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

Aalborg University, Copenhagen Campus on 25-26 August 2015

Lund, Henrik; Mathiesen, Brian Vad

International Conference on Smart Energy Systems and 4th Generation District Heating

Book of Abstracts

AALBORG UNIVERSITY
DENMARK

Innovation Fund Denmark
RESEARCH, TECHNOLOGY & GROWTH

4DH

COPENHAGEN, 25-26 AUGUST 2015

International Conference on Smart Energy Systems and 4th Generation District Heating, 25-26 August 2015

Book of Abstracts

Aalborg University Copenhagen
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Preface

It is a great pleasure to welcome you to the first International Conference on **Smart Energy Systems and 4th Generation District Heating** at Aalborg University, Copenhagen Campus on 25-26 August 2015. The conference is organised by the 4DH Strategic Research Centre in collaboration with Aalborg University and offers more than 70 presentations in 3 parallel sessions with more than 180 participants from 25 countries around the world. 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. 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 hope you all will have a fruitful conference.

Prof. Henrik Lund and Prof. Brian Vad Mathiesen

Conference organisers

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4th Generation District Heating concepts

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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

Fee including materials, coffee, lunches and conference dinner:

- Normal fee: **300 EUR**
- Early registration (for presenters with accepted abstracts): **200 EUR**

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 transportation 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

15 March 2015 Deadline for submission of abstracts

1 April 2015 Reply on acceptance of abstracts

1 May 2015 Early Registration Deadline

25-26 August 2015 Conference

Heat Roadmap Europe 2050

4DH 4th Generation District Heating Technologies and Systems

International Conference on

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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 and future 4th Generation District Heating Technologies and Systems (4GDH). The conference is organized by the 4DH Strategic Research Centre 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.

Location

The Conference will take place at the Copenhagen Campus of Aalborg University located in the central harbour area of Copenhagen not far from Tivoli and the old city.

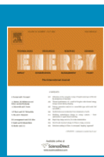
Photo by Jørgen True / StudieE

EnergyPLAN User Summit

The first annual EnergyPLAN User Summit will be conducted as a special session during the Conference. The EnergyPLAN development team will present the philosophy behind EnergyPLAN and a short history of the tool. However, the main part of the programme will be user presentations and feedback to these from other users. To present your work and experience with EnergyPLAN, please submit an abstract for the Conference. You are also welcome to simply attend and learn from the experience of others.

The 2015 Student Awards Ceremony and presentations by the winners will take place at the International Conference on Smart Energy Systems and 4th Generation District Heating.
The DHC+ Student Awards recognise students of extraordinary potential who undertake research in the field of District Heating and Cooling, including technological, environmental, social and legal aspects. Established by the DHC+ Technology Platform, the Student Awards have a separate application process and an independent evaluation committee. More information on the timeline, awards criteria and prizes can be found on http://studentawards.dhcplus.eu/ .

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 Paper Awards** will be given to a selected number of papers at the conference. However, abstracts may be presented at the Conference without uploading to papers, as this is not a requirement.

Please, send your one-page abstract to **4dhConference@plan.aau.dk** before **15 March 2015**.

International Scientific Committee

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
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Morten Abildgaard, Viborg Fjernvarme
Jesper Møller Larsen, Aalborg Forsyning, Varme

Conference Chairs

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

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Tuesday 25 August 2015 · Overall programme

08:30-09:00 Registration and breakfast — **PLENARY ROOM 1.001 (floor 1)**

09:00-11:10 1st plenary session - Chaired by Brian Vad Mathiesen

09:00 Welcome and introduction to Smart Energy Systems and 4th Generation District Heating by Henrik Lund

09:15 Keynote: Xiliang Zhang: *The Role of District Heating in China's Energy Revolution and Related Applications in Northeast China*

09:45 Keynote: Anders Eldrup: *District heating - the Danish case as an export model?*

10:15 Questions and discussion

11:10-12:50 Parallel sessions 1-3

Track 1: Smart Energy Systems **Chair: Jan Eric Thorsen, co-chair: Erik Ahlgren** **Session keynote: Erik Ahlgren** Jean Duquette Amru R. Razani Benedetto Nastasi **PLENARY ROOM 1.001 (floor 1)**	**Track 2: Future district heating production and systems** **Chair: Goran Krajačić, co-chair: Leif Gustavsson** **Session keynote: Leif Gustavsson** David Maya-Drysdale Dražen Balić Oddgeir Gudmundsson Veronika Wilk **AUDITORIUM 1, 1.008 (floor 1)**	**Track 3: Energy planning and planning tools** **Chair: Sven Werner, co-chair: Bernd Möller** **Session keynote: Bernd Möller** Ekaterina E. Iakimetc Lars Grundahl Romain S.C. Lambert **AUDITORIUM 2, 0.091 (floor 0)**

12:50-14:05 Lunch — **PLENARY ROOM 1.001/ CANTEEN (floor 1)**

12:50-13:20 Steering Committee Meeting (4DH SC members only) — **ROOM 2.1.043**

14:05-15:45 Parallel sessions 4-6

Track 4: Low-temperature district heating grids **Chair: Carsten Bojesen, co-chair: Markus Köfinger** **Session keynote: Markus Köfinger** DHC+ Student Award Winner Wiet Mazairac Edgars Vigants Maksym Kotenko Soma Mohammadi **PLENARY ROOM 1.001 (floor 1)**	**Track 5: Low-temperature district heating and buildings** **Chair: Svend Svendsen, co-chair: Anders Dyrelund** **Session keynote: Anders Dyrelund** Julio E.V. Rebollar DHC+ Student Award Winner Susana Paardekooper Kasper Qvist Dorte S. Larsen **AUDITORIUM 1, 1.008 (floor 1)**	**Track 6: Organisations, ownership and institutions** **Chair: Bent Ole G. Mortensen, co-chair: Dagnija Blumberga** **Session keynote: Dagnija Blumberga** Søren Djørup Kirsten Hasberg Sara Fritz DHC+ Student Award Winner Spyridon Provatas **AUDITORIUM 2, 0.091 (floor 0)**

15:45-16:15 Coffee break

Tuesday 25 August 2015 · Overall programme (continued)

16:15-17:55 Parallel sessions 7-9

Track 7	Track 8	Track 9
Track 7: Smart Energy Systems **Chair: Erik Ahlgren, co-chair: Anders B. Hansen** **Session keynote: Anders B. Hansen** Damien Casetta Christoffer Lythcke-Jørgensen Jakob Z. Thellufsen Jørgen Boldt **PLENARY ROOM 1.001 (floor 1)**	**Track 8: Future district heating production and systems** **Chair: Leif Gustavsson, co-chair: Ingo Weidlich** **Session keynote: Ingo Weidlich** Goran Krajačić Oliver Martin-Du Pan Kenneth Hansen Paweł Gilski **AUDITORIUM 1, 1.008 (floor 1)**	**Track 9: Energy planning and planning tools** **Chair: Bernd Möller, co-chair: Sven Werner** **Session keynote: Sven Werner** Stefan Petrović Fanni Sáfián Richard Büchele **AUDITORIUM 2, 0.091 (floor 0)**

17.55 Wrap-up — **PLENARY ROOM 1.001 (floor 1)**

19:30 Conference dinner

19:50 Special guest speaker Steen Gade

Tuesday 25 August 2015 · Content of Tracks

Track 1: Smart Energy Systems - Chair: Jan Eric Thorsen, co-chair: Erik Ahlgren

Session keynote Erik Ahlgren: ***Assessing impacts of a regional collaboration on large-scale excess heat utilization***
Jean Duquette: *Assessing the Impact of Wave Energy Integration in a Remote Canadian Community Equipped With a District Energy Grid*
Amru R. Razani: *Genetic algorithm Technique to optimize the configuration of heat storage in DH Network*
Benedetto Nastasi: *Hydrogen to link Heat and Electricity in transition stage to Future Smart Energy Systems*

Track 2: Future district heating production and systems - Chair: Goran Krajačić, co-chair: Leif Gustavsson

Session keynote Leif Gustavsson: ***Renewable-based heat supply of multi-apartment buildings with varied heat demands***
David Maya-Drysdale: *Matching heat demand with heat supply resources in district heating systems*
Dražen Balić: *District heating as the thermal storage – support to the power system with potential for a higher integration of RES*
Oddgeir Gudmundsson: *Cost of District Heating and Individual Heating Technologies*
Veronika Wilk: *River water heat pumps for district heat supply in large cities in Austria: Study of potential and techno-economic optimization*

Track 3: Energy planning and planning tools - Chair: Sven Werner, co-chair: Bernd Möller

Session keynote Bernd Möller: ***A Pan-European Thermal Atlas of Potentials, Costs and System Properties***
Ekaterina E. Iakimetc: *Heat supply planning in the conditions of development of energy-efficient technologies in construction*
Lars Grundahl: *Comparison of heat atlas results with real-world measurements*
Romain S.C. Lambert: *Optimal multi-stage district heat expansion planning with real options*

Tuesday 25 August 2015 · Content of Tracks (continued)

Track 4: Low-temperature district heating grids - Chair: Carsten Bojesen, co-chair: Markus Köfinger

Session keynote Markus Köfinger:	***Low temperature district heating micro-networks in Austria: comparison of four case studies***
DHC+ SA Winner Wiet Mazairac:	*Integrated Modeling and Simulation of Electricity, Gas and Heat Networks Underlying a Sustainable City Infrastructure*
Edgars Vigants:	*Low return temperature impact to DH system efficiency. Case study*
Maksym Kotenko:	*Minimization of losses in low temperature district heating*
Soma Mohammadi:	*Determination of optimal supply temperature in existing district heating networks by applying new insulation series in pipes – A Thermo-economic analysis*

Track 5: Low-temperature district heating and buildings - Chair: Svend Svendsen, co-chair Anders Dyrelund

Session keynote Anders Dyrelund:	***The District Energy System – a cost effective virtual electricity storage***
Julio E.V. Rebollar:	*Nearly Zero Carbon neighbourhood development in Kortrijk (BE), implementation and first year monitoring results*
DHC+ SA Winner S. Paardekooper:	*Optimal heat pump use in European cities*
Kasper Qvist:	*Ultra Low-Temperature District Heating With 35 °C Supply Temperature*
Dorte S. Larsen:	*Possibilities and costs of preparing existing Danish single family houses from the 1930s for space heating with low-temperature district heating*

Track 6: Organisations, ownership and institutions - Chair: Bent Ole G. Mortensen, co-chair: Dagnija Blumberga

Session keynote D. Blumberga:	***Legislative analysis for the 4th generation district heating in Latvia. Riga case***
Søren Djørup:	*Public Regulation of District Heating Companies in a Smart Energy System*
Kirsten Hasberg:	*Development of an open heating platform – The case of Hamburg*
Sara Fritz:	*The impact of policies in the building sector influence the economic feasibility of district heating*
DHC+ SA Winner S. Provatas:	*An online machine learning algorithm for heat load forecasting in District Heating systems*

Track 7: Smart Energy Systems - Chair: Erik Ahlgren, co-chair: Anders B. Hansen

Session keynote Anders B. Hansen:	***Energy system integration with efficient use of high temperature excess heat***
Damien Casetta:	*Dynamic Modelling of a District Cooling Network with Modelica*
Christoffer Lythcke-Jørgensen:	*A method for designing flexible multi-generation plants*
Jakob Z. Thellufsen:	*Multiple Energy System Analysis of Smart Energy Systems*
Jørgen Boldt:	*Demonstration of 4DH solutions in a large city development area*

Track 8: Future district heating production and systems - Chair: Leif Gustavsson, co-chair: Ingo Weidlich

Session keynote Ingo Weidlich:	***Challenges in smart energy transport using trenchless technology***
Goran Krajačić:	*Contributing global CO2 mitigation by utilisation of food industry heat into smart Croatian DHS via Total Site heat recovery*
Oliver Martin-Du Pan:	*Heat Losses in District Heating Systems and Heat Meters*
Kenneth Hansen:	*Comparing heat supply to heat savings with a levelised costs approach and an energy system approach*
Paweł Gilski:	*Influence of stray currents on district heating pipelines failure rate*

Track 9: Energy planning and planning tools - Chair: Bernd Möller, co-chair: Sven Werner

Session keynote Sven Werner:	***European cooling demands***
Stefan Petrović:	*Ringkøbing-Skjern energy atlas for analysis of heat saving potentials in building stock*
Fanni Sáfián:	*Is there room for renewables in 2030? – analysing the effects of a new nuclear power plant in Hungary*
Richard Büchele:	*Comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling*

Wednesday 26 August 2015 · Overall programme

08:15-08:40 Coffee

08:40-10:20 Parallel sessions 10-12

Track 10	Track 11	Track 12
Track 10: Smart Energy Systems **Chair: Poul A. Østergaard, co-chair: Johan Desmedt** **Session keynote: Johan Desmedt** Lisa Brand Barbara Fricke Magdalena Berberich Natalia Kabalina **PLENARY ROOM 1.001 (floor 1)**	**Track 11: Future district heating production and systems** **Chair: Anders N. Andersen, co-chair: Goran Krajačić** **Session keynote: Goran Krajačić** Matteo G. Prina Leif Gustavsson Gunnar Lennermo Jacek Kalina **AUDITORIUM 1, 1.008 (floor 1)**	**Track 12: Energy planning and planning tools** **Chair: Xiliang Zhang, co-chair: Ralf-Roman Schmidt** **Session keynote: Ralf-Roman Schmidt** Paul Booij Weiming Xiong Tomislav Novosel **AUDITORIUM 2, 0.091 (floor 0)**

10:20-10:50 Coffee break

10:50-12:30 Parallel sessions 13-15

Track 13	Track 14	Track 15
Track 13: Smart Energy Systems **Chair: Frede Hvelplund, co-chair: Justin NW. Chiu** **Session keynote: Justin NW. Chiu** Peter Sorknæs Tim Farrell Johan Desmedt Dietmar Schüwer **PLENARY ROOM 1.001 (floor 1)**	**Track 14: Future district heating production and systems** **Chair: Allan N. Hansen, co-chair: Urban Persson** **Session keynote: Urban Persson** Dominik Bothe Jelena Ziemele Charlotte Marguerite Rasmus Lund **AUDITORIUM 1, 1.008 (floor 1)**	**Track 15: Low-temperature district heating grids/and buildings** **Chair: Morten Abildgaard, co-chair: Jan Eric Thorsen** **Session keynote: Jan Eric Thorsen** Marek Brand Christian Engel Xiaochen Yang José C. Flores **AUDITORIUM 2, 0.091 (floor 0)**

12:30-13:45 Lunch **PLENARY ROOM 1.001 (floor 1)**

13:45-16:45 2nd plenary session - Chaired by Henrik Lund

13:45 Keynote: Eva Hoos: *District heating and cooling in the EU energy policy framework and the EU Strategy for Heating and Cooling*

14:15 Keynote: Philippe Schild: *EU Research and Innovation towards an integrated approach on district heating and cooling*

14:45 Questions and discussion

15:15-15:45 Coffee break

15:45-16:30 Closing ceremony

The 3rd International DHC+ Student Awards

Best Presentation Awards to Senior and PhD Fellow, funded by Danfoss and Kamstrup

16:30-16:45 Closing remarks by Brian Vad Mathiesen

Wednesday 26 August 2015 · Content of Tracks

Track 10: Smart Energy Systems - Chair: Poul A. Østergaard, co-chair: Johan Desmedt

Session keynote Johan Desmedt: ***The role and potential of distributed thermal energy storage systems for active control of district heating networks***
Lisa Brand: *Prosumers in District Heating networks - problems and possibilities*
Barbara Fricke: *100% renewable municipal energy supply: Chances and restrictions of solar thermal district heating*
Magdalena Berberich: *Solar-CHP - development of multifunctional systems combining CHP with solar thermal plant*
Natalia Kabalina: *Exergy analysis of polygeneration DHC system based on the gasification of RDF*

Track 11: Future district heating production and systems - Chair: Anders N. Andersen, co-chair: Goran Krajačić

Session keynote Goran Krajačić: ***Reducing CO2 emissions and increasing the integration of renewables through the utilization of smart district heating system in the City of Velika Gorica***
Matteo G. Prina: *Smart energy systems applied at urban level: the case of the municipality of Bressanone-Brixen*
Leif Gustavsson: *Effects of energy efficiency measures in buildings on different types of district heating systems*
Gunnar Lennermo: *Decentralised heat generation in district heating systems*
Jacek Kalina: *Advanced hybrid and combined small-scale thermal energy conversion systems for efficient use of locally available resources*

Track 12: Energy planning and planning tools - Chair: Xiliang Zhang, co-chair: Ralf-Roman Schmidt

Session keynote Ralf-R. Schmidt: ***Feasibility of micro-DH networks in scattered urban areas using local sources: analyses of technical and non-technical barriers of a case study***
Paul Booij: *Integrated planning, design and operation of 4th generation district heating and cooling networks*
Weiming Xiong: *Case study of the constraints and potential contributions regarding wind curtailment in Northeast China*
Tomislav Novosel: *Heat demand mapping and the utilization of district heating in energy systems with a high share of renewables: Case study for the city of Osijek*

Track 13: Smart Energy Systems - Chair: Frede Hvelplund, co-chair: Justin NW. Chiu

Session keynote Justin NW. Chiu: ***Economic Assessment of Industrial Surplus Heat Transportation***
Peter Sorknæs: *The transition of small-scale CHP into market-based smart energy systems*
Tim Farrell: *District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*
Johan Desmedt: *The H2020 STORM project: Self-organising thermal resource management as future intelligent control of district heating and cooling networks*
Dietmar Schüwer: *The potential of heat and grid orientated block CHP on the minute reserve market and its impacts on CO2 emissions - prospects for the German energy market*

Track 14: Future district heating production and systems - Chair: Allan N. Hansen, co-chair: Urban Persson

Session keynote Urban Persson: ***Current and future prospects for heat recovery from waste in European district heating systems: A literature and data review***
Dominik Bothe: *Thermo-hydraulic simulation of district heating networks*
Jelena Ziemele: *System dynamics model analysis of pathway to 4th generation district heating systems in the Baltic States*
Charlotte Marguerite: *Selection of design scenarios for an industrial waste heat based micro-district heating network supplying low-energy buildings*
Rasmus Lund: *Mapping of potential heat sources for large heat pumps in Denmark*

Track 15: Low-temperature district heating grids / and buildings - Chair: Morten Abildgaard, co-chair: Jan Eric Thorsen

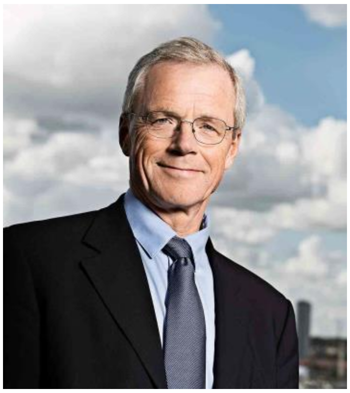
Session keynote Jan Eric Thorsen: ***Thermal length of heat exchangers for the next generation of DH substations***
Marek Brand: *District heating substation with electric booster supplied by 40°C warm district heating water*
Christian Engel: *Highly prefabricated, tailor made District Heating and Cooling networks*
Xiaochen Yang: *Analysis of individual heating unit for domestic hot water production in multi-storey buildings with low temperature district heating*
José C. Flores: *Conceptual Study of the Integration of Decentralized Solar Heat Generation to a Low-Temperature District Heating Network via Substation Net-Metering*

PLENARY KEYNOTE SPEAKERS

Xiliang Zhang, Professor and Director, Institute of Energy, Environment, and Economy, Tsinghua University; Deputy Director, Tsinghua-Rio Tinto RES Research Center

Prof. Zhang holds a Ph.D. in Systems Engineering from Tsinghua University. Dr. Zhang is currently Professor of Management Science and Engineering and director of the Institute of Energy, Environment and Economy, Tsinghua University. He is also deputy director of the Tsinghua-Rio Tinto RES Research Center. Prof. Zhang has conducted research on sustainable energy technology innovation and diffusion, markets, policies, and futures for China. Prof. Zhang served as the co-leader of the expert group for drafting China Renewable Energy Law during 2004-2005, and the energy expert of the expert group for drafting China Circular Economy Law in 2007, both works were organized by the Environmental Protection and Resource Conservation Committee of National People's Congress. Prof. Zhang is currently leading a national carbon market research project which aims at assisting National Development and Reform Commission (NDRC) in designing China's national carbon emission cap and trade scheme. Since 2012 he has been the principle investigator for the four-year research project "China's mid- and long-term low carbon development strategy" which is sponsored by the Ministry of Science and Technology with the support of NDRC. Prof. Zhang is also coordinating a research project entitled China Energy Revolution: targets, pathways and policies, which is tasked by the National Energy Administration. Prof. Zhang has been a lead author of the 4th and 5th IPCC Climate Change Assessment Reports.

Anders Eldrup was the CEO of DONG Energy for 10 years. He was the architect of the reorganisation of DONG's energy production from black to green energy – with a focus on the expansion of wind power and district heating production. Today, Anders Eldrup is an active member of various boards, primarily with a relation to energy.



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.

Dr. Philippe Schild is senior expert in the unit responsible of renewable sources in the Directorate General for Research and Innovation of the European Commission. He was trained as a plasma physicist. After working 10 years as a researcher in the Joint European Torus, the largest European experiment in fusion energy, he joined the team following renewable energy programme and project at the European Commission. He has managed projects in the fields of concentrated solar power, ocean energy, bioenergy and photovoltaics. He is now more involved in the aspect of emerging energy technologies and integration.

CONFERENCE CHAIRS

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

Professor Henrik Lund has served as 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 25 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 200 books or articles and is Editor-in-Chief of Elsevier international journal ENERGY. Henrik Lund is on the Thomson Reuters list of the most highly cited researches in the world within the topic of engineering.

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

Professor Brian Vad Mathiesen is one of Europe's leading researchers in renewable energy systems. His research focuses on the technological, economic and societal shift to renewable energy, through the use of energy savings and wind, photovoltaic and biomass resources. He has had a major impact on Danish renewable energy policies and 100% renewable energy target. Specifically, he has focused his research on Smart Energy Systems with large-scale integration of fluctuating renewable resources (e.g. wind power). For a decade, he has done research in energy planning, technical energy system analyses, feasibility studies, as well as public regulation and technological changes in society. In addition, Brian Vad Mathiesen is an editorial board member of the Journal of Energy Storage and the International Journal of Sustainable Energy Planning and Management. He has been a guest editor of six special issues of Elsevier's Energy – The International Journal and Applied Energy. He has published more than 100 scientific articles and reports and has an h-index of 23 in Scopus (1798 total citations, excl. self-citations).

ABOUT 4DH

The 4DH Research Centre is a unique collaboration between industry, universities and the public sector to investigate the potential for and develop the future district heating systems and technologies, known as 4th Generation District Heating (4GDH). This development is fundamental to the implementation of the European 2020 goals as well as future sustainable energy solutions in general. With lower and more flexible distribution temperatures, 4th generation district heating (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 a big 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, 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 cheapest low-carbon heating sector for Europe.

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

For reasons of copyright, the two journal papers ***4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems*** (Energy 68 (2014) pp. 1-11) and ***Smart Energy Systems for coherent 100% renewable energy and transport solutions*** (Applied Energy 145 (2015) pp. 139–154) are not included in this version of Book of Abstracts.

LIST OF PEER-REVIEWED JOURNAL ARTICLES, BOOK CHAPTERS, PHD DISSERTATIONS AND DEFINITION PAPERS

Journal articles:

- Lund, R.; Mathiesen, B.V.: "Large combined heat and power plants in Sustainable Energy Systems" in Applied Energy, Vol. 142, 2015 pp. 389-395

- Mathiesen, B.V.; Lund, H.; Connolly, D.; Wenzel, H.; Østergaard, P.A.; Möller, B.; Nielsen, S.; Ridjan, I.; Karnøe, P.; Sperling, K.; Hvelplund, F.: "Smart Energy Systems for coherent 100% renewable energy and transport solutions" in Applied Energy, Vol. 145, 2015, pp. 139–154

- Mischke, P., Xiong, W.: "Mapping and benchmarking regional disparities in China's energy supply, transformation and end-use in 2010" in Applied Energy, Vol 143, 2015 pp. 359-369

- Xiong, W.; Wang, Y.; Mathiesen, B.V.; Lund, H.; Zhang, X.: "Heat Roadmap China: New heat strategy to reduce energy consumption towards 2030" in Energy Journal, Vol 81, 1 March 2015, pp. 274–285

- Sorknæs, P.; Lund, H.; Andersen, A.N.: "Future power market and sustainable energy solutions – The treatment of uncertainties in the daily operation of combined heat and power plants" in Applied Energy Vol. 144, 2015, p. 129–138

- Chittum, A. and Østergaard, P.A.: "How Danish communal heat planning empowers municipalities and benefits individual consumers" in Energy Policy, vol. 74, pp. 465-474, November 2014

- Connolly, D.; Mathiesen, B.V.: "A technical and economic analysis of one potential pathway to a 100% renewable energy system" in International Journal of Sustainable Energy Planning and Management, Vol. 1, 2014, pp. 7-28.

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- Markovska, N.; Klemeš, J.J.; Duic, N.; Guzović, Z.: "Sustainable development of energy, water and environment systems" in Applied Energy, Vol. 135, 2014, pp. 597–599.

