Session 1: Smart Energy Systems

Dr Fabian Levihn is working on complex investments and R&D at the utility Fortum Värme. He is also a Research Fellow at the Department of Industrial Economics and Management at the Royal Institute of Technology (KTH) in Sweden.

Session Keynote:

CHPs and HPs to balance renewable power production: Lessons from the district heating network in Stockholm

TeknDr Fabian Levihn*
Investment Analyst and R&D at Fortum Värme, fabian.levihn@fortum.com
Research Fellow at the Royal Institute of Technology, KTH, fabian.levihn@indek.kth.se
Lindstedtsvägen 30, 100 44 Stockholm, Sweden

There is a potential for utilizing a combination of combined heat and power (CHP) plants together with large scale heat pumps (HP) in district heating (DH) systems to balance intermittent renewable power production. The thought is to use a combination of both power production and consumption to balance both surplus and deficit in the power market. Much research has presented different modeling and simulations of such systems.

This particular study presents lessons and metering data from operating such a system. The DH system in Stockholm is large with over 12 TWh of heat demand annually. Since the 1990s the system has been operated with both CHPs and HPs. The installed capacity of the system includes CHPs with a combined output of more than 1000 MW heat and 450 MW of power production. The HPs has a capacity of 500 MW heat production, but also supplies cooling to the district cooling (DC) network. Both the DH and DC system are equipped with storage. Thus the DH system in Stockholm constitutes an empirical example of the above mentioned simulations.

While there is potential for utilizing this combination to balance the power market, it provides several challenges. Non the least, the heating and cooling demands provide season dependent boundaries. But these two boundaries also create a natural shift towards more power consumption in the summer and more power production in the winter. Further the problem of increased heat production when shifting from power production in CHP plants and its effect on other production units in a district heating system is discussed. This problem is important to mitigate as otherwise reducing power production in CHPs increase heat production which in turn results in a need to reduce other heat production. For part of the year the heat pumps production is affected and thus the power consumption, countering the flexibility. This challenge increases importance of energy storage in these types of systems to allow flexibility relative the power market. On the plus side, storing hot or cold water is cheap compared to most other energy storage solutions that might be used to balance intermittent renewable power production.

Katarzyna M. Luc received her M.Sc. degree in Sustainable Energy from the Technical University of Denmark. Currently, she is a PhD student in the EnergyLab Nordhavn project at the Department of Civil Engineering, DTU. Her research focuses on modelling integrated energy systems on a district level with a focus on its thermal part and communication between buildings and energy system.

Energy demand flexibility in district heating systems and buildings – a review

K.M. Luc*[1], A. Heller[1], C. Rode[1] and R.K. Andersen[1]
[1]Technical University of Denmark, Building 118, Brovej, 2800 Kgs. Lyngby, Denmark
kamalu@byg.dtu.dk

Replacing traditional fuel-based energy technologies with renewable energy sources is one of the ways of lowering the environmental impact of energy systems. With the growing share of fluctuating renewable energy sources in the energy systems and the introduction of Smart Grid, providing sufficient flexibility on the demand side becomes more and more important. However, it is difficult to achieve this by concentrating on electricity-only solutions. Additionally, the increasing popularity of heat pumps and air conditioning units may lead to consumption peaks and the need for load shedding. Thus, the next step is to focus on electricity-thermal solutions (e.g. heat pumps, electrical heating and cooling) and thermal system components. For this reason, more detailed investigation of connections between electric and thermal systems is needed.

This literature review focuses on energy flexibility in the context of heat demand in district heating systems and buildings. Due to lack of literature related strictly to the thermal systems, parts of the reviews are based on relevant literature about electric systems. First, previous reviews on flexibility in energy systems are discussed and the scope of the current paper is presented. Second, the definitions of energy flexibility found in literature are discussed, together with indicators used for measuring it. Subsequently, the connection between thermal and electric systems in the context of energy flexibility, both on the demand and supply side, is discussed. An overview of methods and experiments used for investigating heat demand flexibility in literature is presented, mentioning also tools used in those analyses. Additionally, technological solutions increasing buildings' and heating systems' energy flexibility are described.

Based on the literature reviewed, it can be seen that thermal energy systems can act as a source of additional flexibility in an integrated energy system and facilitate its operation and integration of fluctuating renewable energy sources. To fully utilize potential of this flexibility, however, there is a need for more studies using integrated approach that take into account both the supply side and demand side and its physical characteristics.

Peter Sorknæs finished his PhD on bidding and operation strategies in future energy markets in 2015. The PhD focused on how small district heating plants are expected to operate and transit into future market-based smart energy systems based on renewable energy. His current work focuses on seasonal storages in district heating and future electricity markets.

Simulation method for investment analysis of pit thermal storages in district heating

Peter Sorknæs*, assistant professor, sorknaes@plan.aau.dk,
Department of Development and Planning, Aalborg University, Skibbrogade 5, 9000 Aalborg, DK

Seasonal thermal energy storage systems have seen an increasing implementation in district heating in the last years. This is especially true in Denmark where the implementation of seasonal thermal energy storage systems has followed a large expansion of solar thermal in district heating, which has occurred partly due to decreasing electricity prices alongside increasing natural gas costs affecting the economic feasibility of CHP negatively. These seasonal thermal energy storage systems have been implemented to increase the utilisation of solar thermal within the district heating. However, as lower temperatures of district heating increases the amount of potentially available currently wasted heat, it is the hypothesis of this work that the use of seasonal thermal energy storage systems will be even more relevant in future energy systems where lower temperature district heating becomes more predominant.

Besides increasing utilisation shares of solar thermal heat and otherwise wasted heat within the district heating systems, it is also the hypothesis of this work that these seasonal thermal energy storage systems can provide an increase in the overall energy system flexibility by not only being operated by local district heating demands, but also based on overall energy system demands.

As such, it is the hypothesis that these storage systems can help the integration of variable renewable energy sources, not only within the district heating system but also within the electricity sector. This can be either directly by increasing the potential for storing otherwise wasted electricity as heat, or indirectly by providing a more flexible use of e.g. CHP units and electric-driven heat pumps. With the increasing need for seasonal thermal energy storage systems it becomes more important to have the correct tools to do proper investment analyses that take into account all potential gains from having such a thermal storage system in a district heating system. For this purpose a simple simulation approach for a district heating based seasonal thermal storage system in the form of a pit thermal storage system will be presented alongside the use of this simulation approach on a test case.

Peder Vejsig Pedersen holds a M.Sc. degree, and is partner and director in Cenergia. Chairman of Foreningen Bæredygtige Byer og Bygning, FBBB, and AktivHus Denmark.

Smart Active House Building

Peder Vejsig Pedersen, M.Sc., partner and director in Cenergia, pvp@cenergia.dk*
Cenergia, Herlev Hovedgade 195, 2730 Herlev

Keywords: Active house

At the same time as the cost of PV panels and related technologies is still clearly reduced every year, ongoing work is still taking place in Denmark to develop new low cost mounting and integration systems for both roofs and facades, here with focus on ultimate solutions where PV panels can actually substitute normal building materials, so use of nice architecturally integrated BIPV solutions in many cases can be realised at very competitive costs even based on the new legislation for use of PV in Denmark.

In the ongoing ForskVE projects, BIPV Quality Cities and PV Active Roofs and Facades, Gate 21, Cenergia and other partners with Kuben Management, Technological Institute, AAU, EnergiMidt, Solar City Copenhagen and FBBB is working respectively with cities and housing associations to support the development of good BIPV solutions also with a view to use of a so-called "Solar Watch" system to secure principles for detailed monitoring, follow up and quality control. And a number of workshops are here organised with the involved stake holders to support practical implementation work and full understanding of the new PV rules in Denmark, and how you can still realise cost effective PV projects if you base the design on more limited size projects where most of the PV electricity can be used in the hour it is produced in.

In connection to this it has been clear that when you deal with new build and deep renovation projects of the future, then quite small PV systems can actually play an important role not only in securing that e.g. the new low energy class 2020 can be met in practice, but even with a possibility to reach a zero energy or even plus energy building standard. It has now been possible to identify a number of housing associations and cities who is interested in being involved in a dedicated campaign concerning this together with agreements concerning "Performance Documentation", so it is possible to secure a good energy balance in practice both with respect to the actual energy consumption/solar PV production and the total economy for the users. And when the results are being disseminated through the national database for sustainable and energy efficient building in Denmark, which is administrated by the Danish Association of Sustainable Cities and Buildings, FBBB (www.fbbb.dk and www.bæredygtigebygninger.dk), the proposed project can have a strong impact concerning integration of BIPV which will actually be a benefit to society.

A Danish Smart Active House demonstration project has been suggested for 50 new build housing units linked to an existing district heating network, here utilising the international Active House standard. (www.activehouse.info)

It is suggested to combine a local low temperature microgrid distribution network for the houses in combination with a solar heated buffer tank and a local heat pump, which secures very low return temperature to the district heating system. Besides there is 0,5 kWp local building integrated PV for the houses combined with selected roofs near the common house, where the whole roofs are BIPV connected to a local battery system also charging the heat pump and local electrical cars.

As part of the active House design, an integrated and web based local performance documentation system incl. comfort is used.

Hongwei Li is a senior researcher at the Building Energy section at the Civil Engineering Department, Technical University of Denmark. He works in the field of low-temperature district heating, building energy, and energy system simulation.

Load Management in District Heating System Operation

Hongwei Li, Building Energy Section, Department of Civil Engineering*
Technical University of Denmark, 2800 Kgs. Lyngby, Denmark, hong@byg.dtu.dk

Smooth operation of district heating system will avoid installation of expensive peak heat boilers, improve plant partial load performance, increase the system redundancy for further network expansion and improve its resilience to ensure security of supply during severe heating seasons. The peak heating load can be reduced through building demand side management.

The aim of building demand side management is to plan, monitor and operate individual consumer use of energy to produce a favourable effect on utility heat production profile with respect to load shape, time pattern and peak load. Effective demand side management can be enabled to use the building thermal mass to smooth out the heating load variation under the circumstance without jeopardizing the consumer thermal comfort. Building construction material is used as thermal mass due to its ability to store a certain amount of heat. When there is a temperature gradient between the construction material and the conditioned zone, the building material provides inertia to against the room temperature fluctuation. This building self-regulating effect thus allows over-heat or under-heat the building to adapt the desirable district heating load profile.

In this paper, a dynamic building model is applied in the building demand side management. The indoor thermal environment and the building construction are simulated with two nodes which represent the indoor air temperature and the mean temperature of the internal thermal mass. Four multi-story office buildings are analyzed which are characterized with different amount of thermal masses. Each building includes several rooms according to their positions in the building to consider the influence of heat loss and solar heat gain. A control strategy is developed to smooth out the heating load profile and balance the air temperature in different rooms.

Session 2: Future district heating production and systems

Prof. Dr.-Ing. Stefan Holler has a main research interest in the field of energy efficiency, thermal energy storages and renewable energy in district heating and cooling systems. He focuses on holistic approaches of system modelling and simulation.

Session Keynote:

Integration of solar thermal systems in existing district heating systems

Carlo Winterscheid[1], Jan-Olof Dalenbäck[1] and Stefan Holler*[2]
[1] Chalmers University of Technology, SE 412 96 Göteborg, Sweden,
[2] HAWK Hochschule Hildesheim/Holzminden/Goettingen, Büsgenweg 1a, 37077 Goettingen, Germany
Carlow@student.chalmers.se, Jan-Olof.Dalenback@chalmers.se, Stefan.Holler@hawk-hhg.de

Keywords: District Heating, Solar District Heating, Solar Thermal Systems

Modern district heating networks are usually operated with a changing flow temperature to cover the heat load of the supply area, depending on the outside temperature. Due to the minimum temperature requirements of individual customers, district heating (DH) networks also need to operate during the summer months. During this time, the load on the system is relatively low. This requires combustion facilities to operate also on low load levels. These systems have potential of improving the energy efficiency by utilizing other energy sources such as waste heat from industrial processes or solar thermal systems. The overall aim of the presented work is to provide a methodology for the integration of solar heat into district heating.

The feasibility to include solar thermal systems in existing DH networks will be analysed based on the state-of-the-art of solar district heating (SDH). The main focus will be on large DH systems that are mainly supplied by fossil CHP plants considering how such plants can be operated in the future. Results will display characteristic technical, economic and ecological key performance indicators of the transformed DH system.

Miika Rämä works as a Senior Scientist at the VTT Technical Research Centre of Finland. His main interests are overall energy system analysis with special competence in district heating and cooling system simulation, optimisation and concept development.

Comparison of distributed and centralised integration of solar heat in a district heating system

M. Rämä*[1], S. Mohammadi[2]
[1] VTT Technical Research Centre of Finland, PL 1000, Espoo, 02044, Finland, miika.rama@vtt.fi
[2] Aalborg University, Pontoppidanstræde 101, 9220 Aalborg, Denmark, smo@et.aau.dk

Ambitious greenhouse gas (GHG) emission reduction targets set by EU pose a significant challenge for the energy systems in member countries. District heating as an energy efficient solution for heat supply and distribution can potentially play a major part on a European level for meeting these targets. One key issue concerning district heating itself is the efficient integration of renewable energy sources to existing systems. The focus of this study is on introducing solar heating to an existing district heating system either as distributed or as centralized design of solar collectors.

The paper investigates alternative combinations of heat sources including boilers, combined heat and power (CHP) plants, centralized solar collectors and distributed solar collectors by performing a techno-economic analysis. Moreover, the effect of reducing the supply temperature level in different choice of heat sources is studied. Traditional, outdoor dependent supply temperature level (115-80°C) and constant low supply temperature level (60°C) are considered.

Study is made on system level point of view and in terms of energy efficiency and economics using a sample period for a one year for representative energy analysis and 20 year period for long term economic analysis. The distributed and centralised solar collector designs have been defined with same investment costs, but different capacities based on their respective unit costs (€/kW). This approach is used in order to ensure results contributing on finding the most cost-efficient way for integrating renewable energy sources in an existing district heating system.

Heat demand in residential buildings consisting of heating and domestic hot water consumption, alternative sources of heat and district heating network itself are all modelled by individual, dedicated models in order to provide realistic input data for the techno-economic analysis.

Investigation is based on a case study of a small, local district heating system with an annual heat consumption of 1.2 GWh, heat demand density of 0.74 MWh/m located in Finland.

Kenneth Hansen works at Aalborg University and focuses on energy modelling and smart energy systems. He has previously worked on the STRATEGO project creating heating and cooling strategies for various European countries. Current work includes deep analysis of solar thermal concepts in European countries when integrating high shares of renewable sources.

The role of solar thermal in European high-renewable energy systems

Kenneth Hansen*, PhD Fellow, Brian Vad Mathiesen, Professor MSO
Aalborg University, Department of Development and Planning, khans@plan.aau.dk, A.C. Meyers Vænge 15, 2450 Copenhagen, Denmark

Keywords: Solar thermal, district heating, individual heating, renewable energy systems

This presentation deals with the analysis of the future role of solar thermal in energy supply systems in urban environments for a number of European countries. This is carried out by applying energy system models to quantify the impacts of different solar thermal concepts under various conditions and situations. Some of these conditions include the integration of high-shares of renewable energy, expanded district heating networks in the national systems, heat saving measures as well as identifying the balance between building level solar thermal and solar thermal in local district heating networks. The impacts will be quantified by analyzing the possible energy efficiency improvements, the impact on energy system costs and the carbon dioxide emissions. The analysis allows for a comprehensive assessment of the role of solar thermal under different conditions and the findings will indicate whether solar thermal will play similar or different roles across different countries.

Jan-Bleicke Eggers is Dipl.-Ing. at Fraunhofer-Institut für Solare Energiesysteme in Germany.

Energy economical perspectives of solar heat in urban energy supply systems

Andreas Palzer, corresponding author, andreas.palzer@ise.fraunhofer.de (A. Palzer).
Jan-Bleicke Eggers*, Cornelius Kuba, Sebastian Herkel
Division Thermal Systems and Buildings, Fraunhofer Institute for Solar Energy Systems ISE,
Heidenhofstraße 2, 79110 Freiburg, Germany

A strong agreement exists in the German society that renewable energies have to play a dominant role in the future German energy supply system. However, many questions are discussed for instance about the relevance of different technologies such as solar thermal collectors for low temperature heat in the building sector. The objective of this paper is to investigate the potential of solar heat in different urban energy systems for the year 2050 with an energy economic model. This is done by using REMod-D, an energy system model programmed at the Fraunhofer ISE. It is a dynamic simulation tool combined with an optimizer which models the combination and correlation of different technologies for the mobility, heat and electricity sector for a future energy system on an hourly basis. To investigate the impact of urban morphology on the optimized energy system, different urban structures and building types were defined and put into a correlation with solar heat supply technologies. The parameters and boundary conditions for each urban structure and building type were integrated into the model and the economical best subsystem for each urban structure and building type was identified. Additionally, the most crucial parameters which may have an impact on solar heat were defined. Furthermore the parameters' sensitivities were analyzed by defining different cost matrices. The results illustrate that solar heat is going to be a feasible option for the heat generation in 2050 when an anticipated price reduction of 60 % compared to today's values can be achieved. If the specific costs stay the same as today or decrease on a lower rate, other technologies will be the more cost-effective alternative. However, this result only holds for CO_2 emission reduction targets of about – 80 % compared to the reference value in 1990. It is shown that despite higher cost assumptions the importance of heat gathered by solar thermal collectors increases the further the CO_2 emission reduction targets rise. Thus, regarding the share of solar thermal heat, there is complex correlation between the future cost of solar thermal collectors and the potential CO_2 emission reduction target that is planned for a future German energy system. Nevertheless, in the whole the results indicate that solar heat has the potential to help achieve the agreed climate goals of the German federal government to reduce the greenhouse gas emissions. This research was carried out in the context of IEA SHC Task 52 Solar Heat and Energy Economy.

Patrick Reiter, Hannes Poier and Christian Holter work in the Project Development and R&D department at S.O.L.I.D.; a company planning, installing and operating large-scale solar thermal systems.

BIG Solar Graz: Solar District Heating – 500,000 m² for 20% solar fraction

Patrick Reiter*[1], Hannes Poier*[1], Christian Holter[1]
[1] _S.O.L.I.D. Gesellschaft für Solarinstallation und Design mbH, Puchstrasse 85, Graz, 8020, Austria_

Current heat generation for district heating (DH) in Graz, Austria is primarily from waste heat of fossil-fired combined heat and power (CHP) plants. Due to low prices on the European electricity market, the operation of CHP plants is not economic sound anymore and may lead to problems for cities that are highly dependent on the heat of such plants. Thus, the operator of the CHP plants in Graz recently announced their closure in 2020. Almost 80% of the overall heat production has to be replaced.

The research focus of this paper is to analyze the technical and economic potential of integrating a centralized large-scale solar thermal system including seasonal pit storage and heat pumps for DH. Therefore, the purpose of the research is to determine the techno-economic optimum size of such a solar system that can be integrated into the district heating system.

The study includes the design of a technical concept using dynamic simulation, an investigation of appropriate land for collectors and the storage and an economic cost evaluation of its realization.

First estimations for pre-dimensioning the concept are done by examining the current load and temperature profiles of the DH net in Graz and give a maximum solar fraction of 30%, which equals to more than 300 gigawatt hours. First results indicate a techno-economic optimum of the system between 150,000 m² and 650,000 m² providing 9-26% solar fraction of the overall DH demand.

There is a high potential of integrating such a large-scale solar system in the DH net of Graz. Further in depth simulations will be done after all relevant parameters have been clarified in detail. Thereby, the economical optimization and the definition of the final dimensions of the whole system will be done.

