS

AALBORG UNIVERSITY DENMARK
Innovation Fund Denmark
reINVEST
DET OBELSKE FAMILIEFOND
4DH

COPENHAGEN, 12-13 SEPTEMBER 2017

3rd International Conference on Smart Energy Systems and
4th Generation District Heating, 12-13 September 2017

Book of Abstracts

Aalborg University
Department of Development and Planning
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May-Britt Vestergaard Knudsen

Preface

It is a great pleasure to welcome you to the 3rd International Conference on **Smart Energy Systems and 4th Generation District Heating** at Aalborg University in Copenhagen, 12-13 September 2017. This year the conference is organised by two research centres/projects in collaboration with Aalborg University. The one is the 4DH Strategic Research Centre and the other is the project re-INVEST both supported financial by the Danish Innovation Fund.

After the previous two year´s success in Copenhagen 2015 with more than 70 presentations and 180 participants and in Aalborg with 115 presentations and 300 participants, we are indeed happy to be able to announce an increase to 150 presentations in 6 parallel sessions with around 350 participants from 25 countries around the world. We wish to thank everyone for your valuable contributions.

The aim is to present and discuss scientific findings and industrial experiences related to the development of Smart Energy Systems and future 4th Generation District Heating Technologies and Systems (4GDH). This development is fundamental to the implementation of the European 2020 goals as well as future sustainable energy solutions in general.

The Smart Energy System approach was defined in 2011 in the CEESA project. The project addressed Danish scenarios with a particular focus on renewable energy in the transport system in a context with limited access to bioenergy.

The Smart Energy System concept is essential for 100% renewable energy systems to harvest storage synergies and exploit low-value heat sources. The most effective and least-cost solutions are to be found when the electricity sector is combined with the heating and cooling sectors and/or the transport sector. Moreover, the combination of electricity and gas infrastructures may play an important role in the design of future renewable energy systems.

In its research on low-temperature district heating, the Strategic Research Centre for 4th Generation District Heating Technologies and Systems enhances the understanding of supply system design, infrastructure and heat savings.

We hope you all will have a fruitful conference.

Prof. Henrik Lund and Prof. Brian Vad Mathiesen
Conference organisers

For reasons of copyright, the following journal papers are not included in the electronic version of Book of Abstracts 2017:

4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems (Energy 68 (2014) pp. 1-11)

Smart Energy Systems for coherent 100% renewable energy and transport solutions (Applied Energy 145 (2015) pp. 139-154)

Smart energy and smart energy systems
(Energy 137 (2017) pp. 556-565)

International review of district heating and cooling
(Energy 137 (2017) pp. 617-631)

Contents

3rd International Conference on

Smart Energy Systems and 4th Generation District Heating

12-13 September 2017 · Copenhagen

AALBORG UNIVERSITY
DENMARK

Call for abstracts

The Smart Energy System concept is essential for 100% renewable energy systems to harvest storage synergies and exploit low value heat sources. The Smart Energy System approach was defined in 2011 in the CEESA project. The project addressed Danish scenarios with a particular focus on renewable energy in the transport system in a context with limited access to bioenergy. As opposed to, for instance, the smart grid concept, which takes a sole focus on the electricity sector, the smart energy systems approach includes the entire energy system in its identification of suitable energy infrastructure designs and operation strategies. Focusing solely on the smart electricity grid often leads to the definition of transmission lines, flexible electricity demands, and electricity storage as the primary means to dealing with the integration of fluctuating renewable sources. However, these measures are neither very effective nor cost-efficient considering the nature of wind power and similar sources. The most effective and least-cost solutions are to be found when the electricity sector is combined with the heating and cooling sectors and/or the transport sector. Moreover, the combination of electricity and gas infrastructures may play an important role in the design of future renewable energy systems. In its research on low-temperature district heating, the Strategic Research Centre for 4th Generation District Heating Technologies and Systems enhances the understanding of supply system design, infrastructure and heat savings. In future energy systems, combinations of low-temperature district heating resources and heat savings represent a promising alternative to individual heating solutions and passive or energy+ buildings. This change in the heating system also requires institutional and organisational changes that address the implementation of new technologies and enable new markets that can provide feasible solutions to society.

We invite researchers and experts from industry and businesses to contribute to further enhancing the knowledge of Smart Energy Systems and 4th Generation District Heating.

Important Dates 2017

19 April - Deadline for submission of abstracts for speakers
(**NB** Additional upgrade to paper is optional)

5 May - Reply on acceptance of abstracts

22 May - Early registration deadline

Topics

4th Generation District Heating concepts

Smart Energy System analyses

Smart Energy infrastructure and storage options

Institutional and organizational change for Smart Energy Systems and radical technological change

Low-temperature district heating grids and buildings

Future district heating production and systems

District heating planning and organisation

District heating and Geographical Information Systems (GIS)

District heating components and systems

District heating and Renewable Energy Sources

Fee including materials, coffee, lunches and conference dinner:

- Normal fee: **350 EUR**
- Early registration (for presenters with accepted abstracts): **250 EUR**

4DH
4th Generation District Heating Technologies and Systems

Heat Roadmap Europe 2050

re INVEST

3rd International Conference on

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12-13 September 2017 · Copenhagen

AALBORG UNIVERSITY
DENMARK

Aim and Organisers

The aim of the conference is to present and discuss scientific findings and industrial experiences related to the subject of Smart Energy Systems based on renewable energy and future 4th Generation District Heating Technologies and Systems (4GDH). It is organized by the 4DH Strategic Research Centre and the RE-INVEST project in collaboration with Aalborg University. 4DH is an international research centre which develops future 4th generation district heating technologies and systems. This development is fundamental to the implementation of Smart Energy Systems to fulfil national objectives of future low carbon strategies as well as the European 2020 goals. With lower and more flexible distribution temperatures, 4GDH can utilize renewable energy sources, while meeting the requirements of low-energy buildings and energy conservation measures in the existing building stock. RE-INVEST is an international research project which develops robust and cost-effective renewable energy investment strategies for Denmark and Europe.

Location

The conference will take place at The National Museum of Denmark in Copenhagen city centre, and the Conference Dinner will take place at the historic Tivoli Gardens.

Photo by May-Britt Vestergaard Knudsen

Submission Procedure

Both scientific and industrial contributions to the conference are most welcome. Submitted abstracts will be reviewed by a scientific and an industrial committee. Authors of approved abstracts will be invited to submit papers to special issues of ENERGY - The International Journal and the International Journal of Sustainable Energy Planning and Management.

Best Presentation Awards will be given to a selected number of presenters at the conference.

Abstracts may be presented at the conference without uploading papers, as this is not a requirement.

Please send your one-page abstract to **4dhConference@plan.aau.dk** before 19 April 2017 including this submission form.

Photos by May-Britt Vestergaard Knudsen

International Scientific Committee

Prof. Dagnija Blumberga, Riga Technical University, Latvia
Dr. Robin Wiltshire, Building Research Establishment (BRE), UK
Dr. Anton Ianakiev, Nottingham Trent University
Dr. Ralf-Roman Schmidt, Austrian Institute of Technology, Austria
Prof. Dr.-Ing. Ingo Weidlich HafenCity Universität, Germany
Prof. Eric Ahlgren, Chalmers University of Technology, Sweden
Prof. Sven Werner, Halmstad University, Sweden
Prof. Leif Gustavsson, Linnaeus University, Sweden
Prof. Niels I. Meyer, Technical University of Denmark
Prof. Poul Erik Morthorst, Technical University of Denmark
Prof. Svend Svendsen, Technical University of Denmark
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Prof. Neven Duic, University of Zagreb, Croatia
Ass. Prof. Carsten Bojesen, Aalborg University, Denmark
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Industrial Committee

Anders Bavnhøj Hansen, Energinet.dk
Anders Dyrelund, Rambøll
Jan-Eric Thorsen, Danfoss
Birger Laursen, Dansk Fjernvarme
Jørn Urup Nielsen, DESMI Pumping Technology
Anders N. Andersen, EMD International
Anders Skallebæk, Kamstrup
Allan Hansen, LOGSTOR
Per Wulff, Vestforbrænding
Morten Abildgaard, Viborg Fjernvarme
Jesper Møller Larsen, Aalborg Forsyning, Varme

Conference Chairs

Prof. Henrik Lund and Prof. Brian Vad Mathiesen,
Aalborg University, Denmark

Further information

www.4dh.eu www.heatroadmap.eu www.reinvestproject.eu

#SES4DH2017

3rd International Conference on

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AALBORG UNIVERSITY DENMARK

Monday 11 September 2017 · Programme

4DH

Heat Roadmap Europe 2050 — A low-carbon heating and cooling strategy

reINVEST

4DH Technical Tour at EnergyLab Nordhavn

Demonstrating integrated and flexible energy systems

From 2015-2019 the EnergyLab Nordhavn project will develop and demonstrate future energy solutions. The project utilizes Copenhagen's Nordhavn as a full-scale smart city energy lab and demonstrates how electricity and heating, energy-efficient buildings and electric transport can be integrated into an intelligent, flexible and optimized energy system. During the presentation you will meet both HOFOR and Danfoss who are partners in EnergyLab Nordhavn. They will discuss low-temperature district heating, district heating flexibility as well as smart components and heat boosters.

The project is supported by EUDP (Energy Technology Development and Demonstration Programme).

The tour will start outside Vesterbrogade 1E, 1620 Copenhagen

Deadline for registration is September 1st. Registration is binding (Limited to 40 people).

Please register here:
https://http://www.4dh.eu/conferences/conference-2017/technical-tours

Heat Road Map Europe Workshop

13:00 Arrival with coffee and tea
13:30 Introduction to the worshop (Tobias Fleiter)
13.40 The Heat Roadmap Europe project (Brian Vad Mathiesen)
13:50 Discussion of tools and method
13:50 Panel: Tools and methods applied in H/C projects and teaser for group discussion
Hot Maps: **What are the user needs?** (Jørgen Lindgaard Olesen)
PLANHEAT: **Mapping waste heat at urban level (**Stefano Barberis)
PLANHEAT: **How can we map heating and cooling?** (Erwin Cornelis)
progRESsHEAT: **Integrated modelling of heat savings and heat supply** (Stefan Petrovic)
Heat Roadmap Europe: **H&C in energy systems modeling** (Brian vad Matthiesen)
14:20 Break out groups: Discussion on 5 individual topics
15:00 Panel: Summary of conclusions and suggestions for ways forward to improve tools and methods
15:30 End of workshop and networking coffee

Venue: BLOX HUB, Building C, Frederiksholms Kanal 30, 1220 Copenhagen

Please register by sending an e-mail to: HRE4@isi.fraunhofer.de

A progRESsHEAT workshop follows the HRE4 workshop: Navigating the transition to renewable heating and cooling in Europe. The workshop is in the same venue as the HRE4 workshop from 16.00 until 17.45. Registration necessary at http://www.progressheat.eu/

High Temperature Heat Pump Workshop

The workshop will focus on the development and applications of heat pumps for supply of heat at high temperature with a special focus on:

Market for high temperature heat pumps in industrial applications and district heating: Potential, mapping, policies and legislation, barriers for applications
R&D-Projects from academia and industry: Cycle layouts, working fluids and compression technologies
Market ready solutions
Industrial cases

Venue: The National Museum - Prinsens Palæ, Ny Vestergade 10 , Copenhagen, from 9.00 to 16.00 .

Go to: http://www.conferencemanager.dk/HighTemperatureHeatPumps/ for more information and registration. We encourage you to sign up for the workshop until 31 August.

Participants of the 4DH conference on district heating may join the workshop for free.

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DENMARK

Tuesday 12 September 2017 · Overall programme

08:00-09:00 Registration and breakfast — **OUTSIDE THE EGMONT HALL, 1ST FLOOR**

09:00-10:30 ***1st plenary session chaired by Brian Vad Mathiesen:*** **4GDH Perspectives and results**

09:00 Opening speech by Henrik Lund

09:15 Plenary keynote by Professor Sven Werner: **World DH status and Transformation Roadmap for 4GDH**

09:45 Plenary keynote by Morten Abildgaard; CEO Viborg District Heating: **Data Centers and 4GDH in practice - the case of Viborg**

10:15 Questions and discussion

THE EGMONT HALL, 1ST FLOOR

10:30-11:00 Coffee break — **THE EGMONT HALL, 1ST FLOOR**

Parallel sessions 1-6

11:00-12:30 EGMONT HALL 1ST FLOOR
Session 1: Smart Energy Systems
Chair: Morten Abildgaard
Session keynote and co-chair: Rasmus Aaen
Pierre Vogler-Finck
Borna Doračić
Philipp Geyer
Jay Hennessy

11:00-12:30 ASSEMBLY HALL , 1ST FLOOR
Session 2: Future district heating production and systems
Chair: Anders Dyrelund
Session keynote and co-chair: Erik O. Ahlgren
Bernd Windholz
Renaldi Renaldi
Hrvoje Dorotić
Kristina Lygnerud

11:00-12:30 U1, 1ST FLOOR
Session 3: Energy planning and planning tools
Chair: Neven Duic
Session keynote and co-chair: Peter Jorsal
Jigeeshu Joshi
Jürgen Knies
Johan Dalgren
Bram van der Heijde

11:00-12:30 U3, 1ST FLOOR
Session 4: Low-temp district heating grids
Chair: Helge Averfalk
Session keynote and co-chair: Oddgeir Gudmundsson
Kim Rolin
Christian Engel
Ashreeta Prasanna
Markus Rabensteiner

11:00-12:30 U2, 1ST FLOOR
Session 5: Low-temperature DH and buildings.
Chair: Svend Svendsen
Session keynote and co-chair: Anna Volkova
Danhong Wang
Andra Blumberga
Asad Ashfaq
Xiaochen Yang

11:00-12.30 CINEMA GF
Session 6: Future district heating production and systems
Chair: Anders N. Andersen
Session keynote and co-chair: Linn Laurberg Jensen
Nadège Vetterli
Henrik Pieper
Anna-Elisabeth Lehmkuhl
Benjamin Zühlsdorf

12:30-13:30 Lunch — **THE EGMONT HALL, 1ST FLOOR**

12:30-13:00 Steering Committee Meeting (4DH SC members only)

Parallel sessions 7-12

13:30-15:00 EGMONT HALL, 1ST FLOOR
Session 7: Smart Energy Systems
Chair: Jesper Møller Larsen
Session keynote and co-chair: Tobias Fleiter
Hanmin Cai
Sylvain Quoilin
Foteini Rafaela Tsaousi

13:30-15:00 ASSEMBLY HALL, 1ST FLOOR
Session 8: Future district heating production and systems.
Chair: Dagnija Blumberga
Session keynote and co-chair: Louise Ödlund
Jelena Ziemele
Gunnar Lennermo
Johannes Pelda
Ivan Andrić

13:30-15:00 U1, 1ST FLOOR
Session 9: Energy planning and planning tools
Chair: Nina Detlefsen
Session keynote and co-chair: : Niels Frank
Daniel Møller Sneum
Matteo Giacomo Prina
David Drysdale
Hanne Kauko

13:30-15:00 U3, 1ST FLOOR
Session 10: Low-temp district heating grids
Chair: Jan Erik Thorsen
Session keynote and co-chair: Steen Schelle Jensen
Dietrich Schmidt
Paolo Leoni
Stefan Blomqvist
Max Bachmann

13:30-15:00 U2, 1ST FLOOR
Session 11: Low-temperature DH and buildings.
Chair: Sven Werner
Session keynote and co-chair: Svend Svendsen
Knut Bernotat
Soma Mohammadi
Natasa Nord
Ivo Pothof

13:30-15:00 CINEMA, GF
Session 12: Smart Energy Systems.
Chair: Frede Hvelplund
Session keynote and co-chair: Bent Ole Gram Mortensen
Juan P. Jiménez
Ambrose Dodoo
Lennart Rogenhofer
Wiebke Meesenburg

Tuesday 12 September 2017 · Overall programme (continued)

15:00-15:30 Coffee break — **THE EGMONT HALL, 1ST FLOOR**

Parallel sessions 13-18

15:30-17:00 EGMONT HALL, 1ST FLOOR	15:30-17:00 ASSEMBLY HALL,, 1ST FLOOR	15:30-17:00 U1, 1ST FLOOR	15:30-17:00 U3, 1ST FLOOR	15:30-17:00 U2, 1ST FLOOR	15:30-17:00 CINEMA, GF
Session 13: Smart Energy Systems	**Session 14: Future district heating production and systems**	**Session 15: Energy planning and planning tools**	**Session 16: Low-temp district heating grids**	**Session 17: Low-temperature DH and buildings.**	**Session 18: Future district heating production and systems**
Chair: Marie Münster	**Chair: Erik O. Ahlgren**	**Chair: Bent Ole G. Mortensen**	**Chair: Steen Schelle Jensen**	**Chair: Leif Gustavsson**	**Chair: Rasmus Aaen**
Session keynote and co-chair: Carsten Bojesen	**Session keynote and co-chair: Dagnija Blumberga**	**Session keynote and co-chair: Frede Hvelplund**	**Session keynote and co-chair: Helge Averfalk**	**Session keynote and co-chair: Carsten Østergård Pedersen**	**Session keynote and co-chair: Anders N. Andersen**
Benedetto Nastasi	M. Leurent	Stefan Petrovic	Andrew F. Lyden	Johnny Iversen	Alfonso Gordaliza Pastor
Annelies Vandermeulen	Danica Djuric Ilic	Patryk Chaja	Alexei Sednin	Maria Justo Alonso	Thibaut Richert
Mei Gong	Goran Krajacic	Eva Wiechers	Nicole Pini	Roar Nysted	
Miaomiao He	Zikun Wang			Hironao Matsubara	

17:00-17:20 Launch of Heat Roadmap Europe – Pan-European Thermal Atlas 4 version 2.0 (Peta4) — **THE EGMONT HALL, 1ST FLOOR**

17:20-19:30 Break - possible to visit Tivoli Garden before the Conference dinner in GROEFTEN, TIVOLI

19:30- Conference dinner GROEFTEN, TIVOLI

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AALBORG UNIVERSITY DENMARK

Wednesday 13 September 2017 · Overall programme

08:00-09:00 Coffee — **EGMONT HAAL, 1ST FLOOR**

Parallel sessions 19-24

9:00-10:30 EGMONT HALL, 1ST FLOOR	9:00-10:30 ASSEMBLY HALL 1ST FLOOR	9:00-10:30 U1, 1ST FLOOR	9:00-10:30 U3, 1ST FLOOR	9:00-10:30 U2, 1ST FLOOR	9:00-10.30 CINEMA GF
Session 19: Smart Energy Systems	**Session 20: Future district heating production and systems**	**Session 21: Energy planning and planning tools**	**Session 22: Energy planning and planning tools**	**Session 23: Low-temperature district heating and buildings**	**Session 24: Future district heating production and systems**
Chair: Tobias Fleiter	**Chair: Georg K. Schuhardt**	**Chair: Urban Persson**	**Chair: Poul Østergaard**	**Chair: Carsten Bojesen**	**Chair: Louise Ödlund**
Session keynote and co-chair: Kerstin Sernhed	**Session keynote and co-chair: Torben Ommen**	**Session keynote and co-chair: Ralf-Roman Schmidt**	**Session keynote and co-chair: Markus Köfinger**	**Session keynote and co-chair: Matthew Gentry**	**Session keynote and co-chair: Luc Girardin**
Andrei David	Magnus Dahl	Pablo Puerto	Gorm Bruun Andresen	Yasameen Al-Ameen	Julian Formhals
Nadine Aoun	Oliver Martin-Du Pan	Eftim Popovski	Olatz Terreros	Michele Tunzi	Somil Miglani
Søren Møller Thomsen	Patrick Reiter	Kanau Takahashi	Maarten Blommaert	Dorte Skaarup Østergaard	Jukka Aho
Alexander Tureczek	William R H Orchard	Rasmus Lund	Lars Grundahl	Isabelle Best	

10:30-11:00 Coffee break — **THE EGMONT HALL, 1ST FLOOR**

Parallel sessions 25-30

11:00-12:30 EGMONT HALL, 1ST FLOOR	11:00-12:30 ASSEMBLY HALL, 1ST FLOOR	11:00-12:30 U1, 1ST FLOOR	11:00-12:30 U3, 1ST FLOOR	11:00-12:30 U2, 1ST FLOOR	11:00-12.30 CINEMA GF
Session 25: Smart Energy Systems	**Session 26: Future district heating production and systems**	**Session 27: Energy planning and planning tools**	**Session 28: Organisation, ownership and institutions**	**Session 29: Energy planning and planning tools**	**Session 30: Future district heating production and systems**
Chair: Gorm B. Andersen	**Chair: Torben Ommen**	**Chair: Ralf-Roman Schmidt**	**Chair: Ingo Wiedlich**	**Chair: Knut Bernotat**	**Chair: Poul Østergaard**
Session keynote and co-chair: Leif Gustavsson	**Session keynote and co-chair: Georg K. Schuchardt**	**Session keynote and co-chair: Urban Persson**	**Session keynote and co-chair: Marie Münster**	**Session keynote and co-chair: Davy Geysen**	**Session keynote and co-chair: Veit Bürger**
Peter Sorknæs	Joseph Maria Jebamalai	Steffen Nielsen	Søren Djørup/Jakob Zink	Charlotte Marguerite	Daniele Basciotti
Hannes Poier	Marcin Bugaj	Ivan Dochev	Daníel E. Vilhjálmsson	Franz Mauthner	Maksym Kotenko
Sarah Bourgarel	Fabian Bühler	Haichao Wang	Richard Büchele	Ina De Jaeger	Miki Muraki
Mathieu Vallée	Ingo Leusbrock		Thomas Pauschinger	Samuel Letellier-Duchesne	Mikel Monclus

12:30-13:30 Lunch — **THE EGMONT HALL, 1ST FLOOR**

13:30-16:00 ***2nd plenary session chaired by Henrik Lund:*** **Towards smart energy systems in Europe and Drivers to expand District Heating** — **THE EGMONT HALL, 1ST FLOOR**

13:30 Plenary keynote by Professor Brian Vad Mathiesen: Towards a smart energy system approach in Europe
14:00 Plenary keynote by Eva Hoos, Policy Officer in DG Energy: High-performance, smart district heating and cooling
14:30 Coffee break in Egmont Hall
14:45 Panel Debate: Drivers and ownership models—how to spread district heating in Europe. Panel Participants: Eva Hoos, Katrina Folland, Ingo Weidlich, Søren Djørup and Brian Vad Mathiesen
15:45-16:00 Closing session and Award Ceremony

Thursday 14 September 2017 · Programme

4 DH Technical Tour

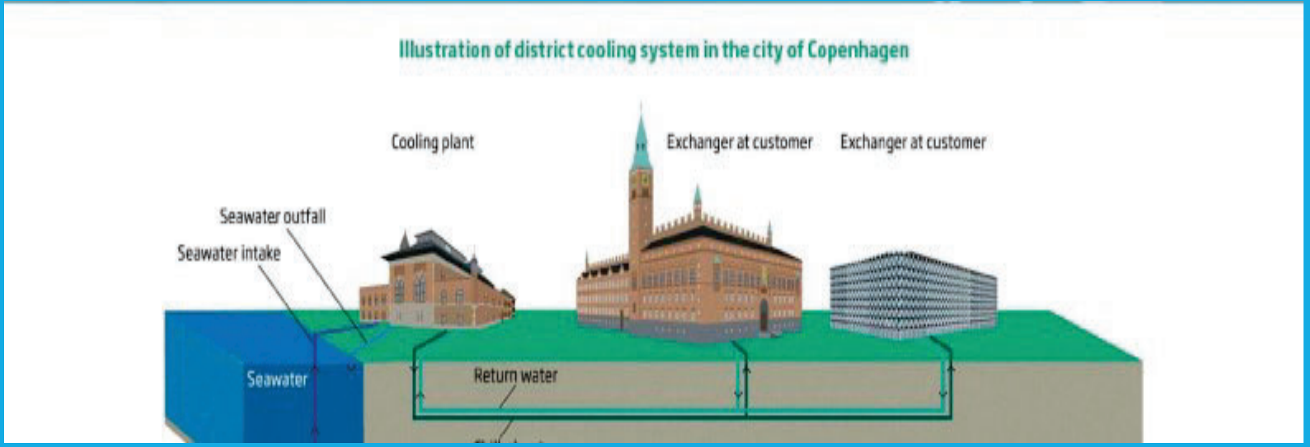
District Cooling Reduces CO2 in Central Copenhagen

In the capital of Denmark, district cooling results in close to 70% reduction in CO2 emissions and 40% reduction in total costs to conventional cooling.

There is an increasing demand for air conditioning and cooling in Copenhagen as in many other cities around the world. The Copenhagen utility company HOFOR, has built a district cooling system, which consists of a distribution net and two cooling plants. The district cooking system users seawater to chill down the water supplied to the customers. The system suppliers commercial buildings such as bank, department stores, and offices as well as cooling for servers and other processers all year round.
Therefore HOFOR can supply the increased demand for cooling in Copenhagen and help reduce CO" emissions by up to 30,000 tonners each year. The cooling system now supplies the centre of Copenhagen with cold water, and the pipe system is expanded in order to supply more customers in the future, and thereby contribute further to Copenhagen's target to become CO2-neutral in 2025.

Date and time: September 14th at 9.30—11.00
The tour will start outside Tietgensgade 33,
1740 Copenhagen
(500 meters from the 4DH Conference)
Deadline for registration is September 1st. Registration is binding.
Please register here:
http://www.4dh.eu/conferences/conference-2017/technical-tours

Note: Limited to 30 people.



Tuesday 12 September 2017 · Content of Sessions

Session 1: Smart Energy Systems

Rasmus Aaen: "Balancing District Heating to increase uptake of low temperature surplus heat sources"
Pierre Vogler-Finck: Online short-term heat load forecast – An experimental investigation on greenhouses
Borna Doračić: Scenario analysis of the renewable district heating system in Ozalj, a small city in Croatia
Philipp Geyer: Technology patterns and business cases for thermo-chemical networks
Jay Hennessy: Techno-economic assessment of heat-to-power use in district heating networks

Session 2: Future district heating production and systems

Erik O. Ahlgren: A system view on carbon impacts of future heating
Bernd Windholz: Application of heat pumps in the district heating network of Vienna
Renaldi Renaldi: Borehole Thermal Energy Storage Modelling in Energy Systems Optimisation
Hrvoje Dorotić: An hourly based optimization model of district heating system with building retrofit with the time horizon of one year, case study of Velika Gorica
Kristina Lygnerud: Risk assessment for industrial heat recovery in district heating systems

Session 3: Energy planning and planning tools

Peter Jorsal: The right pre-insulated pipe system for solar district heating networks
Jigeeshu Joshi: Applying Geographical Information Systems (GIS) to analyse the potential and design of district heating networks
Jürgen Knies: A spatial approach for a future-oriented heat planning in urban areas
Johan Dalgren: The time dependent impact of supply and return temperatures on CHP, HP and FGC production when utilizing a thermal network as energy storage.
Bram van der Heijde: Optimizing thermal energy storage in fourth generation thermal networks

Session 4: Low-temperature district heating grids

Oddgeir Gudmundsson: Cost analysis for Cold District Heating versus Low Temperature District Heating
Kim Rolin: Cost effective 4th generation district heating pipe concepts
Christian Engel: End consumer engagement as a key to successful implementation of 4th Gen DH
Ashreeta Prasanna: Efficiency of centralised and decentralised low temperature district networks compared with individual heating and cooling systems
Markus Rabensteiner: Simulation of bidirectional heat transfer stations in district heating grids

Session 5: Low-temperature district heating and buildings

Anna Volkova: Barriers for transition to 4th generation district heating in existing large networks
Danhong Wang: A methodology on modelling district heating networks with decentralized renewable energy feed-in
Andra Blumberga: Future Buildings as Prosumers Integrated into DH Systems
Asad Ashfaq: Hydraulic control model for the implementation of LTDH in existing boiler based buildings
Xiaochen Yang: Methods of reducing the district heating return temperature from the local substations

Session 6: Future district heating production and systems

Linn Laurberg Jensen: Cold Water District Heating and Cooling Systems as Flexible Energy Exchange Systems – a Promising Concept for the Future?
Nadège Vetterli: Five-year energy monitoring of a low temperature heating and cooling network
Henrik Pieper: Performance analysis of heat pumps utilizing different low temperature heat sources to supply district heating
Anna-Elisabeth Lehmkuhl: Integration of seasonal heat storage systems in existing building structures
Benjamin Zühlsdorf: Potential for performance improvement of booster heat pumps by utilization of mixtures

Session 7: Smart Energy Systems

Tobias Fleiter: Using industrial excess heat in district heating networks - A simulation assessment of potentials and cost-effectiveness for a refinery in Portugal
Hanmin Cai:An Experimental Setup for Investigating Flexibility of District Heating with Fuel Shift
Sylvain Quoilin: Coupling a power system model to a building model to evaluated the flexibility potential of DSM at country level
Foteini Rafaela Tsaousi: The influence of participation in ancillary services markets on optimal energy hub operation<

Session 8: Future district heating production and systems

Louise Ödlund: Cooperation and system perspective for increased sustainability
Jelena Ziemele: Bioeconomy approach in district heating development
Gunnar Lennermo: The value of heat supplied to the return or supply pipe - a comparison of different designs for local heat supply
Johannes Pelda : Quasi-dynamic simulation of district heating systems using hydraulic load factor as key indicator for optimised transition towards 4th generation district heating
Ivan Andrić: The impact of global warming and building renovation measures on district heating networks techno-economic parameters

Session 9: Energy planning and planning tools

Niels Frank: Albertslund – Municipality in transition to low temperature district heating
Daniel Møller Sneum: Socio-economic evaluation of regulatory framework conditions in the heat-electricity interface
Matteo Giacomo Prina: Multi-objective optimization algorithm coupled to EnergyPLAN software: the EPLANopt model
David Drysdale: Low carbon energy system planning in Small and Medium sized Municipalities in Europe
Hanne Kauko: Dynamic modelling of local district heating grids with multiple heat sources and thermal storage

Session 10: Low-temp district heating grids

Steen Schelle Jensen: Smart metering provides the transparency required for efficiency
Dietrich Schmidt: Low temperature district heating for future energy systems
Paolo Leoni: Decreasing district heating network heat losses in the summer months using decentralized systems: A simulation case study
Stefan Blomqvist: Improved energy performance for local ground surface heating in a CHP system
Max Bachmann: Transfer of a 4th generation district heating network from concept study to district level simulation

Session 11: Smart Energy Systems

Svend Svendsen: Solutions for low temperature heating of rooms and domestic hot water in existing buildings
Knut Bernotat: Uncertain Future - How Do Different Ways to Estimate Heat Demand in Retrofitted Buildings Affect District Heating owners?
Soma Mohammadi: Techno-economic analysis of low-temperature district heating network implementation in the city of Nottingham, UK
Natasa Nord: Challenges and potentials for low-temperature district heating implementation in Norway
Ivo Pothof: Maximizing geothermal output by using optimization model for the model-predictive control for a district heating system

Session 12: Smart Energy Systems

Bent Ole Gram Mortensen: Smart Energy Systems and the EU data protection regulation
Juan P. Jiménez :The joint effect of centralized CHP plants and thermal storage on the flexibility of the power system
Ambrose Dodoo: Primary energy benefits of cost-effective energy renovation of a district heated multi-family building under different energy supply systems
Lennart Rogenhofer: Evaluation of innovative heat pump concepts for multi-family houses
Wiebke Meesenburg: Evaluation of the flexibility provided by integrating energy systems using advanced exergoeconomic analysis

Session 13: Smart Energy Systems
Carsten Bojesen: Local Village Heating in a Smart Energy Context
Benedetto Nastasi: Smart Heat sharing for high, medium and low temperature Power-To-Heat solutions
Annelies Vandermeulen: Improving agent-based control performance of thermal networks by inclusion of time delays: a simulation case
Mei Gong: Exergy and cost analysis of heating systems considering energy storage
Miaomiao He: Domestic heat demand prediction and the implications for designing community heat networks

Session 14: Future district heating production and systems
Dagnija Blumberga: Solar collectors versus solar panels in DH
M. Leurent: Socioeconomic potential for deploying large district heating networks using heat from nuclear plants in Europe
Danica Djuric Ilic: Searching for new roles for district heating in a sustainable society
Goran Krajacic: Status and perspectives of district heating systems in Eastern Europe
Zikun Wang: Heat pumps in the UK's district heating: individual, district level, both or neither?

Session 15: Energy planning and planning tools
Frede Hvelplund: Heat conservation incentives and policies for 4th generation district heating systems
Stefan Petrovic: Comparing different district heating supply scenarios with energy savings and individual supply options in six European municipalities
Patryk Chaja: Modelling participation in the Polish Day-Ahead Market (DAM) using a district heating company as a case
Eva Wiechers: Matching district heat demand and excess heat supply using network allocation analysis

Session 16: Low-temperature district heating grids
Helge Averfalk: Pressure situation in low temperature network with a third distribution pipe
Andrew F. Lyden: Unleashing the potential of existing biomass systems via 4th generation district heating and thermal storage: A Scottish perspective
Alexei Sednin: Possibilities of lowering district heating temperatures in Belarus
Nicole Pini: Guidelines for an optimal integration of water-to-water heat pumps in low-temperature district heating networks: lessons learnt from the analysis of three networks in France

Session 17: Low-temperature district heating and buildings
Carsten Østergård Pedersen: Intelligent utilization of pumps in LTDH
Johnny Iversen: Ultra-Low Temperature District Heating Supply in New Build Areas and in Apartment Buildings
Maria Justo Alonso: How low can the heating supply temperature be in different building types in Norway?
Roar Nysted: 4th Generation heating system using geothermal energy as the main source
Hironao Matsubara: The 1st application of 4th Generation District Heating in Japan, its outcomes and lessens

Session 18: Future district heating production and systems
Anders N. Andersen: Distributed CHP units in Denmark are too quickly loosing electricity production
Alfonso Gordaliza Pastor: Renovation towards a smart district heating in Valladolid
Thibaut Richert: Integrating electrical and thermal domains – A case study of the Danish Technical University campus

Wednesday 13 September 2017 · Content of Sessions

Session 19: Smart Energy Systems

Kerstin Sernhed: Synthesis of Swedish District Heating Research between 2013 to 2017

Andrei David: Quantifying the impact of district heating, heat pumps, and electric vehicles in Italy, Romania, and the United Kingdom

Nadine Aoun: A sensitivity analysis to support the modelling of space heating demand in view of developing a load shedding algorithm

Søren Møller Thomsen: The Smart Electricity Storage – District Heating and Cooling with Thermal Storages

Alexander Tureczek: District heat household consumption classification using smart meter data

Session 20: Future district heating production and systems

Torben Ommen: Design considerations for integration of two 5 MW vapour compression heat pumps in the Greater Copenhagen district heating system

Magnus Dahl: Long-term production planning in large district heating systems

Oliver Martin-Du Pan: District Heating Network Pipe Sizing

Patrick Reiter: Focus of IEA SHC Task 55: „Towards the Integration of Large SHC Systems into DHC Networks“

William R H Orchard: Retrofitting the UK domestic sector with Energy Hubs, Exergenius™, and “Keep Hot Flow Pipes

Session 21: Energy planning and planning tools

Ralf-Roman Schmidt: Sustainable heat supply strategies for district heating networks – tools and methodologies

Pablo Puerto: Implementation of distributed co-simulation for urban energy systems

Eftim Popovski: Cost-effectiveness of large scale heat pumps in district heating networks - a simulation model for a case study in Germany

Kanau Takahashi: District heating in Japan – current situation, challenges and possibilities

Rasmus Lund: Heat Roadmap Europe: A Method for linking EU-TIMES and EnergyPLAN energy system models

Session 22: Energy planning and planning tools

Markus Köfinger: Simulation based evaluation of large scale waste heat utilization in the district heating network of Linz (Austria) by optimized integration of a seasonal storage

Gorm Bruun Andresen: User incentives for low-energy renovations in district heating systems of different scales

Olatz Terreros: Comparison of methods for thermal storage sizing in district heating networks

Maarten Blommaert: Towards Adjoint-based Topology Optimization of Thermal Networks

Lars Grundahl: Heat demand mapping implications on energy planning

Session 23: Low-temperature district heating and buildings

Matthew Gentry:L ocal heat, Local Food: utilising district heating systems for urban farming

Yasameen Al-Ameen: Utilizing waste materials from construction and industrial processes as potential ground storage mediums in HGHEs

Michele Tunzi: Design and operation of a low-temperature heat networks in the UK

Dorte Skaarup Østergaard: How to lower the district heating return temperature from historical apartment buildings

Isabelle Best: Low-temperature versus ultra-low temperature solar district heating for low heat density housing developments in Germany

Session 24: Future district heating production and systems

Luc Girardin: Wide scope categorization of DHC systems for the identification of emerging or disruptive technologies

Julian Formhals: Effects of the District Heating Supply Temperature Level on the Efficiency of Borehole Thermal Energy Storage Systems

Somil Miglani: Optimization of solar and ground source district heating system using bottom-up technology models

Jukka Aho: Radically new ways to affect heating energy demand – Case Peak Power Optimization

Session 25: Smart Energy Systems
Leif Gustavsson: Synthesis of Swedish District Energy efficient building blocks and low temperature district heating
Peter Sorknæs: Operational analysis of future renewable energy systems
Hannes Poier: BIG SOLAR GRAZ – Results of a techno-economic feasibility for solar district heating
Sarah Bourgarel: Innovative heat energy supply concepts for multi-family houses: real case evaluation through synergies between simulation and optimization modelling
Mathieu Vallée: Using power-to-heat for flexibility at district level: an overview of use cases

Session 26: Future district heating production and systems
Georg K. Schuchardt: Development of an empirical calculation procedure for determining the thermal conductivity and heat losses of pre-insulated twin pipe systems
Joseph Maria Jebamalai: 4DHC technology guidance and transition strategies for Northwest Europe
Marcin Bugaj: Assessment of primary energy savings through implementation of solar and heat pump hybrid in Warsaw district heating system
Fabian Bühler: Spatiotemporal analysis of industrial excess heat as a resource for district heating in Denmark
Ingo Leusbrock: Tools and methods for modelling district heating systems: A comprehensive comparison

Session 27: Energy planning and planning tools
Urban Persson: Heat Roadmap Europe: Heat distribution costs
Steffen Nielsen: Geographic Placement of Power to Gas Plants in Denmark
Ivan Dochev: Hypothetical heating grid modelling with graph theory. A decision support tool for planning
Haichao Wang: Planning and optimizing the heat production for a district heating system with Chinese demand profiles

Session 28: Organisation, ownership and institutions
Marie Münster : The Danish district heating regulation model in a comparative perspective - and possible impacts of changing it
Søren Djørup/Jakob Zink: Market Structures and Smart Energy Systems
Daníel E. Vilhjálmsson: Identification of potentials and barriers for developing district cooling in Lima, Peru
Richard Büchele: Favourable policy frameworks for renewable heating and district heating – results from local case studies within the progRESsHEAT project
Thomas Pauschinger: Regional Policy and Market Support Initiatives for Solar and Renewable District Heating

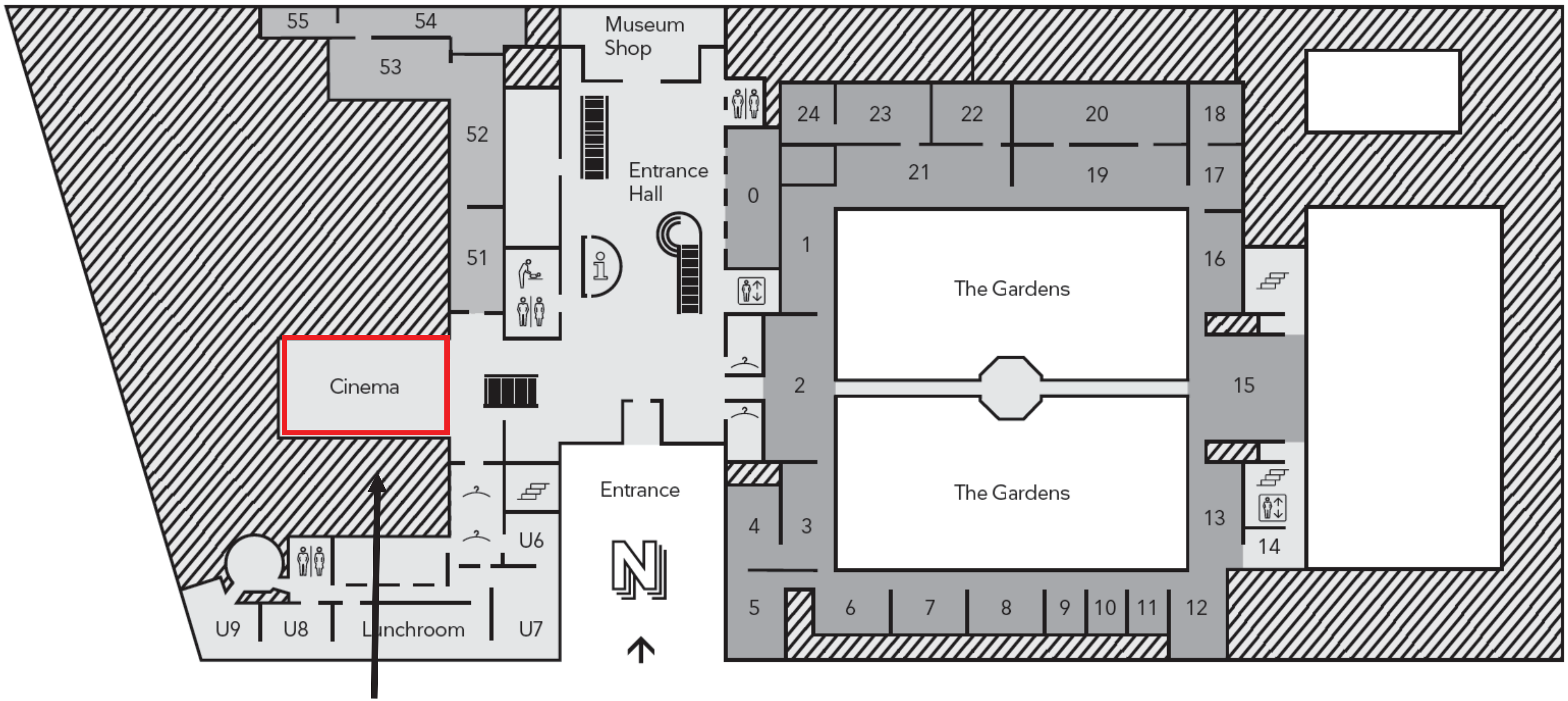
Session 29: Energy planning and planning tools
Davy Geysen : Forecasting of heat demand in district heating systems and their integration into smart grid controllers - Fractals, ensembles and expert advisers
Charlotte Marguerite: Simulation based assessment of retrofitting measures, storage integration and alternative heat sources in the district heating network of Aarhus
Franz Mauthner: Holistic urban energy planning: The benefits and drawbacks of using GIS-based methods
Ina De Jaeger: Impact of building geometry description within district energy simulations
Samuel Letellier-Duchesne: Balancing Demand and Supply: Linking Neighborhood-level Building Load Calculations with Detailed District Energy Network Analysis Models

Session 30: Future district heating production and systems
Veit Bürger: Third party access to district heating systems - Challenges for the practical implementation
Daniele Basciotti: Simulation based analysis of demand side management as enabler for heat pumps in district heating networks
Maksym Kotenko: Drag reducing additives in low temperature district heating
Miki Muraki:1G/2G to 4G? Challenges in the Existing District Energy Infrastructure in Japan
Mikel Monclus: Combined HEat SyStem by using Solar Energy and heaT pUmPs

Nationalmuseet

Floor Plan

Ground Floor



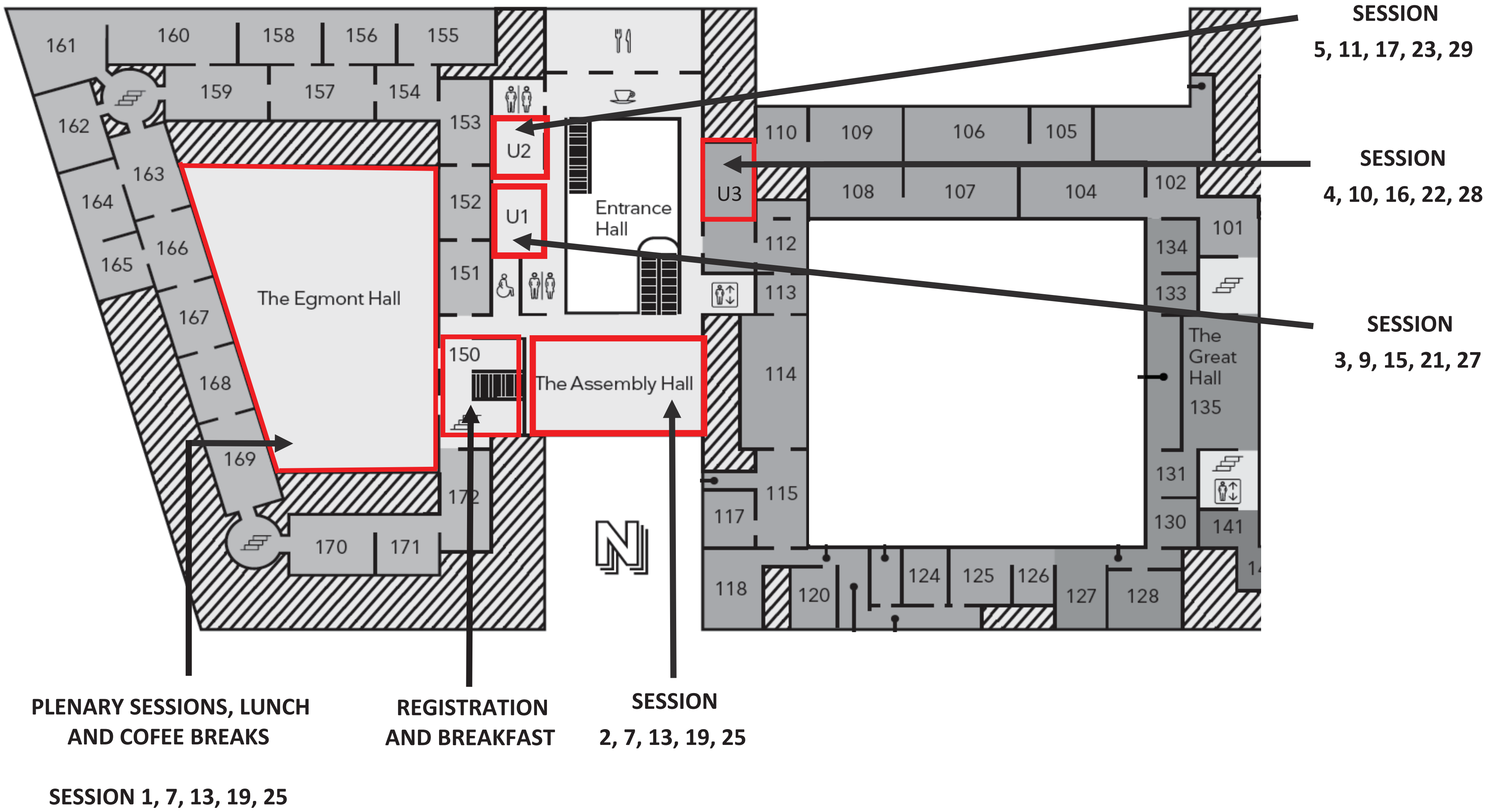
SESSION

6, 12, 18, 24, 30

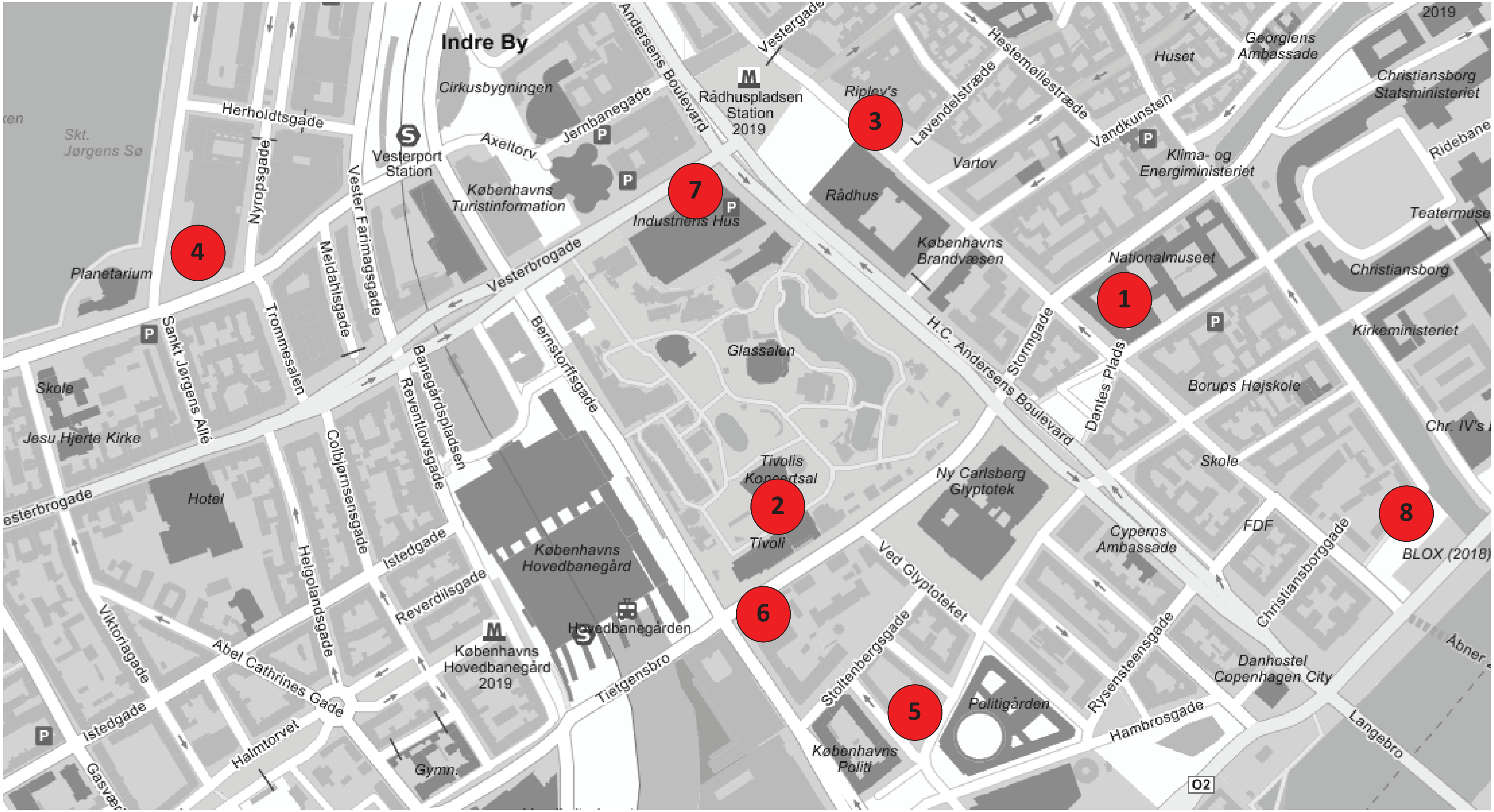
Nationalmuseet

Floor Plan

1st Floor



MAP COPENHAGEN CITY CENTRE



1:The National Museum of Denmark

2: Tivoli, conference dinner

3: Scandic Palace Hotel

4: Scandic Copenhagen

5: Cabinn City Hotel

6: Technical Tour, HOFOR

7: Technical Tour, EnergyLab Nordhavn

8: BLOXHUB, Workshops

Cowi sponsors the conference dinner at Grøften

COWI is one of the leading specialists regarding optimisation and rehabilitation of district heating and cooling systems.