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- Mortensen, B.O.G.: "Legal Framework as a Core Element of District Cooling Success - The Case of Denmark" in Journal of Power and Energy Engineering, September 2014, Vol. 2, No 9, pp. 41-48

- Persson U.; Möller, B.; Werner, S.: "Heat Roadmap Europe: Identifying strategic heat synergy regions" in Energy Policy, vol. 74, pp. 663-681, November 2014

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- Urban Persson: "District heating in future Europe: Modelling expansion potentials and mapping heat synergy regions", Chalmers University of Technology, January 2015

Definition papers:

"Scientific excellence within research in future district heating systems and technologies", 4DH International Scientific Panel and Advisory Board, August 2015

ABSTRACTS

Xiliang Zhang, Professor and Director, Institute of Energy, Environment, and Economy, Tsinghua University; Deputy Director, Tsinghua-Rio Tinto RES Research Center. Prof. Zhang has conducted research on sustainable energy technology innovation and diffusion, markets, policies, and futures for China.

Plenary Keynote:

The Role of District Heating in China's Energy Revolution and Related Applications in the Northeast China

Xiliang Zhang (zhang_xl@mails.tsinghua.edu.cn)
Institute of Energy, Environment and Economy, Tsinghua University, Beijing, China

Facing challenges including serious environmental issues, climate change and supply restraints caused by the rapid growth of energy production and consumption in the last decades, China's government committed to a revolution in the way to produce and consume energy. District heating, which is preliminarily estimated to account for 4.7% of total energy consumption in China, is expected to play a significant role in the energy revolution. Our previous study has demonstrated the potential utilization of large-scale CHP plants, industry heat recovery and heat regulation system could contribute to a decrease in energy consumption for building heating by about 60% with 15% lower heating cost compared with the current, implemented heat strategy.
The "revolution" of district heating requires not only technology innovation, but also the reform of current mechanism among stakeholders. First, current pricing system for residence calculated by heating area rather than energy consumption has negative impact on incentive for energy saving on consumer side. Second, heating companies who take charge of heating grid regulation are owned by municipal government and supported by government subsidy, resulting low management efficiency and slow technical improvement. Third, the relatively stunted and closed heating market constrained the utilization of heat production from various resources and the integration of heating system with other energy system. Facing the complex and immature heating system structure, it is needed to change the way we produce and consume heat, and integrate heating system from system perspective. Thus, we studied the role of district heating in China's energy revolution from multi-regional computable general equilibrium (CGE) model with detailed disaggregation of China (the China Regional Energy Model, C-REM). It is shown that reform of district heating could provide approximately 2% reduction in energy consumption for whole China, together with 50% growth of building area in the next decade. We argue that pricing reform from area to energy consumption and energy contract management in market environment could lead to innovation in both supply and demand side.
Moreover, Case studies of integration between heat and electricity in Northeast China has been discussed. The results also indicate that the implementation of heat storage

systems and heat pumps could enhance the flexibility of an energy system, making it able to accommodate an increase of wind penetration. The potential benefit is also demonstrated in existing “Wind to Heat” projects to decrease wind curtailment and reduce coal consumption in district heating system. On top of this, mechanism reforms in district heating to encourage both technical innovation and management improvement should be evaluated and implemented from energy system perspective in a “revolution” background on the basis of current heating system.

Anders Eldrup was the CEO of DONG Energy for 10 years. He was the architect of the reorganisation of DONG's energy production from black to green energy – with a focus on the expansion of wind power and district heating production. Today, Anders Eldrup is an active member of various boards, primarily with a relation to energy.

Plenary Keynote:

District Heating – the Danish Case as an Export Model?

Anders Eldrup

The first oil crisis in 1973 hit Denmark very hard. That caused a dramatic turnaround in Danish energy policies focusing on renewables (primarily wind) and district heating. Today Denmark is a world leader in both areas.
But new challenges are ahead of us: How do we create a coherent system with a lot of volatile wind turbines and a need for servicing the heat consumption during the cold season? Another challenge is how to export the district heating model - with the same success as we are exporting Danish wind turbines?
The European Union is in a great transition on energy reducing the impact of coal and nuclear. The Danish experiences in sustainable energy production and coherent energy systems can be a useful model.

Track 1: Smart Energy Systems

Erik O. Ahlgren, M.Sc. in Engineering Physics from the KTH, Stockholm, carried out his PhD on solid oxide fuel cell materials at Risø/DTU. After postdoc years at Kyoto University, he joined Chalmers University of Technology, where he is now Professor, to work on energy systems analysis and modelling of biofuels, district heating, and energy and climate policy.
Akram F. Sandvall is a PhD student at Chalmers University of Technology, Energy Technology Division, in Sweden. She holds her master's degree in Energy and Environmental Engineering from Linköping University, Sweden, and received her Bachelor's degree in Chemical Engineering from Sharif University of Technology, Iran. She worked as a Quality Control Manager in Automotive Industry for 10 years in Iran.
Tomas Ekvall, PhD, is an expert in life cycle assessment and systems analysis with a special interest in the development of methodology and with experience from applications in, for example, the energy, waste and forestry sectors. A former Associate Professor at Chalmers University of Technology, he is the author or co-author of 34 peer-reviewed papers and well over 100 other publications.

Session Keynote:

Assessing Impacts of a Regional Collaboration on Large-scale Excess Heat Utilization

Akram Fakhri Sandvall (akram.sandvall@chalmers.se), Erik O. Ahlgren, Department of Energy and Environment, Chalmers University of Technology, Sweden*
and Tomas Ekvall, IVL Swedish Environmental Research Institute, Sweden

Industrial excess heat can be utilised in district heating grids through collaboration between the industry and district-heating utilities. There is a great potential for increased excess heat use in the district heating grids, and with future reduced temperatures in the district heating grids a very large share of the available excess heat can be utilised.
Two types of investments are required to access the heat: heat exchangers within the industries to extract the available heat and heat pipelines connecting industries and urban district heating systems. In many cases, the lengths of the required heat pipelines are considerable and thus the pipeline investment cost constitutes a major barrier to the excess heat collaborations.
We selected a case in West Sweden where discussions on an excess-heat collaboration between a cluster of chemical industries and district heating systems have been initiated. We applied a regional, dynamic modelling approach combined with stakeholder interactions to assess the cost-efficiency of the discussed collaboration and its carbon impact. A long-term assessment time horizon is applied corresponding to the long lifetime of the addressed investment. Two scenarios representing different climate policy futures are assumed.
Since biomass is the most important fuel in Swedish district heating systems, and increased competition for constrained biomass resources are likely in low carbon futures, assumptions of future biomass supply are essential for the study. Based on current regional biomass flows, an initial regional biomass market based on supply curves is

assumed which is gradually substituted by a developing biomass market with international biomass prices.
The results show that the discussed excess heat collaboration would be cost-efficient under most scenarios but also that it is sensitive to assumptions of the development of the district heating systems and the pipeline cost.
The environmental impact of the excess-heat collaborations depends on the district heating fuels being substituted by the excess heat and also on the amount of combined heat and power in the systems. Thus, they are highly case sensitive. The system carbon impact varies from positive to negative depending on the assumptions made on the marginal electricity production. The reason is that the excess heat is likely to reduce the use of combined heat and power and thus leads to reduced electricity generation in the local or regional district-heating grid. Finally, due to the partly counterintuitive results of the environmental impacts calculations, the paper concludes that a careful methodological approach is essential.

Jean Duquette is a PhD student at the University of Victoria in Canada. His research interests include modelling and simulation of renewable energy and CHP based district energy systems. His most recent paper (02/2014, Energy – The International Journal) is a study assessing the potential benefits of widespread combined heat and power based district energy networks in the province of Ontario.

Assessing the Impact of Wave Energy Integration in a Remote Canadian Community Equipped with a District Energy Grid

*Jean Duquette** (duquette@uvic.ca), *Brad Buckham, Peter Wild and Andrew Rowe*
Institute for Integrated Energy Systems, Department of Mechanical Engineering, University of Victoria, Canada

The majority of remote communities in Canada currently rely on centralized diesel generator plants for meeting their electricity needs and decentralized heating plants (i.e. individual building heating systems) for meeting their space heating and domestic hot water needs. Concerns over rising energy costs and growing CO_2 emissions are forcing these municipalities to revamp their energy system infrastructure. Many have begun the transition by displacing diesel capacity with renewable energy technologies; powered primarily from wind, solar, and/or micro-hydro resources. Coastal communities have the added benefit of accessing wave energy as a potential energy resource. Wave energy is considered to be a viable energy source in many coastal regions exhibiting appreciable wave climate. In the current research, the technical viability of integrating wave energy into a remote coastal community grid is assessed. Two scenarios are analyzed. Scenario 1 considers an electrical grid comprised of a diesel plant, a wave energy converter, a battery bank, and a dump load. Scenario 2 considers a district energy grid (i.e. an integrated electrical and thermal grid) comprised of a diesel combined heat and power plant, a wave energy converter, a battery bank, a thermal storage tank, and a boiler plant. In scenario 1, wave and diesel energy are utilized for meeting the electrical load and heating loads are met separately via decentralized heating systems. In scenario 2, wave and diesel energy are utilized for meeting electrical and heating loads simultaneously. Due to the complex nature of the investigation, a community-scale time series model is constructed in Matlab/Simulink and used to evaluate energy system dynamics. Hourly time steps are used in the simulations for the duration of one year. Potential reductions in fuel utilization and CO_2 emissions relative to the reference case (i.e. centralized diesel generation and decentralized heating) are quantified for both scenarios. A case study is developed using the Hesquiaht community, located on the west coast of Vancouver Island in British Columbia. Results show reductions in fuel utilization and CO_2 emissions of 20% and 15% respectively from the reference case to scenario 1, and 35% and 27% respectively from the reference case to scenario 2. The decrease in fuel utilization and CO_2 emissions from scenario 1 to scenario 2 can be attributed in part to greater levels of wave energy and waste diesel heat being directed at thermal loads (e.g. dumped wave energy in scenario 1 becomes useful heat in scenario 2). The study illustrates the efficiency gains made possible when using a district energy grid in lieu of an independent electrical grid for wave energy integration.

A.R. Razani is a Research Associate at Fernwärme Forschungsinstitut in Hannover since 2012 and holds a M.Sc. in Computational Science in Engineering.

Genetic Algorithm Technique to Optimize the Configuration of Heat Storage in DH Network

A.R. Razani (razani@fernwaerme.de) and I. Weidlich*
FFI, Fernwärme Forschungsinstitut in Hannover e.V., Germany

The technical and economical evaluation of heat storage layout and configuration in the DH network is one of important aspects for optimizing the heat production from the heat supplier point of view at one side. In the other side, it is also necessary to adapt the heat customer behaviour and heat demand due to heat production capacity of the supplier.
Generally, this paper has considered three optional planning layouts for DH network. A classical network with centralized heat storage, some decentralized storages in the middle of the network, and decentralized small storages at the substations or in the customer building. All of those heat storage configurations are operated by CHP in a DH system.
As a matter of fact, Genetic Algorithm (GA) is proven to be a robust technique for finding a good approximation of the optimal solution from nonlinear, stochastic data set. In this paper, the proposed investigation will be performed through the implementation of genetic algorithm technique. Three different scenarios will be compared to find the optimal planning of heat storage layout in CHP based DH system according to economical and technical aspects of the network. The investigation includes results from various network planning processes and further results of the simulation in virtual DH network with the comparison of proposed scenarios.

Benedetto Nastasi is Architectural and Building Engineer and PhD Fellow at Sapienza University of Rome, Italy. His research is focused on the role of eco-fuels in transition towards a low carbon city and society, in a new relation between the urban and rural environment in the energy planning field. He is an expert of Sustainable Energy Action Plans, renewable energy technologies and their integration in urban and agricultural planning.

Hydrogen to Link Heat and Electricity in Transition Stage to Future Smart Energy Systems

Benedetto Nastasi (benedetto.nastasi@outlook.com)*
Department of Astronautical, Electrical and Energy Engineering (DIAEE), Sapienza University of Rome, Italy

Combined Heat and Power (CHP) and District Heating and Cooling (DHC) technologies provide clear thermodynamic and environmental benefits as well, thanks to their enhanced system efficiency and integration with Renewable Energy Sources (RES). CHP and DHC are also well-proven options to link heat and electricity production, which will be the energy challenge in smart energy systems at urban, regional and national scale. Currently, two fundamental issues are related to the energy field: the design of new high efficiency systems and the use of new Eco-fuels. However, the substantial contribution should be addressed how to manage this energy transition.
As regards the first issue, waiting for new cutting-edge solutions and their wide deployment, both CHP and DHC can therefore be an essential part of the transition phase towards 4th Generation District Energy Systems. While, in the matter of new fuel, hydrogen (H_2) can play a key role due to its double application: as a fuel for combustion or chemical conversion as well as an energy storage medium for RES mismatch compensation. Indeed, H_2 dual use allows it to be identified as a viable energy carrier and ideal for smart energy systems interaction in producing both thermal and electrical energy.
From such point of departure, the study defines different energy scenarios in which suitability of local and large scale of Renewable H_2 production is discussed along with its uses: a direct use in Fuel Cell (FC) for electricity purpose, a direct mixing in Natural Gas (NG) pipelines or indirect in Hydro-methane (H2NG) blends to feed DHC grids. By use of Carbon Avoidance Cost Analysis, the best solution will be a combination of centralized and distributed generation, involving building, district and regional scales to minimize the need of new national infrastructures.
In order to enable large scale commercial availability of H_2 technologies, this paper makes a first attempt to compare the feasible scenarios, allowing the competitiveness with fossil fuel-based conventional solutions under prevailing economic and regulatory conditions. The results indicate that such scenarios, in current energy transition, should be promoted by a dedicated incentive scheme to achieve overall sustainability levels.

Track 2: Future District Heating Production and Systems

Nguyen Le Truong (main author) is a postdoctoral researcher at the Department of Built Environment and Energy Technology, Linnaeus University, Sweden. He has experience as a consultant and trainer in energy efficiency and renewable energy projects. His research focus is to use the concept of system analysis to compare primary energy use and life cycle monetary cost of different heat production technologies and systems.
Professor Leif Gustavsson (presenting author) has a PhD in Environmental and Energy Systems Studies, a M.Sc. in Civil Engineering and a M.A. in Psychology. His research is linked to sustainable development, especially building construction, energy efficiency and renewable energy. The aim of his research is to increase the understanding of how resource- and cost-efficient systems with low environmental impact can be designed, analysed and implemented.

Session Keynote:

Renewable-based Heat Supply of Multi-apartment Buildings with Varied Heat Demands

Nguyen Le Truong (nguyen.truong@lnu.se), Leif Gustavsson and Ambrose Dodoo*
Department of Built Environment and Energy Technology, Linnaeus University, Sweden

There are various ways to satisfy heat demand of buildings, and renewable-based heating is crucial in the pathway toward a more sustainable energy system. However, cost-optimal options for a multi-apartment building depend on the availability of systems and technologies at the building site and also on the scale of heat demand. District heat based on combined heat and power production (CHP) has proven to be a primary energy-efficient option for heating purposes in the residential sector. However, for customers with a low heat demand, local heat supply options may be more cost-efficient. This study investigates cost-optimal options for supplying heat to an existing multi-apartment building in Växjö city, Sweden. Renewable-based alternatives are considered including district heat from systems of different scales, and local heat production based on electric resistance boiler, ground-source electric heat pump and wood pellet boiler, also combined with solar heating systems. Furthermore, how the change of the annual heat demand profile due to energy-efficiency measures influences the cost and primary energy efficiency of the different heat supply technologies are evaluated. The results show that the availability of heating technologies at the building site and the scale of building's heat demand significantly influence the cost and primary energy efficiency of heating option. District heat, which is primary energy efficient if produced by CHP units, is to be cost efficient for the multi-apartment building but only without energy-efficiency improvements. There is also a trade-off between heating cost and primary energy use in supplying heat to multi-apartment buildings.

David Maya-Drysdale works in the Sustainable Energy Planning and Management Research Group at Aalborg University, Denmark. In this group he focuses on 100% renewable energy system modelling and scenario analysis. He is investigating economic, environmental and political aspects along with the technical analysis.

Matching heat demand with heat supply resources in district heating systems

David Maya-Drysdale (drysdale@plan.aau.dk), David Connolly and Kenneth Hansen*
Department of Development and Planning, Sustainable Energy Planning and Management Research Group, Aalborg University Copenhagen, Denmark

As national heat supply shifts away from fossil fuels towards low carbon sources it is vital to understand the future heat demand of a country and the local heat resource availability to meet this demand. In this study a methodology is described that matches future heat demand with available renewable heat resources for district heating (i.e. solar thermal, geothermal, industrial excess heat, waste incineration, and large scale heat-pumps). Using five European countries as a case study (Croatia, Italy, Romania, United Kingdom, Czech Republic) the methodology was developed and tested. The study highlights the potential for renewable district heat in the future and identifies the potential shortcomings. Some key elements in the present methodology that are described in this paper are about: mapping the country's heat demand, location and demand type; heat supply from CHP and heat plant units; renewable heat resource availability and supply; balancing baseload and flexible heat supply; and matching supply with hourly heat demand distributions. The heat demand and potential renewable district heat is a key component in this methodology since it provides an indication where heat needs to be supplied and by which renewable energy sources. The location of renewable energy resources is also important since this can shape the nature of the district heat supply and can determine the feasibility for renewable district heat and this is very different in each country. The type of heat supply is determined by the heat source, for example it helps determine whether heat is supplied by large or small heat plants. In each country the heat demand profile is different therefore the balance between baseload and flexible heat demand is important therefore this split is quantified in the methodology. The methodology was not applied in isolation from the other sectors of the energy system but was applied in the entire energy system, thus the results are shown for the heat system when combined with the entire energy system. The results are compared to a business as usual energy system from 2050 in order to understand the implications of the renewable district heat system. The methodology can be used as a framework for future heat demand and supply analysis in other countries, where the demands and resources are mapped according to demands and potentials (and costs) and this is balanced in the system. The methodological framework has numerous elements which work in combination.

Drazen Balic graduated summa cum laude from Faculty of Mechanical Engineering and Naval Architecture at the University of Zagreb, Croatia in 2013. During his study, he worked on mathematical modelling and optimization of energy systems. He joined Energy Institute Hrvoje Pozar in 2014 and is currently working on projects related to district heating systems.

District Heating as the Thermal Storage – Support to the Power System with Potential for a Higher Integration of RES

Drazen Balic (dbalic@eihp.hr) and Danica Maljkovic*
Energy Institute Hrvoje Pozar, Zagreb, Croatia

Contemporary energy system faces new challenges on the energy market. Due to the fact that ratio of renewable energy sources characterised by the intermittent electricity production (mostly wind power and photovoltaics) increases steadily as well as the fact that energy efficiency in buildings is being improved, conventional power plants coupled with district heating system must reconsider their role in the energy system. Namely, it can be observed that existing energy system is over capacitated with the installed power of the conventional CHP plants. Moreover, the price of electricity determined by the *merit-order* system additionally decreases the load factor of such plants making them even more uncompetitive or they are even forced to operate with a financial loss. In the present paper the novel approach of how the conventional CHP plants coupled with district heating system can reinforce their position on the energy market is presented. The proposed solution is by participating in the ancillary services, through determination of dynamical performances of district heating system – capability of energy accumulation and thermal inertia. It is concluded that district heating system, i.e. network of pipelines can be considered as a dynamical thermal energy storage in which excess energy can be stored during the various situation of operation of power plant (CHP). In that way decoupling of the fast bond between production of electricity and heat is enabled. In the research presented in paper mathematical model is developed which simulates dynamics of simplified district heating system. In addition, mass flow control as well as rotation speed control of the circulation pump is developed and applied to the model. The input data are for the characteristic winter day for the continental part of Croatia. The simulation has shown that in the case of a network only 9000 m long it is possible to store approximately 870 kWh of thermal energy within 7 hours. However, with an increase in the network length the accumulation capacity of network increases with the gradient of 0.155 kWh per meter. Moreover, the capability of energy accumulation is explored for different parameters, such as: external temperature, distance of the network, supply water temperature etc.

Oddgeir Gudmundsson is M.Sc. in Engineering from University of Iceland in 2008. He has worked as Application Specialist at Danfoss District Energy for 3 years, specialising in all matters related to district energy including product development and establishing and renovating district heating networks.

Cost of District Heating and Individual Heating Technologies

Oddgeir Gudmundsson (og@danfoss.com), Jan Eric Thorsen and Marek Brand*
Danfoss A/S – Heating Segment – Application and Technology, Nordborg, Denmark

With the increasing focus on environmental impact from energy generation in the energy sector, high focus has come on energy efficiency. To achieve the energy efficiency it is important to: a) remove unnecessary energy consumption, b) ensure high efficiency in processes when energy utilization is actually needed and c) generate the energy in the most energy efficient way. Of these a) is the low hanging fruit and can be achieved for example with automatic stand-by of heating installation when people are in the work or smart integration between the heating installation and electric appliances. Once a) has been tackled it is natural to focus on b) by optimizing the processes using energy, this can be achieved for example by optimizing buildings using energy saving measures. At the same time as a) and b) are considered on a building level c) should be addressed by the energy supplier. The energy supplier should focus on utilizing the most energy efficient and environmentally friendly energy source for supplying the required energy. This paper will focus on c) related to heating purposes, which is the single largest energy process in the world. Depending on the location it can represent 30-60% of the final energy consumption in a given country.

It is commonly assumed that the cost of heat from district heating is high. This is often a misunderstanding originating from the fact that establishing a district heating systems requires high upfront investments, typically funded by a single entity, in the distribution grid and the heat plants supplying the heat.

The aim of this article is to provide means to estimate the cost of heat from district heating supplying heat from multiple heat sources to area with heat demand density corresponding to typical outer city areas. The cost of district heating is then compared to the cost of heat from commonly applied individual heating technologies.

The main conclusion of the paper is that district heating is the most sensible way of providing heat to cities both in terms of cost and environmentally friendliness. District heating is and will be an important player in the future heat market.

Veronica Wilk has joined AIT's Energy Department as scientist in 2014 and is primarily involved in R&D projects on heat pump systems for industrial applications. She holds a master's degree in Chemical Engineering and a PhD from Vienna University of Technology, Austria which she received in 2013. She has worked as researcher at Vienna University of Technology and at the competence centre Bioenergy2020+.

River Water Heat Pumps for District Heat Supply in Large Cities in Austria: Study of Potential and Techno-economic Optimization

V. Wilk (veronika.wilk@ait.ac.at), B. Windholz and T. Fleckl*
AIT Austrian Institute of Technology GmbH, Energy Department, Sustainable Thermal Energy Systems, Vienna, Austria

Currently, cities are responsible for 75 % of global CO_2 emissions according to a UNEP report. Owing to continuous urbanization, roughly 80 % of the global population is projected to live in urban areas by 2050.[1)] Therefore, reduction of urban CO_2 emissions is an important goal to address the challenges of climate change and global warming.

Heat pumps for district heating purposes allow for reduction of fossil fuel consumption and decarbonization in cities. They valorize ambient heat and are an efficient technology for electricity-based heating. Large cities are often found close to large rivers, which are an abundant source of ambient heat. Heat pumps that use water from rivers as heat source are well suited to increase the share of renewable heat in cities.

This article presents a detailed simulation on heat pumps for district heating. It is investigated how three major cities in Austria can be supplied with district heat provided by a large scale heat pump system. A slip stream from a local river is used as heat source. The required capacity and condensation temperature of the heat pump system depend on the properties of the river and the demand of the district heating grid. Therefore, seasonal variations of the river flow and temperature are considered as well as the supply temperature and flow of the district heating grid. A year of operation is simulated with these boundary conditions on an hourly basis. There is also a peak load heat source in the district heating grids. Hence, a special focus is set to the comparison of heat pumps as base load and natural gas boilers or electrical heaters as peak load heat source. The aim of the simulation is to evaluate the optimal heat pump configuration in terms of required capacity and condensation temperature. The optimal configuration depends on the different targets that could be achieved by implementing heat pumps in district heating grids. These targets are discussed: minimizing CO_2 emissions and minimizing primary energy consumption and maximizing economic outcome. The techno-economic evaluation is based on actual investment and operation costs for heat pumps, gas boilers and electrical heaters. Differences among the three cities are also evaluated and critically discussed.

[1)] *United Nations Environment Programme. Sustainable, resource efficient cities – making it happen! Technical report, UNEP (2012).*

Track 3: Energy Planning and Planning Tools

Professor Bernd Möller holds an engineering degree in power systems and a PhD in energy planning. Research interest is centred around the geographical link between technology, economy and location of sustainable energy systems. He is in charge of the global M.Eng. programme Energy and Environmental Management in Developing Countries at Europa-Universität Flensburg, Germany.