Considering the framework conditions such as grid temperatures and waste heat potentials the BIG Solar Graz concept is applicable to other cities with DH and may ultimately lead to a more sustainable heat supply for domestic hot water and space heating in the European Union.
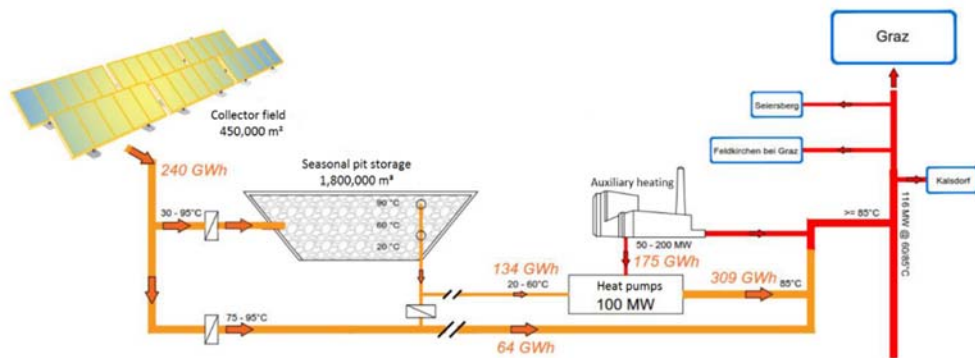
Fig. 1. Big Solar Graz concept: Simulation example with roughly 20% solar fraction

Session 3: Energy planning and planning tools

Neven Duić is a Professor in Energy Planning, Policy and Economics at the University of Zagreb. He is co-Chair of the SDEWES Conference, Editor of Energy Conversion and Management, subject editor of Energy and Editor-in-Chief of JSDEWES. His research covers areas of energy planning, sustainable communities, energy policy, energy economics, mitigation of climate change, energy efficiency and combustion engineering.

Session Keynote:

Energy planning of future district heating systems using heat mapping: Case study for the city of Velika Gorica

Tomislav Novosel, Tomislav Pukšec, Neven Duić*
Faculty of Mechanical Engineering and Naval Architecture, Department of Energy, Power Engineering and Environment, University of Zagreb, Zagreb, Croatia
tomislav.novosel@fsb.hr, neven.duic@fsb.hr

Keywords: District heating, Heat demand mapping, Heat demand modelling, Renewable energy sources, Energy planning

Highly efficient cogeneration and district heating and cooling systems have a significant potential for primary energy savings which are still highly underutilized in most European countries. The flexibility they can provide, especially when heat storage systems and power to heat technologies are used, can have a very positive impact on the increase of utilized intermittent renewable energy sources, for example wind and solar. In order to ensure optimal levels of district heating penetration into an energy system a comprehensive analysis is necessary to determine the actual heating demands as well as the potential energy supply from waste and renewable sources. The goal of this paper is to utilize a combination of hourly heat demand modelling, georeferenced heat demand and supply mapping and energy planning to determine economically feasible limits of district heating utilization from the perspective of an energy system as a whole. The heat demand mapping has been performed using ArcGIS and the energy planning using EnergyPLAN on a case study for the city of Velika Gorica.

Alessandro Capretti has a background as a Postgraduate Specialized Engineer in Energy Efficiency, Renewable Energy Sources and Distributed Generation. His activities are related to the district heating network planning of the Milan systems, with a focus on their optimal development. Apart from this, he is responsible for a working group for the study of low-temperature district heating network development.
Matteo Pozzi holds a MSc in Physics and a Diploma in International Relations and has worked for more than fifteen years in management consulting. Currently, he is the general manager of Optit.

Decision support system for district heating network development optimization

Alessandro Capretti* (A2A Calore & Servizi, DH Network Development):
alessandro.capretti@a2a.eu, via A. Lamarmora, 230, 25124 Brescia, Italy
Paolo Di Pino (A2A Calore & Servizi, DH Marketing): paolo.dipino@a2a.eu, via A. Lamarmora, 230, 25124 Brescia, Italy
Matteo Pozzi* (Optit Srl): matteo.pozzi@optit.net, via Calcinaro 2097, 47521 Cesena (FC), Italy
Andrea Bettinelli (Optit Srl): andrea.bettinelli@optit.net, via Calcinaro 2097, 47521 Cesena (FC), Italy

A2A, one of the largest multiutility companies in Italy and the main Italian player in the DH sector, owns and manages several district heating networks; its DH market share is around 25 % with an heat sales of 2,4 TWh in 2014.

A2A has recently built a transport pipeline in Milan interconnecting two previously independent networks, which allows significant improvements as to heat dispatching policies, but also paves the way for significant opportunities in the implementation of a larger expansion of the network in a densely populated urban area. The resulting system has a huge heat demand potential: the area across the new line accounts by itself for more than 100 MW (130 GWh) in less than 1 km width. Meanwhile there are limiting conditions both for the production side and for transport capacity of the system. For these reasons, A2A needs to analyse and compare a lot of small areas to decide on its DH development plan.

Usually, on the basis of the potential customers, technicians have to assume the new pipes layout and calculate costs, setting the hydraulic analysis tool if necessary. Then the financial department prepares the DCF, with the aim to maximize the IRR (Investment Rate of Return). To reach this goal, they ask for different network configurations (e.g. adding or removing branches), so the process may require some time.

This approach has two strong limitations: first of all, hydraulic simulation tools do not perform optimization, so the comparison has to be made manually. Moreover, the commercial point of view is often absent in these simulation tools and the evaluation of the best commercial alternatives has to be made using fact (excel) sheets that do not take into account physical feasibility.

A2A engaged Optit, a spin-off company of the Alma Mater Università di Bologna (Italy) specialized in the development of Optimization Solutions, whose decision support system (named OptiTLR) is specifically designed to support strategic planning of district heating networks, answering to questions regarding both commercial and strategic development: given a DH network and its current customers, what are the best new pipes to be built and new customers to connect in order to maximize the IRR, respecting technical and economic constraints?

OptiTLR is a Model Driven decision support system, built as a plug-in of an open source Geographical Information System, which uses a Mixed Integer Linear Program (MILP) algorithm integrated with heuristic variable fixing to reduce computing time (where necessary).

This presentation will show how using advanced DSS tools has enabled significant improvements in A2A's capability to generate, analyse and design cost-effective development scenarios.

Ivar Baldvinsson has been working at AIT since 2016. He studied at the University of Iceland in the period 2005-2008 with a focus on Renewable Energy. He worked as a researcher at the Tohoku University in the period 2011-2012, where he is currently finishing his PhD thesis with the topic: Development of a Community Heat Supply System towards Increased Sustainability.

Planning of multi-temperature district heating networks: A geographic information-based mixed integer linear programming model

Ivar Baldvinsson, MSc*, Dr.-Ing. Ralf-Roman Schmidt
Austrian Institute of Technology, Energy Department, Giefinggasse 2, 1210 Vienna, Austria
ivar.baldvinsson@ait.ac.at, Ralf-Roman.Schmidt@ait.ac.at

Keywords: District heating system, Mixed integer optimization, Structural design, Cogeneration, Geographical information system

District heating systems are proven and effective systematic solutions for supplying heat from thermal sources to distributed consumer sites, mainly consisting of commercial and residential buildings. Despite considerable market penetration, especially in northern Europe, it has substantial extension potential and potential for penetrating new markets. For countries like Japan, which is completely dependent on imported fossil fuels and with relatively high heat demand density in its northern part, the fuel flexibility, integration potential and economy of scale of district heating system can provide positive economic and environmental impact. The high investment cost of the distribution network and complexity and scope of the whole system planning is however an issue and restrains the development of district heating systems.

This study proposes a district heating system design and cost assessment model. It presents a multi-period, deterministic, mixed integer linear programming model (MILP) that is integrated with geographical information, finding the cost-optimal topological structure and the size of a distribution network, along with the size and mix of district heating heat plants. The objective cost function consists of the annualized investment and operation costs of the system. A network topology of nodes and edges, providing accurate geographic representation of the district, is generated using a geographic information system and acts as a design constraint in the model. Consumer and heat plant nodes are defined exogenously by the user, along with heat technology candidates. A demonstrative case study is conducted for a district in Hirosaki city, located in the northernmost prefecture of mainland Japan under two design cases.

The results demonstrate the considerable economic benefits of integrating locally available woodchips in heat-only boilers instead of using city gas due to lower fuel costs. Low temperature operation reduces the fuel costs due to less network heat loss compared to medium temperature operation, but it is overcome by the cost of the larger pipe size and the pumping power. Implementation of the district heating system to the case area encourages sustainable development through economic favorability, decreased primary energy consumption and considerable CO_2 emissions reduction, compared to the current heat supply structure.

Xavier Dubuisson has close to 20 years of experience as an engineer in the field of sustainable energy in Ireland and internationally. As a technical manager of the Irish Renewable Energy Information Office, he has worked closely with policy-makers and industry stakeholders to support the deployment of renewable heat. He continues to advise local authorities and community groups on energy planning and supports them in pioneering the transition to renewable energy.

Planning the energy transition with local communities in Ireland and shaping the national energy debate

Xavier Dubuisson, Eng. MSc., XD Sustainable Energy Consulting Ltd, David Connolly PhD, Aalborg University. xavier@xdconsulting.eu, Rocksavage, Clonakilty, Co. Cork, Ireland.*

The Green Plan Ireland study describes how a future renewable energy system in Ireland will require more expenditure on local investments, instead of importing fuels from other countries. These investments will result in more local jobs in the energy system for Ireland, which will require local actors to become more active in the construction and operation of energy infrastructure. To facilitate this, national energy planning will need to form a more systematic connection to local energy plans in the future. This paper presents some of the key technologies that must be implemented at a local level if the national energy system can successfully decarbonize in the coming years, such as district heating, and describes how a more systematic connection could be created between national objectives and their local implementation.

The paper introduces the pioneering work of a number of local authorities and community groups who are planning their energy transition, mapping out their resources and developing a roadmap towards the deployment of integrated energy systems based on 100% renewable energy supply. The paper describes also how Kerry County Council, a rural county in the South West of Ireland, is undertaking heat mapping in the framework of the European project SmartReFlex to support spatial and infrastructural planning, notably for the deployment of district heating in small to medium size towns.

Richard van Leeuwen is a lecturer and a research coordinator in the field of renewable energy at Saxion University of Applied Sciences. He is also a PhD candidate at the University of Twente. Richard obtained his master's degree in automotive engineering at Eindhoven University of Technology and before his academic career gained 10 years of company experience as a consultant and project manager in the energy and transport sector.

Low temperature district heating and renewable energy supply for Meppel-Nieuwveenselanden

_R.P. van Leeuwen_*[1, 2], _J.B. de Wit_[1] _and G.J.M. Smit_[2]
[1] _Saxion University of Applied Sciences, PO Box 70000, 7500 KB, Enschede, the Netherlands, r.p.vanleeuwen@saxion.nl, j.b.dewit@saxion.nl_
[2] _University of Twente, PO Box 217, 7500 AE, Enschede, the Netherlands, g.j.m.smit@utwente.nl_

In this paper the technical and economic feasibility is investigated for low temperature operation of the district heating system of the new district Nieuwveenselanden in Meppel. At present the system is supplied by natural gas boilers and operated at 80°C supply and 25°C return temperatures. The advantages of low distribution temperatures are: (a) less distribution heat losses and (b) enabling more efficient operation of renewable heat supply, e.g. by heat pumps.

The district heating system also contains cooling by compression cooling units which are placed at a central location together with the gas boilers. Feasibility is investigated of low temperature operation and various options to integrate renewable energy within the district heating and cooling system.

To investigate the technical feasibility, loads on the distribution network are calculated and from this the required pumping energy and heat loss are determined as a function of supply temperature. The loads are determined by a stochastic model of warm water usage and dynamic building simulations to determine space heating loads. An analysis of the hot water heat exchanger demonstrates that the minimum required supply temperature is 55°C in order to guarantee a minimum hot water temperature for showering purposes of 45°C for the households.

Although lower supply temperatures decrease the heat loss from the distribution network and save energy costs, pumping energy increases because the flow through the network has to increase for the same amount of thermal energy being transferred into the district. An optimization calculation is carried out which minimizes operational costs in order to find the optimal supply temperature for the present energy system using natural gas boilers. The result is 55°C-60°C as optimum. When heating loads increase towards the peak of the heating season, the pumps will eventually operate on full capacity and the supply temperature has to

increase. This implies that the control system could benefit if predictions are included to predetermine setpoints in time.

Based on related work, measures should be taken to avoid legionella bacteria growth in warm drinking water and measures to avoid scaling and corrosion within the distribution pipe system.

It should also be monitored how households evaluate a change towards lower supply temperatures, as some people presently may use very high temperatures e.g. for hand dish washing. This issue should be communicated and discussed with residents beforehand.

Implementation of renewable energy for heating and cooling is investigated by energy system simulation of two possible concepts. Concept 1 includes a wood boiler and natural gas boiler. Concept 2 includes a heat pump, wood boiler and natural gas boiler. For both concepts, the natural gas boiler only provides peak load support. For both concepts, investments, operational costs and benefits and CO_2 savings are determined in order to evaluate the economically feasibility.

Both concepts have a more or less equal positive business case, mainly due to possible subsidies presently provided by the Dutch government on renewable heating systems. Concept 1 saves the most CO_2, i.e. 129 tons/year, taking into account a fair share of "grey electricity" for the heat pumps of concept 2. Concept 2 has the advantage of utilizing most of the solar electric power provided by the plans to cover 1000 m^2 of industrial roof area as a part of the Meppel heating project. However, the business case of solar PV can be separated from this project as it pays for itself through the SDE subsidy scheme and therefore has no financial contribution to the conceptual choice.

In short, the main result of this investigation is that the choice for a wood boiler supported by a natural gas boiler for peak loads is financially the most attractive option when subsidies are included and leads to large CO_2 reductions. When this is combined with supply temperatures as low as 55°C to 60°C, moving up to 70°C at moments of peak loads, operational costs of the district heating network can be further optimized.

Session 4: Low-temperature district heating grids

Steen Schelle Jensen is the Head of Heat/Cooling Solutions at Kamstrup. The department is responsible for Kamstrup's district energy smart metering solutions consisting of Meter Data Management software and communication infrastructure products for heat and cooling meters. With a solution driven mind set, Steen Schelle Jensen has been a driving force in the development and advancement of smart metering solutions. He is particularly interested in optimizing district energy systems based on creating a fully transparent distribution network using frequent and accurate meter readings and in using metering to identify losses in the network and to run the network closer to the limits to increase energy efficiency.

Session Keynote:

You cannot optimise what you do not measure

Steen Schelle Jensen*, Kamstrup A/S, Industrivej 28, 8660 Skanderborg, Denmark
ssj@kamstrup.com

Keywords: Metering, data driven optimisations, energy efficiency, low temperature

Kamstrup is a world leading supplier of intelligent energy and water metering solutions. At the 2nd International Conference on Smart Energy Systems and 4th Generation District Heating, Kamstrup wishes to unfold the statement that "You cannot optimise what you do not measure". Using examples from Danish district heating, we would describe the necessity and the opportunities of using frequent data from energy meters to work with energy efficiency and to integrate renewable energy sources into a district heating context.

In the future, energy consumption must adapt to the fluctuating production based on renewables, and fully integrated energy systems will be needed to balance them. As renewables are more expensive to produce than traditional energy production, it is increasingly important to exploit them as efficiently as possible. This calls for focus not only on improving energy efficiency, but also on reducing our energy demand.

High energy efficiency requires running production close to the limit making it even more crucial for utilities to continuously manage and optimise their production decisions and distribution network. It also demands increased involvement of consumers and putting into play the energy performance of buildings. All three conditions necessitate transparency and the basis for that transparency is frequent and accurate meter readings.

The use of data offers a range of opportunities. Hourly values on flow, temperature and pressure enable utilities to detect waste in the distribution system and to identify consumers with inappropriate energy consumption. Furthermore, instant access to consumption data encourages energy conscious behaviour among consumers. Increased amounts of data also opens up to introducing alternative tariff models based on, for instance, flexibility rather than consumption, or on hourly variations of prices resulting from the balance in the total energy system. And precise data on a building's performance under different conditions, allows utilities to target the buildings that pose the biggest challenge in the network.

Fabio Sagnelli is a chemical engineer and is responsible for energy efficiency and smart cities projects in D'Appolonia, within the R&I unit. He has 10 years of experience in the energy sector and within the Celsius project, he is responsible for the monitoring, KPIs assessment and strategies definition for increasing energy efficiency in innovative systems for heating and cooling supply.

Giorgio Bonvicini is an Energy Engineer at D'Appolonia and has four years of work experience in the sustainable energy sector. His technical skills, developed in industrial resource efficiency assessments and research projects on smart district energy systems, cover the fields of efficient energy production, use and management, as well as feasibility studies, design, implementation and monitoring of energy-related projects.

Performance evaluation of large scale innovative systems of waste heat recovery from urban facilities to improve efficiency of district heating and cooling systems in cities

G. Bonvicini*[1], C. Ferrando[1], F. Sagnelli[1], A. Boss[2], A. Perez[3], Sebastian Janocha[3]
[1] D'Appolonia S.p.A., Via San Nazaro 19, 16145 Genova, Italy
giorgio.bonvicini@dappolonia.it, fabio.sagnelli@dappolonia.it
[2] SP Technical Research Institute of Sweden, SE-501 15 Borås, Sweden
[3] Technical University of Cologne Claudiusstraße 1, 50678 Köln, Germany

There is enough waste energy produced in the EU to heat the EU's entire building stock, and it has been widely recognized that district heating and cooling systems are crucial towards the achievement of resource efficiency goals in cities. In particular, waste heat available in urban areas from local sources can play an important role in the evolution of sustainable and efficient cities' energy systems considering the high potential of re-use of this urban excess heat either in individual or district energy systems. Despite technologies have proven to be ready for deployment, barriers to waste heat recovery still exist in terms of lack of knowledge on resources and technologies available, inadequate business models and incentives, a reduced capacity of infrastructures and lack of cooperation between public and private stakeholders.

In this framework, the present paper emphasizes the strategic role of systems' performance monitoring in the process of creating knowledge and awareness on innovative and existing best practices for waste heat recovery at urban level. Specifically the paper presents key aspects of the monitoring methodology developed within the demonstration and information transfer project CELSIUS, supported under FP7 European programme at the aim of promoting the widespread of combined efficient large scale integrated urban systems across European cities. The proposed monitoring methodology has been developed for the performance assessment of a set of more than 26 new and existing district heating and cooling facilities, namely the CELSIUS demonstrators. Each demonstrator is monitored following a protocol that starts from the analysis of the demo concept, the identification of

the baseline situation and the definition of a set of KPIs, the definition of procedure for KPI calculations and protocols for monitoring the different parameters. During the whole project, data collection and elaboration are regularly performed with the aim not only to evaluate each demonstrator performance but also to identify replicability conditions, improvements and optimizations for further development to build on.

This paper presents the application of the aforementioned monitoring methodology to four CELSIUS innovative demonstrators that are characterized by a high potential in capturing waste heat in urban areas, a significant short-term replicability potential, and a high degree of modularity that makes them replicable at different scales. Waste heat recovery from Cologne's sewage network, Rotterdam's data centres, London's waste heat recovery from tube ventilation shaft, Goteborg's cooling system using water from one of the nearby river and connection between DHN and ships are presented as best practices to develop urban district heating and cooling networks tailored specifically to the local requirements and differentiated in terms of waste heat source, adopted technology and business model.

Results of the application of the monitoring methodology are presented for each case study in terms of key performance indicators in combination with the description of the adopted business model. According to those main findings replicability conditions and possible enhancements to maximize systems' efficiency and minimize operational costs and carbon emissions are presented for future developments to build on.

The authors have a strong personal background in district heating and renewable energies. **Robert Schneider** co-owns a company in technology transfer business; **Ludwig Heinloth** co-owns a company which offers smart district heating systems, including project design and specialized components.

Superior system efficiency: Case studies and concepts from a German smart-system approach for next generation district heating

Robert Schneider, brainchain, robert.schneider@brainchain.ch, and Ludwig Heinloth*

(Low) energy prices, (limited) governmental spendings and concurrent technologies have an impact on District Heating investments, which DHC investors cannot influence. By contrary Smart District Heating, which we understand as an integrated approach for increased system/energy efficiency, is THE manageable success factor for investors.

The integrated (smart) approach is dominated by the design of a project. This includes the existing energy infrastructure, energy demand forecasts etc. and there are various concepts which contribute to the efficiency, e.g. the well documented use of lower network temperatures, but also optimized design and dimensioning of components. Further there are new and specialized technologies which support efficient systems, e.g. by using superior insulation properties, specialized heat-storages or power-to-heat units etc. The increasing importance of distributed (renewable) energy resources on the supply side requires increased flexibility at the demand side. We will show how flexibility and efficiency of a combined heat and power system can be improved in practical cases, by integrating local units of thermal energy storage and by using specialized components. Finally there are financial, political and local motivations which drive the decisions taken and which will be mentioned as success factors.

The intention of this presentation is to show how a German smart district heating supplier created and realized a large number of (mostly biomass) projects, with superior efficiency. The presentation will refer to theoretical concepts, statistics and technologies, but the major intention and value added is to align this with practical project experience.