COWI deals with all questions related to the planning and establishment of district heating and cooling systems. We both design new systems and handle optimisation and extension of existing networks, and renewal and replacement of worn-out pipeline systems.

Modern tools for optimization

We have a large number of professionals at our disposal in relevant specialist areas, e.g. geotechnology, land surveying, road building and welding technology.

We offer real-time simulation of any district energy system as well as temperature optimisation of the network.

District energy systems

COWI assists a substantial number of Danish and foreign supply companies, either as building consultants, planners or sparring partners. We have provided consultancy in most countries worldwide.

Our experience with district energy systems includes:

- Planning of networks
- Detailed design and documentation
- Relations with authorities
- Procurement of pipeline systems, auxiliary equipment and optimal operational software solutions
- Consultancy to the builder of turnkey projects
- Supervision and management
- Optimisation of operation and maintenance of networks and substations as well as operational parameters through SCADA and real-time hydraulic analyses using TERMIS software.

COWI

ADDRESS: COWI A/S, Parallelvej 2, DK-2800 Kongens Lyngby, Denmark

TLF: +45 56 40 00 00, FAX: +45 56 40 99 99, WWW.COWI.COK

LOGSTOR sponsors the Conference Dinner at Grøften

LOGSTOR is a leading supplier of pre-insulated pipe systems for energy-efficient transportation of liquids and gases for district heating and cooling, marine and industrial purposes as well as oil and gas pipelines.

The initial investment in a district energy system is significant. However, it counts for the minor part of the total cost of ownership; as much as 70% is taken up by ongoing operational expenses, such as heat loss, pumping and maintenance. As a result, operators are looking for more efficient solutions that will deliver the best return on their investment.

At LOGSTOR, we help our customers to lower the total cost of ownership across the network through innovative solutions that deliver effective system designs, a simpler and more sustainable installation process and market-leading technologies that provide minimal heat loss and a lifetime of reliability and performance. We have comprehensive experience in managing the entire process of planning, design, training, installation, maintenance and all aspects of system integration.

The durability and high insulation properties of LOGSTOR's pre-insulated pipe systems make sure as much as possible of the energy generated gets to the end destination, with no leaks and with the absolute minimum of heat loss – even over long distances. This helps dramatically reducing operating costs as well as CO_2 emissions.

Our focus is to reduce complexity and cost at every stage by driving value and efficiency throughout the lifecycle of our customer's pipe system, with the highest and most consistent insulation values over a lifespan exceeding 30 years.

Inventing the pre-insulated pipe technology more than 50 years ago, LOGSTOR has delivered more than 200,000 km of pre-insulated pipes. Today we offer the industry's most extensive range of products and support services with a solution tailored for every need.

Headquartered in Løgstør, Denmark, LOGSTOR has subsidiaries in our main markets as well as a network of agents and sales offices. The LOGSTOR Group's 9 production facilities are situated in Denmark, Poland, Sweden, Finland and Romania.

Utilizing return water in Aars district heating network, northern Jutland. Here a service line to supply a Golf Club is established.

NIRAS is a market leading consultant specialized in utilization of surplus heat sources

We have analyzed how to balance city wide 4G District Heating to enable the uptake of large amounts of surplus heat from the planned Apple Computer Data Center outside the city of Viborg.

Our experts advise district heating companies on how to mitigate heat losses and save money by means of low temperature district heating

In cooperation with Bjerringbro DH Company we tested five different types of innovative substations using ultra low temperatures.

Want to know more?
Join us at 'Session 1'
Tuesday, September 12, 11:00-12:30

Boiler at Hjørring district heating power plant

We outline and design the society of tomorrow

NIRAS is an international, multidisciplinary consultancy company with more than 2,200 employees, 42 offices in 21 countries and 8,000 ongoing projects. Currently, we are very busy with a growing array of exciting projects. If you want to build a career in a company that values customers, projects and, not least, employees over systems and procedures, then you should join NIRAS. We need experienced project managers and specialists to our branches across of Denmark as well as to offices in Germany, Norway, Sweden and the UK.

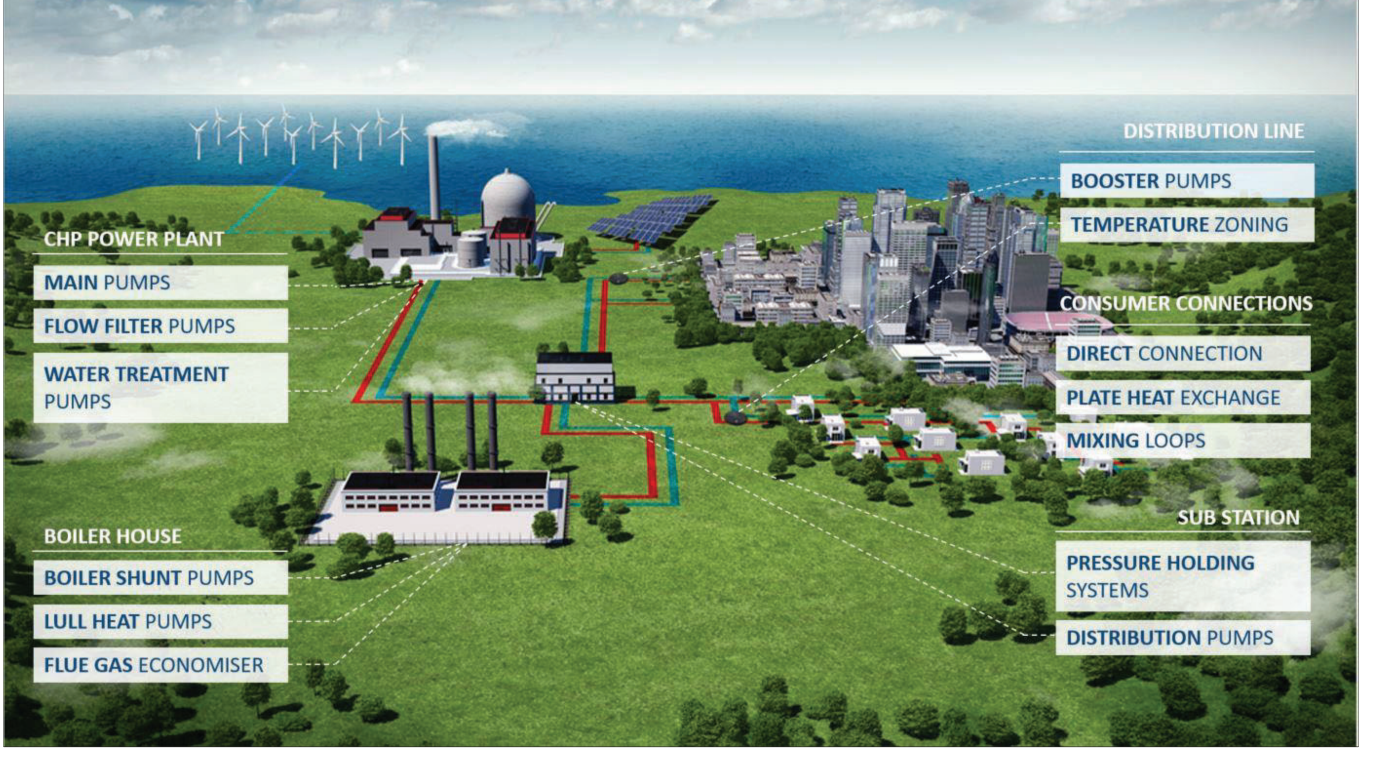
NIRAS sponsors the conference dinner at Restaurant Groeften, Tivoli Garden, tuesday 19:30.

Grundfos sponsors the conference dinner at Grøften

Grundfos was founded in 1945 and is a global leader in the pump industry. We employ 18,000 people and produce 16 million pumps annually that are being sold through offices in 45 countries.
Grundfos is a full-line supplier of pumps and pumping systems for district energy, buildings, industry and water utility.

Our concern for the environment is one of the driving forces in our focus on district energy. We are relentlessly ambitious in optimizing our pump solutions and we work with all decision makers within district energy to develop the most reliable and energy efficient district energy solutions. This approach has proven to be successful all over the world where we have been involved in the design process.

Our latest focus is to help District Heating Utilities to reduce their heat and pressure losses by controlling temperatures, distributing pumps and divide cities into temperature zones by utilizing mixing loops.



PlanEnergi

SPONSOR OF 4DH CONFERENCE 2017 IN COPENHAGEN
(PARTIAL SPONSOR OF CONFERENCE DINNER IN GRØFTEN, TIVOLI)

PlanEnergi offers consulting in all phases of development of renewable energy projects. PlanEnergi has provided consulting services for several wellknown district heating plants based on heat end energy from combinations of:

- Solar heating
- Heat pumps
- Pit thermal energy storage
- Bore holes
- Biogas
- Biomass
- Exces heat

PlanEnergi has extensive experience working with district heating companies, researchers and technology vendors and have participated in several successful development and demonstration projects (EU and EUDP).

Today, we have a strong customer base consisting of some of the most progressive district heating companies, municipalities and regions in Denmark. Our international network are expanded over the years and includes regular partners in particular Germany, Italy, Austria, Ireland, Spain and France as well as projects in China and Japan.

PlanEnergi is at the forefront in the development of renewable energy and energy efficiency within all key areas. We wish to contribute to increasing the dissemination of knowledge and networks while hoping for increasing ambitions in terms of greater reduction in the use of fossil fuels. This has resulted in projects with sustainable islands, cities and countries where renewable energy is not the only goal but a means of better welfare, jobs and a better environment.

MORE THAN 30 YEARS OF EXPERIENCE IN COUNSELING AND DEVELOPMENT OF RENEWABLE ENERGY PROJECTS

Departments in Skørping, Aarhus and Copenhagen

www.planenergi.dk

Best Senior Presentation Award is donated by Danfoss

The presentations made by senior researchers at this year's conference on Smart Energy Systems and 4th Generation District Heating will all be competing for the Best Presentation Award sponsored by Danfoss. Danfoss will donate 1000 euro to the winner of the category.

At last year's conference, the winners were selected on their ability to communicate the science within their field of district heating research and thus making district heating more attractive and useful to the consumer.

Last year Danfoss sponsored the Best Senior Presentation Award. Martin Crane, an independent consultant at Carbon Alternatives Ltd won the Best Presentation Award with "Individual house substation testing – development of a test and initial results".

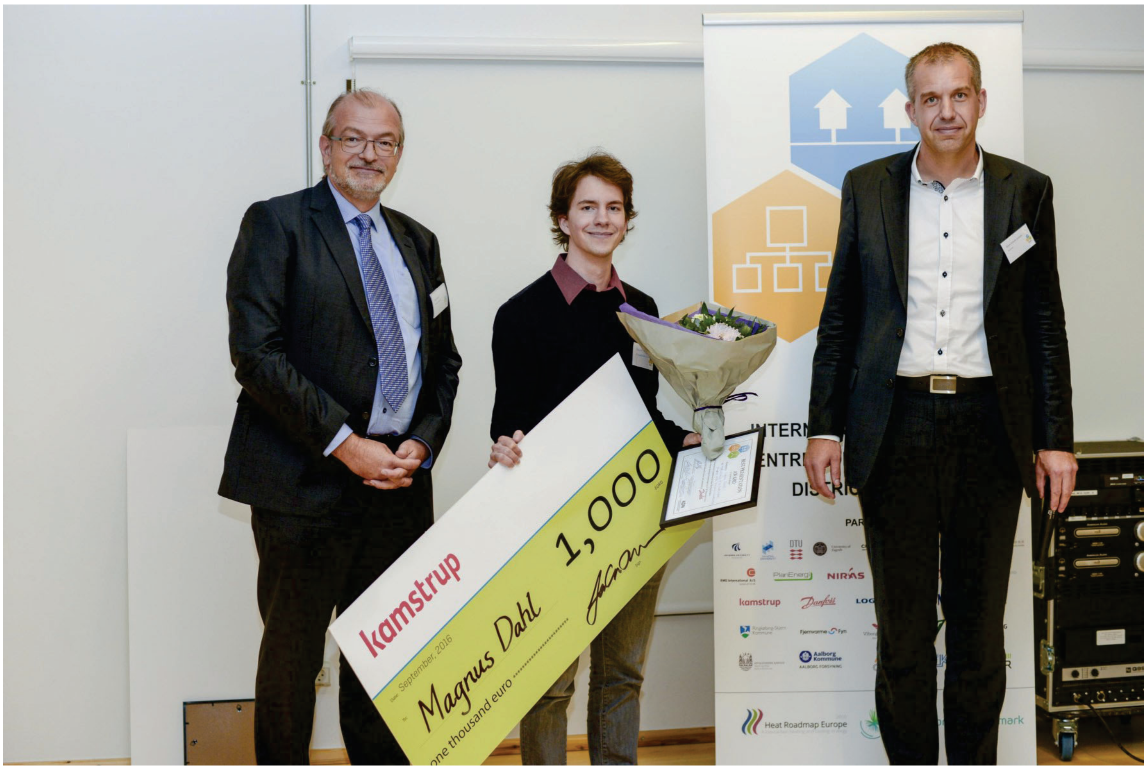
In 2016, Martin Crane was happy to receive his award for best presentation sponsored by Danfoss. Photo: May-Britt Vestergaard Knudsen

Best PhD Presentation Award is donated by Kamstrup

The PhD fellows making presentations at this year's conference on Smart Energy Systems and 4th Generation District Heating will all be competing for the Best Presentation Award sponsored by Kamstrup. Kamstrup will be donating the PhD Award worth 1000 Euro to an aspiring researcher with excellent communication skills.

The award ceremony will take place on the second conference day at 3.30 pm in the Egmont Hall.

Last year, Magnus Dahl from industrial PhD fellow at Aarhus University and AffaldVarme-Aarhus won the award for his presentation “Applications of a heat load forecast with dynamic uncertainties ”.



Last year, Magnus Dahl from Aarhus Universitet won the Best Presentation Award for PhD fellows sponsored by Kamstrup. Photo: May-Britt Vestergaard Knudsen

Conference Chairs

Henrik Lund, Head of 4DH and Professor in Energy Planning at Aalborg University, Denmark

Professor Henrik Lund has served as the head of several large research projects in Denmark as well as in Europe. He holds a PhD in "Implementation of sustainable energy systems" (1990) and a senior doctoral degree in "Choice Awareness and Renewable Energy Systems" (2009). Prof. Lund has more than 30 years of research experience and involvement in Danish energy planning and policy making. Among others, he has been involved in the making of the Danish Society of Engineers' proposal for a future 100% Renewable Energy Plan for Denmark. And Prof. Lund is the main developer of the advanced energy system analysis software EnergyPLAN, which is used by various researchers and energy planners around the world. He has contributed to more than 300 books or articles and is Editor-in-Chief of Elsevier international journal ENERGY. Henrik Lund is on the Thomson Reuter's list of highly cited researchers in the world within the topic of engineering.

Brian Vad Mathiesen, Deputy Head of 4DH and Professor in Energy Planning at Aalborg University, Denmark

Brian Vad Mathiesen, Professor in Energy Planning at Aalborg University, is one of the world's leading researchers in renewable energy systems. He is ranked among the top 1% researchers in the world in the Thomson Reuter's 2015 list of highly cited researchers; he is Vice-Chair of the EU's Horizon 2020 Advisory Group for Energy (AGE) and a member of the EU Commission expert group on electricity interconnection targets in the Energy Union. His research focuses on the technological, economic and societal shift to renewable energy, large-scale integration of fluctuating resources (e.g. wind power) and the design of 100% renewable energy systems. Brian Vad Mathiesen has been one of the leading researchers behind the concepts of Smart Energy Systems and electrofuels. He has published more than 160 scientific articles and reports. His editorial activities include being an editorial board member of the Journal of Energy Storage (Elsevier), associate editor of Energy, Ecology and Environment (Springer) and editor of the International Journal of Sustainable Energy Planning and Management.

About 4DH

4DH is an international research centre which develops 4th generation district heating (4GDH) technologies and systems. This development is fundamental to the implementation of the European 2020 goals as well as the Danish aim of being fossil fuel-free by 2050.

In 4GDH systems, synergies are created between three areas of district heating, which also sum up the work of the 4DH Centre: grids and components; production and system integration, and planning and implementation.

4DH is based on a unique collaboration between industry, universities and the public sector to investigate the potential for and develop future district heating systems and technologies, known as 4th generation district heating (4GDH). With lower and more flexible distribution temperatures, 4GDH can utilize renewable energy sources, while meeting the requirements of low-energy buildings and energy conservation measures in the existing building stock.

4DH has created focus on and knowledge about the future 4GDH potential within the district heating industry. 4GDH systems and technologies will play large part in future cost-effective sustainable energy systems and are likely to replace the import of fossil fuels and create jobs and economic growth in Denmark and in Europe.

Among other results of 4DH, the Heat Roadmap Europe studies have developed the most advanced knowledge about energy planning currently available for analysing the heating sector in Europe and have demonstrated how a simultaneous expansion of heat savings, district heating and heat pumps will result in the most economical low-carbon heating sector for Europe.

Read more about the 4DH Research Centre and its results at www.4dh.dk.

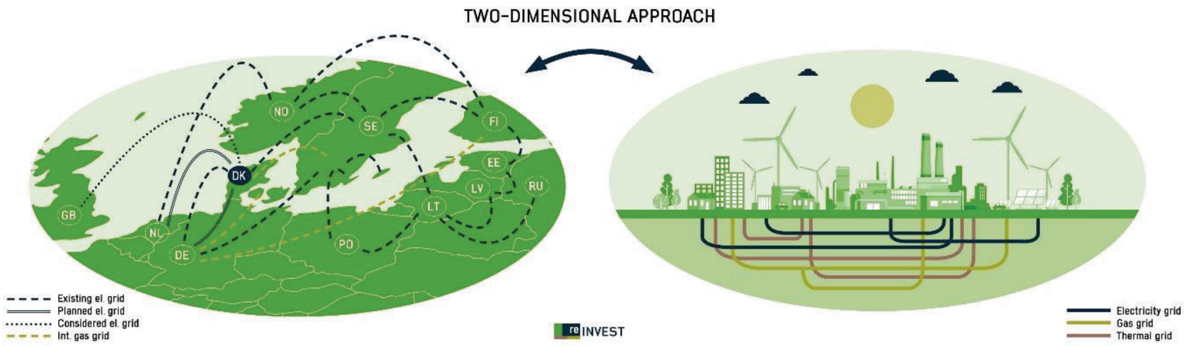
About RE-INVEST

RE-INVEST is a four-year research project that gathers 17 partners from universities and key energy players in a unique approach to the complete redesign of the entire energy system, utilizing the synergies between heat, electricity and transport.

RE-INVEST aims at designing robust and cost-effective investment strategies that will facilitate an efficient transformation towards a sustainable or 100% renewable energy system in Denmark and Europe.

RE-INVEST addresses how to overcome silo-thinking that characterizes traditional energy sectors, by using a two dimensional interconnectivity approach as well as existing and new energy infrastructures. The aims are:

1. to develop the Smart Energy System concept and identify synergies in low-cost energy storages across sectors as well as energy savings on the one side, and international electricity and gas transmission on the other side, when expanding e.g. wind power;
2. to support stakeholders within renewable energy in Denmark and Europe and enable the industrial partners in the project to be early adopters of trends in integrated energy markets, thus having cutting edge R&D for key-technologies in future sustainable energy systems;
3. to share data, results, models and methodologies on open platforms as well as be open for new partnerships.



Read more about RE-INVEST at www.reinvestproject.eu.

List of peer-reviewed journal articles, book chapters, PhD dissertations and definition papers

Journal articles:

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Plenary keynote speakers

Sven Werner is Professor of Energy Technology at the School of Business, Engineering and Science, Halmstad University. He was born in Vänersborg in 1952. Following on from his Master of Science in engineering degree obtained from Chalmers in 1977, he worked for a year in the business world before returning to Chalmers for doctoral studies. He defended his PhD thesis in 1984. He returned to the business world again with the Borås Energi public utility company and the Fjärrvärmebyrån organisation. Sven Werner carries out research about district heating for the future needs in both Sweden and across Europe. His knowledge and research results have been visible in several scientific journals and reports, in textbooks and through numerous lectures. Sven Werner has communicated his research through various activities and presentations in Finland, Norway, Denmark, Iceland, Estonia, Latvia, Poland, Moldova, Ukraine, Germany, Austria, Switzerland, Italy, France, Ireland, UK, Belgium, Netherlands, USA, China and of course in Sweden.

Morten Abildgaard is the managing director in Viborg District Heating Company, one of the medium sized consumer owned district heating companies in Denmark. VDH has increased its ambitions to become a provider delivering green and affordable heat solutions for the citizens in Viborg since Morten joined 4 years ago. Viborg District Heating is a not-for-profit company – as most DK DH companies – with the primary goal to deliver affordable, reliable and green heat and to take an active part in the sustainable development of Viborg as a whole. The city of Viborg has 40.000 inhabitants and the DH Company delivers heat to approximately 90% of these.

Before joining Viborg DH Company as their managing director Morten has been involved in market development in many different industries and sectors primarily in the Telecom industry. Further Morten is also a board member in several companies within contractors, property development, industrial production and IT.

Eva Hoos is a policy officer in the Energy Efficiency Unit of DG ENERGY of the European Commission. Her policy portfolio covers mainly supply side energy efficiency issues, including energy audits, cogeneration, district heating and cooling, industrial energy efficiency, energy networks and energy markets.

Eva Hoos holds a law degree and a business degree in management. She has more than 10 years' work experience in the energy sectors. Before joining the European Commission she held different positions in both the public and private sector as advisor in the fields of international energy law, legal and regulatory affairs in EU energy markets and energy efficiency policy.

Brian Vad Mathiesen, Professor in Energy Planning at Aalborg University, is one of the world's leading researchers in renewable energy systems. Mathiesen researches 100% renewable energy systems and paths to transition the energy system to 100% renewable sources. He is also doing feasibility studies and technical energy system analyses and works on ways to base energy systems mainly on variable renewable energy sources such as wind power. Brian Vad Mathiesen is the coordinator of RE-INVEST, which focuses on a complete redesign of the entire energy system, utilizing the synergies between heat, electricity and transport**.**

Abstracts

Plenary Keynote:

World DH status and Transformation Roadmap for 4GDH

Professor Sven Werner, School of Business, Engineering, and Science, Halmstad University
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The first perspective is the international review of district heating and cooling recently published in the Energy scientific journal. This review provides a presentation of the background for the current position for district heating and cooling in the world, with some deeper insights into European conditions. The review structure considers the market, technical, supply, environmental, institutional, and future contexts. The main global conclusions are low utilisation of district heating in buildings, varying implementation rates with respect to countries, moderate commitment to the fundamental idea of district heating, low recognition of possible carbon dioxide emission reductions, and low awareness in general of the district heating and cooling benefits. However, more efforts are required for identification, assessment, and implementation of the fundamental idea in order to harvest the global benefits with district heating and cooling.

The second perspective is the conceptual Transformation Roadmap elaborated within the IEA-DHC research programme between 2014 and 2017. The main scope was the identification of early and vital information about the transformation process to a future fourth generation of district heating technology. An overview was provided concerning the main focus areas of previous generation shifts, current temperature levels in district heating systems and in customer heating systems, future temperature levels, and concurrent operation of different generations in same system. Documented experiences from previously generation shifts are reported mainly concerning conversion from steam to water-based systems in USA, Canada, Denmark, Austria, and Germany. Current temperature levels in district heating systems were illustrated with national statistics from Denmark and Sweden. In-depth analyses of current temperature levels in customer heating systems were reported by examples from Switzerland. Future temperature levels were presented with early experiences from Denmark. Concurrent operation of different generations in same networks was reported by four different solutions with examples from many countries. Our conclusions were summarised in a condensed Transformation Roadmap.

Plenary Keynote:

Data Centres and 4GDH in practice - the case of Viborg

Morten Abildgaard, CEO Viborg District Heating Company

Viborg District Heating has been supplying the city of Viborg with district healing for more than 60 years. The distribution grid has evolved through the years in order to supply an expanding city as well as the consumption within the individual household has change. Since 1996 the heat has been produced by burning natural gas. The city wants to reduce or even substitute fossil fuels.
In 2015 Apple announced that they are to build a major datacentre outside the city. Since then Viborg District Heating has done a lot of analysing in order to make use of the surplus heat in a competitive manner bringing down CO2 emissions. The analyses concludes that through implementing a "low temperature district heating scheme" the efficiency of electrical powered heat pumps used to boost up the temperature from the data centre will be the most economical feasible way to produce heat compared to the existing CHP-plant. The "low temperature district heating scheme" includes an upgrade of the entire system from the supply delivery point to the consumer installation. The upgrade includes installation of new efficient heat exchangers, change of pipes in strategic areas of the grid and a termis-controlled SRO system to simulate and regulate the temperature and flow. The hole system shows that it is possible by using the anchor points within 4GDH to convert an existing district heating grid into a cost-effective and competitive system based on renewables.

Plenary Keynote:

High-performance, smart district heating and cooling –The evaluative backbone of a balanced energy transition

Eva Hoos, Policy Officer in the Energy Efficiency Unit of DG ENERGY of the European Commission

High-performance, smart district heating and cooling is an evaluative backbone of a balanced energy transition that can be supplied with a very broad range of renewable and recycled energies and are the perfect match with energy efficient buildings. They have the capability to provide low-cost flexibility to the energy system through storage, balancing and demand response that makes them a key enabler of increasing the penetration of variable renewable energy in both the electricity and the heating sector. They allow high level optimisation of the use of resources and good individualised quality; they thus contribute to security and resilience of supply, emissions reduction and effectively address affordability and energy poverty.
Recognising that modern district heating can become an important component of a decarbonised smart energy system, essential for transiting the EU to a low carbon, sustainable and competitive economy, the EU stepped up research and demonstration support in this field and integrated modern district heating into the EU energy policy framework, in particular on energy efficiency and renewable energy. The new Renewable Energy Directive proposed as part of the Clean Energy for All Europeans package integrates for the first time an EU level framework regulation for district heating to ensure its role in the decarbonisation of the heating sector and buildings. The Clean Energy for All Europeans package provides for strong links between renewable energy and energy efficiency and with the proposed new electricity market design. The aim is to drive investment in modern, smart infrastructures and the technologies necessary to realise district heating potentials in renewables' deployment and energy efficiency.
The presentation will provide an overview of what the EU has already done to promote modern district heating. It will explain the current legislative proposals and the objectives driving the policy developments in the field.

Planetary Keynote:

Towards a smart energy system approach in Europe – Enabling robust and cost-effective Renewable Energy investment strategies

Brian Vad Mathiesen, Professor in Energy Planning at Aalborg University, bvm@plan.aau.dk, www.brianvad.eu

There is an urgent need for tangible knowledge about robust and cost-effective investment strategies for technologies used in renewable energy systems. Due to their long technical and economic lifetime, many investments in technologies, infrastructures and storage systems have an impact on our ability to adapt to future situations. Some investments have a high-risk profile for being extremely costly, some technologies are suitable to be combined with others, while some are not. In this keynote presentation, the early signs of risks in the current investment trends in Europe are explored as well as the potential solutions to these challenges using a two dimensional and smart energy system approach.

Whereas Europe, to a large extend, has focused on electricity grids and higher penetrations of fluctuating renewable energy, there is still a need to explore further integration by expanding cross-border interconnections while cost-effectively decarbonising the heating, cooling and transport sectors. In some parts of Europe, there is also a need to expand transmission between renewable energy production and large demands centres. Several countries throughout Europe have, however, the strategy to export fluctuating renewables, e.g. wind power, with increasing penetrations, as well as to import with low penetrations, due to power plant owners struggling to survive. There is a limit to a strategy of sharing fluctuating renewable energy or exploiting, e.g. Norwegian hydro, which there are already early signs of in the markets. In the future energy system, where we will see more and more e.g. wind power with very low levelised cost of energy (LCOE), it is uncertain whether the market principle of bidding using short-term marginal prices will be sufficient to ensure cost-effective electricity system investments. The reason is that wind power and photovoltaic (PV) have very low short-term marginal costs and will, by far, be the dominant technologies. Currently, early warnings of this problem are present in Europe with power plants closing and low earnings for power plant and wind turbine owners. This dilemma will increase in the coming years as Europe is expanding the level of renewable energy sources. Wind power and PV capacity is expected to increase substantially towards 2020 and 2050 and will challenge the current market structure.

The IDA Energy Vision 2050 scenarios are cost-effective 100% renewable energy scenarios that used a two-dimensional interconnectivity approach, able to cope with a situation where Denmark is not able to export energy (physically or with low costs), but also able to exploit imports. This research points to four major risks electricity markets and investors are facing, where two of them are related to the import risks. Firstly, there might be a lack of power plant capacity to produce electricity outside a country due to the current trend of declining capacities. This means that in periods with low wind power production inside a country, situations might arise where it is not physically possible to import due to insufficient power plant capacity. Secondly, in those periods, the electricity prices might escalate due to the increased demand across countries. Low wind power production is likely to occur in the same periods and for one or two weeks, which means that power plant capacities are needed in several countries at the same time. Export risks exist, as the weather patterns are rather similar between neighbouring countries, which means that there will be an excess of wind power and PV power production in these countries during the same periods. Consequently, congestion in transmission lines is likely to occur, making it physically impossible to export, even with higher transmission line capacities than today. Additionally, if transmission capacity is available, because the high wind power production occurs at the same time in the European region, it will lead to a decreasing or even negative electricity price. Thus, these four electricity exchange risks are worth considering when planning for a future energy system. The IDA 2050 scenario represents an energy system design with electricity trade between sectors as the main strategy to increase the cost-effectiveness using the smart energy system approach; i.e., a cost-effective use of electricity in heating and transport sectors together with electricity trade on international markets when good opportunities occur.

There is a trend in Europe to electrify both the heating and transport sectors, not only to decarbonise these sectors, but also to enable a better integration of fluctuating renewable energy. The electrification of the heating sector can be done with two distinctly strategies: one is to use direct electric heating or heat pumps in individual households; the other is to develop a thermal grid and boost temperatures with heat pumps or electric boilers. For both strategies, it is possible to integrate the use of thermal storage and heating savings. While electrification is key for the future energy systems, a full electrification may, however, hinder the use of excess heat that could cover vast amounts of the heat demands in Europe, according to the Heat Roadmap Europe project. Also there are large differences in the infrastructure investment costs for these two investment pathways, which also have to be taken into consideration.

PANEL DEBATE

Drivers and ownership models - how to spread district heating in Europe

In Europe there is so much waste heat that it would be enough to cover the entire heat demand in buildings, if a little heat from renewable energy sources would be added. In the Heat Roadmap Europe study series, a number of benefits have been documented regarding the inclusion of thermal networks in the heat supply in urban areas, and in combination with heat pumps and other heating technologies in rural areas. The questions is: why is the market share with district heating so different throughout Europe and why is the level of renewable energy significantly different from one country to another? With this in mind, this panel debate will follow themes like: ownership and governance models; innovation levels; efficiency improvements; socio-economic and private economic costs; the heat market in general (individual and district heating option as well as heat savings) and more. The debate will be moderated by Henrik Lund from Aalborg University.

Panelists:

Eva Hoos is a policy officer in the Energy Efficiency Unit of DG ENERGY of the European Commission. Her policy portfolio covers mainly supply side energy efficiency issues, including energy audits, cogeneration, district heating and cooling, industrial energy efficiency, energy networks and energy markets. Eva holds a law degree and a business degree in management and she has more than 10 years' work experience in the energy sectors.

Ingo Weidlich is Professor in Infrastructural Engineering at HafenCity University Hamburg. He holds a PhD on the axial cyclic interaction of buried pipelines and is an expert on the on the design and construction of district heating grids.

Søren Djørup is an assistant professor in the Sustainable Energy Planning Group at Aalborg University. He has a master degree in economics and concluded a PhD degree in 2016 in the subject area of energy policies and economics and is currently involved in several research projects dealing with governance structures in the heat and electricity sector, including HotMAPS, IREMB and MobGIS.

Katrina Folland is the overall coordinator of the CELSIUS project, an EU-funded Smart Cities demonstration project to support cities to become more energy efficient through the deployment of smart district heating and cooling systems. Katrina has coordinated several of Gothenburg´s actions for setting up goals, strategies for energy use, energy production, transportation and being a smart city and she has been representing the city in the national and EU context regarding Smart cities, innovation and Horizon 2020.

Brian Vad Mathiesen is Professor in Energy Planning at Aalborg University, Vice-Chair of the EU's Horizon 2020 Advisory Group for Energy and member of the EU Commission expert group on electricity interconnection targets in the EU. His research focuses on the technological and socio-economic shift to renewable energy, large-scale integration of fluctuating resources and the design of 100% Renewable energy systems and has been one of the leading researchers behind the concepts of Smart Energy Systems and electrofuels.

Session 1: Smart Energy Systems

Rasmus Aaen has been working with District Heating as a consulting engineer for more than 15 years, working with development, procurement and construction of energy production facilities and district heating networks. In addition Rasmus have a long history working on innovation and R&D projects within this field.

Session Keynote:

Balancing District Heating to increase uptake of low temperature surplus heat sources

*Rasmus Aaen**, *Senior Projectleader, NIRAS A/S, Mads Hagh, Senior Project Manager, NIRAS A/S*
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Keywords: Surplus heat, Apple Computer Data Centre

An analysis have been conducted of effects and demands on the District Heating system in Viborg by NIRAS, to enable the uptake of large amounts of surplus heat, from the massive Apple Computer Data Centre planned near the city of Viborg. Potentially 90% of the energy consummated by Viborg 9000 consumers could be supplied by the data centre. However, with a supply temperature from the data centre of approx. 30 C, delivered 10 km from Viborg city, utilization of the energy requires extensive development and long term planning of the District Heating system in Viborg. Coinciding with the planned surplus heat from Apple, Viborg District Heating is developing a long term plan of balancing the District Heating network to better accommodate the temperature needs in the different city areas, to mitigate heat loss, and ultimately move toward a 55/30 C network. This presentation will focus on the planning, practical and economic challenges of developing a city wide District Heating system towards lowering temperatures and utilizing large amounts of surpluses heat.

Pierre Vogler-Finck is an industrial Ph.D. candidate with Neogrid Technologies ApS and Aalborg University. The focus of his work is on forecast and predictive control of thermal systems in buildings.

Online short-term heat load forecast – An experimental investigation on greenhouses

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Keywords: Heat load forecast, recursive least squares, greenhouses, weather forecast, model selection.

Greenhouses can represent a significant fraction of the load on some district heating systems, such as on the Danish island Funen. In this case, they can be challenging the local district heating system operator, as they impose the lower bound on the supply temperature. Short-term forecasts of their heat load are therefore expected to contribute to an improvement in system operation and efficiency.
In this work, short-term forecast (next 48h) of the heat load was investigated on historical data from 5 greenhouses from Denmark over a period of 8 months, integrating a third-party weather forecast service. The predictor was built using a simple recursive least squares framework for each individual greenhouse. Explanatory variables supporting the forecasting were selected in an automated forward selection manner, among a set of weekly curve terms and weather parameters.
Results show such a computationally rapid predictor captures well recurring load profiles, but does not capture fast random changes. The root mean square error was found to be within 8 to 20% of the peak load for each greenhouse in the dataset considered, which makes it a potential candidate for practical applications.

Notice:
Please note that this research is about to be submitted for publication to Elsevier's journal Applied Energy.

Borna Doračić graduated from University of Zagreb in 2016, where I continued to work as a research assistant. My work mostly focuses on energy planning of different systems, with the focus on small renewable district heating as a part of future smart energy systems.

Scenario analysis of the renewable district heating system in Ozalj, a small city in Croatia

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Keywords: District heating, renewable energy, heat demand mapping, techno-economic analysis, environmental impact

Heating and cooling represents the most intensive energy sector in the European Union, accounting for around 50 % of its final energy consumption. Therefore, this sector has significant potentials to increase the energy efficiency, while reducing the primary energy consumption. Nevertheless, district heating systems are currently distributed in a rather uneven fashion in the European Union, covering a minor share of the overall heating demand. Furthermore, small renewable district heating systems are practically neglected, especially in the South-Eastern Europe. When managed properly, these systems have a number of potential benefits, including enhancement of the local employment and the security of the supply, increase of the local economy, use of various heat sources (e.g. biomass, solar collectors, excess heat, geothermal energy), etc. District heating will be also very important for future smart energy systems by enabling the integration of the power and heating/cooling sectors with the use of power-to-heat technologies and thermal storage. It is necessary to support and promote these concepts in order to achieve primary energy savings and reduction of environmental impact of the heating and cooling sectors. This is one of the main goals of the CoolHeating project (www.coolheating.eu), funded by Horizon2020 programme (grant agreement No 691679), which aims to support the implementation of "small modular renewable district heating and cooling grids" for communities in South-Eastern Europe. The final outcome of the project will be the initiation of new renewable district heating projects in 5 target communities up to the investment stage.

This paper will provide a brief description of the CoolHeating project and an overview of the techno-economic analysis carried out for the heating sector in the city of Ozalj which is one of the target cities in Croatia. The first step in the analysis was to map the heat demand in Ozalj, in order to define areas of the city which are most suitable for a small district heating system. Input data for this have been gathered by a survey implemented as a part of the CoolHeating project. By analysing the results, two alternative district heating distributions have been proposed and evaluated. Furthermore, a techno-economic analysis has been conducted for two production facility alternatives and the environmental impact of the proposed system has been compared to the current situation. Heat demand mapping has been done by utilising Matlab and qGIS software, while Microsoft Excel and Matlab have been used to calculate the economic and environmental aspects of the analysed system.

Philipp Geyer is assistant professor at the Department of Architecture within the Faculty of Engineering Science of the KU Leuven. His research field is sustainable and energy-efficient design and engineering of the built environment supported by intelligent computation, modelling, and simulation. He has broad international experience by working at the Massachusetts Institute of Technology (MIT), Technische Universität München (TUM) and Swiss Federal Institute of Technology Zurich (ETHZ) .

Technology patterns and business cases for thermo-chemical networks

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Keywords: Thermo-chemical district networks; Multi-purpose networks; Value propositions; Technology patterns.

The EU 2020 project H-DisNet develops and examines technology for thermo-chemical district networks based on absorption and desorption. The contribution will present value proposition for business models that describe potential services offered by such networks. These value propositions consider economic potentials of the technology transforming low-temperature excess heat into thermo-chemical potential and offering its usage in the scope of space heating and cooling, humidity control as well as industrial drying in multi-purpose networks. Reduction, first, of end user cost and, second, of primary energy consumption is the focus. Tailored to the identified value propositions, technology patters have been developed that are exemplarily presented. Following the patterns, technology development is ongoing in the project. Selected lab results from that development will serve to illustrate the performance of the technology in the contribution.

Jay Hennessy received an MSc in 2014, following almost two decades as a software engineer. Subsequently working for Svebio and conducting research for the University of Gävle, Jay joined RISE Research Institutes of Sweden in 2016 as a PhD student. His PhD will focus on novel uses of thermal grids through interactions with the electricity grid and other energy networks.

Techno-economic assessment of heat-to-power use in district heating networks

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Keywords: Smart thermal grids, heat-to-power, heat power, organic Rankine cycle, ORC

Recent improvements in heat-to-power technology have led to an increase in efficiency at lower temperatures and with a lower cost, resulting in an increased potential to use a district heating network as a heat source for electricity generation. The current study makes a techno-economic feasibility assessment of commercially available heat-to-power modules for use within a district heating network.

A future vision for the next generation of district heating, in which it becomes an integral part of a smart energy system, is proposed by Lund et al. (2014). This smart thermal grid concept has been described as including more interaction between district heating and electricity and gas grids within a given community/district.

An organic Rankine cycle (ORC) machine provides a method to produce electricity from heat and is currently used in combined heat and power (CHP) plants and industrial processes. It has been proposed to use the thermal load shifting capacity of district heating in combination with ORC use in industrial processes to create a virtual power plant (VPP) for power balancing. But such a VPP can only provide balancing power as a reduction of existing electricity generation. The idea of using ORC technology for electricity generation from thermal grid heat has been explored in previous research for a specific ORC manufacturer, however that considered the use of ORC electricity and heat by a single end-user only. Research on the general application of ORC in thermal grids for on-demand electricity generation is lacking.

A medium-sized district heating network is analysed to identify scenarios that can be used for benchmarking heat-to-power modules, e.g. under summer conditions when there is an excess of heat available, or when the electricity price exceeds the cost of heat. Similarly, future scenarios can be considered, such as documented forecasts of electricity prices based on increased renewable generation. Indicators are then used to analyse the different scenarios applied to a mathematical model of the heat-to-power modules. The results show in what scenarios the heat-to-power modules are technically and economically feasible.

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Session 2: Future district heating production and systems

Erik O Ahlgren is professor in Energy Systems Technology at Chalmers University of Technology, Sweden. His research is addressing systems aspects of biofuels, district heating, rural electrification and energy and climate policy. He has studied engineering physics at KTH, Sweden, did his PhD on solid oxide fuel cells at Risö/DTU,Denmark, and a postdoc on hydrogen energy at Kyoto University, Japan.

Session Keynote:

A system view on carbon impacts of future heating

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Keywords: Future district heating, carbon impacts, systems view, marginal electricity, alternative biomass use

District heating (DH) is not always the chosen option for heating of new low-energy urban building areas. This is due to various reasons including concerns about the environmental impact of district heating systems, in particular those with fossil fuel generation, even if this is utilized only for peak period heating, but also in DH systems with a base load from municipal solid waste (MSW) incineration waste heat since there is a considerable fossil based fraction in the MSW. Thus, the variety of DH sources also pose a problem for new building areas aiming at becoming entirely “green” with 100% renewable heating. In the Swedish context the main alternatives to DH, also for urban heating, are considered to be heat pumps of different scales and bio-based heating.

Due to the energy systems complexity there might be conflicting views on the best heating option from a climate point of view depending on the systems boundary applied, and due to the long time-scales related to energy infrastructures, the combined short-term and long-term impacts ought to be assessed when heating for new urban areas is planned. Thus, in this paper we aim at analyzing how the carbon impacts of heating of low-energy urban buildings is varying depending on the application of various spatial and temporal scales and system views.

We select three general heating options representing different scales and spatial distributions. They also allow different heating technologies to be applied and fuels to be used. Further, we apply a static and dynamic approach, respectively, to address the importance of near-term and long-term horizons. The study is based on conditions representative of southern Sweden.

The calculations are based on a detailed representation of the heating options: an individual, an on- site and a DH options are being compared, and the DH option is further divided to represent the characteristics of DH systems of three different scales since this is essential to capture the various plants, their fuels and the resulting heating climate impact.

The long-term dynamic calculations are carried out using a TIMES optimizing model covering supply and demand in an urban segment.

The various systems approaches are represented by different assumptions with regards to marginal electricity generation and with regards to alternative use of a limited amount of available biomass.

The results show that is very difficult to determine which technology that is performing best (with regards to reduction of carbon emissions) under the wide range of perspectives applied. Assumptions on competition for limited biomass resources and on future electricity supply have large impacts on the results. The results also show that great care is required when selecting the appropriate system boundaries and calculation approaches.

Bernd Windholz is Research Engineer at the Centre for Energy of AIT Austrian Institute of Technology GmbH. He is mainly involved in integration of heat pumps and solar thermal into district heating and cooling, industrial processes, and commercial applications. His main competences are simulation of these energy systems as well as analysing their performance on the basis of monitoring data.

Application of heat pumps in the district heating network of Vienna

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Keywords: District heating, heat pump, simulation, pilot plant, monitoring data analysis, characteristic curve, optimisation

Heat pumps are a promising technology in order to increase the use of renewable energy in the district heating and cooling networks of Vienna (Austria). Within the research project 'District Boost' (FTI fund), information of international reference plants was collected and possible heat pump applications for Vienna have been examined in general and the most promising concept was simulated. In addition, a pilot plant with a high-temperature heat pump in a converter substation was planned, implemented, and analyzed.

Among the examined heat pump applications for Vienna, the use of waste heat from industry and data centres, as well as the increased exploitation of geothermal heat were investigated. The most important concept is the cascaded use of decentralized heat pumps in converter substations cooling down the return flow of the network and thereby increasing the efficiency of a centralized heat pump using the river Danube as heat source. With decentralized heat pumps additional customers can be added in areas with restricted access to the district heating network. The proposed concept was compared to conventional substations by numerical simulations. Under the chosen simplified assumptions the yearly amount of renewable energy from the Danube is about 157 GWh with state-of-the-art substations, and can be increased by 2.2 % using decentralized heat pumps in the substations. Further simulations are necessary for more realistic scenarios.

As proof of concept, a pilot plant with a decentralized high-temperature heat pump (maximum condensation temperature 90 °C) in a converter substation was planned and implemented. The chosen hydraulic system with a buffer tank allows for a relatively cheap heat pump (smaller peak load), and an efficient heat pump operation (long operating time at nominal capacity). To evaluate the operation, monitoring data have been analysed by monthly values (utilized heat, seasonal performance factor, etc.), as well as time behaviour on a resolution of one minute (temperature levels, coefficient of performance, etc.). Furthermore the most important performance values of the entire monitoring period (nominal load mode) have been aggregated into characteristic curves of the heat pump, showing heat output, coefficient of performance and Carnot efficiency as a function of evaporation and condensation temperatures. Although first optimizations have been done, data analysis revealed that the controls still can be improved to reach temperature set points faster and more accurate, and to avoid switching to partial load mode. Since the measured heat output is up to 23 % below the manufacturer specifications, leakage and amount of refrigerant has to be checked.

Renaldi Renaldi is a final year PhD student at the Institute for Energy Systems, University of Edinburgh, UK. He graduated with MSc. in Sustainable Energy Technology from Eindhoven University of Technology, Netherlands. His research interests include the modelling and optimisation of energy systems, thermal energy storage, and solar energy.

Borehole Thermal Energy Storage Modelling in Energy Systems Optimisation

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Keywords: Seasonal thermal energy storage, Drake Landing Solar Community experimental data, TRNSYS simulation

Seasonal thermal energy storage can significantly increase the solar fraction of a solar district heating system, as shown in the Drake Landing Solar Community (DLSC) which has a solar heating fraction above 95% [1]. However, seasonal storage represents a significant investment cost, and therefore its design and operation need to be carefully considered to achieve economic and environmental benefits. Energy system optimisation can assist on this aspect by ensuring that all relevant options have been considered in finding the (near) optimal solutions. However, the presence of storage units will increase the complexity of the optimisation run, mainly due to the coupling of decision variables between time steps which is particularly severe for long term storage. In this contribution we show that this issue can be overcome by using simplified equipment models and adaptive time steps in the design and operational optimisation. It is important to evaluate the accuracy limit of the simplified model to ensure the overall results accuracy is not significantly affected. We are comparing the results to experimental data and a TRNSYS simulation for DLSC which uses borehole thermal energy storage (BTES). Among the different storage technologies, BTES can have lower investment cost per unit volume of water-equivalent storage and has the additional advantage that it has low space requirements. For BTES, most studied models are designed for dynamic simulation and equipment-level optimisation [2, 3]. These models can be too computationally expensive to be implemented in an optimisation framework. In this study, two BTES models and adaptive time steps are integrated in an optimisation framework and the impacts on computational cost and results accuracy are investigated. Our results demonstrate that adaptive time grids can significantly reduce the computational time while maintaining sufficient accuracy compared to uniform time grids. In addition, this reduced computational time enables the rigorous optimisation of the BTES configuration. In conclusion, the simplified optimisation framework enables the design and operational optimisation of seasonal thermal storage systems which will lead to reduced economic and environmental costs for district heating systems.

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Hrvoje Dorotic is a research assistant at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb. My work is focused on energy planning, integration of renewable energy sources and district heating and cooling

An hourly based optimization model of district heating system with building retrofit with the time horizon of one year, case study of Velika Gorica

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Keywords: District heating system, energy planning, optimization, MILP, thermal storage

District heating systems cover 12% of the total heating supply in the European Union. They represent an effective and economically feasible way of increasing energy efficiency and decreasing greenhouse gas emissions. This is possible due to their capability to utilize waste heat and integrate low-temperature energy sources such as geothermal and solar thermal. In addition, they could increase the overall share of renewable energy sources by using power-to-heat technologies such as heat pumps and electrical heaters. Although district heating systems have significant benefits, their potential is still underutilized in most countries. They are currently on the road to their 4th generation of district heating systems which will integrate heating, cooling, gas and electricity networks, intermittent renewable energy sources, waste heat and thermal storage. Due to the numerous interactions of energy and mass flows in the system, its optimization presents a challenge for energy planners. The model presented in this paper is capable of optimizing the capacities and distribution of operation in the economically most suitable way. Technologies included in the system are: combined heat and power, heat only boilers, electrical heaters, heat pumps, solar thermal collectors and thermal storage. The objective function is the overall cost of the system, i.e. sum of yearly operation and maintenance including the discounted investment cost of each technology. The optimization is carried out with a horizon of one year on one-hour basis. Using this approach, seasonal and short-term energy system characteristics can be acquired and analysed. A building retrofit optimization is also included. The model has been used to create and analyse several scenarios for the district heating system of Velika Gorica. Scenarios have been compared according to the: overall carbon dioxide emissions, total cost and levelized cost of heat.

Kristina Lygnerud (PhD) studies risk management and Business Model development in the Swedish District Heating industry. She is part time in academia and part time in management consulting. She works as risk manager in a large construction project (CHP plant) and as a project leader focusing on sustainable and smart cities

Risk assessment for industrial heat recovery in district heating systems

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Keywords: Industrial heat recovery, risk assessment, risk estimates.

Industrial heat recovery is a possibility within district heating systems to make use of heat that is otherwise lost. Increased usage of industrial heat recovery reduces the need for fuel combustion lowering greenhouse gas emissions, such as carbon dioxide. Industrial companies can, however, move or close down industrial activities. This is apprehended as a considerable risk and lowers the interest of district heating companies to invest in industrial heat recoveries. In Swedish district heating systems, industrial heat recoveries have been undertaken since 1974. Today, these heat recoveries are active in about seventy systems. This leads to the question of how risky it is, for district heating companies, to engage in industrial heat recovery. Forty years of operation statistics from Swedish district heating systems have been collected and the extent is more than 1500 operation years in about one hundred locations. This information has been analysed in order to quantify risk estimates for the long-term risks of industrial heat recoveries. These risks have been estimated from the proportion of actual heat supply compared to expected heat supply without any closure. Various estimates consider risks according to industrial branches, size of heat recoveries, and heat pumps involved. Recommendations include suggestions to management on how to consider risk and consequence when assessing potential industrial heat recovery investments.

Session 3: Energy Planning and planning tools

Peter Jorsal, Educated as engineer from Aalborg University in 1986. He worked as a consulting engineer with district heating projects for 6 years. From 1992 working at LOGSTOR working with sales management. Until 2015 VP Sales for the Nordic Region and our service department. Since 2016 Product Manager for the LOGSTOR Group. Member of the board at DBDH, member of DHC+ and 4 G DH.

Session Keynote:

The right pre-insulated pipe system for solar district heating networks

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Keywords: solar district heating pipe system

A pre-insulated pipe system for a solar district heating pipe system is more difficult to design than a normal district heating network in a city. The reason is the number of temperature cycles in a solar district heating network which can be up till 40-50 times higher than in a normal district heating system. Wrong static design and wrong choice of products are expensive learnings. It is crucial to optimize the static design and choice of products with the right assumptions in order to achieve the expected service life of the pipe system.

The operating costs, stemming from the heat loss are a big part of the total cost of ownership of the district heating network. It is therefore essential to choose the right pre-insulated pipe system together with the right static design so that the total cost of ownership (TCO) will be lowest possible under the given assumptions in a specific project.

M.Sc. Jigeeshu Joshi and Dipl.-Geogr. Hinnerk Willenbrink work in the research group led by Prof. Dr.-Ing. Christof Wetter at FH Münster - University of Applied Sciences, Department of Energy Building Services Environmental Engineering.