Session Keynote:

A Pan-European Thermal Atlas of Potentials, Costs and System Properties

*Bernd Möller** (Bernd.Moeller@uni-flensburg.de), Energy and Environmental Management, Europa-Universität Flensburg*
Sven Werner and Urban Persson, Halmstad University, Sweden

Heating and cooling are important elements in the formulation of energy strategies in all EU member states. One of the elements of such strategies is a transition from individual, carbon intensive and fuel cost sensitive to collective heat and cooling supply based increasingly on renewable energy sources. It is here pertinent to know where and to which extent these systems of district heating and cooling can be developed, at which cost, and with which local resources available. The present paper presents a hitherto unprecedented approach to map heating and cooling demands, the costs of district heating and cooling systems, as well as the available sources of waste heat and renewable energy sources at a very high geographical resolution. A Pan-European Thermal Atlas is being developed, at the core of which there is a common spatial reference of fixed area units such as grid cells. Each of these cells contains data for the potentials as well as costs, mapped as continuous fields. A combined bottom-up and top-down approach associates highly detailed population and land use data to qualitatively and quantitatively describe the urban thermal energy demand pattern by means of spatial statistics. National energy statistics are distributed to small scale statistics of demography and economic development in order to meet the geographical basis of urban energy demands. Costs of district heating and cooling infrastructures are calculated for each location on the basis of calculated heating and cooling demand densities as well as empirically derived cost functions. Coherent urban areas are joined to form agglomerations of heat demand, which may be candidates for district heat development. For these systems a number of properties are derived by means of spatial analysis, such as system size, administrative or topographical data. Potentials for renewable energy sources such as biomass, solar, geothermal or ambient energy (for large-scale heat pumps) are mapped. The overlay of potentials and costs as well as additional system parameters then allows for an analytical approach to cost-supply analysis by means of a relation between cumulative potentials of district energy supply and their marginal costs. In-depth cost-supply analysis enables planners to distinguish between technical and economic potentials and a series of other decision parameters such as size of operation,

socio-economy, or competing technologies. The results show that district heating and cooling supplies are economical in several large metropolitan areas as well as many cities and towns across Europe. By means of cost-supply analysis of potentials by system size and the availability of waste heat and renewable energy resources the socio-economic potentials for integrated sustainable energy systems analysis have been produced. The heat and cooling markets for each member state have been described by potentials, costs and supply technologies. The results of the present paper have been used in the ongoing Stratego project, where district heating and cooling options are identified and analysed as part of national energy scenarios for several target countries.

Ekaterina E. Iakimetc graduated from The Amur State University (Blagoveshchensk, Russia) in 2009. She is currently a Junior Researcher at the Department of Pipeline systems, Melentiev Energy Systems Institute SB RAS. Her area of research is the innovative directions of heat supply systems' development on the basis of an optimum combination of the centralized and distributed energy systems.

Heat Supply Planning in the Conditions of Development of Energy-efficient Technologies in Construction

Ekaterina E. Iakimetc (yakimetse@isem.sei.irk.ru) and Valery A. Stennikov*
Department of pipeline systems, Melentiev Energy Systems Institute SB RAS, Irkutsk, Russia

New challenges, including modern urban policy, formation of the market of power effective technologies and the equipment of wide range of power, increased requirements to reliability, quality, economic availability of heating cause importance of the solution of problems of territory zoning by type of heat supply on centralized and decentralized areas. The modern energy effective technologies which application is regulated by the legislation have reduced heat consumption of buildings by 30-40%. In addition to this, low-rise construction is actively developing. The construction of such energy efficient buildings has changed the map of heat load density. The need to solve the problems of planning and justification of the rational level of centralization and concentration of sources' heat capacity was noted in the law "About a Heat Supply". For the solution of these tasks, authors developed a technique[1,2] which allows to define the locations of heat sources and border of their action at the predesign level of heat supply schemes' development of settlements. Basing on results of the previous researches[3,4], the real work continues and develops main pro-visions of these investigations and takes into account features of a modern situation and new tendencies in a heat supply. Other scientists[5,6] are holding research in this area, but their results cannot be applied to the Russian systems due to the fundamental differences in the conditions of their operation.

In the work, except the technique the algorithm for heat supply planning is offered. In the technique, standard values of heat density per unit of the area (heat density) and per unit of the pipelines' length (linear heat density) are criteria of systems scales restriction. The important task is to find their normative values. Authors offer dependences for determination of standard values of heat density indicators for carrying out the predesign analysis of heat supply systems. Main attention in the article is paid to working out these dependencies. Also, proposals for differentiation of criteria' normal values on the country territory are offered, taking into account economy of regions and features of formation of heat supply systems. Standard values of indicators depend from building density, rise of buildings, type of a heat source, the characteristics of pipes (roughness factor, local resistance, etc.).

The carried out analysis showed that a heat supply of part of consumers is inefficient if the value of heat density indicators less than standard value. The less are heat density indicators in system, the more are specific costs for production and transport of heat energy.

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Lars Grundahl is a 1st year PhD fellow at Aalborg University and part of the 4DH research centre. The focus of his research is to use GIS (Geographical Information System) in the development of energy atlases to support spatial heat planning.

Comparison of Heat Atlas Results with Real-world Measurements

Lars Grundahl (lgr@plan.aau.dk)*
Department of Development and Planning, Aalborg University, Denmark

Recent Danish studies show that higher heat coverage by district heating is an important part of a smart energy system with a high renewable energy penetration. These studies also show economic benefits of expanding the district heating coverage. In order to determine where the border between district heating and individual heating should be, an accurate tool is needed. In Denmark a heat atlas has been developed with the single building as the smallest unit. However, the heat atlas is, to some extent, based on average national values on heat consumption in different building types and ages. It is therefore not a certain measure of the consumption in the specific building as this also depends highly on the use of the building. This study is looking into the differences and similarities between the calculated heat demand of individual buildings in the heat atlas and actual measured data of the heat consumption in the same buildings.
The aim of the study is to investigate the accuracy of the Danish heat atlas by comparing the results with real-world data. In this way, it is possible to identify areas where improvement in the prediction capability of the heat atlas is needed. It is also a verification process of the heat atlas with a focus on defining to what level it can accurately be used to estimate heat demands in areas of buildings.
A comparison between the calculated heat demands of the single buildings in the heat atlas and real world measurements of the actual buildings is performed. Statistical analysis is applied to the two datasets with a two-fold focus. Firstly, to identify similarities in results for building types or areas where the heat atlas has a high accuracy and secondly, to identify buildings types or areas where the need for improvement is high. In this way the focus on improvements to the heat atlas can be focused on the latter.
The study results in higher certainty of the accuracy of the heat atlas. It also identifies building types and areas where there is a need for improvement of the calculation model in the heat atlas.
By verifying the accuracy of the heat atlas, it can be used with more certainty and better knowledge of the accuracy of the results. In this way, the utilization of the tool in actual planning for the Danish heating sector is improved. Further, by identifying in which areas or building types the heat atlas is lacking accuracy it is possible to consider this in the results of calculations using the tool. It also encourages further work on improving the accuracy.

Romain S.C. Lambert is a postdoctoral research associate at Imperial College London at the Department of Chemical Engineering. He is a team lead for the European Commission’s ’CELSIUS’ project on district heating and cooling and has a background in model predictive control. Current research interests include the use of real options for optimal decision making for district energy investments.

Optimal Multi-stage District Heat Expansion Planning with Real Options

Romain S.C. Lambert (romain.lambert08@imperial.ac.uk), Nilay Shah*
Department of Chemical Engineering, Imperial College London, United Kingdom
and John Polak, Department of Civil Engineering, Imperial College London, United Kingdom

Intelligent district heating and cooling network planning is of crucial importance for the development of district energy in EU countries with low market penetration. In order to be competitive with centralized energy markets, it is not only essential to design the most economical networks but also to design a risk-averse staged deployment strategy. Most research efforts have, thus far, been focused on the mapping of heat demand and heat sources through the use of geographical information systems[1)2)] and the use of mathematical programming for cost minimization purposes and for optimal asset sizing[3)4)5)]. In this paper the emphasis is put on the optimal scheduling of capital investment under uncertainty using real options and sensitivity analysis. Real options have been a very successful methodology for strategic investment decision making in the presence of uncertainty[6)7)]. The modular nature of district heating networks makes them a perfect candidate for the use of these financial evaluation techniques. The proposed methodology aims to provide the optimal development strategy for a district heating network via the selection of the best development stages in the presence of demand uncertainty. The approach consists of solving a stochastic multi-stage mixed integer linear program at every time step of the investment horizon as information about uncertain parameters becomes available. This offers the possibility of a planning policy that can adapt to changes in circumstances in order to minimize risk. Other important aspects such as the network robustness and fuel poverty reduction are also taken into account.

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Track 4: Low-temperature District Heating Grids

Markus Köfinger has been working for AIT (Austrian Institute of Technology) in the field of sustainable thermal energy systems for more than 5 years. As project manager and project team member, he is currently involved in national and international district heating research projects. He is also active in the international CEN-Workshop for Eco-efficient substations.

Session Keynote:

Low Temperature District Heating Micro-networks in Austria: Comparison of Four Case Studies

Markus Köfinger (markus.koefinger@ait.ac.at), Daniele Basciotti and Ralf-Roman Schmidt, Austrian Institute of Technology, Energy Department, Vienna, Austria*
Lucas Konstantinoff, Management Center Innsbruck, Austria
Ernst Meißner, Grazer Energieagentur, Graz, Austria
Christian Doczekal, Güssing Energy Technologies, Güssing, Austria
Heinrich Ondra, Wien Energie, Vienna, Austria

In order to economically and ecologically meet the low heat demand (space heating and domestic hot water) of passive and low energy houses by district heating networks, innovative concepts for the production, distribution and supply of thermal energy have to be developed. For that scope one option is to distribute low supply temperatures (defined below 65°C) in the network. This enables on the one hand the use of heat from (renewable and alternative) sources that have so far been neglected due to the high supply temperatures used in conventional district heating systems and on the other hand, lower supply temperatures reduce the heat distribution losses (therefore operational costs) as well as investment costs (possibility to use plastic pipelines).

In the present study economically and ecologically optimized concepts for low temperature district heating (LTDH) micro-networks tailored to different regions in Austria were developed: In particular the following four representative case studies were investigated on a simulation basis: Aktivpark Güssing, Seestadt Aspern (Vienna), Winklweg Siedlung (Wörgl, Tyrol) and Hummel Kaserne (Graz). For all case studies appropriate scenarios were developed and different coupling concepts (e.g. cascaded usage of heat, usage of DH return lines, etc.) and framework conditions were considered with reference to the local consumption and production of heat. At the same time different economic developments were compared and assessed. Customised technical approaches which guarantee the hygienic supply of domestic hot water were developed resulting in 6 alternatives for domestic hot water preparation (e.g. direct heating, additional heating, micro booster HP).

To determine advantages and disadvantages, LTDH network scenarios were compared with conventional high temperature DH scenarios and individual heating systems (e.g. fossil boilers). In the simulation environment Dymola, Modelica models of the case studies were developed and dynamic simulations of the different scenarios were run to display the complex interactions between the different components in the systems and to test different control strategies and connection types. In order to develop economically meaningful options, monitoring concepts were developed and models assuring a high level of consumer acceptance were conceived and discussed resulting in appropriate business models.

Wiet Mazairac is runner-up award winner of the DHC+ Student Award. As PhD Fellow at VITO and Eindhoven University of Technology, The Netherlands, he is developing a city energy networks model, which enables the integrated modeling and simulation of electricity, gas and heat networks underlying a sustainable city infrastructure.

Integrated Modeling and Simulation of Electricity, Gas and Heat Networks Underlying a Sustainable City Infrastructure

Wiet Mazairac (wiet.mazairac@vito.be), (TU/e, VITO), Robbe Salenbien (VITO), Dirk Vanhoudt (VITO), Johan Desmedt (VITO) and Bauke de Vries(TU/e)*

The energy sector faces numerous challenges, e.g. the depletion of fossil fuel reserves and the impact of fossil fuels on our environment. A transition towards a renewable energy system will resolve these issues. However the current energy distribution system, which was designed to distribute energy from few producers among many consumers, is not able to cope with mass integration of renewable energy systems.

Multi-carrier hybrid energy distribution networks will be able to cope with mass integration of renewable energy systems. Instead of a network connecting few producers to many consumers, future networks will interconnect energy units, which are simultaneously producer and consumer. Hybrid energy networks also provide flexibility in the case of network malfunctions, energy shortages or price fluctuations. The strong interconnection between the different energy carriers makes it possible to convert energy from one form to another, which enables consumers to change from carrier or to bypass a broken connection.

This paper presents the ongoing PhD research project in which an approach is being developed to determine the optimal topology of a hybrid energy distribution network. This approach determines the location of energy distribution lines, conversion and storage units, given the location of energy producers and consumers in order to find the optimal balance between capital, operational and maintenance costs on the one hand and revenue on the other hand.

Two optimization techniques have been applied, first to single-carrier networks and then to multi-carrier networks. The first, the cross-entropy method, clearly separates the model and the optimization algorithm, which allows for a flexible, detailed model. The second, the linear programming method, integrates the model and the optimization algorithm, which imposes a restricted model. Both methods return plausible results, however the cross-entropy method is computationally expensive.

In the near future an algorithm, which determines the optimal location and characteristics of possible storage units, will be added to the optimization model. This requires a dynamic optimization model for which load profiles are generated by a hidden Markov model.

Dr.sc.ing. **Edgars Vigants** is a known energy and environmental expert in Latvia, who actively participates in development of energy policy, professional associations and in scientific research. Edgars Vigants leads the companies Ludzas Bio-Energija (heat production from biomass) and BALTENEKO (small-scale cogeneration projects), is a board member of the Latvian Renewable Energy Federation, Latvian District Heating Association and also actively participates in other public organizations.

Low Return Temperature Impact to DH System Efficiency. Case Study

Girts Vigants, Edgars Vigants(Edgars.Vigants@balteneko.lv), Ivars Veidenbergs, Dagnija Blumberg*
Institute of Energy Systems and Environment Riga Technical University, Latvia

The creation of the 4th generation district heating systems is simpler and easier justifiable for the systems which already have reduced temperatures or the operational efficiency of the source depends on water temperature levels in the heat network. It particularly concerns the systems with flue gas condensers after the boilers.

To begin the progress towards the 4th generation district heating system it is necessary not only to analyse the existing system but also to understand what is the main leading parameter in this way. The analysis of the operational data for the Ludza district heating system shows that the energy efficiency of the system can be increased if the temperature of return water is decreased. It can be explained with the fact that wet wood chips (moisture content W = 45-55%) are burned in the boiler house. A correlation has been found between the effectiveness of the condenser and the temperature of return water:

$E_{gc} = 49,698-0,7022t_{rw}$, %,

Where,

$E_{gc} = Q_{gc}/Q_b$ - efficiency indicator of the flue gas condenser,%;

t_{rw} - temperature of the return water, ^{0}C;

Q_{gc} - capacity of the condenser, MW;

Q_b - capacity of the boiler, MW.

To initiate the condensation of water vapor from the flue gas it is cooled to its dew point temperature. Further lowering of temperature will determine how complete the condensation of the vapor will be and how complete the latent heat recovery will be and thus – how effective the condenser will be. The dew point temperature of the flue gas is close to 65 ^{0}C. It is influenced by the moisture content of the wood chips and the amount of oxygen in the flue gas. The changes in the condenser efficiency indicator depending on the network return temperature are shown in the figure.

It can be seen that lowering the return water temperature by 1^{0}C the value of the condenser efficiency indicator increases by 0.7%. DH network return temperature is a variable and it is influenced by the outdoor temperature, the system heat load, the mode of its adjusting, as well as the operation of consumer's heating units and the technical condition of the internal systems. The effect of various indicators explains the data dispersion seen in the figure.

Cooling of the water to be sprinkled in is done in the network heat exchanger with the help of return water. In this way, network water performs the function of cooler, and the efficiency of the cooler is determined by the temperature of return water. This means that the first condition is fulfilled on the way to creating a 4th generation DH system, and an added value is obtained to an engineering and technical solution for the transition to a low temperature DH system.

The authors use the obtained experimental results as input data for a model to compare development alternatives for DH systems both with and without flue gas condensers in the transition to 4th generation DH systems.

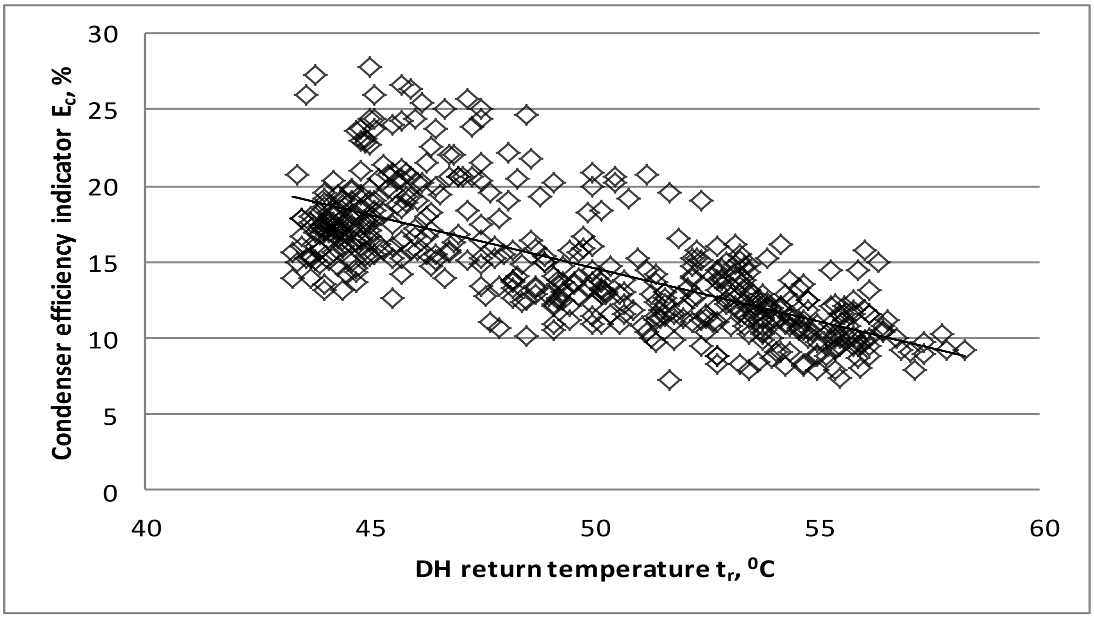

Figure: The changes in the condenser efficiency indicator depending on the DH network return temperature.

Maksym Kotenko was born in Ukraine in 1990. He received the M.Sc. degree in Energy and Environmental Technology from the Telemark University College, Porsgrunn, Norway in 2014. In 2015, he joined the Department of Energy Technology, Aalborg University as a PhD fellow. His PhD research concerns minimization of losses in low-temperature district heating.

Minimization of Losses in Low Temperature District Heating

Maksym Kotenko (mko@et.aau.dk) and Carsten Bojesen*
Department of Energy Technology, Aalborg University, Denmark

Low temperature district heating is one of the opportunities to utilize low temperature energy sources in order to reach the goal of fossil fuel free future in Denmark by 2050. 4th generation of district heating basically faces the same problems such as heat and pressure losses as district heating with supply temperature 80^{o}C. Following measures could be considered to reduce the losses: optimization of the operation of the DH supply; new materials with lower surface roughness, better insulation and flexibility; local temperature boosting by heat pumps or electric heaters; drag reducing aditives which can reduce the pressure losses in the distribution system or alternatively used for increasing the flowrate in systems with low supply temperature for maintaining the same amount of dilevered heat.

Overview of possible operational optimization will be performed. The DH consumers and variations in the distribution affect the operation of the system seriously. Therefore, one of the sub points is to monitor and control individual consumer use of energy to produce a favorable efficiency.

Investigation of possibilities and benefits from local temperature boosting by heat pumps or electric heaters will be shown. For this measure, the temperature level can be reduced with ultra-low supply temperature around 30-40°C and then boosted at the end user.

New pipe and insulation materials can be investigated by performance model in order to outline efficiency and economic profit of this measure. Advanced pre-insulated twin pipes are one of the best examples how to minimize the network heat loss.

Drag Reducing Additives (DRA) can reduce the water circulation pressure loss. Initially polymers were considered to be able to reduce friction losses. However, it loses its efficiency of drag reduction during the process of pumping due to breaking of bonds between the additive molecules and the absence of ability to regenerate. Hence wormlike micelles, when broken, can form new self-association “living polymer”. Research shows that surfactants can lead to savings in pumping power up to 50%. To summarize: Surfactant might be a good opportunity to cut the losses, if the heat transfer reduction in heat exchangers can be solved through temporary degradation of micelles and no indication of serious toxicity or corrosion appears.

Further work should be focused on the feasibilities of above mentioned measures and the possible implementation into the existing system.

Soma Mohammadi received the M.Sc. degree in Advanced Chemical Process Design from The Center for Process Integration, The Manchester University, UK, in 2012. She is currently working on her PhD at the Department of Energy Technology, Aalborg University, Denmark. In her PhD, she is working on modeling district heating networks, transient heat transfer in pipe networks and applying the 4GDH concept in existing grids.

Determination of Optimal Supply Temperature in Existing District Heating Networks by Applying New Insulation Series in Pipes – A Thermo-economic Analysis

S. Mohammadi (smo@et.aau.dk), C. Bojesen*
Department of Energy Technology, Aalborg University, Denmark

In order to increase the share of renewable energy sources in district heating [DH] system, lowering the temperature level in existing DH systems is inevitable. To keep DH systems competitive in future heat market, there is needed to apply stepwise changes in DH systems. The significant proportion of temperature losses and heat loss in DH systems occur in pipe networks, hence it is necessary to give particular attention to them. The soil (surrounding pipe) temperature, pipe structure and pipe insulation are the main cause of heat loss and temperature losses in DH networks. This paper is looking into reducing the temperature gradient and heat loss in existing DH network by improving the pipes insulation.

A model for thermal – dynamic calculation of DH network is developed. The model emphasis on transient temperature changes in DH networks which is mainly because of the time lag between consumers and heat supply unit, heat loss in the pipe network and consumers' dynamic heat load. The developed model is applied for a DH networks in Studstrup, Denmark where 320 consumers are connected to DH system through 14 km pipelines (supply and return). Currently the combination of pipes with series 1 and 2 insulations is used in the network; the existing condition of Studstrup DH network is referred as reference scenario. Furthermore three alternative scenarios are defined in order to implement the objective of this study where pipes with insulation series 2, 3 and 4 are respectively replaced in the pipe network. Improving the pipes' insulation results in reducing temperature gradient and heat losses in the network. It results in lowering the heat demand and reducing the supply temperature in the network. This study is aiming to perform a thermo – economic analysis to find out to what extent it is possible to reduce the supply temperature by employing pipes with new insulation series. The evaluation is based on the energy saving cost and payback period for applying pipes with different insulation series.

Track 5: Low-temperature District Heating and Buildings

Anders Dyrelund is one of Ramboll's leading energy consultants. He has experience from both the private sector, through assignments for Ramboll and from the public sector, through the positions he has held in the Danish Energy Authority. One of the areas in which he has specialized is the solution of techno-economic and organisational problems of district heating and cooling in cities.

Session Keynote:

The District Energy System – a Cost Effective Virtual Electricity Storage

Anders Dyrelund (ad@ramboll.dk) and John Flørning, Ramboll Energy, Denmark*

One of the challenges of the energy system of the future will be to integrate the fluctuating renewable energy in the most cost effective way. Electric batteries are very expensive. Therefore we have to look for other solutions, which can fill-out the gap between the fluctuating production from wind, hydro and solar and the necessary consumption, in order to avoid rotational load shedding.

The 4th generation hot water district heating system is not a stand-alone system. It is an element of the Smart Energy System. It is first of all fully integrated with district cooling forming the district energy system (as two sides of the same coin). The District Energy System for heating and cooling is moreover integrated with the power system through heat pumps, electric boilers and CHP plants and with the buildings though the HVAC systems with low temperature heating and high temperature cooling.

Although the hot and cold water pipes are separated in operation, they share many components, which even, with some modifications, can shift from hot to cold over time, e.g. the treated water, the tanks, the pumps, the pipes etc. A storage tank can e.g. be used to store heat in winter and cold in summer in case the tank is insulated against humidity to avoid corrosion, and an aquifer storage stores surplus heat in summer and surplus cold in winter.

A thermal storage cannot generate electricity, but the impact of generating and storing hot or cold water for later use to avoid later use of electricity has the same impact on the electricity system as a battery.

The first stage is to design the district energy system with sufficient capacity of heat pumps, compressors, electric boilers and thermal storage volumes in tanks, pits and aquifers, given the market for district energy. That will form a virtual electric battery at almost no cost. You only need transparent least cost planning.

The second stage is to take into account the benefit of the virtual battery to increase the market share of district energy. We can start in the buildings to ensure that uncontrolled electricity consumption from electric heating, small heat pumps and chillers are replaced by building level integrated heating and cooling water pipe systems. From there it is possible to establish building level production and storage of heat and cold. In cities we have the opportunity to go further and plan the extension of the district energy system, in

heating and/or cooling systems - city-wide or in suitable districts, depending on the climate conditions and costs of energy.
In the third stage we can increase the storage capacity – if needed, e.g. large underground thermal pit storages. Currently the largest hot water tank is 75,000 m3 and the largest pit storage is 200,000 m3. Due to economy of scale it is possible to extend the systems and the storages even more.

Julio E.V. Rebollar is a researcher in the Building Physics, Construction and Services group, at the Department of Architecture and Urban Planning at Ghent University, Belgium. Participating in the European project 'ECO-Life: Sustainable zero carbon ECO-town developments improving quality of life across EU (EU-FP7)'. Modeling and optimization of district heating system. Studying the performance of district heating substations by means of dynamic simulations.

Nearly Zero Carbon Neighbourhood Development in Kortrijk (BE), Implementation and First Year Monitoring Results

Julio Efrain Vaillant Rebollar(julioefrain.vaillantrebollar@ugent.be), Eline Himpe and Arnold Janssens*

Research group of Building Physics, Construction and Services, Department of Architecture and Urban Planning, Ghent University, Belgium

In Europe, the Energy Performance of Buildings Directive (EPBD) provides a framework toward achieve, by the end of 2020, that all new building consume 'nearly zero' energy. Therefore a better understanding of and improvements to building energy performance and operation are key steps. Hence, building energy use data collection, monitoring, and analysis are an essential basis for building energy examination. In this context an exemplary zero-carbon neighbourhood with about 200 dwellings in being implemented in the city of Kortrijk, Belgium in the context of the CONCERTO ECO-Life project. In 2013, the first phase of the project was finished and as part of the zero carbon neighbourhood a low-temperature district heating system was used for the first time and now delivers heat to 82 low-energy dwellings. This study deals with the energy performance assessment of the first phase of these zero-carbon community and low-temperature district heating system. The present paper presents the analysis of the implemented monitoring system results and other specific measurement campaigns by stressing the influence of relevant parameters such as the performance of components, building load characteristics, space heating comfort, domestic hot water comfort and the implemented control strategies. Hence, the analysis aim highlight the potential of integrating low-temperature district heating systems and low energy buildings as an effective solution towards sustainability in the heating sector.