The presented findings focus on a selection of around 30 projects, with an average size of 0.5 MW heat production, which have been measured over a longer period. Within these projects the average system-efficiency, measured as the ration of produced heat and delivered heat is above 80%, up to 90%. The application of the specialized components and the related design principles within larger project has been used and measured only during the last years. First available statistics show that it is possible to improve the system efficiency – compared to existing standards – in these larger projects as well around 10%, achieving total efficiencies of around 80-85% rather than 90%.

Christian Engel is the Business Development Director of District Energy & Renewables in Thermaflex Group. He has worked for more than 30 years in close cooperation with European Energy Provider. For 8 years, he was the Managing Director of a joint venture between an energy company and a plastic pipe producer. Christian Engel is a board member of Euroheat & Power and a member of CEN 107, WG 10 "flexible preinsulated pipes" and WG 14 "district cooling pipes".

Barriers and solutions for implementing 4th generation district heating

Christian Engel, Business Development Dir. District Energy and Renewables, Thermaflex International, Veerweg 1, 5145 NS Waalwijk, The Netherlands, c.engel@thermaflex.com*

This paper describes the barriers to go for low-temperature networks and which kinds of solutions have been used to overcome such barriers. Below just a first set of examples.

Experienced Barriers: conservative engineers - existing building stock demand higher temperatures - too low heat density with low energy houses - lack of prosumer approach, just to name a few.

Proposed Solutions: wider stakeholder involvement, prosumer approach, new eco districts, where new solutions can be planned from the very beginning.

Christian Sjøstrann Jørgensen studies civic engineering in energy technology at the University of Southern Denmark, which teaches a broad list of subjects regarding the energy system. This project investigates if low-temperature district heating with different booster units is economically viable in Aarup.

A study of the feasibility of low-temperature district heating solutions for Aarup comparing booster and electrical cartridges for boosting the temperature for domestic hot water use

Christian Sjøstrann Jørgensen*, jrgensen.christian@gmail.com Energy Technology, University of Southern Denmark

Motivated by the Danish long-term energy policy for 2050, stating that the energy demand from the transport sector, electricity- and heat consumption must be satisfied without fossil fuels, the project seeks to find an efficient solution to satisfy the heat demand of the town of Aarup located on Funen. The town is presently supplied by a natural gas grid. It consists of 1210 households, most of which rely on natural gas boilers for individual heating, and has 3120 inhabitants.

A total of 9 scenarios are developed, of which two are references and the other 7 are custom scenarios for boosting district heating temperatures. The custom scenarios consist of one scenario with 60°C supply temperature, 5 scenarios with 40°C supply temperature and different booster unit setups, in order to provide domestic hot water and one scenario where the booster unit is needed to supply both space heating and hot water. All 7 custom scenarios are supplied by a central district heating solution consisting of a 4 MW heat pump and a biomass boiler of either 5.7 or 5.4 MW, depending on whether it is 60 or 40°C forward temperature.

As reference scenarios for the developed district heating scenarios are chosen the existing natural gas based configuration and a configuration with individual heat pumps.

The different decentral unit setups consist of three scenarios with a micro booster heat pump, two scenarios with electric cartridges and one scenario with a booster heat pump providing both space heating and domestic hot water.

The heat loss for both 40°C and 60°C scenarios has been calculated using the modelling tool called Termis and is found to be respectively 9 % and 17 % of the total demand of 30.800 MWh/year.

All scenarios have been modelled in EnergyPro with the intention of finding the scenarios which have the lowest heating prices, socio-economically and business economically.

Socio-economically, the reference scenario with individual heat pumps was found to be the best solution. Among the district heating scenarios, the best socio economic solution was found to be, the low temperature district heating scenario with an electric cartridge and the hot water storage tank on the district heating side. The only low-temperature (40°C) micro

booster heat pump scenario that is cheaper than the 60°C scenario is the scenario with the storage tank on the district heating side and the district heating return flow as heat source.

The analysis also shows, that low temperature district heating is not socio-economically viable, if the consumer needs 60°C for space heating.

Regarding the business economic part of the analysis, the current natural gas based system achieves the lowest heating price, even with a reinvestment required. Among the district heating scenarios none of the low temperature scenarios, are cheaper than the scenario with 60 °C district heating. But the low temperature scenario with an electric cartridge and a district heating side storage tank is close in terms of heat price.

As the analyses show, the reduced loss from lower supply temperatures is only enough to offset the increased costs levied by decentral units for domestic hot water production in a socio economic perspective.

Session 5: Low-temperature district heating and buildings

Erik O. Ahlgren studied engineering physics at KTH, Sweden, did his PhD on solid oxide fuel cell materials at Risö/DTU, Denmark, a postdoc on hydrogen diffusion materials at Kyoto University, Japan, before joining Chalmers University of Technology, Sweden, where he is now professor, to work on energy systems analysis and modelling of biofuels, district heating, and energy and climate policy.

Session Keynote:

Heat supply to low energy building areas – modelling economically optimal solutions

Akram Fakhri Sandvall[1], Erik O. Ahlgren*[1] & Tomas Ekvall[2]
[1] _Energy Systems Technology, Division of Energy Technology, Department of Energy and Environment, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden,_
akram.sandvall@chalmers.se
[2] _Swedish Environmental Research Institute (IVL), SE- 400 14 Gothenburg, Sweden,_

European Directives and Swedish national goals aim at increasing buildings' energy efficiency. The construction of low energy building (LEB) areas in Sweden is increasingly attracting attention due to national support. Compared to conventional buildings, LEBs require little space heating during the cold seasons. Still, there are various options for supply of the required heating. Thus, this study aims at comparing the long-term system cost of three heat supply options to three hypothetical LEB areas, all assumed to be located close to an urban area. The three heat supply options are: an "individual" (i.e. separate heat supply), an "on-site" (i.e. local district heating (DH) system) and a "large heat network" (i.e. heat production in a nearby DH system and transmission to the LEB area). In a sensitivity analysis, the importance of the scale of the district heating network is tested by applying data for DH systems of three different scales. Data for the three hypothetical LEB areas are based on real cases representing different types building areas represented by their plot ratios.

A dynamic approach is applied allowing the modelled heat supply system to develop with time. A TIMES energy system model being able to account for the interactions between the building, heat and power sectors, was developed and utilised for the calculations. Two climate policy scenarios are applied to address the uncertainty in future carbon and energy prices, etc.

A systematic analysis is designed to investigate the threshold for cost-effectiveness by different combinations of three key parameters: heat supply options (including the distance between the LEB areas and their nearby DH system), plot ratio of the LEB areas, and scale of DH system.

The results indicate that the district heating option is the most cost-efficient for most parameter combinations but that the results are sensitive to the DH transmission distance. The results show also the importance of the transmission/distribution costs and, further, that the explicit representation of different DH scales has a considerable impact on the results.

Yasameen Al-Ameen is currently a PhD researcher in Civil Engineering at Nottingham Trent University. Her research interests lie in geotechnical engineering and thermal energy storage. She is currently working on enhancing soils for underground thermal energy storage to be used for heating applications in buildings. Yasameen received her bachelor's degree in Civil Engineering from Nottingham Trent University in 2014.

Effective use of Renewable Energy and Ground Thermal Energy Storage in Low Temperature Home Heating Applications

Y. Al-Ameen*, A. Ianakiev, R. Evans
School of Architecture, Design and Built Environment, Nottingham Trent University, Maudslay Building, Burton Street, Nottingham, NG1 4BU, Yasameen.alameen@ntu.ac.uk

Keywords: Sand, PV, Thermal Energy Storage, Heating

In most home PV installations only 20-30% of the generated energy is used locally, the rest is directed to the local electricity network. In order to use more effectively the clean energy generated from the PV panels, the processes of generation and energy use need to be decoupled. One of the most effective means of achieving this is by storing energy as heat. In this project the authors investigated the possibility to store electrical energy in a soil ground storage unit as heat and later extracting the stored heat by water for home heating applications. It is aimed to achieve water temperatures of 40-55^0 C, which is in line with the Low Temperature District Heating (LTDH) standard for home heating applications. This paper reports the preliminary findings from an on-going investigation into enhancing sands for heat storage, in relation to the overall temperature distribution and the ability to keep heat over a period of time. Experimental work is complemented by numerical simulations to optimize the storage design.

Peter Heßbrüggen is a Sustainable Innovation Manager and Lecturer at European University Flensburg for Energy Innovation and Entrepreneurship and Green Engineering. Peter Heßbrüggen is doing his PhD research on a methodology framework (Sustainable Generation Model) to foster sustainable innovations. To evaluate the methodology framework he analyzes, conducts and assesses innovative cases related to energy systems.

Use Case of Sustainable Generation Model methodology: Infrared Heating in combination with indoor multi reflection insulation systems to overcome lock in effects for low enthalpy sources

Peter Heßbrüggen*, peter.hessbrueggen@uni-flensburg.de, Wolfgang Horn

A new methodology to analyse, assess and develop innovations in a sustainable manner called "Sustainable Generation Model" is introduced. As application, a proposal of a disruptive innovation is presented. The key customer is a home owner of a building with more than 250 kWh/m^2a heat demand a year. The value proposition of the proposed solution is a decarbonised, cosy and healthy building with same or lower monthly energy costs than today. Compared to existing industry solutions for energy refurbishment and adapt energy infrastructure a cost reduction of more than 30% can be achieved

It is more likely that the Paris Climate Conference targets can be achieved by satisfying customers' needs. For the heating sector key technologies like heat pumps, solar thermal heating and heat storage solutions combined with renewable electricity from wind and solar sources as well as district heating networks are key technologies for decarbonized energy provision.

One main restriction to use this kind of technology is low flow temperature in order to a proper efficiency for turning electrical energy into heat energy. This limitation applies to existing old buildings to a much greater extent than to new ones. The effort in time and money required from owners of old buildings in order to reduce the energy demand is economically not feasible. Amortization rates are higher than 30 years.

Taken the market segment of old buildings with a refurbishment backlog and a need of more than 30,000 kWh of heat power a year, the main research question is: Are innovative solutions available in the market, which make it possible to rebuild these types of buildings and furthermore are economically feasible and support the climate and societal objectives of sustainability?

To overcome this restriction, the Sustainable Generation Model (SGM) methodology has been used to identify, assess and develop key sustainable innovations. Existing and innovative technologies were reviewed against the backdrop of customer desires, responsibilities towards the need of the environment and societal obligations.

One disruptive innovation was selected and will be developed further to use the SGM methodology. The proposed solution is using existing technology in combination with an innovative system design. The innovative system design is based on the reduction of convective flux by consequently utilizing the inertia of air. A low-temperature water driven

(26 °C) infrared heating system provides sufficient energy to make buildings cosy and healthy for the residents. By using a high efficient reflective indoor wall insulation (30mm) the infrared light can furthermore be reflected into the building. Infrared-transmitted energy is thereby absorbed by matter inside the building and becomes a 23°C infrared heat source. The reduction of convective and conductive heat flux results in a high radiation infrared energy flow. Further side effects of this system design are dry walls with high conductive insulation, and healthy indoor atmosphere.

First prototypes of the proposed solution could be assessed by using the SGM methodology. The results will lead to further improvement towards the system design. In addition a proper business model has to be designed to scale the innovation to product market fit.

Luyi Xu is a doctoral researcher in the unit Building Physics and Services at Eindhoven University of Technology, the Netherlands. Her research focuses on developing models to estimate the building energy demand of district energy systems, supported by the NWO-JSTP project. She also contributes to IEA-EBC Annex 60, Activity 2.2.

A review of modeling approaches for analyzing building energy demand in district energy systems

L. Xu*, l.xu2@tue.nl, dr. J.I. Torrens, prof.dr.ir. J.L.M. Hensen
Department of the Built Environment, Eindhoven University of Technology, The Netherlands
De Rondom 70, 5612 AP Eindhoven, The Netherlands

This research introduces a review of modeling approaches for building energy demand analysis applicable to district energy systems. Nowadays, district energy systems tend to involve more and more technologies which increases the complexity in design. The intermittency and fluctuation of some energy supply sources, especially renewable energy sources such as solar and wind, raise the problem of dispatching energy to meet the demand. Short and long term energy storages are introduced to compromise the mismatch. More design aspects need to be considered to achieve a cost-efficient district energy system. Interactions among system components become more complex and significant. Thus district energy systems become more sensitive to dynamic behaviors of building energy demand due to outdoor temperature change, uncertainties in occupant behavior, etc. Besides, there are different stakeholders that have different aims and requirements along the life span of a district energy system. Hence proper models for analyzing building energy demand in district energy systems need to be applied for different objectives of system design. This research gives an overview of building energy demand models in district level that are currently used in research and their corresponding aims. Various aspects are taken into consideration, such as input parameters, spatial and temporal resolution and system types. In conclusion, we summarize the most commonly used building energy demand models in line with specific objectives from different stakeholders and suggestions on further research.

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

Development of heat saving platform in the system dynamics model for transition to 4th generation district heating

Jelena Ziemele[*1], *Lasma Chernovska*[2], *Armands Gravelsins*[3], *Andra Blumberga*[4], *Dagnija Blumberga*[5]
Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia
[1] *M.sc.ing., PhD student, Researcher, Jelena.Ziemele@rtu.lv;*
[2] *Baccalaurean student, lasma.cernovska@inbox.lv;*
[3] *Magister student, scientific assistant, armands.gravelsins@gmail.co;*
[4] *Dr.sc.ing., Professor, Andra.Blumberga@rtu.lv;*
[5] *Dr.Hab.sc.ing., Institut of Energy Systems and Environment Director, Professor, Dagnija.Blumberga@rtu.lv*

The implementation of 4th generation district heating (4GDH) systems is associated with significant changes at all district heating (DH) stages - the source, where the future emphasis is on the renewable energy sources; the heat energy transmission system, which is transitioning to low-temperature regime; and the consumer. Multifaceted issues arise especially at the consumer, where energy efficiency measures must be carried out to reduce heat energy consumption and the existing installed equipment at heat substations must be revised, as well as the compliance of installed radiators for the low-temperature regime must be assessed. The 4GDH concept introduction is associated with several barriers: technological, economic, organizational, behavioral and others.

The platform with energy efficiency measures was incorporated into the existing system dynamics model which assesses its impact on the 4GDH transition and evaluates the energy savings measures, economic benefit, the dynamics of alternative energy sources and the impact on the environment. The model was evaluated on an existing district heating system with specific heat energy consumption of 167 kWh / m2 per year (space heating 36,465 m2), which is currently provided by fossil fuels (natural gas) and 2th generation temperature regime (105/70). The buildings were constructed in the 70s however the heat network has been renovated in the past 5 years to a two pipe (supply and return) system. The DH system operation can be evaluated by heat tariff determination which counts as a reference parameter which then regulates the replace to another heat energy production technology on the basis of economic profitability (the lowest tariff). In the supplemented system dynamics model there are evaluated various measures of cost-effectiveness and estimated

costs necessary for the transition from existing DH to 4GDH system. The introduction of energy efficiency measures saves 24.47% of thermal energy. The discounted pay-back time is 8.8 years (50% support from European project) and the IRR of project's - 6.11% (lifetime 20 years).

A causal loop diagram was established on the basis of 4GDH concept that explains the changing interaction by low-temperature network developments. DH system analysis has multi-criteria, which combine quantity and quality together to allow to assess their interactions and to find optimal solutions. There are included environmental, economical and social indicators to determine the 4GDH system's sustainability and to assess the used energy resources that in long term conduce as sustainable DH system development as country's energy independence.

Session 6: Smart Energy Systems

Gorm Bruun Andresen is an assistant professor at the Department of Engineering, Aarhus University. Here he is leading a new group in the domain of applied smart energy and thermodynamics. The research of the group covers large-scale integration of wind and solar energy, storage and power transmission, next generation district heating, and new smart energy technology. Gorm Bruun Andresen holds a PhD in experimental physics.

Session Keynote:

Grid integration of solar PV and electrical vehicles for multi-apartment buildings

Gorm Bruun Andresen*, Assistant professor, PhD, M.Sc., Department of Engineering, Aarhus University, gba@eng.au.dk
Smail Kozarcanin, M.Sc., Department of Engineering, Aarhus University, smailkozarcanin@hotmail.com

Keywords: Smart grid, solar PV, electrical vehicles

It is well known that solar electricity production in residential distribution grids may cause over-voltage issues. This can happen during mid-day when solar power is injected into the grid simultaneously from a high number of installations because production exceeds local consumption. The effect has been investigated in a number of studies of low voltage networks, where the problems are particularly likely to occur. In its nature, solar power production is nearly perfectly synchronized in a small area, so overvoltage may occur when production peaks. In a similar way, electric vehicles are anticipated to cause undervoltage issues if a high number are connected simultaneously, e.g. after work hours, in the same grid. Different so-called smart grid technologies have been suggested to alleviate these and related problems. The technologies include: Control of the ratio between active and reactive power at some or all the connection points along the low voltage line. Coordinated charging of batteries or electric vehicles; and flexibility in the local consumption with the possibility of moving increasing or decreasing demand at certain times, e.g. moving refrigeration cycles. Typically these solutions require some form of communication and additional control and monitoring hardware to be installed in the network.

In this study, the focus is primarily on distribution networks in residential areas with many multi-apartment buildings. While these buildings have an internal low voltage distribution network, the buildings will often be connected in parallel to the nearest medium voltage transformer station. Furthermore, solar panels installed on the rooftop and other new installations, e.g. electric vehicles, may also be connected in parallel to the buildings. As a consequence, voltage differences at low voltage does not accumulate but are instead averaged between all parallel connections at the transformer station. The setup reduces the chance of overvoltage in the LV grid and increases the ability of centralize control at the transformer station.

Here, two multi-apartment areas Bärnstenen and Alabastern in Växjö, Sweden are used as study cases for large solar PV and electrical vehicle installations. For these areas, it is found that active smart grid control or the introduction of new controllable load is not required.

These findings are contrary to the studies of typical single-family housing residential low voltage distribution grids. Mainly because the new installations can be connected in parallel to the combined demand from each building and not as a number of independent units along the low voltage line. Thus, overvoltage issues are transferred to the MV level where their relative impact is much lower.

The consequence is that multi-apartment residential areas may be ideally suited for large-scale solar PV installations. Although many existing low voltage grids can in fact handle installations with an annual energy yield that corresponds to the annual electricity consumption.

Charlotte Marguerite is working at AIT as a scientist. She is involved in European research projects related to district heating networks integrated in smart cities. She has a PhD in Energetics; her thesis concerned a new tool to model district heating networks to allow a strategic management.

Assessment of alternative heat source and storage integration in the district heating network of Aarhus using dynamic network simulations

Dr. Charlotte Marguerite*[1], Dr. Ralf-Roman Schmidt[2], Gorm Andresen[3]
[1] Dr. Charlotte Marguerite (corresponding author, presenter), AIT,
Charlotte.Marguerite@ait.ac.at,
[2] Dr.-Ing. Ralf-Roman Schmidt, AIT, Ralf-Roman.Schmidt@ait.ac.at,
[3] Gorm Andresen, PhD, M.Sc., Aarhus University, gba@eng.au.dk,
Inge Lehmanns Gade 10, DK-8000 Aarhus C
[1,2]AIT Austrian Institute of Technology, Donau-City-Straße 1, 1220 Vienna, Austria

Keywords: Smart cities, low-temperature district heating networks, dynamic simulations

Nowadays European cities gather 78% of the citizens [1] and therefore a large range of Europe's energy, economy and societal challenges. Integrating key urban sectors (build environment, urban mobility and energy, ICT solutions, etc.) in a smart global system will increase the life quality along with the competitiveness and sustainability of cities.

Within the READY project (http://www.smartcity-ready.eu/) as part of the European FP7 SMART CITIES framework, a set of various measures will be implemented in the two European cities Växjö, Sweden and Aarhus, Denmark. The objective is to demonstrate how the overall energy demand, fossil fuels use and CO2 emissions can be reduced to nearly zero. Using a whole city approach, including retrofitting actions, new solutions for low-temperature district heating, components and management ICT systems, flexible combined grid balancing/energy storage solutions for buildings and renewable energy systems (RES), utilization of local surplus heat, these two demonstration cases will be a showcase for a sustainable development path for other European cities.

This contribution addresses selected results of the READY project, in particularly regarding the optimization of the overall district heating networks of Aarhus. Following measures will be evaluated in different scenarios:

- The integration of alternative heat generation units such as recovered waste heat, local renewable energy such as solar collectors, PV/T and heat pumps including the design of the systems (e.g. hydraulic integration variants, supply location within network) and the control strategies (e.g. based on the priority order or temperature levels).
- The integration and management of central and distributed storage tanks (long term and short term) in order to facilitate and improve the use of fluctuating and or non-controllable heat sources, including the optimization of their design (sizing, direct/indirect connections, etc.) and operation.