Applying Geographical Information Systems (GIS) to analyse the potential and design of district heating networks

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Keywords: GIS, open data, heat mapping, spatial network analysis, spatial planning

Within the Dutch-German research project “Heat in the EUREGIO” (www.WiEfm.eu) applied tools are developed to carry out systematic district heating (DH) planning using GIS. DH networks are a core element for a future sustainable energy system, which does not only provide higher efficiencies and better pollution control but also allows the utilization of different energy sources. In Germany, DH has a market share of around 14 % in the residential buildings sector, which is way below some of the other EU member states. Lack of required data to produce spatial information used for planning of DH is found to be one of the barriers for its rather stagnant growth. As can be seen in Denmark, map based infrastructure planning is an important factor to realize DH networks beside fiscal and legislative frameworks.

This work is an attempt to accelerate the expansion of DH systems in Germany by taking advantage of open GIS data available from programs like INSPIRE (Infrastructure for Spatial Information in Europe) and OSM (Open Street Map). The developed tools are I) a heat map tool to identify hotspots in a given region, II) a tool to automatically design a heat grid and III) a tool to design a heat source for the given heat grid. These GIS tools provide user friendly and interactive ways to perform the tasks mentioned above. They are developed based on ArcGIS technology from ESRI (Environmental Systems Research Institute).

Their functionalities are tested using open GIS data from INSPIRE for the region of Muensterland in Germany. The outcome of the heat map tool for the study area shows 219 potential districts with a total area of nearly 6,700 hectares and total heat demand of about 2,500 GWh/a. These are ‘hotspots’ with a substantially high potential for DH-networks and an indicative for expansion in neighbourhoods for a more complete future energy system. Nearly 500,000 t CO_2 could be reduced every year if CO_2 neutral DH networks would be implemented for the determined potential regions. The developed tools for the design of DH network were also tested for selected towns and the results are being discussed with local municipalities for their feasible implementation. The accuracy of locating the heat demand and designing the heat grid was verified with local know-how and previous studies.

The tools thus enable quick and easy implementation of DH and, since inputs to the tools are essentially open data, the results can be published and presented in form of web maps. This allows public participation and easy access for local bodies and decision makers.

Jürgen Knies. Currently Research Associate at the Jade University of Applied Sciences in Oldenburg (Germany). Worked for 10 years in a spatial planning company with focus on energy issues (wind, solar). Then worked for around 4 years at the Institute of Informatics and the Institute of Pipe Technology with focus on smart grid and spatial planning, developing the research field Energetic Neighbourhood.

A spatial approach for a future-oriented heat planning in urban areas

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Keywords: Future heat supply systems, suitability maps, energy planning

The current climate protection goals will lead to a profound change of the energy system, more than in the past. The integration of renewable energy sources into the power system was a first step, which is not finished yet. The transition towards a decarbonized heat supply system will be even more complex, because now the process will have a deeper impact into the urban system, consisting of various complex subsystems with different spatial extents (technical, economic, social and planning systems).

The action level of the so called Heat Transition is the building and its structural embedding in the district. But for the decision making process, regarding the necessary system change, these levels are too small. On the other side, a too broad view is not very helpful for the local transition process. The challenge is to find an appropriate shape and size to enable a transition process in the built environment.

This contribution shows an innovative way to analyse heat demand data with the help of fuzzy logic and the spatial mapping of the suitability of different heat supply systems. A heat demand driven and explicit spatial approach, which also consider the reduction goals and future development, supports the decision making process on the level of urban planning. The study takes place in the City of Oldenburg (Germany, ca. 160.000 citizens) and in the Cities of Bramsche and Wallenhorst (Germany, ca. 53.000 citizens).

Depending on the analysed heat density different options of future heat supply systems and their degree of suitability (from single supply systems via island solutions to 4th generation district heating systems etc.) are mapped. This also involves an assessment with regard to future heat demand. Additionally, the possibilities to integrate industrial waste heat and solar energy are taken into account.

Different parameters, like edge effect, the different structure of the settlements, the influence of the shaping etc., are evaluated in order to demonstrate the robustness and the limits of the approach.

The following and necessary detailed energy planning process can use the results as guard rails for a more transparent decision making process.

Johan Dalgren has worked at Fortum Värme for ten years and since 2008 been focusing on optimization of the district heating network in Stockholm (operation and design). I'm now studying 50% as an industrial PhD in a cooperation project between Fortum Värme and the Royal Institute of Technology (KTH), personally focusing on temperature optimization in DH.

The time dependent impact of supply and return temperatures on CHP, HP and FGC production when utilizing a thermal network as energy storage.

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Keywords: 4GDH, Thermal Energy Storage, System Optimization, Supply Strategies, Supply Temperature Strategy

To combat climate change, district heating (and district cooling) provides a promising solution to decarbonize the heating sector. Transferring hot water in piping networks, district heating provides with hydrodynamic and thermodynamic inertia opportunities for optimizing supply.

Much recent research has focused on utilizing the mass and flow of water within the network as energy storage. In theory increasing the temperature at low demands and decrease at high demands to avoid utilization of peak boilers during peak hours. This keeps the supply temperature as low as possible (increases the performance of combined heat and power plants, flue gas condensation and heat pumps) and the network flow as high and even as possible (optimize heat losses towards pumping power).

In a network with several production plants there is a challenge though. Since the starting order of the plants and units ideally are set by the production cost, a changing heating demand in the network affects the supply area of the operating plants. With varying areas of supply the system curve (pressure loss as a function of flow) and thereby distribution capacity from the individual plants varies. In order to run the production units in the right starting order the supply temperature needs to be adjusted, giving another parameter to the optimization of supply temperature. This has more impact the more plants that are in production and also if the network has a lot of bottlenecks.

This has not been previously covered in the present academic literature. This paper discusses and defines these phenomena and in particular quantify its impact on system efficiency. Conclusions for future modelling of networks as energy storage are made with a supply temperature strategy which takes this phenomenon into consideration. The conclusions are further exemplified with simulations for the Stockholm district heating network.

Bram van der Heijde received a dual master degree in Energy for Smart Cities from KU Leuven and KTH in 2014. He is pursuing a doctoral degree at EnergyVille/KU Leuven, focussing on thermal energy storage in thermal networks.

Optimizing thermal energy storage in fourth generation thermal networks

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Keywords: Thermal networks, thermal energy storage, system optimization, optimal design, linear optimization

Future renewable energy systems will need to integrate thermal energy storage in order to bridge periods of low renewable energy availability and to optimize system operation. On the other hand, the integration of storage can reduce curtailment during periods with excessive renewable energy availability. Sensible TES shows great potential in the latest generation of thermal networks (4th generation thermal networks), which are expected to be very performant in coping with waste heat sources and distributed generation based on renewable sources [1].

This research aims at optimizing the location and size of different possible sensible TES systems in a thermal network. Linearized component models are used, combined with an optimal control strategy. This control strategy assumes perfect knowledge of disturbances and comfort constraints are incorporated. The implementation of the novel pipe model described by van der Heijde et al. [2] is crucial to obtain realistic optima. For thermal networks supplied with low temperature differences, which is the case in 4th generation networks, the relative importance of the heat losses increases and this necessitates the use of realistic heat loss models.

An important question to be answered is whether the best option (in terms of cost, or energy use) is to install a large central storage system, or to have a number of smaller decentralized units at strategic locations in the network. A simulation case study in the city of Genk (Belgium), which consists of 18 000 buildings and spans an area of over 80 km^2, is selected in order to have a realistic virtual test bed for the optimization algorithm.

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Session 4: Low-temp district heating grids

Oddgeir Gudmundsson MSc. in mechanical and energy related engineering. He holds a PhD in the topic of fouling detection of heat exchangers based on numerical methods. Main working areas are to analyse different concepts of DH systems and energy systems in general. Consultant work has been performed in regard to DH and District Cooling systems.

Session Keynote:

Cost analysis for Cold District Heating versus Low Temperature District Heating

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Keywords: Low Temperature District Heating, Cold District Heating, Total Cost of Ownership, Centralised Heat Pump, Decentralised Heat Pump

The trend in district heating (DH) is to lower the network temperatures to integrate more renewable heat sources with better economy and increase the network efficiency, by addressing the distribution challenges towards future low-energy buildings. In case the source temperature is lower than needed for direct production of domestic hot water (DHW) and heating (HE), the temperature of the DH supply must be boosted. This boosting can be done by means of a heat pump, which enables better utilization of fluctuating renewable based electricity.

The systems compared are cold district heating (CDH) and low temperature district heating (LTDH). The sources of energy is shallow geothermal for both cases at a temperature of 8°C. For the CDH system the supply temperature in the network is 8°C and boosted by heat pumps placed decentralized in the buildings, by means of a conventional individual heat pumps providing DHW and HE. For the LTDH system the heat pump is located centralized at the shallow geothermal source, and boosts the DH network supply temperature to 55°C. The installation in the building is a LTDH substation providing DHW and HE.

In this paper an economic analysis is made to compare CDH and LTDH for two cases in Denmark. The first case is including 15 one family houses, and the second case includes 275 one family houses and 4 apartment buildings. For both cases the buildings are low energy class 2015. The analysis takes into account the investments, heat pump operation costs, distribution heat losses and operation of distribution pumps. The result is expressed in total cost of ownership pr. year. (TCO)

The results show the TCO for the LTDH system is lower compared to the CDH system, given the assumptions for the analyzed cases. One major impact is the increased cost of the decentralized heat pumps compared to the centralized heat pump. This is not counter balanced by the lower investment costs for the CDH network. Other arguments supporting the concept of LTDH compared to CDH includes more cost efficient integration of other sources, easier to operate and maintain due to centralized equipment, easier combination with centralized energy storage to address variations in electricity price and higher efficiency for the centralized heat pump.

Kim Rolin has years of experience in designing 4DH pipe systems with focus on long life-time and low cost. Kim has been active adopting the newest findings in the International standards for district heating pipes.

Cost effective 4th generation district heating pipe concepts

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Keywords: Low cost of district heating network, low heat losses, long life-time of district heating network

The competitive market for district heating grids depends on many factors. The two most important are the heat density and the network investment. Whereas we can-not change the heat density, we definitely can influence the cost effectiveness of the construction of the network.

The lower investment cost per km trench – the more buildings can be connected and benefit from the low carbon heat supply which can be distributed through the grid.

In the first and second generation DH, expensive concrete ducts were the dominating solution, which limited the supply areas.

In the third generation preinsulated have taken over, but often with certain constrains, which increase the costs.

The fourth generation network is characterized by a number of features, which reduce the life cycle costs of the network, e.g.:

Preinsulated bonded pipes, maximal design temperature below 110 dgr.C

Maximal operation temperature below 90 dgr.C or lower, which increases life-time from at least 30 to at least 60 years and reduces the need for expansion joints

Fixed installation without any expansion joints

Curved pipes to fit to trenches and avoid bends

Gas pipe technology for assembling above ground

Gas pipe technology for no-dig crossing of e.g. large roads and rails

Back-fill of soil

Welded muffs

Twin pipe systems

Low heat losses

These features have proven their performance in the Danish market. Pipes which were installed 30 years ago based on most of these principles are still in good shape and may have another 30 years of life time. One of the barriers against district heating in many countries is that local standards and regulations are not taking into account this new low cost technology.

In the presentation we will show cases from Denmark and other countries, which have adapted the proven Danish experience cutting down costs of the district heating network life cycle costs.

Christian Engel. 30+ years in close cooperation with European Energy Provider. 8 years Managing Director of a Joint Venture between an Energy company and a plastic pipe producer. Today international Business Development Director District Energy & Renewables at THERMAFLEX Group•Board Member of Euroheat & Power•Member of CEN 107, WG 10 „flexible pre-insulated pipes"and WG 14 „district cooling pipes"

End consumer engagement as a key to successful implementation of 4th Gen DH

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Keywords: Low temperature District Heating, fast implementation, satisfied end consumer, economical installation, innovative Energy supplier, circular economy, sustainable solutions

This paper describes 3 projects where end consumer engagement has been a key element to successful implementation of low temperature District Heating networks.
In close cooperation with key stakeholder – municipality – end consumer – energy provider – contractor – equipment manufacturer – the most convenient implementation concepts has been developed and applied.
Key challenges during the installation of the new network in an existing neighbourhood were

- minimum traffic restrictions
- maximum saving of plants and trees
- minimum disturbance for the citizens (parking, access to their houses, noise, dirt)
- maximum safety for the installed systems (cables, pipes, etc.)
- long-term durability and performance of the new system

Two examples from the Netherlands and one from Romania are giving insights to the applied solutions.

Ashreeta Prasanna is an energy systems engineer with a background in mechanical engineering. She has more than four years of work experience in district energy systems. She currently works at the Urban Energy Systems Laboratory at Empa, which is a research institute affiliated to the Swiss Federal Institute of Technology in Zurich (ETHZ). Her work involves evaluating quantitative and qualitative advantages of decentralised and renewable energy production in districts.

Efficiency of centralised and decentralised low temperature district networks compared with individual heating and cooling systems

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Keywords:

Low temperature district networks (LTNs) supply both low temperature heat and cooling to multiple buildings. LTNs could have a centralised production of heat and cooling but also decentralised production. Alternatively, buildings could have individual heating and cooling systems, for example stand-alone heat pumps or chillers.
The aim of this paper is to compare the energy efficiency of centralised and decentralised LTNs with that of individual heating and cooling systems. These district energy system (DES) concepts are assumed to supply heat, domestic hot water, and cooling demand of a district in Switzerland. A simulation model is used to derive the total electricity consumption of the different DES concepts which are only electricity based, and include various types of heat pump systems (described in figure 1).
The results are used in a comparison of the different systems on the basis of hourly and annual energy consumption as well as self-consumption of decentralised renewable energy production. The results will be further developed, and in combination with other indicators can be used to provide guidelines for design of sustainable DES for new buildings and districts.

	Decentralised Low temperature network (8°C - 22°C supply)	**Centralised** Low temperature network (50°C supply, 20°C return)	**Individual** Heating and cooling systems (35°C SH, 55°C DHW, <18°C Free-cooling/Cooling)
Demand	Space heating Domestic hot water Cooling	Space heating Domestic hot water Cooling	Space heating Domestic hot water Cooling
Renewable supply	PV/PVT	PV/PVT	PV/PVT
Space heat + Domestic hot water supply	2-stage ground source heat pumps + Borehole field	Ground source heat pump + Borehole field Or Air source heat pump	2-stage ground source heat pumps + Individual boreholes Or Reversible air source heat pumps
Cooling	Free-cooling	Absorption chiller	Electric Chillers Free-cooling
Supplementary equipment	Network pumps	Heat distribution loss Network pumps	

Figure 1. District energy system concepts considered in the evaluation. The combination of the sub-systems for provision of space heating, domestic hot water and cooling for each concept is based on standard practices.

Markus Rabensteiner is a senior researcher in the non-university research facility 4ward Energy Research GmbH. The focus of my work is on thermodynamic processes, heating networks and simulation. The project MULTI-transfer to which this work relates has been in process since April 2016.

Simulation of bidirectional heat transfer stations in district heating grids

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Keywords: Bidirectional heat transfer station, simulation, MATLAB/Simulink

The secondary-side integration of renewable energy into district heating systems can be considered as complex in many cases. The properties of the renewable energy must be considered such as their available temperature level, their performance class and their logistics. Energy management systems that guarantee a system-wide control of district heating systems are already state of the art. However, a bidirectional heat transfer station (for heat supply and uptake) in combination with an intelligent control strategy for the entire district heating system (for new constructions and for existing systems) still has to be developed. Requirements of the primary (e.g. energetic optimization of the heating plant, minimizing distribution losses) and secondary side (e.g. security of supply) must be taken into account.

The simulation model in Matlab/Simulink, consisting of two parts, allows to investigate the bidirectional heat transfer station. The first model part depicts the primary side of the district heating system as detailed as possible, including the central heat source and the heat distribution system. Data from a real-life medium-sized district heating system is used as reference. Measured data based on a minute interval integrated into the model. Among others, a model validation can be carried out using the minimal differential pressure between forerun and return at different points in the grid.

The second part of the model forms the secondary side and is individually set for each prosumer. A solar collector (ordinarily an evacuated tube collector) or waste heat from a commercial refrigeration machine (temperature is increased by a heat pump) serve as decentralized heat source. The model considered multiple layer storages located at different consumers. The integrated layer storage can exchange energy with either the directly at the location of the customer being charged by the decentralized heat source and discharged by the heat output of the corresponding consumer or with the district heating system, where charging and discharging depend on the storage temperature and the prevailing temperatures of the system forerun and return. Additionally, the type of prosumer integration into the system has a decisive influence on the regulation. Therefore, a distinction has to be made between return and forerun riser and an integration of the return to the forerun.

The model of the secondary side can be used to predict the time of heat input (into the district heating system) and the temperature level of this heat. The two model parts allow an energetic and economical investigation of district heating systems with a large number of prosumers. This is enabled by combining the secondary and primary side model. The primary side model receives data on the prosumers' strategy from the secondary side model. Hydraulic problems such as flow reversals can be also investigated.

Session 5: Low-temperature DH and buildings

Anna Volkova Dr.sc.ing. senior researcher in Department of Energy Technology, Tallinn University of Technology. She defended PhD thesis in 2008, in Riga Technical University (Latvia). Anna Volkova has been as a posdoc researcher and later senior researcher since 2009 in Department of Energy Technology, Tallinn University of Technology (Estonia). Anna Volkova is author and co-author of more than 30 scientific publications. The main research topics are district heating, thermal energy storage, CHP and energy efficiency.

Session Keynote:

Barriers for transition to 4th generation district heating in existing large networks

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Keywords: District heating, district heating networks, 4GDH, renewable energy, energy efficiency

Today, the 4th generation of district heating (DH) is one of the hottest topics in energy world as it is sustainable and effective way to deliver heat energy to houses. The 4th generation is described with keywords as low temperature, low losses, renewable and surplus energy utilization and high efficiency.

The main goal of the study is to make the overview of technical, legislative and economic problems, related to the transition process to 4th generation district heating in large DH networks (DHN).

In spite of the fact, that 4th generation district heating concept has been implemented in European DHN, there are still numerous DHN that can be described as a second or third generation networks. The main questions, that should be answered are, why these networks are not transited by now, why the transition process is slow, what are the obstacles and possible solutions for transition process to 4th generation district heating.

All DHN consist of three main parts: production, distribution and consumption. The production side mostly meets the requirements of 4th generation network: renewable energy as biomass is often used to cover base load, lot of low-temperature waste energy is ready give energy to be used in DH. Network planning and construction technologies are well developed and already used in most networks, but more precise planning can be used. The most problematic side for implementation of 4th generation DH in large and old networks is a consumer side. Heat emitting devices were mostly installed, taking into account higher parameters and they are not able to pass enough energy from low temperature sources. In order to overcome this problem, consumer should be stimulated from DH companies and government to use best available technologies – the key for existing networks transition. In addition, changes in one part of the network require changes in other parts – the modernization process should be well planned and done at the same time.

The study will be focused on the evaluation of barriers related to the following 4th generation DH characteristics: low temperature DH, low temperature tap hot water, low network losses, energy recycling from low temperature sources, integration with cooling and electricity grids, smaller pipe dimension.

Danhong Wang is a PhD student from Swiss Federal Institute of Technology, Zurich, Switzerland. Her research work is focusing on decentralized energy system modelling and optimization at urban scale.

A methodology on modelling district heating networks with decentralized renewable energy feed-in

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Keywords: Thermal Hydraulic Model, Decentralized Renewable, District Heating Networks

The future district heating system is envisioned to meet heating demand of buildings, through enabling the utilization of renewable energy technologies within a district.

District heating systems are generally composed of 3 subsystems, namely heat production, distribution networks, and multiple consumers. The integration of heat production from renewable energy sources such as solar energy or waste heat can be realized through feed-in of energy both at centralized or decentralized location at the consumer side. Modelling the interactions between these subsystems can be challenging because, the effective utilization of distributed energy sources with low energy quality such as waste heat requires to capture the temperature dynamics. Additionally, as distribution networks serve as thermal transmission grids, the interaction between the energy feed-in (i.e. production) and withdrawal (i.e. consumption) at multiple locations within distribution networks have to be taken into account.

This paper describes a methodology of modelling district heating networks with decentralized feed-in of energy which incorporates factors mentioned above. The aim is to develop a flexible modelling methodology which can be applied to any kind of district, to evaluate the feasibility of a thermal network with decentralized feed-in, and additionally allows to investigate different operational strategies. As a starting point the dynamic energy demand of buildings and supply through renewable energy sources is captured with a building energy simulation tool. In a second step, the network configuration is designed with geographical information system (GIS) taking district layouts into account . The network simulation model is formulated as a thermal hydraulic model in Matlab, whereby the network structure is represented by graph theory with edges and nodes. It is based on hourly time step steady state physical system modelling approach. Additionally, pipe mass flow rates, as well as pressure and temperature at key nodes (water feed-in and withdrawal) to account for hydraulic head loss and thermal losses is incorporated in the modelling methodology. Identified energy sources and consumer substations are represented by simplified low order component models which are connected with the network as source and sink. To demonstrate the approach, the model is applied to a case study district which is composed of 20 buildings with rooftop-mounted flat plate solar thermal collectors as decentralized renewable source. Additionally, an ideal centralized source is added at a feasible location, to overcome periods when there is not enough solar energy available. The network configuration is evaluated for the specific location, and the network model is constructed with the above mentioned methodology. To evaluate the operational strategy of the network, two different scenarios for supply temperature levels (medium and low) are investigated. The system performance of both scenarios is evaluated based on total thermal losses within the network and renewable energy share throughout the year.

Andra Blumberga is research dean in Faculty of Power and Eletrotechnics. Her research area is connected with energy efficiency in buildings particularly historical buildings and system Dynamics modelling. Ruta Vanag is, PhD student. Main research field is energy efficiency in buildings and biomimicry. Professor Dagnija Blumberga is director of institute of Energy Systems and Environment. The main research area is renewable energy resources.

Future Buildings as Prosumers Integrated into DH Systems

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Keywords:

The energy-efficiency improvement measures in buildings have begun to drain all the possibilities that are provided by cost-effective technological solutions. It is impossible to increase the thickness of thermal insulation of buildings to infinity. Increasing the heat insulation layer benefits decrease and it is not possible to justify an economically.

Innovative solutions which gives the possibility to reduce the energy consumption of buildings use in biomimicry concept. This paper is devoted to the building of Contemporary Art museum in Riga, which will be connected to DH system, increasing energy efficiency by use of particular cells with lens to concentrate solar energy. Solar are integrated into building walls with the phase transfer materials. The building project design is close to the final phase of the development.

On the south wall and roof of the building, which is directed to the south, will be incorporated solar cells. They consist from sandwich type elements, which include multiple layers: lens, insulating layer, metallic plate with a high emissivity factor, the phase transfer material layer and the internal wall of the room. A metallic plate with ribs placed in the phase transfer layer both improves heat transfer conditions for the material and plays the role of accumulation box.

Solar cells were used for implementation of multifactory research in laboratory as well as in , in an outdoor climatic conditions. Experimental study results showed how the building solar cells are starting to play the role of energy producer and supplier by becoming as prosumer at the moment when the sun is shining and accumulating the energy transfer phase of the material. Use of the computer program COMSOL allows to develop a mathematical model of the building, which was validated using experimental data. The simulation of heat and mass exchange processes allowed to determine the quantities of energy from solar radiation on an annual basis.

The article ends with the results and museum walls scenarios analysis, which is based on the energy balance of the building. The base scenario is drawn up on the current energy consumption in the heat load duration curve. The other three scenarios illustrate the benefits that are compared with the energy efficiency improvements and the reduction of energy consumption.

In the paper appear solutions of flexibility of district heating demand response.

Asad Ashfaq is currently a PhD student in the Nottingham Trent University. Previously, he has done his bachelors in electrical engineering, masters in power engineering and performed research at Aarhus University, Denmark. His research interests lie in the energy system, renewable energy, and mathematical optimization of energy system. Currently, he is working on an innovative 4th generation district heating systems in Nottingham

Hydraulic control model for the implementation of LTDH in existing boiler based buildings

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Keywords: District heating; hydraulic balance; differential pressure; excess heat

We present a simple weather based autoregressive model for maintaining hydraulic balance during the implementation of low temperature district heating (LTDH) in existing buildings. In this paper, the aim is to improve the delta t of radiators inside the buildings by optimizing the mass flow-rate, differential pressure and maintaining ambient indoor temperature with respect to the measured outdoor temperature data. The heat demand simulations are performed in IDA-ICE and the optimum control strategy for maintaining hydraulic balance in different scenarios is calculated from the mathematical optimization model built in Python. Results from the simulation are verified with on-site field monitoring and show strong agreement with the. It is calculated that, in addition to the energy savings, reducing the pumping costs and improving the carbon footprints of the building, the excess heat losses can be reduced by almost 14%.

Xiaochen Yang works as Postdoc at DTU Civil Engineering. She has been working in the DH field for many year. Her current research activities cover the low temperature district heating and ultra-low temperature district heating system analyses, simulation for domestic hot water system, low exergy energy system, synergy between power and heating grids and etc.

Methods of reducing the district heating return temperature from the local substations

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Keywords: District heating, return temperature, domestic hot water circulation, circulation heat pump, heat loss

The return temperature is of great importance for the district heating system. On one hand, low return temperature can improve the energy efficiency on the heat production side by increasing the heat recovered from the flue gas condensation process. On the other, the overall capacity for the network can also be increased if the return temperature is lowered. For the current district heating system, one barrier of lowering the return temperature is the domestic hot water circulation. Since the circulation is normally operated at 50oC, the district heating water cannot be sufficiently cooled down during low-tapping or non-tapping period. In this paper different methods that aim at reducing the return temperature from the local substation. For the buildings with small domestic hot water circulation systems, the method that combining better insulation for the domestic hot water circulation pipe and good control of the storage tank is designed. For the building with large domestic hot water circulation system, to install a circulation heat pump between the storage tank and circulation circuit is considered as a solution. The energy performance and operation cost of those two solutions were investigated.

Session 6: Future district heating production and systems

Linn Laurberg Jensen. Project engineer for national and international projects concerning integration of RE in DHC networks. M.Sc. in Sustainable Energy Planning and Management, AAU, B.Sc. in thermal energy technology, AAU.

Session Keynote:

Cold Water District Heating and Cooling Systems as Flexible Energy Exchange Systems – a Promising Concept for the Future?

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Keywords Ultra low temperature district heating, district heating and cooling, excess heat, networks, storage, heat atlas, energy sources and sinks.

The FLEXYNETS concept makes it possible to provide contemporary heating and cooling by means of a combined district heating and cooling (DHC) network operating at "neutral" temperatures (e.g. 20 °C). Typical drawbacks of traditional DH such as significant heat losses and the highly unexplored integration potential of different available low temperature energy sources are avoided or minimised. The FLEXYNETS concept does not necessarily substitute nor is it opposed to traditional DH networks. An important outcome of the project is an identification of circumstances where the FLEXYNETS concept is suitable compared to alternatives such as individual supply or traditional DH.

Several configurations and properties of such a concept are analysed, e.g. the assessment of combinations of energy sources and sinks, and investigations on DHC network typologies and the pathways through the built environment. Since the FLEXYNETS concept allows recovering and recycling excess heat available along the network path, i.e. heat normally rejected by buildings, from supermarket chillers, data centres, various industrial processes etc., the production costs can also be lower than in traditional DH. Reversible heat pumps will be used to exchange heat with the DHC network on the demand side, providing the necessary cooling and heating for the buildings, thus making it possible to supply heating and cooling simultaneously in the same network. Intelligent control systems can promote the use of surplus electricity in case of large shares of fluctuating (e.g. wind and solar based) electricity production. This way, the concept can help balancing future electricity grids with an increased share of renewables.

The possibility of using heat storages to balance the demand and supply over time is addressed in different scales and quantities. The modelling is performed for a range of excess heat quantities, a range of storage temperatures and for both daily and seasonal heat storages. The results indicate that storing the heat at the temperature of the source (which is assumed to be higher than the FLEXYNETS temperature level), before injection to the network, could be technically and economically feasible for the integration of energy sources that do not match the heating or cooling demand profile. For sufficiently large external heat sources, it could be feasible to transmit the excess heat over several kilometres.

Compared to traditional DH, lower investment costs are expected to be reached due to the use of series 1 pipes (low insulation class pipes) or plastic pipes with some or no insulation, suitable for the low temperatures of the network. Different network layout options have been analysed by means of a GIS tool capable of locating the shortest route possible of the network, where demand points are represented by the Heat Atlas which includes coordinates and demand of each building. The GIS tool makes it is possible to determine the pipe dimensions and thereby the investment costs in the network together with hydraulic parameters such as linear pressure loss and heat loss. Different scenarios for the FLEXYNETS concept and traditional DH temperature levels have been compared for both branch and ring structures.

FLEXYNETS is a H2020 European Project under grant agreement no. 649820 with a runtime from July 2015 to June 2018. Find more information at www.flexynets.eu.

Nadège Vetterli obtained her Master of Science in Engineering from the Swiss Federal Institute of Technology Lausanne (EPFL) in 2008. She has been working as a senior research associate at the Centre for Integrated Building Technology (ZIG) since 2012. She is head of the research group "Simulation and Analysis of Buildings and Districts", which focuses on simulations and data analysis

Five-year energy monitoring of a low temperature heating and cooling network

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Keywords: Low temperature district network, monitoring, performance gap, assessment

Low temperature networks (LTN) (less than 20°C) are new promising solutions to increase the use of distributed renewable energy sources (REDS) at district level. In these systems, most buildings are prosumers, i.e. they supply heat to as well as consume heat from the LTN. The "Suurstoffi" district in Central Switzerland is a newly constructed site that uses a LTN for heating as well as cooling. The vision and main objectives for this site is to ensure a fully renewable energy supply and CO_2-neutral operation. In order to assess these objectives, a comprehensive energy monitoring of the LTN was installed, which has been analysed by the Lucerne University of Applied Sciences and Arts (HSLU) over the last five years.

Through energy monitoring, an important data base and benchmark of a LTN was generated and could be used for similar projects in the future. In this analysis, the monitoring results have been compared to the initial design calculations on a regular basis, which allowed calculating and benchmarking the effective energy efficiency of the decentralised energy systems, identifying and quantifying the deficient regeneration of the seasonal storage, determining a higher-than-expected heat demand and thus a significant performance gap. To predict the network's heat balance in its final state and verify the robustness of the energy concept, a comprehensive simulation model of the entire district was developed and verified with the monitoring data. Additional building simulations helped to achieve an in-depth understanding of the performance gap and the users' influence on it. Based on these holistic insights, the performance gap has been addressed by targeted operational optimisation measures, e.g. the integration of hybrid solar panels (PV and thermal) and an improvement of the basic design for the next construction phase.

The observed stabilisation of the LTN's temperatures indicates that the taken measures also improved the flexibility and robustness of the system.

The energy monitoring of the "Suurstoffi" district also revealed a substantial complexity on the stakeholder side, indicating that a professional supervision of planning and operation plays a central role. Firstly, the integration of innovative decentralised energy systems and of a comprehensive monitoring system was a challenge due to the stakeholder's lack of experience and knowledge. Secondly, the stakeholder's dynamics in combination with an ongoing development of the project site made it necessary to constantly adapt and develop the energy concept and the monitoring process, accordingly. Thus it must be argued that solely technical approaches and solutions like the presented monitoring are too short handed and should be completed by a systemic approach. The involvement of the stakeholders and the consideration of their expectations along the project implementation should be an integral part of the systemic approach.

In this case, we will discuss how such a systemic process should be designed and which process elements or key measures, respectively, should be taken into account.

Henrik Pieper is a PhD student at the Department of Mechanical Engineering at Technical University of Denmark at the Section Thermal Energy. His current research is about developing new system designs for district heating and district cooling networks. The focus is on heat pumps utilizing low temperature heat sources.

Performance analysis of heat pumps utilizing different low temperature heat sources to supply district heating

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Keywords: District heating, Heat pumps, Low temperature heat sources, Optimization

The city council of Copenhagen, Denmark, agreed on a climate plan to become the first CO_2 neutral capital in the World by 2025. District heating (DH) dominates the heat supply covering 98% of the heat demand in the city. In 2015, 53% of the supplied heat was CO_2 neutral. This indicates the need of transferring the DH network even further. One possibility is integrating large-scale heat pumps (HPs). Often, a constant coefficient of performance (COP) over the entire year is used to investigate potentials of integrating HPs. The COP however may vary depending on the load and temperature variations of heat source and heat sink.
In the present work we present a theoretical study on how the variation in COP influences the choice of HPs utilizing different heat sources. It is investigated how hourly changes of COP affect the performance when supplying heat to a DH network. Considered heat sources were: groundwater, seawater and air. Linear programming was used for optimizing the hourly operation of HPs with the aim of minimizing annual costs. The study is based on data for the area of Copenhagen, Denmark. Two cases were investigated: one with a base load unit supplying a constant load during the entire year e.g. a combined heat and power (CHP) plant, and one without base load. One evaluated parameter was a weighted COP based on the supplied heat of each heat pump (HP) at every hour.
The results showed that the seawater and air HP performances calculated according to their dispatched hours were different than the theoretical mean performances over the year without accounting for their operating time. The weighted COP of the HP utilizing seawater decreased by 12% and the one based on air by 16%. In addition, hourly calculations of COP revealed significant variations for these two heat sources. The COP of the HP utilizing seawater varied between −16% and +29% around its theoretical mean value. The minimum COP of the HP based on air was 30% lower than its mean value, while its maximum was 62% higher. Groundwater was found to be the most favorable individual heat source with constant COP. The COP of HPs based on a mix of heat sources depended on the share in HP capacity of the heat sources. The COP of the system was found to be 3% greater than the COP of the system using a HP based on only groundwater when no base load was present. There was no increase in performance with base load. For achieving high COP without base load, the groundwater HP capacity should be within 45% to 65% of the maximum heat demand. The HP capacity utilizing seawater or air should be between 0% and 20%. The availability of different heat sources resulted in prioritizing the HP with highest COP for every hour, and thus exploiting the heat more efficiently.

Anna-Elisabeth Wollstein-Lehmkuhl, civil engineer, PhD student at Boysen-TU Dresden-Graduiertenkolleg since 2015, field of work: civil engineering, construction management, research topic: seasonal heat storage systems and their economical feasibility

Integration of seasonal heat storage systems in existing building structures

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Keywords: Seasonal heat storage systems, economic and ecological feasibility study, solar heating, decentral heat supply

More than 50% of the total energy consumption in Germany is about heat. The climate protection goals of the German Government can only be reached by a further change of the energy transition into a heat transition. Within the building sector, it is not enough to improve only the energy efficiency of the buildings in order to reduce the consumption of fossil energy sources. Therefore the use of renewable energy for the heat production has to increase. The existing building structures in Germany are one of the key factors in this consideration. To supply those building structures with renewable energy is one of the future goals. Seasonal heat storage systems can support this process because the storage enables heat supply and heat demand to be decoupled time-wise.

Within this background, the topic is focused on the energetic and economic research about the integration of a seasonal heat storage system in an existing building structure. The style of the existing development is characteristic for urban areas. The existing development involves a trilateral built-up inner courtyard with apartment buildings consisting of over 200 accommodation units. In the future, the heat supply shall be ensured by a solar heat system and seasonal heat storage. The seasonal hot-water storage will be buried within the inner courtyard, with the result that the structure is harmoniously integrated into the landscape. Furthermore it is possible to reduce potential heat losses arising from the heat grid because of the short distances between storage and buildings.

For the study a specific technical solution for the building refurbishment of the existing development was found. The first focus of the study was on the energy efficiency of the buildings as well as on the integration of the solar heat system, the heat storage and the heat grid between the storage and the buildings. Within the building refurbishment the characteristic energy values of the building shell has been improved. This was done with specific measures like the application of composite heat insulation systems or the replacement of external doors and windows.

An energetic model has been established on the basis of the specific heat load of the building and the heat capacity of the storage as well as the heat balance of the solar heat system. This contains factors as follows:

- primary and end energy consumption of the buildings,
- heat balance of the solar heat system,
- the capability of the storage to accumulate heat-energy for the purpose of dimensioning and design,
- consideration of the required heat grid.

Subsequently a heat supply concept for this structural unit of an urban area was developed. The impacts of the building with his related energetic characteristics on the heat storage had priority. Thus it was possible to identify opportunities and weak spots of the seasonal heat storage. Likewise the security of supply has been verified. The study is currently only based on the energetic level. An economical study needs to be conducted afterwards in order to evaluate capital expenditure and operating expenses. Therefor a complete finance plan will be established. Based on many risky factor in it, the results will be verified and evaluated with a stochastic simulation.

The investigation can demonstrate that the decentralized heat supply within urban areas is part of the future and sustainable heat supply in Germany. Besides the ecological point of view an economic solution will be found, which is important for the competitiveness of the system.

Benjamin Zühlsdorf is a PhD student at the Department of Mechanical Engineering at the Technical University of Denmark. His research focuses on high-performance heat pump cycles for low temperature heat sources.

Potential for performance improvement of booster heat pumps by utilization of mixtures

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Keywords: Booster Heat Pump, Zeotropic Mixture, Working Fluid, Optimization, Performance Increase

Decreasing the district heating forward temperature has been proposed to increase the overall energy efficiency of district heating systems and promote the integration of renewable heat sources. In the case of ultra-low temperature district heating the supplied forward temperature is too low to allow for domestic hot water production through direct heat transfer. Thus, local booster heat pumps are considered to increase the temperature of a fraction of the district heating supply for domestic hot water production.

The effects of working fluids with high global warming potential (GWP) and ozone depletion potential (ODP) have caused regulations to eliminate many commonly preferred refrigerants. This results in a request for solutions with improved performance that also respect environmental and legal constraints, e.g., by using natural refrigerants.

Extending the choice of working fluids, to not only pure, but also to mixtures, does not only increase the search space for feasible solutions, but also enables to benefit from mixture specific characteristics. Unlike pure fluids, zeotropic mixtures imply a temperature glide during phase change, which allows matching the temperature glide of heat sink and source with the working fluid, and accordingly, reduces the irreversibility's of heat exchange processes. Additionally, it is possible to influence specific medium properties, such as flammability and pressures by designing the mixture optimally.

The present study focuses on the optimization of a booster heat pump, which uses the district heating forward flow both as heat sink and heat source. The district heating forward temperature was assumed to be 40 °C, which is increased to 60 °C in the condenser in order to supply domestic hot water to the building. The district heating forward stream is also used as heat source, and is cooled in the evaporator and discharged into the district heating return line. The discharge temperature was 25 °C.

The study presents the screening process among different sets of working fluids. It includes simulations for all considered working fluids and possible mixtures among them and comparisons to alternative state of the art equipment. The performance was evaluated based on economic and thermodynamic performance, while other relevant parameters, such as flammability were also reported.

The results showed a significant performance increase of 34 % in COP for the best mixed working fluids when compared to the best pure fluids from the set. It was concluded, that the use of mixed working fluids can be a suitable measure to provide improved heat pump cycles, and hence to reach economically feasible solutions.

Session 7: Smart Energy Systems

Tobias Fleiter began work at the Fraunhofer ISI in in 2007 and coordinates the business unit for energy demand analysis and forecasts since 2013. He obtained his PhD in 2012 at Utrecht University on the topic “The adoption of energy-efficient technologies by firms”. His work focuses on energy systems modelling with a focus on energy demand and the industry sector.

Session Keynote:

Using industrial excess heat in district heating networks - A simulation assessment of potentials and cost-effectiveness for a refinery in Portugal

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Keywords: Excess heat, waste heat, district heating, refinery, heat network, energy planning

Using excess heat from industrial installations can be an economically viable as well as energy-efficient solution that contributes to a decarbonisation of the heating and cooling sector. Often, excess heat potentials are used inside the company boundaries, e.g. for pre-heating combustion air or materials - if at all. Large potentials for further use of excess heat have been identified in recent studies, mainly related to large plants from the basic materials industries (steel, cement, paper, refineries, chemicals, etc.). Often, however, remaining excess heat potentials are available at relatively low temperatures, which are not suitable for re-use in industrial processes. Compared to industrial processes, district heating grids operate at relatively low temperatures of up to 100°C and can be a suitable user of available excess heat. Currently, only a few projects have been implemented that use industrial excess heat in district heating. E.g. in 2010 the largest refinery in Germany was connected to the district heating grid in Karlsruhe, providing about 520 GWh heat per year. Similar opportunities exist at other refinery locations in Europe, of which only few are connected to district heating. Here, we aim to assess the cost-effectiveness of using excess heat from a refinery in Portugal to provide heat and cold for a nearby commercial area with large multi storey buildings. We aim to assess key performance indicators including CO2 mitigation, capital expenditures as well as the cost-effectiveness of the heat and cold and cold supply. The assessment is based on a detailed simulation using the energy system model Energy Pro. It performs an hourly simulation of heat demand and heat supply. The use of excess heat is benchmarked with other supply options including today's supply mix based on natural gas boilers and compression chiller but also alternative supply options include (individual) solar thermal, photovoltaics and tri-generation based on biomass. Cost-effectiveness is assessed based on the levelised cost of heating/cooling per kWh. Both a private economic as well as a (simple) socio-economic perspective are taken. The costs cover all energy system elements. This includes the district heating and cooling network (approx. 5 km trench length) and the installation of a recovery system (shell and tube heat exchanger and absorption chiller), which is installed at the refinery. The heat exchangers are assumed to cost 2000 euros/m² with an efficiency of 85% and 15 years lifetime. The capital expenditures for the DHC grid are about 600-700 euros/m grid lengths (diameters of 120-150mm). The refinery provides heat at around 90°C, which is used for the generator of the absorption chiller, while the condenser works with seawater at 20°C. Capital expenditures for the absorption chiller are 250 euros/kW. It works at an average efficiency of 65% with 20 years lifetime. Results show that from a (simple) socio economic perspective the use of excess heat from the refinery has the lowest levelized cost of heating/cooling (LCOHC). This even leaves room for a possible price increases plus margins for the refinery and a heating/cooling distribution company. Thus, this case study provides strong evidence for a very high cost-effectiveness of utilizing the available excess heat. Ongoing discussion with the refinery, the municipality as well as the possible heat/cold consumers about the possible implementation of this project as well as the assumptions about available excess heat potentials will allow the final presentation and paper to provide even more robust results and recommendations.

Similar screening studies should be conducted also for the other nearly large 100 refineries in Europe.

Hanmin Cai is currently a PhD student at DTU. He is working on demand side management to assist heat and electric network operation, and is involved in Nordhavn project.

An Experimental Setup for Investigating Flexibility of District Heating with Fuel Shift

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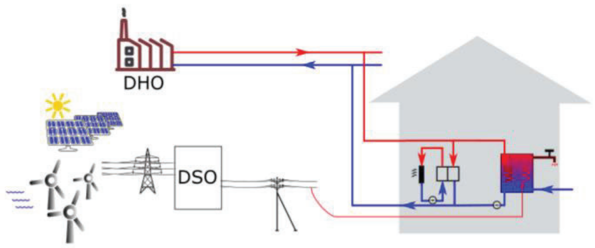
Keywords: Energy integration; domestic hot water; fuel-shift; low-temperature-district-heating; flexibility; ancillary service

Low Temperature District Heating (LTDH) has been investigated as a way of heat loss reduction and facilitating renewable energy integration. The technology is promising for space heating in well-insulated buildings, for example, those constructed in Nordhavn. However, LTDH alone is not sufficient for domestic water heating, which requires 50 °C for circulation and 60 °C as set point temperature for the storage tank due to hygiene concern. One solution is using electric heater at the house substation to increase tank water temperature. This setup also gives additional controllability for end users. Centre for Electric Power and Energy (CEE) at DTU has built a flexible heat system (FlexHeatSystem illustrated in Fig. 1) at DTU Risø Campus as combined heat and electricity research facility, which is also integrated into SYSLAB as part of the platform for Decentralized Energy Resources research.

This experimental setup consists of three parts. District heating heat source is emulated by using a 22.5kW electric heater in Fig 2, which can supply hot water up to 85 °C. With the possibility of varying the supply water temperature, this heat source can be used to study both low and high temperature district heating scenarios. Electric heater in Fig. 3 is installed at the house substation inside a residential building, to boost the tank water to be over 55 °C when LTDH is assumed. Dump load installed next to the house substation as shown in Fig. 4 is used to simulate water draw scenarios and test whether water temperature at the tapping point can comply with national codes. Flow rate and temperature sensors are installed at selected points to measure energy flow and support controller design and verification

We will study fuel-shift solution using this experimental setup. Research will firstly focus additional flexibility that local electrified heating alternatives can offer to the DH system while guarantee user comfort. Furthermore we will study its potential for providing ancillary services to power system. We will conclude with the research with fuel-shift feasibility and implications for industrial application.



Sylvain Quoilin is a research associate at the University of Liège and at the Joint Research Centre of the European Commission. His topics of interest are the modelling of (smart) energy systems, including power systems, electrical and thermal storage, decentralized consumption and generation. His research mainly focuses on the coupling between the power and heat sector and on the aggregation of decentralized resources.

Coupling a power system model to a building model to evaluated the flexibility potential of DSM at country level

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Keywords: Flexibility, DSM, Power Dispatch, Heat pump, Thermal Storage
The integration of renewable energy sources in the electricity production mix has an important impact on the management of the electricity grid, due to their variability. In particular, to ensure grid balancing, there is a rising need for flexibility, both on the supply and demand sides. A possible solution to help achieve grid balancing is the smart modulation of the electrical load in a "demand following supply" scheme through demand-side management.

In this context, the objective of this work is to assess the maximum amount of flexibility that can be harvested from the management of residential thermostatically-controlled loads (TCL) and, in particular, through the use of heat pumps, electrical heaters and thermal storage. To that end, a modelling framework is developed to couple a power system model (in this case the open-source Dispa-SET v2.2 model) with the model of a set of building typologies using heat pumps or electrical heaters for space heating and/or domestic hot water production.

Dispa-SET is an MILP optimal dispatch and unit commitment model, covering the European area and based on a detailed dataset of power plants, renewable generation, demand profiles, power plant outages, hydro time series, etc. Its spatial and time resolutions are NUTS1 and one hour, respectively.

The building model is a two-zone reduced-order thermal model including storage and HVAC systems. To account for the heterogeneity of the building stock, the latter is characterized in terms of age, type of construction, insulation level and energy vector based on the results of a previous project for the Belgian case. A tree-structure was developed and validated with the aggregated historical consumption data. This structure is used as inputs to the building model.

Because of the computational intensity of simulating a large number of house typologies and occupation profiles simultaneously, an aggregation method based on the clustering of heterogeneous loads in semi-homogeneous subsets is proposed. Similarities between loads are determined based on occupant-related constraints for space-heating and domestic hot water needs.

To investigate the potential of flexible loads to shift load from peak to off-peak periods with different storage options, both models are coupled and run under different scenarios of renewable, heat pump and electrical heaters penetration. Results from the simulation of the Belgian case indicate that, depending on the renewable penetration, the optimal control of TCLs can significantly reduce curtailment levels, day-ahead market price and variability, and the cycling requirement of traditional generation. Since these results are obtained under a perfect foresight hypothesis, they should be considered as an upper limit of the achievable flexibility through DSM.

Fonteini Rafaela Tsaousi is a MSc student in Energy Science and Technology at ETH Zurich, Zurich, Switzerland. She also works as a student assistant in Siemens Building Technologies, Zug, Switzerland. On 2014 she received a MSc in Mechanical Engineering from the National Technical University of Athens, Greece. Her research interests include power market modelling, energy systems optimization, and sustainability.

The influence of participation in ancillary services markets on optimal energy hub operation

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Keywords: Energy hub, ancillary services, urban energy systems, stochastic optimization, frequency control

Increased deployment of renewable energy technologies and decentralization of energy production are important features of future sustainable development in the electricity sector. However, the variable nature of these sources can lead to instabilities in the electricity grid. Ancillary services (AS) play an important role in balancing the electricity grid, ensuring the secure operation of the system. In each grid area, the grid operator is responsible for providing these services and ensuring security of supply. There are a number of types of ancillary services in Switzerland, one of which is frequency control. The main goal of frequency control is to maintain the balance between energy production and consumption thus stabilizing the system frequency to a nominal value. In case frequency deviations occur, reserve capacity is used by the grid operator to re-stabilize the grid. This capacity is offered by producers and consumers through organized markets. There exist three different types of frequency control, which are primary, secondary and tertiary control, each with a separately organized market.

Distributed multi-energy systems (DMES) – such as district and community energy systems – can participate in AS markets in Switzerland. As such, these systems can contribute to frequency control while at the same time increasing their revenue. An energy hub (EH) approach frames DMES in terms of inflows, outflows, conversions and storage of energy streams. The hub represents a conceptual node where energy inflows are being consumed or stored and converted to energy outflows [1]. The *Ehub Modelling Tool* is a tool developed to investigate the optimal design and operation of EH systems under different circumstances. EH are modelled as mixed-integer linear programs that optimize DMES operation and/or design while minimizing costs and/or carbon emissions [2].

While there is extensive literature on participation in AS services for producers or individual consumers, this project extents this research field by considering AS participation for DMES under the EH approach. More specifically, the project investigates the effect of participation in the AS markets on the possible operation outcomes of an EH in Switzerland. A two stage stochastic optimization model is developed that represents the participation of an EH in the Tertiary Control market. The objective is to minimize the operational cost for each week over a total time horizon of one year. The first stage is comprised of the optimization of the bids in the capacity market. The decision on the bidding capacities is made, taking into account a fixed bid price. The second stage consists of the optimization of the EH dispatch schedule after participation in the energy market. The decision for participation in the energy market is made after the energy prices are revealed. The results highlight possible scenarios with profitable participation in AS markets for an EH. Comparison of the stochastic model with the deterministic version not including bidding is used for evaluation and to indicate the benefits of AS market participation.

Session 8: Future district heating production and systems

Louise Ödlund is a professor in Energy Systems at Linköping University, Sweden. Her research area concerns sustainable energy systems with a focus on system perspective on energy use and supply, and is performed in close cooperation with different actor as for example energy utilities, industries, property owners, and governments.

Session Keynote:

Cooperation and system perspective for increased sustainability

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Keywords: System perspective, energy efficiency, conversion, renewable energy sources, CO2 emissions

Today's greatest challenge is to find methods that will help society to shift towards increased sustainability. Measures that includes increased efficiency at a system level and at the same time reduced climate impact are therefore important to find and implement.

A system perspective where supply and use of energy are correspondingly valued is a prerequisite for a fully balanced and renewable energy system. To meet the target of a long-term and resource-efficient region it is vital to have an interaction between different energy services. No energy service alone can be the sole provider of the total energy demand for a specific region. Through increased cooperation with other energy services in the region a CHP plant can reduce the demand of peak loads, ie get a square load curve, and also disconnect the electricity from the heating / cooling demand and instead maximize electricity when electricity prices are high. To achieve a successful implementation of analyzed measures it though requires a close cooperation with energy companies, industries and property owners where the total energy system of the region is taken into consideration.

In this project optimizations of the total energy system of a region will be combined with different production plans for CHP plants. Results will show how a system perspective on a regions total demand for energy, together with increased cooperation between various energy services, will lead to reduced global emissions of C02 as well as reduced production costs.

Jelena Ziemele M.sc.ing., Riga Technical University, Latvia. She worked in JSC "Ligija Teks" as manager of Boiler and Turbine House, JSC "Latvijas Gaze" as a main engineer. Now J.Ziemele is continuing the doctoral studies in Environmental Science. This article is part of her doctoral work which provides 4th generation district heating in Latvia and other Baltic States.

Bioeconomy approach in district heating development

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Keywords: District heating, 4GDH, bioeconomy, heat energy tariff, sustainable energy

4th Generation District Heating (4GDH) systems implementation is related to the new challenges and several barriers, which requires development of prudent strategy for each DH company. The strategy should be based on coherent modernization principles. The coherent modernization approach allows simultaneous development of all stages of DH – heat source with stress to renewable energy sources, distribution networks with transition to low-temperature regime and end users who take energy efficiency measures to reduce the total heat consumption. More and more energy in Latvia is produced in the cogeneration process (75% in 2014.) and fossil fuels are replaced with wood. The bioeconomy approach provide much more sustainable local resource (wood) using that involves the use of these resources in order to obtain the highest added value.