Susana Paardekooper graduated this summer as M.Sc. in Sustainable Cities from Aalborg University, Denmark. She is a 1st prize winner of this year's DHC+ Student Award for her project about the best scale at which heat pumps should be employed in urban areas.

Optimal Heat Pump Use in European Cities

Susana Paardekooper (susanapaardekooper@gmail.com)*
Aalborg University, Denmark

Thermal energy is attracting increasing attention within the energy sector as a key part of an energy transition in Europe. This research aims to understand in what manner heat pumps could most optimally be utilised in European cities as an alternative to gas boilers. A context-independent case study compares scenarios from a lock-in perspective, and along security, fuel- and cost efficiency, and applicability to the urban setting. A comparison is made between a scenario where gas boilers are optimised, where heat pumps are applied at the individual building level, and where large-scale heat pumps are used in combination with district heating.

While both heat pump scenarios show a markedly higher fuel efficiency, the individual-scale heat pump scenario is more costly than both the gas boiler and large-scale heat pump scenario. Moreover, individual-scale heat pumps are unlikely to be suitable for the urban environment. In the large-scale heat pump scenario, the losses in the grid are offset by higher, more dependable COPs. The system is equally fuel efficient to individual-scale heat pumps, and very well suited to the urban environment. Costs are significantly lower per year than both scenarios although high up-front costs are required. This provides a strong impetus for change from the suboptimal gas boiler scenario to a district heating network supplied by heat pumps. However, more knowledge is required on how heat pumps behave at close proximity to eachother, the role of cooling, and the potential of heat demand reductions in the urban environment. Knowing this, planners can start to understand how the TIC must be adjusted to achieve change, and from what perspective solution strategies can be applied.

Kasper Qvist is an Energy Planner at Grontmij A/S in Aarhus and holds a M.Sc. in Sustainable Energy Planning and Management from Aalborg University. He is primarily working with low-temperature district heating and heat pumps.

Ultra Low-Temperature District Heating With 35 °C Supply Temperature

Kasper Qvist (KQV@grontmij.dk), Christian Nørr Jacobsen, Johnny Iversen*
Grontmij A/S, Aarhus, Denmark

The trend of district heating (DH) is to move towards low-temperature district heating (LTDH) or 4th generation district heating. There are several benefits associated with lower network temperatures, e.g. reduced system losses and increased potential for integration of low-grade heat sources. However, lower network temperatures are also associated with several limiting issues. With system temperatures below 50°C, it becomes increasingly challenging to deliver domestic hot water (DHW) and prevent legionella bacteria issues.

Through a project funded by the Danish Energy Technology Development and Demonstration Programme (EUDP), Grontmij A/S led a joint collaboration between various companies aimed at developing a new energy efficient, next-generation concept for DH consumer substations. As a result, an individual consumer substation with an integrated heat pump with DHW priority (microbooster) was developed. The integrated heat pump can boost preheated DH water, if necessary, to 55°C which is then stored in a storage tank on the substation's primary side. The stored 55°C hot water is used for instantaneous DHW preparation via a heat exchanger, while space heating is provided directly via the low-temperature DH supply. This concept separates the link between the DH supply temperature and DHW temperature and prevents legionella issues, since hot water is stored on the primary side, making it possible to use DH supply temperatures well below 55°C (as low as 30°C or even lower during summer).

The microbooster concept shows very promising results. As a field test, microbooster substations were implemented in 2012 in four existing houses in Birkeroed, Denmark, supplied from the DH return pipe. Current results show that the concept is able to uncouple supply temperatures from DHW, making it possible to implement LTDH with temperatures below 50°C and still maintain the same level of consumer comfort. Measurements from the winter of 2013-2014 and the summer of 2014 show that the system works as intended with sufficient DHW capacity and a heat pump COP of approx. 4.5. The concept even results in reduced return temperatures in the summer, contrary to conventional DH systems. To substantiate the results from Birkeroed, a second and larger test is currently underway in the village of Geding near Aarhus, Denmark, where all of the 25 village houses have been converted to the new microbooster concept. The village offers a unique setting for testing new DH systems as it has its own separate DH network, which makes it ideal for testing microbooster substations in a closed system without interference from a main DH network. Currently a comprehensive measurement program

is undergoing to determine the impact on performance of the DH consumer substations and the DH network.
The ability to uncouple supply temperatures from DHW is one of the concept's key features. This allows for overall lower system temperatures in the summer months, where there is little or no need for space heating. It is thus possible to significantly reduce the heat losses that normally are very high during these months.

Dorte Skaarup Larsen is a newly started PhD fellow in the 4DH network. She is performing dynamic simulation and evaluation of existing buildings and analysing how to provide space heating for existing buildings with low-temperature district heating.

Possibilities and Costs of Preparing Existing Danish Single Family Houses from the 1930'ies for Space Heating with Low-temperature District Heating

Dorte Skaarup Larsen (dskla@byg.dtu.dk), Svend Svendsen*
Department of Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

Low-temperature district heating is a promising technology for ensuring energy efficient heating of our dwellings in the future. However, it is of great importance to ensure thermal comfort in existing Danish single family houses when district heating temperatures are lowered. In order to do this it may be necessary to increase the size of radiators in critical rooms. This study therefore investigates the radiator sizes in 4 existing Danish single family houses from the 1930'ies. The purpose is to evaluate if the existing space heating systems are suitable for low-temperature district heating or if there are critical rooms where the radiator sizes need to be increased. The investigation is performed by comparing existing heating power and heat demand in all rooms of the chosen case houses. The heating power in each room is estimated based on measurements of all radiators. The heat demand in each room is calculated using a building simulation model in IDA ICE. In order to ensure that realistic indoor temperatures can be maintained, the calculated heating powers are based on measured indoor temperatures in all rooms of the 4 case houses. The costs of replacing critical radiators are estimated and compared to the savings obtained by operating district heating systems with lower temperatures.

Track 6: Organisation, Ownership and Institutions

Professor Dagnija Blumberga leads the Institute of Environmental Protection and Energy Systems at Riga Technical University, Latvia. She has a Thermal Engineer Diploma and two steps doctoral degree diploma. The main research area is renewable energy resources and energy efficiency, including 4th generation district heating systems. She has participated in different local and international projects related to energy and environment as well as being the author of 156 research publications and 9 books.

Session Keynote:

Legislative analysis for the 4th generation district heating in Latvia. Riga case

Dagnija Blumberga (dagnija.blumberga@rtu.lv), Institute of Energy Systems and Environment, Riga Technical University, Latvia*
and Dace Cīrule, Turiba University, Latvia

Due to several reasons the 4th generation district heating systems undeniably are future of the Baltic States. First, by substantially reducing the water temperature in heat network, they reduce heat losses and allow for cheaper pipe materials. Second, they lead to intensive substitution of fossil fuel with renewable energy sources: sun (installation of sun power collectors) and wind (if heat pumps are used). Third, they motivate end-consumers to increase energy efficiency and to reduce energy consumption by switching to the low temperatures without essentially reconstructing the heating elements.
However, historic experience shows, that diffusion of innovations is hindered by several obstacles: rapid development of new renewable technologies; reduction in specific investment, if applied to one unit of the installed capacity; adjustments performed by end-consumers to reduce energy consumption and payments for heating; political aspects of fossil fuel supply, etc. One of the major obstacles is the previous investment, which was made without considering any usefulness and sustainability aspects. Another major obstacle is the poor legislative basis for the introduction in Latvia of the 4th generation district heating.
Article focuses on obstacles existing for the introduction of sustainable and innovative technologies. Analysis is based on a real life example: development of Daugava right bank district heating system of Riga city. Article points out reasons, due to which end-consumers of this system have become hostages of the former generation technologies. Namely, in 2008 a research on energy sector development of Latvia identified a necessity to construct a new 100MW wood-chip boiler in TEC-1 territory of Riga, in order to cover the peak load during heating season and hot water supply during summer. Instead, investment was used to construct a condensation cogeneration station fueled by natural gas. Now, 7 years later, investor has appeared who is prepared to invest into a new boiler house, which would have 100MW wood-chip boiler and 40MW natural gas boiler, and would be connected to the existing district heating, thus in fact cutting out Riga TEC-1 station.

The described solution does not consider that only now end-consumers of Riga are prepared to implement building energy efficiency measures, which may lead to a 30-40% cut in the heat load of buildings. Also, this solution ignores that new renewable energy technologies are available, for instance, sun power collectors to accumulate heat for hot water preparation during summer. In addition, this solution aggravates the fact, that the currently effective legislation on district heating and tariffs are not friendly to the introduction of the 4th generation district heating systems in Latvia. Consequently, as processes of innovation diffusion are not considered as well, it is easy to predict that installation of the new boiler house is useless and economically unjustified investment, lagging behind for 7 to 10 years.

Søren Roth Djørup is a PhD fellow in sustainable energy planning at Aalborg University and has been part of the 4DH research centre since September 2013. Working with the economic conditions for 4th generation district heating with a main focus on the integration of electricity and heat markets.

Public Regulation of District Heating Companies in a Smart Energy System

Søren Roth Djørup (djoerup@plan.aau.dk)*
Department of Development and Planning, Aalborg University, Denmark

The technological change in the electricity sector with increased amounts of wind power creates a need for an institutional reform to maintain a resource efficient integration of heat and electricity production in Denmark. From technical system analyses, it is known that installing large scale heat pumps in the district heating sector could improve the system ability to integrate growing amounts of fluctuating wind power productions. Likewise, technical system analyses indicate that natural gas based CHP are well suited as back up capacity in the electricity sector for fluctuating renewable resources, and thereby offers system benefits which are not reflected in the short term marginal production costs. While the development in the Danish energy system so far has succeeded in increasing the wind power capacity, the system capacity to integrate wind power has not developed with the same pace. The empirical data shows that large scale heat pumps have not been installed in any significant amounts. Meanwhile, natural gas based CHP is under economic pressure in the Nord Pool spot market since this production form is crowded out by the increasing amounts of wind power. This resource inefficient development is a result of a malfunctioning institutional structure that does not sustain the flexible and efficient integration of heat and electricity markets which is a vital part of the smart energy system. The current tax structure in Denmark does not deliver the required incentive structure neither at the investment nor operation level. The present work project will seek to propose various reform models which could ensure a technical and economic efficient integration between heat and electricity markets. It will aim for a public regulation which incentivises the appropriate investment and operation behaviour in the district heating sector. Concrete public regulation models will be presented which promote the required investments decisions and a flexible daily operation.

Kirsten Hasberg is an economist with 10 years of experience in Danish and German energy policy. Kirsten Hasberg works with companies and public entities to help navigate the changing energy markets at the intersection of business development, policy analysis and public affairs.

Development of an Open Heating Platform – the Case of Hamburg

Kirsten Hasberg (kirsten@energydemocracy.tv), Hasberg Media UG, Hamburg, Germany*
Matthias Sandrock, Hamburg Institut Consulting GmbH, Germany

The district heating grid of Hamburg is the second largest in Germany, following Berlin. 1200 km heating network supplies appr. 500,000 consumers (equally divided between private households and commercial customers).

Today, the district heating network of Hamburg consists of 25-30 different grids, of which the largest one, covering appr. 80% of consumption, is owned and operated by Vattenfall. District heating covers only 20% of the overall heat supply, but induces 30% of the CO_2 emissions of the heating sector. The primary form of heat supply in Hamburg is individual heating based on natural gas.

In contrast to the German electricity supply, there is almost no renewable energy in the heating sector.

Because heat production is coal-based, the CO_2 emissions from district heating in Hamburg are higher than those of individual gas-based heating.

There is a large public and political resistance towards coal based district heating, and therefore a push towards increasing the share of renewable energy sources in the heating sector, and the need of developing an ”open heating platform” is part of the discourse.

As a result of a referendum held in 2013, the district heating system will be ’re-municipalized’ in 2019 and hence be sold from Vattenfall and EON to the City of Hamburg (FHH, Freie und Hansestadt Hamburg). After the referendum, Hamburg does virtually not have any heat planning, since until now, this was the responsibility of the private actors.

With an open heating platform, there is potential for integrating new heat suppliers, e.g.:

- Heat from the river Elbe via large heat pumps
- Wastewater heat via large heat pumps
- Integration of wind energy from Schleswig-Holstein (Power2Heat): According to the
- Think Tank ’Agora Energiewende’, the potential for wind used in the heating sector is 2.3 TWh/year by 2023, due to low electricity prices. Today, taxes and duties prevent such a use of wind in the heating sector.

Falling electricity prices constitute a risk element for district heating based on co-production of electricity and heat, especially after the coal powered power plant Moorburg started operating in February 2015. This reinforces the price dampening effect on electricity prices from increased wind production in northern Germany. Basing district heating on heat sources not based on co-production with electricity therefore becomes increasingly important.

Sara Fritz joined the Energy Economics Group at Vienna University of Technology, Austria in 2013 and holds a degree in Mathematics in Economics at the Vienna University of Technology. She works as a research associate and is a PhD Fellow in an interdisciplinary Doctorate Course in the field of smart cities. Her main research interests cover the evaluation of the interaction between the long-term heating related investment decisions in buildings, the resulting development of the buildings heat demand and the future potential for existing district heating networks under various scenario assumptions.

The Impact of Policies in the Building Sector Influence the Economic Feasibility of District Heating

Sara Fritz (fritz@eeg.tuwien.ac.at) and Julia Forster, Vienna University of Technology/Energy Economics Group, Vienna, Austria*

An urban district heating network represents an energy efficient way to supply the cities heat demand. The extension of district heating and the increase of its share in heat supply allows replacing ecological inefficient heating technologies. The economic feasibility of the extension and expansion and the operation of a local district heating network is a major issue. Hence the investment decision of a local district heating company is influenced by the current and future installed capacity for heat generation, the trend of energy prices, as well as the development of the regional heat density. Therefore, apart from production and distribution, it's also necessary to convince the society to make use of the network and the development of the buildings' heat demand should be considered explicitly.

The approach is divided in two steps: First, the decision behavior of the building owners is simulated with the existing bottom-up model Invert/EE-Lab[1,2)]. A multinomial logit approach with policies, subsidies and directives as scenario-framework and a time horizon up to 2050 simulates their investments in thermal refurbishments and new heating systems and the resulting energy demand. Based on the decision makers' willingness to connect to the existing district heating system and the correspondent heat demand, an investment optimization for the extension and expansion of district heating is conducted in a second step. This optimization model considers the development of the buildings' heat demand explicitly for the considered time horizon, for both, the already connected buildings as well as for the buildings, which consider a change to district heating. The models objective is to maximize the profit taking account of the European targets and the impacts on the whole heat market. Besides different energy price scenarios for heat generation, also different installed capacities up to 2050 are considered and the impacts on the economic feasibility are analysed.

The results of the integrated approach allow the analysis of the impacts of international and national policies in the building sector on the future design of an urban district heating network. The case study conducted for Vienna points out economic feasible investments strategies as multiple scenarios are compared. In addition, the results are visualized in a GIS-based, spatial simulation environment to support stakeholders in their decision process (URBEM_platform[3)]).

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2) Müller A. The development of the built environment and its energy demand for space conditioning and domestic hot water supply. A model based scenario analysis. [Wien]: TU Wien, ongoing; 2015.
3) http://urbem.tuwien.ac.at

Spyridon Provatas is a runner-up award winner of this year's DHC+ Student Award and has completed a master's degree in Computer Science at Blekinge Institute of Technology, Sweden. His research interests lie in the areas of machine learning and data mining, and their application in district heating systems.

An Online Machine Learning Algorithm for Heat Load Forecasting in District Heating Systems

Spyridon Provatas (spyvatas@hotmail.com), Blekinge Institute of Technology, Sweden*

Optimization of heat production in district heating systems is important both from a financial and an environmental standpoint. In particular, energy companies aim at minimizing peak boiler usage, optimizing combined heat and power generation and planning base production. To achieve resource efficiency, the energy companies need to estimate how much energy is required to satisfy the market demand. Heat load forecasting enables effective planning and decision-making. In this paper, we suggest an online machine learning algorithm for heat load forecasting. Online algorithms update the prediction or regression model when new information becomes available. These algorithms are increasingly used due to their computational efficiency and their ability to handle changes of the predictive target variable over time. The proposed algorithm was evaluated on operational data from a district heating system. The results of the study show that the algorithm has a solid predicting ability with a mean absolute percentage error of 4.77%. Robust heat load forecasting is an important part of increased system efficiency within district heating, and the presented algorithm provides a concrete foundation for operational usage of online machine learning algorithms within the domain.

Track 7: Smart Energy Systems

Anders Bavnhøj Hansen, Loui Algren and Rasmus Munch Sørensen are working in the department of Energy analysis at Energinet.dk (TSO for power and gas in Denmark). Their field of expertise is strategic planning of integrated energy systems. Presenter Anders Bavnhøj Hansen has been working with energy system analysis at the Danish Energy Agency and at ABB Corporate Research in Sweden. He graduated in energy technology (M.Sc.) from Aalborg University, Denmark.

Session Keynote:

Energy System Integration with Efficient Use of High Temperature Excess Heat

Anders Bavnhøj Hansen (abh@energinet.dk), Loui Algren and Rasmus Munch Sørensen*
Energinet.dk, Denmark

Denmark has the political ambition that the total energy supply should be independent from fossil fuels in 2050. Wind power, solar and bio-residues are expected to be major energy resources in this fossil independent scenario. A number of scenario studies of this transition towards a fossil free energy system have been carried out e.g.[1,2,3)] As a TSO for power and gas system Energinet.dk has analyzed how more integration of power and gas systems with the heating system might be needed when the energy system needs to handle large amounts of wind- and solar power in the Nordic system in a cost-efficient and resilient way[3)].

The district heating system in Denmark is found to be essential for obtaining energy efficient, resilient and competitive energy supply based on wind and bio-residues. However the role of the district heating system is found to change significantly in the scenario from today's heat supply based on CHP production and the current trend of solar heating and biomass boilers, to a system with a completely different supply of the district heating system. The common denominator for the future district heating supply technologies are, as it was also originally intended, to utilize surplus heat. The heat source, however, changes from previously mainly thermal electricity to numerous other processes with different main products.

As such, a number of new technologies are introduced in the scenario study, including thermal gasification of biomass and waste, catalytic processing of synthesis gas to liquid and gaseous fuels, power-to-gas (electrolysis), high temperature heat pumps for industrial processes etc. A number of these novel technologies have the ability to deliver excess heat at temperatures in the range 150-500 degrees or even higher temperatures. The excess heat from these processes could cover a major part of the total demand in district heating systems. However it might lead to a substantial loss of exergy to use this high temperature heat directly for comfort heating in homes via district heating, which can be done with other heat sources delivering lower temperatures.

A number of processes in industry- and service require heat in the temperature range from 100-250 degrees. Today, this demand is primarily covered via fossil fuels in boilers and CHP units at the factories, but is in the scenario to some extent covered by excess heat from fuel production.

Some power-to-gas technologies (eg. SOEC) have the ability to use high temperature heat as input energy in the production of gas (output). Flexible use of the high temperature excess heat as input for industry/service and electrolysis has been investigated in the scenario.

The excess heat is to some extent available for district heating at a later stage, if captured from the industry as excess heat with temperatures below 80 degr.

Furthermore a number of heat pumps for production of district heating is introduced and together with a minor CHP production leads to a district heating system covering approximately 65% of the total heating demand in Denmark.

The study is a screening of various possibilities, and has to be further investigated. Particularly the potential of lower temperature district heating, in combination with the options described, is an area that requires more in-depth analysis. The results of the scenario study indicates that efficient use of high temperature excess heat is essential for obtaining a high energy efficiency, and the combination with the district heating system to capture the excess heat at a lower temperature level is found to give a resilient and robust energy system.

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2) *Energi 2050, Vindsporet, Energinet.dk, 2011*
3) *Energikoncept 2030, Energinet.dk, 2015, www.energinet.dk/energianalyse*

Damien Casetta is an engineer graduated from the "Energy and Environment" department of the National Institute of Applied Science of Lyon, France. Master's thesis written at Chalmers University of Technology, Gothenburg, Sweden, about "Implementation and Validation of a Ground-Source Heat Pump in Matlab". PhD fellow at MINES Paristech, working with the company CLIMESPACE about "Dynamic Modelling and Multi-Criteria Operational Optimization of District Cooling Network".

Dynamic Modelling of a District Cooling Network with Modelica

Damien Casetta (damien.casetta@mines-paristech.fr), Pascal Stabat, Dominique Marchio, MINES ParisTech, PSL Research University, CES Centre d'efficacité énergétique des systèmes, Paris, France*
Cynthia Nerbollier and Guillaume Brecq, CLIMESPACE, Paris, France

CLIMESPACE operates and develops the district cooling network (DCN) of Paris since 1991. 10 compressor-driven production plants and 3 cold storage sites supply cooling water to 550 customers for a global cooling capacity of 310 MW. The distribution network is 70 km long and divided into 3 fully independent sub-networks. In this paper, only the sub-network of Eastern Paris (44 MW, 42 customers) is considered as a case study. The aim of the research is to improve operation performance using control optimization methods. A model of the network has been developed with Modelica and under the environment Dymola. The model is dynamic (representing the thermal capacity of pipes), physical (temperature, pressure along the network) and detailed (cooling plants, distribution pipes, customer substations). This modelling approach allows to observe the dynamic response of the system during transient periods and to study interactions between network cooling demand and cooling plant efficiency. The chiller model based on performance data determines thermal performances and electrical power depending on temperature conditions on evaporator and condenser sides and part-load ratio. The hourly cooling demand and the customer return temperature for the year 2013 are used as inputs for the simulation. Simulation results are compared to measured data (flow rate, pressure, temperature and electricity consumption) and presented in this paper. Calibration and validation processes are carried out both at the component level and at the system level. The simulation tool is evaluated in terms of computational time and accuracy.

As an application, an innovative control strategy defining the optimal conditions of operation of substations is studied. Both customer supply temperature and differential pressure are controlled by a set of two-way valves on the primary side. Network return temperature is function of customer return temperature and of heat exchanger effectiveness. In order to reduce flow rates in the distribution network, required secondary return temperature is increased. Improvements on distribution pumps electricity consumption (lower flow rate) and on distribution thermal losses (higher average distribution temperature) are evaluated. A modification of operation conditions of chillers is investigated. Subsequent improvements on chilled-water pumps electricity consumption and on chillers efficiency are evaluated.

Christoffer Lythcke-Jørgensen is a PhD fellow from DTU Mechanical Engineering, Denmark. His research is centred around the conceptualization and optimization of flexible polygeneration plants. Ongoing work is carried out in cooperation with EPFL IPESE and DTU Management Engineering.

A Method for Designing Flexible Multi-generation Plants

Christoffer Lythcke-Jørgensen (celjo@mek.dtu.dk), Fredrik Haglind, Mechanical Engineering, Technical University of Denmark*
Adriano Viana Ensinas, Industrial Process and Energy Systems Engineering, École Polytechnique Fédérale de Lausanne, France
and Marie Münster, Management Engineering, Technical University of Denmark

Flexible multi-generation plants (FMGs) are non-static facilities that convert one or several energy resources into multiple energy services and other valuable products, e.g. electricity, heating, cooling, bio-fuels, and bio-chemicals. The main advantages of FMGs are: The embedded possibility for optimizing operation by altering feedstock sources and end products depending on demand and market price[1)] ; the possibility of integrating and balancing production from intermittent renewable energy resources such as wind, solar, wave and tidal[2)], which is essential in renewable energy systems[3)]; and the possibility of achieving high aggregated conversion efficiencies through process integration[4)]. In principle, FMGs can be seen as efficient energy system valves that counteract energy system imbalances by integrating the various layers, and may therefore play an important part in the development of smart energy systems[5)].

This study presents a novel method for designing FMGs. The method applies a node-based superstructure representation and a multi-period mixed integer-linear programming approach for selecting, dimensioning and integrating processes, and optimizing operation with respect to both short-term demand fluctuations and long-term system development within a defined energy system context. Multi-objective optimization with respect to both net present value and 100-years global warming potential is carried out using a genetic algorithm. Uncertainty analysis is applied to handle data uncertainty and evaluate errors from neglecting dynamics in the operation optimization. To demonstrate the use of the method, a case study of the Maabjerg Energy Concept is included. Preliminary results were presented in[6)].

In conclusion, the design method presented is useful for conducting quick and reliable feasibility analyses of FMGs, where it is now possible to integrate fluctuating prices as design parameters. Further development possibilities include the integration of biomass supply chain models and dynamic operation optimization.

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2) A. Coronas, S. S. Murthy, and J. Carles Bruno, "Editorial for the special issue of applied thermal engineering on polygeneration," Appl. Therm. Eng., vol. 50, no. 2, pp. 1397–1398, 2013.

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4) Z. Yuan and B. Chen, "Process synthesis for addressing the sustainable energy systems and environmental issues," AIChE J., vol. 58, no. 11, pp. 3370–3389, 2012.
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Jakob Zinck Thellufsen is a PhD fellow in the CITIES research project working with Energy System Modeling and Analysis of multiple energy systems. Primarily focusing on linking local energy systems with plans for future national energy systems, and the relation between energy systems and energy savings.