Therefore, the district heating network, the relevant supply units and the connected customers of the Aarhus district heating network will be modelled and simulated using the dynamic simulation environment Modelica/Dymola on an aggregated level. The impact of the described measures and the efficiency of the systems will be evaluated. One particular focus is on the variation of the supply and return temperatures in the network.

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Sebastian Bykuć graduated from Gdansk University of Technology in 1999. He has been an employee of the Institute of Fluid Flow Machinery Polish Academy of Science since 2000. From 2014, he has been an Acting Head of the Department of Distributed Energy and responsible for the development of KEZO Research Centre – Energy Conversion and Renewable Resources. Sebastian Bykuć's recent research lies in the field of CHP, energy storage and smart energy systems technologies.

Optimal heat sources for cooling buildings using absorption chiller technology

Sebastian Bykuć*[1], Marta Kierek[1], Anders Andersen[2,3], Poul Alberg Østergaard[2],
Katarzyna Bogucka-Bykuć[4]
[1] Department of Distributed Energy, Institute of Fluid-Flow Machinery Polish Academy of
Sciences, ul. Fiszera 14, 80-231 Gdańsk, Poland
[2] Department of Development and Planning, Aalborg University, Skibbrogade 5, 9000 Aalborg,
Denmark
[3] EMD International A/S, Niels Jernes Vej 10, 9220 Aalborg Ø, Denmark
[4] Department of Heat Transfer, Institute of Fluid-Flow Machinery Polish Academy of Sciences, ul.
Fiszera 14, 80-231 Gdańsk, Poland
Sebastian Bykuć, sebastian.bykuc@imp.gda.pl

A large part of the energy demand in buildings comes from the cooling needs. Different technologies of cooling may be used and one of the more energy efficient is the absorption technology. Its advantage is that cold is produced from heat that may come from different, potentially renewable, sources. Thus combining absorption chillers with solar collectors gives an almost fully renewable source of cooling right at the moment when it is needed, but when there is not enough heat from solar collectors, other sources of heat may be utilized.

This article describes different scenarios of cooling buildings using the case of the KEZO Research Centre building which is equipped with absorption chiller technology and different sources of heat. Heat from solar collectors, biomass and gas boilers and CHP units are taken into account and are compared from an environmental and economic point of view. The important aspect of the analysis is the varying occupancy of the building giving very different demand (cooling, heat and electricity) profiles under the same weather conditions. The energy systems simulation software EnergyPRO is used for this purpose. Different sets of profiles of cooling, heating and electricity demands are analyzed.

The analysis show that depending on the cooling, heating and electricity demand profiles different heat sources should be combined with the absorption chillers for cooling purposes to get optimal economic configuration.

David Drysdale is currently a research assistant in the Sustainable Energy Planning research group at Aalborg University. He completed his master's degree in Sustainable Cities in 2014. He specialises in researching and planning 100% renewable energy systems at a national level. He will initiate his PhD midway through 2016 focusing on the role and function of cities within the transition to renewable energy systems.

Clarifying the role of the Danish building stock in the future 100% renewable energy system

_David Drysdale_*[1], Brian Vad Mathiesen[1], Jens Jensen[1], Henrik Lund[2], Jakob Thellufsen[2], Susana Paardekooper[1]
[1] _Department of Development and Planning, Sustainable Energy Planning and Management Research Group, Aalborg University, A. C. Meyers Vænge 15, 2450 København SV_
[2] _Department of Development and Planning, Sustainable Energy Planning and Management Research Group, Aalborg University, Skibbrogade 5, 9000 Aalborg_
drysdale@plan.aau.dk, bvm@plan.aau.dk, jsti@plan.aau.dk

The concept of a smart city has been developed in recent years as a possible solution to enable the transition from the current fossil-based energy system to the future energy system supplied with 100% renewable energy. It is used to describe the role that cities may play in the future energy system and it is often associated with cities becoming more intelligent through the use of ICT which enables energy to be intelligently managed in production, storage and consumption which is required with the increasing penetration of fluctuating renewable energy, such as wind and solar electricity. The smart city concept attempts to make the system more resilient in these situations. Today, cities in Denmark have a large energy demand. The energy is consumed in the form of liquid, gas and electric energy in transport, buildings, municipal utilities, and industry. A large part of this consumption is from residential and service buildings in the form of electricity, heating and cooling demands. Numerous studies have investigated how Denmark can transition to a 100% renewable energy system. This paper provides a synthesis of recent research about the possible future 100% renewable energy system in Denmark and about the most feasible role that buildings will play in the future "smart cities". The paper shows that buildings in Denmark will play a key role in the future energy system particularly in three key areas, 1) through long term renovation efforts that reduces overall heat demand in the building stock 2) by changing user-behaviour and operation of the buildings to ensure heating and electricity savings are achieved, and 3) buildings will need to be ready to enable new heat supply technologies such as low temperature district heating. All three of these factors are a prerequisite to achieve the 100% renewable energy system. The paper presents the current state of the Danish building stock and describes the current research trajectory related to the role of buildings in the renewable energy system and provides recommendations for

redirecting research and development efforts. The paper also introduces the investment costs that will be required in Denmark for the building stock and the energy system to shift from the energy system of 2015 to the 100% renewable energy system in 2050 and provides policy recommendations required to encourage these investments.

Session 7: Future district heating production and systems

Dr Oliver Martin-Du Pan is a performance engineer working at E.ON-UK community energy. He has an engineering doctorate from Loughborough University where he assessed the performance of district heating systems. At E.ON, he is in the operations team which operates approximately 35 district heating systems and 12,000 consumers.

Session Keynote:

Exergy Meters in District Heating Systems

Dr Oliver Martin-Du Pan*, Exergy meters in district heating systems. E.ON-UK. 47-53 Charterhouse Street - London EC1M 6PB. oliver.martin-du-pan@eon-uk.com

Exergy is defined as the theoretical maximum work which can be obtained from an energy system. The sources of energy can be divided into two groups: High and low grade energy. The conversion of high grade energy to shaft work is exempted from the limitations of the second law of thermodynamic that states that in a natural thermodynamic process, there is an increase in the sum of the entropies of the participating systems. Josiah Willard Gibbs (1839 – 1903) was accredited with being the originator of the availability of energy concept by indicating that the environment plays an important part in evaluating the available energy. Following this, the term exergy was finally proposed in 1956 by Zoran Randt (1904 – 1972) with the concept of quantifying in a coherent way the quantity and the quality of the different forms of energy considered.

Currently, Energy Service companies (ESCo) sell heat and electricity to consumers. However, heat is also found in the environment. Hence, ESCo do not sell heat and electricity but sell useable heat and electricity to consumers. In the UK, heat meters are installed at every consumer on the primary side. As it is installed as such, the metered supply temperature is closely related to the DH network flow temperature. As consumers' cumulative heat consumption is calculated after metering the flow rate and the flow and return temperatures of the primary flow, the end-user has a direct influence on the operational performance of the DH network and system. Energy Service companies (ESCo) can then access remotely each consumer's heat meter and bill them accordingly.

This study proposes to replace the current consumers' heat meters by exergy meters. As such, the end-user could maintain its similar heat demand requirement, but exergy meters would encourage consumers to consume less heat exergy from the primary flow by cooling it further and by consuming heat at times when the primary flow has got a lower heat exergy density. In a typical DH system, the supply flow temperature varies throughout the day and is supplied at higher temperature to reduce the electricity consumption for pumping at times

with higher heat demand. Hence, exergy meters would encourage consumers to reduce their heating cost and improve the performance of the DH system by:

- Reducing the electricity consumption for pumping the DH network flow by cooling it further;
- Flattening the daily heating load and enabling more generation of heat by the most exergy efficient supply unit and by generating heat at an average lower temperature;
- Reducing the heat losses by circulating a flow and return of lower temperature in pipes of smaller diameters.

The performance of a DH system can be assessed and visualised using a Sankey and a Grassmann diagram. The Sankey diagram gives the DH system's energy flow whereas the Grassmann diagram gives the DH system's exergy destruction and losses.

Pimlico District Heating Undertaking heating load was used in this study and the plant was assumed to operate with a single 2-stage open-loop heat pump. The flow temperature would range with a varying COP between 60°C and 90°C and would return to the energy centre at 60°C (Martin-Du Pan O., Operational Performance Assessment of Decentralised Energy and District Heating Systems, 2015, Loughborough University). On the left in the Figure below is an energy flow diagram and on the right a Grassmann diagram of this DH system. The Grassmann diagram shows that the exergy destruction from transferring the DH network heat to the DHW and SH are high and equal 21%. However, this exergy destruction could become marginal by instead supplying heat to the Blocks at the set DHW and SH temperature. Reducing this exergy destruction would enable the generation of heat at a lower temperature and the heat pump would operate with a higher COP. Hence the exergy destruction from operating the heat pump would simultaneously reduce.

Please note that the location of the heat or exergy meter is indicated by a "M" in the below Grassmann diagram. Thus, the heat meters are installed before the heat exergy destruction from the DH network.
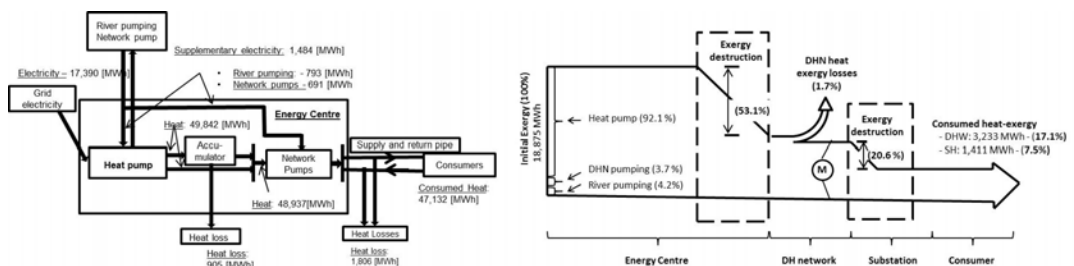
Gunnar Lennermo is active as a consultant and a PhD student with expertise in solar thermal. He is engaged more or less in all district heating-connected solar thermal systems built in Sweden.

Feed-in from distributed heat sources in district heating systems

Gunnar Lennermo*, MSc, Mälardalen University, gunnarl@energianalys.net
Patrick Lauenburg, PhD, Lund University

There is a huge potential to supply district heating systems with heat from small, distributed sources. Typical examples of such sources are solar thermal systems and surplus heat from industrial processes and cooling machines which supply cold to e.g. offices, super markets and data centres. Some 20 DH-connected solar thermal facilities in Sweden were mapped out in a previous study and it was found that their performance was lower than expected. There were signs that this was caused by fluctuations in the feed-in flow. In this paper, we analyse and describe the (dis)function of existing feed-in substations. The work has been conducted through measurements and experiments on several DH-connected solar thermal installations in Sweden.

Main findings with this paper are that (i) a fundamental principle for a well-functioning feed-in is that the feed-in heat power must, as good as possible, match the heat power generated by the heat source if no storage is used. It is often beneficial to avoid storage for practical and economic reasons. A distributed heat source can be connected in different ways, but (ii) the most common way, which also is most beneficial for the DH system, is a so called R/S connection, implying water being withdrawn from the return pipe, heated in a heat exchanger, and fed back into the supply pipe. There are in turn several connection and control principles for R/S feed-in which can be divided into two main groups, (iii) flow-controlled and (iv) temperature-controlled systems. In flow-controlled systems, no short-circuit flow (shunt) is used, and the whole feed-in control is based on the feed-in pump to achieve correct feed-in flow, possibly with help from a serial-connected control valve. In temperature-controlled systems, there must always be a shunt flow which means that the pump only has to provide a large enough pressure head in order to facilitate a feed-in flow. One or two control valves will then make sure that the feed-in flow is correct. (v) A general fact is that the feed-in control becomes more complicated the smaller the heat source and the higher the DH differential pressure at the feed-in location. The more varying heat generation, also makes the control more difficult. For a small solar facility, located close to a large heat plant, it may be difficult to obtain correct heat power feed-in.

Distributed generation represents a very small share of the total heat supply in DH systems today and fluctuating feed-in in existing installations have a very small impact on the DH systems, and may be accepted as long as the total amount of fed-in heat is small enough. However, in the perspective of a desirable development with substantially increased recovery of surplus heat and solar heat in DH supply, it will eventually become crucial to obtain properly functioning feed-in installations.

Henrik Pieper is a PhD student at the Department of Mechanical Engineering at the Technical University of Denmark. His current research focuses on novel designs and optimization of district heating and cooling systems utilizing low-temperature heat sources.

Modeling and analyzing solar heating plants to predict thermal performance

Henrik Pieper[*1], Brian Elmegaard [2], Stefan Wuust Christensen [3],*
Christoffer Ernst Lythcke-Jørgensen [4], Anders Dyrelund [5]
[1] PhD student, Technical University of Denmark, Department of Mechanical Engineering, Nils Koppels Allé Building 403, 2800 Kgs. Lyngby, henpie@mek.dtu.dk, phone: +45 50 30 09 61
[2] Associate professor, [3]PhD student at Technical University of Denmark, Department of Mechanical Engineering
[4]Logistics Specialist at Dong Energy,
[5]Senior Market Manager at Ramboll Denmark

More and more renewable energy sources enter the power and heat market to reach Denmark's goal of becoming CO_2 neutral by 2050. This results in fluctuation of power prices and challenges in stabilizing the system. One solution could be a more flexible demand, another to improve forecasts of power and heat generation from renewables. Predicting the energy output of e.g. solar heating plants can help stabilizing and optimizing the energy system in combination with heat pumps when much wind power is present. It allows a reduced heat production of CHP plants and increases security of supply. Furthermore, the outlet flow temperature of a solar heating plant can be optimized based on expected thermal performance.

This study presents an efficient and flexible model with the purpose of predicting thermal performance of solar heating plants for district heating. Calculations of basic heat transfer and heat losses are applied to achieve high accuracy for situations in off-design conditions. This may be more precise than an efficiency expression of solar collectors, which is typically provided by data sheets. The developed model uses weather data, such as ambient temperature, solar irradiation on the collector tilt and wind speed, as well plant specific information. This allows applying the model basically to any location and to predict the thermal performance based on weather forecasts. The model is intended to be implemented in energy system optimization tools like Mentor Planner.

As a case study an existing solar heating plant in Gram, Denmark was chosen to validate the model. The investigated solar field consists of an area of 10,000 m^2 with a maximum heat output of 7 MW. Relevant data, such as temperatures and loads, were measured from May till September 2015 with a 10-minute time step. The solar heating plant was modelled by a collector row and a single solar collector to investigate calculating time. The system inertia of the plant was investigated using a constant time delay. The analysis focused on the energy output and outlet flow temperature of the solar heating plant.

The results show that the entire solar heating plant can be represented by a single solar collector to reduce calculating time. Furthermore, the analysis highlights the importance of the system inertia of the plant when calculating thermal performance. A constant time delay of 40 minutes of the fluid outlet temperature improves the accuracy significantly. Finally, the results show that the model calculates the energy output and outlet flow temperatures of the solar heating plant within a tolerance of ± 0.3 MW and ± 7.5 °C in 75% and 72% of all cases, respectively.

Richard Büchele joined the EEG in 2014. He studied electrical engineering at TU Wien and holds a master's degree in power engineering with a focus on energy economics and energy supply. In his master's thesis, he developed a cost minimizing investment and dispatch model. After working on the comprehensive assessment for CHP and efficient DH in Austria, he now works on an EU project fostering renewable energy sources in heating and cooling.

Comparison of two methods for finding least cost solutions for heat saving and heat supply

Richard Büchele, TU Wien, Energy Economics Group, Gusshausstrasse 25-29, A-1040 Vienna,*
buechele@eeg.tuwien.ac.at,
Marcus Hummel, Lukas Kranzl, Andreas Müller, TU Wien, Energy Economics Group,
Marie Münster, Stefan Petrovic, Sara Ben Amer, DTU

Keywords: Heat and energy saving in buildings, cost curve, heating system, district heating

Energy demand in buildings contributes with a large share to the total final energy demand. Existing buildings are known to provide a remarkable potential for energy savings. In this context two important questions arise: 1) which heat savings in the building stock can be reached at which costs?, and 2) what could be the optimal combination of heat savings and the supply of heat by individual heating systems or district heating? Cost curves for heat savings and for heat supply can contribute to find answers to these questions by linking heat saving costs and potentials with heat supply costs and potentials. However, there are different ways to determine and use heat saving and supply cost curves. In this paper, two methods to determine the cost-optimal amount of savings versus supply via heat saving and supply cost curves are compared. In Method 1 a heat saving cost curve is developed containing selected possible renovation options and then compared with a heat supply cost curve in order to find an optimal mix between saving and supply for each building in a given building stock. In contrast, in Method 2 a combined heat saving cost curve for savings via renovation measures and change in heating systems is developed, choosing the least cost option for each building to be reflected in the resulting cost curve.

Method

The comparison of two different methods to derive cost optimal levels of savings in currently existing buildings is made for two different municipalities in Europe. The stock of buildings is structured in different building classes and building segments (Building classes are building categories like single family house, multi-family house, office buildings etc. with different construction periods and different renovation states leading to different useful energy demands; Building segments are building classes with different heating systems). In Method 1, first heat saving cost curves as well as heat supply cost curves on the basis of annualized costs for the different building classes in the stock are derived. From both curves the cheapest saving and supply options are chosen in order to meet the existing demand,

thereby valuing savings as a form of supply. In Method 2 for each building segment the costs of all possible combinations of renovation measures and changes in supply technologies are calculated and compared to the resulting energy saving on the basis of net levelized costs of heat savings. For each building segment then the cheapest combination is chosen to be reflected in the resulting cost curve for the overall building stock. The calculations with both methods thereby are performed underlying the same input data regarding costs, saving options and performance of heating systems. For each of the methods the resulting savings in useful and final energy demand compared to the actual state are calculated and compared, as well as the mix of supply technologies in the resulting cost optimal solutions.

Results

The main differences between both methods is the indicator for the comparison of energy savings and supply (useful vs. final demand) and the combined vs. separated calculation of costs of savings and supply. It is expected that this leads to slight differences in the resulting optimal levels of savings and changes in heating systems. Also the visualization in form of cost curves is different in both methods: in method 1 cost curves for all different classes of buildings are derived, thus allowing an easy visualization of the resulting least cost combinations for each building; in method 2 one cost curve is derived allowing for an easy visualization of the costs and overall savings of the least cost combinations of savings and supply options for all buildings.

A detailed analysis and discussion of the difference in the results for both methods will be presented in the full paper.

Session 8: Energy planning and planning tools

Bernd Möller develops geographical information systems for energy systems analysis. A heat atlas for Denmark was the first to be used in projects like Heat Plan Denmark (2008), while Pan-European Thermal Atlases have been developed for the Heat Roadmap Europe initiative since 2012. Bernd Möller holds a PhD from Aalborg University where he has developed GIS for energy planning as a field of research. Since 2013, he has been in charge of the global master's programme "Energy and Environmental Management in Developing Countries" at the University of Flensburg, Germany.

Session Keynote:

A Pan-European Thermal Atlas for urban and rural heat supply strategy development

Prof. Dr. Bernd Möller*, Energy and Environmental Management, Europa-Universität Flensburg, Germany. bernd.moeller@uni-flensburg.de, Munketoft 3b, 24937 Flensburg, Germany
Sustainable Energy Planning Group, Aalborg University, Denmark
Eva Wiechers, M.Eng., Energy and Environmental Management, Europa-Universität Flensburg, Germany
Dr. Urban Persson, Halmstad University, Sweden
Lars Grundahl, M.Eng., Assoc. Prof. David Connolly, PhD, Sustainable Energy Planning Group, Aalborg University, Denmark

Keywords: Heat Roadmap Europe, Peta, GIS, Heat demand

The first Heating and Cooling Strategy of the European Commission has highlighted the importance of describing heat and cooling demands across Europe. How thermal needs are satisfied, which potentials exist to improve efficiency in the built environment, and what the possibilities are to establish district energy systems, need further attention in research. Geographical information systems (GIS) may be used to map drivers for thermal demands and for the highly geographically sensitive supply options at high spatial resolution. So far, the Heat Roadmap Europe research initiative has published thermal atlases for Europe on increasing levels of detail and comprehensiveness. The present paper describes the development and application of Peta, the Pan-European Thermal Atlas version 4, which aims at quantifying heating and cooling demands at 100m resolution for all of Europe (EU28 plus EFTA countries) and for urban as well as rural areas alike. The future heat supply of Europe will probably be more differentiated between cities and the countryside, and it will to a higher degree be oriented towards the utilisation of excess heat sources from industry and power generation, as well as renewable energy sources. Peta 4 is an attempt to draw a continuous and coherent picture of the geography of heating and cooling, which is to be used to model a transition of the European thermal sector from individual, fossil fuels to increasingly system-integrated, renewable energy thinking. By means of cost-supply curves the sectoral, technological and geographical relations between potentials and costs are described for further analysis in simulation-based and equilibrium-driven energy models.