The research provides combining of 4GDH development with the bioeconomy approach by study development scenarios for DH company "Fortum" Jelgava. Current Fortum's activities are related to the two cogeneration plants (CHP) operation. The biggest CHP is operated by wood chips with electric power of 23 MW and heat power of 45 MW. CHP often operates by condensing regime for economic reasons that is not a sustainable solution. Company sells electricity to Nord Pool market. Second CHP is operated by natural gas. Research provides a number of "Fortum Latvia" development scenarios and is looking for economic feasible and sustainable solutions. One of the scenarios offer building biofuel factory near biomass CHP, thereby creating products with added value and leaving an effect to economic, technological and environmental indicators change. Biomass combustion combined with biofuel production would expand industrial symbiosis in DH company "Fortum Latvia". The next possibility could be using waste heat from biofuel production processes and creating new innovative product from combustion process waste (ash). One more alternative - the DH system expands heat load by adding new consumers, whose heating and hot water load is around 10 MW. Transition to 4GDH related with energy efficiency measures by end users and the transition to a low-temperature regime in distribution networks. Result of energy efficiency measures by end users and their impact on the development of DH studied by one of scenarios separately and by other - together with building of the biofuel factory and adding of heat load. Heat energy tariff and changes in the fixed and variable components of it are calculated for all scenarios. Research identifies the long run marginal costs, which will provide the energy production and the installation of biofuel production capacity.

4GDH concept combining with the bioeconomy approach affords as sustainable development of DH system in the long-term and the shift towards a low carbon system as provides a national energy independence.

Gunnar Lennermoi is active as consultant in Energianalys AB and PhD student at Mälardalen University with expertise on solar thermal systems. Engaged more or less in all district heating feed-in solar thermal systems built in Sweden.

The value of heat supplied to the return or supply pipe

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Keywords: Solar district heating, Feed-in systems, R/S-connection, R/R-connection, Solar Thermal

There are four ways to connect a local feed-in plant to a district heating network. A feed-in plant is per definition a decentralized heat source that is not connected to the central heat generation in the district heating network. The four different systems are R/R (return/return), R/S (Return/Supply), S/R (Supply/Return) and S/S (Supply/Supply). The different systems have different advantages and disadvantages. The most advantageous feed-in system is R/S, but the for a solar thermal (ST) plant R/R can give a higher heat generation.

The efficiency will decline in a ST plant if the mean temperature in the solar collectors rises. The two feed-in alternatives, where the water is withdrawn from the return pipe, R/R and R/S, improves solar collector efficiency compared to the others two systems since the inlet temperature to the solar collector is kept lower. An important difference between R/R and R/S connection is that the feed-in temperature in the R/S system needs to be higher than a given temperature while the feed-in temperature in a R/R connection can be at any level.

A new ST feed-in plant is under construction in Ystad, in south of Sweden. The collector area is a little more than 500 m². The feed-in concept is a combination between of R/R and R/S. The feed-in substation is premanufactured and the ST system is small in comparison with the district heating (DH) system. The heat generated in the Ystad DH system is coming from forest waste, a boiler with flue gas condensation, other solid biofuels, waste dump gas and 2 % fuel oil (2016). The efficiency in the flue gas condensation is improved with a lower return temperature.

The ST plant shall be evaluated in two different ways, solar-COP and efficiency. The solar-COP will be calculated as feed-in heat divided by used electricity and it will be calculated for different levels of solar insolation. The efficiency is calculated as feed-in heat divided by the total solar insolation and it will be calculated for different levels of solar insolation. Readings from the summer 2017 will be reported.

There are mainly two reasons for why the return temperature should be low in a DH network. One is that the network can deliver more heat power with the same supply temperature and flow. The other reason is that some heat generation units have a better efficiency if the inlet temperature is lower. The inlet temperature corresponds to the DH network return temperature.

Depending on the actual heat generation in the central heat plant, in Ystad or in other DH networks, it is possible to estimate if a kWh at the return pipe will have a lower value than a kWh on the supply pipe.

A feed-in kWh on the supply pipe will reduce the electricity use in the main pumps but this will not be the case if the feed-in kWh is on the return pipe.

The aim is to investigate if a R/R feed-in connection gives a higher ST production efficiency and solar-COP in comparison with a R/S feed-in connection with production figures from a real installation. The second step is to analyse the central heat generation and try to estimate if an R/S kWh has a higher value than an R/R kWh. These two parts together will result in a recommendation: if a ST feed-in plant with these conditions it is an advantage to connect by R/R, R/S or both?

Johannes Pelda is a researcher in the field of energy systems in regional areas and district heating systems. Modelling and simulation of energy systems

Quasi-dynamic simulation of district heating systems using hydraulic load factor as key indicator for optimised transition towards 4th generation district heating

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Keywords: Waste heat, decentralised heat storages, transition, 4th generation district heating, thermo-hydraulic simulation, hydraulic load factor

Introduction The transition of existing district heating systems (DHS) towards 4th generation DHS involves several economic and technical challenges. The need for transformation of existing DHS results from two main aspects. Firstly, the demand for reduction of CO_2-emissions in heat generation and secondly the decreasing heat demand due to improved thermal insulation of buildings.

Integration of CO_2 neutral low-temperature heat sources demands for transformation of DHS towards lower supply and return temperatures. At supply temperatures of 70 °C down to 30 °C alternative heat sources such as low-grade waste heat from sewage or industry as well as renewable heat sources can be integrated, resulting in reduced CO_2-emissions of the district heating system. Furthermore, following easier piping reduces cost of investment.

Research question In existing DHS, where renovation rate of buildings is low, the heat demand decreases slowly and over long time periods. Therefore, the reduction of supply temperature in the short term generally demands an increase of mass flow, due to reduced temperature difference between supply and return flow. As fixed pipe diameters result in pressure increase within the system, higher mass flow causes higher pumping costs. How can technical solutions avoid these thermo-hydraulic limitations when transforming DHS towards future needs?

Methodology Using the model of existing DHS the effects of reduced supply and return temperature on heat generation, heating grid and heat consumer are analysed by quasi-dynamic simulation. A newly developed algorithm represents the behaviour of the DHS at lowered supply temperature. The algorithm balances heat demand, consumption and losses. Within given parameters it calculates all data needed, like flow of mass, temperature and pressure. A hydraulic load factor (HLF) is introduced for the characterisation of the flow of mass within the pipe at different operation conditions. Simulation results show that HLF varies in different sections of the DHS. Taking HLF as benchmark parameter hydraulic limitations within the system are identified and technical options for influencing HLF are analysed. Different technologies to overcome the identified limitations are integrated into the model and are evaluated from technical, economic and ecological perspective.

Result / Conclusion Simulation results show that integration of decentralised heat sources and storages can compensate hydraulic limitations in the transition process of DHS. A methodology is given that allows the optimisation of DHS by determining the best location and optimising the technical parameters for different options. In addition to thermal storages, power to heat technologies and renewable heat sources as well as the integration of low-grade waste heat are considered as another possibility to cope with thermo-hydraulic limitations.

The results contribute to develop strategies to an economic feasible transition of DHS towards 4th generation considering technical and economic aspects. The used programming language python ensures open source and broader application of the methodology.

Ivan Andric is a double Ph.D. candidate enrolled in EMJD SELECT+ Ph.D. program within the field of thermal energy generation and distribution, and InnoEnegy Ph.D. School within the field of innovation & entrepreneurship. His research interests cover the direct and indirect impacts of climate change on techno-economic and environmental performance parameters of energy systems, with focus on district heating networks.

The impact of global warming and building renovation measures on district heating networks techno-economic parameters

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Keywords: Global warming, building renovation, district heating, techno-economic analysis

District heating networks are commonly proposed in the literature as an environmentally friendly solution for providing the urban environment with heating services, due to their multiple benefits. However, these systems require significant investments for construction and infrastructure placement, which are returned trough heat sales. Thus, according to current business models, network economic parameters are closely related to heat sales (and consequently to heat demand). Due to changing weather conditions caused by the global warming and building renovation measures triggered by new building energy efficiency policies, heat demand in the future is likely to decrease. This effect could consequently impact the techno-economic parameters, feasibility and environmental performance of district heating networks. The main goal of this study is to evaluate the impact of global warming and building renovation on the operational and economic parameters of district heating networks. As a case study, a prototypical French district was created based on the district of St. Felix, which is located in Nantes (France), and currently not connected to district heating network. The district consists of 622 single-family and multi-apartment buildings that vary in construction period and that can be used as representative for the French building stock. Weather scenarios for the studied period (2010-2050) were developed based on historical weather data and the outputs from the HadCM3 global circulation climate model. Building renovation scenario was based on the current and predicted market penetration rates of building envelope renovation measures. Moreover, as an additional aspect, the addition of solar thermal collectors as a building renovation measure was studied. Heat demand for all scenarios was calculated with a model based on the thermo-electrical analogy, previously developed and validated by the authors, while the network techno-economic parameters were calculated using a tool developed by the industrial partner (Veolia) for the internal use. Two cases were considered for district heating networks: case one, where the district heating network already exists within the district; and case two, where the district heating network is planned for construction based on a current district state (in this case capital investments costs for heat production units and network infrastructure construction were considered). The results showed that the decrease of heat demand proved to be the highest after the first year of renovation (2020), decreasing by 52% of the reference value. Accordingly, linear heat density decreases bellow the profitability minimum for traditional district heating networks. For each 18% decrease in heat demand, relative heat losses (in percent of the production) increased by 3% (percentage points). The participation of natural gas peak boiler in heat production increases over the studied period, while the participation of base load biomass boiler decreases, due to the fact that the numbers of hours with heat demand bellow the technical limit of the base load boiler was increasing. Accordingly, CO_2 emissions increase on average by 49kgCO_2/kWh per decade, reaching a peak in 2050 with 261kgCO_2/kWh, which is almost five times higher than in the reference year (2010). Heat production costs increased in both network cases, with higher increase rate for the scenario where the new district heating network is planned. Considering the renovation scenario with solar thermal collectors, the annual output from the collectors was higher than the annual heat demand. However, there was a discrepancy between the heat demand and collector production, which implies the necessity for heat storage. To amortize these impacts of climate change, new district heating technical solutions and business models that account for heat demand decrease and the implementation of heat prosumers in the network infrastructure should be developed.

Session 9: Energy Planning and planning tools

Niels Frank has been working the last 5 years in COWIs district heating department as a project coordinator or manager, on a number of district heating projects, mainly preparing tenders for renovation or construction of district heating networks. the last two years I've also been head of District heating I, consisting of 11 people.

Session Keynote:

Albertslund – Municipality in transition to low temperature district heating

Theodor Møller Moos, Chief project manager, COWI A/S, Niels Frank*, Head of section, COWI A/S, Jens chr. Skous vej 9, 8000 Aarhus, nifr@cowi.dk, +45 41767818

Keywords: Low temperature, renovation, Heat loss reduction

In the Copenhagen suburb of Albertslund the municipality and Bo-Vest (a local Housing association) are undertaking a large renovation program, completely renovating around two thousand homes in the southern part of Albertslund. The goal of the renovation is to bring the dwellings up to current standards and to reduce the overall energy consumption of each dwelling.

After renovation, the dwellings will have significantly reduced energy consumption and will be designed for connection to a low temperature district heating network. This will assist with further reduction in energy use and will help both Albertslund and Greater Copenhagen district heating system meet their goals to maximize the use of green energy sources and minimize CO_2.

As part of the renovations, Albertsund Forsyning (the municipality district heating company) is replacing the entire district heating system, which was originally installed in the mid 1960's. The old system consists of black steel tubes installed in the crawlspaces beneath the floorboards covered in mineral wool with a flow temperature of 90 °C. This will be replaced by a system of modern pre insulated double pipes. The new system will have a flow temperature of 55 °C and a return temperature down to 30 °C and will reduce the heat losses from the distribution system by at least 50 % compared to the old system.

Reducing temperatures also provides possibilities for green initiatives on the production side of the system, allowing for a higher overall efficiency in the CHP and making way for the introduction of low temperature heat sources such as industrial process and geothermal energy, both directly and via heat pumps.
The 1st phase of the project included 1050 dwellings and began in October 2012, the work on phase 1 was concluded in 2016, resulting in satisfied residents and the renovated dwellings meeting the expected 60 % reduction of energy consumption calculated in the planning phase. Work has started on the next 550 dwellings and the project is scheduled to be complete at the end of 2020.

The current success of the project has resulted in Albertslund municipality deciding that the entire municipality should be converted to low temperature district heating before 2026.

Daniel Møller Sneum former analyst in IEA, Green Energy and PlanEnergi, conducts his PhD-studies within the Energy Economics and Regulation-group in DTU Management Engineering. Focus in the research is on flexibility in the energy system, and how this is facilitated through markets and regulation. This research is primarily conducted in the auspices of the Flex4RES-project, funded by Nordic Energy Research.

Socio-economic evaluation of regulatory framework conditions in the heat-electricity interface

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Keywords: Heating, regulation, policy evaluation, smart energy systems, socio economy, methodology

Introduction
Coupling of heating and electricity systems can increase flexibility, which is needed to integrate increasing amounts of renewable energy. Such integrated energy systems, *smart energy systems* [1], should include regulation that is adapted to integration of renewable energy, comprising fiscal regulation, i.e. taxes and subsidies[1]. Regulatory changes for increased flexibility in the energy system entail socio-economic consequences, which must be evaluated in addition to the consequences for flexibility, to provide a comprehensive analysis of the impacts. Whereas current methodologies for socio-economic studies of energy systems are well-developed, and their use have covered a broad range of elements in analysis of energy systems, these methodologies, and the regulation they evaluate, have been formulated before the increasingly integrated energy systems. Thus, we ask: *Do smart energy systems necessitate a need for revisions in the socio-economic methods for evaluation of regulation in the heating-electricity interface? If so, which parameters could be changed or added to improve evaluation of regulatory framework conditions?*

Methodology
The identification of parameters of particular importance for improved socio-economic studies, builds on a review of existing studies. While this initial review provides the current state of the art, a review among experts explores whether these methods are sufficient in socio-economic analyses of regulation in future energy systems. Based on the results, a methodology is proposed and tested with different types of regulation on a single energy system.

Results
The review of methodologies provides an insight into socio-economic impacts and how they arise. This knowledge is useful for regulatory design in smart energy systems. Traditional socio-economic elements such as deadweight loss and tax distortion losses, appear to be generally applicable, while it remains to be determined whether changed or additional socio-economic evaluation parameters will benefit analysis of regulation in future energy systems. The study provides a methodology for socio-economic evaluation of regulatory framework conditions affecting flexibility in the heat-electricity interface. This methodology can be used to compare different types of fiscal regulation, and to evaluate the socio-economic impact from a single regulatory condition.

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[1] Results might prove useful regarding other types of regulation as well, e.g. direct regulation on permitted fuels

Matteo Giacomo Prina after graduation at Politecnico di Milano in sustainability and energy management, I have worked at EURAC research, institute for renewable energy, within the regional energy modelling group. In November 2015, I started a PhD program in Energy and Nuclear Science and Technology with collaboration between EURAC research and Politecnico di Milano.

Multi-objective optimization algorithm coupled to EnergyPLAN software: the EPLANopt model

<u>Matteo Giacomo Prina</u>[1,2,], Marco Cozzini[1], Giulia Garegnani[1], Giampaolo Manzolini[2], Ulrich Filippi Oberegger[1], Roberta Pernetti[1], Roberto Vaccaro[1], David Moser[1] [1]EURAC Research, Institute for Renewable Energy, Viale Druso 1, I-39100 Bolzano, Italy [2]Dipartimento di energia, Politecnico di Milano, Via Lambruschini, 4, 20156 Milano (MI), Italy *MatteoGiacomo.Prina@eurac.edu, +39-0471-055587*

Keywords: Energy scenarios, EnergyPLAN, EPLANopt, renewable energy, energy planning

The planning of an energy system with high penetration of renewables is becoming more and more important due to environmental and security issues. On the other hand, high shares of renewables can lead to grid integration issues. In order to reduce these issues, the diversification of renewable energy technologies, programmable and not, coupled with different types of storage, daily and seasonal, is recommended. The optimization of the different energy sources is a multi-objective optimization problem because it concerns economical, technical and environmental aspects. The optimization analysis on these competing objectives produces a Pareto front of the best future configurations of the energy system. The aim of this study is to present the model EPLANopt, developed by Eurac Research, based on the deterministic simulation model EnergyPLAN developed by Aalborg University coupled with a Multi-Objective Evolutionary Algorithm based on the Python library DEAP (https://gitlab.inf.unibz.it/URS/EPLANopt).

The model is applied to the energy system of South Tyrol and results obtained through this methodology are presented. The 2014 baseline of the South Tyrolean energy system is created in EnergyPLAN and validated on the same year value of total tracked CO_2 emissions. The input parameters of the optimization analysis are selected for the specific application: capacity of photovoltaics, biogas power plants, electric storage, heat pumps and thermal storage of the district heating network, solar thermal, energy efficiency and heat pumps for the individual heat sector. Particular attention is dedicated to the analysis of the energy efficiency of buildings. A curve representing energy efficiency strategies marginal costs depending on the annual energy saving is built (Figure 1) and applied to the model through an external Python script. This curve allows to consider the energy efficiency costs for different types of buildings depending on the construction period and geographical location. Figure 1 shows the Pareto front of the best energy system configurations in 2050. The two objectives considered within the multi-objective optimization are total annual costs and CO_2 emissions.

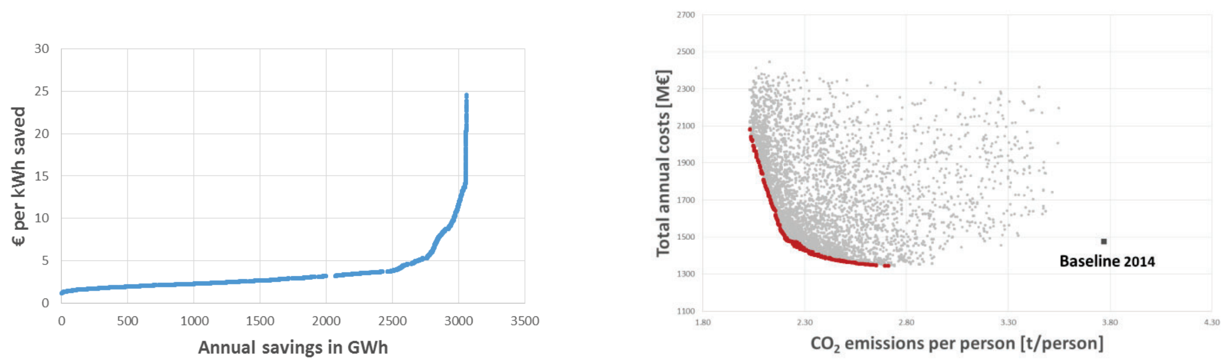

Figure 1 On the left, the curve representing energy efficiency measures marginal costs depending on the annual energy saving. On the right, the Pareto front final results of best configurations of the energy system of the South Tyrol province.

This methodology allows evaluating the best energy system options under total annual costs and CO_2 emissions minimization. Through this methodology it is possible to identify a cost-optimal solution for the fixed CO_2 targets considering the potential of variable renewable energy (VRE) and energy efficiency interventions. The final Pareto front is a tool that can support energy strategy makers, depending on their spending policy and target of emission reduction, to select the optimum configuration of the future energy system in terms of renewable energy technologies.

David Drysdale is a PhD fellow at Aalborg University. He works in the Sustainable Energy Planning Research Group in Copenhagen. He has been researching highly renewable energy systems as a researcher since 2014 and in 2016 he began his PhD. His PhD is focused on how municipalities in Europe can do low carbon energy planning.

Low carbon energy system planning in Small and Medium sized Municipalities in Europe

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Keywords:

The Paris Agreement adopted at COP21 highlighted the increased role of cities to achieve the goal of reducing global warming well below 2C. Cities are expected to scale up activities and reduce emissions and promote regional and international cooperation. Efforts to achieve this are already underway, for example in the European Union Horizon 2020 research and innovation programme Smart Cities and Communities (SCC) projects. SmartEnCity is a SCC project that aims to develop a systemic approach for European cities to maximise renewable energy and lower carbon emissions. The project will develop strategies that can be replicated around European municipalities. The project will also develop a city network in which small and medium sized municipalities (SMM) can share information between themselves to facilitate greater learning and action. This paper will describe some of the current challenges for SMMs to do low carbon energy planning. The challenges relate to, among other factors, available methods and tools, local capacity, knowledge and competing approaches. The SmartEnCity project is used as a case study in the paper, and data is sourced from a literature review as well as from a selection of cities including the Lighthouse Cities in the project - Vitoria-Gasteiz, Sønderborg and Tartu. The paper will also describe how municipal networks could play a role in low carbon energy planning by SMMs in the future, specifically focusing on what they are and how they could operate.

Hanne Kauko works as a research scientist within thermal grid modelling, thermal energy storage, and heat pumping and refrigeration systems. MSc Karoline Husevåg Kvalsvik works with advanced system modelling in Dymola and Comsol Multiphysics, within fluid- and thermodynamics, refrigeration and heat and mass transfer.

Dynamic modelling of local district heating grids with multiple heat sources and thermal storage

Hanne Kauko[1], Karoline Husevåg Kvalsvik[1], Daniel Rohde[2], Natasa Nord[2] and Åmund Utne[3] [1]SINTEF Energy Research, Kolbjørn Hejes vei 1 B, Trondheim 7491, Norway [2]Department of Energy and Process Technology, Norwegian University of Science and Technology (NTNU), Kolbjørn Hejes vei 1 B, Trondheim 7491, Norway [3]Statkraft Varme AS, Sluppenvegen 17 B, 7005 Trondheim, Norway *hanne.kauko@sintef.no, tel. +47 968 766 51*

Keywords: Thermal networks, thermal energy storage, system optimization, optimal design, linear optimization

Future district heating (DH) grids will supply heat to buildings with low heat demands, and include decentralized heat supply from renewable and waste heat sources as well as thermal energy storage (TES). Design and operation of such systems will imply new challenges as opposed to conventional DH grids with centralized production and high heat demands. Modelling and simulation is required in order to find the most optimal solutions regarding production, distribution and storage of heat. For detailed physical modelling of DH systems, the dynamic simulation program Dymola using the object-oriented modelling language Modelica has proven to be a flexible and efficient tool [1-3].

In this study, Dymola has been applied to model a local heating grid for a building area in Trondheim, Norway. The building area consists of low energy buildings of different types, with a total heated area of 186 000 m² and a linear heat demand density of 1.84 MWh/(m·year) (per DH pipe line). Details of the simulated building stock have been described in [3]. In the present work, the effects of including multiple distributed heat sources and seasonal TES have been investigated. The following four cases were simulated: (i) reference case with heat supply from the main DH network at high temperatures (115-75 °C with outdoor temperature compensation); (ii) low-temperature (LT) grid with heat supply from the main DH network and a constant supply temperature of 65 °C; (iii) LT grid with additional heat supply from waste heat sources (condenser heat from cooling and refrigeration systems); and (iv) self-sustained LT grid with heat supply from waste heat sources and solar collectors as well as borehole TES. The aim of the analysis was to evaluate key performance indicators such as heat loss, pumping power, costs, and environmental impact, in order to investigate the competitiveness of low temperature district heating (LTDH) systems.

The simulation results show that lowering the distribution temperature reduces the heat losses significantly, however a considerable reduction in the total heat costs and environmental impact is only obtained with the inclusion of heat supply from additional heat sources. Considering design and operation, a heating grid with multiple heat sources has to possess routines for prioritizing heat delivery from the different sources based on availability, costs and environmental impact. This was included in the model. In the summertime when the availability of condenser and solar heat is high and heat demand is low, water flow might reverse in several pipelines, inducing challenges in the flow control. Furthermore, seasonal TES is required to store any excess heat available in the summertime to be able utilize it in the winter. Dynamic modelling allows proper sizing of the thermal storage and the heat production and distribution facilities.

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[3] Kauko, H., K. Kvalsvik, D. Rohde, A. Hafner and N. Nord (2017). Dynamic modelling of local low-temperature heating grids: a case study for Norway. Under review in Energy.

Session 10: Low-temp district heating grids

Steen Schelle Jensen As Head of Product Management for Heat/Cooling Solutions at Kamstrup, my focus is on developing solutions that enable utilities to optimise their business and day-to-day operations by unfolding the full value of their meter data. I am inspired by helping our customers on the journey towards a digital heat supply where decisions are based on facts rather than theory – because you cannot optimise what you do not measure!

Session Keynote:

Smart metering provides the transparency required for efficiency

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Keywords:

As the complexity of the utility industry increases on its journey towards 4^{th} generation district heating so does the number of decisions utilities have to make every day. But how do utilities ensure that they are making the *right* decisions – not only from an economic perspective but also in terms of quality of supply, demands for energy efficiency and the risk they run? Traditional theory, gut feeling and assumptions are not sufficient for managing an energy efficient production and running a distribution network as close to the limits as possible. Real-time decisions require real-time data. When utilities are able to see the actual state of their distribution network at all times, they can use this knowledge as their basis for continuously making optimisations and evaluating the effect of their actions. In this way, having to wait until tomorrow to find out what you should have done today, will become a thing of the past. At the International Conference on Smart Energy Systems and 4^{th} Generation District Heating, we wish to illustrate why data-based transparency in the distribution network is the very foundation for utilities to be able to make the right decisions about their production and distribution in an integrated energy system that includes a growing number and variety of heat sources.Frequent and accurate data on flow, temperature and pressure are essential to achieving information about the actual state of the distribution network. Equally important is having the right tools for analysis and visualisation in order for utilities to get a complete overview and fully utilise the data they have. From our collaborations with Danish utilities, we have identified and tested specific application areas where data from smart meters has been a crucial element in optimising operations and reducing losses in the distribution network. The basis for making those optimisations are monitoring of:

- Substation performance and end-user behaviour
- Building characteristics and performance
- Actual forward and return temperatures in the network
- Pressure in distribution and service lines
- Retention times and hydraulics in the network

Visualising these parameters geographically as an added layer on top of the pipe network constitutes a valuable tool for the utility. By essentially bringing data to life, this visualisation provides utilities with instant decision support, the ability to see the consequences of their efforts as well as full documentation for end users.In addition, smart meter data enables utilities to significantly improve their asset management and network design. With detailed knowledge about losses in the distribution network, utilities can map out the condition of the individual zones in their supply area. This will allow them to identify and target the areas where their optimisation efforts and investments will generate the most value as opposed to basing those decisions on traditional factors like the age of pipes and other network equipment. Finally, it enables utilities to better utilise the capacity in their existing network thereby deferring or even avoiding the heavy expenses involved in digging up and replacing old pipes with new – and potentially oversized – ones.

Ultimately, in the intelligent and integrated energy system, smart meter data is the key not only to navigating effectively but also to unlocking the full potential of the opportunities it brings.

Dietrich Schmidt Head of department Heat and Power Systems of the Fraunhofer Institute for Wind Energy and Energy System Technology in Kassel Germany, made his PhD at KTH – The Royal Institute of Technology, Stockholm, Sweden. He is currently the coordinator of the international cooperation projects IEA DHC Annex TS1 and IEA EBC Annex 64 and completed approx. 150 publications.

Low temperature district heating for future energy systems

D. Schmidt[1], A. Kallert[1], M.Blesl[2], S. Svendsen[3], N. Nord[4] and M. Rämä[5] [1] Fraunhofer Institute for Wind Energy and Energy System Technology IWES Königstor 59, DE-34119 Kassel, Germany Email: dietrich.schmidt@iwes.fraunhofer.de Tel.: +49 561 804 1871 [2]University of Stuttgart, Inst. of Energy Economics and Rational Use of Energy, Stuttgart, Germany [3]Technical University of Denmark, Department of Civil Engineering, Lyngby, Denmark [4]Norwegian University of Science and Technology, Trondheim, Norway [5]VTT – The Technical Research Centre of Finland, Department Energy Systems, Espoo, Finland*

Keywords: Low Temperature Supply Structures and District Heating

The building sector is responsible for more than one third of the end energy consumption of societies and produces the largest amount of greenhouse gas emissions (GHG) of all sectors. This is due to the utilisation of combustion processes of mainly fossil fuels to satisfy the heating demand of the building stock. District heating (DH) can contribute significantly to a more efficient use of energy resources as well as better integration of renewable energy into the heating sector (e.g. geothermal heat, solar heat and biomass from waste), and surplus heat (e.g. industrial waste heat). Low temperature district heating offers a fairly easy and cost effective way to realise a fossil free heating system compared to solutions based on renewable energy production on each building. Low temperature district heating offers prospects for both the demand side (community building structure) and the generation side (properties of the networks as well as energy sources). Especially in connection with buildings that demand only low supply temperatures for space heating. The utilisation of lower temperatures reduces transportation losses in pipelines and can increase the overall efficiency of the total energy chains used in district heating. Community scale synergies can be maximised when building and building supply systems are treated as integrated components of an energy delivery system. To optimise the exergy efficiency of a community supply systems the LowEx approach can be utilised, which entails matching the quality levels of energy supply and demand in order to optimise the utilisation of high-value energy resources, such as combustible fuels, and minimising energy losses and irreversible dissipation (internal losses).

The paper presents the outcome and gives insights in the final report of the international co-operative work in the framework of the International Energy Agency (IEA), the District Heating and Cooling including Combined Heat and Power (DHC|CHP) Annex TS1.

Paolo Leoni is working at AIT since 2016 in the field of district heating and cooling. Before, he was working at different divisions of ENEL since 2004 as Project Manager and Engineer in the fields of biomass, geothermal and solar thermal energy. His academic education is from the Sant'Anna School of Advanced Studies and the University of Pisa

Decreasing district heating network heat losses in the summer months using decentralized systems: A simulation case study

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Keywords: Summer losses, efficiency, storages, solar thermal supply

Network heat loss is typically the main reason of low efficiency in district heating systems with low density or in periods with low heat demand. In particular in the latter case, the technical and economic advantages of a centralized heat production in the winter season can be strongly affected or even offset by an improper summer operation of the heating network. A solution to face this criticality can be a decentralized production in the summer period, which would allow to turn off the network and avoid in this way the relevant thermal loss.

In the present study, the case of an Austrian district heating network with 1.3 MWh/(m·a) linear heat density (LHD) and large discrepancy between heat demand in summer (875 MWh from May to September) and winter (4765 MWh from October to April) is illustrated. This discrepancy reflects on the highly different value of network thermal loss compared to the heat demand: 9.7% in the winter period, 28.1% in the summer one.

As possible measures to reduce the impact of the network heat loss in the summer months, two solutions were considered and compared. The first solution is based on decentralized solar systems: according to the collector area and the storage capacity, a 100% solar coverage can be continuously possible over a certain period. The second solution, characterized by much lower investment costs, is based on decentralized thermal energy storage (TES) systems designed on the basis of the daily heat demand. Each TES is charged every day by the district heating network, which is in operation just for the charging time and turned off the rest of the day.

The technical evaluation of these solutions was carried out with a simulation tool taking into account the network set-up and the actual operation and meteorological data on hourly basis over the entire year. The results are presented in terms of primary energy consumption and economic parameters. While in the first solution, if adequately sized, the network loss over the summer period can be theoretically offset, in the second solution some loss remains, since it requires a short network operation every day. Nevertheless, the efficiency of the second solution can be significantly increased if, after charging the decentralized TESs, the flow in the heating network is reversed back until the hot water in the supply line is completely discharged into the central storage tank. In this way, the network is turned off at a lower temperature, with heat flux from the line towards the ground consequently reduced.

Stefan Blomqvist. is a Ph.D. student with a Master of Science degree in engineering. His research is conducted at the division of Energy Systems at Linköping University and concerns sustainable energy systems with a system perspective including energy use and supply.

Improved energy performance for local ground surface heating in a CHP system

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Keywords: District heating, resource efficient, simulation, system perspective

The heating of streets and pedestrian areas by means of circulating warm water in embedded plastic coils, has been practiced for decades. The primary objective of such a ground surface heating (GSH) system is to proactively avoid risk of slipping. A GSH system also reduces the need for snow removal by heavy machinery and makes road salt and sand unnecessary.

The aim of this study is to identify measures in order to improve the systems energy performance and also analyse economic savings. The method includes gathering of data, considering weather and operating data, and analyse of these to find improvement measures. A computational simulation model was created to test different set ups of control parameters and measures. A case study was conducted on a GSH system in Linkoping, located in the southeast of Sweden. The system is mainly found in the city centre in the commercial streets. The total area of the system is 30 400m^2 and it is divided into nine subsystem, which all uses water from the local CHP system.

Findings indicate a need to improve and standardize the control system of each subsystem to get a full overview of the GSH system. The results of the simulation model show a possible reduction of 55% in end-use energy and economic savings of 53% during the time of study. Moreover, the temperatures used in the model indicate that a GSH system of this type needs low temperatures, approximately 20-25°C.

Max Bachmann We are scientific employees at the Hermann-Rietschel-Institute of TU Berlin since 2015 and 2014. The Hermann-Rietschel-Institute is the oldest university institute in fields of building services worldwide. As part of the LowExTra-project, founded by the German Federal Ministry for Economic Affairs and Energy, a decentralized, low exergy multilevel district heating network with additional heat storage capacity was developed.

Transfer of a 4th generation district heating network from concept study to district level simulation

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Keywords*:* District heating, LowEx, Modelica, smart heating networks, sustainable heating and cooling

Today's mainly used district heating networks (DHN) can be assigned to the 3rd generation. These networks are primarily characterized by supply and return pipes using supply temperatures around 100°C. This temperature regime is significantly higher than the needed supply temperature of many heat consumers within a district. This yield in unnecessary high exergy destruction, high heat losses and it hampers the integration of low temperature energy sources e.g. solar thermal and waste heat. Therefore, a 4th generation district heating network concept was developed at the Herman-Rietschel-Institute of the TU Berlin. This network uses a hydraulic decoupled multi-level network which reacts totally flexible regarding withdrawal and feeding. Accordingly, this network can provide heat on an optimized temperature level for each consumer and ease the integration of decentral heat generators and low temperature renewable energy sources.

To bring this concept further within the developing process it was applied to a test area in the Berlin-Pankow district. This area is distinguished by a mixed structure of heat consumer and producers. Consumers designed to high supply and return temperatures of 90/70°C are present as well as buildings with low temperature space heating units. Heat generators vary from low temperature gas boilers up to modern heat pumps and solar thermal collectors. Because of this variety this district is representable for many areas in central Europe. The main goal of this investigations was to prove the transferability of the concept into district level. Moreover, it should be proven if the network can be operated successfully and reliable over a whole year period.

Therefore, a dynamic and parametric simulation model was developed and applied to the considered test area using the Modelica language. The temperature levels were optimized regarding the present heat consumers and adjusted using the ambient temperature. The controllable heat generators, e.g. gas boilers and heat pumps, were controlled using a new developed control principle for multi-level DHGs. Furthermore, the distribution losses in comparison to a supply scenario of a 3rd generation DHG and primary energy consumption in respect to a supply scenario with individual heat generation were compared.

Regarding to the simulation model it could be proven, that the LowExTra network concept can be applied within a district level. Each consumer type was supplied reliable by an optimized temperature level over the whole year. Furthermore, low temperature environmental energy was integrated reliable to the network. Moreover, the distribution losses are significantly lower if compared to the 3rd generation scenario. The primary energy consumption was reduced by almost one third related to the scenario with individual heat generation of each building.

Thereby, this simulation was a successful step forward to low primary energy consumptive heat generation on district level which is an important step to sustainable heat supply of our future cities.

Session 11: Low-temperature DH and buildings

Svend Svendsen is professor at the Technical University of Denmark, Department of Civil Engineering and is leader of WP1 in the 4DH Research Centre. Svend Svendsen started working on development of low temperature district heating in 2005 and has initiated a number of research projects and PhD-projects in this area.

Session Keynote:

Solutions for low temperature heating of rooms and domestic hot water in existing buildings

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Keywords: Low temperature heating of buildings, Radiators, Domestic Hot Water. Supply and return temperature, District heating

Implementation of 4th generation district heating systems in areas with existing buildings must be based on lowering the operation temperature of room heating system and the domestic hot water system. With a lower return temperature from the buildings the district heating network and the heat producing plant can work with improved efficiency. With a lower supply temperature to the buildings, the district heating system can use heat sources at lower temperatures, which is very beneficial for use of waste heat and renewable energy. With an equal reduction in return and supply temperature the heat transport capacity of the district heating network remains unchanged and may even be increased in peak load situations by use of higher supply temperatures.

The part on room heating systems in the article is focused on existing buildings with radiators because they represent the major challenge for low temperature operation as other heating systems as floor heating by nature is a low temperature heating system. The supply and return temperatures of room heating systems in existing buildings with radiators depends on the following parameters:

Type of pipe system supplying heat to the radiators – i.e. one or two string system

Type of radiators – i.e. high elements with vertical downwards stratified flow or low elements with horizontal mixed flow

Type of control system – i.e. centrally of heating system and individually on each radiator

Design criteria – i.e. design load and design operation temperatures

Actual heating load of rooms – i.e. realistic heating load of actual partly energy renovated building during the heating season.

Solutions for lowering the return temperature as step 1 and the supply temperature as step 2 have been investigated and are presented in the article.The part on domestic hot water heating systems in the article includes typical systems used in large buildings with a DHW circulation system and small single-family building without DHW circulation system. The required supply temperature and the possible return temperature of the water in the district heating system depends on the following parameters:

Type of DHW production system – i.e. with storage tanks or instantaneous heat exchanger

Type of DHW distribution system – i.e. with or without circulation system

Type of control system

Design and real DHW load

Design and real heat transfer capacity of heat exchanger system and heat loss of distribution system

Solutions for lowering the return temperature as step 1 and the supply temperature as step 2 have been investigated and are presented in the article.

Knut Bernotat works at KTH, Department of industrial Economics and Management in the unit of Sustainability and Industrial Dynamics with research aiming to understand the transformation of industrial systems and sectors with focus on district heating and heat metering.

Uncertain Future - How Do Different Ways to Estimate Heat Demand in Retrofitted Buildings Affect District Heating owners?

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Keywords:

The greatest share of energy consumption in the building stock today is dominated by the energy consumption of old buildings, which represent the majority of the total building stock and which have a very poor energy performance compared to new buildings. A phenomenon that is not only valid in Sweden but also in the rest of Europe.

Retrofitting levels within European states vary between 1-2% annually, causing a transition period of 50 and more years. This long transition period requires an action plan for the non-retrofitted building stock. During the building's overall life time of a hundred years or more, several partial retrofits are necessary, such as roof, facade or window renovations, to maintain the building's function. Large building refurbishment often starts with the need of partial retrofits.

There has been a great effort to retrofit this old building stock with various success. Some claim a large saving potential while other complain, that the estimated saving potential has not been reached in the retrofits that have been carried out. Realized energy savings have been lower than expected causing longer return on investment periods than planned. The reason for this dilemma has been identified by different methods estimating the heat demands before and after refurbishment is estimated.

The performance of buildings can be estimated by two different methods, one the calculated energy demand (CED) applying the technical building standard and its energy use based on the building thermal conditions when the building was planned and built or on the measured energy consumption (MEC) of the last one to three years giving a picture of the buildings current heat demand depending on its current use, tenant behaviour and legal framework.

Due to the large building stock of not refurbished buildings this causes a large uncertainty on future heat demand planning to not over or under dimension DH networks. The paper is analysing the different methods and its influence on the future heat demand for district heating and low temperature district heating.

Soma Mohammadi works as a research fellow at the School of Architectural Design and the Built Environment, Nottingham Trent University, UK. She holds a PhD in Energy from Aalborg University, Denmark. Her Current work is part of the H2020 Remourban Project. Her main research interests are low-temperature district heating system, heat transfer, and mathematical modelling and low-energy buildings.

Techno-economic analysis of low-temperature district heating network implementation in the city of Nottingham, UK

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Keywords: District Heating Network, Low-temperature District Heating, Buildings Retrofit

According to the Nottingham city 2020 Energy resolution, Nottingham is aiming at reducing its CO_2 emissions by 26% and increasing the share of renewables and low-carbon energy sources by 2020. The 73% expansion in the city's existing district heating (DH) network is required to meet the city's energy objectives. The Nottingham existing DH network consists of 68 km of insulated pipe network which distributes heat to around 5000 dwellings and commercial buildings. The network operating temperature alters around 85-120°C through the year with return temperature around 70°C. The existing network high return temperature presents the sufficient capacity to be used for implementing a low-temperature district heating (LTDH) network. Furthermore, providing heat from existing DH network return pipe results in reduction in the heat losses and improvement of the network overall efficiency.

It has been proposed a branch coming from the city's existing DH network return pipe provides LTDH to the project demo site at Snienton including four retrofitted maisonette blocks with total of 94 flats. The Supply temperature to the demo site varies between 50-60°C. However, in order to guarantee the sufficient level of supply temperature and to prevent the risk of legionella growth, a shortcut flow from the existing DH network supply pipe is taken; it can be applied as a temperature boost. To introduce the LTDH, all flats at the demo site have undergone some energy retrofit measures, i.e. their external wall insulations have been improved significantly. The flats' existing gas-boiler is replaced by a heat interface unit (HIU) which transfers heat between DH network and consumers.

This paper demonstrates the feasibility of implementing LTDH in the city of Nottingham through performing a techno-economic analysis. Furthermore, the obtained results are applied to evaluate the possibility of the LTDH replication at other areas in the city. The following steps are included in the current study; Firstly, the buildings' heat demand profile is obtained. Secondly, a model for simulating the buildings' HIU (substations) is developed, which is applied to calculate the return temperature at the primary side of the HIU. Thirdly the pipe network dimensioning is implemented according to the buildings' heat demand and the maximum pressure gradient at the longest route through the network. Next the thermal-dynamic modelling of the DH network operation is carried out through the model developed in Matlab Programming Language where the variation in the supply temperature to the network and the bypass operation are included. Therefore, a precise overview of the whole network operation through the year is obtained comprising the annual heat demand and the annual heat losses for alternate choice of pipe types in the network and various retrofit levels at buildings. Finally, an economic analysis is performed which accounts for operational, capital and overall costs of different alternatives.

Natasa Nord is Associate Professor since 2012 and teaches in building energy supply courses and Thermodynamics 1. Here research field is within: building energy supply, energy planning, district heating, lifetime commissioning, zero emission building, building energy monitoring, simulation of buildings and HVAC systems, and energy analysis.

Challenges and potentials for low-temperature district heating implementation in Norway

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Keywords: Low-temperature district heating, low energy buildings, heat density, distribution losses

Current district heating (DH) system with high temperature is facing many challenges. In low energy buildings there is no need for heating at high temperature levels and heating demand is decreasing. High temperature levels are unfavourable in terms of renewable energy sources and waste heat utilization. Finally, due to higher share of the distribution losses in the total heat demand, competitiveness of the DH system in the low heat density area is decreasing. Low temperature district heating (LTDH) system has better opportunities for utilization of waste heat and renewable heat sources, as well as lower distribution losses. However, on the way to transition to the LTDH, there is a problem with high return temperature and low temperature difference between supply and return temperature in the network. Therefore, the first aim of the study was to estimate the challenges in the transition process from the current DH to the LTDH system, while integrating low energy and passive house buildings. The second aim was to estimate possibilities and increase competitiveness of the LTDH in the low heat density area.

In this study two network structures were analysed: high and low heat density area. The measured heat demand in the buildings built according to the passive house and low energy building standard were used as input for these study. The areas consisted of residential blocks, a school, a kindergarten, a hospital, an office building, and a sport hall. The buildings were located in Trondheim, Norway. The model of the LTDH network was developed in MATLAB and included both thermal and pressure losses. The pressure level analysis was also part of the study. The model input were hourly heat demand profiles, while the output were the DH performance data such as temperature and pressure levels in the network, hourly pump rate, heat losses, etc. To analyse the challenges in the transition to the LTDH system, different operation scenarios with fails were introduced: control of the supply temperature at the consumer side, short-circuit flows between supply and return pipe, fails at heat exchangers in the consumer substations, oversized radiators, and consequences of occupant behaviour. In the transition to the LTDH, it was assumed that the pipe size would be the same as if an existing DH system convert to the LTDH.

The results showed that the heat loss could be reduced by 25 % by lowering the supply temperature from 80°C to 55°C for both high and low heat density network. The maximum pumping power increased 107 % and annual electricity use of the pump increased 58 % for the low heat density area. Analysis of the return temperature showed that the low temperature system with 55°C could provide a lower return temperature than the DH system with 80°C supply temperature, regardless of the existing fails. The increase in the return temperature induced by the short-circuits was higher for the high temperature system (80°C) than for the LTDH system. Ratio between the pump energy and delivered heat (kWhel/kWhheat) had a very stable trend regardless of the heat density and started to increase when the heat density was lower than 1 MWh/m for high and low heat density area. The analysis showed that much higher values of the specific pressure drop values (R-value (Pa/m)) would be possible and it would not increase a lot the pump energy in the LTDH. Finally, dimensional analysis was performed. Some of the most important conclusions are that that the ratio between the pump energy to the delivered heat would have very similar values for both, low and high heat density areas, meaning that the LTDH would be competitive in the low heat density areas.

Ivo Pothof has been working for 20 years at Deltares as specialist in the hydraulics of pipelines systems. The last years he has been working as R&D leader within Deltares for renewable energy, which includes the fields of hydropower, tidal energy, salinity gradient energy and district heating and cooling

Maximizing geothermal output by using optimization model for the model-predictive control for a district heating system

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Keywords:

Renewable sources need to be used more and more to reach the goals of the agreements made in Paris. This is important for the electricity production, but also for space heating of building, which can have a large contribution to CO_2 emissions. Therefore reuse of waste heat and use of renewable source, like geothermal and aquifer thermal energy storage should increase. But to make these sources economically viable their output should be maximized. In this paper we present a method to maximize the usage of a geothermal source in an existing district heating system without major modifications to the buildings (e.g. different radiators, better isolation etc).

The challenges in usage of geothermal source lies in the fact that conventional heating systems have a high heat demand in the morning, which requires also a higher supply temperature, which often results in a higher return temperature, whereas a geothermal source ideally works with a low return temperature (40°C) and a low supply temperature (70°C), which is the well temperature in the Netherlands at 2 km depth. Furthermore a geothermal source has a constant output of energy. To reduce this high peak demand in the morning, peak shaving should be applied. This can be done manually, but this will not result in the most optimal solution. For this an optimisation model was created within the RTCtools 2.0 software of Deltares. RTCtools is the open source optimisation toolbox. The main focus is inland water systems, but it can be easily extended towards other domains like district heating systems.

Within the RTCtools 2 framework a LEA-model of the building is included. LEA is an acronym for Low Energy Architecture and this is software developed by Deerns which can be used to predict the energy consumption of a building. The building model in RTCtools 2 calculates the inside temperature, based on the hourly supplied heat, outside temperature, building characteristics etc. Next to this, simple models of available sources are implemented which can supply heat to the buildings. With these components a real-time optimisation model of the district heating system can be built, which delivers real-time advice (decisions) on the heat supply per building, minimum supply temperature per group of buildings and optimised source allocation. This model can then be used to minimize the total CO_2 production of the sources, while maintaining a comfortable climate inside (e.g. keeping the temperature within the specified bounds).

As example case the district heating system of the campus of the Delft University of Technology is used. For a standard climate year the results of the optimisation model are compared to the conventional results without any peak shaving. It is shown that the usage of the geothermal source is increased if the optimisation model is used. This has all been done without any changes to the buildings, improvements to the buildings can even further increase the use of the geothermal source.

Concluding the geothermal usage for a district heating system can be maximized by using model-predictive optimisation of the system. This might result in a business case without any modifications to the buildings.

Session 12: Smart Energy Systems

Bent Ole Gram Mortensens field of research is Energy law, data protection law and marketing law. Research assistant Christensen, L. Field of research is Energy law, data protection law and the legal framework for handling and processing of energy data.

Session Keynote:

Smart Energy Systems and the EU data protection regulation

Professor Bent Ole Gram Mortensen. bom@sam.sdu.dk , +45 6550 2160, Research assistant Lisa Christensen*., lch@sam.sdu.dk, +45 2341 9484, Department of Law, University of Southern Denmark, Campusvej 55, 5230 Odense M.*

Keywords Smart Energy systems, data protection, EU legal framework, EU General Data Protection Regulation (GDPR)

Smart energy systems require an early awareness of their massive implications with data protection and privacy issues. It is the aim for this presentation to address the smart energy systems challenges to the fundamental rights to privacy and personal data protection under the EU data protection regulation (GDPR), and discuss the way the EU has addressed them. When developing smart energy systems there are an increased data monitoring, processing and transferring of consumer data. Insight with consumer data can help energy companies develop energy systems and be beneficial for the entire energy system.

The GDPR is the most important change in data privacy regulation in 20 years[2]. By May 18th 2018 the regulation will come to force and at which time those non-compliant organizations will face substantial fines. In general the access to use data is regulated to whether or not data will be defined as personal data. *Personal data* is defined as any information relating to an identified or identifiable natural person; whereas an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier. Our research shows that consumer data regarding to billing and meter readings are personal data, as it is very specific for that one person. Another key definition is under which circumstances processing of data is regulated under GDPR. The EU defines *processing* as any operation or set of operations which is performed on personal data or on sets of personal data, such as collection, use, structuring, storage, adaptation or alteration, disclosure by transmission, dissemination or otherwise making available, erasure or destruction. A significant part of data flows in smart energy systems are regulated under the GDPR.The scale of the collection and sharing of personal data has increased significantly. Technology allows both private companies and public authorities to make use of personal data on an unprecedented scale in order to pursue their activities. The energy sector will as a consequence of the above be affected by the GDPR in terms of requests for data mapping, profiling, DPO's and in particularly Data Protection Impact Assessment (DPIA) also known as Privacy Impact Assessments (PIA). Our research will investigate the circumstances under which smart metering data under EU law is defined as personal data and when it can be lawfully processed. Furthermore it must be clarified when both types of data can be legally transferred or can disclosures to third parties or used in types of profiling to predict help the future demand. Profiling is defined as any form of automated processing of personal data consisting of the use of personal data to evaluate certain personal aspects, in particular to analyse or predict aspects concerning that person's reliability, behaviour, attitudes etc.

The right to the protection of personal data is not an absolute right. It must be considered in relation to its function in society and be balanced against other fundamental rights, in accordance with the principle of proportionality and fair use. Consumer's privacy rights and the interests of energy companies' eagerness to use data may be contradicting. The realization of a digital single market with further use of data is of high importance of the EU. In this process consumer rights must not be overheard when pursuing a fully integrated smart energy system. Our paper and presentation will address these concerns through the GDPR.

[2] Regulation (EU) 2016/679 of the European parliament and of the council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data.

Juan P. Jiménez BA in Mechanical Engineering, MSc in Energy Sustainability in Buildings and Processes and PhD candidate. Project Officer in the Knowledge for Energy Union unit of the Joint Research Centre working in sustainable energy technologies and linkage between heating and electricity sectors in particular.

The joint effect of centralized CHP plants and thermal storage on the flexibility of the power system

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Keywords: Heating & electricity coupling, optimal operation of CHP plants, thermal storage, flexibility

The coupling of the heating and the electricity sectors is of utmost importance when it comes to the achievement of the decarbonisation and the energy efficiency targets. A fundamental element of this coupling is centralized cogeneration plants connected to district heat networks.

Despite the efficiency benefits, the effects of introducing combined generation to the power system are sometimes adverse. Reduced flexibility caused by contractual obligations to deliver heat may not always facilitate the penetration of renewable energy in the energy system. Thermal storage is acknowledged as a solution to the above.