Multiple Energy System Analysis of Smart Energy Systems

Jakob Zinck Thellufsen (jakobzt@plan.aau.dk)*
Department of Development and Planning, Aalborg University, Denmark

To eliminate the use of fossil fuels in the energy sector it is necessary to transition to future 100% renewable energy systems. One approach for this radical change in our energy systems is Smart Energy Systems. With a focus on development and interaction between smart electricity grids, smart thermal grids and smart gas grids, Smart Energy Systems moves the flexibility away from the fuel as is the case in current energy systems and into the system itself. However, most studies applying a Smart Energy System approach deals with analyses for either single countries or whole continents, but it is unclear how regions, municipalities, and communities should deal with these national targets. It is necessary to be able to provide this information since Smart Energy Systems utilize energy resources and initiatives that have strong relations to local authorities and communities, such as onshore wind power, biomass, solar power, district heating, and demand reductions.

Thus, it is essential to develop a tool with the capabilities of splitting country analyses into regions, states, and municipalities. Such a tool can help in securing both overall national targets, but also enable more specific guidelines to municipalities in the transition to future 100% renewable Smart Energy Systems. A tool with such capabilities enables better discussions of energy systems and can potentially handle multiple country analyses.

This paper discusses the development and consequences of modelling an energy system analysis tools capable of handling multiple system. This includes a review of how interconnection works, and what assumptions make sense when integrating them in large scale analysis of national energy systems. The result of the paper is the development of an actual tool capable of simulating and analyzing Smart Energy Systems consisting of multiple systems. The basis for developing the tool is the advanced energy system analysis computer model EnergyPLAN that currently has the capability of modeling and simulating Smart Energy System but not the possibility of allowing for analysis of multiple systems.

Jørgen Boldt is Head of the Production Section in the Energy Planning Department at Greater Copenhagen Utility (HOFOR), among others responsible for smart energy and development projects. His knowledge of the energy sector is extensive and comprehensive, stemming from a multitude of different activities for more than 30 years. Primary focus areas have been renewable energy, generation of electricity and heat, energy sector policies and planning, and climate change.

Demonstration of 4DH Solutions in a Large City Development Area

Jørgen Boldt (jobo@hofor.dk), Project Manager at Greater Copenhagen Utility (HOFOR) and Kirsten Ledgaard, Chief Consultant, Copenhagen City and Port Development*

Nordhavn is Scandinavia's largest city development area with expected 40,000 new residents and 40,000 new working places. The planning process to transform Nordhavn into a vibrant city for residents and business began some 10 years ago and will continue over the next 50 years. The vision is that the area will develop into a real-life energy laboratory and be a showroom for future energy solutions and smart energy technologies. The vision got life in a Master Plan for the area in 2008.

Nordhavn shall contribute to Copenhagen's ambitious goal of becoming CO_2-neutral by 2025. The development has already started, but a major part of the area has not yet been planned in details. In this dynamic setting, a large development project EnergyLab Nordhavn was launched in April 2015. For four years, and with a budget of 17 million €, Copenhagen Municipality, Copenhagen City and Port Development, the two energy supply companies DONG Energy (electricity) and HOFOR (district heating), the Technical University of Denmark and 5 private companies shall develop Nordhavn into a live laboratory for developing, testing and demonstration of new energy solutions, optimised for the future, dense urban areas.

In terms of district heating the focus is on low temperatures, low heat demands, delivering flexibility to the power system, intelligent heat storage in traditional heat stores, pipelines and buildings, flexible heat pumps and electric boilers, integration of smart energy buildings with smart district heating distribution, autonomous local SCADA systems, data sharing, and the need for new tariff systems.

EnergyLab Nordhavn has received financial support from the Danish R&D&D support scheme EUDP.

Track 8: Future District Heating Production and Systems

Ingo Weidlich has been the scientific head of the Fernwärme Forschungsinstitut in Hannover e.V., Germany since 2014, author of the book "Earth pressure on Pipelines" and has had 37 publications since 2002.

Session Keynote:

Challenges in Smart Energy Transport by Using TRENCHLESS Technology

I. Weidlich (weidlich@fernwaerme.de)
FFI, Fernwärme Forschungsinstitut in Hannover e.V., Hemmingen, Germany

The expansion of energy grids is one major step in the near future development of infrastructure in the EU. The interconnection of European countries is an essential task on the way to a liberalized electricity market. The integration of renewable energy challenges the European electricity market even more. Since 50% of the primary energy consumption is heat expansion and improvement of the heating grids have to be integrated into smart energy concepts.

Sustainable and safe energy grids have to be built economically. Smart solutions for construction are needed. Accurate and safe design must be coupled by economic, flexible and innovative laying methodologies. A promising laying technology is trenchless. This technology is wide spread for several supply applications. Nevertheless operational loads and needs of energy grids for electricity and heat have to be taken into account. Special demands are reported for district heating pipes. For an accurate analysis the contact forces between pipe and soil have to be clearly determined in every case - after installation and during operation. One focus for electricity cables is the expected thermal conductivity of the surrounding soil after trenchless installation.

The presented investigation gives an overview on challenges in smart energy transport by using trenchless technology. For electricity grids conceptual aspects for construction with focus on the expected thermal conductivity using horizontal directional drilling are discussed. For district heating grids full scale field measurements of trenchless installed district heating pipes are shown. The investigation includes results from the installation process and further more results for real heating conditions.

So far, the special operation conditions of energy transport seem to be the biggest barrier using trenchless technology. Different recommendations and investigations for the calculation of the initial contact conditions are available. Some evaluation of existing application rules is given and further recommendations are derived from the results.

Goran Krajačić received his PhD degree in Mechanical Engineering from the University of Zagreb, Croatia in 2012. Since 2014, he has been an Assistant Professor at the University of Zagreb. In 2007, he was a guest researcher at the Instituto Superior Técnico, Lisbon, Portugal. He has been working on national and European scientific projects. He participates in teaching the courses 'Introduction to Energy Management' and 'Energy Planning'.

Contributing Global CO_2 Mitigation by Utilisation of Food Industry Heat into Smart Croatian DHS via Total Site Heat Recovery

S. Boldyryev, G. Krajačić (Goran.Krajacic@fsb.hr), N. Duic and T. Novosel*
Department of Energy, Power Engineering and Environment, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia.

The production of food, which is maintaining the energy metabolism in human, needs the considerable consumption of natural resources, mainly the coal, petroleum and natural gas. The statistics indicate on noticeable energy consumption in food industry: to produce 1 J of food energy 10 J of primary energy is required. The population growth and its food supplying are causing the annual energy consumption rise on 24 – 40%. On the other hand it leads to fast deterioration of surrounding environment owing to CO_2, NO_x, SO_x, dust, soot and other industrial emissions. The steep rise of energy prices in recent years, as well as the necessity to curb carbon dioxide emissions, have intensified the need for solutions that are increasing energy efficiency in the food industry.

Heat integration is a key tool for energy saving achieved by heat recovery in process industries. Energy saving has an important role in achieving a sustainable future development. Heat recovery at Total Site level can provide a considerable potential for energy saving. Use of excess heat can provide a way to reduce the use of primary energy and to contribute to global CO_2 mitigation. The methodology can be successfully implemented in different industrial sectors such as in sugar production, ethyl alcohol, glucose, dried milk, tomato paste, oil and bottled goods.

The utility levels supplied to the process may be a part of a centralised site-wide utility system as well as smart district heating systems. Process integration extends to the site level, wherein appropriate loads on the various steam mains can be identified in order to minimise the site wide energy consumption. Process integration therefore provides a consistent methodology for energy saving, from the basic heat and material balance to the total site utility system. It provides the utilisation of low potential waste heat for district heating systems.

The paper is focused on allowing heat recovery for district heating needs of both new designs and as retrofits to existing sites to ensure fast, widespread and cost-efficient industrial deployment. Targets also be set for the utility loads at various levels (e.g. steam and refrigeration levels).

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Oliver Martin-Du Pan completed an industrial thesis at Loughborough University, UK and sponsored by Buro Happold on the operational performance of district heating systems and has now been working at a UK-based company for 6 months in the community heating team to reduce the heat losses. The company operates 27 district heating systems and aims at operating 100 by 2020.

Heat Losses in District Heating Systems and Heat Meters

*Oliver Martin-Du Pan**

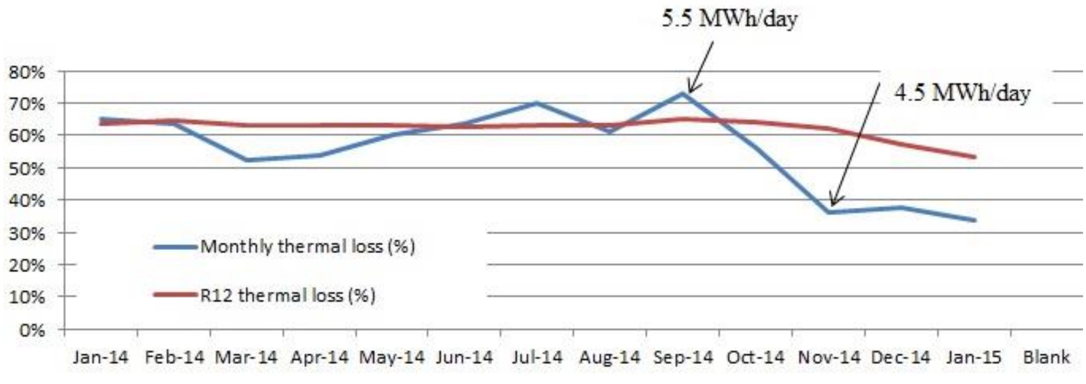
The monitored heat losses of district heating systems in the UK are high and this can be explained because of their poor designs and operations. The design could be improved to reduce the heat losses by:

- Improving the insulation level; 40 mm insulating foam on all pipes.
- Reducing the number of heat exchangers that are installed between the supply unit and the end-users. This would firstly avoid their heat losses and would secondly enable to reduce the supply temperature from the energy centre to the substations and the consumers.
- Supplying heat from a substation to the end-users with the use of a double pipe configuration instead of a single oversized pipe. As a pipe heat losses increase linearly with the flow temperature and its diameter, a double pipe configuration could reduce the heat losses by pumping a lower flow temperature for the space heating and operating a single pipe of reduced diameter during the summer season.
- Reducing the length of the service pipes. The service pipes are the pipes connecting the DH network to the substations and the pipes connecting the laterals to every consumer's heat interface unit.

The current heat losses could also be reduced by minimising the operational cost to pump the heat to the consumers. This operational cost includes the electricity required for pumping and the heat losses to the environment and it may be minimised by controlling both the flow rate and the supply temperature in every circuit.

It was also confirmed by this study that the heat consumption is under monitored by the consumers' heat interface unit heat meter. Thus, the operational cost minimisation of a DH system becomes very challenging. The metering error from heat meters can firstly be explained because the heat can be supplied at varying flow rates and temperatures and a heat meter calculator does not read continuously a sensor's measurement: The Sharky 775 ultrasonic compact heat meter is set to meter the flow every second and the flow and return temperature are measured ever 4 or 16 seconds depending on its operating mode. Although a flow meter measures the flow velocity at a given time, the used resistance temperature sensor, such as the Pt100, is not always in equilibrium with the flow temperature as the sensor needs a little amount of time to heat to the flow temperature. For both reasons, it can be concluded that the maximum difference of

temperature between the flow and return cannot be measured and the heat consumption is under monitored.
Furthermore, the Sharky 775 heat meter installed on a 22 mm pipe supplying heat to a heat interface unit measures the flow with the use of a transit-time ultrasonic flow meter which is influenced by flow disturbances related to viscosity and whether the flow is turbulent or laminar. This is because a transit-time ultrasonic flow meter calculates the additional time that an ultrasonic wave requires to cross a flow when following a linear path going against the flow and the measured velocity is then calculated. Thus, this measured velocity is influenced by the flow profile and a correction factor is then used to calculate the mean velocity of the flow. As the flow profile changes when passing from laminar to turbulent, the correction factor also changes from approximately 0.76 to 0.94 respectively. A turbulent or laminar flow is identified when the Reynolds number is over and under approximately 5000 and 2000 respectively. If the Reynolds number is between both values, the flow profile and the correction factor are unknown. However, heat meters are also set to calculate heat consumption in these conditions, but they then under meter the heat due to the rather uncertain and concave nature of the correction factor joining both Reynolds number. As an ultrasonic wave flows at approximately 1,480 m/s, this error also remains significant in laminar conditions because of the reduced additional time required by the ultrasonic wave to cross a pipe against the flow. The similar reasoning can be used to justify that an ultrasonic heat meter measures the flow velocity more precisely in a larger pipe than in a reduced 22 mm diameter pipe that is used to supply the heat in a 10 to 30 kW heat interface unit used to heat dwellings.



This study compares the heat losses reduction from a DH system composed of 587 flats distributed throughout 6 Blocks and connected with 5 substations. Originally, the centrifugal pumps in the Blocks' substations were operating at maximum velocity. Also, the energy centre did not pump the DH flow at a constant temperature and the secondary flow would then vary in temperature from approximately 60°C to 67°C and cooling of less than 1.5°C. The original operation of the DH system was modified in September 2014 by controlling the pumps in the energy centre to operate with a differential pressure set at 0.5 bar while supplying the heat at an increased temperature of 80°C. The pumps supplying the heat in a first Block was then also set to operate as the pumps in the energy centre but to supply the heating flow at a constant 75°C. Progressively during the month of October, the other Blocks connected to the DH system were at their turn also set to operate as such. However, as the energy plant generates heat with an undersized CHP engine and oversized boilers and does not make use of its thermal store, the energy centre is still unable to maintain a flow of 80°C during the morning peak load. The Figure hereafter shows the billed heat losses reduction that was finally achieved by increasing ever flow supply and cooling temperatures. In summary, although the "real" heat losses to the environment increases by supplying heat at a higher temperature, the billed heat losses reduces of approximately 20% by increasing the cooling of the DH flow and supplying the heat at a constant temperature.

Kenneth Hansen is working at Aalborg University, Denmark dealing with energy modelling and smart energy systems. He was educated as an engineer from Aalborg University and has since been working on the STRATEGO project creating heating and cooling strategies for various European countries. The project continues the work previously developed in the Heat Roadmap Europe research series.

Comparing Heat Supply to Heat Savings With a Levelised Costs Approach and an Energy System Approach

Kenneth Hansen (khans@plan.aau.dk), David Connolly and David Drysdale*
Aalborg University Copenhagen, Denmark

Findings from existing studies indicate that the cost of heat savings increase as more heat savings are achieved due to the state of the building stock and hence, alternatives other than savings typically become more economically feasible at a certain level of heat reductions. Heat saving cost curves are developed for a number of European countries to identify the heat saving potentials and the associated costs. It is important to identify when the cost of heat savings become more expensive than the cost of sustainable heat supply, so society does not overinvest in heat saving measures. Hence, levelised heat supply costs are calculated for solutions related to either individual heating or community solutions. These heat saving potentials and the associated costs are then compared with a range of levelised heat supply costs (i.e. €/kWh for heat savings compared to the €/kWh for heat supply), to identify feasible levels of heat savings from a cost perspective for a number of European countries.

Furthermore, the heat saving levels are analysed from an energy system analysis perspective for the same countries by developing reference energy systems and implementing various levels of heat savings. This approach will allow for a more detailed investigation of heat saving impacts on a full energy system scale and will shed light on how factors such as energy efficiency and environment, beyond the economic perspective, is affected by different levels of heat savings. This also ensures that the heat savings are compared with the specific mix of heat supply options currently in use within each country.

Finally, the levelised heat supply approach will be compared to the energy systems analysis approach in order to identify differences and highlight impacts that can only be captured in a systems approach rather than a levelised costs approach. This will allow for a discussion about how different heat saving levels relate to the local conditions of a country's energy system.

Paweł Gilski has been employed at Veolia Energia Warszawa for about 3 years in the R&D department called Heat-Tech Center. Presenter at two conferences: 2nd International DHC+ Research Conference in Brussels 2013 and The 14th International Symposium on District Heating and Cooling in Stockholm 2014.

Influence of Stray Currents on District Heating Pipelines Failure Rate

Paweł Gilski (pawel.gilski@veolia.com)*
Heat-Tech Center Veolia Energia Warszawa, Poland

The article presents the results of an analysis of stray currents influence on district heating (DH) pipelines failure rate with use of data from Geographical Information System (GIS).
DH in Poland supplies 41% of citizens and has very high market penetration in the cities. In Warsaw, the capitol city of Poland, the DH supplies 80% of buildings in the city. Such a result requires a large infrastructure. The length of DH network in Warsaw is about 1700 km (1 km of network = 1 km of supply pipeline + 1 km of return pipeline), it is the largest DH network in European Union.
Cities have also other infrastructure systems than DH pipelines: roads, tap water pipelines, sewer pipelines, gas pipelines, tramway tracks, and others. Those systems run through cities and cross with each other and have an impact on each other. Any failure in one system may cause a failure in another. However, in case tramway tracks the situation is a little bit different. During the operation of trams and trains the stray currents is generated with may conduct through a ground and underground metallic infrastructure and cause an electrochemical corrosion, which damages the pipeline.
With a use of historical data about failures of DH pipelines and GIS data about pipelines and tram infrastructure an analysis was performed in order to compare a failure rate (failure/km/year) of pipelines near tram electric substations with failure rate of pipelines not in vicinity. However, some zones of DH network have installed cathodic protection, a devices which collects stray currents and sends them back to tram system. Those zones are also included in the analysis.
The results show that in fact the zones of DH network with electric tram substation have a higher failure rate. Moreover, zones with installed cathodic protection have a significantly lower failure rate.

Track 9: Energy Planning and Planning Tools

Sven Werner is Professor in energy technology at Halmstad University, Sweden. Co-author of the European textbook about district heating and cooling. Active in the 4DH strategic research centre.

Session Keynote:

European Cooling Demands

Sven Werner (sven.werner@hh.se)*
School of Business, Engineering and Science, Halmstad University, Sweden

Cooling demands are normally not measured when chillers are used as cold source. Neither do national energy balances contain any specific information about cooling demands for residential and service sector buildings. Hereby, information about European or national cooling demands is very rare, since they are not available from statistical authorities. According to the EU directive on energy efficiency from 2012, member states shall carry out and notify to the Commission a comprehensive assessment of the potential for the application of district cooling before the end of 2015. This can be difficult to accomplish when the cooling demands are not known. In order to solve this energy planning dilemma, European cooling demands have been estimated by location and member state. This estimation was based on aggregated cold deliveries from twenty European district cooling systems, where the cold delivery always is measured for each customer. These estimations were also correlated to the European Cooling Index, estimated within the Ecoheatcool project in 2005. From this correlation, the average cooling demand in the service sector was estimated for all locations in Europe. Aggregated European cooling demands were also compared to other recent estimations of the European cooling demands.

Stefan Petrović received his B.Sc. and M.Sc. degrees in electrical power systems from the University of Belgrade, Serbia in 2010 and 2012, respectively. In 2012, he joined the Energy Systems Analysis group, DTU Management Engineering, Denmark and the 4DH Research Centre as a PhD fellow. His main research interests are GIS and energy system modelling.

Ringkøbing-Skjern Energy Atlas for Analysis of Heat Saving Potentials in Building Stock

Stefan Petrović (stpet@dtu.dk) and Kenneth Karlsson*
Department of Management Engineering, Technical University of Denmark, Roskilde, Denmark

Ringkøbing-Skjern is Denmark's largest municipality, located in the west part of Central Denmark Region. Achieving 100% renewable energy system starting from 2020 has been declared as the main goal of the municipality's energy strategy "Energy2020" published in May 2011. The strategy has defined five courses of action to be performed in order to reach this target: production from wind, bioenergy and other renewable energy sources needs to be increased, heat demand in buildings needs to be reduced while transportation sector needs to be converted to renewable energy. More specifically, it is expected that heat demand in existing buildings will be reduced by 50% in the analysed period.

Technical, economic, environmental and geographical aspects need to be taken into account when analyzing such drastic change of municipality's energy system. For that purpose, GIS-based energy atlas has been developed for Ringkøbing-Skjern municipality. The data about energy supply and demand, transmission and distribution infrastructure, energy resources, societal and other energy data have been geographically referenced and combined with tools built in ArcGIS software to create the municipality's energy atlas. The focus in the energy atlas is put on geographical level of details, such as locations of buildings and district heating pipes, but the objects have also been described with technical parameters and historical values. The present paper utilises Ringkøbing-Skjern energy atlas together with heat demand model based on a monthly calculation of heat losses and usable heat gains to perform analysis of heat saving potentials and associated costs in the municipality's building stock. Ringkøbing-Skjern energy atlas was used to feed the data about building stock to the heat demand model and to spatially represent the results. 1 km^2 Danish square was used for geographically representing the results.

Two main conclusions can be drawn from the present analysis. First, geographical scope of analysis highly influences the results. Namely, residential heat demand calculated using national averages and calibrated with the Danish Energy Statistics proved to be 26 % lower than the residential heat demand stated in the municipality's energy statistics. Heat saving potential with annuitized marginal costs lower than 2 DKK/kWh appears to be 30 % higher when the calculation is performed on the level of municipality compared to national level. If affordability issues are taken into account, the difference drops to 22%. When the calculation calibrated with Ringkøbing-Skjern's energy statistics have been compared with the consumption data provided by district heating company in the city of Ringkøbing, smaller differences have been observed – heat demand in single family buildings defers by 6% while heat demand in multi-family buildings defers less than 1%. Second conclusion is that heat saving measures represent inexpensive solution for reducing heat demand in residential building stock. Reduction of residential heat demand by 50% can be achieved for average annuitized marginal costs of 0.7 DKK/kWh.

Fanni Sáfián is a geographer (M.Sc.), PhD fellow at Eötvös Loránd University and project assistant at Energiaklub Climate Policy Institute and Applied Communications, Budapest, Hungary. She participated as a guest student in the SEPM programme at Aalborg University (2011); and in the EnergyPLAN PhD course (2013). Her research area includes planning sustainable energy systems, energy modelling with EnergyPLAN, and community energy production and regional development.

Is There Room for Renewables in 2030? – Analysing the Effects of a New Nuclear Power Plant in Hungary

Fanni Sáfián (safian@energiaklub.hu)*
Eötvös Loránd University and Energiaklub Climate Policy Institute and Applied Communications, Budapest, Hungary

Hungary has several problems regarding energy management, which will culminate in the following decades: high level of energy dependence; poor distribution of sources of imported energy; low possibilities of power plant regulation; old and outdated power plants with low efficiency; power plants closing down because of cheap import electricity etc. As a solution, the Hungarian TSO and the government decided to build a new nuclear power plant with 2400 MW physically next to the old, 2000 MW nuclear power plant, which will work together for approximately 6 years.
According to our hypothesis, the new nuclear power plant will not provide a sustainable, secure, technologically and economical feasible solution to the Hungarian energy situation. On the contrary, by strengthening the centralised character of the Hungarian electricity grid, producing around 10% excess electricity and utilizing all financial sources, it will hinder renewable energy technologies from spreading. However, these small-scaled, local renewable-based applications – especially in community-lead projects – could ensure energy production with high efficiency while creating opportunity to provide complex solutions through local economical and societal benefits.
In order to analyse the opportunity of transition to a decentralised, renewable-based energy system in Hungary, two energy models were created with the EnergyPLAN software for the year of 2030. One is based on a Hungarian energy vision by 2030, outlined by Energiaklub. The main concept of this vision is to create a model in which energy conservation, energy efficiency and renewable energy utilization have priority, without the new nuclear power plant. In other words, this is not a normative scenario, which considers the present opportunities of the Hungarian economy by holding the transition process on a realistic path. The other model is based on the official projection of MAVIR (the Hungarian TSO), and on some future projections from the previous vision. The new nuclear reactors have priority there, while also a new, large gas-fired power plant will be built. The renewable energy development is modest in this scenario. Both visions were created based on Hungarian and European historical statistics and projections and calculations of numerous Hungarian and international strategies, reports, scenarios and on own calculations.

The two models were analysed with EnergyPLAN energy system analysing tool, to answer two main questions: is the Hungarian energy system able to work without the new nuclear power plant, and with more intermittent renewable energy sources? And regarding the second model: is it possible and with what consequences to integrate more renewable energy sources into the Hungarian energy system with more than 50% nuclear electricity production? The results show that even by a conservative development, more than 27% renewable electricity production is possible in Hungary by 2030; and that a second nuclear power plant would considerably prevent small-scale, decentralized energy production – especially regarding intermittent renewable-based sources – while also critical export issues arise.

Richard Büchele joined the Energy Economics Group in Austria in 2014. He studied electrical engineering at the Vienna University of Technology, Austria and finished his master's degree in power engineering with a focus on energy economics and energy supply in 2013. In his master's thesis he developed a cost-minimizing investment and dispatch model. Currently he is working on a comprehensive assessment to identify the potential for the application of high-efficiency cogeneration and efficient district heating and cooling in Austria.

Comprehensive Assessment of the Potential for the Application of High-efficiency Cogeneration and Efficient District Heating and Cooling

Richard Büchele (buechele@eeg.tuwien.ac.at), Andreas Müller, Marcus Hummel, Lukas Kranzl, Michael Hartner*
Energy Economics Group, Vienna University of Technology, Austria
Yvonne Deng and Marian Bons, Ecofys

Space heating and cooling accounts for almost one third of the final energy use in Austria and plays a central role in achieving energy efficiency targets. As part of the EU Energy Efficiency Directive (2012/27/EU) all Member States have to develop a comprehensive assessment of the potential for the use of high-efficient combined heat and power (CHP) and efficient district heating and cooling by the end of 2015. In a first step relevant heating and cooling demand regions exceeding certain consumption or production thresholds listed in the directive have to be identified and the potential of renewable energy and efficient technologies should be determined for each region. For these regions an economic cost-benefit analysis has to be performed in a second step. In this paper the Austrian approach and methodology for this comprehensive assessment is described.