Results indicate that a large potential of district energy systems exists in the intermediate zones identified at Local Assignment of Restricted Supply Areas (LARS Areas), where technical conditions for district energy are fulfilled for incrementally increasing supply costs, but where the absence of policy favours individual heat supply choices. The extent of these LARS Areas is presented, and the supply options are being discussed.

Lars Grundahl is a PhD Fellow and part of the 4DH research centre at Aalborg University. He works with energy planning using GIS, mainly focused on heat planning.

Comparison of heat mapping methodologies – an investigation of the performance of top-down and bottom-up approaches

Lars Grundahl*, PhD Fellow
Sustainable Energy Planning Group, Aalborg University, Denmark, Skibbrogade 5 1, 9000
Aalborg, Denmark, lgr@plan.aau.dk
Erwin Cornelis, Senior Expert in Energy Policy, VITO NV, Belgium
Nele Renders, Expert in Energy Efficiency, VITO NV, Belgium
Prof. Dr. Bernd Möller, Energy and Environmental Management, Europa-Universität Flensburg, Germany and the Sustainable Energy Planning Group, Aalborg University, Denmark

In this study, two heat maps of the same area but developed using different methodologies are compared. The comparison is done for the Province of Limburg in Belgium on both provincial and municipal scales. The heat maps are the locally developed Flemish Heat Map and the European scale Pan-European Thermal Atlas. The heat maps are compared both in the amount of heat demand found and in how well they reveal the location of the heat demand. The local heat map is found better at representing local variations, which the methodology behind the European scale map does not allow. On the other hand, it is found that the method used to locate the heat demand in the European map is performing better at this. Overall, a heat map developed with local metered data will better represent the actual heat demand but the methodology in the European scale map can be used to more accurately account for the location of the heat demand. Further, a European scale heat map ensures comparable heat demand estimates across borders and is found to agree well with the local results.

Malte Schwanebeck is a master's student at Kiel University (Master's course: "Umweltgeographie und -management") and a student assistant in the ANGUS+ project.

Mapping of heat demands and district heating potential for the federal state of Schleswig-Holstein, Germany as part of a project to integrate underground energy storage options into spatial planning

B. Sc. Malte Schwanebeck*[1], Dr. Michael Nolde[1], Prof. Dr. Rainer Duttmann[1]
[1] Christian-Albrechts-Universität zu Kiel, Geographisches Institut, LGI/ZfG
Neufeldtstraße 10, Laurispark - Geb. 32, 24118 Kiel, Germany, mschwanebeck@gis.uni-kiel.de

In Germany, the so-called 'Energiewende' aims at restructuring the German energy system from centralized, fossil fuel and nuclear based towards decentralized, renewable energy production in the sectors of power, heat and transport. So far this process is focused mostly on the power sector, where in 2014 countrywide 27 % of the consumed electric power could be provided by renewable energy sources (BMWi 2015). For the North German state of Schleswig-Holstein, this figure even reached 87 % in the same year because of a high number of on- and offshore wind power plants installed in the federal state's area (MELUR 2015a).

But since renewable energy sources like wind and solar are fluctuating producers and the state's power grid is currently undersized, during the last years, a certain amount of power (1.092 GWh in 2014) produced by mostly wind and solar power plants could not be fed into the grid due to grid stability reasons (MELUR 2015b). Storing this surplus power in the shallow or deep underground in form of heat, compressed air or gases like hydrogen and methane could help to solve this issue in the long-term (Bauer et al. 2013). But since other uses of the underground already exist (groundwater, oil and gas extraction and storage sites) and more usages like geothermal heat production, shale gas extraction or carbon capture and storage are under discussion there is an ongoing debate about a possible integration of underground matters into regular spatial planning schemes (Bartel and Janssen 2015).

In a project called 'ANGUS+', researchers at Kiel university and other institutes work on parameters for modeling, assessing and monitoring spatial magnitudes of thermal, hydrological, mechanical and chemical impacts of such underground storage options (Dethlefsen et al. 2014, Bauer et al. 2015, Popp et al. 2015) in order to integrate underground energy storage into existing spatial planning in the long-term. The project's work packages presented here deal with the parametrization of energy related above ground infrastructure and with mapping energy demand and supply for the example of Schleswig-Holstein. The aim is to identify possible suited underground spaces for energy storage and connect this information with spatial data on existing and planned energy infrastructure, demand and supply hot spots and existing above ground spatial planning areas. Therefore a web based 3D

GIS was developed to integrate, explore and analyze both underground and land-surface data sets (Nolde et al. 2015).

One data set created in the course of this project is a so called 'heat atlas' that quantifies and locates heat demands for room heating and hot water for residential and non-residential buildings in the total area of the federal state of Schleswig-Holstein (Schwanebeck 2016). This statewide GIS based mapping was realized via rudimentary 3D models of all buildings in Schleswig-Holstein provided by the federal sates survey agency. By calculating numbers of floors and heated areas for each building and in combination with existing statistical values on heat demands of specific building types like single family homes or buildings for commercial uses, it was possible to estimate yearly heat demands for every single building. Heat demands were then aggregated in 1-km² grid cells. Using a spatial based threshold value (150 MWh/ha per year) used in practice (MELUR 2014), areas with a potential for the installation of a district heating network could be identified in Schleswig-Holstein.

In combination with geological information as well as spatial data on quantities of surplus power, which could be converted to heat via Power-to-Heat (Böttger et al. 2014), the presented heat atlas could help to identify potential areas suited for future renewable energy district heating systems that should also integrate heat storage in the underground in order to couple power and heat energy systems.

Pablo Puerto holds a master's degree in energy from the Ecole des Mines d'Albi in France and has been working for two years at the Centre de Recherches Energétiques et Municipales in Switzerland on simulation of energy networks for urban energy system planning. In 2016, he started a PhD thesis mainly focused on co-simulation methods for complex energy system design.

Methodological review of co-simulation approaches for complex urban energy system planning

Pablo Puerto* [a, b, c] (Dipl.-Ing.), Jessen Page[b], Jakob Rager[c]
CREM, Av. Du Grand-St-Bernard 4, CP 256, 1920 Martigny, Switzerland,
 Pablo.puerto@crem.ch,
[a] Ecoles des Mines d'Albi
[b] Haute Ecole Spécialisée de Suisse Occidentale Valais-Wallis,
[c] Centre de Recherches Energétiques et Municipales

Comparing different co-simulation approaches shows that a simple test case already contains a high degree of complexity. The test case implements the following technologies and networks: thermal and electrical networks, several consumers and building typology, a combined heat power plant and dynamically fluctuating thermal and electrical resources.

Tight coupling and loose coupling methods will be compared. The co-simulation will be mainly conducted on two existing open source tools: Mosaik (Faschang 2015) and OpenBuildNet (Gorecki 2015). Several simulation tools based on a range of technology (Matlab, Python, proprietary and black-box like software) will be used for different parts of the test case with various communication protocols and link set-up configurations. Results and implementation process will be discussed as well as needed precision for control strategies and operation constraints integration in technologies models.

Current leading concepts and technologies for district heating and cooling systems involve being an integrated part of the operation of more and more complex and smart urban energy systems. It implies that technologies and components of heating and cooling systems need to be designed and operated along with power grid and natural gas networks. These complex urban energy systems include conversion technologies and largely distributed and various energy sources (Lund 2014).

Moreover, coordinating planning, design and operation in the electricity and district heating and cooling sectors can create energy savings synergies in energy systems (Thellufsen 2015). While attempting to calculate such effects, synergies and interactions for a large complex urban energy system an advanced multidisciplinary approach is needed to overcome difficulties in modelling correctly real phenomena (Manfren 2011).

(Allegrini 2015) shows that tools already exist for all the parts and aspects of an urban energy system, but none of them can fully cover all aspects or the whole complexity of a smart urban

energy system. Co-simulation methods can combine existing specialized tools in order to model and simulate the complete behaviour of a complex smart energy system.

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Session 9: Low-temperature district heating grids

Peter Jorsal graduated as an engineer from Aalborg University in 1986. He worked as a consulting engineer with district heating projects for 6 years. From 1992, he worked at LOGSTOR with sales management. Until 2015, he worked with VP Sales for the Nordic Region and the service department. Since 2016, he has been a Product Manager for the LOGSTOR Group. Peter Jorsal is member of the board at DBDH, Chairman of the board at FIF Marketing, member of DHC+ and a partner in the 4DH Research Centre.

Session Keynote:

Secure the lowest Total Cost of Ownership in District Heating networks

Peter Jorsal, Product Manager, LOGSTOR A/S, Danmarksvej 11, 9670 Løgstør, pjo@logstor.com

In many existing district heating networks, the heat loss cost, which is the main part of the operating costs, is up to 70% of the total cost of ownership.

The challenge of designing district heating projects that are competitive in relation to individual alternatives is increasing, as long as consumers are using less and less energy.

To secure the competitiveness of district heating projects, it is therefore essential to minimize the heat loss cost and design systems, which will secure the lowest possible total cost of ownership. The perfect design must take its starting point in the local long-term conditions in relation to consumers, finance, operational issues like flow and return temperature and the best available material technology.

The lowest total cost of ownership is not only heat loss cost. It is also about securing the most optimal investment in materials and contractor work.

The newest and best available material technology must secure a flawless operation during the expected lifetime of more than 50 years.

José Fiacro Castro Flores is 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 MSc degree in Sustainable Energy Technologies. His research interests cover smart energy networks and the integration of sustainable energy sources into the energy system.

A.R. Espagnet is a master's double degree student in Sustainable Energy Engineering, completing the master's thesis at KTH University, Stockholm. He has previously studied at UPC, Barcelona, and Politecnico di Milano (Bachelor). This article is part of his master's thesis, which aims at defining the benefit of TES coupled with 4th generation district heating.

Techno-economic assessment of Thermal Energy Storage integration into Low-Temperature District Heating networks

A. Rossi Espagnet [a], 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, Brinellvägen 68, Stockholm, SE-100 44, Sweden*
[b] *Department of Energy Systems and Environment, École des Mines de Nantes, 44307, Nantes, France, jfcf@kth.se*

Thermal energy storage (TES) systems are technologies with the potential to enhance the efficiency and the flexibility of the coming 4th generation low-temperature district heating (LTDH). Their integration would enable the creation of smarter, more efficient networks, benefiting both the utility and the end consumers. This study aims to develop a comparative assessment of TES systems, both latent and sensible heat based. First, a techno-economic analysis of several TES systems is conducted to evaluate their suitability to be integrated into LTDH. Then, potential scenarios of TES integration are analysed in a case study of a LTDH network. This is complemented with a review of current DH legislation focused on the Swedish case, with the aim of taking into consideration the present situation, and changes that may support some technologies over others. The results of the analysis show that sensible heat storage is still preferred to latent heat when coupled with LTDH: the cost per kWh stored is still 15% higher for latent heat in systems below 5MWh of storage size; though, they require just half of the volume. However, it is expected that the cost of latent heat storage systems will decline in the future, making them more competitive. From a system perspective, the introduction of TES systems into the network results in an increase in flexibility leading to lower heat production costs by load shifting: by running the production units with lower marginal heat production costs for longer periods and with high efficiency, and thus reducing the operating hours of the other more expensive operating units during peak load conditions. These results may also be extended to the case when heat generation is replaced by renewable, intermittent energy sources; thus increasing profits, reducing fuel

consumption, and consequently emissions. This study represents a step forward in the development of a more efficient DH system through the integration of TES which will play a crucial role in future smart energy system.

Soma Mohammadi works as a PhD fellow and research assistant at the Department of Energy Technology, Aalborg University. She is mainly working on dynamic modelling of pipe networks and alternative solutions to minimise heat loss and temperature loss in district heating systems.

Presenting a thermal-dynamic modelling tool for district heating networks – toward low-temperature district heating

S. Mohammadi*[1], C. Bojesen[2]
[1]_Aalborg University, Pontoppidanstræde 101, 9220 Aalborg, Denmark, smo@et.aau.dk_
[2]_Aalborg University, Pontoppidanstræde 111, 9220 Aalborg, Denmark, cbo@et.aau.dk_

District heating plays an essential role in building the future sustainable energy system; However, the recent studies reveal that there is a need to implement drastic changes in the existing district heating system towards low-temperature operation to remain competitive in future energy system. Reducing the heat losses in the existing distribution networks is one of the challenges on the journey towards low temperature district heating. Lowering the district heating networks operating temperature, applying smaller pipe dimensions by reducing the peak flowrate in the network, improving the pipes insulation, improving the bypass configuration in the networks and intelligent metering at consumers are some of the main elements towards decreasing the grid losses.

This study is presenting a tool to evaluate alternative design concepts and strategies for a DHN towards low-temperature, conducting a comprehensive heat loss analysis in distribution network, simulating temperature propagation in distribution network and modeling district heating network operational performance. Moreover, it provides an open source tool for thermal-dynamic modelling of district heating networks which is of interest for both researcher and small district heating companies.

As both the distribution network dynamics, comprising time delays in the network, the heat losses and heat storing in the pipes, and the consumers' dynamics have substantial influence on the heat losses and overall performance of DHN, it is vital to include these effects on analyzing alternative scenarios towards lowering the grid losses. The tool is relevant for both modelling an "existing" DHN and building a "new" DHN from scratch. The heat transfer coefficient is obtained based on the thermal resistance method and the heat capacity of the pipes, the heat accumulation in pipes and the heat transfer interaction between two neighboring pipes are accounted for which make the model more precise in estimating the heat losses than similar tools.

Given the input data, including time-dependent consumers' heat demand profile, consumers' return temperature profile, the supply temperature to the network, the pipe network data and network map, the tool returns the supply temperature and flowrate at each consumer and the return temperature to the production at regular time intervals. Moreover, the

temperature distribution and heat losses in the network considering transit heat transfer are obtained.

Sofia Akhlaghi and Sofia Carlson are master's thesis students at Lund University, Faculty of Engineering. They have studied Environmental Engineering with a master in Energy Systems. The master's thesis was about low-temperature district heating and the possibilities of implementing LTDH in Malmö, Sweden.

Possibilities of low-temperature district heating in Malmö, Sweden

Sofia Akhlaghi*, MSc, Sofia Carlson*, MSc, Lisa Brange, MSc,
Department of Energy Sciences, Lund University, Box 118, Lund, SE-221 00, Sweden
sofia.goransson_akhlaghi.003@student.lu.se, sofia.carlson.859@student.lu.se

In the Swedish heat market, district heating (DH) has the largest market share and accounts for half of all the heating. Furthermore, new legislation and techniques result in a more efficient energy use in buildings. This opens up for the supply of low temperature district heating (LTDH). LTDH enables the possibility to use cheaper material and integrate low-grade excess heat in the DH grid. This study aims to investigate and compare two different ways of applying a LTDH system in a district in a fictive area in Malmö, Sweden.

The two cases were investigated and simulated with respect to legionella safety and comfort within the decided parameters in the DH network. The first case was a low-temperature system with a supply/return temperature set to 65/35°C and the second case was an ultra-low temperature system with a supply/return temperature of 45/20°C in combination with an electrical microbooster for the domestic hot water preparation. The two LTDH-cases were compared with a traditional district heating system. The investigated area consisted of 35 multifamily houses and 15 villas. The energy use for the buildings was developed using Swedish data for low-energy buildings. The share of tap water use was calculated according to numbers from the Swedish Energy Agency. The calculations were performed in the simulation program NetSim, a commercial simulating program used for both district heating and cooling.

The results indicated that both LTDH-cases would be fully applicable for the area. Both cases operate within the minimal pressure difference of 1 bar and a maximum flow velocity of 1m/s and 2m/s in the service pipe and the main pipe respectively. The linear heat density for the area was calculated to 8 MWh/m. The low-temperature system would theoretically reduce the heat losses from 4.6 % to 2.8% on a yearly basis in comparison to the reference case. For the ultra-low temperature system heat losses would be reduced to 1.5 %. The electricity demand for the ultra-low temperature system would be 2 MWh for the villas and between 11 and 165 MWh/year for the multifamily buildings. The low-temperature system was shown to be less expensive than the reference case. In the ultra-low temperature system this is not as obvious since it depends on the price of the microbooster as well as the electricity price.

High return temperatures had a high impact on both grids. With an outdoor temperature of -10°C, the return temperature could not exceed 35°C if the velocity criteria were to be fulfilled

for the low temperature case. At an outdoor temperature of 0°C, the return temperature could not exceed 55°C to fulfil the same criteria. For the ultra-low temperature case, the return temperatures could not be above 25° at -10°C outdoor temperature and 35°C at 0°C outdoor temperature.

If it would be possible to solve the legionella problem in other ways than according to the Swedish legislation, this would simplify the implementation of LTDH grids. As seen in the simulations, a low return temperature is crucial for a well-functioning LTDH system. The problems are often connected to the low incentive for the customers to maintain their substations and secure a good cooling in the heat exchangers. Should the DH-companies own the substations they could more easily maintain them. Moreover, a temperature loss in the heat exchanger is inevitable. With indirect connection generally used in Sweden, it is crucial that the temperature loss is minimized in the heat exchanger.

Session 10: Low-temperature district heating and buildings

Jan Eric Thorsen holds a MSc. in mechanical and energy related engineering and is the director of Danfoss Heating Segment Application Centre. His main focus is on positioning the district heating technology in the future energy system. He has provided consultancy 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 and has published a number of papers in this regard.

Session Keynote:

Impact of increased thermal length of heat exchangers for district heating substations by case example

Jan Eric Thorsen*, Director Danfoss Heating Segment Application Centre
Oddgeir Gudmundsson, Director Projects, Marek Brand, Application Specialist
Danfoss A/S, Nordborgvej 81, DK-6430 Nordborg
jet@danfoss.com, og@danfoss.com, marek.brand@danfoss.com

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 and return temperature will be reduced where ever possible. However, to realize this future trend the performance specifications for the applied components on the building side need to be reconsidered accordingly.

Among the components that have significant impact on the cooling of the supply are the applied heat exchangers. To analyse the impact on the DH return temperature by increasing the thermal length of the heat exchanger a case example is presented, where the focus is on heat exchangers that are used for heating and domestic hot water preparation. The cases are based on a typical one family house in Denmark with a floor area of 225 m^2, built in 1979 and supplied by DH.

For the heating circuit an indirect heating system is applied. The return temperature and flows are monitored and analysed for two different types of heat exchangers. The reference heat exchanger has a thermal length of 0.73, where the heat exchanger with increased thermal length has a thermal length of 1.00, corresponding to an increase of 37%. The heat exchangers have same size, number of plates and thus the same area.

For the preparation of domestic hot water the principle of instantaneous heat exchanger is applied. Also in this case the return temperature and flows are monitored and analysed for two different types of heat exchangers. The reference has a thermal length of 0.73, where the heat exchanger with increased thermal length has a thermal length of 1.00,

corresponding to an increase of 37%. The heat exchangers have the same size, but the area is increased, corresponding to a plate number increase from 26 to 40.

The analysis includes the costs due to material and installation of heat exchangers with longer thermal length and the incomes due to the decreased return temperature. In Denmark it is normal practice that a lower return temperature results in reduced energy cost for the end customer.

The main finding is that the additional cost of the heat exchangers with longer thermal length is balanced by the DH distribution energy saving achieved by reduced return temperatures.

Maria Jangsten graduated as a M.Sc. in Sustainable Energy Systems at Chalmers University of Technology in June 2016. Her master's thesis was about radiator systems supplied by district heating. Maria Jangsten graduated as a B.Sc. in Mechanical Engineering from Manhattan College, New York. She has two years of experience from project management of HVAC system installations in office buildings.