This work investigates the optimal operation of cogeneration plants combined with thermal storage. To do so, a CHP plant model is formulated and incorporated into DISPA-SET, an in-house unit commitment and dispatch model. The cogeneration model defines technical feasible operational regions for different technologies. Different energy system scenarios will be used to assess the implications of the heating–electricity coupling to the flexibility of the power system and to the achievement of the decarbonisation goals.

This approach is demonstrated in an existing independent power system, where CHP plants provide heating and electricity to nearby energy dense areas.

Ambrose Dodoo is an Associate Professor in Building and Energy Technology and his background encompasses Building Technology and Environmental Science. His research focus is on building simulation and life-cycle modelling of energy, cost and environmental implications of building and infrastructure systems.

Primary energy benefits of cost-effective energy renovation of a district heated multi-family building under different energy supply systems

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Keywords: District-heated buildings, energy efficiency measures, cost-effectiveness, discount rate, energy price, final and primary energy savings, renewable energy

In the European Union (EU), including in Sweden, improved energy efficiency in buildings is a major part of the efforts to reduce fossil fuels use and associated greenhouse gases emissions. The EU roadmap to a resource efficient Europe highlight the need to consider resource efficiency in existing policies for building energy efficiency improvements. Besides, the EU energy performance of buildings directive also emphasizes the need to take cost-effectiveness into account when measures are implemented for improved building energy efficiency. In this study, we investigate cost-effective energy renovation measures for a district heated building under different contexts, including varied locations, energy supply systems and economic scenarios. We determine the final and primary energy savings of cost-effective energy renovation packages for the building in the different contexts. The measures analysed include: improved insulation for attic floor, basement walls, and exterior walls; improved windows and doors; resource-efficient taps; heat recovery of exhaust ventilation air; energy-efficient household appliances and lighting. We consider three existing Swedish energy supply systems of varying district heat production scale and tariffs, and also plausible renewable-based energy supply systems. Our analysis calculates the final energy savings of the measures including the cost-effective renovation packages on hourly basis and links these to the different energy supply systems. The cost-effectiveness analysis is based on a double-stage optimization method, considering total and marginal investment costs of renovation measures as well as associated net present values of total and marginal cost savings. The results show that significant final and primary energy savings can be achieved when energy renovation measures are implemented for the building in the different contexts. This study shows that heat demand in existing Swedish building could be about halved while electricity use may be reduced about 40% with cost-effective energy renovation measures. The economic viability of the renovation measures is sensitive to the economic regimes especially discount rates and energy price increase.

Lennart Rogenhofer is a master student at the Professorship for Renewable Energy Carriers at ETH Zürich under Prof. Dr. Aldo Steinfeld. I am currently completing my semester thesis at the Urban Energy Systems lab at EMPA under supervision of Viktor Dorer on the evaluation and design optimization of heat pumps in multi-family houses.

Evaluation of innovative heat pump concepts for multi-family houses

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Keywords: Heat Pump, Low-temperature, Weather predictive control, CO_2 borehole heat exchanger, Free-cooling, Borehole Regeneration

The City of Zurich electricity utility (ewz) installs and operates innovative energy systems in real buildings, with an aim to provide sustainable solutions which use renewable energy resources and have low carbon emissions. Eight multi-family buildings were built in Zurich equipped with different components and configurations of heat pump (HP) / borehole ground coupling energy systems (as a source for the heat pumps and for free-cooling) and solar PV panels. Operation began in January 2017, with the 8 buildings expected to have comparable heat demand.

The buildings are structured into a standard building, a second building equipped with a CO_2 based borehole heat exchanger, another building with PVT (instead of PV) panels for borehole regeneration, and one with weather predictive control. The remaining four multi-family houses each share one larger, two stage heat pump between two houses. In the frame of a related pilot and demonstration (P+D) project, comprehensive monitoring will be performed. Measured data will allow assessment of the actual component and system performance, comparison of the different systems and contrast them to planning values and results from complementary building energy simulations.

The aims of this of this paper are to derive energy demand and energy system performance indicators from analysis of monitoring data. In addition, borehole efficiency, performance of geo-cooing concepts, and borehole regeneration potentials will be evaluated.

With monitoring data starting from February 2017, results of the data analysis and interpretations are expected by June 2017.

Wiebeke Meesenburg is a PhD student at the Department of Mechanical Engineering at the Technical University of Denmark. Her current research focuses on the optimal integration of heat pumps into future district heating systems.

Evaluation of the flexibility provided by integrating energy systems using advanced exergoeconomic analysis

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Keywords: Integrated energy system, heat pump, flexibility, exergoeconomic analysis

Integration of the electricity and the heating sector is a promising strategy to enhance the efficient use of transient renewable energy sources and increase the overall share of renewable energy in the energy system. Conversion units, such as heat pumps and electric boilers are expected to be a key technology for integrating the electricity and heating sector. They play an important role within both the district heating system, supplying heat from renewable sources, as well as in the electricity system because of the ability to balance out transient electricity supply in the grid. The corresponding operation strategy of conversion units will have to respect both the needs of the heating system and of the electricity grid.

This leads to the questions of how the different benefits provided by the flexible operation of conversion units should be valued, who actually benefits from the flexible operation, what are the additional costs of providing flexibility, and where do potential additional losses and cost occur.

The value provided by the flexible operation of conversion units was assessed by conducting an advanced exergoeconomic analysis for a model of the energy system in a newly built city quarter, in this case Arhusgadekvarter in the new development area of Nordhavn in Copenhagen. A dynamic model was implemented in the modelling language Modelica. It includes large scale conversion units, i.e. heat pump and electric boiler, electricity and heat storage and individual conversion units. The heat and electricity demand of the city district, as well as grid losses were considered as lumped components. The transient electricity supply, district heating and heat source temperature were inputs to the model.

Different scenarios regarding the units in the system and the availability of district heating were considered in this study.

For the advanced exergoeconomic analysis the exergy destruction and cost for every component were split into an endogenous and an exogenous part and the influence of the dynamic behaviour of the components was analysed. The method was found to be suitable to understand how the components in an integrated energy system interact. The sources of additional exergy destruction and cost due to flexible operation could be identified and the actual cost of flexible operation of conversion units was determined.

The advanced exergoeconomic approach was shown to be a viable method to determine where the actual benefits of flexibly operated components in integrated energy systems appear and how the flexible operation should be valued to make the provision of flexibility a viable business case for the conversion unit owner.

Session 13: Smart Energy Systems

Carsten Bojesen graduated from the department of Energy Technology at Aalborg University in 1985 and was awarded the Business PhD in 1989 working with two phase heat transfer in plate and frame heat exchangers. From 1989 to 2007 he worked as lead development engineer, project manager and technical manager at APV Heat Transfer A/S, a manufacturer of plate type heat exchangers.

Session Keynote:

Local Village Heating in a Smart Energy Context

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Keywords: nZEBH, heat pump, reneweable system, energy integration, smart control

The discussions and the projects related to smart energy and smart energy systems often have their main focus on urban areas with typically large utility installations like CHP's, large boiler stations and a well-established district heating grid.

When it comes to rural areas outside the existing or planned district heating grid it appears that only one solution for the future heat supply: Individual heat pumps.

The primary aim of this presentation is to give some inspiration to how the smart energy thinking can be a source for alternative ways of establishing a more clever future heat supply in building clusters and villages.

On one hand there are big challenges related to technical solutions, ownership and financing. On the other hand, the clusters and villages do not carry the burden of outdated distribution grids and old utility installations. This gives a nice opportunity to explore and install the newest and optimized technologies in distribution systems and layouts, components and operation of the supply system.

Benedetto Nastas Architectural Engineer and Energy Planner. His research focused on the role of Eco-Fuels in transition towards a low carbon city and society, in a new relation between urban and rural environment in energy planning field. Passionate about Hydrogen Economy. Expert of Sustainable Energy and Climate Action Plans, renewable energy technologies and their integration in urban and agricultural planning.

Smart Heat sharing for high, medium and low temperature Power-To-Heat solutions

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Keywords: Energy Storage; Heat Pump Technologies; Power to Heat; High, Medium and Low Temperature Heating; Energy Transition; RES

Foreseeable decrease in the supply temperatures for heating the built environment provides a great opportunity to the deployment of Heat Pump technologies. However, challenges have to be faced from legislative, technical and economic point of view. Recent EU projects demonstrated high energy savings linked to 3rd and 4th generations of heating systems as well as their district networks. As a matter of fact, temperature levels play a key role in the thermal energy demand of urban contexts affecting their associated primary energy consumption and the integrated Renewable Energy Fraction. A Smart Heating strategy accounts for those supply features requiring new solutions to be effectively renewable and, at the same time, to solve the RES capacity firming. The way to meet the energy demand is shifting from fuel-based to electricity-driven one with the aim to integrate high share of electric renewables. In this matter, Power-To-Heat is conceived as the strategy to modernize the high and medium temperature heating systems by electricity-driven machines to switch from Fuel-to-Heat to Electricity-to-Heat solutions. Yet, current cities are still composed by different qualities of thermal energy demand even in the same typology of end-user, e.g. residential sector. Therefore, waiting for comprehensive energy retrofitting interventions to make more efficient the building stock as well as more suitable for low-temperature heat supply, from end-user side, and for building and running new district heating infrastructures fed by renewable-driven Heat Pumps, from production side, the Smart Heat sharing concept is introduced.

The authors investigated on different urban energy scenarios at RES share increase from 25% up to 50% in the energy mix to evaluate Heat Pump-based heat supply at different temperature levels for meeting the different kind of urban thermal energy demand. The District Heating infrastructure is meant as the key for handling the urban energy transition as provider of low temperature heat for well-insulated buildings and a heat sink to be further boosted by different Heat Pump technologies at district and at building level. Trans-critical CO_2, Gas Adsorption, 2-stage and air-to-air HPs are the technological solutions chosen for meeting the different heating demand, i.e. high, medium and low temperatures, respectively.

Considering the Primary Energy Consumption as the objective function, the study shows how the interaction of a growing 4th generation district heating grid and the selected HP technologies could provide consistent energy benefit in the transition phase. Three Reference Cities were chosen as reference scenarios. The results of the urban energy scenarios for each Reference City were evaluated in terms of amount of Renewable Heat delivered.

Notice:
Please note that this research is about to be submitted for publication to Elsevier’s journal Applied Energy.

Annelies Vandernmeulen obtained her Master of Engineering: Energy in 2016 at KU Leuven. She is currently pursuing a PhD at EnergyVille/KU Leuven on the use of control to unlock flexibility in thermal networks.

Improving agent-based control performance of thermal networks by inclusion of time delays: a simulation case

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Keywords: District heating systems, thermal networks, flexibility, agent-based control, pipe models, time delays, simulation

Thermal energy storage can provide flexibility in a district heating or cooling network (thermal networks in general). This flexibility provides a number of benefits: it increases the efficiency of centralized heat generation plants and the use of renewable energy sources, it decreases peak power, reduces energy cost, assists robust operation of the electricity grid, etc. Agent-based control is considered to be a promising control strategy that can unlock this flexibility and ensure the end users' demands are met [1], [2]. However, to date, the agent-based controllers developed for district heating and cooling networks do not take into account the travelling time of thermal energy (heat/cold) in the network, i.e. the time delays. This simplification may degrade the control performance severely in case of geographically extensive networks. In this context, this paper discusses the performance of a hierarchic agent-based controller that takes the time delays into account by including an appropriate pipe model [3] in the optimization. More specifically, this improved hierarchic agent-based controller is evaluated through simulation of a thermal network providing heat to the city of Genk (Belgium), which consists of 18 000 buildings and spans an area of over 80 km^2.

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Mei Gong is Ass. Prof. in Energy technology at Halmstad University, Sweden since 2011. She received her master degree at Chalmers University of Technology in 1999 and Ph.D. degree at Linköping University in 2004. Main research interests are the energy and exergy analysis, optimization of industrial energy system, and district heating and cooling system.

Exergy and cost analysis of heating systems considering energy storage

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Keywords: Energy storage, exergy, renewable energy

About three quarters of the total final energy consumption is in the form of electricity and district heat and 49 TWh of district heat was used in Sweden in 2015. The energy supply and user demands vary and do not always match. The electricity production depends on the available energy resource that often is renewable, such as wind, solar and hydro power. The heat demand strongly depends on outdoor temperature and the weather conditions. Electricity and thermal storages are needed in order to reduce the losses from the lack of match between production and consumption. The cost of energy examined by others shows that electricity storage is about 100 times more expensive than thermal storage. However, in this study cost of exergy is only 20 times more for electricity than thermal. This study views electricity and district heat from source to end use and analyze the cost of exergy with storage. With a surplus of electricity the most efficient and cheapest way is to use electricity storage, such as battery or hydro storage on the purpose of electricity usage. The advantage of thermal storage depends strongly on the purpose of use, e.g. if it is for heating purposes. Heat pump is a method to convert electricity to district heat with 56% exergy efficiency. This paper will analyze different cases in order to give a more detailed discussion. Further studies of more cases are needed in the future.

Miaomiao He is a research associate at building energy research group, School of Civil and Building Engineering, Loughbrough University, UK. Her research interests include building physics, dynamic thermal modelling, housing stock retrofits, renewable heat and heat network design and modelling.

Domestic heat demand prediction and the implications for designing community heat networks

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Key words: domestic heat demand; community heat networks; dynamic modelling; system design

The domestic sector accounted for 29% of total final energy consumption in the UK, with space and water heating accounting for around 80% of domestic energy consumption (BEIS, 2016). Improving the energy efficiency of the fabric of the existing housing stock can reduce space heating demand, but its impact is limited, as demonstrated in a case study for the housing stock in the North East region in the UK (He et.al. 2017). To achieve the UK Government's ambitious carbon reduction target, more efficient systems for delivering space and water heating are expected to play a significant role. Community heat networks have great potential for supplying heat to groups of buildings efficiently (Carbon Trust & Energy Saving Trust, 2004). Such networks can make better use of heat from renewable source, e.g. geothermal and solar, and waster heat from industrial processes. Heat and electricity networks can be integrated to form community energy systems. This will allow energy produced locally to be used locally, and therefore improve the system efficiencies for both heat and electricity, as well as for the whole supply system.

In a live UK project, called SCENe (**S**ustainable **C**ommunity **E**nergy **Ne**twork), a community energy system will be implemented to provide heat and electricity for 33 homes in a new housing development in Nottingham's Trent Basin. This energy system will consist of PV generation and battery storage, with ground source heat pumps and thermal storage providing heat.

Despite the advances in dynamic building simulation, and its popularity in the research context, steady-state models are still widely used for sizing heating systems by design engineers. This can lead to sub-optimal design, oversizing and thus system inefficiency.

In this study, we will firstly use steady-state methods to calculate the space heating and hot water demands of the Trent Basin community, by adopting the UK standards which are commonly used in sizing a conventional heat system in the early design stage. The space heating demand of the community of the 33 homes will then be compared to the dynamic thermal modelling software i.e. EnergyPlus. An in-house tool will be used to generate the input files for each home automatically. A stochastic approach will be used to generate the occupancy profiles for each home. The space heating demands and internal gains will be assumed to be correlated to the occupancy profiles. The hot water demand of this community will be benchmarked against the empirical hot water consumption data collected in 20 homes in the UK. Finally, the implication of the model predictions for the sizing and operation of the community heat network will be evaluated, and recommendation will be made. The preliminary results suggest that the steady-state methods over predict the space heating and hot water demand. This would not cause problems for conventional heating systems, but it could have a huge impact on the sizing a community heat network, especially given the trend towards low and ultra-low temperature heat network. The research highlights the need for clearer and better guideline and legislation for designing community heat network in the UK.

Session 14: Future district heating production and systems

Dagnija Blumberga has been part of academic staff of Faculty of Energy and Electrotechnics, Riga Technical University since 1976 and director of Institute of Environmental Protection and Energy Systems since 1999. The main research area is renewable energy resources. She has participated in different local and international projects related to energy and environment as well as is author of more than 200 publications.

Session Keynote:

Solar collectors versus solar panels in DH

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Keywords: District heating, solar collectors, solar panels, thermal energy storage

Solar energy is an important alternative energy source that needs to be used for the successful transition to the 4th generation district heating (4GDH) system. The engineering parameters of 4GDH system allow integrating irregular energy sources in more efficient way as they are low-temperature systems.

There are several possibilities for solar energy productions such as solar collectors, PV panels, thermal PV systems etc. Both heat and power can be generated for DH purposes. Thermal energy can be directly used by consumer, but the power can be either used in the heat plants or fed into the grid.

Solar DH systems need to be flexible to the heat and power load variations. The necessity of energy accumulation systems and most suitable way of energy storage needs to be taken into account when considering solar energy use.

Another aspect of the study is changes in solar DH system when lowering heating network temperature. It results in higher efficiency of solar collectors, as well as lower heat losses in heating network.

The article describes the methodology and algorithm which allows evaluating the possibility to integrate solar energy in DHS for space heating, domestic hot water supply or power generation. Article evaluates the gains from solar energy use from economic and environmental aspects. Methodology is based on district heating system analysis in Latvia.

M. Leurent is a Ph.D. candidate whose research focuses on energy efficiency. The recoverable heat exists widely in nuclear plants. In order to promote sustainable heat production it would be beneficial to transfer this heat to residential areas for district heating use. By doing this, a great deal of primary energy, fossil fuels consumption and GHG emissions can be reduced.

Socioeconomic potential for deploying large district heating networks using heat from nuclear plants in Europe

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Keywords: *District heating, cost benefit analysis, urban area, nuclear, cogeneration, Europe*

District heating (DH) has the potential to support the decarbonisation of the heating sector of the European Union (EU) by taking advantage of a variety of heat sources. Recovering industrial excess heat and distributing the recovered heat to dwellings through DH networks is encouraged by the EU and its member states. Nuclear plants generate a large amount of excess heat that could safely be used for DH, and yet this alternative is rarely considered by policy makers.

This article evaluates the socioeconomic potential of theoretical DH networks using nuclear combined heat and power plants (NCHP) for base loads. The work follows the methodology described by Leurent et al. [2017], where a systematic approach is proposed for investigating the socioeconomic potential of DH+NCHP systems in terms of primary energy consumption, greenhouse gases (GHG) emissions and heating cost. The heart of the data is based on STRATEGO [2015. Peta, the Pan-European Thermal Atlas], accounting for land area with heat density greater than 100 TJ/km^2. This is above the threshold for DH feasibility commonly identified in the literature. Data for the 2015 heat demand are extrapolated to 2030, taking into account the potential decrease in demand due to improved energy efficiency of buildings

The method is applied to 16 nuclear sites located less than 100km from large cities. Despite of significant capital costs, heat transportation over long distances has been shown to be technically feasible (with heat losses below 2%) and potentially profitable in the long run [Hirsch et al., 2016]. There are 22 cities concerned, over 8 European countries: Czech Republic, Finland, France, Hungary, Poland, Slovenia, Switzerland and the United Kingdom. All these countries use or consider using nuclear energy, and have shown interest in DH+NCHP systems [NEA, 2015]. The studied cities are at different stage of deploying DH networks. However this is not an issue since the methodology used accounts for the total cost of DH networks, including investment costs of new equipment. Considering all costs allows a comprehensive comparison of DH+NCHP systems with local electric and gas boilers servicing a single building or potentially a group of buildings.

Simulations will provide at least two key results:

- The potential heat density of modelled DH networks in cities where no large DH exists in 2017;
- For each DH+NCHP project, the associated GHG emissions, primary energy consumption and heating cost. By comparison with the actual heat sources used in those cities, the environmental and economic potential of DH+NCHP projects will be assessed on a case by case.

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Danica Djuric Ilic works as researcher and assistant lecturer at Linköping University, Sweden. She is mostly interested over how different energy systems through better cooperation can contribute to a sustainable development of society. Her research is mainly focused on district heating, but by a broad systems perspective covers other energy systems as well

Searching for new roles for district heating in a sustainable society

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Keywords: District heating; Energy cooperation, Sustainable development

District heating (DH) is characterized by a number of environmental benefits, such as flexibility in the fuel mix, the possibility of industrial excess heat utilization, the possibility of energy recovery from waste, and the possibility to reduce the fossil fuel share in the power sector through combining heat and power (CHP) production. However, due to the likely sustainable development in the society DH producers will face new challenges in the future. The benefits of CHP production would be less obvious since the electricity production in the power sector will be linked to lower greenhouse gas emissions. The amount of the waste which needs to be destroyed by incineration will gradually decrease due to an improved waste management, as well as the amount of the available industrial excess heat. Moreover, climate changes and better building insulation will lead to a lower DH demand in the building sector. Development of new business strategies for DH producers may ensure a new role for DH in the sustainable society. In a number of previous studies, cooperation between DH and other sectors was recognised as strategy which may ensure an important role for DH in a future sustainable energy system.

In this study, wider system boundaries around a DH system were applied in order to identify some of those new strategies. Two examples of the most interesting strategies are: integration of biofuel and DH production (which reduce biofuel production costs and enable development of local biofuel supply chains and hence facilitate the introduction of biofuel in the local transport sectors) and cooperation between power and DH sectors by regulating the DH production from heat pumps and micro CHP plants depending on the variation of the electricity production in the supply-driven power sources (which opens up a possibility for increasing share of supply-driven renewable power sources).Co-production of other products, such as electricity, pellets and renewable transport fuels, play a decisive role for the economic performance of DH production and efficient utilization of primary energy (fuels). A general conclusion is that there might be a new role for DH in a sustainable society and, not least, that DH may play a decisive role in reaching sustainability.

Goran Krajacic is assistant professor at the DEPEE (UNIZAG FSB). He defended his PhD thesis at UNIZAG FSB in 2012. Since 2002, he has been member of LOC of SDEWES Conference and worked on many EU projects: GERONIMO, SMART, BIOSIRE, BEAST, STRATEGO, 4DH, PHOENIX, HRE. A result of his work is published in more than 30 papers listed in CC/SCI.

Status and perspectives of district heating systems in Eastern Europe

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Keywords: District heating systems, Eastern Europe, implementation of renewables, share of DH in households

District heating systems are currently available throughout Europe. They can significantly contribute to the achievements of national energy policy objectives, especially concerning increasing share of renewables in the total energy consumption. They allow large-scale integration of renewable energy sources like biomass, geothermal and solar energy in heavily populated urban areas, which can lead to decreasing pollution in large cities. In this paper, the status of district heating in 22 Eastern European countries was analysed with a review of the share of district heating in the final energy consumption for heating in the household sector. Data related to the gross final energy consumption from district heating systems in the household sector both with final heat energy consumption needed for heating in this sector are also presented for each country.

District heating in Eastern European countries faces ageing of energy generation infrastructure and requires large investments in rehabilitation of existing district heating systems. This results in low DH efficiency and high emissions. The main characteristics of DH systems in Eastern Europe are high distribution losses, from 15% to 25% of heat supply, a high number of refills per year, from 10 – 30 times, and high production losses, from 15% to 40% of fuel energy. Another problem in Eastern European countries is customer dissatisfaction with heat distribution systems, which reduces total heat demand from DH systems and revenue. There also exist an issue of high customer heat consumption, which ranges from 70-90 kWh/m^3. DH system refurbishment will increase overall system efficiency, reduce emissions and improve the quality of DH service.

The main goal in countries that do not have large deposits of fossil fuels is to decrease their dependence on fossil fuel import. Usage of locally available fuels can help in achieving that goal. Biomass is the most available for district heating, while the availability of geothermal and solar energy is limited. In the last decade, biomass district heating systems have been used more extensively in the Eastern European countries. More than 70 new biomass systems have started with the operation, are under construction or planned with the heat capacity ranged from 0.5 MW to 120 MW. Geothermal energy is extensively used in DH systems only in Hungary and Poland, to some extent in Romania, Russia and Slovakia, while in other countries their usage is very limited. Solar energy for district heating is used only in Poland, where it is used in several systems, Bosnia and Hercegovina, Slovenia, Montenegro and Ukraine where it is limited only to one system. Heat storage and incineration of municipal solid waste have a very limited number of applications in the Eastern European countries. Substitution of fossil fuels with renewable energy sources will considerably reduce emissions and increase the security of supply. Orientation to own resources is going to lead to job creation in local communities.

Zhikun Wang is a PhD student at University College London Energy Institute. My research interests lie in the fields of energy and environmental policies, low-carbon technologies in power and heating sectors. Previously, I was an environmental geologist and my educational background includes an MRes in energy demand and an MSc in energy and environmental economics and policy.

Heat pumps in the UK's district heating: individual, district level, both or neither?

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Key words: low-carbon heat, heat pump, district heating

Current domestic heat demand is predominantly supplied by direct burning of fossil fuels in the UK. It is imperative to examine potential alternative domestic heating supply options to replace conventional gas-fired systems. Prospective technologies, policies and incentives need to be examined and implemented appropriately to support future development and deployment of low-carbon heat technologies according to different building types and heat demand densities.

Electric heat pumps together with decarbonised electricity are proposed as promising solutions that could replace gas heating and contribute to the low-carbon heat mix for the UK. However, applications of heat pumps in district heating networks are relatively new, and there are technical, social and economic challenges for their deployment in the UK.

The aim of this project is to analyse potential low-carbon heat technologies and the role of heat pumps and district heating in the UK by assessing the topological configurations of heat pumps, district heating networks and thermal storage solutions for a range types of buildings on different scales.

This study investigates heat pumps at individual households versus district heating networks, in order to further explore their comparative advantages from different aspects, including technical and social impacts, carbon emission, energy efficiency, hot water storage, financial practicability and policy uncertainties.

Session 15: Energy Planning and planning tools

Frede Hvelplund, Dr. Techn. and professor in energy planning at Aalborg University. He has a background in economics and social anthropology. His approach is interdisciplinary between technique and economics and social science. He has written several books and articles on energy planning. The focus is upon concrete institutional economics, and the intention is to make analysis that supports concrete policy development.

Session Keynote:

Heat conservation incentives and policies for 4th generation district heating systems

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Keywords: 3 generation district heating tariffs blocks the way for energy conservation and low temperature district heating systems.

The Danish energy policy aims at reducing heat demand from residential houses by around 40% per m2 before 2050. At the same time the m2 area is supposed to increase, so that the total demand for heat in 2050 is supposed to be just slightly lower in 2050 compared with 2015.

This reduction in heat demand per m2 is supposed to be carried through concurrently with a radical change in the energy supply side. There are good reasons to believe that the main heat supply system will be wind power in combination with district heating, heat pumps and heat storage. This will be supplemented by geothermal, solar and some biomass heat.

In this process of change, the heat market is increasingly used as one of the ways of integrating an increasing production of fluctuating wind power.

Energy conservation therefore increasingly has both technical and economic links to the supply system in which it may be embedded in the future.

Consequently energy conservation should be implemented:

- **a. In the right amount, which is a 40-50% reduction of the heat losses in existing buildings.(ref)**
- b. **In right time,** so that the heat consumption level is "in place" before the supply system is dimensioned. If heat conservations come too late, the supply system will be oversized compared to later lower demand levels.
- **c. In the right way.** The supply systems will use solar heating and wind power in combination with heat pumps and heat storage in district heating systems. The efficiency of the heat pumps (COP factor) is dependent upon the heat level in the district heating system. And if the houses are insulated to the right degree, it is possible to lower the temperature in the district heating system, and still keep 21 degree C inside the houses. So well insulated houses with the right size of radiators and regulation system makes low temperature district heating possible, and consequently a higher COP factor at the heat pump in combination with lower heat loss in the district heating network, reducing the kWh input per m2 heated area lower. e

But this does not happen with the present incentive structure in the district heating areas, where amongst others the tariff structure with a relatively high fixed share hampers the incentives for energy conservation. And therefore also reduces the incentives for energy conservation that can make the needed low temperature systems in 4th generation district heating systems easier to implement. So in a way the tariff structure from the 3th generation district heating system is hampering the low temperature district heating system of 4th generation district heating system. Policies to overcome these incentive problems are developed and described in the presentation.

Stefan Petrovic received BSc and MSc degrees in electrical power systems from University of Belgrade in 2010 and 2012, respectively. In 2012, he joined Energy Systems Analysis group, DTU Management Engineering where he obtained PhD degree in 2017. Since then, he works as a Postdoctoral researcher in the same group. His main research interests are energy system modelling and GIS.

Comparing different district heating supply scenarios with energy savings and individual supply options in six European municipalities

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Keywords: Energy planning, renewable energy, heat savings, district heating and cooling, smart energy system analyses

Reducing CO_2 emissions from the heating sector is an important task, because this sector constitutes almost half of the total energy consumption in Europe. Renewables-based and efficient heating and cooling systems are part of many city-level CO_2 emission reduction plans. Decarbonisation can succeed if different technologies, relevant for local climatic conditions and heating and cooling demand, are implemented. A detailed analysis requires a methodology that allows comparing the costs of individual heating supply, heat savings and district heating to derive a cost-optimal mix. The methodology should also account for local renewable energy potentials and district heating expansion potentials.

This study analyses six cases: Ansfelden (Austria), Brasov (Romania), Helsingør (Denmark), Herten (Germany), Litomerice (Czech Republic) and Matosinhos (Portugal). All the cases differ regarding fuel mix and coverage with district heating, heating demands of buildings stock, availability of renewables and waste heat etc. Therefore they represent the different challenges and opportunities on the local scale well. The main objective of the study is to analyze how technological district heating supply scenarios compete with heat savings and individual heat supply from a socioeconomic perspective up 2050.

The methodology in this paper consists of district heating modelling with energyPRO and iterative modelling of heat supply and heat savings costs with a purposely-developed Least Cost Tool (LCT). First, the technological scenarios for district heating supply are modelled in energyPRO, resulting in district heating production costs, depending on increasing or decreasing heating demand and district heating production technologies. Next, the building stock is aggregated according to construction periods and use, while the potentials and costs of heat savings are obtained from Invert/EE-Lab model. Then, the annuitized costs of heat from individual heating technologies are computed. Finally, for each municipality, a cost-optimal combination of heat savings, district heating and individual supply is calculated.

The results depict the different challenges and opportunities for decarbonisation of municipal heat supply in Europe. In general, heat savings and district heating expansion pay off in all the cases analysed, but the source and share of renewables vary in each case. This analysis is further extended in the policy assessment, which investigates policy instruments enabling the technical solutions identified in this paper to be feasible from a private-economic perspective.

Patryk Chaja. Ph.D, has used his experience within IMP-PAN in the field of developing software for ship propeller design to create a new programme for the design and analysis of axial turbines (water and wind). His work has focused specifically on calculation of the geometry of turbine blades, and verifying results obtained using experimental and numerical analysis. He also conducted a series of experimental studies using a flow tunnel to determine the hydrodynamic characteristics of axial turbines.

Modelling participation in the Polish Day-Ahead Market (DAM) using a district heating company as a case

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Keywords: District heating, day-ahead market, energy systems analyses, energyPRO

Energy market is a complicated mechanism but it is also important that it functions in the best possible way. All of the companies, but also government and economy relies on the functionality of an energy market.

Poland is going through a lot of changes now, also from the energy point of view. Market is opening for new energy producers. In the nearest future the polish energy market , according to the plans of Ministry of Energy, will be made available also for heat and power plants. Dynamically changing situation on the energy market in Poland results in higher demand for different energy analyses, helping with setting the frames for functioning of energy market in Poland.

In this article authors present the current situation of polish energy market, using real data obtained from a functioning of a heat and power plant on the polish market.

The article examines and verifies a model of the existing functioning of a heat and power plant and checks the opportunities for DH in Legionowo to participate in the Polish Day Ahead market – including the payback time of new flexibility measures (e.g. a thermal store or a heat pump).

As a test case for the article authors are using a District Heating company located in Legionowo, central Poland. The company works since 1978 and its main responsibilities are production, transmission and distribution of thermal energy. In addition it also conducts business activity in transactions and distribution of electric energy.

For the modelling of a test case is used the well-known energy systems analysis tool energyPRO. energyPRO is an advanced software for combined techno-economic optimization of variety of different energy systems.

Ewa Wiechers graduated from the Master of Industrial Engineering programme Energy and Environmental Management at the University of Flensburg. In the Heat Roadmap Europe 4 Project she assists in developing the Pan-European Thermal Atlas, Peta

Matching district heat demand and excess heat supply using network allocation analysis

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Keywords: District heating, Excess heat, GIS, Network Allocation

Excess heat from industry, power generation or waste incineration could satisfy a significant proportion of heat demands in buildings across Europe. The precondition is the establishment of district heating grids, of energy efficiency in the built environment, and the availability of other, renewable sources of heat. As part of the Heat Roadmap Europe project, heat demands and the locations of prospective heat supply areas have been mapped. The result is a coherent model of heat demand and supply applicable for all of the European Union. Also, potential excess heat sources have been mapped using emission databases and sector and branch-specific assumptions on fuels, efficiencies, and temperature levels. The question that remains is how much of the potential excess heat is located within economically and technically acceptable distances to existing and possible district heating systems, and how much of it can be used? The present paper applies geographical information systems and a network-based location-allocation analysis to apply a so-called “Maximize Capacitated Coverage Solution” to the problem of reducing the total transmission pipe length while maximizing the amount of excess heat, which can be used in nearby district heating systems. A mathematical function replicates the increasing specific costs of connecting smaller systems via transmission pipelines of increasing length. The results show that the actual geography of heat demand and excess heat supply is a considerable limitation to utilising excess heat. A future scenario is being contemplated, which identifies important locations for heat synergies between industry, a smart energy system, and urbanised areas that benefit from decarbonised heat supply.

Session 16: Low-temp district heating grids

Helge Averfalk Ph.D student at Halmstad University since 2015 with special interest in fourth generation district heating systems. Main focus is developing the technical layout for obtaining and keeping an annual average return temperature of about twenty degrees. Aiming at obtaining Ph.D degree in 2019.

Session Keynote:

Pressure situation in low temperature network with a third distribution pipe

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Keywords: Low temperature network, three pipes, pressure situation

A technical challenge with fourth generation district heating networks is to really reach very low return temperatures in the vicinity of 20 °C as annual average. This can be accomplished by introducing a third pipe taking care of the recirculation flow when the ordinary delivery flow is zero. This situation appears during times when neither space heating nor domestic hot water is requested, as during summer nights. The recirculation flow is required in order to keep an acceptable supply temperature for the connected substations at these times. The annual proportion of these recirculation flows will be higher in areas with buildings with low specific heat demands, since times with no demand will be longer compared to current areas with buildings with high specific heat demands. By introducing a third pipe for taking care of the recirculation flow, a strategy is applied for not blending this recirculation flow with the return temperature from the delivery flow (as performed today in two pipe systems). Hence, this return flow will not be contaminated with recirculation flow containing the supply temperature. In this paper, the pressure situation is simulated for the three parallel pipes in a case area with low heat density. Parameters analysed for this future low return temperature strategy include one central or many decentralised pumps for the third pipe and various pipe sizes for the third pipe.

Andrew F. Lyden Ph.D student at the University of Strathclyde in the field of research of orchestrating community renewables in smart energy systems with a focus on integration of renewable energy sources through the implementation of 4th generation designed district heating and smart control.

Unleashing the potential of existing biomass systems via 4th generation district heating and thermal storage: A Scottish perspective

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Keywords: Biomass, thermal storage, district heating, smart control

Several communities in Scotland are attempting to transition to low-carbon energy through initiatives including locally owned wind farms, grants for PV panels on rooftops, and the installation of small and medium sized biomass boilers for schools and hospitals. Traditionally Scotland has developed a gas grid in urban areas and used oil and electricity to heat homes in rural areas. This, coupled with incentives, has made biomass an economically favourable alternative in rural areas with the added benefit of the perceived low-carbon aspect.

Currently there are 1,457 accredited, non-domestic biomass boilers with a total capacity of 250 MW and an average capacity of 171 kW in Scotland. These installations are typically set-up to provide heat for large public buildings, and are often built by local councils to meet sustainability targets. A relative lack of design and planning expertise in the area of biomass and district heating has led to a number of these boilers being underutilised due to poor design and control. Two case studies are presented in depth, a small village and a large housing estate, along with a wider reaching survey.

Findhorn is a village in the north-east of Scotland with a focus on ecological living resulting in an ambition to transition to a local, low-carbon energy system. Two biomass systems supplying micro-district schemes of 199kW and 50kW currently exist. One serves 10 community buildings and the other supplies 6 houses. The 199kW system currently has no useful thermal storage, simply relying on buffer tanks. This has resulted in an oversized biomass boiler to directly meet peak demands. It is conceivable that these two district heating schemes could be extended to cover almost all heating requirements with the addition of thermal storage, and the utilisation of other local renewables. The village also own an adjacent wind park, raising questions over the suitability of biomass as a fuel source when there is the potential for the electrification of heating using low or zero carbon electricity with heat pumps and/or direct electric immersion heaters.

West Whitlawburn is a housing cooperative consisting of a large housing estate which aims to improve the conditions of living for their tenants. With fuel poverty a large problem on the housing estate, grant funding was sought to perform retrofit building improvements along with the installation of a new centralised district heating system to replace the poorly performing individual electric heating which existed. A 600kW biomass boiler and 2.25MW of gas with 50m^3 of thermal storage now provide the heat for nearly 600 dwellings, mainly small flats. Poor control of the system has led to deficient use of the thermal storage resulting in inefficient use of the biomass boiler.

Design methods inspired by 4th Generation District Heating Initiatives are applied to both case studies to highlight the mismatch between the current and best practice in design, and to illustrate the potential improvements that can be gained from applying best practice in design and operation.

A survey of a number of biomass boilers around Scotland shows a similar pattern emerging: biomass boilers with no or an underutilised thermal storage which only meet the demand of a single building. District heating can provide a means of providing new demand and with proper use of thermal storage the boilers can perform closer to their capacity, maximising efficiency and financial performance. Smart controls can also ensure proper usage of the thermal storage. Finally a discussion is offered in the context of Scotland regarding the sustainability and future of biomass as a fuel source for heating.

Alexei Sednin Head of Research, Development and Innovation Centre for Automation and Control Systems in Heat and Power Engineering and Industry (DIC ACS HPE), Assistant Professor. During the past 10 years I have been working as a lecture (now professor assistant) at Byelorussian National Technical University. The basic directions of scientific work are thermal and nuclear power plants, district heating systems, small-scale cogeneration power plant (biogas, orc-cycle and so on). For last ten years more than 80 research papers have published (mostly in Russian).

Possibilities of lowering district heating temperatures in Belarus

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Keywords: District heating systems, combined heat and power

The history of the district heating systems development in Belarus is more than 100 years old. The rapid development of district heating systems (DHS) based on combined heat and power generation began at 50-s years last century. Nowadays, about 60% of heat supplying to DHS are produced by cogeneration plants.

Studies on DHS modernization are constantly ongoing. Determination of the best directions for DHS future development including adaptation of the worlds advanced technologies (incl. 4-th Generation District Heating) to the Belarus current conditions is well-timed.

In this paper, we will focus basically on supply and return water temperatures for DHS. Due to technical capabilities initially DHS systems were operated with constant flow rate and variable temperatures (max. 150 °C for supply and 70 °C for return) depending only on outdoor temperature.

In the 90-ies, installation of large number of control systems particularly on consumer's side led to lower temperature level as well as forcing the DHS operate with variable flow rate.

Now it is proposed to implement dynamic temperature optimization for DHS using the criteria of minimum energy costs for the heat production and distribution.

The question is whether it is possible to reduce the water temperature parameters in the current conditions of the existing DHS in Belarus.
The main consumers in DHS are households with heating and hot water systems. The social standard for the hot water supply temperature is 50 °C. Domestic heating systems are designed and built for temperature parameters 90/70 °C. According to the winter period outdoor temperature conditions, the average water temperature can be considered 75/55 °C, in summer period - 62/45 °C.

For these conditions it is difficult to lowering supply temperature without renovation of existing buildings, but it is possible to reduce the return temperature.

In most of the Belarusian large cities, mainly in old districts, a trimeric system for the distribution of district heating water has been remained: a heat source, a central heat supply station, an individual heat supply station. Central heat supply stations are situated at the boarder of distribution and quarterly networks and distribute the heat energy between the heating and hot water supply systems. It is supposed to redesign central heat supply stations installing additional heat pumps, electric water heaters and heat accumulations tanks.

Reducing the water return temperature will minimize heat loss and also allow wider implementation of condensate economizers and low-temperature ORC-units.
Thus, district heating systems have a certain reserve to improve their efficiency without significant investment in the heating systems of the existing households.

Nicole Pini: received a M.Sc. in Energy Engineering from the Politecnico di Milano, Italy, in 2013. Since then she works as research engineer at the European Institute for Energy Research, founded by EDF and KIT (Karlsruhe, Germany), on district heating and cooling, renewable heat production and Power-to-Heat in public funded projects and activities for EIFER's industrial stakeholders and field clients.

Guidelines for an optimal integration of water-to-water heat pumps in low-temperature district heating networks: lessons learnt from the analysis of three networks in France

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Keywords: Heat pump, low-temperature district heating, monitoring system, flexibility, data analysis

Water-to-water heat pumps are a key component of low-temperature district heating networks, as they enable heat recovery from low-grade heat sources. To ensure an optimal integration of heat pumps, the impact several technical and operational parameters have to be analysed in detail, among which are some characteristics not often provided by manufacturers and installers. Furthermore, the quality of the monitoring system and the choice of the network architecture (centralised or decentralised, with or without heat storage) play as well a key role in the energetic and financial results of the project.
The monitoring data over several years of operations, the initial business plan, the service contract and the client invoices have been studied for three low-temperature district heating networks in France.
The three networks differ in:
- Architecture: two decentralised, with heat pumps in each substation and on-off power modulation, and one centralised – with step power control;
- Service provided: only heating and domestic hot water or cooling as well;
- Type of heat source: sea water, heat recovered from wastewater treatment, geothermal heat.

Qualitative and quantitative guidelines have been derived from the analysis to allow future similar installations to benefit from the lessons learnt.
When selecting the size and technology of heat pump it is fundamental to investigate and quantify:
- The daily and seasonal variations of the heat source, to calculate the COP in all operating conditions;
- The power modulation technology: "on-off" for stable demand profiles, step modulation for average annual load rate above 50% and dynamic power modulation with inverter for shorter cycles;
- Impact of the load rate on the COP and the heat production temperature, depending on the power modulation technology, especially to ensure the provision of domestic hot water;
- Technical constraints for frequent start and stop cycles and for operation beyond the design temperature.

An optimal integration of water-to-water heat pumps relies as well on:
- A robust and adapted monitoring system to enable preventive maintenance, particularly important for decentralised systems;
- A transparent, collaborative and continuative relationship with the heat pumps manufacturers and installers to adapt the control strategy to the system needs;
- A close supervision of the substation construction and heat pumps installation, to ease the ordinary maintenance of the installation;
- A strong knowledge of the characteristics of the cold source, to avoid rapid performance deterioration.

Session 17: Low-temperature DH and buildings

Carsten Østergård Pedersen has been working within Business Development in Grundfos for the past 7 years where he has been focusing on energy optimization and sustainable solutions. The latest year he has been responsible for setting the global agenda on District Energy and earlier He has focused on solutions for commercial buildings and is part of the Board in the Active House Alliance that focuses on creating sustainable comfort in buildings.

Session Keynote:

Intelligent utilization of pumps in LTDH

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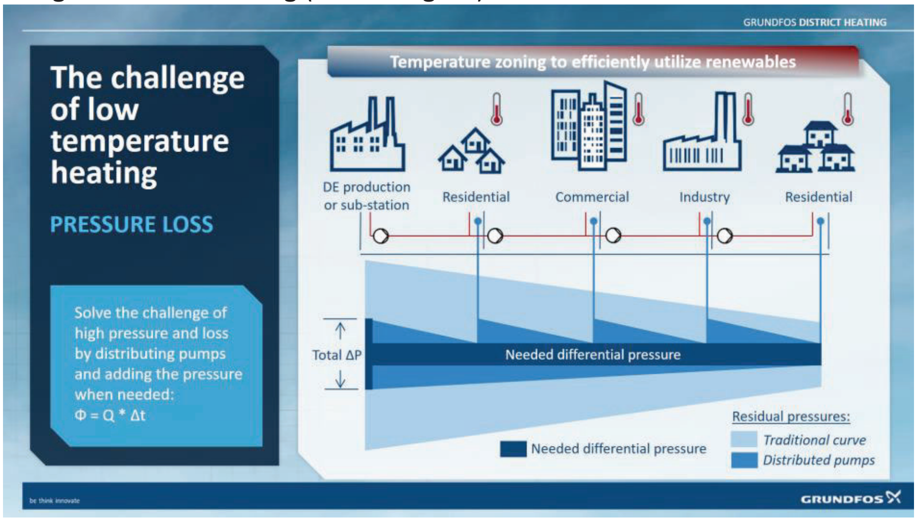
Keywords: Low temperature district heating, Implementation of renewables, Heat loss reduction, Pressure optimization, Temperature zoning

District Heating is on the rise, since it is considered the most efficient way of distributing energy in most European cities. It is also considered the best way of utilizing various renewable energy sources and surplus heat from factories, data centers etc.
Based on these two statements, Grundfos has developed a District Heating concept that (1) helps ensuring that renewables and surplus heat can be utilized effectively and that (2) heat losses are reduced significantly.
To make effective use of renewables and surplus heat, it is a requirement that the temperatures in traditional district heating is lowered, e.g. for heat pumps to work effectively.
When lowering temperatures in district heating, the differential temperatures will at some point also be reduced, meaning that higher flows are needed ($\Phi = Q * \Delta t$). This will result in too much pressure in the beginning of the system which can result in control and leakage challenges, which are why we suggest distributing the pumps and operating the system with pressures that is just enough to feed the next pumps in the setup (see the figure).
To make it even smarter, instead of only installing distributed booster pumps, it will in many cases be relevant to install mixing loops to divide the cities into different temperature zones. This way you only deliver the temperature needed and reduce heat losses significantly - e.g. for newer residential areas/zones using underfloor heating (see the figure).



Today pressures and temperatures are also exceeding the needs in the critical parts of the system, because it is not measured and operated on real-time basis. So, by installing pressure and temperature sensors with real-time feedback (e.g. in the by-passes), further optimization of the system can be achieved.
All-in-all, this makes it possible to do a controlled decrease of temperatures, which contributes with significant heat loss reductions and the possibility to utilize renewables and surplus heat.
Grundfos is currently establishing field tests with Energy-Service that provides intelligent bypasses, pit measure points and the software needed for temperature optimization.

Johnny Iversen holds a M. Sc. degree in Mechanical Engineering supplemented with a Bachelor degree in Economics and Finance. He has 30 years of experience within the Energy Sector (Planning, Carbon Finance, Renewable Energy, Power Production, District Heating, Energy Efficiency etc.). He is a specialist in thermal energy systems, heat and power production plants and district heating systems.

Ultra-Low Temperature District Heating Supply in New Build Areas and in Apartment Buildings

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Keywords: Ultra-Low Temperature, District Heating, Consumer Substations, Flexible Distribution Nets, Heating and Ventilation, Micro-booster, Domestic Hot Water Production, Space Heating, Hot Tap Water

For the last 5-10 years, major efforts have been made to improve the competiveness of district heating compared to individual heating solutions. District heating systems have been challenged by high investment costs (especially in grids) together with high heat losses relative to the still decreasing heat demand as building codes tightens and building envelopes improves. Further, the energy sources to produce district heat are changing from classic fossil fuels towards renewable energy sources like solar, geothermal, heat pumps, waste heat etc.

With support from the Danish Energy Technology Development and Demonstration Programme Sweco leads several projects supporting competitiveness of new district heating schemes. One of them is development of a new distribution and consumer substation scheme for new built areas comprising two major components: 1) Flexible distribution pipes in plastic demonstrating a new and cheaper grid structure, and 2) New consumer substation structure combining uncoupled heat supply (space heating and hot tap water) with ventilation.

The new built area comprises 105 family houses (three different types) supplied with ultra-low district heat (35-40°C). All space heating and approx. 2/3 of the tap water is provided by district heating. A small heat pump in the ventilation system provides the remaining part of the hot tap water.

A second supported Technology Development and Demonstration Programme is deployment of the ultra-low district heating concept to a rather new block of flats (senior homes), which has floor heating. Especially, the lowering of the return temperature benefits to the system efficiency at the production site. Concept will be presented together with preliminary measuring results from an ongoing measuring program.

The system is a retrofit design for hot tap water production by an applied heat pump drawing on the ultra-low district heating supply temperature (approx. 35°C), hereby decoupling the temperature requirement of space heating and hot tap water respectively. The concept is, however, applicable to new designs as well.

Ultra-low district heating mainly contributes to system optimisation by:

- Allows efficient integration and use of renewable energy sources like (solar heat, waste heat, geothermal heat, heat pumps etc.),
- Substantially lowers heat losses in distributions systems,
- Improves energy efficiency at production site by ex. Improved flue gas condensation, improved electrical efficiency at CHP plants).

Maria Justo is a researcher at SINTEF Building and Infrastructure working with heat supply to buildings by means of heat pumps and district heating. She has widely worked with zero emissions buildings and now with Zero Emission Neighbourhoods. She has also worked with primary energy factors calculations.

How low can the heating supply temperature be in different building types in Norway?

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Keywords: Low temperature district heating, Zero Emission neighbourhoods, renovated buildings, new buildings, old buildings

Zero Emission Neighbourhoods (ZEN) are conglomerates of different types of buildings that can conveniently be grouped into three categories: (1) new buildings with very high insulation levels and very efficient systems, (2) old buildings that are renovated achieving higher energy efficiency to some extent and (3) old buildings whose energy performance cannot be significantly improved due to architectural reasons (e.g. downtown buildings).

Supplying the heat demand of ZEN with 4th generation district heating (4DH) solutions opens for two strategies. One strategy is to connect the buildings with higher temperature requirements on the supply pipe (evt. of a pre-existing DH system with high temperature) and the most efficient buildings in the return pipe. The other one is having a low temperature DH system dimensioned to supply the efficient buildings and use local boosters (at building level), e.g. heat pumps or boilers, in the buildings with higher temperature requirements. Either way, the fundamental constraint is how low can the heating supply temperature be in different building types? In turn, this will determine the minimum DH supply temperature for each building type in the ZEN.

This paper performs such analysis for residential buildings in Norway using as the starting point the archetypes defined in the Tabula/Episcope projects. The building stock is divided in 21 segments, consisting of 7 age-classes and 3 building types; a synthetic average building is defined for each segment, whose characteristics are representative of the most common features found in the segment based on best available knowledge. Each synthetic average building is described in 3 levels of energy performance (original, standard renovation, ambitious renovation) for a total of 63 archetypes. These archetype buildings are simulated in the simulation program IDA Indoor Climate and Energy (IDA ICE), focusing on the properties of the thermal envelope and of the heat emission system. The effect of renovation on the envelope or the heat emission system or both on the minimum supply temperature is studied.

The results are presented for a selected number of archetypes, driving the discussion on how different building types in a ZEN can be supplied by 4DH solutions.

Roar Nysted The team is involved in developing and implementing advanced energy solutions for buildings and areas. These included the integration of locally available renewable energy sources as well the use of waste energy sources. The focus is on energy efficiency in combination with the economic feasibility of the energy concepts.
Close cooperation of ZEnergy and research (IRIS) ensures the implementation of advanced technological solutions and the integration of latest developments.

4th Generation heating system using geothermal energy as the main source

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Keywords: 4th generation heating system**,** Renewable energy, Heat recovery, Energy storage, Process integration, Operational experience

Advanced heating systems for buildings, blocks of buildings and districts are to be designed for low temperature heating, allowing for making use of low temperature heat sources and waste heat recovery. These systems are theoretically described in several publications while only limited information systems implementation and on operational experience is available. In 2015 was such a 4th generation heating system, which was combined with energy storage, waste heat recovery and intelligent control, designed and implement into a residential area in Stavanger, Norway.