To determine relevant demand regions for district heating the actual demand for heating and cooling is identified and two scenarios for the year 2025 are developed using the techno-economic bottom-up model INVERT/EE-Lab. This model calculates the building related demand for space heating, cooling and hot water on a highly disaggregated level of a 250x250 m resolution. Then the current state of supply in terms of existing plants and district heating networks is investigated to include relevant infrastructure into the cost benefit analysis. Regional technical potentials for high efficient technologies are determined by using technical approaches like the suitable roof area for solar thermal collectors, the availability of natural gas within a certain distance or existing waste capacities for incineration plants. Based on these steps a cost benefit analysis is conducted for the relevant regions. To calculate the economic capacities and the full load hours of the CHP plants hourly electricity prices, hourly heat demand and the opportunity costs of covering the load by a central gas boiler are considered but no dynamic interdependency between the electricity market and the CHP output were taken into consideration. The load-dependent heat generation cost for each technology includes investment costs, O&M costs, fuel and emission certificates costs. For the technologies connected to a district heating network additional costs for transmission and distribution pipes depending on the distance from the supply technology to the network and the heat density within the network are considered. Therefore every region was divided into sub-regions with different heat densities using the results given by the INVERT/EE-Lab model. The network costs are calculated for a model network with fixed parameters for size, layout and temperature level. Furthermore the costs for a peak load gas boiler that covers 10 % of the peak energy demand are included. According to these costs a technological merit order is established for every region. Starting from the sub-regions with the highest density and with existing net infrastructure the cheapest technology in the merit order is used to cover the demand until the potentials or a maximal connection rate is reached.

Using the INVERT/EE-Lab model to determine the relevant demand regions showed that the in the EED suggested plot ratio of 0.3 was achieved only in very few areas in Austria. This is why a modified approach using a combination of plot ratio, heat density and heat demand is used to.

These criteria lead to 38 main regions suitable for district heating representing 40 % of the energy demand for space conditioning and hot water in Austria. The remaining regions, which do not fulfill the adapted criteria, are classified into 30 types of regions according to similar characteristics. For both the main regions as well as the remaining regions the cost benefit analysis is conducted.

Track 10: Smart Energy Systems

Johan Desmedt works at the research institute Vito, Belgium as project manager within district heating and cooling networks. He is involved in research projects FP7 E-hub on smart energy management, as technical coordinator of the FP7 Resilient project and as coordinator of H2020 STORM project on intelligent control of district heating networks. He is also involved in DHC+ and RHC platforms.

Session Keynote:

The Role and Potential of Distributed Thermal Energy Storage Systems for Active Control of District Heating Networks

Johan Desmedt (johan.desmedt@vito.be), Dirk Vanhoudt and Bert Claessens*
Flemish Institute for Technological Research (VITO), Mol, Belgium

In this work we consider a small district heating network (DHN) fed by a CHP, heating a neighborhood of 100 single-household houses. The electricity produced by the CHP simultaneously with the heat production is sold on the electricity spot markets. Since the variance in the price of electricity, it is profitable to produce electrical power when the price is high. To synchronize the demand of thermal power to the demand of electricity thermal energy storage is required then. Usually, this storage consists of one large central water storage tank placed next to the CHP. In this work however, the use of distributed storage is studied, consisting of small water storage tanks (200-400 l) placed inside the individual buildings or the thermal mass of the building.
A simulation model was built to quantify the profit of the CHP plant during one representative winter week. As a reference, a situation without storage was examined whereby the CHP is controlled heat-driven. Afterwards, three storage cases were considered. In these cases the operation of the CHP is optimized to the electricity price (so called 'active control cases'):

1. A central storage tank placed at the CHP plant is used as thermal storage ('active control – central buffer')
2. Thermal mass of the buildings is used as distributed thermal storage ('active control – no buffers')
3. Thermal mass of the buildings + small water vessels are used as distributed thermal storage ('active control – distributed buffers'). In this case the sum of the volumes of the small buffers is equal to the volume of the central buffer in case 1.

The results of the simulations and lab tests show that all active control cases were able to significantly increase the profit of the CHP, as can be seen in the picture below. Very interesting however is that the distributed storage cases (with distributed storage and with thermal mass only) perform better than the central buffer case. The reason is that the thermal mass of the buildings corresponds to a very large storage capacity. This is also the reason why the addition of small water tanks only slightly increases the profit.

The general conclusion of this work is that active control of a CHP can be very profitable in for district heating and cooling networks of the future. Another very important finding definitely is the fact that thermal mass of buildings can be very promising to actively control district heating grids.

Lisa Brand is in her second year of PhD studies at the Department of Energy Sciences at Lund University, Sweden. She has so far published one article and has had one conference article. These articles as well as her PhD studies aim to investigate and explain how the introduction of district heating prosumers affects the district heating network and relevant environmental values.

Prosumers in District Heating Networks - Problems and Possibilities

Lisa Brand (lisa.brand@energy.lth.se) and Patrick Lauenburg*
Department of Energy Sciences, Lund University, Sweden

With increasing environmental awareness in the society, district heating (DH) companies are facing several new challenges. These challenges often involve renewable energy and more effective utilisation of resources[1)]. One way to address this is to enable the possibility for customers in the DH network to deliver heat to the DH network, as this heat is often either renewable, i.e. from solar panels, or recovered, such as excess heat from supermarkets. These customers would then be called prosumers, as they are both producers and consumers of DH[2)]. The aim of this work is to illustrate both the technical and environmental issues connected to an introduction of prosumers into the DH network.

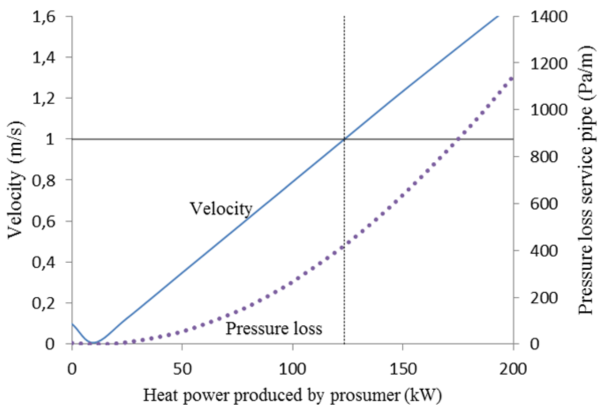


Figure 1. Velocity and pressure loss in the service pipe to a heat-plus house with solar collectors.

The calculations of the technical parameters in the pipes were mainly performed in NetSim, a commercial simulation programme for both district heating and cooling[2,3)]. Both a probable future scenario of solar panels in the district "the Western Harbour" in Malmö, Sweden, and fictitious scenarios were tested. For the environmental aspects, another area in Malmö called Hyllie was investigated. Both the Western Harbour and Hyllie are areas that consist of newly built buildings with various purposes, both office buildings, residential buildings and public service buildings, such as schools. The buildings in both areas are also prepared for a lower supply temperature than usual in DH networks, around 60°C. This is a prerequisite for the kind of prosumers investigated, as the efficiency of their thermal appliances else would be very low. The investigation mainly considered the environmental impact of utilising excess heat from cooling machines in offices and raising the temperature to around 60°C with a heat pump, for delivery of heat to the DH network. A solution of integrated cooling machines and heat pumps was applied.

The results regarding the technical parameters in the pipes showed that due to the often lower supply temperature from the prosumers than from the conventional DH production units, the flow and the velocity in the pipes near the prosumer often increased. In some cases, the service pipe had to be dimensioned according to the supply flow from the prosumer and not according to the demand flow, which is customary, to avoid disturbing noise. Figure 1 shows an example of the velocity and pressure loss in the service pipe to a house with solar collectors dimensioned for producing the whole annual net heat demand of the building on the roof. According to the local energy company, 1 m/s is the highest velocity allowed in service pipes, to avoid disturbing noise. Other results showed that the pressure drop in the pipes increased due to higher flows in the pipes. This has to be taken into account when introducing new prosumers, as the differential pressure else may become too low at nearby customers.

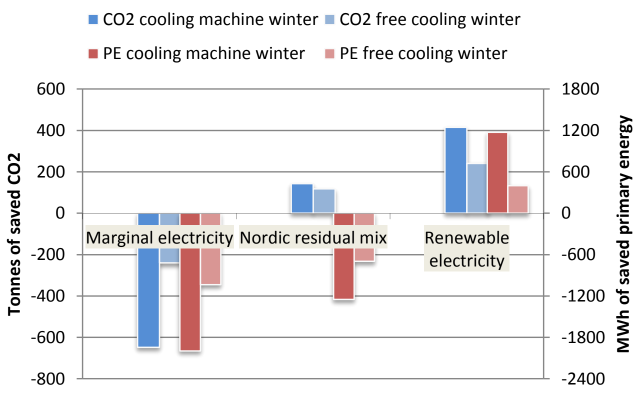


Figure 2. The environmental effect of recycling the heat from cooling machines.

The environmental results show that there might be lower carbon dioxide emissions and primary energy (PE) use if the electricity for the cooling machines/heat pumps used for raising the temperature in the excess heat is generated by renewable sources. If the electricity used is instead Nordic residual mix, the carbon dioxide emission are still lower with the excess heat from the cooling machines instead of conventional DH, but the primary energy use is higher. When marginal electricity is used, it is better from both a carbon dioxide and from a primary energy point of view to use conventional DH. This can be seen in Figure 2, which shows the case of Hyllie with six offices with integrated cooling machines and heat pumps for simultaneous production of DH with a supply temperature of 60°C and office cooling. Both the results for when the cooling machines are used throughout the winter (cooling machine winter) and for when the cooling machines are turned off throughout the winter and the offices receives their cooling via free cooling (free cooling winter) are showed.

Prosumers in the DH network will probably be more common in the future, just like in the electricity system. It will however take a long time to change all the existing and old DH networks into new low temperature DH networks. It is thus very important to investigate how prosumers will affect the existing DH networks. The results show that it is possible to introduce prosumers into existing DH networks, but there are some aspects, such as velocities and pressure levels, that need to be reviewed beforehand. The prosumers also often have a higher efficiency with lower supply temperatures, why it is easier to introduce them in parts of the DH network where the buildings are adapted to lower supply temperatures.

It is also important to notice that the use of excess heat from the cooling machines only result in clear environmental benefits when renewable energy is used for the extra electricity needed in the cooling machines. It is thus important to analyse the results on a system level. In a system with marginal electricity consisting of fossil fuels, it is thus better to use conventional DH. In other systems, it could be beneficial to instead use the excess energy from the cooling machines and raise the temperature with a heat pump.

Further work on this subject include a study of Hyllie, to identify typical DH prosumer buildings and examine how much excess energy that with existing technology could be utilised in DH networks, and also the environmental outcome of this.

1) Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009, 2009.

2) L. Brand, A. Calvén, J. Englund, H. Landersjö och P. Lauenburg, ”Smart district heating networks – A simulation study of prosumers' impact on technical parameters in distribution networks,” Applied Energy, vol. 129, pp. 39-48, 2014.

3) Vitec, ”An onlinemanual from Vitec NETSIM,” 27 09 2013. [Online]. Available: http://doc.energy.vitec.se/ManualData/ve/en/vitechelp.asp?produkt=NetSim&folder=netsim. [Found 27 02 2015].

Barbara Fricke, with a diploma in mechanical engineering focused on renewable energies, has been conducting research in the field of ecobalancing and development of future energy supply systems since 2007. An additional master's degree in energy management allows her also to take into consideration the social, political and legal aspects of future energy system changes.

100% Renewable Municipal Energy Supply: Chances and Restrictions of Solar Thermal District Heating

Barbara Fricke, Sebastian Steininger, Anette Anthrakidis*
Solar-Institut Jülich of Aachen University of Applied Sciences, Jülich, Germany

The Solar-Institut Jülich (SIJ) of the Aachen University of Applied Sciences in Germany examines renewable energies and concepts for the future energy supply[1)]. In the project "The municipal efficiency revolution for climate protection in German cities – requirements, transformation paths and effects" (KomRev) two concepts of a 100 % renewable energy supply in the year 2050 were developed and simulated for a city of 75,000 inhabitants (Rheine in North Rhine-Westphalia, Germany).
In the two concepts "Maximum-Decentralised" and "Moderate-Decentralized" high shares of local energy potentials were used in a highly efficient way and with a smart interconnectedness between electricity, heat and mobility. For the demand side a high efficiency level was introduced based on a consistent set of assumptions. The building structure as well as the industrial base was unchanged. On basis of a geographical information system (GIS) these structures could be captured to constitute their space and warm water heat demand including its geospatial reference. The geospatial information allowed differentiating between so called "peripheral" regions and regions with a higher heat density. In both concepts the periphery heat supply was realised object-related in form of geothermal probes combined with brine-to-water heat-pumps. In the "Moderate-Decentralized" concept the space and warm water heat demand of the city was completely supplied this way.
In the "Maximum-Decentralized" concept all areas with sufficient heat density were supplied using district heating networks with seasonal storages sized up to 100,000 m^3 and fed by solar thermal energy. The availability of solar energy could be spotted using the GIS information about available roof surface suitable for solar use in each district heating network. In addition to the solar collectors, grid connected heat pumps supported the heat provision during winter by shifting heat in the seasonal storages from low to high temperature zones.
With yearly weather and heat consumption data on an hourly basis the provision and consumption of solar heat and electricity using heat-pumps were simulated. In the district heating areas solar energy on average covered 95% of the space and warm water heat demand with a backup of 5% current heating via heat pumps.
The different heating supply approaches of the two concepts showed considerable differences in the resulting residual electricity loads and load curves. The different heat

storage sizes provided demand side management availabilities that differed strongly in the two concepts.

[1]) Selected research projects:
"Reduction of greenhouse gas emissions by expansion, smart crosslinking and optimization of decentralized fluctuating renewable energy supply in Germany", supported by the German Federal Environmental Agency, 2010
"EC2Go – The Car sharing E-Mobility model for urban regions", supported by the Ministry of Economic Affairs and Energy of the State of North Rhine-Westphalia and the European Union, 2013

Magdalena Berberich has completed studies of energy and environmental technologies in Ansbach and Athens and sustainable energy competence in Stuttgart. Master’s thesis within the research projekt Solar-CHP. Since February 2015 she has been working for Solites - Steinbeis Research Institute for Solar and Sustainable Thermal Energy Systems in Germany.

Solar-CHP - Development of Multifunctional Systems Combining CHP with Solar Thermal Plants

Magdalena Berberich (berberich@solites.de), Lisa Willwerth, Laure Deschaintre and Thomas Schmidt*
Solites Steinbeis Research Institute for Solar and Sustainable Thermal Energy Systems, Stuttgart, Germany

Increasing amounts of fluctuating renewable energies in the electricity grid lead to decreasing electricity prices and decreasing operation hours of conventional combined heat and power (CHP) plants. New solutions are needed to cover the heat demand in district heating networks and to ensure profitable operation of CHP plants. With a solar district heating (SDH) system consisting of CHP combined with large-scale solar thermal plants and heat storage a contribution to a reliable and feasible energy supply in residential areas and cities can be possible.

In a Solar-CHP system the CHP plant is operated power-led, i.e. the electricity can be commercialised profitably by using the power exchange EPEX and the market of control energy. The produced heat is used in the district heating network which is supplied as well by the solar thermal collectors. In case of low heat production from CHP and solar collectors the lack of heat is covered by an additional fossil peak load boiler. Important for the system is the heat storage which enables the flexible operation of the CHP plant and the reliable heat supply of the district heating network.

In this research project this type of SDH system is developed in the simulation program Trnsys. The target is to analyse how the whole system can be operated in an economically feasible way and which ranges of dimensions of the single components are best suitable for this kind of system and operation mode.

For the simulation model of a CHP plant the electrical and thermal efficiency are calculated by using performance maps. In addition the time-based behaviour of start-up and run-down processes and load alternations is modelled with characteristic curves. The developed sets of parameters allow the simulation of engines, gas turbines, back-pressure as well as extraction steam turbines and combined cycle plants. The parameters are based on literature values and a survey of data from manufacturers and operators of CHP plants. Mean values are used to represent each technology.

A control strategy for an electricity power-led operation of the CHP plant was implemented in the simulation. It uses the EPEX and the tertiary control market to commercialise the electricity. With information of plant operators and additional research concerning the commercialisation of electricity produced in CHP plants, the control was

developed. Data from the energy exchange EPEX and the market for control energy were analysed for the years 2012 and 2013.
As a reference the system is simulated with three different dimensions of the CHP plant and small heat storage. The dimensions of the CHP plant, heat storage and solar thermal collectors are varied in the simulations.
First system simulations with a motor CHP plant showed the reduced heat supply of a compact motor CHP plant operated with the implemented power-led control compared with the heat-led operation. This reduced heat supply of the CHP plant can increase the potential for solar thermal heat in the described system. By adapting the configuration parameters in the simulation model different types of CHP plants with different economic boundary conditions can be simulated.
The simulation study results show how the operation of CHP plants in district heating systems can profit from the integration of large-scale solar thermal plants and large heat storages.
The sole responsibility for the content of this publication lies with the authors. It does not necessarily reflect the opinion of the German Federal Ministry for Economic Affairs and Energy (BMWi). Neither the funding organization nor the authors are responsible for any use that may be made of the information contained therein.

Natalia Kabalina is a mechanical engineer, graduate from Moscow Power Engineering Institute, Moscow, Russian Federation, 2010. Currently she is pursuing her PhD degree in the collaboration between Instituto Superior Technico (Lisbon, Portugal) and Royal Institute of Technology (Stockholm, Sweden) through the framework of the EMJD program Select+.

Exergy Analysis of Polygeneration DHC System Based on the Gasification of RDF

Natalia Kabalina[*1,2] *(natalia.kabalina@ist.utl.pt), Mario Manuel Goncalves da Costa*[1]*, Weihong Yang*[2]*, Andrew Martin*[2]*, Massimo Santarelli*[3]
[1]*IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*
[2]*ITM, Kungliga Tekniska Högskolan, Stockholm, Sweden*
[3]*DENERG, Politecnico di Torino, Torino, Italy*

A majority of district heating and cooling (DHC) systems still operate on fossil fuels. Such reliance might be reduced by a system shift to polygeneration via deploying new technologies for the diversification in both fuel input and energy services provided, including sale of value-added products. Fuel selection for the polygeneration DHC system can be based on two main criteria - feedstock availability and sustainable system development. One favorable energy source that satisfies both parameters is refuse derived fuels (RDF), i.e. products of municipal solid waste (MSW) plant processing. Recently due to the introduction of waste management Directives 2006/12/EC and 1999/31/EC, RDF derived from MSW presents itself as a plentiful resource waiting to be utilized.

For the purpose of the complete RDF energy potential recovery, a case study was selected with focus on a DHC system located in a residential area of Lisbon, Portugal, with retrofitting of a gasifier and product gas upgrading equipment. With this approach the polygeneration system could fabricate the following value-added products: syngas (SG); synthetic natural gas (SNG); and char.

The objective of this study is to carry out an exergy analysis of the upgraded polygeneration DHC system and to compare the different scenarios of value-added products (char; SG and char; SNG and char; SG, SNG and char). The analysis is to be complimented with a parametric study for highlighting key component influence (i.e. gasification temperature, steam to carbon ratio, equivalence ratio and others) on the system capability with the most promising scenario to be selected.

It was found that in the most basic scenario, when char is the value-added product (all SG generated in gasifier is consumed in CHP for boosting heat and power output), the exergy efficiency of the polygeneration system is equal to 65.0%. In the next scenario, if SG is fabricated as the added-value product (10% extra to those used in CHP) complimentary to char, the exergetical efficiency slightly increases (66.0%). It continues its further growth till 73.9% along with the SG output rise. In contrast, the production of SNG and char results in a slight drop in overall exergy efficiency (64.6%) with its subsequent decline in case of SNG generation output growth (23.7%). Finally, for the scenario with all three system value-added products, where 10% extra SG is produced in the gasifier to sell and to convert into SNG, there is a relatively small increase in efficiency to 65.4%. Whereas

when the further growth of SNG and SG output is made, the system exergy efficiency lowers to the value of 54.6%. Comparison between scenarios reveals that SG and char production are the most beneficial for the system performance, as it exhibits higher exergy efficiency with further increase in value-added product output.

Track 11: Future District Heating Production and Systems

Javier Felipe Andreu (main author): This abstract consists as part of his master thesis done during his Erasmus program at the Faculty of Mechanical Engineering and Naval Architecture in the University of Zagreb to finish his studies of industrial engineering at the School of Engineering and Architecture in the University of Zaragoza.
Goran Krajačić (presenting author) received his PhD degree in Mechanical Engineering from the University of Zagreb in 2012. Since 2014 Professor Associate at University of Zagreb. In 2007 he was a guest researcher in the Instituto Superior Técnico, Lisbon, Portugal. He has been working on the national and European scientific projects. He participates in teaching the courses 'Introduction to Energy Management' and 'Energy Planning'.

Session Keynote:

Reducing CO_2 Emissions and Increasing the Integration of Renewables through the Utilization of Smart District Heating System in the City of Velika Gorica

Javier Felipe Andreu[1] (javierfelipeandreu@gmail.com), Nikola Matak[1], Tomislav Novosel[1], Tomislav Pukšec[1], Mario Marjanović[2], Dragutin Bavoljak[2], Marko Ružić[3], Goran Krajačić[1], Neven Duić[1], Daniel Rolph Schneider[1]*
[1] Power Engineering and Environment, Department of Energy, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Zagreb, Croatia
[2]HEP Toplinarstvo d.o.o., Local Boiler Plants, Zagreb, Croatia
[3]City of Velika Gorica, Office for Environmental Protection, Velika Gorica, Croatia

The City of Velika Gorica is facing several key issues regarding its heating sector. The biggest among them is the utilization of 14 small and distributed heat plants each providing energy to a separate and individually disconnected heating grid. Of the 14 installed plants only 2 are gas operated, 34% of the installed capacity, while the rest use fuel oil resulting in a high level of CO_2 emissions. Other issues include distribution loses and a high specific heating consumption of roughly 190 kWh/m^2 on average for residential buildings and 200 kWh/m^2 on average for public buildings. Modernization of the district heating system and a high penetration of renewables with a decrease in energy consumption of residential and public buildings can result in a reduction of costs and CO_2 emissions of the system. Smart district heating systems could have an important role in the integration of intermittent renewable energy sources because they could insure flexibility of the future energy system.
The goal of this paper is to evaluate the integration and connection of 14 small heating grids into one smart district heating system of the City of Velika Gorica with integration of renewable energy sources like biomass and solar. Three different utilization scenarios of solar energy including heat storage, preheating and individual heating as well as the utilization of biomass in cogeneration have been analysed to identify the optimal energy mix in the city with the purpose of reaching the highest energy performance with an affordable cost.

Matteo Giacomo Prina was born in Milan, Italy. After graduation at Politecnico di Milano in sustainability and energy management, he started working at EURAC research, Institute for Renewable Energy, within the regional energy modeling group. Its aim is to develop RES high penetration scenarios for the regional area in order to support future energy policy.

Smart Energy Systems Applied at Urban Level: The Case of the Municipality of Bressanone-Brixen

Matteo Giacomo Prina (MatteoGiacomo.Prina@eurac.edu), Marco Cozzini, Giulia Garegnani, David Moser, Ulrich Filippi Oberegger, Roberto Vaccaro and Wolfram Sparber*
EURAC Research, Institute for Renewable Energy, Bolzano, Italy

The present contribution focuses on the energy system of the municipality of Bressanone-Brixen, located in the north of Italy. Bressanone, a small town with about 20,000 inhabitants and an alpine climate (elevation: about 560 m), joined the Covenant of Mayors in 2013 and already prepared a Sustainable Energy Action Plan (SEAP, developed by EURAC), where information concerning its current energy system and possible future actions can be found. Within this context, EURAC is investigating various possible energy scenarios for this interesting case study.
In particular, the proposed paper will focus on the following aspects:

- Analysis of the current situation and resource assessment. The following main aspects will be considered: electricity demand, heating demand, PV installed capacity, individual boilers, district heating network.
- Analysis of the possibilities to extend the existing district heating (DH) network to cover a larger fraction of the residential buildings of the town.
- Analysis of the possibilities to extend the DH network in combination with a significant increase of PV capacity, a large thermal storage and a large heat pump (HP). In this way, it would be possible to exploit the thermal storage of the district heating network as a means to perform peak shaving on the electric grid (during periods of excess PV production with respect to the local demand), via the use of the heat pump. This could yield important benefits in terms of grid stability. Moreover, assuming that the additional PV capacity could be connected to a local sub-grid, improved economic figures could arise from the incentives for PV self-consumption.
- A comparison between the described thermal storage solution and a solution based on electric storage. The electric storage possibilities are being analysed by EURAC in an independent work. In the present work, we aim at discussing the relative convenience of these two approaches and their possible interaction in a hybrid storage system.

The existing energy scenario as well as the proposed ones will be analysed with EnergyPLAN. The figure below, obtained with EnergyPLAN, shows the peak shaving effect that could be obtained with large PV penetration combined with a suitable thermal storage.