Survey of Radiator Temperatures in Buildings Supplied by District Heating

Maria Jangsten* B.Sc., Johan Kensby Tkn. Lic., Jan-Olof Dalenbäck Professor, Anders Trüschel PhD
Division of Building Services Engineering, Department of Civil and Environmental Engineering, Chalmers University of Technology, Gothenburg, Sweden
Maria Jangsten, marjang@student.chalmers.se, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden

Keywords: Radiator temperatures, Low-temperature district heating, 4GDH, Existing buildings

In order to maintain the competitiveness and improve the environmental performance of district heating in the future it may be of essence to transition to lower operating temperatures over those of the current third generation district heating systems. This is due to the fact that heat demands are expected to decrease as buildings become more energy efficient as well as new types of heat sources are likely to be integrated. The third generation district heating systems operate at annual average temperatures of 75-90°C supply and 40-50°C return in Sweden today. However these temperatures are well above the customer temperature demands which are to heat buildings to approximately 20°C and provide domestic hot water at 50°C. Therefore future supply and return temperatures of 50-55/20-30°C for the next fourth generation district heating systems have been suggested.

Radiators in buildings constructed prior to the 1980's have in Sweden typically been designed for supply temperatures of 80°C to provide space heating. However, as buildings are renovated, this temperature must be lowered to avoid overheating. For buildings constructed subsequent to 1982 the radiator design supply temperature should be a maximum of 60°C. Several previous studies have established what the temperatures on the primary side of the district heating systems are, however there is a lack of documentation on the temperatures of the secondary side. The purpose of this project is therefore to investigate the radiator temperatures on the district heating secondary side.

In this research project, data for 125 radiator systems for multi-family dwellings in the city of Gothenburg, Sweden, has been analyzed. These buildings were constructed between 1938 and 1993, with the majority being built in the 1950's. Supply and return temperatures for the design outdoor temperature have been calculated based upon available data measurements for one year. Several factors affecting the operating temperatures of the radiators, such as building heat demand and year of construction, have been examined.

Preliminary results reveal that the supply temperatures for design outdoor temperature of -16°C vary between 50 and 82°C for the buildings investigated and the return temperatures

vary between 25 to 57°C. The temperature difference between supply and return in the radiator systems was found to range from 5 to 41°C. For large durations of the year, the required supply temperatures are significantly lower than those at design outdoor temperature. For example, for an outdoor temperature of 0°C approximately 80% of the radiator systems have supply temperatures of lower than 55°C. It was also found that radiator supply temperatures are not correlated with the energy performance of the buildings.

The main conclusions that can be drawn at this stage in the research is that low-temperature district heating of 50-55°C primary supply would not suffice to provide space heating for existing buildings at design outdoor temperature. However, for parts of the year these temperatures would be adequate for a majority of the radiator systems surveyed. There are remaining factors influencing the supply temperatures yet to be analyzed, likely to add further conclusions of this study. This research will provide useful input for a future transition to lower operating temperatures for existing district heating systems and existing buildings as well as in exploring the possibilities of implementing temperature reductions in the district heating system during parts of the year more promptly.

Martin Crane worked for British district heating utility SSE for 8 years before becoming an independent consultant focusing on improving the performance of DH designs and DH in operation and also exploring the scope for community ownership of DH in the UK.

Individual house substation testing – development of a test and initial results

Martin Crane*
Carbon Alternatives Ltd 16 Belvedere Rd, Oxford, OX4 2AZ UK, martin@carbonalternatives.com

Keywords: Substation, testing

There has been a surge in District Heating (DH) development in recent years in the UK, with a large proportion of this due to DH now being required in all new large housing developments in London. With the motivation behind these DH systems being mainly to meet a legal requirement and with limited DH experience in the UK in many cases there has not been sufficient focus on the schemes being efficient in operation.

These DH networks commonly use an individual apartment substation, with an instantaneous heat exchanger for domestic hot water (DHW) and indirect connection for the space heating. Heat meter data and design documents shows there is quite a variation in the specification and performance of the substations in operation. UK Government research funding allowed Carbon Alternatives and Guru Systems to develop a substation test as part of a larger project to use heat meter data to identify causes of poor DH system performance.

The Swedish District Heating Association substation test F103-7 was taken as a starting point to develop a new UK test to establish the performance of individual house substations.

The paper discusses the development of the test protocol and the thinking behind the chosen tests e.g. with lower space heating loads of 1-4kW and DH flow temperatures of 75°C and 65°C.

The paper presents data from the 6 substations, a mix of mechanical and electronically controlled substations, tested at SP in Sweden and comments on some of the interesting results such as heat exchanger sizing. The paper then presents the use of test data to calculate a Volume Weighted Average Return Temperature (VWART) as a measure of the performance of each substation, based on typical DHW, space heat and standby patterns of use.

Xiaochen Yang finished her PhD from the Technical University of Denmark in June 2016. 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 Centre. Her research interests now include energy, economy and exergy analysis for various system configurations for supplying DHW with LTDH/ULTDH meeting comfort and hygiene requirements.

Different electric supplementary heating approaches for domestic hot water supply with ultra-low-temperature district heating

Xiaochen Yang*, Hongwei Li and Svend Svendsen
Civil Engineering Department, Technical University of Denmark, Denmark, Building 118, Brovej, DK-2800 Kgs. Lyngby, Denmark, xiay@byg.dtu.dk

To make the utmost use of the available low-temperature heat sources, for example, the heat production by a heat pump, the ultra-low-temperature district heating is one option. The target supply temperature of ultra-low-temperature district heating system is around 35°C to 45°C, but it also depends on the heat sources, as well as the energy and economy feasibility. With proper operation on the heat production side, the annual space heating demand can be covered by ultra-low-temperature district heating without compensate any thermal comfort. However, for domestic hot water supply, supplementary heating approaches should be combined to meet the comfort and hygiene requirement. In this study, three different electric heating approaches are investigated as the supplementary heating for ultra-low-temperature district heating: a small-size electric tank on the consumer side, a small-size electric tank on the primary side, and a direct electric heater on the consumer side with bypass to guarantee short waiting time. The energy performance, the economy performance, and the average return temperature to district heating of each scenario are analysed and compared. The results are of great importance to specify the optimal supplementary heating approach for ultra-low-temperature district heating.

Session 11: Smart Energy Systems

Karin Ericsson's research concerns the transition to sustainable energy systems. Her research consists of cross-disciplinary energy system studies that involve energy system analyses, technology, environmental and economic assessments, scenario analysis and policy analysis. Bioenergy, renewable energy, district heating, the forest industry and energy and climate policies are important areas in her research.

Session Keynote:

Potential for power-to-heat in balancing the Swedish electricity system

Associate Professor PhD Karin Ericsson* [a], karin.ericsson@miljo.lth.se
Associate Professor PhD Patrick Lauenburg [b], patrick.lauenburg@energy.lth.se
MSc Jonatan Rantzer [a], jonatan.rantzer@gmail.com
Mag MA Gerald Schweiger [a,c], g.schweiger@aee.at
MSc Gregor Zahrer [d], gregor.zahrer@tugraz.at
[a] Environmental and Energy Systems Studies, Lund University, Lunds Tekniska Högskola, P.O. Box 118, SE-221 00 Lund, Sweden
[b] Department of Energy Sciences, Lund University, Energy Sciences, PO Box 118, Sweden
[c] AEE INTEC Institut für Nachhaltige Technologien, Feldgasse 19, 8200 Gleisdorf, Austria
[d] Institute of GEOinformation, TU Graz, Steyrergasse 30 8010 Graz, Austria

The main challenge for future electricity systems is to match the available electricity from renewable resources with the electricity demand in place, time and quantity. There are a number of options for increasing electricity system flexibility, including increasing the supply and demand flexibility, improving the grid infrastructure and interconnections or different energy storage technologies. This paper investigates the opportunity to use power-to-heat (P2H) technologies in the Swedish district heating systems for the purpose of balancing the electricity system. Two crucial facts that motivate the study are: (i) Sweden has an extensive amount of district heating, in 2014 accounting for 58% of the energy supplied to buildings [1]. Also, the Swedish district heating systems have shown great flexibility in the past with regard to energy sources [2] (ii) There has been a rapid growth in the installation of Swedish wind power during the past few years, and the growth is expected to continue in the future. Swedish wind power production amounted to 16 TWh in 2015, which corresponded to 12% of the electricity consumption [3].

Based on data for the annual production of all district heating systems in Sweden [4], we calculate the hourly heat production for every system by exploiting a linear correlation between outside temperature and head demand [5]. The results are validated by comparing them to measured data. The hourly heat production defines the upper limit for using P2H. In order to meet uncertainties of future developments in the Swedish power system, a number of scenarios are designed for 2050 with regard to the level of electricity consumption and

production. The scenarios draw on existing energy scenarios for 2050 [6, 7]. For each of the scenarios, hourly values for the power residual are simulated. The potential for P2H can finally be estimated by comparing (on an hourly basis) the power residual to the heat demand, while taking into account assumptions on P2H and heat storage capacities.

The main contributions of the paper are: (i) a first detailed study on the potential of P2H in Sweden, (ii) a GIS-database that is publicly available for further investigations. The database contains information on all Swedish district heating systems concerning production units, storage size/capacity, share of waste heat, etc.; outdoor temperature trajectories for each county (used to calculate the hourly heat load); data on the power-system and (iii) the development of a heat storage model and storage strategy to analyse the impact of different storage sizes on the potential of P2H. Our first results show that the annual potential of P2H for different scenarios is in the range of 0.5-5.0 TWh. Key parameters that affect the actual potential are: Flexibility of hydro-power, annual variation in wind production and its share of total power generation, competitiveness with heat produced from waste incineration and industrial waste heat and the availability and size of heat storage units.

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Danica Maljkovic is Deputy Head of the Department for Energy Management and Organisation in Energy Institute Hrvoje Pozar, a Croatian leading research and consulting authority. She graduated in 2005 from the University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture in Power Engineering. Her work is focused on energy efficiency, district heating, sustainable energy production and security of supply.

Modelling the impact of installation of heat cost allocators in DH systems using decision tree model

Ms. Danica Maljkovic, Energy Institute Hrvoje Pozar, Savska cesta 163, 10 000 Zagreb, Croatia, dmaljkovic@eihp.hr*
Mr. Drazen Balic, Energy Institute Hrvoje Pozar, Savska cesta 163, 10 000 Zagreb, Croatia, dbalic@eihp.hr

Following the regulation of EU Directive on Energy Efficiency, specifically Article 9, individual metering in district heating systems has to be introduced by the end of 2016. These directions have been implemented in member state's legal framework, Croatia being one of these states. The Directive allows installation of both heat metering devices and heat cost allocators. Mainly due to bad communication and PR the general public false image was created that the heat cost allocators are devices that save energy. Although this notion is wrong, the aim of this work is to develop a model that would precisely express the influence of installation heat cost allocators on potential energy savings in each unit within multifamily buildings. Heat consumption is dependent on a number of factors, such as heating degree days, building envelope characteristics, occupancy, existence of individual metering as a basis for change in user's behaviour, etc. It is a complex system to model the exact influence of the change of one of the heat consumption factors on overall consumption. In previous research there have been a number of studies on building energy consumption modelling and the usual methods used are traditional multiple regression models, simulation methods and methods of artificial neural networks. At the same time, in recent years, a science of machine learning has gain larger application in various fields, as it is proven to give good results in cases where large amounts of data are to be processed with an aim to recognize a pattern and correlation of each of the relevant parameter as well as in the cases where the problem is too complex for a human intelligence to solve. A special method with machine learning, decision tree method, has proven an accuracy of over 92% in prediction general building consumption. In this paper a decision tree method will be used to isolate the sole impact of installation of heat cost allocators on a single building in multifamily houses connected to district heating systems.

Jakob Zinck Thellufsen is a PhD fellow in the CITIES research project working with Energy System Modeling and Analysis of multiple energy systems. He primarily focuses on linking local energy systems with plans for future national energy systems, and the relation between energy systems and energy savings.

Modelling Smart Energy Systems in Different Energy System Analysis Tools

Jakob Zinck Thellufsen, PhD Fellow, Department of Development and Planning, Aalborg University, Skibbrogade 5, 9000 Aalborg, Denmark, jakobzt@plan.aau.dk*

Smart Energy Systems emphasizes the integrated energy system in the transition to 100 % renewable energy system. This means that to cope with the challenges of energy systems with high shares of variable renewable energy, the different sectors in the energy system has to be linked. This specifically means the implementation of smart gas grids, smart district heating grids and smart electricity grids.

Plenty of energy systems analysis tools exist, but to model Smart Energy System solutions, a certain range of requirements are needed. First, all the necessary sectors of the energy system must be included in the tool and the tool needs the capability of linking them. Second, the tool needs to be capable of modelling the fluctuation of production and demand specifically due to the focus on variable renewable energy, and third, the tool needs to model storages both in terms of thermal, gas and electricity storage. Even though this list of requirements narrows the number of tools, a number of tools still exists, and potentially a discrepancy exists in the results depending on the tool.

Therefore, this study investigates the consequences of choosing different energy system models in analyzing Smart Energy System. The tools chosen are both hourly simulation tools: one deterministic input-output model that depends on analytical programming – EnergyPLAN, and the other a linear optimization tool also based on hourly simulation – Sifre. Besides being hourly models, both tools have capability of investigating and linking different sectors of the energy system, and include storages in all sectors. The study seeks to investigate corresponding inputs in the two different models, to analyze a smart energy system. The results are based on comparing the outputs from the two models to identify the consequences of using different tools to analyze Smart Energy Systems. An added benefit of comparing the two tools is not only the identification of possible differences but also the identification of how they can supplement each other in reaching better energy systems modelling by utilizing the benefits that each model provides.

The study uses the case of IDA's Energy Vision 2050 that is a model of a 100 % renewable Danish Smart Energy System. The case was originally modelled in EnergyPLAN, so this study creates a comparable model of IDA's Energy Vision 2050 in Sifre.

Gerald Schweiger is doing a PhD in the field of simulation and optimization of hybrid energy systems. The research hypothesis of his dissertation is that linkages between electricity and district heating networks provide a flexibilisation potential that could make a significant contribution to future energy systems.

A framework for model predictive control of hybrid district heating systems

Mag. MA Gerald Schweiger* [a], g.schweiger@aee.at
PhD Per-Ola Larsson [b], per-ola.larsson@modelon.com
PhD Stéphane Velut [b], stephane.velut@modelon.com
PhD, Assistant Professor Patrick Lauenburg [c], patrick.lauenburg@energy.lth.se
[a] AEE INTEC Institut für Nachhaltige Technologien, Feldgasse 19, 8200 Gleisdorf, Austria
[b] Modelon AB, Scheelevägen 17, 223 63 Lund, Sweden
[c] Department of Energy Sciences, Lund University, Energy Sciences, PO Box 118, Sweden

The design of flexible energy systems integrating large shares of fluctuating renewables while improving the overall system efficiency is a major challenge for future energy systems. Previous research has shown that heating infrastructure such as district heating and different storage technologies will play a key role in this context [1]. Here, a smart linkage of different energy domains such as electricity, heat or gas offers huge flexibility potential. We define hybrid district heating systems (HDH) as district heating systems that are linked to other domains through storage and hybrid technologies. The main scientific contribution of this work is a first integrated framework for model predictive control of HDH based on a non-causal, equation based modelling language and a high-level, large-scale dynamic optimization method. The framework provides tools for dynamic simulation, aggregation of networks and dynamic optimization. Compared to most of the state of the art tools which are based on imperative and domain specific methods, this offers a lot of advantages, including flexibility, modular expandability, reusability of models, and applicability to multiphysics problems. Innovative system configurations, dynamics between supply, distribution, demand and storage and their optimal interaction can be investigated by formulating a model predictive control scheme. Furthermore, this approach provides energy suppliers with a framework to improve the efficiency of existing systems. Limitations of standard methods rely often on simplified models, static relationships and single-domain approaches. Therefore standard approaches are restricted and thus unsuitable to investigate many issues of future hybrid energy systems.

The modelling language Modelica [2] is used to model and simulate HDH. The optimization problem contains discrete (units/storage on/off) and continuous variables and it is part of the class "Mixed Integer Nonlinear Programming". Since there are no robust methods available to solve this class of problems, the problem is divided into two sub problems: the discrete unit commitment problem, which is solved by a linear mixed integer quadratically constrained program (implemented in Python), and the continuous optimal control problem,

which is addressed by a collocation method that transfers the infinite-dimensional problem into a finite-dimensional nonlinear problem (implemented in JModelic/Optimica Compiler Toolkita [3,4]). The major advantages of including model coherences based on physical laws into the optimization formulation compared to conventional approaches are high accuracy and the possibility to impose constraints on physically relevant variables such as temperature, pressure or mass flow, based on physical and operational limitations of the real system. A precise model representation of the entire system is required to analyse the impact of applying an optimal control strategy. The paper shows also that Modelica is a suitable modelling language to describe and efficiently simulate HDH. First tests of the framework in optimizing the supply temperature incl. handling constraints at costumers show promising results. Other interesting approaches in the field of simulation and optimization of district heating systems are found in [5-8].

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Session 12: Future district heating production and systems

Julio Efrain Vaillant Rebollar is a researcher at the Building Physics, Construction and Services group, of the Department of Architecture and Urban Planning at Ghent University, Belgium. He is participating in the European project 'ECO-Life: Sustainable zero carbon ECO-town developments improving quality of life across EU (EU-FP7)'. Julio Efrain Vaillant Rebollar works with modeling and optimization of district heating systems and studies the performance of district heating substations by means of dynamic simulations.

Session Keynote:

Sensitivity analysis of heat losses in collective heat distribution systems using an improved method of EPBD calculations

Julio Efrain Vaillant Rebollar*, Eline Himpe and Arnold Janssens
Ghent University, Department of Architecture and Urban Planning, Research group of Building
Physics, Construction and Services, Jozef Plateaustraat 22, B-9000 Gent, Belgium
julioefrain.vaillantrebollar@ugent.be

Keyword: Dwelling heating substations, Heat distribution systems assessment, Sensitivity analysis

This paper studies the sensitivity of heat losses in collective heat distribution systems in well-insulated and well controlled low-temperature networks by using a simplified heat loss calculation method. A generalized approach for the development of more accurate heat loss calculation methods in the context of the legislative energy performance of building standards in Europe (EPBD) is proposed. The approach is applied to a specific type of collective heat distribution system design where networks distribute heat for both space heating and domestic hot water to low-energy houses. The proposed methodology takes into account suitable design parameters influencing the thermal performance of the heat distribution system. For instance, the thermal properties of the heat exchanger in the dwelling heating substation and the nominal return temperature of domestic hot water are considered. In addition, the recirculation control strategy, the length of service branch which is included or not in the recirculation as well as, the share in a building of dwelling heating substation with similar characteristic and control strategy among other parameters are also taken into account. The present study assesses the impacts of some potential variations in the input variables, on the conclusions of the methodology. To that aim a study was conducted through a sensitivity analysis by means of an experimental design, consisting of the combinations of parameters which were varied from the levels at which they were set. Results show how sensitive the solution is in the face of different parameter values as well as under what circumstances the solution would change. Furthermore, the potential of the improved calculation method which allow the combination of different design conditions within a single heating distribution system was demonstrated. In addition, the suitability of

sensitivity analysis for the search of optimal design parameters in collective heat distribution systems was verified.

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

Applications of a heat load forecast with dynamic uncertainties

Magnus Dahl*, industrial PhD fellow, M.Sc., Department of Engineering, Aarhus University and AffaldVarme Aarhus, Bautavej 1, 8210 Aarhus V, magnus.dahl@eng.au.dk
Gorm Bruun Andresen, assistant professor, PhD, Department of Engineering, Aarhus University, Inge Lehmanns Gade 10, 8000 Aarhus C, gba@eng.au.dk
Adam Brun, business developer, PhD, AffaldVarme Aarhus, Bautavej 1, 8210 Aarhus V, adbr@aarhus.dk

Operators and production planners in district heating are faced with decision making under uncertainty, and risk management is becoming increasingly important in the district heating sector. Much of this uncertainty stems from the forecast of the heat demand in the next few days, but uncertainty related to the production of variable renewable energy is also becoming more important. Short term heat load forecasting has been studied thoroughly in the literature and a number of commercial tools for the purpose exist. However, the uncertainty of the forecast is rarely quantified in terms of prediction intervals, and when it is, constant intervals are used. In this study we are first to present a heat load forecast with dynamic weather-based prediction intervals. The dynamic nature of the uncertainty originates from the time-varying uncertainty on the weather forecast that enters the heat demand model. We estimate the time-varying uncertainty using the technique of ensemble forecasting. An ensemble weather forecast consists of a multitude of forecasts that ideally cover the whole range of possible weather conditions and can be used to estimate the probability of different scenarios. We create an ensemble of heat load forecasts by using a weather ensemble forecast as input for a heat demand model. This way we provide a heat load forecast with dynamic uncertainties, depending on the uncertainty of the weather forecast.