This paper describes the implemented heating system, which is making use of shallow geothermal heat, integrates solar energy as well as recovers otherwise wasted heat. The results of heat balances based on measured data and operational experience demonstrate the energy efficiency of a 4th generation system. The overall specific performance of the system is compared with a conventional one, which was designed and built at the same time and is also located in the area of Stavanger. The impact of the 4th generation system on reduced emissions of greenhouse gas is shown. Even though short term investment costs for a 4th generation system are higher than for a standard one contributes the higher efficiency to longer term cost reduction especially when considering increasing price of energy.

Hironao Matsubara Chief Researcher of Institute for Sustainanle Energy Policies. Research fields are statistics database, scenario study, policy framework and business model of renewable energy in Japan. An editor in chief of Renewables Japan Status Report since 2010. A degree as doctor of Engineering for Energy Conversion from Tokyo Institute of Technology in 1990.

The 1st application of 4th Generation District Heating in Japan, its outcomes and lessens

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Keywords: 4th Generation District Heating, Biomass, Japan

In Japan, conventional district heating systems have been developed in urban areas which have high heat density such as group of buildings or factories using energy source of fossil fuel historically. Because the rural area of Japan has great deal of biomass resources from forest or agriculture, feasibility study of 4th generation district heating(4GDH) system for the rural area using biomass sources have been made to realize the system in the two model areas, Shimokawa Town and Ogata Village in northern part of Japan. It could be found several outcome and lessons to demonstrate the 1st application of 4GDH system in Japan.

Shimokawa Town located in Hokkaido is planning to introduce new CHP plant which power output 1.8MW and heat output is almost 2MW using pellets made by wood as fuel. Then, they plan to construct new 4GDH system in the centre of the town which may have enough heat demand mainly for space heating. The system will be constructed in 3 steps, the first step is for hospital and school area, second step will be for area of government office, and third step will be for area of residential. This plan will include heat storage to manage peak demand and intermittence of heat supply from CHP.

On the other hand, Ogata Village located in Tohoku area is planning to construct new 4GDH system and introduce biomass boiler as heat source using agricultural residue such as rice husk because this village heavily depends on rice cultivation. As the first step of the study, heat demand including space heating, hot-water and rising temperature of hot spring are measured to matching heat supply by the DH system. And existing facility of several buildings of hotel and spa are investigated to integrate with the DH system.

Session 18: Future district heating production and systems

Anders N. Andersen Head of the Energy Systems Department , EMD International A/S. Ext. Associate Professor, Aalborg University. Bachelor of Commerce. Master of Science in Mathematics and Physics

Session Keynote:

Distributed CHP units in Denmark are too quickly loosing electricity production

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Keywords:

Distributed Combined Heat and Power plants connected to District Heating and Cooling Plants (DHCP CHP) have an important role to play in the transition to a renewable energy system, but the role changes radically between the three phases in the transition. In Phase 1 the DHCP CHPs' task is to displace fossil fuelled condensing mode power plants as well as to displace production on individual and communal boilers, thus producing as much electricity as the heat demand allows. In Phase 2, where wind power and photo voltaic (PV) cover a major part of the electricity demand, the DHCP CHPs participate market-based in the integration of these fluctuating productions and produce less electricity compared to Phase 1. In Phase 3 in the transition to a renewable energy system, the DHCP CHPs are producing even less electricity and are instead providing needed electrical capacity in the hours, where wind power and PV do not produce sufficient to cover the electricity demand.

This obvious consequence of the transition to a renewable energy system when developing wind power and PV is amongst others described in the Danish Transmission System Operator´s (TSO) plans for 100% renewable energy, which state that today's cogenerated 90 PJ of heat in Denmark will in 2035 have gone down to 40 PJ and in 2050 have gone down to 5 PJ.

But the production at the Danish DHCP CHP´s have already today been halved compared to the level of xx in 19cc which is too fast.

The Danish central power plants produced around 40% of the electricity demand in 201x, half of it being in condensing mode and half of it being in extraction mode with heat delivered to the big cities. It is thus to be noticed that the decrease in DHCP CHP happens even if there are still central power plants producing in condensing mode, which is in contradiction to Phase 1 operation. Two general factors are at play here; a) whether condensing power generation occurs at times where there is a non-CHP covered heat demand in the DHCP CHP systems and b; whether the DHCP CHPs are competitive.

One of the reasons why DHCP CHP are not any more competitive with central power plants producing in condensing mode is to be found in reduced support schemes and tax exemptions. An historic review of these support schemes and tax exemptions and their consequences for the bidding prices is presented.

Alfonso Gordaliza Pastor MSc. in Mechanical Engineering (Energy) by the University of Valladolid (Spain), writing my Master Thesis in the Technical University of Dresden (Germany). I have been working in VEOLIA as research engineer since 2015, developing energy efficiency projects and participating in two EU-funded demonstrative projects related to district heating optimization: CITyFiED (FP7) and REMOURBAN (H2020).

Renovation towards a smart district heating in Valladolid

Alfonso Gordaliza Pastor, Research Engineer, Veolia Servicios LECAM (*) Javier Martín Sanz, Project Manager, Veolia Servicios LECAM Enrique Martín Guillem, Research Engineer, Veolia Servicios LECAM José Ramón Martín-Sanz García, Research Engineer, Veolia Servicios LECAM **Corresponding author:** *Alfonso Gordaliza Pastor, Research Engineer, Veolia Servicios LECAM alfonso.gordaliza@veolia.com +34 983 268 442 Avenida del Euro, 7 – Edificio B – Oficina 308/ 47009, Valladolid/ España*

Keywords: : District heating; energy efficiency; renewables; pre-insulated pipes; low-energy district; heat storage; variable flow; smart control

Nowadays, a large portion of the energy consumption in cities is due to space heating in the residential sector. As many of these systems are based on fossil fuels, this leads to a continuous increase of the pollution in urban areas. In this regard, the development and optimization of district heating solutions that connect a group of buildings over the same network enables significant enhancements related to energy efficiency, cost savings and security of supply. Moreover, as energy is generated and distributed on a large scale, the integration of renewables in the system reduces the dependency on external factors, mitigates the CO_2 emissions and stabilises the cost of the energy supply.

The aim of this paper is to provide some general guidelines that contribute to the improvement of the overall performance of district heating solutions and then provide a real example of this transition towards a low-energy district. In this sense, the paper is focused on FASA district in Valladolid, where an integral renovation of the buildings and energy facilities is carried out within the EU-funded project REMOURBAN. Some of the main energy conservation measures implemented in the district heating are listed below:

- Reduction of the buildings' thermal energy demand by external insulation on the façades;
- Change from pressurized super-heated water (T>100ºC) to a hot water (T<80ºC) network;
- Transition from fossil fuels (oil and gas) to a renewable-based system (biomass and solar);
- Optimized-power generation facility thanks to new high-performance boilers and heat storage systems (buffer tanks);
- Deployment of variable flow pumping units;
- Replacement of the obsolete pipeline network by new pre-insulated pipes;
- Installation of high-efficient heat exchangers, balancing valves and DHW tanks at building level;
- Centralization of the DHW production in the same district network;
- Deployment of smart control, metering and DAQ (data acquisition) devices at all levels;
- Installation of heat cost allocators in the dwellings' radiators allowing individual billing.

In this case, we will discuss how such a systemic process should be designed and which process elements or key measures, respectively, should be taken into account.

Thibaut Richert is currently doing a PhD in the Energy Sytem Operation and Management research group at the Danish Technical University (DTU) in Copenhagen. He is involved in the Centre for IT-Intelligent Energy Systems in cities (CITIES) project which aims at establishing an integrated research centre covering all aspects of the energy system. He focuses on Smart Classification and Aggregation of Energy Components.

Integrating electrical and thermal domains – A case study of the Danish Technical University campus

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Keywords: Integrated systems, District Heating network, Electrical network, Heat pump, Heat storage

The Danish energy sector is evolving rapidly to reach a fossil fuel free society by 2050. Large penetration of fluctuating renewables in the power system, over the past decades, has led to grid stability concerns, drastic operational changes and a great need for flexibility. The electrification of the heating and transport sectors will keep renewables penetration on the rise in the upcoming years. Energy systems coupling have shown to bring additional flexibility to systems with high penetration of renewables and to perform better than decoupled energy systems from the energy, techno-economic and environmental perspectives.

The 4th Generation of District Heating (4GDH) concept, foresees future district heating and cooling networks as an integrated part of the operation of smart energy systems. The latter suggests smart thermal grids with bi-directional flows, storage at different spacial-temporal levels and proliferation of power to heat technologies. Power-to-heat technologies are crucial for the 4GDH concept since they link the thermal/cooling domain to the electrical domain. However, there is a general lack of knowledge regarding the physical synergies at the network level and operational challenges resulting from systems coupling. Domains integration increases complexity due to additional operational, physical, temporal and spatial constraints. Moreover, multi-energy systems (MES) correlate different uncertainties and there is a gap in operational time-scales of the systems being coupled which makes it challenging for analysis and simulation but also for designing operational strategies (i.e. control). Control strategies of domain linking components such as a heat pump can be various (flow, temperature, electricity price based) and challenging due to multi-level repercussions where actions taken in one network have an impact into another. Research on these concepts are believed to be valuable knowledge to support the energy transition; specifically with respect to the 4GDH and the smart grid.

In this paper, we introduce use cases (UCs) based on a holistic validation and testing methodology which are representative of integrated electrical/thermal systems. One of the UC is mapped to an existing system configuration from the Danish Technical University (DTU) campus. The smart-campus initiative is going to implement a large heat-pump (HP) which will connect waste heat from a cooling process to the campus DH network and an underground water storage. This large HP will be part of a highly collaborative energy system which calls for the design of suitable operational and control strategies. Our study focuses on the challenges for operating such a HP and derives general conclusion for future smart energy systems with high share of power-to-heat technologies.

Session 19: Smart Energy Systems

Kerstin Sernhed works as an assistant professor at the Department of Energy Sciences at Lund University teaching several energy related courses. Her research interest lies within the fields of district heating and energy efficient systems with a focus of customer relations, energy services, DSM and maintenance in DH grids.

Session Keynote:

Synthesis of Swedish District Heating Research between 2013 to 2017

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Keywords: District heating, district cooling, research program, sustainability, customer perspective, transition of the energy system

In Sweden, District Heating (DH) meets half of the heat demand on the heat market. As a result of high interest of DH ample research has been conducted and Sweden is one of the forerunners in terms of DH innovation.

In this paper a synthesis is made on the Swedish research frontier. A review of the third phase of the Swedish district-heating research program “Fjärrsyn”, that was undertaken between 2013 and 2017 has been conducted. The program has had an interdisciplinary and multidisciplinary approach with the ambition to facilitate business solutions and future energy technologies where electricity, heat and cooling can be produced with low greenhouse gas emissions.

The research program Fjärrsyn is run in collaboration with the Swedish Energy Agency and the district heating industry and has had a turnover of approximately SEK 19 million a year. The first phase of the program started in 2006. The last phase started in July 2013 and is ongoing until June 2017.

The review of the research program was made from three different perspectives:

- Sustainability perspective: How well does the program incorporate sustainable development in the research projects? In what ways is this handled? Are the three pillars (economic, social and environment) of the sustainability concept covered in equal measure?
- Customer perspective: How is the customer perspective handled in the research projects? Are the research questions about issues that are important also from a customer perspective? Are the customers viewed as an important part in the energy system? How? Are the empirical studies based on input from customers in first hand or second hand? Are the research reports written also to target customer stakeholders?
- The role of district heating and cooling in the transition of the energy system: How can the results from the research projects contribute to the transition of the energy system? In what ways? What are the main barriers in the transition of the energy system according to the research conducted in the program?

The findings from this study identify what the Swedish research frontier in DH is, it identify research gaps and indicate areas of interest for future research.

Andrei David is a research assistant in the Sustainable Energy Research Group at Aalborg University in Copenhagen. His research profile is on the cross-sector integration of the components of an energy system, with a focus on heating. He is working on topics related to the future role of large-scale heat pumps in district heating systems, the development of new guidelines for strategic heat planning, energy system analysis and contributes to the development of technological pathways for producing electrofuels.

Quantifying the impact of district heating, heat pumps, and electric vehicles in Italy, Romania, and the United Kingdom

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Keywords: Wind power; solar power; EnergyPLAN; district heating; heat pumps; electric vehicles.

The decreasing costs of wind and solar power combined with the future low-carbon energy targets will enable the integration of more renewable electricity in all the European countries. The costs of wind and solar power are expected to be similar in the next decades, making it relevant to analyse which of the two technologies provide more integration benefits in each of the three countries. Thus, the aim of the paper is to analyse how much wind and solar power can be integrated into various European energy systems by the year 2050. Italy, UK, and Romania are used as case studies since they vary considerably in terms of population, area, and climate.

An incremental increase in wind and solar power is simulated in each of these countries using the energy system analysis tool EnergyPLAN for four 2050 scenarios: business-as-usual (1), district heating and large heat pumps (2), individual heat pumps (3), and electric vehicles (4). Wind and solar power is increased in 10% steps for each of the two technologies, until reaching 100% of the total electricity demand. The optimal integration values in regards to critical excess electricity, primary energy supply, carbon emissions and costs are chosen for both wind and solar and for each of the four steps. The results indicate that: (1) for all three countries, all the steps bring reductions in terms of primary energy supply, carbon emissions and costs; (2) integrating either more wind or more solar has the same advantages; (3) district heating and large heat pumps bring more carbon reductions than the other steps; (4) the electric vehicles bring the highest costs reductions. Therefore, adding wind power, solar power, or both in the energy system reduces fuel consumption, carbon emissions and costs for the entire energy system, if complementary measures are added on the demand side, such as district heating, heat pumps, and electric vehicles.

Nadine Aoun is a PhD student whose thesis was launched jointly by CEA and ADEME in 2016 at the French National Institute for Solar Energy. Her research involves modelling and optimization of district heating systems, with a main focus on the demand aspects. Holder of an MS in mechanical engineering, Nadine had pursued a Master's Degree in Energetics and Environmental studies prior to her doctorate.

A sensitivity analysis to support the modelling of space heating demand in view of developing a load shedding algorithm

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Keywords: District heating demand, Occupants behaviour, Furniture thermal inertia, Modelica, Monte Carlo.

Heat demand in District Heating Systems (DHS) is a highly time-varying quantity because it directly depends on external weather conditions and heat consumption habits. In traditional control strategies of DHS, heat production is contingent on heat demand, thus resulting in peak loads during certain hours of the day. Advanced control strategies relying on Load Shedding (LS) offer an alternative by shifting heat production to off-peak periods. However, ensuring consumers' thermal comfort is of vital importance in this context. Therefore, a careful assessment of all heat gains and losses as well as short-term heat storage capacity due to buildings' thermal inertia including furniture is pivotal for LS.

Dynamic Thermal Simulation (DTS) applied to buildings is a powerful tool for the development and assessment of optimal LS control strategies. However, the parameterization of such tools can be rather cumbersome. As a first step towards the development of an LS algorithm, we intend in this communication to present the results of a sensitivity analysis performed to identify the most influencing parameters. Many studies have recognized the important and stochastic impact of occupants on a building's energy balance (e.g. [1]). Most studies considered empty buildings; whereas in [2], the authors emphasized the influence of furniture's thermal mass on heat consumption. Wherefore, we developed a building numerical simulator and we included disturbance signals for internal heat gains and windows opening, as well as additional partition walls representing furniture. Two categories of multi-floors buildings are considered: poorly insulated buildings representing old dwellings, and well-insulated buildings representing recently built ones.

Modelica language is used for this end, since it is an object oriented language with a well-suited inherent bottom-up non-causal modeling approach. The *MixedAir* component of the *Buildings* library [3] is adopted to model a 4-zones floor. *RadiatorEN442_2* is a hydronic radiator model, also found in the *Buildings* library and used to maintain a set point temperature inside the thermal zones. Dynamic profiles of occupants' behavior and furniture dimensions are varied within certain ranges. Then, the DTS of the model is run over a period of 50 days (**Fejl! Henvisningskilde ikke fundet.**). A Monte Carlo simulation is used for the sensitivity analysis. Conclusions of this study give recommendations on parameters that should be considered for DHS advanced demand control strategies.

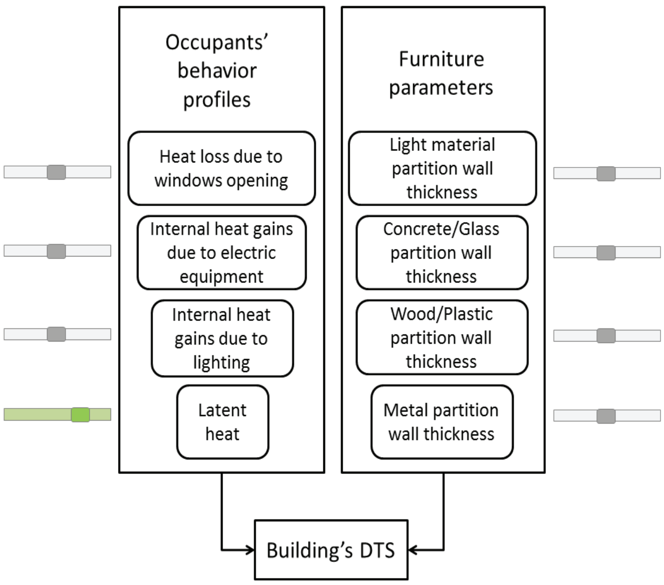

Figure 2: A particular scenario of the performed series of simulations where the latent heat dynamic profile is being varied within lower and upper limits, all other profiles and parameters being fixed to reference values.

[1] D. Yan *et al.*, “Occupant behaviour modelling for building performance simulation: Current state and future challenges,” *Energy Build.*, vol. 107, pp. 264–278, Nov. 2015.

[2] H. Johra and P. Heiselberg, “Influence of internal thermal mass on the indoor thermal dynamics and integration of phase change materials in furniture for building energy storage: A review,” *Renew. Sustain. Energy Rev.*, vol. 69, pp. 19–32, 2017.

[3] M. Wetter, “Modelling of heat transfer in rooms in the modelica buildings library,” 2013.

Søren Møller Thomsen is currently working as energy planner at Rambøll. He has a master degree within sustainable energy spezializing in electricity systems from the Technical University of Denmark. At Rambøll he works mainly with energy system analysis, economic assessment studies and master planning of energy projects.

The Smart Electricity Storage – District Heating and Cooling with Thermal Storages

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Keywords: Smart Energy, Thermal Storage, DH&C, Virtual Battery

Variable Renewable Energy Sources (VRES) are becoming a dominant energy producer in electricity systems, increasing the need for fast responding flexible producers/consumers to ensure grid stability. District Heating and Cooling (DH&C) systems, which profitably utilize the fluctuating electricity prices caused by VRES, can provide the same ancillary services, as fast responding gas engines and electric batteries. Storing large amount of electricity in batteries is expensive. Fortunately, DH&C can also produce thermal energy, based on fluctuating VRES production, by using heat pumps and electric boilers, and store it for later use in thermal storages, reducing curtailment of VRES and socio economic losses. Furthermore, CHP plants can generate back-up electricity for the VRES. From an electric system perspective, the DH&C system offers the same service as an electric battery, acting like a virtual battery.

Hot water storage tanks are a proven technology and have been used for several decades. In some Danish district heating systems, large-scale solar heating has been the driver for large seasonal thermal heat storages – so called pit storages – which have excess storage capacity. And, in DH&C system, the ATES (Aquifer Thermal Energy Storage) benefits from being a seasonal thermal storage, using combined heat and cold production from a heat pump. The thermal storages provide a cost effective solution to the integration of VRES, allowing flexible DH&C operation in the various electricity markets. In the Smart Energy Barrier and Solution Catalogue[3], the DH&C system with large thermal storages is found crucial in a 100% renewable energy system. Furthermore, EU has also discovered the benefits of smart energy systems in a package of directives[4]. However, in most countries, the framework conditions are not fully developed for a smart energy system. Electricity tariffs and contracts must take into account time of consumption, quality of power, net load and the cost structure. A smart energy tariff provided to interruptible loads is needed. The question is of course; will it be profitable to establish a DH&C system?

Using a Danish urban development district, which in the future will have a mix of commercial and residential buildings including a new hospital, I show how the virtual battery is made available to the electricity system for no extra cost. The total land area is 1.8 million m^2 and the total heated floor area will be 660,000 m^2, of which 470,000 m^2 is expected to have a cooling demand. The peak capacity demand at building level is estimated at 14 MW for heating and 13 MW for cooling. The alternative to DH&C is individual heat pumps and chillers, which have less flexible response to electricity prices. In the DH&C solution there is co-generation of heating and cooling and an ATES system. Furthermore, the electricity consumption for cooling can be optimized with a cold water storage tank, and for heating, it can be optimized with a heat storage tank and connection to the local district heating network. The interesting point is that the total investments in the baseline with individual supply and the DH&C alternative are almost the same. In other words, the virtual battery is available at no additional cost. The benefits of optimal storage operation and reduced energy and maintenance costs will create an economic incentive for the municipality, the developer and the building owners to invest in the DH&C solution instead of the individual solution. Moreover, development of DH&C systems can be stimulated by introduction of a smart energy tariff allowing for better integration of VRES. The only requirement is to organize the society to establish the thermal energy infrastructure. Exploiting the synergies between energy systems holds the key for optimal planning of future energy systems with high amounts of VRES.

[3] http://efkm.dk/media/8011/smartenergi_ramboell.pdf
[4] https://ec.europa.eu/jrc/en/publication/efficient-district-heating-and-cooling-markets-eu-case-studies-analysis-replicable-key-success

Alexander Tureczek received his M.Sc. in Applied Statistics from Technical University of Denmark I 2009. Before returning to academia he applied his knowledge of machine learning, statistical classification and pattern recognition for customer segmentation and fraud detection for financial institutions and the Danish Tax Administration.

District heat household consumption classification using smart meter data

Ph.D candidate A. Tureczek[1], Senior Researcher P. S. Nielsen[1], Business Developer A. Brun[2], Professor H. Madsen[31] Management Engineering, Technical University of Denmark [2] AffaldVarme Aarhus[3] Compute, Technical University of Denmark*

Keywords: District heat consumption, classification, smart meter data, machine learning

The district heating systems in Denmark successfully supplies Danish households and companies with cheap heat. Originally intended for utilizing the excess heat from electricity production it is continuously being improved and optimized for greater efficiency. In an effort to optimize a district heat system it is important to recognize the impact of the end—user on the entire system and not only focus on technical solutions for optimizing grid, flow and lowering forward heating temperature. In a district heating system that is continuously being technically optimized, inefficient household consumption is able to negate the incremental achievements reached. Better understanding of end user behaviour and their role in the district heating system can help educate consumers to become more aware of their behaviour/consumption habit without sacrificing comfort. Increasing knowledge of consumption behaviour is needed if undesirable consumption patterns are to be identified and alleviated.

Though district heating has received much scientific attention little focus has been on classification and characterization of consumption patterns using smart meter data. Contrary to this in the past decade electricity smart meter data have been successfully applied to segment electricity consumption and consumers using classification methods from machine learning. Simple, fast and robust methods such as K-means and hierarchical clustering have been frequently applied. This paper will apply learnings from smart meter electricity consumption analysis on district heating consumption data to identify consumption patterns and segments for better understanding the end-user behaviour in a household setting.

A Literature study has shown k-means to be very prevalent and successful in electricity consumption classification. The method is very robust but fails to include information about autocorrelation, which is expected to exist in the data. K-means will constitute the benchmark for testing an alternative classification technique, which in contrast to k-means does account for the possible autocorrelation in the smart meter data. Furthermore, the project will develop methods for selecting number of clusters as there is no unambiguous way to identify the optimum number clusters,

Data utilized in this project is kindly supplied by Aarhus waste incineration plant AVA (Affald Varme Aarhus), which incinerates waste in a CPH plant, supplying the area of greater Aarhus, approximately 50.000 households with heat and power. The data consists of smart meter readings on 1 hour basis of every district heat consumer in Aarhus.

It is expected that the District heat and Electricity consumption data exhibit the same general structure and hence the methods and learnings from electricity clustering can to a wide extent be applied to District heat data. The improved understanding of consumption patterns in the existing District heat grids, can be utilized for developing tools for optimizing the current grid and scaling future District heat grids when grids are expanded or new grids are laid down.

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Session 20: Future district heating production and systems

Torben Ommen is an expert on modelling and optimisation of energy systems as well as detailed design, optimisation and experimental analysis of specific thermal energy technologies, such as cogeneration plants, heat pumps, refrigeration systems and district heating/cooling.

Session Keynote:

Design considerations for integration of two 5 MW vapour compression heat pumps in the Greater Copenhagen district heating system

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Keywords: District heating, Heat pumps, Heat sources

The municipality of Copenhagen, together with the Greater Copenhagen Area in Denmark, has the target to supply CO2 neutral district heating (DH) by 2025. In 2015, 53 % of the supplied heat was classified as CO_2 neutral by means of CHP conversion to biomass and with a significant contribution from waste incineration plants. Electrically driven heat pumps (HPs) are considered as one of the needed technologies in order to address the remaining share of fossil fuels in DH. A study from 2014 found, that by 2035 a total of 300 MW installed capacity of electric HPs would lead to the optimal reduction of heat cost for the Greater Copenhagen system. Of this equipment, a total capacity of 130 MW should be in operation by 2025.
However, large scale HPs face a number of barriers preventing a large-scale introduction. Among others, the barriers include high cost of the produced heat, availability of heat sources, and lack of knowledge and operation experiences. To examine the barriers, the SVAF project was initiated in order to construct and test two electric 5 MW HP systems based on three different heat sources: waste- and sea water and geothermal heat. The two HP systems are expected in operation by 2018 and 2019, respectively.

A number of important design considerations were analysed, with the objective to establish which solution presents the lowest cost of produced heat. For both cases it was found that a system configuration with two HPs operated in series presents a good trade of between investment and performance of the system.
For the geothermal HPs, the technical feasibility as well as the economic viability of this installation was investigated for a range of optimal configurations. The analysis recommends a HP configuration with a COP of 6.1, resulting in a system exergetic efficiency of 63 %.
For the waste- and sea water HP, the installation type employs a complex heat exchanger network for the heat sink, which, depending on the chosen configuration, has significant influence on the design and off-design operation of the unit.
The results attained from the analysis of the two cases will be used in the future work of developing a decision support tool for large scale HPs. The purpose of the tool is to frame configurations with favourable economic and technical merit for potential HP installation in the DH system. In order to support the introduction of HP capacity in large systems like the one of Greater Copenhagen, the tool should further take into consideration the possible component design and specifications. In this way the tool may be used for a range of capacities, a range of DH supply and return temperatures and various heat sources. In the Greater Copenhagen district heating system it is expected that HPs of capacities of 5 MW to 50 MW are favourable, mainly due to economy of scale of the installation.

Magnus Dahl is an industrial PhD fellow at Aarhus University and AffaldVarme Aarhus, the municipal district heating company in Aarhus, Denmark. He holds a M.Sc. degree in physics with a focus on renewable energy networks. His research is focused on cost and risk assessment in district heating systems.

Long-term production planning in large district heating systems

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Keywords: Long-term production planning; weather-driven modelling; planning under uncertainties; combined heat and power; district heating

In temperate climates, the heat demand is considerably lower during summer than during winter. As a consequence, some heat plants can become superfluous during summer operations, in large district heating systems with multiple production units. There is significant economic potential in a complete shutdown of one or more production units for a period during the low-demand season. The optimal times for shutting down and re-opening superfluous production units vary from year to year. Therefore, a district heating providers' ability to reap the economic benefit of summer-shutdown is highly dependent on accurate timing and long-term prediction of shutdown and opening.

As a case, we use the district heating system in Aarhus, Denmark's second largest city. In Aarhus, most of the annual heat demand is covered by the combined heat and power plant in Studstrup (SSV). The economic potential of shutting down SSV during a period in summer is between 3% and 7% of the total annual heat production cost or about 4.5-7.6 million euro annually. When the heat demand is low enough, cheaper production units e.g. waste incineration plants can cover the demand. However, if the demand rises above a certain level, and SSV has been taken out, the excess demand must be covered with heat from expensive and environmentally problematic oil boilers. Thus, the shutdown and opening of SSV must be timed carefully, in order to realize the economic potential of the shutdown.

Using 38 years of weather data and a simple heat load model, we characterize the optimal scheduling of shutdown and opening of the plant. The optimal shutdown date can be as early as April 23 and as late as June 1. Likewise, the optimal opening date varies between September 30 and November 13.

Based on the characterization of the optimal scheduling, we proceed to formulate a set of decision rules. These decision rules allow a production planner to determine when to shut down and when to re-open the plant. Simple decision rules, such as "shut down on May 14", can realize some, but not all of the economic potential. More complex decision rules, based on weather forecasts, can perform better from year to year.

Finally, the performance of the different decision rules is benchmarked. The uncertainty in weather forecasts on different forecast horizons is taken into account. There is a trade-off between the length of the planning horizon and the accuracy of the of the shutdown scheduling. In this trade-off, we estimate how far in advance it is feasible to plan a shutdown.

The presented methodology can be applied to any large district heating system to schedule optimal shutdown of plants that are superfluous during the low-demand season.

Oliver Martin-Du Pan is a mechanical engineer and completed an engineering doctorate in district heating systems and decentralised energy. I have now been working at E.ON for 2.5 years as a performance engineer in the Community Energy team.

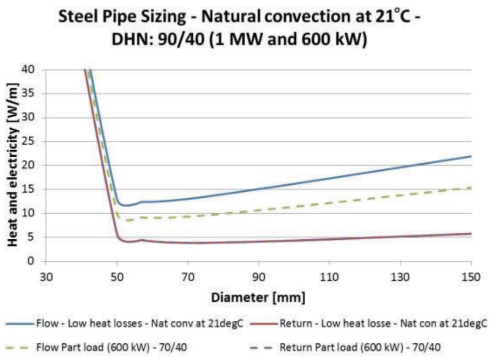
District Heating Network Pipe Sizing

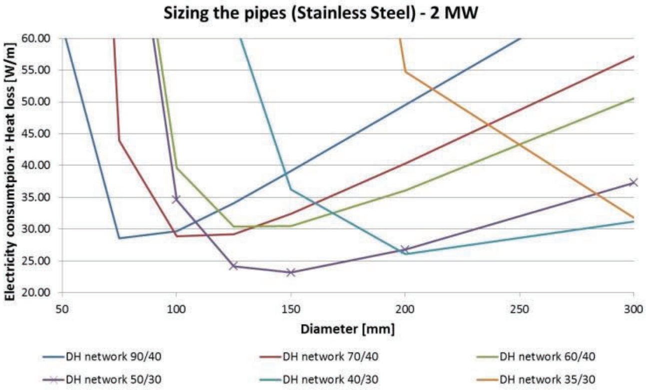
*Dr Oliver Martin-Du Pan**, *District Heating Pipe Sizing. E.ON-UK, oliver.martin-du-pan@eon-uk.com, +44 (0)78 133 69 246, 47-53 Charterhouse Street - London EC1M 6PB.*

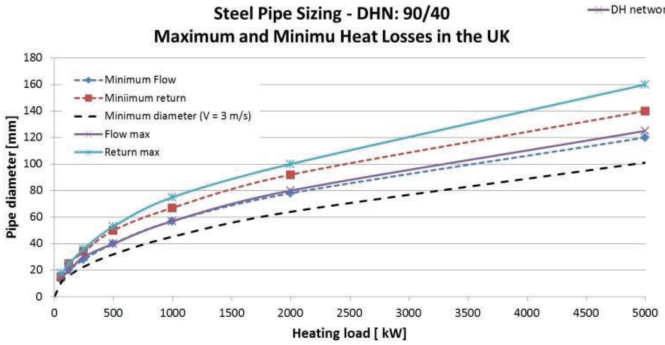
Keywords: District heating systems, Pipe Sizing, Design software

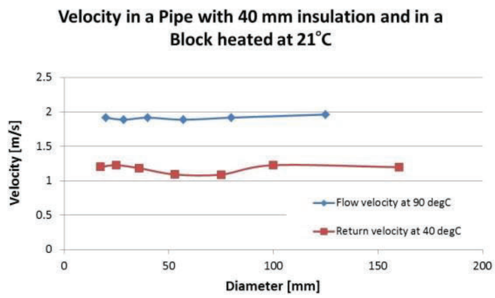
A new methodology to size pipe diameters is being developed with aim of reducing the currently oversized pipes in the UK. Currently pipes are sized in the UK based on setting a known ΔP per metre of pipe. However, this methodology is not appropriate because to minimise the operational cost, the optimal ΔP must increase when reducing the pipe diameter and heating load. Thus, this new methodology is aimed to reduce the operational cost of our district heating networks which includes heat losses, electricity consumption for pumping and a heat gain resulting from the flow friction with the pipe. To carry out this exercise and to reduce pipe diameters, this research covered an analysis of current standards and recommendations and it was assumed that the pipes are insulated with 40 mm insulation thickness around them and that the thermal conductivity of the insulation is of 0.025 W/(m*K). As the sizing of pipe diameters is also dependent with their heat losses, a maximum and a minimum heat losses environment scenario was assumed with effect of obtaining a minimum and maximum pipe diameter when installed in the environment with the maximum or minimum heat losses environment respectively. The maximum heat losses environment was assumed to be when pipes are buried in a moist soil of 12°C with a flow and that the flow in the soil would maintain by forced convection the external surface of the insulation at 12°C. That temperature corresponds to the soil temperature in London when reaching a depth of six metres and under. The minimum heat losses environment was assumed to happen when the pipes are installed horizontally in a heated Block at 21°C and natural convection would occur around them. Please note that this proposed pipe sizing methodology is to size pipes which have a direct influence on the pump's ΔP. However, for most laterals in a Block and service pipes connecting the laterals to each heat interface unit fitted in individual dwellings, the pressure drop of these pipes will have no or a negligible impact on increasing the ΔP of the main pump. Thus, it is proposed to size these pipes to enable the maximum permitted flow velocity to circulate through them. Please note that the flow maximum velocity value is still under investigation and may vary considerably depending on the used pipe material. Currently, only recommended maximum values have been found with no consistency in various manuals. However, on the bottom Chart on the left is a black dashed curve giving the pipe diameter that the pipe could be sized to if a velocity of 3 m/s was the selected factor to size the pipe at. That Chart also gives the pipe sizing result for stainless steel pipes of a suitable quality when the pipe is in the discussed environment with either high or low heat losses respectively and with direct influence on the pump ΔP.

From the top Figure on the right, it can be noticed that less energy is consumed when operating a DH network with higher ΔT and at lower temperatures. It can also be noticed that to operate a 90/40 or a 70/40 DH network have a similar amount of energy consumption when sized and operating at the same maximum load and using 2 MW as showed on the Figure. However, the advantage from a 90/40 DH network is that the flow temperature could for example be reduced to 70°C in the summer with effect of then operating a 70/40 DH network in smaller pipes with result of operating the network with less heat losses than the original 70/40 DH network, which will be in summer composed of oversized pipes. This is showed in the top Figure on the right when the 90/40 1 MW DH network has a reduced load of 600 kW. Also, a 90/40 DH network would enable the retrofitting of the UK building stock in the most cost effective way while keeping the current used radiators circulating heat at a higher temperature. Finally, the bottom Chart on the right shows that DH network pipes should not be sized based on a ΔP, but it would preferably be sized based on an optimal velocity that is determined by the flow temperature and the external environment.


Steel Pipe Sizing - Natural convection at 21°C - DHN: 90/40 (1 MW and 600 kW)
Heat and electricity [W/m]
Diameter [mm]
Flow - Low heat losses - Nat conv at 21degC
Return - Low heat losse - Nat con at 21degC
Flow Part load (600 kW) - 70/40
Return Part load (600 kW) - 70/40


Sizing the pipes (Stainless Steel) - 2 MW
Electricity consumtpion + Heat loss [W/m]
Diameter [mm]
DH network 90/40
DH network 70/40
DH network 60/40
DH network 50/30
DH network 40/30
DH network 35/30


Steel Pipe Sizing - DHN: 90/40
Maximum and Minimu Heat Losses in the UK
Pipe diameter [mm]
Heating load [kW]
Minimum Flow
Miniimum return
Minimum diameter (V = 3 m/s)
Flow max
Return max


Velocity in a Pipe with 40 mm insulation and in a Block heated at 21°C
Velocity [m/s]
Diameter [mm]
Flow velocity at 90 degC
Return velocity at 40 degC

Sabine Putz Head of R&D since 2009 and COO since 2015 of SOLID. Sabine Putz has 18 years of experience in photovoltaic power and solar thermal energy and has been partner and/or coordinator of more than 20 national and European funded research projects. She is Operating Agent of IEA SHC Task 55 (Large scale solar thermal district heating).

Focus of IEA SHC Task 55: „Towards the Integration of Large SHC Systems into DHC Networks“

Putz, Sabine, Ing. ; Provasnek, Anna Katharina, Dr. Mrs. Sabine Putz, OPERATING AGENT IEA SHC Task 55 s.putz@solid.a +43 316 292840-45 ; Puchstrasse 85, A-8020 Graz, Presenter Patrick Reiter, p.reiter@solid.at*

Keywords: Solar District Heating (SDH), Solar District Cooling (SDC), Solar thermal systems, Solar thermal large scale applications, modular construction, monitoring, networks

Solar thermal large scale installations provide less than 1% of heat for DHC networks globally. The interest into solar thermal energy installations increases, but still strong measures are necessary to promote the technology across countries and energy policy frameworks. So how can the share of solar thermal energy be increased in district heating and cooling networks globally? Today, technical, economic, and policy measures still restrict a profound market development and limit the integration of large scale solar systems into different types of energy networks (Solar Heat Worldwide 2014)[5], despite the huge potential of the technology to provide heat based on renewable sources. Several technical design characteristics determine the specific energy output of the systems, such as collector field losses, low temperature operations, or low return temperatures into solar collectors critical to storage losses. One major specific problem of regions with strong seasons are system and operational losses during winter times. The integration of solar thermal large scale applications into district heating networks is problematic: Solar radiation is low while temperatures of the district heating network are high (90°C – 140°C flow temperature). Additionally, the performance of collectors and their performance in field constructions does not correspond to their designated lab test results. Storages, hybrid technologies (industrial waste heat, heat pumps, or storage types) and optimized system components have to be aligned with all-year system requirements of district heating and cooling networks to guarantee a high solar fraction.The new IEA SHC Task 55 integrates past findings and extends research towards district heating and cooling networks, main system components and hybrid technologies. Additionally, the new Task provides a new platform for scientists and industry partners to share their knowledge and solve pressing technical, political, and economic problems. It aims to provide options on how to best integrate solar thermal large scale installations in combination with hybrid technologies (such as seasonal heat storages or adsorption heat pumps) into district heating and cooling networks. It is central to focus on the integration of solar thermal systems into network technologies, and on which challenges limit current integration efforts. The main objectives of SHC Task 55 are:

- Description of low cost and high performance large-sized SDH/SDC systems, their main components and guidelines for their construction
- Simulation of the integration of large seasonal storages, hybrid technologies and large collector arrays into different district heating networks
- Description of crucial components of modular conception and construction of SDH/SDC systems
- Elaboration of business and financing calculation models
- Validation of measurement methods of tests on field collector performances and singular collector tests in the laboratory
- Country reports, license requirements, feasibility studies and a database on large SDH/SDC systems in established and new markets

One central objective of Task 55 is the analysis of solar thermal systems, which already provide significant amounts of energy to district heating/cooling systems and also integrate hybrid technologies. In contrast to past research projects, where solar fractions where clearly limited, increasing solar fractions require a holistic investigation of the total heating system. These focal points will be elaborated in 4 Subtasks across 4 years.

[5] http://www.iea-shc.org/data/sites/1/publications/Solar-Heat-Worldwide-2016.pdf 18-07-2015 15:20

William R H Orchard contributed to BSRIA CHP guides, EU pipe standards. His six EU national energy policy studies used the "Orchard Method" CHP. His Brexit Paper identifies CHP misallocations EU directives and EUETS. He hopes, "Exergy Economists", Anti Legionella Exergenius™, "Keep Hot Pipes", CHP / heat pump "Energy Hubs", replace low pressure gas for UK domestic dwellings by 2035.

Retrofitting the UK domestic sector with Energy Hubs, Exergenius™, and "Keep Hot Flow Pipes

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Keywords: "Retrofit UK Domestic" Anti Legionella" "Exergenius™ "Keep Hot Flow Pipe" "Nuclear CHP" "Engine Energy Hubs" "EU misallocations" "Exergy Economists" "Gas pipes for return water" "Hubs heat pump no insulation for return to nuclear and large base load CHP"

The paper addresses optimal ways to retrofit the UK domestic sector to heat networks by upgrading some of the heat rejected in 2035 by new nuclear and other UK thermal power generation. Ref 3 estimates if we used all the heat we can invest £78.3Bn in heat networks.

The paper will evaluate our keep hot pipe concept. A second pipe inside the flow pipe keeps it hot by returning water from the end of the pipe using the static pressure to return some of the water to its source. This system will also allow return pipes to go cold. We can also use the supply pipe more effectively as a heat store varying its temperature.

We will evaluate our concept of dwelling ventilation by heating outside air with return water from the radiators and domestic hot water heating.

Our analysis indicates we can use existing HDPE gas pipes for our return water as we convert dwellings from low pressure local gas to local gas fired CHP making better use of the gas. We increase national security of electricity supply, vulnerable to disruption of National Grid from cyber or physical attacks. Stored liquid fuel acts a standby as well as a lower cost way to back up a period of no winter wind periods for our 10GW wind. Investment.

The paper extends our Exergy analytical work, Ref 5 to seasonal changes of "Carnot environment" temperature as an optimal way to evaluate the use of fuel and other scarce energy resources to match the much greater demands for heat in the UK than power on coldest days.

The References below contain current publications that form the background to the abstract they can be found at http://www.orchardpartners.co.uk

1. Making the most of CHP. CIBSE Journal April 2014. Optimal solution to retrofit UK domestic sector radiators designed for Flow "F" 180- Return "R" 160F & "F" 82C and "R" 72C or 60C is to raise the flow to 95C and increase the Delta "T" by dropping the return temperature and pipe size. Proposal for Exergy metering. *Charge in same way as gas is sold fixed heating return at 15C consistent with higher CV evaluation for gas.*

2. DECCs UK National Comprehensive Assessment of Combined Heat and Power and District Heating: Reasons it significantly underestimates the potential for heat networks by assuming a plot ratio of 0.3. OP 2016

3. Why CHP should meet the UK'S energy needs. "Heat networks fed by nuclear or fossil fuel CHP are a better investment than air source heat pumps justifying investment of £73.8 BN in heat networks to utilise higher temperature heat rejected in power generation in 2035 compared to using the electricity in air source heat pumps. CIBSE Journal September 2016. *Source of power plant heat at 30C higher than air temperature in heating season.*

4. How increasing flow temperatures reduces heat losses in heat networks. OP paper July 2015. *Pipe size reduces.*

5. International Association of Energy Economists European Conference Dusseldorf 2013. A review of methodologies to analyse electricity and heat production from Combined Heat and Power and their signals

to the heat and electricity sectors. Cross subsidy of the electricity sector by the heat sector. Revised and updated 2016. Title Brexit 2016 an Opportunity to Reform Anomalies in EU Energy Sector Directives? Revisions clarification of Exergy analysis.

6. The pricing of the joint products from CHP and the “Orchard Method” for the allocation of fuel burn” An OP policy discussion paper author John Macadam September 2015.

Session 21: Energy Planning and planning tools

Ralf- Roman Schmidt is working at AIT since 2009, where he is responsible for the field "District Heating and Cooling". After finishing his studies in production engineering at the University of Bremen, he received his PhD-degree in the field of thermo-fluid dynamics. Ralf-Roman Schmidt is vice chairperson of the European DHC+ Technology Platform and active in a number of IEA Annexes

Session Keynote:

Sustainable heat supply strategies for district heating networks – tools and methodologies

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Keywords: District heating, decision support, heat supply strategies, low carbon sources, integration of renewables

Changing market conditions (especially energy prices, regulative conditions and by trend decreasing final heat demand) as well as the need for reducing the primary energy demand and at the same time increasing the supply of renewable energy sources in order to reduce the CO2-emissions imposes major challenges to many district heating (DH) network operators for sustaining a competitive heat supply with a high security.

As a consequence, for the development of future perspectives and transformation strategies for their current DH infrastructure, various uncertainties, new boundary conditions and conflicting requirements have to be considered, leading to difficulties for the decision towards the type and size of the supply units to be used in the future.

In this contribution, tools and methodologies for developing sustainable heat supply strategies for district heating networks will be analyzed and a structured decision support process will be described. This is including:

1. Heat demand analyses and scenarios, potential of demand side measures (load shifting, return temperature reduction)
2. Assessment of the current status of the supply units and identification of potentials for alternative/ new heat sources
3. Preliminary concept development (analyses of heat generation costs for different technologies and preliminary design of supply units/ additional storages based on load duration curves)
4. Linking to the electricity markets and operational optimization, adaptation of the supply design based on operation strategies
5. Scenario assessment and comparison, qualitative (e.g. SWOT analyses) and quantitative comparison of different criteria (economic, ecologic, technical, other …)
6. Network assessment (if required: network topology and design modifications as well as hydraulic integration for decentralized supply)

Pablo Puerto is a computer science aficionado, an urban energy system engineer and a applied physics PhD student. He studied engineering at the Mines d'Albi-Carmaux french engineering school and after a year and a half as research engineer in a Swiss research institute focused on urban energy system planning and design, he started a doctoral thesis in March 2016.

Implementation of distributed co-simulation for urban energy systems

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Keywords: Co-simulation, multi-platform, tool coupling, urban energy system

Simulation can support an optimal design and operation strategy of multi-energy systems. One approach being co-simulation allows the use of dedicated software and tools for each subsystem.

Except for tools offering Functional Mock-up Interface (FMI) functionalities, there is no common standardized interface that can be used for the co-simulation of such multi-energy systems. Rather than trying to create new standards, the goal here is to create a robust and adaptable co-simulation platform, acting as a easily linkable backbone.

This presentation is the opportunity to show how we implemented a distributed multi-platform co-simulation using containerization concept and an orchestrator to link tools such as TRNSYS, EnergyPlus, Modelica, Matlab and Python based tools, with or without FMI.

Currently a lack of robust software implementation skills can lead to misused, unused or unmaintainable academic tools. The presented platform will enable non computer specialists to exploit the possibilities of co-simulation techniques while respecting standards for tool development that will make their contributions reusable by others and easily maintainable.

We will present the application of the co-simulation platform on a use case based on the city of Vevey (Switzerland) combining a low temperature district heating and cooling network with decentralized heat pumps, an electricity network with power to gas technologies and a gas powered combined heat and power production plant supplying a high temperature district heating network and compare the use of the distributed co-simulation platform with that of a classical monolithic simulation using Modelica.

This method is applied for the implementation of distributed multi-platform co-simulation for hybrid urban energy systems in the IntegrCiTy project funded by the ERA-NET Cofund Smart Cities and Communities.

Eftim Popovski began work at the Fraunhofer ISI in May, 2016. He obtained his Masters at Kaiserslautern University of Applied Sciences on the topic "Assessing Technical Options for a Renewable and Energy-Efficient Heating and Cooling Supply in a City District". His work focuses on design and analyses of heat generation units used in district heating networks, with the main focus on the economic feasibility of solar thermal panels and large-scale heat pumps.

Cost-effectiveness of large scale heat pumps in district heating networks - a simulation model for a case study in Germany

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Keywords: Heat pumps, district heating, energy system analyses, policy recommendation, energy planning, decarbonisation, levelized cost of heat

The market share of the DH (district heating) in Germany is around 13 %. Even though there is still a space for future expansion of the DH network, Germany has one of the biggest DH market shares in the EU. Heat production is dominated by large-scale CHP plants that are driven by either coal or natural gas and together account for about 80% of total DH production. With the goal of the German energy transition to reduce greenhouse gas emissions by -80 to -95% compared to 1990 up until 2050, , there is an increased pressure on the DH operators to increase the share of renewable energy source (RES) in the supply mix. With the increasing share of RES in the electricity generation, heat pumps represent one of the possible options of de-carbonizing the DH network. While countries like Denmark show a substantial market introduction of large scale heat pumps, they are not yet applied in Germany. This study analyses the technical and economic aspects of integrating large-scale ground source heat pumps in the DH network. Our assessment is based on real circumstances of a small size city in Germany (Herten) with an existing district heating system currently supplied by coal-fired CHP. The study is conducted in the frame of the Horizon 2020 project progRESsHEAT (www.progressheat.eu).

The methodology consists of energy system modelling using the simulation software energyPRO. Heat demands and possible expansion of district heating are based on detailed assumptions about the future development of the thermal energy demand of the building stock in Herten. The levelized cost of heat (LCOH) of the heat pumps is compared with the costs of the existing coal-fired CHP plants, which are currently supplying the DH network in Herten. As the city of Herten and its neighbours are former coal mining cities, the pit water from the past activities has to be pumped to prevent flooding. Therefore, the pit water can be used as a heat source for the heat pump. The investment costs are about 1500 EUR/kW of installed thermal capacity and lifetime of 20 years, with a variable operation cost of 3 EUR/MWh and fixed operation cost of 1% of the initial investment. In order to assess all relevant dimensions of the cost-effectiveness we systematically adapt the following levers in sub-sequent simulations:

- Heat pump size
- Heat source temperature
- Heat sink temperature (lowering temperature in DH network)
- Electricity tariff (inclusion of taxes and charges)
- Capital expenditure

Results show that neither from a (simple) socio economic perspective nor a private perspective the heat pump is cost competitive with the existing coal-fired CHP units at today's energy prices and policy framework. In order to improve the competitiveness, several policy measures and recommendations have been proposed and assessed. Due to the high electricity price in Germany, investment grants or loans are not sufficient to make heat pumps cost-effective. A measure that has a large influence on the LCOH is electricity tax reductions similar to the ones for the energy intensive industries. If these measures are implemented and the heat pump is sized in the manner that will have the largest amount of full load working hours, the LCOH of the heat pump can be reduced to the same level of the coal-fired CHP plants.

Kanau Takahashi is a master student in Japan who has been studying energy policy, mostly focusing on the heat utilization of biomass. He has working experiences as an intern at Institute for Sustainable Energy Policies (Japan), which is well-known NPO in Japan in the field of renewables and at PlanEnergi (Denmark), which has over 30 years of experiences in district heating.

District heating in Japan – current situation, challenges and possibilities

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Keywords: Energy system, Energy policy, Japan, DH market, Challenges for deployment of DH

District heating (DH) is even hardly recognized in Japan. Primary heating devices has been individual installations such as air-conditioner, oil stove, gas boiler etc. which lead to large investment as a whole, bad room air quality, low degree of integration of renewables and so forth. Additionally, as there is no infrastructure like DH that enables the utilization of heat, most of excess heat from electricity production and industry processes has been just thrown away and producing large amount of energy losses.

In this presentation, history of energy policy in Japan - more precisely heat policy - will firstly be introduced and the reasons why Japan has failed to pay attention on heating sector will be described. Then, current and foreseen challenges for deployment of DH will also be investigated. Besides from lacking awareness on DH itself, poor insulation performance of buildings, low taxes on fossil fuels and absence of policy support are the major challenges. Among few of DH experiences in Japan, some of the so-called “leading” examples which in fact have serious flaws in its design will also be introduced to supplement the explanation of current situation in Japan. Finally, solutions that can overcome the challenges above and the future possibilities of DH in Japan will be discussed.

Rasmus Lund is working within energy planning and energy systems analysis. The last years with a focus on modelling and analysis of the heating sector and its role in future renewable and smart energy systems.

Heat Roadmap Europe: A Method for linking EU-TIMES and EnergyPLAN energy system models

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Keywords: Energy system analysis, Energy modelling tools, Scenario development, Hourly simulation, EU member states

Many computer tools for energy system modelling have been developed for different purposes and with different approaches. The process of developing a new tool is a time-consuming task and includes not only the initial programming of the tool, but also the continuous fixing of bugs, updating of functions and general maintenance to consolidate and prove the capability and relevance of the tool. Hence, for a specific purpose where no single tool already exists, it might be worthwhile integrating two existing established tools.