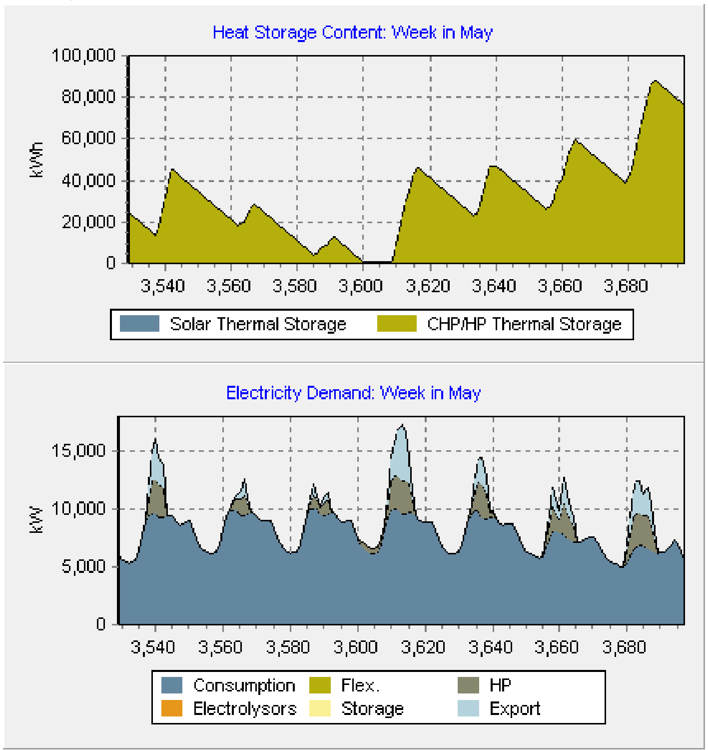


Figure 3. Results obtained in a scenario with large PV penetration (20 MW).
Top panel: electricity demand profile for a typical week. The large heat pump associated to DH starts during periods of excess electricity production (part of the generated electricity is still exported).

Lower panel: thermal storage behaviour during the same week (thermal storage capacity fixed to 100 MWh). The heat storage is loaded during periods of excess electricity production, where the operation of HPs is more favourable. Unloading occurs during remaining periods, in order to satisfy the DH demand.

The scenario corresponding to the figure is obtained by increasing the PV capacity to 20 MW, which seems an achievable target considering the installed capacity equal to 7.4 MW in 2013 and the rooftop potential capacity of 50 MW within the city of Bressanone. The used assumptions and details of the calculation will be described in the paper.

Nguyen Le Truong (main author) is a postdoctoral researcher at the Department of Built Environment and Energy Technology, Linnaeus University, Sweden. He has experience as a consultant and trainer in energy efficiency and renewable energy projects. His research focus is to use the concept of system analysis to compare primary energy use and life cycle monetary cost of different heat production technologies and systems.
Leif Gustavsson (presenting author) has a PhD in Environmental and Energy Systems Studies, a M.Sc. in Civil Engineering and a M.A. in Psychology. His research is linked to sustainable development, especially building construction, energy efficiency and renewable energy. The aim of his research is to increase understanding of how resource- and cost-efficient systems with low environmental impact can be designed, analysed and implemented.

Effects of Energy Efficiency Measures in Buildings on Different Types of District Heating Systems

*Nguyen Le Truong and Leif Gustavsson**
Department of Built Environment and Energy Technology, Linnaeus University, Växjö, Sweden

Energy efficiency measures in district-heated buildings have been proven to be primary energy efficient. However, the primary energy savings depends on both the final energy savings and the energy efficiency of the supply system. In this study, we evaluate primary energy savings of different energy efficiency measures in a typical district-heated building constructed 50 years ago during the Swedish programme to build a million residential buildings. We consider various locations of the building and consider district heat production systems (DHS) of different scales, technical characteristics and heat-load profiles. We show that the primary energy savings of energy efficiency measures vary with the type of energy efficiency measure and with the type of district heat production system. Energy efficiency packages give large final energy savings but the primary energy savings vary significantly. Of the energy efficiency packages, the package that gives electricity savings but increases the use of district heat is the most primary energy efficient package in relation to the final energy savings. Least primary energy efficient is heat savings during the summer months. Energy efficiency in buildings connected to small-scale DHS using heat-only boilers is more primary energy efficient than that in buildings connected to medium- and large- scale DHS using CHP units. Evaluation of energy efficiency measures in district-heated buildings requires a systems perspective where the final energy savings in buildings are matched to the actual DHS.

Gunnar Lennermo, PhD fellow at Mälardalen University in Västerås, Sweden, has been working as a consultant for 35 years with a focus on designing solar thermal (ST) systems in combination with district heating. Together with Patrick Lauenburg, Lund University, he is currently analyzing and improving the performance of decentralized feed in systems.

Decentralised Heat Generation in District Heating Systems

Gunnar Lennermo (gunnarl@energianalys.net), Energianalys AB, Sweden*
Patrick Lauenburg, Lund University, Sweden

District heating systems need to improve integration of decentralised heat generation. Micro production, prosumers and smart grids are terms becoming more and more common in connection to the power grid. Concerning district heating, the development is slower, although improving. There is today a number of such decentralised units for heat generation, mainly solar, that have been partly evaluated. Previous studies have shown there is a need to develop better control of the connection to the network. It is mainly the substantially varying differential pressure (DP) in the network that cause problem for many of the solutions used today and also that the DP is not dependent on the feed-in flow. Of main interest in order to further facilitate the implementation of decentralised heat generation in the form of prosumers, is to develop a technical concept for how heat can be supplied to the district heating system in a way that benefit both customer and utility.

In the project, which is to be finalised by June 2016, we have so far focused on mapping out the nature of the district heating network DP and how it affects the feed-in function of decentralised heat generation installations. DP measurements with high resolution (10 seconds) have been carried out in connection with about ten installations. The measurements indicates substantial variation in DP, both in terms of magnitude as well as how rapid the variations are. In 1-2 minutes, it can differ with an amplitude of 25-100 kPa. This pressure difference is larger, or much larger, than the internal, flow-dependent, pressure drops in the feed-in circuit consisting of heat exchanger, pipes and valves.

A closer look at pump curves for some of the feed-in pumps used in the installations tells us that the pressure variations easily cause the feed-in pump to “fall out” of the pump curve. A very small raise in DP can bring the feed-in flow to zero and a very small decline in DP can cause a much larger flow. This change in DP and a badly performing regulation is likely a great cause of the cyclic behaviour of the feed-in flow that has been observed. Further work in this project will aim at improving the feed-in control and to test it in practice. Tests will be performed both in real installations as well as and in a new lab installation together with an international partner.

Jacek Kalina has been working in the field of energy systems engineering since he graduated from the Silesian University of Technology, Poland in 1997. He is currently employed at this university in the position of Assistant Professor. The specific fields of his interests are: thermal energy conversion processes, small-scale cogeneration and tri-generation, technical and economic optimisation of thermal systems.

Advanced Hybrid and Combined Small-scale Thermal Energy Conversion Systems for Efficient Use of Locally Available Resources

Jacek Kalina (jacek.kalina@polsl.pl)*
Institute of Thermal Technology, Silesian University of Technology, Gliwice, Poland

The paper is focused on theoretical investigations related to the search for new technological solutions in the field of electricity generation in small-scale distributed generation systems, including the combined processes such as cogeneration and trigeneration. The research program of the project has been built on the hypothesis that it is nowadays possible to use the small-scale individual energy conversion technologies, that are either commercially available or at the final stage research and development, for construction of advanced, highly efficient hybrid and combined plants. It has been assumed that the implementation of such solutions would allow for an improvement of energy, environmental and economic performances in the aspect of the use of locally available different dispersed energy resources.
The objective of paper is to present possibilities and conditions for designing complex multi-component technological structures of distributed energy conversion systems. The issues related with applications of such solutions is presented on a sample analysis of cogeneration system that consists of microturbine, high temperature fuel cell, inverted Bryton cycle module and biomass gasification island. The project assumes supporting use of natural gas and cooperation of the plant with a low-temperature district heating network. Thermodynamic parameters, indices of energy effectiveness, impact on the environment and economic performance figures are examined. The plant is modelled using commercially available computer software Ebsilon Professional. Characteristics and input data of individual elements of the investigated systems are adopted form the literature.

Track 12: Energy Planning and Planning Tools

Ralf-Roman Schmidt has been working at the AIT in Austria since June 2009, where he is responsible for the field “District Heating and Cooling”. After finishing his studies in production engineering at the University of Bremen in 2005, he received his PhD degree in the field of thermo-fluid dynamics in 2013. Ralf-Roman Schmidt is vice chairperson of the European DHC+ Technology Platform.

Session Keynote:

Feasibility of Micro-DH Networks in Scattered Urban Areas Using Local Sources: Analyses of Technical and Non-technical Barriers of a Case Study

Ralf-Roman Schmidt (Ralf-Roman.Schmidt@ait.ac.at) and Daniele Basciotti*
Energy Department, Austrian Institute of Technology, Vienna, Austria

Urban energy systems have traditionally been based on centralised supply of fossil fuels or biomass. Due to unstable prices for fossil fuels and an increasing competition for biomass, an increasing share of distributed, non-controllable and fluctuating energy sources (such as solar thermal and geothermal energy, ambient heat via heat pumps and industrial waste heat) needs to be integrated.

In the framework of the masterplan “Smart City Salzburg”, the new build “Bildungscampus Gnigl” (educational campus with an innovative concept) should be realized as “plus-energy-building”, exploiting local energy sources as much as possible in order to reach CO2 neutrality for the whole district. Since no district heating network is available in this area, one option is the installation of a local micro-district heating network connecting the Bildungscampus (collecting possible surplus heat), the surrounding building stock in the district and a small industrial bakery for waste heat supply.

In this contribution, the technical barriers (structure the building stock, data quality, limited availability of (waste) heat sources…) and non-technical barriers (planning and design process of the Bildungscampus, short term nature of the industry…) will be described.

Paul Booij received the M.Sc. degree (with honors) in Electrical Engineering from Eindhoven University of Technology, The Netherlands in 2009. He now works as research scientist at TNO, in The Hague, The Netherlands. Research activities include modeling and control of smart hybrid energy networks, with focus on district heating and monitoring and control of three dimensional fluid dynamics (patents pending).

Integrated Planning, Design and Operation of 4th Generation District Heating and Cooling Networks

Paul Booij and Martijn Clarijs*
TNO, The Netherlands

Heating and cooling is responsible for 46% of all consumed final energy in Europe. District heating and cooling networks (DHCN) can utilize various streams of renewable heat sources and recycled energy. However, many DHCN currently face significant challenges, such as volatile prices for fossil fuels and biomass, decreasing space heating demand and unprofitable operation of CHPs due to low electricity prices. One significant solution to this problem is the transformation towards the next (=4th) generation of DHCN and thus enabling one to:

- utilize waste heat and environmental energy sources at low temperatures, often intermittent and uncontrollable,
- integrate and coordinate multiple heat sources, often distributed throughout the network,
- reduce low transportation losses and investment costs,
- integrate other energy infrastructures, like electricity and gas networks.

However, there are currently no tools available to plan, (re-)design, assess and optimize costs and benefits of 4th generation district heating and cooling systems.

Problem

Current industrial processes and tools for the planning and design of DHCN are aimed at traditional DHCN. Design decisions are made based on a worst case scenario: peak load at weather extremes. Such an approach, often combined with additional safety margins, leads to over-dimensioned systems that require high investment and operational costs.

Proposed solution

A 4th generation DHCN is inherently dynamic, with at its heart a smart thermal controller. Such a controller enables cooperation between the various components in the DHCN and coordinates toward optimization at a system level. An example of this is peak-shaving, where the various producers, consumers and storage facilities in an DHCN are operated as to minimize peak load. The results of such new operational optimization methods can be so significant, that the design of a system (e.g. pipe diameters) can be altered to lower the investment and operational costs. Moreover, different decisions in system planning and design, e.g. inclusion of distributed storage, can further enhance the potential of the operational optimization, in turn leading to an even leaner system design.

Therefore, we propose a novel integrated approach, where DHCN forecasting, planning, design and operation are considered holistically. All phases are integrated into one tool that dynamically simulates the DHCN, spanning timescales ranging from minutes in operational control to decades in scenario forecasting, thereby immediately linking technical design and operational strategies to quantified system-wide results on costs, sustainability and reliability.

Presentation

In the presentation, the integrated approach will be further explained and supported by simulation results from previous projects (e.g. FP7 project E-Hub). Furthermore, a demonstration will be given of the described tooling, with a focus on complex heating network topologies and a novel smart thermal controller that can operationally optimize heating systems with such topologies. Finally, an outlook will be presented toward proposed Horizon 2020 project SODA4HEAT, in which this tooling will be enhanced and expanded and made available to academia, research institutes and industry, partially in open source.

Weiming Xiong is a PhD fellow at the Institute of Energy, Economy and Environment (3E) at the Tsinghua University, China. His research is focused on engineering-based, technology-rich energy, power, renewable energy and district heating planning and modeling for energy and climate policy analysis in China.

Case Study of the Constraints and Potential Contributions Regarding Wind Curtailment in Northeast China

Weiming Xiong[a,*] *(xwm11@mails.tsinghua.edu.cn), Yu Wang*[a]*, Brian Vad Mathiesen*[b] *and Xiliang Zhang*[a]
a. Institute of Energy, Environment and Economy, Tsinghua University, Beijing, China
b. Department of Development and Planning, Aalborg University, Denmark

Despite explosive growth since 2005, the wind power industry in China is faced with the obstacle of ineffective use due to severe wind curtailment. In 2012, wind curtailment in China exceeded 20 GWh, meaning that 17% of the total wind power generation was rejected by the electricity grid. Wind curtailment is most problematic in northeastern China, accounting for about 45% of the national annual total. Using a detailed representation of the electricity and heat sectors in an energy-system-modeling tool called EnergyPlan, Northeast China was considered as a case study to evaluate the potential of technical improvements that could be implemented to increase wind integration. First, the different regulations and modes of operation of existing power and combined heat and power plants were compared and analyzed based on a reference scenario. Then, sector integration between the heat and electricity sectors was simulated assuming heat storage and large-scale heat pump use.

We argue that while current regulations hamper wind integration, there are no apparent technical barriers to flexible ramping up/down of wind power generation. With the greater flexibility provided by operating coal-fired power plants under undemanding grid regulation rules, it is concluded that it is possible to integrate a larger proportion of wind power into the electricity system. The results also indicate that the implementation of heat storage systems and heat pumps could enhance the flexibility of an energy system, making it able to accommodate an increase of wind penetration. A comparison in terms of CEEP shows that integration of the heat and electricity sectors, brought by the implementation of heat pumps and heat storage facilities, could increase system flexibility when the heat sector could participate in the regulation of the electricity grid in following wind power output.

Our discussion indicates that mature technical solutions could make great contributions to the integration of wind power in Northeast China. On top of this, mechanism reforms to encourage flexible dispatch modes and strength in interaction between the electricity and heating sectors should be evaluated as potential solutions to adopt greater wind generation in the future. To drive the related reforms, hourly market integrated with both sectors of electricity and heat should be considered as core innovation for Chinese power system as pricing signals is the effective information carrier to promote flexible reflection for wind variation.

Tomislav Novosel is a research assistant at the University of Zagreb, Croatia and currently on exchange at the University Sts. Cyril and Methodius in Skopje, Macedonia. The majority of his work revolves around the integration of renewable energy sources in future energy systems with a strong focus on district heating and cooling and the mapping of heating and cooling demands.

Heat Demand Mapping and the Utilization of District Heating in Energy Systems with a High Share of Renewables: Case Study for the City of Osijek

T. Novosel[123] (tomislav.novosel@fsb.hr), T. Pukšec[1], G. Krajačić[1], N. Markovska[2], V. Borozan[3] and N. Duić[1]*

[1]*Power Engineering and Environment, Department of Energy, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia*

[2]*Macedonian Academy of Arts and Sciences, Skopje, Macedonia*

[3]*Faculty of Electrical Engineering and Information Technologies, University Sts. Cyril and Methodius, Skopje, Macedonia*

Highly efficient cogeneration and district heating systems have a significant potential for primary energy savings which are still highly underutilized in the EU. Their potential to greatly increase the flexibility of the overall energy systems through the utilization of power to heat technologies and heat storage makes them a very important factor when it comes to the planning of future energy systems with high shares of intermittent energy sources like wind and PV. The integration and expansion of district heating in existing energy systems requires extensive mapping of heating demand to ensure its optimal design from a technical and economic aspect and to maximize the utilization of waste heat sources, geothermal energy and so on. The goal of this work is to present and utilize a heating demand mapping methodology on a case study for the city of Osijek in Croatia. The obtained data has been used to create scenarios for the development of Osijek's energy system utilizing district heating and renewable energy sources. The EnergyPLAN modelling tool has been used to perform the energy system analysis created for this paper.

Track 13: Smart Energy Systems

Justin NW. Chiu obtained his PhD in the field of Thermal Energy Storage in 2013. He is currently a postdoc research associate working on transportation of industrial surplus heat for use in district heating networks.

Session Keynote:

Environomic Assessment of Industrial Surplus Heat Transportation

Justin NW. Chiu[a] *(Justin.chiu@energy.kth.se), J. Castro Flores*[a,b]*, V. Martina*[a]*, O. Le Corre*[b] *and B. Lacarrière*[b]
[a] *Department of Energy Technology, Royal Institute of Technology, Stockholm, Sweden*
[b] *Department of Energy Systems and Environment, École des Mines de Nantes, France*

The fourth generation low temperature district heating network (LTDH) has to meet challenges in supplying low temperature heat, achieving low grid losses, integrating renewable heat sources, assimilating smart energy system and ensuring suitable planning structure. The new generation LTDH has promising potential in utilizing low grade waste heat where heat at temperature of as low as 55°C can be injected into the system. Industry generated surplus heat is often released to the ambient environment due to their remote location from end users. A solution is presented here to exploit the potential of recycling low grade industrial surplus heat for use in LTDH network.
Mobile Thermal Energy Storage (M-TES) is used for shifting thermal energy to meet supply and demands that occur in different locations and that are shifted in time. M-TES technology is explored in this paper for utilization of industrial surplus heat in LTDH. Technical feasibility has been previously established with finned pipe and tube & shell type heat exchangers, however the economic justification is not always demonstrated. In this paper, parametric study on operating conditions, operating strategies and component costs will be performed. Furthermore, environmental impact from CO_2 emissions due to different transportation means production will be evaluated against other heat production possibilities, such as conventional natural gas boilers. The results of the study show the optimal transportation distance, transportation means, partial/full storage operating conditions, storage means and power to energy ratio (PER) under which M-TES are technically, economically and environmentally sound for transportation of industrial surplus heat for use in the 4th generation LTDH network.

Peter Sorknæs is a finishing PhD fellow part of the 4DH research centre. The focus of his research is on the daily operation of distributed CHP plants which also participate in electricity system balancing tasks. The presentation will be the main results of this PhD work, which started mid-2012. The results have also been presented in a number of scientific papers. He was a consultant within the energy sector for two years before starting as a PhD fellow.

The Transition of Small-scale CHP into Marked-based Smart Energy Systems

Peter Sorknæs (sorknaes@plan.aau.dk)*
Department of Development and Planning, Aalborg University, Denmark

It is the political goal in many countries to increase the integration of intermittent renewable electricity sources (RES) in the energy system. It is expected that with increasing intermittent RES the balancing of the electricity system will become increasingly important, due to the production nature of intermittent RES. Balancing of the electricity system is needed as the electricity demand always has to equal the electricity production as electricity cannot be stored in the electricity grid. District heating systems with electricity producing or consuming units, e.g. combined heat and power (CHP), can play an active role in the balancing of the electricity system, providing both a flexible and resource efficient balancing capacity for the system. In the EU the balancing of the electricity system has to be market based, where those that can and want to participate in the balancing enter bids, and winning bids are paid according to the rules of the specific market. CHP plants normally trade electricity on wholesale markets, however, trading both electricity on wholesale markets and providing balancing on the separate balancing markets makes the daily operation more complex. This especially poses a challenge for the distributed CHP plants as they do not have the manpower to analyse such complex participation on a daily basis. This complexity is further increased when a CHP plant utilizes heat storage systems, as this makes it a multidimensional problem.
The main results of a PhD project dealing with these challenges will be presented. The PhD project analyses the challenges in the daily operation of distributed CHP plants that are both trading electricity on wholesale markets while providing balancing for the electricity system under market conditions. On the basis of the analysis, daily operation strategies for these plants are developed alongside policy recommendations on how to facilitate an increased integration of distributed CHP plants in the balancing markets.

Tim Farrell, since joining C2E2 in June 2014, has been involved in the SE4ALL Global Energy Efficiency Accelerator Platform. He works together with Lily Riahi on the District Energy Accelerator. Currently the Chair of the UNECE Group of Experts on Energy Efficiency. Prior to joining C2E2, he was working for the Australian Government to accelerate energy efficiency. For six years he was in the APEC Expert Group on Energy Efficiency and Conservation and also delivered projects in the Pacific region.

District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy

Lily Riahi, Advisor on Sustainable Energy in Cities, UNEP, France
Tim Farrell (tifa@dtu.dk), Senior Advisor, Copenhagen Centre on Energy Efficiency, Denmark*

In 2013, the United Nations Environment Program (UNEP) initiated research on and surveyed low-carbon cities worldwide to identify the key factors underlying their success in scaling up energy efficiency and renewable energy, as well as in attaining targets for zero or low greenhouse gas emissions. District energy systems emerged as a best practice approach for providing a local, affordable and low-carbon energy supply. District energy represents a significant opportunity for cities to move towards climate-resilient, resource-efficient and low-carbon pathways.

Among the core components of the transition to a sustainable energy future are the integration of energy efficiency and renewable energy technologies, and the need to use "systems thinking" when addressing challenges in the energy, transport, buildings and industry sectors. Tackling the energy transition will require the intelligent use of synergies, flexibility in demand, and both short- and long-term energy storage solutions across different economic sectors, along with new approaches to governance. The UNEP Report, *District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*, was released in 2015 and provides a glimpse into what integration and systems thinking look like in practice for heating and cooling networks, and showcases the central role of cities in the energy transition.

The development of modern (i.e., energy-efficient and climate-resilient) and affordable district energy systems in cities is one of the least-cost and most-efficient solutions for reducing greenhouse gas emissions and primary energy demand. A transition to such systems, combined with energy efficiency measures, could contribute as much as 58 per cent of the carbon dioxide (CO_2) emission reductions required in the energy sector by 2050 to keep global temperature rise to within 2–3 degrees Celsius.

Johan Desmedt works at the research institute Vito, Belgium as project manager within district heating and cooling networks. He is involved in research projects FP7 E-hub on smart energy management, as technical coordinator of the FP7 Resilient project and as coordinator of the H2020 STORM project on intelligent control of district heating networks. He is also involved in DHC+ and RHC platforms.

The H2020 STORM Project: Self-organising Thermal Resource Management as Future Intelligent Control of District Heating and Cooling Networks

Johan Desmedt (johan.desmedt@vito.be), Dirk Vanhoudt and Bert Claessens*
Flemish Institute for Technological Research (VITO), Mol, Belgium

In the H2020 STORM project a generic district heating and cooling (DHC) network controller will be developed and demonstrated in two real life district heating and cooling networks with the ambition to increase the use of waste heat and renewable energy sources in the DHC network. The project is coordinated by the research institute Vito from Belgium. The other partners are the Minewater project, Heerlen (The Netherlands), The Vaxjo site (Sweden), Veab as district heating company (Sweden), Noda as hard-and software platform manufacturer (Sweden), Zuyd university for the educational activities (The Netherlands) and Sigma Orionis (France) as dissemination and replication partner
The general applicability will be guaranteed by the following measures:

- Applying self-learning control techniques instead of model-based control approaches, will make the controller easy to implement in different configuration and generations of DHC networks.
- Three control strategies are included in the controller (peak shaving, market interaction, cell balancing). Dependent of the network, one or more of these strategies can be activated.
- The controller will be an add-on to many existing DHC network controllers and SCADA systems.

To present this general applicability, the controller will be demonstrated in two existing grids: one highly innovative low temperature DHC network In the Netherlands and a more common medium-temperature district heating grid in Sweden. Since additional value is created by applying the control strategies in the controller, innovative business models will be developed to distribute this value amongst the different market players (producers, transporters, consumers of energy). This will also be addressed in the project. Also a plan will be developed on how the developed controller can be replicated to other countries than the ones of the demonstrators, taking into account different market organizations and legal framework. With respect to dissemination two levels of dissemination will be applied. A international dissemination will address the international research community, DHN network controller suppliers, international energy companies etc… Besides that, an additional local level will be implemented where two local dissemination platforms will be installed integrating all local stakeholders (the energy

company, users, local educational institutions, local politicians…). Special attention is foreseen for education activities.
This presentation will give a look at the aim and objectives of the project and will highlight the first results of the controller.

Dietmar Schüwer is project co-ordinator in the Research Group "Future Energy and Mobility Structures". Study of mechanical engineering in Dortmund, Bochum and Almería, Spain (solar thermal power plants). 4 years of professional experience in engineering offices. Since 2013 research at the Wuppertal Institute, Germany in the field of energy systems and scenario analysis, renewable energy and innovative heat supply technologies and CHP.

The Potential of Heat and Grid Orientated Block CHP on the Minute Reserve Market and Its Impacts on CO_2 Emissions - Prospects for the German Energy Market up to 2030

Dietmar Schüwer (dietmar.schuewer@wupperinst.org), Frank Merten, Arjuna Nebel and Christine Krüger*
Wuppertal Institute for Climate, Environment and Energy, Wuppertal, Germany

More than 25% of the electricity produced in Germany is generated by renewables, mostly by fluctuating sources such as wind and solar power. As a result, a growing demand for balancing power to compensate for forecast deviations is anticipated, especially in the minute reserve market. The German Federal Government's CHP act of 2009 (KWKG 2009) aims to increase the share of combined heat and power (CHP) in electricity production to 25% by 2020. In principle, small or distributed block CHP units can run more flexibly and are suited to providing balancing power, thereby contributing to the integration of renewable electricity. However, two preconditions must be met: sufficient large heat storage - to uncouple power and heat demand - and (virtual) pooling to a market-compatible total electric capacity.