Knowledge of dynamic uncertainties of a heat demand forecast can be used to quantify operational risk related to security of supply and financial risk in the energy market. Here, the following example applications will be discussed: I) In the operation of a heat exchanger, safety margins on the water flow that ensure the security of supply can be made dynamic instead of constant. This makes it possible to lower the supply temperature and reduce heat losses to the ground in a number of peak load hours. II) In the context of production planning, knowledge of the dynamic uncertainties can help decision makers quantify risk in unit commitment situations and when operating heat storage units coupled to the electricity market. This can be done by optimizing the operation of a CHP plant with heat storage and

an electric boiler to mitigate the risk taken on the electricity market, for instance by making sure that deals can be kept even if the heat demand is larger or smaller than expected. Risk management will become even more relevant in the district heating systems of the future due to the coupling of different energy sectors in smart energy systems and due to the increasing penetration of variable renewable energy sources.

Mikko Wahlroos has worked in the Laboratory of Energy Efficiency and Systems at Aalto University's School of Engineering since 2013. He is preparing his PhD on smart district heating systems, which includes demand side management, waste heat utilization, energy efficiency and pricing of district heating. Mikko is a lecturer on the Energy Markets course at Aalto University.

Utilizing data center waste heat in district heating – impacts on energy efficiency and prospects for low-temperature district heat networks

M. Wahlroos, MSc., S. Rinne, MSc., S. Syri, Professor,*
Department of Mechanical Engineering, Aalto University, School of Engineering , P.O. Box 14100,
FIN-00076 Aalto, Finland, mikko.wahlroos@aalto.fi
J. Manner, Professor, Department of Communications and Networking, Aalto University, Espoo, Finland, jukka.manner@aalto.fi

Energy efficiency of data centers is becoming more and more important as the number of data centers is growing fast. It is estimated that data centers already accounted for 1.1-1.5% of world's total electricity consumption in 2010. Data centers require vast amounts of cooling energy. The electricity consumed in the data center almost completely converts to heat. However, the heat is mostly not utilized, even though different solutions already exist.

Cold climate in Nordic countries is extremely suitable for data centers by providing the much needed cooling energy. Furthermore, there is a high demand for heat in these countries and industrial waste heat is already utilized in different processes and district heating (DH) on larger scale, especially in Finland and Sweden (waste heat in district heating in 2013, 2% and 6.4% respectively). DH with highly efficient CHP (Combined Heat and Power) is exceptionally common in Finland and Sweden.

As the housing stock is becoming better insulated, DH networks are striving towards lower temperatures, which would enable feeding lower quality heat to the DH network. To comply with the EU regulations, for example Finland is aiming at near zero energy buildings (nZEB) in the new building stock by the year 2020. The very low energy demand of the new buildings is particularly suitable for low-temperature heat supply. Therefore, there may be even more potential utilizing the waste heat from data centers in the future. If the supply temperature of the DH network can be decreased to as low as 50°C, lower quality heat would be easier to feed into the system. Typically waste heat from data center is low quality (<85°C) and thus it cannot be utilized in current networks to its full extent.

Data center operators are competing on energy efficiency of the data centers. Nowadays the most common metric to analyze energy efficiency in data centers is PUE (Power Usage Efficiency), which only takes into account the total power into the data center and IT equipment power. Thus, the PUE is not adequate measurement as it does not take waste heat recovery into account. As long as PUE is the dominant metric, data centers might not be

eager to utilize the waste heat as waste heat utilization may in fact decrease the PUE value as heat pumps are used to increase the quality of waste heat. We propose that energy efficiency metrics such as ERE (Energy Reuse Efficiency) and ERF (Energy Reuse Factor), which take into account the reuse of waste heat, should be heavily promoted instead of PUE by the Nordic countries.

In this study we analyze the potential for data center waste heat utilization in low temperature DH networks. For this, we utilize the real data from data center connected to the Espoo DH network. We show with examples how the different metrics are able to reflect the real energy efficiency of the data centers.

Nazdaneh Yarahmadi has been working as a scientist and project leader in 20 years. She has worked with degradation and life time estimation of polymeric products. She has also worked with the development of new polymeric materials with enhanced properties and reduced environmental impact such as polymer nanocomposites and bio-based plastics. She has published 16 peer-reviewed papers and 25 conference proceedings.

Determination of degradation pathways influencing service life of polyurethane insulation in district heating pipes

Nazdaneh Yarahmadi*[1], Alberto Vega[1], Ignacy Jakubowicz[2]
[1] SP Technical Research Institute of Sweden, Gibraltargatan 35, Gothenburg, SE40022, Sweden
[2] SP Technical Research Institute of Sweden, Brinellgatan 4C, Borås, SE50115, Sweden
Nazdaneh.yarahmadi@SP.se

Keywords: Polyurethane, District heating pipe, Thermal degradation, Accelerated ageing, Life time prediction

Supply heating by district heating (DH) system is an accepted safe, efficient and low cost solution for most consumers in Europe. Hot water is a common heating media in the modern DH pipes. In spite of many improvements to reduce heat losses there are still challenges such as life time prediction and status assessment that are driving development of DH systems and in particular DH pipes.

Pipes and joints must have the ability to withstand displacement as a result of axially applied forces occurring between pipes and the insulation system. Consequently, a good adhesion of the foam to the pipes is necessary to ensure the long-term performance of the pipe composite. High mechanical properties, such as compressive strength, are also required to enable the foam to withstand high loads, e.g. when the pipe composite is transported or buried in the ground. As district heating networks operate with high service temperatures up to 120°C, a good long-term heat resistance is necessary to maintain the most important properties e.g. good adhesion of the foam to the pipe and good insulation efficiency.

In this project deterioration of the mechanical and insulation properties of pre-insulated heating pipe (with steel media pipe, polyurethane (PUR) insulation and HDPE as jacket) was investigated as a result of ageing. The focus is on degradation mechanisms of the PUR material at high temperatures by study of PUR material aged in three different conditions. The first condition is when the new pipes are subjected to accelerated ageing, the second condition is when the PUR material itself is aged in different atmospheres and the third condition is when the PUR material is naturally aged in the field during usage time. Mechanical properties were evaluated using a plug method for the determination of adhesion and three point bending to determine flexural strength and the insulation properties were measured using a hot-disk method. Characterization of the PUR material has been done by Fourier Transform Infra-red spectroscopy (FTIR), differential scanning

calorimetry (DSC), thermal gravimetric analysis (TGA) and scanning electron microscopy (SEM) in order to identify degradation mechanisms and degradation products.

Preliminary results suggest that the degradation mechanism is a combination of physical and chemical phenomena. Changes in the properties that are observed during the early ageing periods are mainly caused by physical effects while chemical degradation is expected to occur on the long term basis.

Session 13: Energy planning and planning tools

Marie Münster is a senior researcher at the Technical University of Denmark. She has 16 years of experience working with energy planning and renewable energy technologies from both private consulting and research. Her field of research is energy system analysis of energy technologies with a focus on waste, biomass and gases and the use for district heating and transport.

Session Keynote:

Implications of different future energy systems on optimal waste treatment and use for energy

Marie Münster*[1], Amalia Pizarro[1], Raffaele Salvucci[1], Ciprian Cimpan[2], Henrik Wenzel[2], Hans Ravn[3]

[1] Systems Analysis Department, Management Engineering, Technical University of Denmark, Produktionstorvet 426, DK-2800, Kgs. Lyngby, Denmark, maem@dtu.dk
[2] Institute of Chemical Engineering, Biotechnology and Environmental Technology, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark
[3] RAM-løse edb, Æblevangen 55, DK-2765 Smørum, Denmark

Keywords: District heating, waste treatment, future energy scenarios

Although we will increase the level of recycling in the future, it may still be relevant to utilise some waste fractions as resources for energy production. For that reason, the future optimal treatment of waste will depend on the development of the energy system. Taking into account a holistic approach between the electricity, district heating and waste management system including transport, this article tries to give answers to the following questions:

Given the Danish targets for recycling and reduction in climate gas emissions - what is the optimal treatment of waste from a socio-economic perspective?

To which degree is it optimal to invest in central material recovery facilities (MRFs) on top of source segregation (in order to increase recycling and facilitate a higher share of waste storage)?

Will incineration in large scale CHP plants in the future be replaced by decentralised CHP units or by heat only boilers?

Should we transport source segregated organic waste from the East of Denmark to the manure in the West in order to produce biogas?

What influence might the competition with future district heating production technologies such as bio-refineries have on the way we should use waste for energy?

In the study, the energy system analysis tool, Balmorel, is linked with the newly developed waste and district heating system analysis tool, OptiWaste. Both tools are based on linear programming and facilitate optimisation of investments and operation based on least cost optimisation, but where the Balmorel model covers the Nordic electricity market and district heating systems, the OptiWaste model has a detailed geographical division of Denmark

implemented, which facilitates joint optimisation of the waste management system (including transport) and the district heating system.

As a result of the analysis, different waste treatment alternatives prove optimal in different future energy scenarios, but robust waste treatment solutions also emerge.

Ryota Ii is a M.Eng. from Kyoto University and a nationally qualified Professional Engineer (JP) of environmental conservation planning and waste management, Class3 electrical and Class2 IT engineer. Ryota Ii has 18 years of experience as a consulting engineer for research and planning commissioned by national and local governments, research institutes and universities. He has co-authored around 10 papers in international and domestic journals like Applied Energy, Waste Management and IJLCA.

District heating and cooling using heat supply from WTE facilities in Japan

Ryota Ii* (Mr.) and Yurie Shirakawa (Dr.) (Pacific Consultants Co., Ltd., JP)
3-22, KandaNishiki-cyou, Chiyoda-ku, Tokyo, 101-8462, Japan,
Ryouta.li@tk.pacific.co.jp

Keywords: WTE, CHP, district heating and cooling, heat pump, exergy efficiency

In Japan, there are more than 1,000 incinerators of local governments for MSW (municipal solid waste) besides those of private companies including those for industrial waste. Recently improvement of power generation efficiency from WTE (Waste to Energy) has been politically promoted especially for incinerators of MSW in Japan. Moreover utilizing of heat supply like CHP (combined heat and power) are also considered to be one of the promising options for achieving higher energy saving effect. Until now many feasibility studies have been focused on heat supply from WTE to DHC (District Heating and Cooling), but they mostly deal with the comparison against steam-driven system supplied by simple combustion of natural gas. However lower carbon technologies like electric heat pump as non-combustion one or dispersed power system by CHP using internal combustion engines are considered to be much more introduced in the future LCS (low carbon society).

In this presentation, we will firstly introduce the latest situation of heat supply from WTEs mainly focusing on those to DHCs in Japan with evaluation by using exergy efficiency as well as enthalpy efficiency. Then, we will show our detailed calculation of net carbon emission of CHP from WTEs, comparing with the CHP system by gas engine and electric heat pump system of both central HVACs and dispersed HVACs under the different energy mix of power generation of the electricity grid in now and 2030. (Dispersed HVACs are based on heat pumps for both winter and summer, and they have been widely spread recently in Japan). Finally, the reasons and barriers for the cases of not adopting CHPs from WTE are illustrated based on the questionnaire survey to municipalities. This presentation will be mainly based on the published research report commissioned by the Japan MOE (Ministry of the Environment).

Amalia Pizarro-Alonso is a PhD student at the Technical University of Denmark in the division of Energy Systems Analysis. Her field of research is system analysis of energy technologies, focusing on optimal integration of waste and biomass resources. Amalia Pizarro-Alonso contributes to developing a new model that optimizes between different waste-to-energy alternatives, assessing the impact of waste on the energy system.

Smart use of waste-to-energy: impacts of modelling storages and geography

Amalia Pizarro-Alonso [a],*, Marie Münster [a], Hans Ravn [b]
[a] Systems Analysis Department, Management Engineering, Technical University of Denmark, Produktionstorvet 426,DK-2800 Kgs. Lyngby, Denmark, aroal@dtu.dk, maem@dtu.dk,
[b] RAM-løse edb, Æblevangen 55, DK-2765 Smørum, Denmark, hans.ravn@aeblevangen.dk

Currently, incineration of Municipal Solid Wastes (MSW) in Denmark provides around 20% of the total district heating consumption and 5% of the electricity demand, from 19 combined heat and power (CHP) plants with an average input capacity of 180,000 ton/year and from 7 boilers with an average input capacity of 42,000 ton/year.

Traditionally, waste-to-energy plants provide base load power and district heating (DH) and their ability to ramp-up and down at short notice to compensate for temporary supply deficits or surpluses is limited. Future fossil-free energy systems will be characterized by variable resources, such as wind power production, resulting in fluctuations in electricity prices. Furthermore, part of the base load district heating production might be produced from excess heat from biorefineries in large centralized areas, where incineration plants are also mainly located. Therefore, a fully decarbonized energy sector would benefit from waste-to-energy technologies that can operate flexibly in order to accommodate a high degree of variable resources, and to maximize the value of the electricity and district heating produced.

A number of challenges exist in this respect: waste can be stored and burnt at periods when the district heating demand is high. Industrial waste is mostly dry and could be stored between seasons; however, household MSW should go through a Material Recovery Facility, to sort out the organic fraction prior storage, which implies an additional cost, apart from the storage cost itself. Flexible burning of MSW throughout the year will also require investment in incineration over-capacity, as plants will operate during less full load hours. Furthermore, flexible operation of CHP incinerators to react to electricity price fluctuations, which occur on an hourly basis, would be limited.

For all the above mentioned reasons, this study aims to analyze the impact that modelling short and long-term storages might have when optimizing investments and operations of waste-to-energy technologies in future fossil-free energy systems and to identify the affected energy production. The study also looks at the impact of detailed modelling of geography in many district heating/ waste generation areas. A holistic approach between the waste and the energy sector is taken in order to avoid suboptimal solutions in both systems.

Investments and operations in the energy sector, including heat storage devices, are optimized with the Balmorel energy system tool, which is soft-linked with a waste and DH system model called OptiWaste, which optimizes transport, waste treatments and district heat production.

Future CHP incineration plants may be backpressure units with a by-pass valve to avoid electricity production when power prices are low and to increase the heat output subsequently. Short-term heat storages, such as accumulators, would allow storing heat and using it whenever the demand is larger. Short-term storages and by-pass valves both increase the flexibility of CHP incinerators for electricity dispatching.

Long-term heat storages on the other hand allow operation of the incinerator plants at almost a constant rate throughout all the year, avoiding investments in over-capacity and in large waste storages, and maximizing the value of the DH provided. This might be of the utmost importance e.g. if the transportation sector relies heavily on domestic production of biofuels, which will generate base load district heating, which might compete directly with heating from incinerator plants.

Melissa Carina Gabert finished her bachelor's degree in Business Administration and Engineering at the Baden-Wuerttemberg Cooperative State University in Heidenheim, Germany. For her master's degree, Melissa Carina Gabert studies Environmental Engineering at the University of Southern Denmark. The work of this study is part of her master's thesis elaborated in collaboration with Svendborg Fjernvarme.

Waste and Energy System Integration – The Role of Refused Derived Fuel in Future District Heating

_Melissa Carina Gabert_*, Ciprian Cimpan, Abid Rabbani, Henrik Wenzel,
henrik.wenzel@kbm.sdu.dk
Environmental Engineering, University of Southern Denmark

Nowadays, Denmark´s district heating systems obtain heat by around 70% from combined heat and power plants burning fossil fuels, waste and biomass. The demand for district heating will increase in the coming years as municipalities and district heating companies have the incentive to expand the existing grids from the urban centres to the suburbs. At the same time, European countries face radical changes in their current waste management and energy systems. On the one hand, the European Union obligated its member states to recycle 50% of municipal solid waste by 2020. Denmark aims to achieve and even extend this goal to 65% by 2035, while other countries are willing to treat their waste for possible export as refused derived fuel (RDF) and thereby avoid landfilling. On the other hand, energy systems are progressively turning their production into renewable sources by simultaneously phasing out fossil fuels.

These conditions lead to the increasing concern about heat bottlenecks, hours of electricity oversupply and largely fluctuating electricity prices in Denmark in the future. Hence, making use of waste import appears very likely for Denmark´s district heating systems as in the majority of cases, waste incineration plants are already existent. Additionally, heat pumps could be one solution for the integration of electricity overproduction in the heat sector. This could prevent the sale of electricity at negative prices in hours of oversupply. Applying thermal heat storage in combination with heat pumps enhances the flexibility of heat production in hours of low electricity prices and heat utilization in hours of high electricity prices.

Consequently, the aim of this study was to analyse the feasibility of storable waste together with heat pumps in a district heating system and to answer the question whether storage is feasible to include. This was done on the basis of the current district heating system of Svendborg, a medium-sized city in Denmark, for the timelines 2020 and 2035. Hence, the existing incineration plant was included in the scenarios of 2020 with changed shares of local waste input and excluded in 2035. In addition to that, different sized heat pumps were added to the system, supplemented by biomass boilers which were comparatively replaced by RDF boilers. For 2035, scenarios including storage were modelled in addition to scenarios without storage. The energy systems were modelled with the help of the software energyPRO,

considering both socio economics and business economics in comparison. All scenarios were compared by their system heat prices. Moreover, the competiveness of RDF and biomass boilers has been analysed for each scenario, by finding the breakeven with RDF import prices. The results of the study demonstrate that the most feasible alternative in 2020 is the system of the incineration plant supplemented by 75% heat pump capacity and 25% RDF boiler capacity under business economic and socio economic conditions. From all scenarios of 2035, the alternative of 25% heat pump, 50% RDF boiler capacity and a thermal storage of 61,000 m3 has the lowest heat price under business economic conditions. Given socio economics here, the system of 25% heat pump and 25% RDF boiler capacity added by a seasonal heat storage of 550,000 m3 appeared to be more feasible. Furthermore, the derived breakeven prices of imported RDF are higher than the current gate fee for all scenarios, except one, varying from -268 to -195 DKK/ton in 2020 and from -10 to 170 DKK/ton in 2035 under socio economics.

In conclusion, the study presents the most feasible district heating system for the case of Svendborg under future conditions, comparing technologies of biomass or RDF boiler and heat pumps with or without thermal storage. It further shows that scenarios including heat storage are to be preferred from a business and socio economic perspective. Finally, the results show that RDF boilers can compete with biomass boilers in the short term and particularly in the long term, even if RDF import fees were reduced.

Session 14: Low-temperature district heating and buildings

Dr. Anton Ianakiev is a Reader of Finite Element Modelling at Nottingham Trent University. His research and teaching are focused on using numerical simulation in sustainable materials, structures and buildings. He is leading a research group of 5 partners in the H2020 REMOURBAN Smart Cities and Communities project in developing an area of energy efficient buildings and sustainable transport in Sneinton, Nottingham.

Session Keynote:

Innovative Delivery of Low-Temperature District Heating System in Nottingham, UK

Dr. Anton Ianakiev*[1], Dr Jia Michelle Cui[1], Steve Garbett[2], John Beardmore[3]
[1] Nottingham Trent University, Maudslay 312, Nottingham Trent University, Burton Street, NG1 4BU, UK, anton.inakiev@ntu.ac.uk, michelle.cui@ntu.ac.uk
[2] Enviroenergy Ltd., Nottingham, UK
[3] T4 Sustainability Ltd., Derbyshire, UK

This paper is based on a recently completed feasibility research – Report of the Innovative low temperature district heating – for the EU Horizon 2020 project REMOURBAN (REgeneration MOdel for accelerating the smart URBAN transformation). REMOURBAN is a major Future Cities demonstrator project supported by an investment of EU Lighthouse project scheme (REMOURBAN, 2015). District Heating (DH) / Low Temperature District Heating (LTDH) is one the three main REMOURBAN renovation areas that include energy, mobility, and ICT. One major project partner – Enviroenergy Ltd. – is managing to extend the existing district heating network to serve 94 homes in four maisonette blocks of low-raised social housing flats at Nottingham. Nottingham's existing extensive Energy from Waste (EfW) district heating network, currently supplies approximately 4,900 homes close to the demo site at Sneinton, Nottingham. It was proposed in the feasibility research that a branch emanating from the return pipe of the primary mains would be created to use low temperature heating for the first time at such a scale in the UK. This will provide a primary supply of flow water at approximately $50^{\circ}C$ to $60^{\circ}C$. Innovative solutions have been put forward to overcome certain barriers, such as legionella related risks and peak load during extreme heating seasons or occasional maintenance. This paper aims to explore these innovative aspects in the planning stage of such a major investment project. It also demonstrates the identified metering and control scheme that will optimise the LTDH performance. The current feasibility study ushers the next REMOURBAN project stage of implementing the selected methods in the secondary loop design at the user side and the real-time field monitoring.