The energy system modelling need in the project Heat Roadmap Europe 4 (HRE4) is used as a case to assess the feasibility of integrating two different energy system tools, since no single one provides all necessary functions. The HRE4 project requires long-term scenario development for 14 EU member states from 2015 and to 2050, based on expected implementation pathways and the evolution of the system. However, the project also needs a detailed hour-by-hour modelling of system dynamics and integration between sectors such as electricity and heating, which can show radical technological change and is free of institutional boundaries. Two tools have been found in combination to provide the needed functions, which are EU-TIMES and EnergyPLAN. The EU-TIMES model provides the long-term scenario development and EnergyPLAN provides a detailed simulation of the hourly system dynamic.

The soft linking of the models is done via a standardised template, which is a list of model parameters such as unit capacities, efficiencies, annual fuel consumption etc. This is used as a proxy between the models, where the EU-TIMES model produces an output, which is put into the template. The outputs from EU-TIMES in the template format is then converted into the EnergyPLAN input data format. This template to convert EU-TIMES output data into EnergyPLAN input data is applied for 14 selected EU member states, constituting approximately 90% of the heat demand in the EU. The baseline for each country scenario is modelled for 2015, 2035 and 2050, which totals 42 baseline scenarios.
The results are expected to show that such combination is possible and provides a good estimation of the expected results, when comparing the outputs of EU-TIMES to the outputs of EnergyPLAN. This should enable the benefits of both modelling tools to give a more comprehensive view of the energy system and save time compared to development of a new tool.

Session 22: Energy Planning and planning tools

Markus Kölfinger is working for AIT (Austrian Institute of Technology) in the field of sustainable thermal energy systems for more than 7 years. As project manager and project team member he is currently involved in national and international district heating research projects

Session Keynote:

Simulation based evaluation of large scale waste heat utilization in the district heating network of Linz (Austria) by optimized integration of a seasonal storage

Markus Köfinger, MSc.*[1]*; Dr. Ivar Baldvinsson*[1]*; Daniele Basciotti, MSc.*[1]*; Olatz Terreros, Msc.*[1]*; Dr. Ralf Roman Schmidt*[1]*; Julia Mayerhofer, MSc.*[2]*; Dr. Simon Moser*[2]*; Dr. Robert Tichler*[2]*; Hubert Pauli, MSc.*[3] [1] *Austrian Institute of Technology GmbH, Energy Department, Giefinggasse 2, A-1210 Vienna* [2] *Energieinstitut an der JKU Linz, Altenberger Straße 69, A-4040 Linz* [3] *Linz AG, Wiener Straße 151 A-4021 Linz* markus.koefinger@ait.ac.at*, Tel. +43 50550-6248*

Keywords: District heating, waste heat, seasonal storage, economic and ecological assessment, operation strategy

Guaranteeing a secure, affordable and sustainable heat supply is a key challenge but also a key asset of a smart industrial site or city. Sustaining the very good level of district heating infrastructure in the city of Linz (Austria) requires continuous improvement and punctual adaptation. The integration of industrial waste heat in urban district heating (DH) systems is essential for a sustainable, low-carbon heat supply and therefore a key element for a smart energy system. Achieving this integration requires the investigation of optimal technical and infrastructural integration options, as well as economic analyses for improved implementation. In Linz, industries have significant unused waste heat potentials. These potentials can be realized by integration into the urban district heating system, considering a seasonal storage for optimized resource efficiency.

This presentation focused on the possibilities of integrating existing waste heat potentials in the Linz DH network by analyzing the associated integration of a large seasonal heat storage, back-up systems and new funding possibilities for the storage investment. One major challenge for seasonal storages is the limited number of cycles, usually one cycle of charging and discharging per year, which leads to small revenues. Therefore different concepts and optimized operation strategies for seasonal storages were analyzed and simulated, while simultaneously economic studies were carried out and suitable financing concepts were identified.

The results show that a “hybrid” usage of the large storage could increase the number of cycles and thereby increase the revenues of the system significantly. This is related to the utilization of the storage in a seasonal approach to shift waste heat from summer into winter period and also use the storage in the transitional period as a short term buffer for the network to increase the profit by an active participation in the electricity market with the existing CHP plants. Due to these measures the high investment costs of large scale storages can be compensated more easily. Nevertheless there are still uncertainties in the amortization of these systems. Depending on the future market framework as well as the costs for energy and resources, the payback time can vary a lot. Therefore the next steps in the project include further economic analyses and the development of financing concepts.

Gorm Bruun Andresen is doing research in system integration of renewable energy. His research ranges from continental scale systems to cities. The current focus is on energy conversion and storage, district heating, and the impact of climate change. GBA is assistant professor at Department of Engineering, Aarhus University. He obtained his PhD in experimental physics in 2010.

User incentives for low-energy renovations in district heating systems of different scales

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Keywords: District heating, Company size, pricing models, cost oriented prices, business models, tariff

Danish district heating is a non-profit business regulated under the law on heat supply. District heating companies today are either municipality owned, mainly in the larger cities, or consumer owned, in medium sized or smaller district heating areas. The difference in company size has an influence on heating prices, as larger companies will be a mixture of many different production units and distribution networks. Smaller district heating companies typically rely on a single production facility that sets the price. The larger companies might not be cheaper than the smaller, but the variation in price decreases as company size increases.

Aarhus is the second largest city in Denmark and the local district heating company AffaldVarme Aarhus (AVA) supplies more than 50,000 consumers with heat by means of a city-wide pipe network. Here, Aarhus is used as a case to investigate the difference in heating prices between a single large district heating company and about 50 smaller companies covering the same total system.

By averaging the heating prices of consumers in many district heating areas with different properties, some consumers will experience an increased economic incentive for district heating compared to alternative heating solutions. Clearly, other consumers will experience the opposite. This effect does not directly impact the socio-economic value of district heating, but it does influence the consumer economy significantly. We find that due to the difference in distribution networks cost and heat losses, cost-real consumer prices would vary by more than a factor of two between the individual distribution networks in the Aarhus area despite the fact that heat production prices are identical throughout the city, as they share the same central heat transmission network. Heating prices thereby are influenced by the company size, and this concern can't be overlooked when doing energy planning.

In a similar way, the consumer price model can be used as an instrument to incentivize or disincentivise low-energy renovations. In this study, we split the heating cost into fixed and variable components for each district heating area and relate these to existing and alternative consumer price models, which also have both fixed and variable components. In cases where the consumer cost does not match the corresponding cost composition, we quantify the direct and indirect consumer savings that occur due to the mismatch. In certain cases, we find that consumers do not benefit proportionally from low-energy renovations while other consumers are rewarded beyond the savings they are actually causing. City planners may use these results to better understand and control where and when low-energy renovations occur in the city.

Olatz Terreros holds a master´s degree in Industrial Engineering from the Technical University of Bilbao (Spain). She has been working for the AIT (Austrian Institute of Technology) in the field of sustainable thermal energy systems since 2014. She is currently involved in national and international projects related to district heating networks in smart cities.

Comparison of methods for thermal storage sizing in district heating networks

MSc. Olatz Terreros, Dr. Ivar Baldvinsson, MSc. Daniele Basciotti, Dr. Ralf-Roman Schmidt. Austrian Institute of Technology GmbH, Energy Department, Giefinggasse 2, 1210 Vienna. olatz.terreros@ait.ac.at, tel. +43 50550 6359*

Keywords: District heating, thermal storage sizing, waste heat, solar thermal, design and operational optimisation, mixed-integer linear programming

District heating (DH) operators face currently several challenges associated to uncertain fuel prices and limited revenues from electricity in those cases with combined heat and power (CHP) production. The integration of decentralised heat sources in DH networks leads to a reduction in fuel consumption and improvement in security of supply. The national project *heat_portfolio* aims to develop technical basis for increasing the share of decentralised alternative heat sources with fluctuating generation and low temperature levels, particularly industrial waste heat, heat pumps and solar thermal energy, in DH networks. Therefore, an analysis on the hydraulic integration of thermal storages is carried out within the framework of the project.

Thermal storages are a key component in DH networks due to their potential for decoupling production and consumption over time, especially in combination with solar [1] or CHP plants [2,3]. The potential for peak load reduction through thermal storages in DH networks have also been investigated in several studies [4,5]. The sizing of thermal storages is based on different methods, such us engineering methods (e.g. design rules from manufacturers) or mathematical methods (e.g. analyses of producers and consumers profiles). This study introduces a simulation method which enables the assessment of optimal solutions for thermal storage sizing in representative DH networks in Austria. Multiple sets of rural and urban scenarios, characterised by different types and shares of decentralised renewable energy sources (such as industrial waste heat, solar thermal and heat pumps), are presented. An operation optimisation model based on the mixed integer linear programming (MILP) method provides the cost optimal operation strategy for every scenario, evaluating the most suitable storage size. Both short-term and long-term thermal storages are analysed. The model is implemented in Matlab and executed through the intlinprog solver.

The results obtained allow the comparison between engineering, mathematical and simulation methods for sizing a thermal storage in a DH network with decentralised alternative heat sources.
Thus, district heating systems have a certain reserve to improve their efficiency without significant investment in the heating systems of the existing households.

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Maarten Blommaert is post-doctoral researcher at KU Leuven University, and at EnergyVille, Belgium. He completed his PhD on the subject of optimal nuclear fusion reactor design at RWTH Aachen University (Germany) in collaboration with Forschungszentrum Jülich, Institute for Energy and Climate Research. Maarten's research interests lie in the development and application of optimal design methodologies for applications in the field of energy research.

Towards Adjoint-based Topology Optimization of Thermal Networks

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Keywords: Thermal networks, network optimization, adjoint method, topology optimization

The high infrastructure costs associated to thermal networks require a careful design to maximize profits and efficiency. Yet, given the many design variables involved – the many potential routes for network piping, the location and dimensions of heat storages, and network operation parameters – manual or intuitive designs will often lead to suboptimal solutions. As such, several computer aided tools have been considered in literature to assist the design of thermal network lay-outs by reformulating it as a mixed-integer program. These problems are then solved with combinatorial or meta-heuristic optimization algorithms. Unfortunately, the complexity of the optimization problems involved are governed by a multitude of discrete decision variables. This leads to a strong scaling of the computational cost with the problem-size. Starting from the nonlinear flow equations, the developers are then forced to simplify the equations by approximating them with linear relations and/or use aggregation techniques to reduce the problem size.

In this contribution, an alternative optimization approach is explored, inspired by the research field of structural topology optimization. There, continuous optimization methods based on so-called *adjoint* gradients are used to obtain a gradient calculation cost that is roughly independent of the number of design variables. The decision variables are then made discrete by strongly penalizing intermediate design variable values. Since this penalized problem per definition yields multiple local optima, numerical continuation techniques have to be used to avoid getting 'trapped' in practically valueless designs. Hereby, a smooth proxy for the final problem is solved first and gradually converted to the problem of interest.

As a first step, it is shown how numerical continuation schemes are able to increase the applicability of gradient-based continuous optimization algorithms for network optimization problems. This is illustrated for a simple flow network optimization problem where the goal is to minimize the pumping power, with an analytical solution readily available. Then, the novel optimization techniques are benchmarked with combinatorial optimization algorithms on a larger-scale network optimization problem. The adjoint-based algorithms are found to reduce computational costs significantly and are able to find improved configurations. Therefore, they may provide a valuable alternative to combinatorial optimization techniques in large-scale applications. Finally, the application of this new algorithm to the design of district heating networks is discussed.

Lars Grundahl PhD Fellow and part of the 4DH research center. Working with energy planning using GIS, mainly focused on heat planning

Heat demand mapping implications on energy planning

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Keywords: District heating, heat mapping, GIS, spatial analysis

This study investigates the potential effects heat demand mapping have on energy planning. Heat demand in buildings has often been seen as an accepted part of the energy system with the focus mainly on supplying the demand and possibly reducing it. The sector has been treated as an independent energy outlet almost without implications on the energy planning in other sectors, such as, electricity and transportation. District heating in some countries has led to cross-sectorial integration where heat and electricity is produced jointly. However, in a majority of countries there has been a low level of cross-sectorial integration.

Heat demand mapping occur in many variations with different levels of detail. Often the highest possible resolution of a heat map is restricted by the availability and access to data. Some maps have a high resolution with the single building as the smallest unit, whereas others summarize the heat demand in larger areas. The leads to different potentials in overall energy planning. However, it is found that both types of heat maps has the potential to interact with overall energy planning and both types are needed if a large scale implementation of cross-sectorial integration is to be accomplished.

- This study investigates and highlights some of the potential impacts heat demand mapping can have on energy planning as a whole and how heat demand mapping is a prerequisite for a cross-sectorial energy planning. It further investigates the different use cases depending on the resolution of the available mapping of heat demand.

Session 23: Low-temperature DH and buildings

Matthew Gentry is a post-doctoral researcher in plant growth and development at the Swedish University of Agricultural Sciences.

Session Keynote:

Local heat, Local Food: utilising district heating systems for urban farming

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Keywords: District heating, district heating networks, 4GDH, renewable energy, energy efficiency

By 2050, it is estimated that 70% of the world's population will live in urban areas. This growth in cities creates a demand for fresh produce to ensure a healthy population, produce that often has to travel a long way to reach the consumer, not only losing quality and nutrition along the way, but also requiring a significant fossil fuel cost for transportation and storage. The ingredients for a simple strawberry yoghurt, for example, will travel over 3,500 km before it reaches your plate. There is potential within District heating (DH) areas to move farming indoors and into the heart of the urban environment.

Municipalities in Sweden have recognised this need and have begun funding urban farm projects in Malmö and Stockholm, but production is restricted by the limitations of outdoor allotments and the Swedish winter. To overcome these obstacles, we need to shift production indoors to space efficient, vertical, hydroponic farming. Currently large scale indoor farming in greenhouses is done outside of the DH areas in Sweden, while within the DH areas in cities, high overhead costs prevent indoor hydroponic farming from being economically sustainable. Integrating low energy grow houses into the DH grid in Swedish cities to utilise sustainable heat would allow for hyper-local food production that would shift the energy cost from

The paper will present how hydroponic farming can be integrated in different building structures such as supermarkets, single houses, and public spaces to improve the local environment, availability of fresh food, and also the sparse consumption of energy resources of low temperature DH. Within the DH grid, Hydroponic farming can become an economical CO_2-neutral alternative to traditional greenhouse farming. By using less energy to transport and less energy to store, urban farming can become a competitive alternative to the current The study will be focused on the evaluation of barriers related to the following 4th generation DH characteristics: low temperature DH, low temperature tap hot water, low network losses, energy recycling from low temperature sources, integration with cooling and electricity grids, smaller pipe dimension.

Yasameen Al-Ameen is currently a PhD researcher in Civil Engineering at Nottingham Trent University. Her research interests lie in Geotechnical Engineering and Thermal Energy Storage. She is currently working on horizontal ground heat exchangers to be used for heating applications in buildings.

Utilizing waste materials from construction and industrial processes as potential ground storage mediums in HGHEs

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Keywords: Waste Material, Recycled, Energy, Heating, HGHEs

Horizontal ground heat exchanger systems (HGHEs) consists of straight, coil or slinky looped pipes, which are buried in a ground trench at a depth of approximately 1-2m. HGHEs offers a cost-effective and environmentally friendly alternative compared to other methods of heating, however, large shallow land areas are required for GHE pipe installations. This study investigates the possibility of using recycled waste materials from construction and industrial procedures in ground heat storage applications to decrease the soil volume required in HGHEs. The materials included a comparison of eight soils types (LB, BS, WS, GA, LI, MM and COM) to waste materials including: basalt rock, broken thermal bricks, crushed concrete, copper slag, mill-scale, iron (pellets and fine powder form) and rubber mulch. Physical and thermal properties of the materials including water content, density, thermal resistivity and thermal conductivity were determined. Experimental testing is also developed to simulate the heat storage and release processes of these recycled materials. This paper reports initial experimental results using various materials as heat storage materials stand alone and then when mixed with sand. In addition, the amount of heat transferred, the heat transfer rate, and the heat storage capacity are discussed. The obtained experimental results showed that mill-scale and copper slag were the two best materials compared to others for heat storage purposes. Further results on these two materials indicate that separating the materials into certain gradation sizes (<1.18, 1.18-2.36 and 2.36-5mm) further improved the heat storage capacity of the materials.

Michele Tunzi is a research associate at building energy research group, School of Civil and Building Engineering, Loughbrough Univesity, UK. His research interests are related to district heating technology, resilient communities and modelling of buildings and smart energy systems

Design and operation of a low-temperature heat networks in the UK

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Key words: community heat networks; low temperature district heating; domestic hot water preparation; Legionella prevention

By consuming 44% of the total UK primary energy (DECC 2013 and 2016) the heat market decarbonization became central in the political agenda and will be crucial to achieve the national emissions' targets. In line to the EU objectives for CO_2 emissions, UK has outlined its own domestic targets where a reduction of 50% and 80% to the 1990 carbon emissions level were set respectively for 2027 and 2050 (Fourth carbon budget, 2010) . Due to its flexibility and capacity of offering a faster and cheaper integration of renewable sources (UNEP, 2015), district heating (DH) was recognized as one of the key technologies in the transition towards a low carbon society for the UK heat market. In this direction, despite the actual share of approximately 2%, future forecasts highlight how the DH technology could achieve respectively 14% and 43% of the total UK heat demand in buildings in a cost effect way by 2030 and 2050 (DECC 2012 and 2013).

This paper presents results from a UK live project named SCENe (Sustainable Community Energy Network). It consists of 33 new housing development in Nottingham's Trent Basin and integrates a heat network, fuelled by ground source heat pumps (GSHPs), and a smart grid, embedding PV panels and batteries.

Focusing on heat side of the project, this study assessed different systems' response to varying operating temperature and their capability to comfortably meet the heat demand for space heating (SH) and domestic hot water (DHW). The benchmark average supply and return temperatures are 52/23 °C and detailed energy, economic and environmental analyses were implemented to define SH and DHW systems' performances. The evaluation comprises low-temperature radiators (LTRs) and underfloor heating (UFH) for SH demand; de-centralized flat stations for instantaneous DHW preparation.

Different supply temperatures, down to 35 °C, were also investigated, highlighting the impact on the heat elements and in particular the technical modification needed to safely deliver DHW without any risk related to Legionella. Due to the novelty of implementing low-temperature heat networks, the results illustrate detailed comparisons of different technical solutions and operating temperatures that can provide insightful information to designers, district heating operators and policy makers in the UK.

Dorte Skaarup Østergaard, Ph.D. student in the 4DH network. Performing dynamic simulation and evaluation of existing buildings. Analysing how to provide space heating for existing buildings with low-temperature district heating.

How to lower the district heating return temperature from historical apartment buildings

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Keywords: Low-temperature district heating, hydraulic radiators, thermostatic radiator valves, heating system control,

Lowering the return temperature in the district heating networks can be seen as a first step towards low-temperature district heating. Lower return temperatures will help ensure that existing district heating networks have the hydraulic capacity to allow a reduction of the supply temperature in the future. Additionally, lower return temperatures provide direct economic benefits through reduced heat losses in the network and more efficient heat production, without requiring significant investments in improved heating installations inside the buildings. In this study we investigated the possibility of lowering the district heating return temperature from a typical apartment building in the Copenhagen area. Firstly, the district heating substation and domestic hot water tanks in the building were examined, to correct errors in the central control system. Secondly the heating system was examined and improved, and all hydraulic radiators in the apartments were equipped with new electronic thermostats to improve heating system control. The study found that the district heating return temperature from the building in the winter time was lowered by 10 °C – from approximately 55 °C to 45 °C. Such temperature reduction can result in an economic benefit for the occupants of more than 700 Euro per year, as many Danish district heating companies provide an economic incentive for customers to lower the district heating return temperature.

Isabelle Best is in her third year of PhD studies at the Institute of Thermal Energy Engineering, Department of Solar and System Engineering at the University of Kassel, Germany. Her focus is on low-temperature district heating networks and solar heat integration. She is conducting system modelling and dynamic simulation for system design and optimization.

Low-temperature versus ultra-low temperature solar district heating for low heat density housing developments in Germany

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Keywords: Solar district heating, low linear heat density, ultra-low-temperature district heating

District heating reduces its competitiveness as the linear heat density of a district decreases, which limits the number of such projects. For a new housing development in Germany, two solar district heating concepts at different supply temperature levels are examined in terms of economic and efficiency aspects.

The planned new housing development "Zum Feldlager" (Kassel, Germany) is comprised of 131 buildings on a land area of 115,000 m². It will consist mainly of single family houses, resulting in a low building density (plot ratio of 0.25), which represents a heat demand sparse area with a very low linear heat density of around 500 kWh/m/yr (1.8 GJ/m/yr). In this case, a district heating system risks increased heat losses, making the heat distribution temperatures crucial. Two solar district heating concepts for the new housing development at low supply temperature (supply 70°C /return 40°C) and ultra-low supply temperature (supply 40°C /return 25°C) are examined.

In Denmark, the implementation of solar heating plants is characterized by large central ground-mounted solar thermal collector fields connected to the district heat network with seasonal storages, as demonstrated by various projects in recent years. The opposite case occurs in Germany. An expansive implementation of ground-mounted large-scale solar thermal collector fields in district heating systems is limited because of high land prices. Individual solar heating systems are currently dominating the German market.

The first concept analysed in this paper is similar to the Danish system in Braedstrup and in Crailsheim (Germany). The supply temperature ensures the preparation of domestic hot water and space heating via a low-temperature district heating network. The heat supply system consists of:

- A central large-scale, ground-mounted collector field
- A central heat pump supplemented by a buffer storage and an electric peak load heater
- A Borehole Thermal Energy Storage (BTES)
- And a district heating network of 70°C supply and 40°C return temperature

The second concept is a semi-decentralized concept based on an ultra-low-temperature district heating network. The supply temperature ensures space heating. Supplementary components for domestic hot water preparation are needed. This heat supply consists of:

- Distributed solar thermal systems (mounted on the building roofs) for domestic hot water preparation
- Uncovered solar thermal collector fields for thermal ground regeneration
- A central heat pump supplemented by a buffer storage and an electric peak load heater
- A BTES
- And a district heating network of 40°C supply and 25°C return temperature

Depending on the required heat distribution temperature level, the system design differs. The heat network design (pipe diameters, pump sizes) is adapted according to the distribution temperatures. The cost reduction due to economy of scale for a solar thermal collector field instead of distributed individual solar thermal units is taken into account. Regarding ground installations for solar thermal collectors, the price for land is also considered. The low-temperature heat supply concept will be compared to the ultra-low-temperature heat supply concept for low heat density housing developments in Germany taking following criteria into account: investment costs for heat supply components (individual versus central solar thermal system, heat pump, electric peak load heater, BTES, buffer storage), investment costs for the distribution infrastructure (material and burying costs for pipes), prices for land, operating costs, energy efficiency, and performance indicators.

Session 24: Future district heating production and systems

Luc Girardin joined the Industrial Process and Energy Systems Engineering (IPESE) group as a Scientist in April 2016.Prior to working at IPESE, he worked at BG Consulting Engineers in Geneva where he performed as a senior project engineer in Territorial Energy Planning.Luc Girardin holds a masters in mechanical engendering and PhD the Swiss Federal Institute of Technology in Lausanne.

Session Keynote:

Wide scope categorization of DHC systems for identification of emerging or disruptive technologies

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Keywords: Future district heating and cooling systems, Promising technology; Technology classification, Technology forecasting, Energy integration

The magnitude of the coming energy transition is a significant challenge: the shift from fossil fuel to low carbon fuel and the withdrawal from nuclear energy involve a shift from the centralized, common energy infrastructure to a decentralized and intermittent energy system. With 50% of the final energy consumption and 75% of the European population concentrated in urban areas, district heating and cooling (DHC) of the whole housing stock constitutes in itself a key sector in the energy transition.

The optimisation of distributed and renewable energy systems in buildings has shown that zero energy systems, using existing technologies, is within reach in the household sector where the thermal and electricity systems can support each other to increase renewable energy harvesting, co-generation and waste heat recovery. However, targeting energy autonomous systems at urban scale will require a step further in the development of the infrastructure and a closer look at emerging or disruptive technologies for advanced 4th Generation District Heating and Cooling network (4GDH) and the next generation of Heat Pumping (HP) renewable systems.

Looking at past and recent trends in DHC systems in Europe allows to highlight driving factors in favour of the development of the next generation of DHC and renewable HP systems. A classification of emerging or disruptive technologies is proposed starting from the definition of an analytic grid linking categorized technologies with their aptitude to enable or meet a list of identified strategic challenges. The impact of the promising DHC technologies in each category is assessed by the characterisation of their temperature level, energy capacity, exergy efficiency, technology readiness and time to production.

Finally, a set of good engineering practices for the integration of the promising DHC technologies are proposed in line with the design of future 100% renewable urban energy systems.

Julian Formhals field of work is the integration of borehole thermal energy storages into district heating systems. He has studied industrial/ mechanical engineering and Energy Science and Engineering at TU Darmstadt where he is now a PhD student at the Department of Geothermal Science and Technology. Furthermore he is a member of the Darmstadt Graduate School of Excellence Energy Science and Engineering.

Effects of the District Heating Supply Temperature Level on the Efficiency of Borehole Thermal Energy Storage Systems

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Keywords: Borehole thermal energy storage, solar district heating, co-simulation, grid flow temperature, 4GDH

The mismatch of high heat demand in winter and high solar heat supply in summer can be compensated by solar district heating (SDH) with borehole thermal energy storage (BTES) systems. Transient simulations are imperative to attain a good understanding of the system behaviour and to determine an optimized system design. In this context, the models of SDH systems and BTES pose very different requirements on their simulation environments. Taking this into account, a coupled simulation, in which both models can be realized in separate and specialized simulation environments becomes favourable. In the presented work, a SDH modelled in SimulationX (Modelica) and a BTES modelled in FEFLOW (Finite Element subsurface FLOW system) were simulated simultaneously and coupled via a TCP/IP connection. An adaptive communication step size control was implemented, to minimize both the error in transmitted energy and the computational effort.

Recent studies have shown that the performances of the single components of SDH with integrated BTES – and thus the whole system – strongly depend on design parameters like size, system architecture and control strategy. With the aforementioned method the strong interdependencies and the complex system behaviour can be simulated in high detail, which allows for a comprehensive analysis and subsequent identification of energetic inefficiencies. The temperature level of the district heating flow proves to be a parameter, which has a strong effect on the storage performance as well as on the system efficiency. A case study is carried out, to illustrate the difference in efficiency of BTES integrated into district heating grids with different flow temperatures. It analyses the potentials of an integration of a BTES into the existing district heating grid of the TU Darmstadt with and without a reduction of the grid flow temperature. During summer, a solar thermal collector field and buffer storages are used to the charge of the BTES system, whereas a heat pump was added for discharging it in winter.

The results support the general opinion that low district heating flow temperatures and respectively low return temperatures are crucial for an efficient operation of SDH systems with integrated BTES. The storage, the solar thermal collectors and the heat pump can be operated in an energetically much more favourable way. As a consequence it can be said that not only district heating systems profit from the integration of seasonal BTES, but the efficient operation of the storage itself is highly dependent on the shift to 4th generation district heating.

Somil Miglani works as a PhD student at the Chair of Building Physics at ETH Zurich, Switzerland. He holds a master's degree in Energy Science and Technology from ETH Zurich. His current research focusses on quantitative evaluation of renewable energy based standalone systems and district heating for residential buildings in urban neighborhoods

Optimization of solar and ground source district heating system using bottom-up technology models

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Keywords: District heating, GSHPs, Solar thermal, Optimization

Renewable energy based district heating systems are known for their relatively low CO_2 emissions as compared to the traditional fossil fuels based combined heat and power plants. Moreover, they can provide low temperature heat to buildings with lower heat demands increasing energy efficiency. Ground source heat pumps (GSHPs) are one of the potential renewable energy technologies that can be used for district heating. Large-scale GSHPs commonly use arrays of vertical Borehole heat Exchangers (BHEs) to extract low temperature heat from the ground. Continuous heat extraction can lead to ground cooling lowering the heat pump efficiency. The closely positioned BHEs which have limited ground volume to extract heat lower the ground temperature and thereby the heat pump efficiency further. The use of solar thermal collector arrays can deliver excess solar heat to the ground mainly during summer, recharging it to a normal state for the heating season in winter. This results in higher heat pump efficiency and overall seasonal performance of the system. Traditional approaches on the optimal design and operation of low temperature DH systems neglect the thermal behaviour of the BHEs/ground and the seasonal effects of solar recharging on ground temperature.

This study describes a methodology for the optimal design and operation of a solar and ground source DH system for a residential neighbourhood. Detailed thermal models of the BHEs and solar thermal collectors are integrated within an optimization framework. The operational constraints related to ground cooling, heat pump and solar regeneration are included in the model. The methodology uses a GIS based workflow to design the layout of the DH network. State of the art building energy simulation tools and DH network simulation models are used to calculate the net hourly heating demand for the entire neighbourhood. For the optimization of the design parameters of the system, a genetic algorithm (GA) which minimises the total annual costs and CO2 emissions is used. A mixed integer linear program (MILP) is nested within the GA which calculates the optimal operation of the system and the corresponding costs and CO2 emissions. Additional technologies such as daily hot water storage tank and natural gas boiler are included in the model to provide additional degrees of freedom and enable satisfaction of the heat demand at all times. The methodology is applied to a residential neighbourhood in Zurich with 170 buildings. Optimal design parameters for all technologies and optimal hourly operation of the system for the whole year are obtained. The thermal behaviour of the BHEs, the effects of solar regeneration on the ground temperature and seasonal performance of the system are analysed.

Jukka Aho is the co-founder and CEO of Leanheat. He has over 10 years' experience in working with district heating companies and housing associations. Under his leadership Leanheat has reached strong growth and is currently in use in 15000 apartments in Finland.

Radically new ways to affect heating energy demand – Case Peak Power Optimization

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Keywords: Demand response, load shifting, peak power optimization

For district heat companies peak power is very valuable – in Finland price of 1 MW of peak power is about €200 000. In densely populated areas (such as Wien, Austria), the cost can be as high as €1 million per MW of peak power. This is the reason why peak power reduction is receiving a lot of interest from all the district heat providers across Europe as it provides an effective option for lowering their costs. Although the total energy consumption is declining thanks to the higher energy efficiency of new buildings, the peak power demand remains the same. This trend is causing heat providers a higher fixed cost per unit of energy produced because they need the same production capacity that is used for a shorter amount of time.

Leanheat uses a dynamical model for each building to optimize heating control. The model is estimated from key measurements including apartment temperatures, supply water temperature and weather conditions. Using weather forecasts, the supply water program is optimized for the following days to minimize heating costs while preserving comfortable inside conditions.

Optimization is also used to reduce peak power consumption by adding extra cost for large values in the predicted power consumption. This makes the peak power lower by moving some amount of the energy consumption of high peaks before and after the peaks. In practice, buildings are heated before and after cold weather more than normally in order to require less energy during the cold period.

Leanheat Peak Power Optimization was piloted in 2016-2017 heating season in 200 sites, around 8 000 apartments in Finland:

- A single site saved 26% in peak power (outside temperature adjusted) without reduction in minimum inside temperature.
- The average peak power reduction was 17%, but there is a lot of room for further development.

Session 25: Smart Energy Systems

Leif Gustavsson has more than 30 years of research and work experience. His main field of research is systems analysis from a bottom-up perspective linked to sustainable development, especially building construction, energy efficiency, renewable energy, forestry and the interaction between these fields. The aim of his research is to increase understanding of how resource-and cost-efficient systems with low environmental impact can be designed, analyzed and implemented.

Session Keynote:

Synthesis of Swedish District Energy efficient building blocks and low temperature district heating

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Keywords: Energy efficient building, renewable energy supply, low temperature district heating, climate change impact

Major changes in the European building sector are essential to achieve the 2050 low-carbon and resource-efficient economy objectives of the European Union. There is great potential to build new energy-efficient building blocks using more resource-efficient renewable materials in combination with resource-efficient renewable energy supply systems. Such a development will contribute to achieve national energy and climatic goals as well as the overall aim for a sustainable development. In this project, we analyse cost and primary energy efficiency of heating new building blocks with low temperature district heating and compare such heating option with conventional district heating and electric-based heat pumps. The energy performances of the buildings are cost optimized and compared to those designed to fulfil the Swedish building code or passive house criteria. We analyse the impact of climate change on heating and cooling demands of buildings and explore how cooling demands may be avoided. The results can be basis for planning and designing new building blocks and their energy supply systems to reduce primary energy use and increase the use of renewable energy in the built environment. An increased use of renewable energy allocated to efficient-energy chains and energy-efficient buildings will help to achieve national energy as well as climate targets and the overarching objective of sustainable development.

Peter Sorknæs finished his PhD on bidding and operation strategies in future energy markets in 2015. The PhD focused on how small district heating plants are expected to operate and transits into future market-based smart energy systems based on renewable energy. The current work focuses on seasonal storages in district heating and future electricity markets.

Operational analysis of future renewable energy systems

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Keywords: Electricity markets, renewable energy, smart energy system

Future renewable energy systems are expected to be based largely on the electricity production from variable renewable energy source (RES), such as wind power and photovoltaic. This is a shift from the currently mostly fuel based electricity sources, especially with regards to the production cost structure of these units. The variable RES hence imposes a new paradigm within the markets for electricity, where currently many central electricity auctions are based on the marginal costs principle, where all participants are expected to bid into the market based on their own short-term marginal cost of producing the electricity, and all participants are settled according to the most expensive winning bid. In electricity systems based on consumption of fuels and a diverse portfolio of production units, this price principle has proven to be a useful approach to the daily operation of the electricity system. However, as more variable RES is being implemented into the electricity systems, a larger share of the electricity production will be provided by units with a short-term marginal production cost of zero or close to zero, which has already shown to reduce the price on the electricity auctions based on the marginal cost principle. This lowering of the market prices reduces the incentive for investing in electricity production units. This is especially a problem for CHP and power plants, which will most likely see a reduction in energy production, but will still be needed for their capacity in hours without or with low wind or solar energy. It is therefore uncertain whether this market principle will be useful going forward, especially for providing the correct incentive for investments. To estimate this, it is therefore relevant to estimate the future operation of units in the energy system in systems based on renewable energy. In this presentation, a method for estimating the challenge will be presented, where the operational characteristics of the different energy units will be analysed in more detail, with a focus on how this would affect the organisation of electricity markets. The method will take its departure in the energy system analyses tool EnergyPLAN, which has been used for a number of 100% renewable energy system scenarios for a number of countries. The scenarios presented in “IDA Energy Vision 2050” from 2015 are used as examples of future energy systems based on RES.

Hannes Poier is working at SOLID since 2012 in the R&D department. Besides coordinating and supporting several R&D projects he is involved in feasibility studies referred to Solar District Heating. He has published several papers at national and international conferences.

BIG SOLAR GRAZ – Results of a techno-economic feasibility for solar district heating

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Keywords: Solar district heating; large-scale solar thermal system; seasonal pit storage

Current heat generation for district heating (DH) in Graz, Austria is primarily from waste heat of fossil-fired combined heat and power (CHP) plants. Due to the massive drop in electricity prices on the European electricity market, full operation of CHP plants is not economically sound anymore and operating hours are being reduced. This development poses a serious threat especially to cities such as Graz, that are highly dependent on waste heat of CHP plants for DH. Recently the operator of the CHP plants in Graz announced their closure in 2020. Almost 80% (400 MW) of the overall heat production has to be replaced.

The research focus of this paper is to analyze the technical and economic potential of integrating a centralized large-scale solar thermal system including seasonal pit storage and absorption heat pumps for district heating (DH) in Graz, Austria. Therefore, the purpose of the research is to determine the techno-economic optimum size of such a solar system that can be integrated into the district heating system. The study includes the design of a technical concept using dynamic simulation, an investigation of appropriate land for collectors and the storage and an economic cost evaluation of its realization.

The results indicate a techno-economic optimum of the system at a collector field size of 450,000 m² providing 20% solar fraction of the overall heat demand. Especially, the use of a series of absorption heat pumps with a total capacity of 96 MW is a key element in the system in order to accelerate the cooling down process of the seasonal pit storage and enables a higher solar fraction.

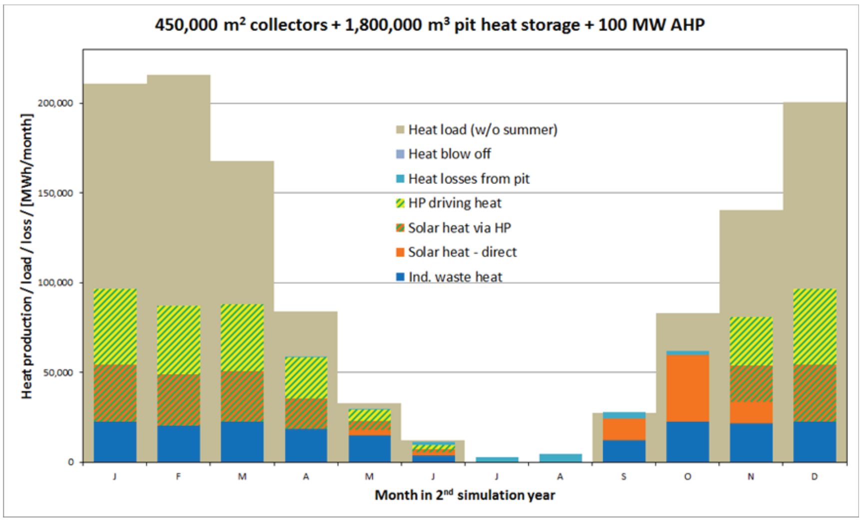

Fig. 1 Monthly heat production for DH in Graz by the techno-economic optimum scenario of the BIG Solar concept

Sarah Bourgarel is a M.Sc. student in environmental engineering specialized in sustainable building and energy systems, Ecole Polytechnique Fédérale de Lausanne (EPFL, Switzerland); master thesis done at the Swiss Federal Laboratories of materials and Technology (EMPA, Switzerland).

Innovative heat energy supply concepts for multi-family houses: real case evaluation through synergies between simulation and optimization modelling

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Keywords: Heat pump, simulation, optimization, CO_2 borehole heat exchanger, borehole regeneration, free cooling.

Buildings are responsible for the largest share of the energy consumption in Europe, thus there is an aim towards substantial energy savings in this sector. In Switzerland, with the context of energy transition, there is keen interest in new sustainable and efficient technologies for building energy supply. In this frame, 8 multi-family buildings were built in Zurich (Switzerland) with innovative energy supply systems which mainly use renewable resources (solar and ground heat). The main components of the energy systems include a heat pump (HP); a borehole heat exchanger as a source for the heat pump and for free-cooling; and solar photovoltaic (PV) and hybrid photovoltaic (PVT) panels. The first system variant which is considered as the base case for comparison includes a HP with a borehole heat exchanger. The second system variant is equipped with a CO_2 based borehole heat exchanger. The third system variant uses heat from PVT panels for borehole regeneration. Comprehensive monitoring of the energy supply systems will be performed in relation to system electricity consumption and production.

This paper aims to assess the energy, cost and greenhouse gas emissions of the different energy system variants through synergetic simulation and optimization. Models of the different variant systems are simulated with the same generic energy demand and external conditions, allowing for comparison of the energy efficiency and performance of the different systems. Hourly monitoring data is used for calibration of and comparison with simulation model results. The results will be used to propose improvements and identify the best operation strategy for the systems, through minimization of non-renewable energy consumption, cost and environmental impacts.

Mathieu Vallée received a M.Sc. in artificial intelligence from ENSTA-ParisTech and Université Paris-Sorbonne, and a Ph.D. in computer science in 2009. His research covers software architectures and algorithms for the smart management of physical devices, applied to several domains (home appliances, manufacturing, district energy systems). He is the co-author of more than 20 papers in conferences and journals.

Using power-to-heat for flexibility at district level: an overview of use cases

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Keywords: Smart Energy Systems, District Energy, Power-to-Heat, District Heating, Use cases

Using power-to-heat devices as a means to improve flexibility at the district level is a recent idea consistent with the Smart Energy Systems vision [1]. Indeed, while converting power to heat is generally seen as inefficient, it could be beneficial at the system level when the converted power yields a surplus production from renewables. In this case, well-managed power-to-heat devices can provide flexibility services to the grid and improve its stability, while producing thermal energy and storing it at relatively low cost. This strategy could result in an efficient alternative to expensive upgrades to the grid infrastructures and to the systematic deployment of electric storage solutions.

However, the practical efficiency of such a strategy is strongly dependent on the dynamic operational optimisation at district-level. In particular, installing renewable power production, power-to-heat equipment and thermal storage will result in a viable economic model only if they are managed together in the most optimal way. On the contrary, a sub-optimal control could incur additional expenses, lower efficiency, and impact the grid in an unexpected manner. Additionally, a key issue is that production and storage equipments are often owned by different operators at the district level - and their cooperation is inevitable for an optimized energy delivery scheme.

In the context of the PENTAGON project [2], a multi-vector flexibility management platform is proposed as one of the key enablers for local operators to participate in such a district energy optimisation. Using the platform, local district energy operators, e.g. district heating operators, smart grid operators, and individual building operators, will be able to coordinate their energy management strategies in order to not only optimise renewable energy use at district level, but also to provide flexibility services at the grid level. In the proposed talk, we briefly introduce the multi-vector flexibility management platform, and we focus on the validation approach in the project.

In order to provide a representative assessment of the operational feasibility and benefits, this validation approach has two facets: (1) running 'live' demonstration scenarios on small-scale experimental facilities, and (2) assessing the benefits at the district and distribution grid levels, using a full-featured simulation platform. To describe the validation approach, we present some of the use case scenarios we investigated as a part of the project, covering aspects such as building-level/district-level power-to-heat, centralised/decentralised optimisation, and optimization objective functions such as maximising self-consumption or minimizing peaks. For each use case, we provide details on the relevant variables and indicators, and we would like to invite the researchers to comment on the proposed scenarios.

Session 26: Future district heating production and systems

Georg K. Schuchardt, Head R&D at FFI Fernwaeme Forschungsinstitut – District Heating research Institute and former PhD student in mechanical engineering on ”Optimization of Small Scale DH networks”. Today’s work focus on (i) transformation and optimization of DH infrastructures and energy systems and future perspectives for DH

Session Keynote:

Development of an empirical calculation procedure for determining the thermal conductivity and heat losses of pre-insulated twin pipe systems

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Keywords: Pre-insulated twin pipe systems, heat losses, stresses, statics, standardization, simulation

Pre-insulated twin pipe systems (PTPS) for heat distribution offer advantages for heat supply companies. Utilizing these piping system, trench dimensions for heat supply systems of District Heating (DH) networks might be reduced. This reduces costs in civil engineering. In addition, heat losses of the DH network may be reduced, decreasing operational costs of these systems. On the other hand, operational heat losses and theoretical heat losses of PTPS significantly differ in many cases. This may inhibit the application of this technology in DH networks.
Against this background, a standard measurement procedure of thermal properties of PTPS shall be developed, validated and tested at FFI. Within this context, preliminary tests are done in a climate chamber. These tests will be based on standard measurement procedures for single pipe systems described in EN ISO 8497 and modified for PTPS. In parallel, numerical simulations on heat losses will be done at IGTH and iteratively fitted to data generated from measurements.
In a second step, numerical simulations on stresses occurring due to operational temperatures within PTPS are done. Internal stresses due to temperature gradients within the PTPS, as well as external stresses due to interactions of the PTPS with the bedding material/ ground will be examined. In addition, interactions of bedding materials, operational conditions and heat losses in situ will be assessed.
First results obtained will be presented in this paper. Focus of this paper will be on the development of a standard measurement procedure for thermal properties of PTPS, as well as results of numerical calculations regarding heat losses of these systems. One goal of this project funded by the “BMWi – Federal Ministry for Economic Affairs and Energy”, is to discuss and mirror project results in order to modify existing standards, e.g. EN 15698, EN 15632 and EN 13941. Defining quality standards for PTPS that are verified in a standardized measurement procedure for this technology, will increase its acceptance in the DH sector. This supports small and medium sized enterprises (SME) utilizing and producing these systems.

Joseph Maria Jebamalai is a Ph.D. researcher at Ghent University, Belgium. Previously, Joseph worked as a researcher on solar thermal power plants at Fraunhofer, Germany. He graduated with honors from KTH Royal Institute of Technology, Sweden in Sustainable Energy Engineering. His area of interest includes district heating & cooling networks and thermal storage. He is currently involved with the HeatNet EU project.

4DHC technology guidance and transition strategies for Northwest Europe

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Keywords: 4th generation District Heating and Cooling (4DHC), HeatNet, technology guidance, transition roadmaps, pilot projects, Northwest Europe

Currently, District Heating and Cooling (DHC) is most widely used in North, Central and Eastern Europe, with market shares often greater than 50%, in contrast with Northwest Europe (NWE) where the average share is only 5%. Many advanced countries are now moving to 4th Generation DHC (4DHC), while NWE is currently 'locked-in' to the current heating sector norms (i.e. individual fossil fuel systems) and therefore find it difficult to 'un-lock' the many socio-economic benefits of 4DHC.

HeatNet is an EU project that aims for 4DHC technology guidance and transition strategies for the integration of this technology in the NWE energy system. This project helps NWE DHC systems by leading the way in this sector and pioneering this best practice in the region. Developing a pathway to 4DHC leads to the improvement of current heating systems and provides an opportunity to shift towards advanced energy systems. HeatNet project partner Ghent University has the responsibility to develop 4DHC technology guidance.

The HeatNet project will address the challenge of reducing CO_2 emissions in NWE by creating an integrated NWE approach for supply of renewable and low carbon heat (incl. waste heat) to residential and commercial buildings, to be developed and tested in 6 local District Heating and Cooling (DHC) networks in UK, Ireland, Belgium, France, and the Netherlands.

The main outputs of HeatNet are to develop innovative tools (HeatNet Model) and transition roadmaps specific to the needs of the heating sector in NWE, and use the exemplar pilot projects to test and re-evaluate such HeatNet tools, resulting in visible and measurable results. The concept will also require the development of new institutional and organizational frameworks. The project will result in 15,000t CO2 saved per annum at its end.

Marcin Bugaj specializes in hybrid energy systems of buildings and poligeneration from renewable energy, assistant in the Department of Thermodynamics, MEiL PW Faculty, head of the Laboratory of Sustainable Energy Systems, employee of the Research Center of the Polish Academy of Sciences "Energy Conversion Renewable Sources

Assessment of primary energy savings through implementation of solar and heat pump hybrid in Warsaw district heating system

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Keywords: CHP, 4DH, Renewable energy, Heat pump, TRNSYS, DHW, PVT, Hybrid systems, Solar energy

The Warsaw district heating system is the largest one in the European Union and it is mainly based on coal-fueled CHP. To ensure reduction of the primary energy usage renewable energy sources introduction to DH is needed. The solar and heat pump system combined with the district heating substation could be the solution suitable for Polish climatic conditions. To determine the benefits of this concept, the short field test and the long term TRNSYS simulations have been conducted. Research site have been located in the building of Warsaw University of Technology standing in the one of the main district of the capital city. Analysis of the PV/T and the solar collectors impact on the ground heat pump seasonal performance factor has been done. Authors have considered the bivalent parallel and partial parallel operation modes of the heat pump and the district heating substation. The contribution of a two-way electric meter usage in the primary energy consumption savings has been evaluated. The results showed that only solar assisted ground heat pump can be competitive heat source in relation to the Warsaw district heating system. More than value of 4.4 of seasonal performance factor was achieved. Thanks to the new legislation, which allows the use of the national power grid as a seasonal electric energy storage facility, additional reduction in the primary energy usage was obtained. The study confirmed technical possibilities and proper operation of the district heating substations and ground heat pump connected in series. The results presented in this paper have measurable meaning for the primary energy reduction in the Warsaw district heating system. They allow to estimate impact of the takeover of the domestic hot water supply function by the solar and heat pump system in the DH and the energy efficiency improvement thanks to heat losses diminution during summer periods.

Fabian Bühler is a PhD fellow at the section of Thermal Energy Systems at the Technical University of Denmark. His research is centred around the thermodynamic analysis of industrial processes and energy efficiency in the industry.

Spatiotemporal analysis of industrial excess heat as a resource for district heating in Denmark

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Keywords: Excess heat, District heat, demand profiles, supply profiles, GIS, Heat pump, Cost analysis

Industrial excess heat could be utilised for district heating and thus replace existing expensive or environmentally unfriendly technologies. Recent works analysed the distribution of excess heat by temperature intervals and their geographical distribution relative to district heating consumers. Based on these analyses, the available excess heat was compared with district heating demand on an annual level. The results have shown that industrial excess heat from thermal processes can be used to supply 5.1% of the Danish district heating demand. Around half of that potential can be supplied directly, while for the other half a heat pump is needed. This potential needs to be analysed further to investigate the relation of the individual industrial locations to the district heating networks. A more detailed analysis is thus required, which takes into account the temporal match between industries and district heating, as well as the costs for implementation and operation of the systems. Therefore, the aim of this work is to investigate and assess the suitability of using excess heat from specific industries to provide district heat.

The current work takes the mapping of industrial excess heat sources and district heating networks in Denmark as a point of departure. A spatial analysis of available excess heat and district heating demand was conducted in the previous work, to match individual industrial sites to district heating areas. For each of the considered industries, the present work introduces load profiles and compares them to demand profiles of district heating areas composed of residential, public and service buildings. For each match the investment and operation costs were found to determine the annuitized cost of the delivered heat. The assessment considered the connection costs, based on the location of the industry and nearest district heating network, as well as investment and operation costs of the required heat recovery equipment (heat pumps or heat exchangers). By aggregating the individual matches over industrial sectors, recommendations on preferable industries and heating areas for excess heat utilization can be made.

The results show the industries that can contribute the most to district heating based on the properties of the excess heat source (time profiles, location, excess heat temperature and amount) and the costs for utilizing the excess heat. Furthermore, the distribution of annuitized heating costs, as well as type and size of heat recovery equipment are shown. The largest share of district heat from industrial excess heat could be provided from oil refineries, and the production of cement. When accounting for the feasibility of delivering heat to district heating networks, industries in the pulp & paper, building material and food sector should be targeted. These industries obtain the lowest average unit costs for the delivered heat, as only a few heat pumps with high average COPs are required to recover the excess heat.

Ingo Leusbrock is head of the group „On-Grid Energy Supply and Systems Analysis“ at AEE INTEC in Gleisdorf, Austria. The work of his group focusses on optimization of existing district heating systems and development of new approaches for urban energy systems, centered on district heating and cooling. The use and further development of simulation tools is vital for these tasks.