Against this background, the Wuppertal Institute, in cooperation with BHKW-Consult, carried out a technical analysis of the potential and the ecological impact of CHP plants on the minute reserve market. The research was supported by the German Federal Environment Agency (UBA) (ref: FKZ 3710 97 114). The aim was to determine the technical balancing potential of CHP in Germany and its impacts on GHG emissions for the years 2010, 2020 and 2030. Typical CHP plants were related to typical supply cases in different sectors by means of heat load curves. The size of the systems ranged from 1 to 50 kW_{el} (10 representative residential building types), 20 to 1,200 kW_{el} (5 representative non-residential building types), 2,800 kW_{el} (one district heating network) and 50 kW_{el} (one industrial application). The technical potential of small CHP to contribute to the minute reserve market was determined using an optimisation model, which simulated a heat and a reserve power orientated operational mode for one year with a temporal resolution of 15 minutes. The results were scaled up to the national level using scenario analysis in accordance with assumptions made by the Federal Ministry of the Environment for the future development of CHP.

Furthermore, this study considers the following questions:

- to what extent different flexibility measures increase the potential provision of balancing power;
- how CO_2 emissions will be affected by the new operational strategies; and

- what barriers CHP faces in supplying the minute reserve market and how can these be overcome.

Based on the identified flexibility options and minute reserve potential, the paper focuses on how a changed CHP operational strategy will impact on the CO_2 emissions balance. The CO_2 emissions from a grid-orientated mode are compared to those from a conventional heat-orientated mode and to the reference case of uncoupled production of heat and power by using the Alternative Generation Method. In addition, the emissions are contrasted with operational modes based on three chosen flexibility measures: a) double plant size b) fourfold storage volume and c) emergency cooler.
Key findings demonstrate that distributed block heat and power plants could contribute significantly to the provision of minute reserve in future decades. Flexibility options would further enhance the theoretical potential. The grid-orientated operational mode slightly increases the CO_2 emissions compared to the heat-orientated mode, but it is still better than the uncoupled generation of heat and power in reference power plants and boilers respectively. However, the impacts of a flexible mode highly depend on the application and the power-to-heat ratio of the individual CHP system.

Track 14: Future District Heating Production and Systems

Urban Persson has a mechanical engineering degree in energy and environmental technology and a PhD degree in energy and environmental technology. Main research interest is district heating and cooling systems in a European perspective, structural energy efficiency measures, waste and excess heat resources, resource efficiency, energy systems analysis, and GIS mapping. Lecturer in energy technology at Halmstad University, Sweden.

Session Keynote:

Current and Future Prospects for Heat Recovery from Waste in European District Heating Systems: A Literature and Data Review

Urban Persson[a] (urban.persson@hh.se), Marie Münster[b] and Sven Werner[a]*
[a]*School of Business, Engineering and Science, Halmstad University, Sweden*
[b]*DTU Management Engineering, Technical University of Denmark, Denmark*

Household and industrial waste has seen increasing annual volumes for many decades in contemporary Europe and constitutes, if not properly managed and handled, an environmental problem due to pollution of public areas, local landscapes, and the atmosphere. European legislation has provided conceptual guidelines for most efficient and environmentally most beneficial treatment of such waste flows, but for many European Union Member States today, complying fully with the waste hierarchy principles is still a significant and yet to meet challenge. From an energy perspective, mainly due to combustible fractions consisting of carbon rich materials, waste is also an alternative fuel for power and heat generation and incineration of waste represents one effective means by which to reduce landfilling and avoid greenhouse-gas emissions from such disposals, while simultaneously reducing the equivalent demand for primary energy supply. However, as current environmental policy discourse aims to move future European waste treatment up the waste hierarchy, essentially focusing on prevention, reuse, and recycling, according to the principles of the circular economy, the role of waste disposal in the form of incineration with energy recovery is at question. A key factor for obtaining the full synergetic benefits of this definitive waste treatment option is the presence of local heat distribution infrastructures, without which no large-scale utilisation of recovered excess heat is possible. For this reason, an evaluation and assessment of future prospects for European waste incineration should consider in alignment also the anticipated development and expansion of future district heating systems. In this paper, which aims to determine the amount of household and industrial waste that is available for district heating in EU27 Member States, a literature and data survey is performed to investigate the status of waste management in Europe today as well as to assess possible future trends and availabilities. Two main conclusions are that more heat can be recovered from current European Waste-to-Energy facilities, operating on average at low heat recovery rates, and more waste can be incinerated in general due to excessive landfilling still occurring in many instances. In a long-term future for 2050, household and industrial waste flows are expected to decrease in Member States with dedicated policy

programs targeting such ambitions, but there are no indications at current that the unfortunate production of waste will decrease in the next of years to come.

Dominik Bothe is a PhD fellow at the Vienna University of Technology, Austria and focuses his work on modelling and analysing supply networks for heat and gas. His thesis is a subproject of the Doctorate Course URBEM (Urban Energy and Mobility Systems), urbem.tuwien.ac.at.

Thermo-hydraulic Simulation of District Heating Networks

Dominik Bothe (dominik.bothe@tuwien.ac.at) and Karl Ponweiser*
Institute for Energy Systems and Thermodynamics, Vienna University of Technology, Austria

Current developments of the European energy markets are influencing the operation strategy of heat suppliers. Especially providers of district heating systems fed by conventional heat production (i.e. CHP) have to react with appropriate measures to these changes. The integration of thermal storages, decentralization of the heat production, changing heating technologies or adjusting the temperature of district heating networks make it necessary to be able to simulate and analyse existing and future designs of district heating systems. Therefore a simulating tool for flow networks was developed in Matlab®.

In order to achieve comparable conclusions about operating behaviour of district heating systems, it is essential to create a corresponding model including all its main components like pipes, pumps, storages and valves. The basic idea of the created numerical model is the combination of a steady state hydraulic and a transient thermal calculation of the district heating network. The results of the iterative hydraulic calculation are the pressure and velocity distribution of the pipe network[1)]. These pressures and velocities are serving as Input-parameter of the thermal calculation. To simulate the thermal behaviour of the district heating network a discretised one dimensional pipe model is used. The discretisation is done by the Finite-Volume-Method and the resulting equation system can be solved explicitly or implicitly. A common way to define the topology of networks is the usage of a node-edge matrix. This so called incidence matrix is generated automatically from given GIS data. Thus it is possible to apply the graph theory to optimize a given or future design of district heating networks concerning different network parameter[2)].

The result of the combined thermo-hydraulic calculation is the distribution of pressure, velocity and temperature of the flowing water in the entire district heating network. Furthermore it´s possible to calculate the heat and pressure losses of each pipe and subsequently doing exergy analysis. The introduced simulation tool serves as basis for analysing and optimizing different designs of heating networks, which can be used to support economic analysis from a technical point of view.

1) H. Walter, A. Glaninger, „Berechnung von Rohrnetzwerken mit Baumstruktur", KI Luft- und Kältetechnik 11/2004
2) P. Hensel, „Optimierung des Ausbaus von Nah- und Fernwärmenetzen unter Berücksichtigung eines bestehenden Gasnetzes", Dissertation, Universität Paderborn, 2013

Jeļena Ziemele, M.sc.ing., Riga Technical University (RTU), Latvia. She worked in JSC 'Ligija Teks' as the manager of Boiler and Turbine House, JSC 'Latvijas Gāze' 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.

System Dynamics Model Analysis of Pathway to 4th Generation District Heating Systems in the Baltic States

Jelena Ziemele (Jelena.Ziemele@rtu.lv), Armands Gravelsins, Andra Blumberga and Dagnija Blumberga*
Institute of Energy Systems and Environment, Riga Technical University, Latvia

The aim of the research is to evaluate the possibility to use the 4th generation district heating systems and to establish, which political instruments may further and motivate refusal from the traditional district heating (DH) systems. In this case, a non-linear and dynamic approach for setting the problem is used to form the system dynamic model. Hypothesis of the dynamic development of the 4th generation district heating system is based on the fact that shift to the low temperature heating systems is possible with a delay in time, which is illustrated by diffuse inertia of innovations. This delay can be explained with the wear and tear period of comparatively new DH systems.
Formation of system dynamic model commences with the identification of operation variables of the district heating system, and evaluation of their suitability for the use in model. Technical and economic parameters were selected: different energy resources, different technologies for their use, dependence on installed capacity and time of installation by the innovative technology investment amount required for the 4th generation district heating systems. Important independent variables are costs of energy resources and electric power, as well as operations and maintenance costs. Model formation includes three independent, but mutually interrelated elements of the district heating system: heat power sources, transmission network of DH system, and energy consumed by end-users (buildings). Within the sub-model of heat power source (the first module) the main stock includes the following equipment capacity: wood and natural gas boilers, sun power collectors and heat pumps with accumulation reservoirs. Investment in technologies changes the respective stock. These are described with two characterizing curves: dependency of investment amount on the installed capacity (exponent) and time period, during which the investment is made (exponent). The sub-model of district heating transmission network (the second module) includes the following: capital investment into DH network, alterations of heat power losses in pipelines, electric power costs for transportation of water, as well as operation and maintenance costs of district heating system. The sub-model of energy end-user (the third module) includes both insulated and non-insulated buildings. The speed of building insulation affects alterations of the specific heat power consumption by the heat supply system, as the efficiency of heat power source and heat network losses do change. This in turn affects the total heat energy consumption and causes changes to the tariff.

Verification of system dynamic model is performed to clarify whether the model border line corresponds to the set aim, whether it includes all explanatory quantities of problems for DH system development. Policy formation is based on testing of different policy instruments. To define scenarios, policy instruments are used, and each scenario includes one policy instrument or a combination of several policy instruments. The policy instruments include tax policy (tax discount or additional taxes), subsidies and grants for the enhancement of the 4th generation district heating system development, as well as the use of information package.

The first system dynamic model results are approbated in Latvia, and they confirm that, it will be possible to introduce the 4th generation of district heating system only after 2030, if based on the currently effective policy.

The work has been supported by the National Research Program "Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)".

Charlotte Marguerite has recently joined the AIT's Energy Department and is involved in several European projects related to district heating networks integrated in smart cities. During her education in France, she studied energy management at urban scale and did a PhD thesis on the development of a new tool to model district heating networks to allow strategic management.

Selection of Design Scenarios for an Industrial Waste Heat Based Micro-district Heating Network Supplying Low-energy Buildings

Charlotte Marguerite (Charlotte.Marguerite@ait.ac.at) and Ralf-Roman Schmidt*
AIT Austrian Institute of Technology, Vienna, Austria

District Heating (DH) networks have a crucial importance in the energy strategies at different levels, particularly because they allow reducing the primary energy consumption, using renewable and local heat sources. Many technical and technological improvements (such as low temperature DH networks, micro-dh networks, integration of different renewable sources and prosumers, hybrid grids, etc.) are currently studied in order to increase the efficiency and competitiveness of DH networks. In this context, local resources such as industrial waste heat should be used as much as possible. However such sources present some difficulties to be integrated in a network and to be operated because they are sometimes only available at low temperature level and their availability doesn't match with the demand. To take advantages of these types of local heat sources, it is beneficial to set up small micro-dh networks in combination with heat pumps and storages.

There are many different ways to integrate components (renewable sources, storages and energy efficient buildings) into a micro-dh network. The various possible control strategies that can be applied to each configuration make the design phase of a network even more complex, but offer the possibility to connect the components in an efficient way. However the best solution is not always straightforward and simulation tools are often needed to select the optimal design according to specific criteria. The project CITYOPT is a collaborative project supported by the European Commission (http://www.cityopt.eu/) which aims to improve urban sustainability by optimizing energy systems in smart cities. An optimization platform developed within the project will determine to best design among a set of scenarios, according to energetic, environmental and economic indicators.

This paper briefly presents the objective of the CITYOPT project and the case of the micro-dh studied with the different systems that should be taken into account in its design : three energy efficient office buildings, existing renewable energy solutions and thermal storages (long and short term) are considered, as well as the utilization of the industrial waste heat available on-site. In a second part, the paper deals with different possible designs possibilities for an industrial waste heat based micro-dh network, supplying low-energy buildings and the control strategies involved: considering the case study, which questions arise that necessitate the assessment of different scenarios? Which scenarios are interesting to evaluate and compare? Why are these comparisons not straightforward and why do they require the use of specific simulation and optimization tools? Which indicators should be chosen to compare these scenarios?

Rasmus Lund is doing a PhD within sustainable energy planning, under the topic Energy Scenarios for Denmark, as a part of 4DH. He is currently working with the technical and economic potential of large heat pumps and low-temperature sources and district heating technology in Denmark. He did his master's thesis on large heat pumps and thermal storage.

Mapping of Potential Heat Sources for Large Heat Pumps in Denmark

Rasmus Lund (rlund@plan.aau.dk), Department of Development and Planning, Aalborg University Copenhagen, Denmark*

Urban Persson, School of Business, Engineering and Science, Halmstad University, Sweden

In future renewable energy systems there will be a significantly higher penetration of fluctuating electricity production, like wind or solar PV. This will generate a demand for integration measures to balance these fluctuations. It will also reduce the share of production at existing combined heat and power (CHP) and power plants, and thereby the co-production of heating for district heating (DH) supply. In 2013 in Denmark, 73% of DH supply was produced at CHP plants. Heat pumps in DH would be able to integrate some of the fluctuations from wind and solar PV by operating flexibly according to the fluctuations and at the same time produce heat to replace the decreasing heat production from CHP plants in an efficient way. Heat pumps need a suitable heat sources, and such are not available everywhere though. Denmark is an interesting case for this study because of the high and increasing wind penetration, the currently high share of heat production from CHP and the lack of large heat pumps in the current system.

A number of studies have analyzed the quantity of waste heat from industry and potential heat sources for integration of heat pumps in Denmark, but no study has yet connected the geographical location of the potential heat sources with the location of DH systems. The proximity of heat sources and the DH demand is a crucial factor in the analysis of the potential for heat pumps in DH in Denmark. There are a number of categories of heat sources for heat pumps. In this study three categories are chosen; industrial excess heat, waste water treatment and ambient heat sources. These are seen as the critical sources in a future energy system and important to map in this context.

The potential for industrial waste heat is assessed on the basis on geographical data on the industries with large energy consumption, and from here a derived potential excess heat production. Also the temperature level of the excess heat is assessed to determine the quality and the need for heat pump application for its utilization. For the waste water treatment heat potential the locations and annual flow of water correlated with data about temperature levels of waste water. The ambient heat sources count sea, river, lake and ground water sources. Geographical data about the occurrence of these sources will be used together with temperature levels of the given sources and possible cooling to determine the potential of the heat source.

The results can be compared to scenarios for how the energy system in Denmark is expected to develop to give indications on what is possible and where special focus should be put in relation to integration of large heat pumps. The results gives an indication on what kind of heat sources it is relevant to look for in different areas for integration of heat pumps in DH. Heat sources with low temperatures generally have lower efficiencies, so it is a matter of prioritizing sources with high temperatures where possible. The results can also be used to assess the improvement in the heat pumps efficiency by converting to low temperature DH.

Track 15: Low-temperature District Heating Grids and Buildings

Jan Eric Thorsen has a background as M.Sc. in mechanical and energy related engineering. His main focus is on positioning the district heating technology in the future energy system. Consultant work has been performed in regard to district heating and district cooling systems. He has participated in a number of governmentally funded projects regarding low-temperature district heating and 4th generation district heating. Besides this he is responsible for research activities on conceptual development of heat exchangers. This includes theoretical and practical studies on basic heat transfer theory.

Session Keynote:

Thermal Length of Heat Exchangers for the Next Generation of DH Substations

Jan Eric Thorsen (jet@danfoss.com), Oddgeir Gudmundsson and Marek Brand*
Danfoss District Energy Application Centre and HEX research, Nordborg, Denmark

In light of the continuous requirements for increased energy efficiency and utilisation of renewable sources in the future it is inevitable that the district heating (DH) supply temperature will be reduced where ever possible. However, to realize this future trend the performance specifications for the applied heat exchangers on the building side need to be specified in regards to energy efficiency and system cost optimisation.
To analyse the impact of the thermal length of the heat exchanger a dynamic simulation model is applied. The model estimates the DH return temperature from an indirectly connected building heating system. The results include trade-offs between the DH distribution energy savings due to reduced return temperatures and the cost of the heat exchanger depending on the applied thermal length.
Using the results from the simulation specific suggestions for the needed heat exchanger area and the thermal length are suggested.
The main finding is that the lower DH supply temperature requires a longer thermal length for the heating heat exchangers as well as a larger heat transfer area, compared to what is typically specified today. The additional cost of the heat exchanger is balanced by the DH distribution energy saving achieved by reduced return temperatures.

Marek Brand is a PhD in low-temperature district heating from DTU, Denmark (2013). During the last one and half years, he has been working as an Application Specialist in Danfoss Heating Segment – Technical Application Center. Participating in EU and EUDP projects as 4DH, Ready, etc.

District Heating Substation with Electric Booster Supplied by 40°C Warm District Heating Water

Marek Brand (marek.brand@danfoss.com), Danfoss Heating Segment, Nordborg, Denmark*
Niels Vilstrup, COWI; Christian Holm Christiansen, Danish Technological Institute and Lars Lisberg, Odder Varmeværk

Low temperature district heating systems with supply temperature of about 50°C has been demonstrated in recent years with success, e.g. in Lystrup, Denmark. In such systems the domestic hot water with temperature of about 47°C is prepared efficiently by use of special low-temperature heat exchanger technology. Such a low supply temperature goes hand in hand with increasing demand for establishing more renewable and energy efficient energy productions and makes possible use also low-temperature heat sources. In fact there exist an extreme amount of waste heat from industry throughout the world at a temperature around 40°C which is mostly not used and thus simply lost because the temperature is considered as too low. However the heat with temperature 40°C can be directly delivered by district heating systems for supply of areas of buildings equipped with low-temperature space heating systems and it is also enough for producing domestic hot water at a temperature of 37°C. The domestic hot water temperature can then be boosted by an electric instantaneous water heater to the level required by national legislations, e.g. 45°C in Denmark. This is exactly what has been demonstrated in a project carried out by Danfoss, COWI, Teknologisk Institut and Odder Varmeværk in city of Odder in Denmark.

This paper describes the technical setup and considerations behind the design of the in-house substation for ultra-low temperature district heating equipped with efficient low-temperature heat exchanger combined with instantaneous electric heater. The concept was demonstrated in five detached houses from late 1990s heated with a mix of underfloor heating and radiators while large data material was collected. The results show that the units deliver domestic hot water with required temperature and flow and the heat loss from the district heating network is reduced compared to the operation with traditional temperatures. The results furthermore includes analysis of grid constraints in both the electrical and the district heating distribution network and analysis of ability to run the district heating network at a flow temperature of only 40°C for a large part of the year. Finally the results also include cost-feasibility of the project considering the investment and operation costs seen from both a district heating utility and a consumer perspective.

Christian Engel was born in 1957 in Vienna, Austria; Master's thesis: Energy Analysis of building materials; Working in 30+ years in close cooperation with European Energy Provider; International Expert and Business Developer for District Heating & Cooling at THERMAFLEX Group; Board Member of Euroheat & Power; Member of CEN 107, WG 10 "Flexible preinsulated pipes" and WG 14 "District cooling pipes".

Highly Prefabricated, Tailor Made District Heating and Cooling Networks

Christian Engel (c.engel@thermaflex.com)*
Business Development District Heating and Cooling, Thermaflex International, Waalwijk, The Netherlands

This paper describes the benefits of highly prefabricated tailor made solutions for the fast, secure and sustainable development of low temperature District Heating networks.
Warmtenet Hengelo, Stadsverwarming Purmerend and Nuon Warmte are together with Thermaflex preparing for the next step in the development of their low temperature district heating schemes. To support a fast and economical installation of district heating piping systems, highly pre-fabricated networks, adapted to the specific situation, have been co-developed with such innovative Energy supplier.
Complete house connections and even complete network sections have been installed already with convincing results. In Purmerend connections for attached houses have been refurbished with minimum disruption for the citizens and the environment. In Hengelo a new record has been established by installing a pre-fabricated network from the coil within 1 day.
Taking the most challenging parts of the network installations, branches and connections, as much as possible out of the field (with all its unpredictable external influences) and prefabricating these on the 100% controlled factory floor, proved to be highly beneficial for many stakeholders. The prefabricated house connection reduces the number of connections on site with 70%, compared to the traditional way.
It's a new concept for low temperature District heating and an inspiring solution for the 4th generation of smart district heating and cooling systems.

Xiaochen Yang is a PhD fellow at the Technical University of Denmark. Her project is "Supply of domestic hot water at comfort temperatures without legionella", which also belongs to WP1 of the 4th Generation District Heating Research. The research work includes reviews of different sterilization methods and alternative solutions, analysis on energy and economy performance without violating any comfort or hygiene requirements.

Analysis of Individual Heating Unit for Domestic Hot Water Production in Multi-storey Buildings with Low Temperature District Heating

Xiaochen Yang(xiay@byg.dtu.dk), Hongwei Li and Svend Svendsen*
Civil Engineering Department, Technical University of Denmark, Denmark

District heating is a cost-effective way of supplying heat to high heat density area. For the new generation district heating (4^{th} generation), low temperature district heating (LTDH) is the most important concept to realize. However, there is concern about the potential Legionella problem in domestic hot water system caused by it. In this study, individual heating unit was analyzed as one solution to this problem for multi-storey buildings. The energy and economy performances of different scenarios were investigated with keeping the comfort and sanitation requirements in mind. Comparison were made among conventional hot water system with normal DH supply temperature, real application of individual heating unit with normal DH supply, and reinforced individual heating unit system with low temperature DH supply. Therefore, the viability and energy-saving potential of this solution can be provided as reference for the LTDH planning in the future.

José Fiacro Castro Flores is currently a PhD fellow conducting research within the field of district heating since 2013. He previously worked as a development and applications engineer in power generation technologies and holds a M.Sc. degree in Sustainable Energy Technologies. His research interests cover smart energy networks and the integration of sustainable energy sources into the energy system.

Conceptual Study of the Intregration of Decentralized Solar Heat Generation to a Low-Temperature District Heating Network via Substation Net-Metering

*J. Castro Flores**[a,b], *J. NW. Chiu*[a], *B. Lacarrière*[b], *O. Le Corre*[b] *and V. Martin*[a]
[a] *Department of Energy Technology, Royal Institute of Technology, Stockholm, Sweden*
[b] *Department of Energy Systems and Environment, École des Mines de Nantes, France*

At present, the viability and feasibility of Low-Temperature District Heating (LTDH) systems has already been tested and demonstrated. Even so, for LTDH to be successfully implemented, further ideas are needed in order to effectively improve the flexibility and effectiveness of these systems. LTDH has the potential to enhance the utilization of low-grade thermal energy sources, and to increase the solar thermal energy share and its conversion efficiency. Still, in the built environment, the availability of land for the installation of solar collectors is often a challenge. Thus, decentralized roof-mounted systems become a necessary alternative.

In conventional DH systems, solar collector fields may be designed to meet 15 to 20% of the total annual heat demand in combination with short-term storage, and more than 50% with large seasonal heat storages. With LTDH systems, the solar fraction can reach up to 90% when coupled with seasonal storage. Moreover, some building owners already connected to the conventional DH network have installed roof-mounted solar collectors, establishing feed-in contracts with the DH suppliers in a few European countries. In such cases, by applying heat net-metering as in distributed heat supply, when the solar heat generation is greater than the building's heat demand, the building owner will be paid for the thermal energy going into the DH grid. The network serves as a short-term storage buffer and thus the investment related to large heat storages is avoided.

In this study, we analyze the performance of a local LTDH network for a multi-dwelling low-energy building supplied by both a roof-mounted solar collector and the conventional DH network via a LTDH substation. At the LTDH substation, net-metering of the solar thermal energy takes place, so no heat storages are required. The collector's size is chosen based on the available roof area, independently from the building's loads. Conventional DH is employed as serial backup heating for the building, and a mix of both the main DH forward and return flows are used as thermal energy sources. Based on preliminary estimations, the results show that nearly 15% of the total annual heat demand in the LTDH network can be covered by the roof-mounted solar collectors. With a feed-in contract, heat costs savings may reach 10% annually. Moreover, the required volume from the DH supply flow is further reduced by 20% by using the flow from the main DH network's return line.

Therefore, LTDH in combination with solar heat represent a further step in achieving a better match of the energy quality of the supply and demand. It also facilitates the replacement of high-quality fossil fuels, thus contributing to low GHG emissions and to the improvement of the overall energy system efficiency.

Dr. Philippe Schild is senior expert in the unit responsible of renewable sources in the Directorate General for Research and Innovation of the European Commission. He was trained as a plasma physicist. He has managed projects in the fields of concentrated solar power, ocean energy, bioenergy and photovoltaics. He is now more involved in the aspect of emerging energy technologies and integration.

Plenary Keynote:

EU Research and Innovation towards an Integrated Approach on District Heating and Cooling

Philippe Schild
Senior Expert, DG Energy, European Commission

Since the first EU research and innovation programmes on energy in the 1980's, technology development and demonstration on district heating have been pursued with success. Now with the penetration of renewable energy also in households, new challenges and new opportunities are arising. The Strategic Energy Technology Plan with its integrated technology roadmap and the goals of the Energy Union are looking towards a more integrated energy system. District heating and cooling is part of such system.

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