Tools and methods for modelling district heating systems: A comprehensive comparison

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Keywords: District Heating; Modelling, 4GDH

Energy systems are currently undergoing fundamental changes towards increased shares of renewable energy sources. Previous research has identified district heating and cooling and related infrastructures such as thermal storage as key technologies in this context [1,2]. For district heating networks, these trends lead to new challenges but also opportunities, e.g. to offer energy storage capacity and demand side management potential for the electric grid. To design our future district heating systems and to improve our current ones, we need simulation and modelling tools which can account for future challenges such as multiple heat sources, prosumers, dynamic events and model predictive control [1]. Currently, tools and methods are available for (quasi) steady-state simulations as well as dynamic simulation [3]. As reported in recent studies [3,4], more efforts are needed to explore, evaluate and utilize the full benefit of innovative district energy systems, including district heating systems. This requires sophisticated and reliable quantitative background information. It is argued that a shift to fully dynamic models and sophisticated control design would be supportive [4]. However, there is no comparative study available which looks at the broader perspective and (i) states the challenges for simulation tools with future systems and (ii) compares fully dynamic thermo-hydraulic simulation tools with quasi steady-state tools. This study addresses these gaps. Apart from this, we compare procedural modeling approaches with equation based approaches and give an evaluation of which tools, software and approaches are preferable for various circumstances and tasks (f.i. co-simulation, optimization, multi-domain modelling, etc.).This paper presents a comparison of the following tools: IDA ICE, Dymola, STANET and TRNSYS. IDA ICE

is a commercial software that uses the modelling language called Neutral Model Format. Dymola is a commercial modelling and simulation environment based on the open Modelica modeling language. STANET is a program package for stationary and dynamic calculation of utility networks. TRNSYS is a commercial Fortran-based energy modelling program. These tools were compared and validated by measurements for a single pipe element. The experimental set-up was rigged at the Thermodynamics Laboratory of the University of Liege [5]. In order to compare these tools in regards to future simulation requirements (e.g., for new 4th generation district heating systems), a fictional use-case based on an actual planned district heating network was defined. This case was adopted to test among others (i) the integration of decentralized production units, (ii) temperature wave propagations, (iii) zero and reverse flow states, (iv) pressure distributions in each of the tools and (v) maximum number of nodes, which can be calculated in each of the tools. The results of the tools are compared and evaluated in terms of computational and numerical parameters (e.g. calculation time) as well as technical results (e.g., flow rates, peak pressure, energy losses). Results show that all evaluated tools deliver trustworthy and reliable results for simple events and configurations with a limited degree of dynamics in the boundary conditions. First tests for more sophisticated tasks show that (i) with specific-domain tools (STANET) it can be cumbersome to adopt existing and new models whereas (ii) multi-domain tools (Dymola, IDA ICE, TRNSYS) already have different sophisticated libraries for district heating modelling.

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Session 27: Energy Planning and planning tools

Urban Persson's general research interest is the development of tools and methods whereby to assess and plan future deployment of competitive and energy efficient district heating and cooling systems in a European context. Special interests involve heat and cold demands, assessments of excess heat and renewable heat resource availabilities, heat distribution investment economics, and spatial data analysis in geographical information systems

Session Keynote:

Heat Roadmap Europe: Heat distribution costs

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Keywords: District heating, distribution capital cost, heat demand density, plot ratio, GIS, EU

This work presents the second step in the development of a comprehensive distribution capital cost model for assessing specific investment costs for district heating systems in a European context. The first step, a study reported in [1] (Persson and Werner, 2011), included the theoretical reformulation of linear heat density, necessary to perform systematic feasibility analyses at novel district heating locations, and the model being applied to 1703 heterogeneously shaped Urban Audit city districts in 83 cities (in France, Belgium, the Netherlands, and Germany). This first study identified a clear three-fold directly feasible expansion possibility from current deployment levels of district heating in these cities. For a broader conclusion, however, it was recognised that the generality of the results would be improved by using (*i*) a larger selection of study objects, and (*ii*) a uniform and homogenous spatial unit for land area. To meet these two conditions, this paper reports on the progressive work within the Heat Roadmap Europe project (during the years from 2012 until present), to coherently distribute, by an ever-increasing level of raster resolution, residential and service-sector heat demands spatially. By definition, such distributions depict (heat) demand density why this paper also develops the original conceptual framework from step one by introducing this concept explicitly. Study results and findings are presented in analogy with step one, i.e. cumulative combinations of marginal distribution capital costs and the corresponding heat markets shares – with the significant difference of national heat markets (not urban) here being the reference. Among main study outputs are the theoretical and technical possibilities to identify demand and cost levels for district heating opportunities at a resolution of one hectare for the European continent. In this paper, these opportunities are aggregated and reported as national EU Member State averages, while the full reward of these possibilities – for the swift transition to a more energy efficient heat supply to many European buildings – is available mainly through interactive web map services and other web-based interfaces storing or relating to the study output layers.

[1] Persson U, Werner S. Heat distribution and the future competitiveness of district heating. Applied Energy. 2011;88(3):568-76.

Steffen Nielsen. Both authors' works as part of the Sustainable Energy Planning Group, Department of Planning at Aalborg University. Steffen Nielsens specializes in geographic analyses combined with energy system planning. His previous work is mainly related to the expansion of district heating systems and nets zero energy buildings. Iva Ridjan Skov is an expert in the role of power-to-gas technologies in smart energy systems.

Geographic Placement of Power to Gas Plants in Denmark

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Keywords: GIS, Power-to-gas, Investment analysis, Denmark

In transitioning to 100% renewable energy system storing electricity becomes a focal point, as the resource flexibility is lost and design of energy system needs to provide flexibility and balancing options to integrate intermittent renewable resources. Using technologies such as power-to-gas therefore offers an opportunity to store electricity into chemical form as a long-term storage option. This paper investigates potential location for power-to-gas plants in Denmark, specifically focusing on biogas upgrade and CO_2 methanation path. The locations of the plants are determined by carbon source potential, proximity of the grid and costs of grid transmission and investment costs of the technology itself.

By combining these types of data, it is possible to identify the investment costs of the power-to-gas plants in different areas in Denmark. In the analysis, power-to-gas plants with an annual gas production of 60 GWh are analysed. The findings of this analysis indicates that the biogas upgrade paths, at the present cost level, is the cheapest path of the two, but due to the relatively small number of biogas plants in Denmark, is limited to around 60 plants with the chosen plant size. CO_2 methanation is on the other hand more costly, but has a larger potential of around 800 plants.

As the analysis is based on the current sources for biogas and CO_2, it is important to note that the potential for CO_2 methanation plants can be expected to diminish in the future as more renewable energy is introduced, lowering the need for thermal energy producers, while biogas production could be expected to increase in the future. Yet, this analysis shows a good indication of the extent of the power-to-gas resources in Denmark.

Ivan Dochev and Hannes Seller are Masters of Science in Urban Planning (Dochev) and Ressource Efficiency (Seller), currently starting PhDs in the field of Infrastructure Planning at the HafenCity University Hamburg. The focus of their research is building energy-efficiency, GIS and decision support for the planning of heating grids.

Hypothetical heating grid modelling with graph theory. A decision support tool for planning

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Keywords: Heating Grids, Heat Demand Cadastres, Linear Heat Density, GIS, Graph Theory

The challenge of meeting CO2 emission goals has led to the development of a variety of technologies and practices but also to the "re-discovery" and intensified research into some more traditional ones – for example district heating grids. Although a relatively old concept, heating grids are currently gaining increased attention mainly due to their flexibility which is the much needed element to complement the introduction of renewable energy in the heating sector. Nevertheless, in Germany, heating grids are not as developed, as for example in Denmark, and present a future opportunity.

Many cities and municipalities in Germany now prepare "heat demand cadastres" (maps depicting building characteristics connected with energy and more concrete – with heat) in order to support two main aspects of heat planning – building refurbishment and heating grids. These cadastres, when made public, are seen as decision support tools for public as well as private initiatives. However, whereas depicting heat demand for buildings already supports building refurbishment strategies and policies, it can be insufficient for supporting heating grid planning. The latter is more complicated since estimating potential for heating grids in urban space requires not only information on individual buildings, but also on the urban fabric – distances between buildings, plot borders and ownership rights, street layout (since the supply infrastructure tends to traverse public areas) and others.

We present on-going research into the topic of heat demand cadastres aimed specifically at supporting heating grid planning. The conceptual approach is to depict not only building energetic properties, but also heat densities and more concrete linear heat density (*Wärmebelegungsdichte* in German). Linear heat density is defined as the ratio between the total heat demand of a certain building stock and the length of the grid needed to supply it. It is one of the main parameters that influence the economic viability of heating grids and therefore a main estimator of potential.

In order to compute it, we make use of GIS-based "hypothetical heating grids" – geometric representations of heating grids, the exact route of which in urban space may not necessarily be achievable, but the total length of which is very plausible. These hypothetical grids connect small groups of neighbouring buildings, grouped by a mutual street front (overlooking the same street) and are thus seen more as parts of potential grids rather than individual grids. In this way an urban territory can be divided into the small building groups, each with a small hypothetical grid connecting each building and computed linear heat density. Depicting this in a map gives a very good overview of heating grid potential and thus provides decision support. The method to generate the hypothetical heating grids is based on graph theory, making use of weighted graphs to compute both an optimal and a semi-optimal (but more plausible) graph representation of a heating grid.

Since the grouping of buildings is currently fixed according to the described logic, which is a constraint to the map user, we aim to add a more dynamic component in the future – being able to calculate and visualize a hypothetical heating grid and its linear heat density "on the fly" for an arbitrarily chosen group of buildings.

Haichao Wang obtained double doctoral degrees, Ph. D from Harbin Institute of Technology China, in Heating, Ventilating and Air Conditioning (HVAC) engineering; D.Sc from Aalto University Finland, in energy technology. His research is mainly focuses in the combined heat and power and district heating, modelling and optimization of complex energy systems including renewable energy source and energy storages.

Planning and optimizing heat production for a district heating system with Chinese demand profiles

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Keywords: District heating (DH); Thermal energy storage (TES); Heat production; Optimization

China is now undergoing a fast urbanization, increasing the total district heating (DH) demand. DH systems are gradually expanded and the size of individual system is dramatically growing. At the end of year 2012, the total DH production of China was over 2×10^7 TJ, and the production increment per year is about 2×10^6 TJ, this means about 10% increasing per year. Meanwhile, the design, planning, operation and management (O&M), as well as control technologies are developing slowly, which lead to a large extent of mismatch between DH demands and supplies. In addition, the thermal energy storage (TES) has still not been widely used. One reason is that people are not realized about the importance of TES on the O&M of DH system and the reduction in the fuel cost as well as the potential to increase the total income.

It is necessary to mention that most of the DH system only cover the space heating in China and this means DH system only operate in part time of the year called a heating season when outdoor temperature is lower than 5°C. However, in the beginning and ending period of a heating season, temperatures usually are greater than 5°C during the day, in these cases, DH system will not stop running, but need to maintain a base load as of outdoor temperature at 5°C. This is the way that a Chinese DH system plans the operation before a heating season, but this can lead to a waste of heat when outdoor temperature is higher than 5°C, and result in uncomfortable high room temperatures. According to the literature review, this problem can be solved by utilizing a TES.

In this paper we first build a model for a Chinese traditional DH system with two coal-fired heat only boilers (HOB) as base plant and a gas-fired boiler for peak shaving plant using EnergyPRO software. Then we study the influences of two different heat demand profiles based on Chinese traditional method mentioned above and the degree day method on the operation of the DH system. Secondly, we will study the influence of a TES on the operation of the DH system and determine the optimal capacity of the TES considering a discounted annual cost of the TES investment. Thirdly, the environment impact of the DH system with/without TES will be evaluated. This study will help people realize the importance of optimizing the energy planning and operation of the TES assisted DH system.

Session 28: Organisation, ownership and institutions

Marie Münster is senior researcher at Technical University of Denmark. She has 16 years of experience working with energy system modelling and renewable energy technologies from both private consulting and research. Her field of research is energy system analysis of energy technologies with focus on integrated energy systems (power, heat, gas and transport).

Session Keynote:

The Danish district heating regulation model in a comparative perspective - and possible impacts of changing it

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Keywords: Supply sector, district heating and cooling, ownership, regulation

The Danish district heating sector is unique in terms of the coverage which includes around 60% of the Danish houses and around 45% of the heat consumption. Due to a concerted effort, average district heating prices have been kept low simultaneously with a steady increase in the share of renewable district heating and a contribution to the development of technologies which form part of the substantial Danish export of energy technologies. These results have been achieved through a regulatory framework, which includes mandatory heat planning in municipalities, division of natural gas and district heating areas, priority of CHP, mandatory connection if socio-economically feasible, non-profit regulation of utilities and access to cheap municipality backed loans. The Danish results can be considered positive when compared with district heating in countries with a different organisational and regulatory set-up such as Germany and Sweden.

More than 400 district heating grids deliver district heating to the Danish consumers at very different prices, indicating a potential for efficiency improvements in some grids. Currently, the Danish Government is considering changing the regulation to increase the economic efficiency of the sector. The suggested regulation will introduce incentive regulation (benchmarking) and abolish some of the regulatory measures such as mandatory connection and priority of CHP. This paper asks the question whether the changes will achieve the expected efficiency gains without resulting in a poorer heat supply in terms of consumer prices, security of supply and greenhouse gas emissions. The answer will include the experience from the district heating sector in Germany and Sweden.

Data from the district heating sector in the three countries will be analyzed. The analysis will focus on the links between ownership, size, prices and emissions. Results from Denmark and Sweden e.g. show that contrary to some beliefs, large district heating companies do not necessarily deliver heat at the lowest prices, whereas the opposite is the case in Germany. An outcome of analysis will be recommendations for the future Danish regulation of district heating, as well as for regulation in other European countries.

Søren Djørup and Jakob Zinck Thellufsen are both appointed in the Sustainable Energy Planning Research Group at Aalborg University, and work in the field of energy system analysis, energy economics and energy politics.

Market Structures and Smart Energy Systems

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Keywords: Smart energy systems, energy economics, market design, renewable energy systems

The transition from fossil fuel based energy to smart energy systems based on variable renewable energy sources significantly changes the layout of the energy system. In current fossil fuel based energy systems, the primary electricity producing units are large scale power plants and combined heat and power plants, supplemented with some renewable energy. The heating demand is covered through individual fuel boilers, electric boilers or district heating. Thus, the flexibility in relation to supplying the demand is related to fuel consumption. The smart energy systems primary energy producing units are technologies that utilise variable renewable energy; wind turbines, photovoltaics, solar thermal, and so on. Through the utilisation of system integration, these resources are used throughout the energy system, both for supplying heat and electricity, but also to fulfil transport and industry demands. Due to the fluctuation in the production, the primary flexibility of the smart energy system is no longer found through the fuel, but instead through the system design.

At the same time, the primary energy production itself is undergoing a substitution of fuels with physical capital.

This study therefore argues that smart energy systems require different markets than the current traditional energy system. Currently, electricity markets are in most cases based on a short term marginal cost approach. This makes sense in a fuel based energy systems where the supply costs are more closely linked to the short term marginal costs, for instance fuel costs.

With the introduction of large quantities of variable renewable energy sources, two critical issues arise in comparison to current market structures.

1) There is no correlation between production and demand. Thus, the technology might produce in hours with no demand, and demand might exist in hours with no production.
2) There are no fuel costs associated with variable renewable energy sources. In other words, there are no to very little short term marginal costs.

This means that the costs of operating an energy system with large quantities of variable renewable energy are associated to the system design needed to accommodate the variable renewable energy. Thus, consumer prices should no longer primarily reflect the fuel costs of energy production only, but instead reflect the investment in the necessary technologies to integrate as much variable renewable energy as possible.

Using energy systems analysis, the study investigates scenarios with large shares of variable renewable energy and the use of a smart energy system design. This analysis identifies the system operation costs at every hour of the year. The study investigates how system costs and consumer prices relate and deviates under current and alternative market structures.

Daniel E. Vilhjálmsson and Miguel are recent graduates from the Sustainable Energy Planning and Management program at Aalborg University. During their studies they have done various projects that have focused on energy related issues in emerging and developing countries.

Identification of potentials and barriers for developing district cooling in Lima, Peru

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Keywords: District cooling; Lima, Peru; energy mapping; energy efficiency; energy policy

This paper focuses on uncovering the implications of developing district cooling in Lima's financial district, San Isidro, under the current Peruvian context of emerging energy efficiency and sustainable construction initiatives. This district was selected as area of study due to the high density of commercial and business buildings prevalently using centralized air conditioning systems, corresponding to high energy demand for space cooling. Under this context, our analysis aims at addressing the following research question: "Is the provision of district cooling in commercial sector buildings in Lima's financial district a viable alternative under the current context of Peru's energy efficiency goals? "

For this purpose, we present an exploratory case study in which we (i) engage with local actors through in-depth interviews to identify the main institutional barriers and opportunities under the current framework conditions; (ii) conduct a mapping of the energy demand to identify the main hotspots for space cooling; (iii) test, through modelling, the techno-economic viability of district cooling scenarios against the business-as-usual case with air conditioning; and (iv) identify the socio-economic benefits of potential district cooling developments.

The implications of these analyses point towards several institutional and technical barriers to successfully implementing district cooling in Lima. In this sense, we argue that San Isidro district proves to be a critical case; where the viability of district cooling at large for other Peruvian cities can be tested.

Richard Büchele joined the Energy Economics Group in 2014. He holds a master's degree in power engineering with focus on energy economics and energy supply. In his master's thesis he developed a cost minimizing investment and dispatch model. After working on the comprehensive assessment for CHP and efficient DH in Austria he now works in EU projects fostering renewable energy sources in heating and cooling

Favourable policy frameworks for renewable heating and district heating – results from local case studies within the progRESsHEAT project

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Keywords: Policies, District Heating, Renewable Heating, Energy Savings

Overview

Decarbonising the heating sector is essential to reach the climate goals agreed on COP 21 meeting held in Paris. Nevertheless, there are open questions regarding the cost-optimal level of energy savings and the respective supply system that matches best with these savings. Even more, there are open questions about which policy framework can contribute to a high share of renewables in the heating sector. This work tries to answer the question of favourable policies by quantifying the effect of different policies on certain indicators using a modelling framework able to find the cost-optimal combination of heat savings and supply options, developed within the progRESsHEAT project. The work is based on findings from the very different local case studies of Ansfelden, Brasov, Elsinore, Herten and Litomerice spread over Europe and all investigated in the project.

Method

The overall methodology comprises the calculation of the cost-optimal combination of heat savings with either district heating or individual supply technologies for different desirable technological future scenarios and the calculation of the effects of different policies on indicators for each of these scenarios. To find the cost-optimal combination of savings and supply the existing district heating system and possible alternative supply portfolios were modelled in energyPRO to obtain the district heating price and compared with the levelized costs of heat for individual heating technologies and with costs and potentials for heat savings, calculated for different building types with different construction periods with the Invert/EE-Lab model. For each cost-optimal combination, different indicators such as CO_2 emissions, share of renewables and average heating costs are calculated. These calculations are done for various policy frameworks that contribute to a higher integration of renewables (e.g. taxes, subsidies and regulations) and compared to a no policy scenario to assess the effect of the respective policy.

Results

The policy assessment showed that different regions in different countries face very different challenges and therefore there is no standard policy that fits for all. Nevertheless, there are some common findings on how a policy framework could look like to integrate a high share of renewables into the heating sector: As the assessed policies targeted the share of renewables, most of them had no effect on the heating demand and the resulting demand was mainly determined by the costs and potential for heat savings. Only the connection obligation led to lower heat savings because building owners forced to connect to the district heating network do not implement savings. Therefore, policies should not contradict renovation measures and ensure that building owners perform thermal renovation instead of maintenance work on the building envelope. Second, the policy assessment showed that in the reference scenario without any policy, individual natural gas boilers are still the cheapest option for big buildings where individual biomass boiler cannot be installed. In the Brasov case only an emission based CO_2-tax of around 80-100 €/t_{CO2} can discriminate fossil fuels enough to make other renewable heating options attractive in these buildings. This is because there are currently almost no taxes on fossil fuels. And third – as stated at the beginning – district heating is seen as an important technology to decarbonise the heating sector especially in urban areas. Therefore policies should be implemented that lead to a competitive and renewable district heating system. The policy framework should enable long term horizon for infrastructure investments and high connection rates of customers.

They have a bigger impact than free connection to the network as the district heating price is highly determined by capacity costs due to high network investments and few customers. Nevertheless, all policy measures should be accompanied by intensive and target-group oriented information campaigns and involvement of all stakeholders to agree on a common long-term target where everyone is willing to contribute.

Thomas Pauschinger is member of the management of Solites responsible for international cooperation on research, demonstration, market introduction and know-how transfer regarding the use of solar thermal, other renewable energy sources and energy efficiency in the heating and cooling sector. Since 2009 he coordinates the international cooperation on the field of solar district heating between DH and solar thermal stakeholders within the EU SDH projects.

Regional Policy and Market Support Initiatives for Solar and Renewable District Heating

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Keywords: District Heating, Renewables, Solar Thermal, Policy, Support Measures, Communication

Most European countries have defined ambitious objectives for the reduction of greenhouse gas emissions and the transition of their energy systems. Reaching these objectives implies a strong increase of the share of renewable energies and efficiency technologies in the heat sector, combined with a reduction of the heat demand by building refurbishment. Here, district heating plays an important role as a smart and flexible, organizational and technical solution for the energy transition in the heat sector. In particular, it enables a relatively fast introduction of high shares of renewables.

Some European regions have recognized this opportunity and started action. Frontrunners are for example the 15 regional Ministries and authorities that participate as project partners in the IEE project SmartReFlex (www.smartreflex.eu) and the Horizon 2020 project SDHp2m (www.solar-district-heating.eu/SDHrelatedprojects). Their cooperation aims at an active development and implementation of policy instruments and market support measures for solar and renewable district heating.

In the proposed contribution, we present two to three selected best practice cases of these regional policy and market support initiatives (e.g. Auvergne Rhone-Alpes (FR), Styria (AT) and / or Baden-Württemberg (DE)). This includes a discussion of the policy instruments and measures implemented at regional level, the impact achieved and lessons learnt. The concerned authorities will be involved in the elaboration of their cases. The presentation further gives a feedback on the experience gathered by Solites in accompanying the process of renewable district heating market development in European regions.

Session 29: Energy planning and planning tools

Davy Geysen was born in Mol, Belgium. He obtained his Master degree in electrical engineering from the Katholieke Hogeschool Kempen (KHK), and the M.Sc. Computer Science degree from the Katholieke Universiteit Leuven (KUL). In 2007 he started working at Cronos as a business integration engineer. Since May 2009 he has been working at the Flemish Institute for Technological Research (VITO) as a researcher on smart grid related optimization algorithms and modelling.

Session Keynote:

Forecasting of heat demand in district heating systems and their integration into smart grid controllers - Fractals, ensembles and expert advisers

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Keywords: District heating, digitalisation, heat load forecasting

The digitalisation effort in modern district heating systems facilitates the collection of large amounts of online data. This data can be used to implement a range of refined analysis methods in general and model generation techniques in specific. Such models can, for example, be used for forecasting thermal demand in a district heating system. The ability to forecast demand is a vital component of most optimisation approaches for the operation of the network, and this especially applies to the more data-driven and automated approaches used in modern 4^{th} generation networks.

The authors have recently published work on machine learning based approaches to solve operational heat demand forecasting in district heating systems. Johansson et al presents a generic ensemble method using three different forecasting algorithms, while Davy et al presents an expert advice system [1,2]. In parallel with this, other authors have presented related approaches. Recent work on fractal forecasting methods have been used to predict day-ahead heat demand, and it has been shown that heat load demand time series display the statistical self-similar characteristic of fractals [3]. In this paper, we further this research by combining and refining these approaches while also integrating them in an operational expert advice system.

Initial results do indeed indicate the desired self-similar characteristics in the relevant time series data. The rescaled range analysis gives a Hurst exponent of about 0.9, which suggests persistence and predictability of the time series and motives further research. In this study, we use operational data from the district heating systems in Karlshamn and Rottne in Sweden to verify our finding. The study also elaborates on how these models can be integrated in an operational smart grid controller such as the STORM project [4].

[1] Johansson, C., Bergkvist, M., De Somer, O., Geysen, D., Lavesson, N. and Vanhoudt, D. *Operational Demand Forecasting in District Heating Systems Using Ensembles of Online Machine Learning Algorithms*. The 15th International Symposium on District Heating and Cooling, 2016, Seoul, South Korea

[2] Geysen, D, De Somer, O., Johansson, C., Vanhoudt, D. and Brage, J. *Operational Thermal Load Forecasting in District Heating Networks Using Machine Learning and Expert Advice*. Energy and Buildings, 2017 (in review)

[3] Piotr Aleksiejuk. Fractal Theory Application for Heat Demand Forecasting in District Heating Systems. *Unpublished*

[4] Vanhoudt, D., Claessens, B., Desmidt, J. and Johansson, C. *Status of H2020 STORM-projekt*. The 15th International Symposium on District Heating and Cooling, 2016, Seoul, South Korea

Charlotte Marguerite is working at AIT as a scientist. She is involved in European research projects related to district heating networks integrated in smart cities. She has a PhD in Energetics; her thesis concerned the development of a tool to model district heating networks for a strategic management.

Simulation based assessment of retrofitting measures, storage integration and alternative heat sources in the district heating network of Aarhus

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Keywords: Low-temperature district heating networks, renewable sources, storages, dynamic simulations

One of the main actual challenges of district heating (DH) networks, is the integration of more renewable energy sources, with the aim to reach 100% renewable energy systems. The challenge is recognized by European and national governments and attractive due to very low operational costs. However this objective is realistic only if combined with a reduction of the heat demand, through retrofitting measures or new performant buildings, and the combined use of storages and decentralized renewable and waste heat sources.

Within the READY project (http://www.smartcity-ready.eu) as part of the European FP7 SMART CITIES framework, a set of various measures will be modelled/implemented in the two European cities Växjö, Sweden and Aarhus, Denmark. The objective of the project is to assess the reduction potential of the overall energy demand and fossil fuels use with the goal of bringing CO2 emissions to nearly zero.

Specific results of the READY project are presented in this contribution, in particular regarding simulation based assessment and optimization of the overall district heating networks of Aarhus. With the objective of facilitating and improving the use of fluctuating and or non-controllable heat sources, three scenarios are implemented to assess the following measures:

- Retrofitting measures applied to the oldest buildings connected to the district heating system of Aarhus, in order to reduce the heat demand as well as the return temperature in the network.
- The integration and management of centralised and decentralised storage tanks to smooth the heat demand during peak hours and reduce the operational costs of the DH network, including the optimization of their design and operation strategy.
- The integration of alternative heat generation units such as recovered waste heat, heat pumps including the design of the systems and the control strategies (e.g. based on the priority order or temperature levels).

The impact of the described measures and the efficiency of the systems are evaluated using the dynamic simulation environment Modelica/Dymola and a dynamic plant scheduling optimization algorithm implemented in Matlab. The results show that for the DH network of Aarhus, extensive retrofitting measures as well as large centralized thermal storages are necessary in order to have notable impact on the network performances in terms of primary energy use, heat losses and return temperature reduction CO2 emissions and costs.

Franz Mauthner is researcher at AEE – Institute for Sustainable Technologies in Gleisdorf, Austria. Educational background is energy and environmental engineering (University of Applied Sciences Pinkafeld) as well as geoinformatics (University of Salzburg). Key fields of expertise include holistic energy system planning and analysis as well as design and analysis of solar process heat and solar district heating applications.

Holistic urban energy planning: The benefits and drawbacks of using GIS-based methods

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Keywords: Urban energy planning, GIS, Smart cities, (geospatial) Data management

The global trend towards urbanization is one of the most influencing issues to be considered in the long-term planning of low-carbon energy systems. The global degree of urbanization increased from 30% in 1950 to already 54% in 2015. In 2050, two thirds of the global population is predicted to be living in urban environments [6]. In terms of energy, the concentration to urban areas is even more strongly pronounced: 67% of the global primary energy demand was associated with urban areas in 2006 and is expected to increase to 73% till 2030 [7]. These shifts have major impacts on energy markets, energy efficiency potentials or environment and health issues [8] and demand for adapted strategies in the field of urban (energy) planning. Besides of the political will, appropriate tools and methodologies are needed that support and facilitate decision finding processes amongst urban actors with heterogeneous professional backgrounds (politics, urban planners, architects, energy planners, etc.). In this context, this paper presents a methodological approach for energy planning on an urban scale where geographical information systems (GIS) play a key role in (spatial) data management, data manipulation, energy system analysis, (co-)simulation as well as illustration and communication of results. In detail, preliminary outcomes on GIS-based energy system analysis coupled with dynamic building and energy system simulation for two Austrian study areas (city of Gleisdorf, urban district “Salzburg-Schallmoos”) for a reference year and for future scenarios are shown.

The energy master planning process in both study areas is triggered by local energy targets: For Salzburg-Schallmoos, the superior goal is carbon-neutral energy supply in 2050 whereas for the city of Gleisdorf a 100 % renewable energy supply in 2050 is envisioned. Both targets demand a thorough analysis of the current status quo in terms of energy supply and demand. This includes an acquisition of available (geo-) data on energy infrastructures including characterization of the building stock, of the current energy supply technologies, on energy consumption and on local energy resources such as waste heat, solar, or geothermal. If necessary, information is gathered from open geospatial data (e.g. OpenStreetMap, open government data, remote sensing data) and is supplemented by statistical and empirical assignments on the building stock (e.g. building category, year of construction, occupation, state of renovation, building energy supply system, etc.). Finally, for the assessment of the building energy load profiles the entire building stock is modeled with the dynamic multi-zone simulation software IDA ICE. Here, an automated method was developed that transfers gathered information from a geo-database to IDA ICE and adds missing building parameters such as wall/roof/window details, specifications on technical equipment, demand profiles for domestic hot water or household electricity reflecting user behaviour, etc. for full characterization of the building envelope incl. HVAC [9]. Selected simulation outputs (e.g. load profiles, internal gains and losses, passive solar gains, possible active solar gains by PV or solar thermal) are transferred back to the geo-database and made available for analysis / visualization in the GI-environment. Results of this approach are currently used in discussion with local stakeholders

6 United Nations, 2014

7 IEA WEO, 2008 p.179

8 Araujo, 2014: The emerging field of energy transitions: Progress, challenges, and opportunities (http://dx.doi.org/10.1016/j.erss.2014.03.002)

9 Nageler, Mauthner et al, 2017: Novel validated method for GIS based automated dynamic urban building energy simulations (under review)

and planning departments to evaluate past actions in urban energy planning as a part of community planning and to discuss and develop future interventions. In this context, current results and experiences show that spatial analysis, simulation and mapping of results offer a valuable addition to conventional urban planning processes. Nevertheless, this approach is data-intensive and as such relying on good communication with and between local stakeholders, data availability and data security. Thus, alternatives for data-poor environments and limitations for the presented approach are discussed as well.

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Ina De Jaeger is a MSc graduate in architectural engineering from KU Leuven. As a PhD fellow at the Building Physics Section of the KU Leuven, she focuses on buildings within district energy models. Her PhD research aims to assess the reliability of district energy simulation results due to the uncertainty and intrinsic variability of the required input data.

Impact of building geometry description within district energy simulations

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Key words: urban building energy models; district energy simulation; geometrical representation; GIS; CityGML

An accurate quantification of the energy demand of a district serves as an important boundary condition for a correct assessment of the feasibility of district heating and cooling systems. In order to quantify the district's energy demand, a considerable number of input parameters is required for each building. These include geometry and location, building envelope characteristics, heating, ventilation and air conditioning systems, renewable energy systems, building appliances and occupant behaviour. Due to the scarcity of input sources and the lack of an efficient methodology to process the input parameters on district level, current district energy simulations are often carried out using an archetype approach. In this approach only a limited set of representative buildings – archetypes – is used to model the district's building stock. However, these archetype approaches fail to include the unneglectable variability in type and size of buildings that is characteristic for the existing building stock. Especially, on a smaller scale (~100 dwellings) the use of archetypes may therefore no longer be representative.

The focus of this paper is on the influence of the geometrical representation of single-family dwellings within these district energy simulations. Using recent developments in geographical information systems (GIS), the variability in geometry can be introduced more accurately in district energy simulations. Nonetheless, detailed geometry descriptions – in the CityGML standard – are not yet available for all locations. Ideally, each building is characterised by its particular shape and defined in terms of surfaces that represent roof, ground floor or façade or parts of these. This corresponds to models with level of detail 2 (LOD2). In Flanders, GIS data contain a precise two-dimensional (2D) geometrical representation of the territory, including building footprints amongst others. These 2D files are combined with LiDAR data to derive the building ridge height and are then used to generate LOD1 CityGML models, in which buildings are represented by extruded volumes. However, the extrusion of the building's footprint to its ridge height causes a significant overestimation of the building volume and its total envelope surface area.

Within this context, this research quantifies the differences between four LOD1 models and a LOD2 reference model, as the LOD1 models fail to include particular roof shapes and usually also building extensions. Furthermore is analysed how LOD1 models could be enhanced in order to obtain a more accurate geometrical representation of the considered district. To establish this analysis, the traditional LOD1 models are first compared extensively to the LOD2 model through the evaluation of the ground floor area, the roof area, the external wall area, the total loss surface area and the building volume as geometrical key performance indicators (KPIs) as well as through the assessment of the peak power, the total energy use and overheating as energetic KPIs. FME is used to setup the CityGML models, TEASER to translate these CityGML models into IDEAS Modelica models and OpenIDEAS to run the district energy simulations in Dymola. Finally, this research presents guidelines for the generation of improved geometrical representations of single family dwellings within district energy models. To which extent should building models include roof shape and/or building extensions? Is e.g. a building model that distinguishes extensions from main volume but characterizes them both by a flat roof sufficient?

Samuel Letellier-Duchesne, PhD candidate, Through his research at Polytechnique Montréal, Samuel is interested in bridging the gap between building mechanics and architecture & planning. He intends to do so by developing tools that allow a better flow of information between the two fields.

Balancing Demand and Supply: Linking Neighborhood-level Building Load Calculations with Detailed District Energy Network Analysis Models

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Keywords: District Energy Simulation Tool, Supply Network, TRNSYS, Rhino, umi.

Background

Operational building energy has long been recognized as both a major contributor of as well as an opportunity to save carbon emissions. To do so, one may follow two paths, reduce the energy use in buildings (demand) or provide the required energy in more efficient ways (supply).

In the literature, extensive research has been made on both fronts and at different levels of detail. This led to the development of different workflows such as EnergyPlus and ESP-r on the Demand side and NetSim and Termis on the Supply side [1]. Other tools such as SUNTOOL, CITYSIM and UMI have tried to better integrate those models to some extent. Umi, a Rhino-based link to Radiance and EnergyPlus, is developed at the MIT Sustainable Design Lab [2]. It contains an early design module that supports the comparison of different supply scenarios based on hourly loads and ambient temperatures, giving an indication of whether a district energy system is a promising approach for a given neighbourhood design. However, if the first screening of several energy supply options points towards a district system, further analysis is necessary for confirm validity of the approach.

This manuscript describes a modelling workflow based on a new Rhinoceros-based plugin that combines an urban building energy model with an actual district energy supply system design.

Bridging the gap

The new plugin builds on the foundation of umi as an addition to the demand simulation module. This supply module allows users to model thermal plants as well as distribution networks. The tool uses TRNSYS as the simulation engine which allows to accurately model the interaction between the building loads, the hydraulic network, and the supply plant. Moreover, it supports varying levels of simulation detail, allowing the user to choose between fast and simplified or more computer-intensive and accurate models. Finally, a basis for a system of thermal plant templates is presented. It is inspired by the way building descriptions have been developed for UBEM models [3]. In turn, templates can describe models such as CCHP plants, DHC plants or solar thermal plants in a more efficient way.

Finally, with this plugin, users are given a set of interactive tools to draw the network over a 3D representation of the buildings. The tool interactively generates the dck file, the text-based input document users of TRNSYS are familiar with. Most importantly, the tool can also serve as a stepping stone from Rhinoceros to a full-fledged TRNSYS project as users can open the dck file in the TRNSYS Studio and discover a fully functional project with component properties already auto sized and organized. Advanced users can then bring their project to a deeper level of complexity without spending as much time laying the foundation of the network.

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Session 30: Energy planning and planning tools

Dr. Veit Bürger, Deputy Head of Energy & Climate Division at Oeko-Institut; expert in the development, design and assessment of policy instruments for heating and cooling, especially for RES-HC and with regard to the transformation of the building sector towards climate neutrality; involved in the development of the impact assessment for the draft revision of the RES Directiv

Session Keynote:

Third party access to district heating systems - Challenges for the practical implementation

Dr. Veit Bürger [a], Dr. Jan Steinbach[b], Dr. Lukas Kranzl[c], Dr. Andreas Müller[c], [a] Öko-Institut e.V., Merzhauser Straße 173, 79100 Freiburg, Germany; phone: +49-761-45295259; v.buerger@oeko.de, [b] Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Str .48, 76139 Karlsruhe, Germany , [c] Energy Economics Group, TU-Wien, 1040 Vienna, Austria*

Keywords: District Heating, Third Party Access, Renewable heating and cooling

The European Commission aims at gradually increasing the share of renewable energies in district heating and cooling networks (DHC). For that reason Article 24 of the proposed revised Directive on the promotion of the use of energy from renewable sources provides that Member States adopt measures to ensure non-discriminatory access to DHC systems for heat or cold produced from renewable energy sources and for waste heat or cold. This non-discriminatory access shall enable direct supply of heating or cooling from such sources to customers by suppliers other than the operator of the DHC system.
In our contribution we explore technical, regulatory and economic challenges and implications that arise from the practical implementation of this provision. Moreover, we analyse, whether TPA of independent heat/cold producers alone is sufficient to stimulate the uptake of renewables in DHC systems or if additional regulations such as preferential third-party DHC grid access including a purchase obligation for renewables were required.

As a first step, we summarise literature on TPA for DHC and link it to lessons learned of other markets with crucial infrastructure, i.e. electricity and natural gas. Secondly, we describe representative cases of district heating grids in Austria, Germany and other EU countries regarding size, ownership structure, supply etc. For these DHC types, thirdly, we perform a detailed market and stakeholder analysis including the company structure and their operation on the heat, gas and electricity market as well as the analysis of end consumers connected to DHC.

Third party DHC access (TPA) might gradually transform the topology of a DH system that is rather centralised today to a decentralised system with a variety of different heating/cooling sources with different characteristics being connected to the grid. This change in the topology might require technical adaptations to ensure the technical performance of the grid. In addition system specific technical requirements for grid access and usage of grid need to be defined. The respective rules need to ensure that independent heat/cold producers gain grid access on equivalent terms compared to the production plants of the integrated grid operator.

In addition to the technical challenges TPA regulations need to be adapted as to ensure that e.g. grid losses or the costs of technical grid adaptations or upgrading the grid infrastructure are distributed among the DH participants in a fair and non-discriminatory way. The same applies to the establishment of technical requirements regarding feed-in and offtake from the grid, the provision of reserve capacity and balancing heat and how the grid-charges are set. Finally, if the proposed preferential TPA stimulates many renewable energy producers to access a DHC system and if increasing demand within the DHC does not compensate for the additional renewable production, existing non-renewable heat and/or cold producers (e.g. operated by the integrated DHC system operator) will be replaced by the new entrants. This might lead to stranded investments if the replaced capacities had not been fully amortised. Accordingly the question arises of how to allocate the respective costs.

Furthermore, we analyse competition issues possibly arising with preferential TPA considering the interlinkage of DHC, electricity and gas markets as well as the housing sector. TPA can be facilitated either by the single-buyer model or via the so-called network access model where producers use the (open) DHC grid to supply their own end-customers. Currently the single buyer model is the dominating market model for DHC in most European states. Legal statements of national regulatory authorities do not see the need for changing the single buyer model from a competition policy point of view. We will discuss if the underlying market definition is appropriate or whether the definition might be too narrow considering that DHC companies are often gas distribution system operators at the same time. In this respect we also challenge the theory that there is no need for further competition by TPA in a single-buyer-model since district heating has to compete against decentralised heating technologies.

Daniele Basciotti is working at AIT since 2008 as Scientist and he has specialised in the fields of district energy system modelling, simulation and optimisation. Daniele holds a BSc in Aerospace Engineering from the Seconda Università degli Studi di Napoli as well as a MSc in Aerospace Engineering from the University degli Studi di Pisa.

Simulation based analysis of demand side management as enabler for heat pumps in district heating networks

**Daniele Basciotti, MSc.; Ankit Takle, BSc.; Dr. Ralf-Roman Schmidt, Austrian Institute of Technology (AIT), Giefinggasse 2, 1210 Vienna (Austria), daniele.basciotti@ait.ac.at; +43(0)6642104991*

Keywords efficient heat supply, simulation-based study, heat pumps, demand side measures

Efficient electricity and heat supply is a major challenge for sustainable energy systems. The aim of increased generation potential by renewable energy resources is shadowed by the non-regularity issue of renewable generation sources (specifically PV and wind). Energy conversion technologies like Heat Pumps (HP) can represent a potential technology to cope with fluctuating generation sources by coupling unreliable electricity generation with, in first order, stable heat demand of district heating (DH) network systems.

HP in combination with an optimal control of the DH network with supply and demand side measures (e.g. load shifting, heat storage units, network as storage) ensure the smooth operation of the district heating systems thus avoiding the need for installation of high cost peak heat boilers, improve plant partial load performance, enable further network expansion and improve its resilience to ensure heat supply security.

Different set-up and variations as well as control strategies for HP in DH networks are developed and evaluated within the simulation environment Modelica/Dymola. The process includes the definition of detailed simulation models for a) heat production units including the HP itself, b) the distribution grid and c) costumer models. Characteristic Austrian rural biomass DH networks are defined and modelled. Appropriate demand side measures are applied to the DH network and a comparative analysis is carried out on different heat pump integration configurations.

This study defines optimal configurations identifying technical and non-technical barriers for the integration of heat pumps into DH networks and describing possible feasible solutions in combination with demand side measures.

Maksym Kotenko is a PhD fellow at Aalborg University. The topic of my PhD stusdy is “Optimization of low temperature district heating”. Currently I am working with drag reducing agents as one of measures that can optimize district heating by saving pumping energy.

Drag reducing additives in low temperature district heating

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Keywords: Drag reducing additives; surfactant, pressure loss.

A drag reducing additive (a DRA) is an agent that can reduce friction in pipelines consequently reducing pumping costs. Drag reduction effect of the high molecular weight polymer solution was discovered by Toms B.A. in 1948. Then in 80-s new type of drag reduction agent was discovered which is called surfactant. Surfactants can reform after break of the molecular structure what polymers are unable to do. Currently such surfactants are highly used in petrochemical industry and have huge potential to be used in district heating, especially low-temperature district heating where higher flow is demanded to maintain same heat supply. Application of drag reduction additives can lead up to 80% reduction in pressure loss which was shown by various previous researches. Biggest full scale test was done in Herning and total drag reduction of 70% was achieved. Though the project was closed due to unsolved problems connected with heat transfer reduction in shell tube condenser.

Tests of different known polymers were carried out at the test rig at Aarhus University. Experiments included testing different polymers of high molecular weight that can induce so called Toms effect. Our main focus was polyethylene oxide. Tests were done to verify the experimental setup before investigating new created surfactants. Experiment showed drag reduction of maximum 15 % which is at least three times lower comparing with previous studies. Therefore after several examinations of test rig it was concluded that bad mixing and possible precipitation of polymer occured in the rectangular tank which should be replaced or modified. Smaller test rig was built at Aalborg University to avoid mistakes and problems of wrong planed setup at Aarhus University.

Future goal is to show results from initial experiment and start solving heat transfer reduction problems in different types of heat exchangers by intentional temporary degradation of surfactant structure. Moreover main objective is to bring a substance to full scale test at district heating transmission pipeline.

Miki Muraki expertise includes city planning, area management, PPP, revitalization of central urban areas and sustainability. She has been involved in advisory board of district heating projects in Japan.

1G/2G to 4G? Challenges in the Existing District Energy Infrastructure in Japan

Miki Muraki, Professor 1Kanau Takahashi, Master Student*2 *1 The Trade Council / Royal Danish Embassy, Tokyo*2 Graduate School of Global Environmental Studies, Kyoto University Corresponding Author: Izumi Tanaka, Senior Commercial Officer (Energy and Environment) E-mail address: muraki@tu.chiba-u.ac.jp,*

Keywords: District energy infrastructure, District heating market in Japan, regulatory frame work, policy, 4th generation district heating

Energy security, especially with only three of the nuclear power plants currently operating compared to before the nuclear disaster in 2011 when nuclear plants were providing about one quarter of electricity in the country, is a big issue for Japan. Currently, 82% of Japan's electricity generation relies on imported fossil fuel imports. Energy consumption for heating and hot water supply consists over half of residential energy consumption, yet very little is being done to incorporate renewable energy and to supply heat through district heating. Additionally, the existing heating infrastructure with thermal capability of over 21 giga Joules per hour which are regulated by Heat Supply Business Law is mainly operating on steam or high temperature hot water; they are between first and second generations of DH. However, attention on efficient use of heat using renewable sources has increased especially after the earthquake in 2011 and has brought decentralized energy system to light. The liberalization of the heat market is also under way in Japan.

The presentation will explore the background in the establishment of the Heat Supply Business Law and the existing district energy infrastructure covered by the law. The current status and the trend of these installations will be introduced, as well as the challenges they face in the decline of number of customers and operation and maintenance of such systems. The presentation will also include implications of the change in regulatory framework for heat supply, including liberalization of the heat market, and the obstacles the existing infrastructure face to renovate to a more efficient system; to explore if the existing 1G/2G systems can be upgraded to 4G in the future.

Mikel Monclus is involved in building physics, energy and sustainability in the built environment. Has prepared sustainability and energy reports and performed analysis on dynamic thermal modelling to measure overheating in buildings, heating and cooling loads, EPCs, renewable energy feasibility, carbon reductions and compliance with global and local plans and regulations across a range of new build and refurbishment projects in residential and commercial buildings.

Combined HEat SyStem by using Solar Energy and heaT pUmPs

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Keywords: Energy storage; Heat storage, Heating system; Heat pump; Renewable Energies; Solar Energy; Retrofitting solution

Chess Setup is a project funded by the European Commission, in the framework of **the H2020 program**. The project is carried on by a consortium made by ten members, coming from five different European States and from different professional backgrounds (consultants, architects, public bodies…).

The project addresses the **growing needs of heating and domestic hot water (DHW) in the building sector**. Its objective is to design, implement and promote a system able to meet those needs all year-long, and supplied by renewable energies.

This system relies on tested and approved technologies: hybrid photovoltaic and solar thermal (PV-ST) panels, seasonal thermal storage tanks and heat pumps. This set of tools will allow the buildings to be heating and DHW **self-sufficient during the sunny months, and to rely on their heat reserves** the rest of the year.

To ensure the **reliability** of the system, a simulation software was developed by the consortium. Indeed, taking into account the geographic location, and several parameters related to the building, it provides the **optimum dimension**s of the hybrid solar panels and of the water tank. A further analysis was held in order to select the most efficient heat pumps and mixtures to supply them. To confirm the software's forecasts, the system will be implemented in three different pilot cases;

- A small-scale prototype on Lavola's headquarters in Manlleu (Spain),
- At a **district-level in households** under construction Corby (United-Kingdom),
- In a sport centre in Sant-Cugat (Spain).

Thus, the project faces the **selfconsumption challenge in urban areas**, proposing a solution both for new buildings and existent ones (retrofitting business).

Later on, the consortium will study further applications for the system;

- Its ability to contribute to a **smarter grid**, supplying the main grid with electricity produced by the solar panels.
- The adaptation capacity of the system, taking into account the electricity prices and the **inertia** given by the water tank, to optimize the decision to use the heat stored, or to rely on the distribution network.

A **business model** will be edited, in order to make the project's industrialization profitable.

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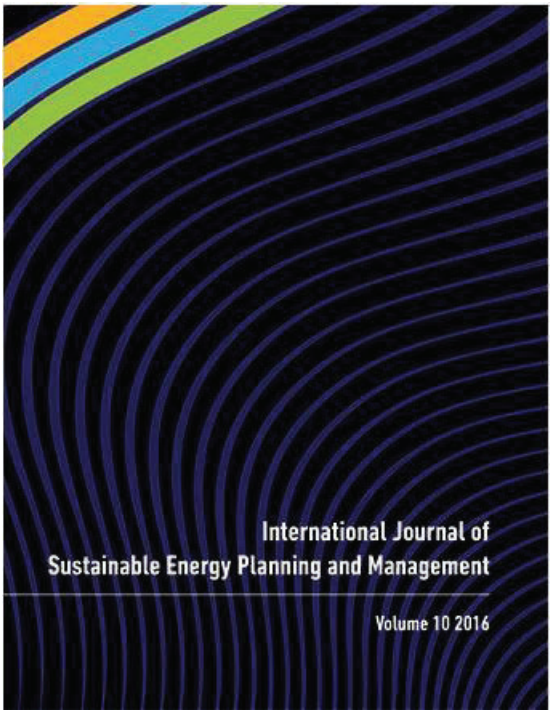

Smart energy systems and 4th generation district heating

Poul Alberg Østergaard, Henrik Lund, Brian Vad Mathiesen

Comprehensive Assessment of the Potential for Efficient District Heating and Cooling and for High-Efficient Cogeneration in Austria

Richard Büchele, Lukas Kranzl, Andreas Müller, Marcus Hummel, Michael Hartner, Yvonne Deng, Marian Bons

A genetic algorithm technique to optimize the configuration of heat storage in DH networks

Amru Rizal Razani, Ingo Weidlich

Smart energy systems applied at urban level: the case of the municipality of Bressanone-Brixen

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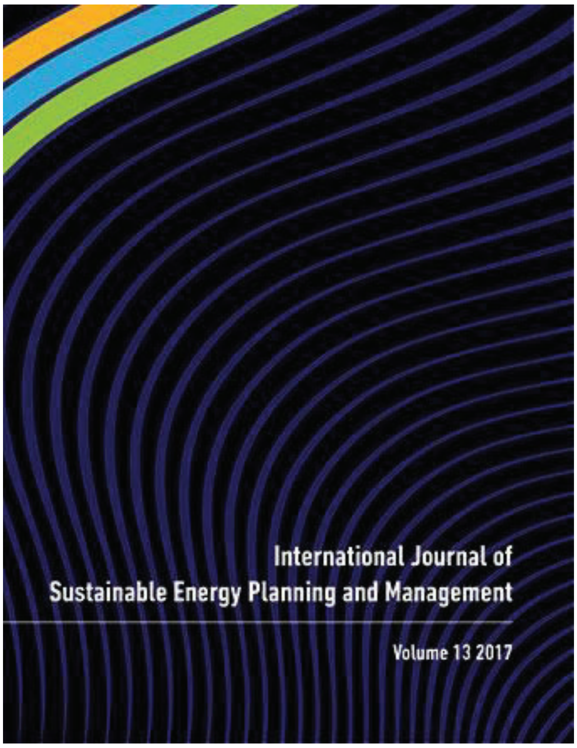


Smart district heating and electrification

Poul Alberg Østergaard, Henrik Lund

Comparison of Low-temperature District Heating Concepts in a Long-Term Energy System Perspective

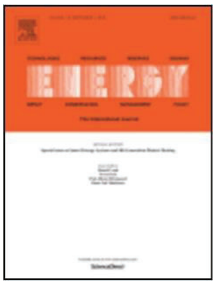
Rasmus Lund, Dorte Skaarup Østergaard, Xiaochen Yang, Brian Vad Mathiesen

Flexible use of electricity in heat-only district heating plants

Erik Trømborg

Innovative Delivery of Low Temperature District Heating System

Anton Ivanov Ianakiev



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Edited by Henrik Lund, Neven Duic, Poul Alberg Østergaard
and Brian Vad Mathiesen

Smart energy systems and 4th generation district heating
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Weiming Xiong, Yu Wang, Brian Vad Mathiesen, Xiliang Zhang

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Xiaochen Yang, Hongwei Li, Svend Svendsen

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Dorte Skaarup Østergaard, Svend Svendsen

System dynamics model analysis of pathway to 4th generation district heating in Latvia
Jelena Ziemele, Armands Gravelsins, Andra Blumberga, Girts Vigants, Dagnija Blumberga

Complex thermal energy conversion systems for efficient use of locally available biomass
Jacek Kalina

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Rasmus Lund, Urban Persson

Industrial surplus heat transportation for use in district heating
J.NW. Chiu, J. Castro Flores, V. Martin, B. Lacarrière

European space cooling demands
Sven Werner

Optimal planning of heat supply systems in urban areas
Valery A. Stennikov, Ekaterina E. Iakimetc

Ringkøbing-Skjern energy atlas for analysis of heat saving potentials in building stock
Stefan Petrović, Kenneth Karlsson