Dorte Skaarup Østergaard is a PhD student in the 4DH Research Centre. She performs dynamic simulation and evaluation of existing buildings analysing how to provide space heating for existing buildings with low-temperature district heating.

Experiences from a practical test with low-temperature district heating for space heating in 5 existing single-family houses from the 1930s

Dorte Skaarup Østergaard*, Svend Svendsen
Technical University of Denmark, Department of Civil Engineering, Brovej, Building 118, DK-2800 Kgs. Lyngby, Denmark, dskla@byg.dtu.dk.

In this study we monitored the heating system operation in 5 existing single-family houses by tracking how heat was distributed to each radiator in the houses. The aim was to investigate the feasibility of heating existing single-family houses with low-temperature district heating with supply and return temperatures of 55°C / 25°C for most of the year. This paper shows the results of the monitoring, and illustrates the problems encountered with the heating system control in the houses. Additionally the paper reports on the benefits obtained through adjustments of the heating systems control. Two main barriers for optimal implementation of low-temperature space heating were encountered. Firstly a few radiators were seen to be too small to deliver the necessary heat with a low supply and return temperature. Secondly improper control and malfunctions of thermostatic radiator valves were seen to cause poor heating system operation in some houses. Ultimately the study found that there is a large potential to use low-temperature district heating in existing housing areas. Furthermore the study indicates that low-temperature district heating will be an economically beneficial solution for energy efficient heat supply in the future.

Marko Cosic is a Cambridge and MIT trained engineer who began his career at a startup in California that used high speed autonomous UAVs to harvest wind energy. His speciality is designing for target performance at target cost: the difference between a prototype and a solution suitable for volume manufacture, large-scale deployment, and ongoing operation at a profit. As Technical Director at COHEAT, he applies a process control and mass manufacturing approach to the traditionally artisanal heating industry.

## Creating 5th generation actively managed residential heat networks

Mr. Marko Cosic*, COHEAT Ltd, Future Business Centre, Kings Hedges Road, Cambridge CB4 2HY, United Kingdom, marko@coheat.co.uk

5th generation heat networks are 4th generation heat networks whose performance is enhanced using active management of heat loads and verified against what the consumer requested at the point of use.

To understand and improve how heat networks perform needs:

- Visibility of what the network is being asked to provide
- Visibility of what is happening on the network
- Visibility of what the network is delivering at the point of use
- Control over how the how the system delivers what it is asked to provide

A platform to do this was created by integrating a heat network controller with every sensor and actuator used to deliver heating and hot water; every consumer and operator interface; and 3rd party data feeds such as weather forecasting and payment collection services.
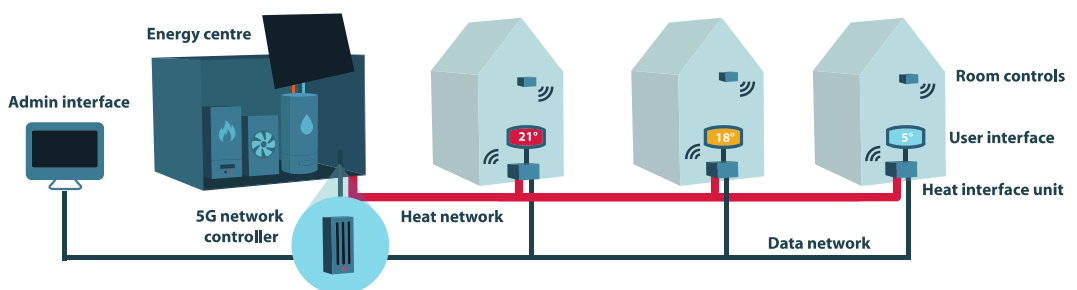
The heat network controller is aware of what the network is being asked to provide through the consumer and operator interfaces. It has full visibility of what is happening on the network and in the home with sensors down to individual room level. It has full electronic control authority over every actuator in the system down to individual radiator valves so can implement any control strategy in order to deliver what it has been asked to provide.

The UK Department of Energy and Climate Change funded the design and build of a prototype 5th generation heat network in Birmingham, UK, from May 2015 through March 2016. This was used to:

- Avoid network capacity constraints and mitigate their impact when they do occur; meaning that more customers can be served using smaller pipes, pumps, and heat sources.
- Reduce energy costs and emissions by optimising network operating temperatures, pressures, and space heating strategies; to improve equipment efficiency and reduce network losses.
- Improve user experience and reduce commercial operating costs through real time feedback on the cost implications of changes to heating schedules and remote real time visibility of the actual service levels achieved within individual properties and the reasons for any underperformance.

This paper outlines the challenges in integrating from user interface to energy centre to radiator in real-time, the potential benefits of active management for reducing the capital and operating cost of heat networks, and seeks to demonstrate that "service level" for hot water and space heating is a metric that can be specified and measured against.

Rasmus Pedersen is an industrial PhD student employed at Aarhus District heating, working on the READY project under WP3. His area of research is within the field of business models and consumer motivations increasing the level of cooperation between the district heating supplier and end consumers.

Direct and indirect district heating network energy savings from building retrofit

_Rasmus Pedersen_*, industrial PhD student, MSc., AffaldVarme Aarhus, Bautavej 1, 8210 Aarhus V,
raspe@aarhus.dk
Martin Heine Kristensen, PhD student, MSc., Department of Engineering, Aarhus University,
mhk@eng.au.dk
Steffen Petersen, Associate professor, PhD, MSc., Department of Engineering, Aarhus University,
stp@eng.au.dk
Adam Brun, Business Developer, PhD, AffaldVarme Aarhus, Bautavej 1, 8210 Aarhus V,
adbr@aarhus.dk
Gorm Bruun Andresen, Assistant professor, PhD, MSc., Department of Engineering, Aarhus University, gba@eng.au.dk

Keywords: District heating, building retrofit, buried heating pipes, distribution

Efficiency in both production and consumption is increasingly relevant in light of ambitious targets for CO_2 reductions to mitigate climate change. In this context, district heating may be a key technology in areas with sufficiently high population density, as district heating networks allows efficient use of both renewable energy as well as waste heat from e.g. power plants or industrial processes.

Designing a district heating distribution network requires detailed knowledge about both total and peak heating demand within the specified area. An inadequate design leads to inefficient use of the network. This could mean higher expenses due to larger heat losses, extra need of pump capacity and/or the chance of the network being incapable of delivering enough heat to the area during peak loads. In areas where a district heating network is already in place, conditions may change over time due to e.g. building retrofit or urban densification. Typically, a reduced demand in the area may provide an opportunity for increased efficiency of the network, while an increased demand may challenge the original design.

In the analysis presented here, the economic value of district heating temperature reductions is quantified by relating total heat production and consumption with supply and return temperatures, and ground temperature. For the study, data from AffaldVarme Aarhus, Denmark, will be used to compare results for up to 50 different distribution networks. The study includes different scenarios of lowering the temperature, postponing or avoiding renovations, upgrades of the distribution network, or installation of decentralized heating to boost peak production at critical locations. The value of these solutions is compared with a list of retrofit scenarios of the different building types placed within the network area to

identify win-win situations, where the saving in the network is larger than the expenses related to the retrofit. For example, in the areas where the total building mass is expected to be increasing due to urban densification, the network capacity limit will at some point be exceeded, and action is needed. Retrofitting the existing buildings and thereby lowering their heat demand, makes room for new building without substituting the pipe network with a new. In other areas, retrofit leads to an overall lower demand for heat. The resulting overcapacity of the exiting network can in this case be traded to a reduced heat loss to the ground from the distribution system. This will cause lower expenses for the district heating company, and thereby lower prices for the consumer. However, only some building owners have actively contributed to these saving, and therefore one could argue whether only active consumers should be awarded with the lower prices.

Session 15: Smart Energy Systems

Henrik Wenzel has 25 years of experience in system analysis including Life Cycle Assessment and Energy System Analysis. His research approach to system analysis follows a holistic and so-called consequential systems approach within which a technology or sub-system is studied by identifying its influence on the overall system. He has comprehensively studied bioenergy systems by revealing its role and influence in the whole energy system.

Session Keynote:

Prioritizing the use of agricultural straw in the Renewable Energy system – comparing biogas and 2G bio-ethanol

Henrik Wenzel*, Associate Professor, SDU Life Cycle Engineering, University of Southern Denmark
henrik.wenzel@kbm.sdu.dk, SDU, Campusvej 55, DK-5230 Odense M, Denmark
Julie H Hansen, PhD student, SDU Life Cycle Engineering, University of Southern Denmark
juhh@kbm.sdu.dk, SDU, Campusvej 55, DK-5230 Odense M, Denmark
Abid Rabbani, post doc, SDU Life Cycle Engineering, University of Southern Denmark
abir@kbm.sdu.dk, SDU, Campusvej 55, DK-5230 Odense M, Denmark
Daniel Petrov, Master's Thesis student, SDU Life Cycle Engineering, University of Southern Denmark dapet14@student.sdu.dk, SDU, Campusvej 55, DK-5230 Odense M, Denmark
Lorie Hamelin, Assistant Professor, SDU Life Cycle Engineering, University of Southern Denmark
loha@kbm.sdu.dk, SDU, Campusvej 55, DK-5230 Odense M, Denmark

Keywords: Smart energy systems, agricultural straw residue, biogas, bioethanol, system integration

Many energy system analysis and design studies have revealed that biomass may prove to be a constrained and attractive resource in a future full renewable energy system. The reason is the inherent qualities of biomass as a key carbon resource for hydrocarbon fuel production and a storable fuel, or source of storable fuels, for balancing fluctuating electricity and, to some extent, thermal energy production in industry and the heat sector. A large variety of full renewable energy system studies for the future Danish energy system have demonstrated that a widely integrated system with a high degree of electrification of transport and heat supply and a high integration of hydrogen is needed in order to keep biomass demand at a sustainable level.

Integrating electricity production, heat (and cooling) production and transport fuel production and harvesting potential synergies between these sectors are, thus, mandatory in order to achieve high overall system efficiency, reduce costs and stay at a reasonable biomass demand level. Our recent research, further, demonstrates the need to integrate also agricultural practices and the energy system in order to ensure proper nutrient and carbon balances of agricultural soils on a longer term. Our study shows that maintaining the same long term soil carbon level has hugely different implications depending on the intended

pathway of energy conversion of agricultural straw residues. If straw is used as a co-substrate for biogas production, the hard degradable straw fibres enter back into the soil and contribute to the long term soil carbon level. If straw, on the contrary, is used for incineration-based conversion into electricity and/or heat or conversion to ethanol, no fibre returns to soil. If the target is to maintain the same long term soil carbon level independent on the straw conversion pathway, there is a huge difference in how much straw can be harvested for energy purposes in the first place, depending on the conversion pathway. Whereas a straw potential of 75 PJ/year for energy use was found in a projected future Danish agricultural system, only 25 percent of this is available for energy purposes, if no carbon fibre is returned to soil as in heat and power production or 2G ethanol production. This is potentially the most significant difference in the system implication of prioritizing straw for one energy conversion pathway or the other.

Further, the heat and hydrogen integration aspects of using straw for ethanol or biogas are hugely different. Biogas-CO_2 upgrading by hydrogen assimilates four hydrogen atoms per carbon atom, whereas ethanol only assimilates two hydrogen atoms. Further, the potentially very significant process heat production from hydrogen production and reaction with CO_2 is better and easier utilized for thermal energy when using straw for biogas than for ethanol, because the scale of ethanol production is so large that it is difficult to find district heating grids that can assimilate all the heat, whereas the scale of biogas and the related process heat is such that it fits the vast majority of district heating grids.

Abid Rabbani is a postdoctoral researcher at the University of Southern Denmark. His main research involves the design, integration and process improvements in energy systems, with particular focus on modelling and simulation of energy processes, PEM fuel cells, optimization of thermal energy systems, heat transfer, energy efficiency and system analysis.

An integrated gas grid model for upgraded biogas in future renewable energy system

Abid Rabbani*, SDU Life Cycle Engineering, University of Southern Denmark
abir@kbm.sdu.dk, SDU, Campusvej 55, DK-5230 Odense M, Denmark
Prof. Henrik Wenzel, SDU Life Cycle Engineering, University of Southern Denmark,
henrik.wenzel@kbm.sdu.dk, SDU, Campusvej 55, DK-5230 Odense M, Denmark

The future of energy will include a mix of emerging and renewable technologies, such as wind and solar power which are inherently sporadic in nature; therefore there is a high need of balancing supply and demand in future energy systems. In this context, biogas plants can play a major role in achieving higher integration of renewable electricity and balancing such energy systems. In addition to enhancing diversity of supply and GHG reduction, biogas upgrading can potentially serve as a buffer for wind power by utilizing low-cost excess electricity for hydrogen production through electrolysis. A possible solution for storing excess wind power is to inject the produced bio-methane into the natural gas grid. Since volume of biogas production is projected to increase in the coming years, the present gas networks could be gradually converted to supply gas derived from renewable sources and still be used for transporting energy to end consumers in the future.

This paper presents an integrated energy model of Funen, Denmark to realize the potentials of biogas and bio-methane for the island and assess the system capacity to assimilate electricity, heat, transport, industry and agriculture sectors. Entire energy system is modelled in SIFRE simulation tool developed by energinet.dk. Optimization possibilities of the gas grid are further explored by creating independent local gas grids that are connected to near CHP plants and industries. By switching between power generation from biogas when electricity prices are high and upgrading when prices are low, establishes a concurrent and cost-effective dual-mode solution. Another aspect of using traditional natural gas grid for bio-methane deals with optimum gas injection and operating pressures. The effects and operational strategies of gas compression at different pressure levels in the transmission and distribution grid are also a part of this study. Key findings include the extent of peak wind shaving, electrolyzer capacities, shares of energy supply and demands for each sector, bottlenecks in the grid, gas compression and pressures, conditions and ratio of bio-methane imports and exports. The developed model will further be expanded to a national level. Results from such a dynamic and integrated energy model could help not only in assessing biogas as a technology, but also open new opportunities to see at biogas as a system integrator, dual-mode power balancer and a key element of future smart energy systems.

Stefan Blomqvist is a PhD student with an MSc in engineering. His research is conducted at the division of Energy Systems at Linköping University and concerns sustainable energy systems with a system perspective including energy use and supply.

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

System benefits of introducing ground surface heating

Stefan Blomqvist*, Louise Trygg
Division of Energy Systems, Linköping University, SE-581 83 Linköping, Sweden
stefan.blomqvist@liu.se, +46 (0)13- 28 89 32

Heating of streets and pedestrian areas by circulating warm water in embedded plastic pipes has been practiced in Sweden since the 1960s. A ground surface heating system within a district heating system has a primary objective to melt snow, rain which freezes upon contact with the ground and keep the surface dry. A system of such is often seen as a non-necessary system. At the same time it has its major benefits, not only for the obvious reasons as avoiding snow removal by machine and less injuries due to slippery streets, but also by reducing the return temperature of district heating (DH).

In Linköping, Sweden, the municipality owned energy company Tekniska verken AB delivers, among other things, ground surface heating. The systems are mostly located in the city center at the commercial streets. The aim of this study is to show how a well-functioning ground surface heating system can contribute to a reduced return temperature of the district heating. The system is analyzed in order to find improvement options in terms of energy performance and use. The effect of the overall district heating system is also analyzed.

Initial results indicates that the temperature needed for a such system is in the low range, approximately 20-25°C, which is significantly lower than the return temperature of district heating. Based on that preliminary results show that a system for ground surface heating can give social benefits as well as reducing the return temperature of DH, which in turn can lead to i.e. a higher efficiency in the flue gas condenser and by thus a more resource efficient district heating system.

Jeppe Mols and **Ulrik Gregers Jørgensen** are engineering students of energy technology at the University of Southern Denmark. Their field of study is energy system analysis. This project reviews possible district heating solutions for a town with 3200 inhabitants.

A study of possible district heating solutions for the Aarup area

Jeppe Mols* and Ulrik Gregers Jørgensen*, uljoe11@student.sdu.dk, Energy technology, University of Southern Denmark

Motivated by the Danish long-term energy policy for 2050, stating that the energy demand from the transport sector, electricity- and heat consumption must be satisfied without fossil fuels, the project seeks to find an efficient solution to satisfy the heat demand of the town of Aarup, located on island of Funen. The town is presently supplied by a natural gas grid. It consists of 1210 houses and has 3120 inhabitants. A total of 20 scenarios are developed/chosen of which two are reference scenarios and 18 are custom scenarios for a district heating system. The district heating scenarios are composed of heating supply units in terms of groundwater heat pumps, solar heater and a wood chips boiler in varying combinations and with varying capacities.

As reference scenarios for the developed district heating scenarios, the existing natural gas based configuration and a scenario with individual heat pumps, are chosen. The remaining scenarios varies from one another by different capacities of the production units and with either 40°C or 60°C supply temperature. The heat loss for both 40°C and 60°C scenarios have been modelled in the modelling tool called Termis and is found to be respectively 9 % and 17 % of the total heat demand, and the difference between these equals 2604 MWh/year.

All scenarios have been modelled in EnergyPRO with the intention of finding the scenarios, socio-economically and business economically, which have the lowest heating prices.

Socio-economically, the reference scenario with individual heat pumps was found to be the best solution. Among the district heating scenarios, the best socio-economic solution was found to be the scenario with a forward temperature of 60°C, and a supply consisting of 10 % solar heating combined with heat pumps, supplying all of the rest (8,73 MW-heat). The analysis shows that woodchip boilers are not a viable socio-economic solution.

Focusing of business economics, the current natural gas based system achieves the lowest heating price. Among the district heating scenarios, the best scenario is the one with a forward temperature of 60°C, and a supply consisting of 10 % solar heating, 2 MW-heat groundwater heat pump and 6.73 MW-heat woodchip boiler. The analysis concludes interestingly that, even though the electricity consumption is imposed with high taxations, the 2 MW-heat heat pump scenario is better economically than a pure biomass boiler scenario. This is due to the fact that the saved investment costs, by having a 2 MW-heat heat pump instead of a larger biomass boiler, justifies the operation costs of the heat pump, because the heat pump will off-set the investment of peak capacity biomass boiler, which investment-wise turns out to pay off.

As both analyses show, none of the optimal solutions are low forward temperature scenarios, which means, that the economic savings from the reduced heat loss are not large enough to make up for the additional investment costs in these scenarios. This is due to the fact that in the low temperature scenarios, booster heat pumps are assumed in every household and the investment costs of these are too high compared to the reduced transmission heat loss savings. Interestingly, however, when using electrical cartridges for boosting the temperature of the domestic hot water consumption in the household, the heating prices in the low temperature district heating scenarios become similar to the ones in the normal temperature scenarios.

Session 16: Smart Energy Systems

Philipp Geyer is an assistant professor at the Department of Architecture within the Faculty of Engineering Science at the KU Leuven. His research field is sustainable building design, construction and technology supported by intelligent computation, modelling, and simulation. He holds a Diploma and a Doctor of Engineering in architecture (PhD) from the Technical University of Berlin. He is a committee member of the European Group for Intelligent Computing in Engineering (eg-ice), has more than 40 publications in international journals, books and proceedings and coedited three scientific peer-reviewed publications.

Session Keynote:

Thermo-chemical technology for smart district networks

Prof. Dr.-Ing. Philipp Geyer[1,], Dr.-Ing. Martin Buchholz[2], Christian Engel[3]*
[1] *KU Leuven, Architectural Engineering Division, Kasteelpark Arenberg 1 - box 2431,*
3001 Leuven - Belgium, p.geyer@kuleuven.be,
[2] *Watergy GmbH, Berlin, Germany,*
[3] *thermaflex, Vienna, Austria*

Keywords: Thermo-chemical district network; Open sorption technology; Residual heat usage

Thermo-chemical technology has the potential to significantly contribute to smart energy systems based on future district networks. Thermo-chemical absorption and desorption has a far higher energy potential than the energy transported in the thermal capacity of water, which reduces pipe diameters, installation costs and transport costs. Furthermore, thermo-chemical potential can be stored and transported without thermal losses, which allows long-distance transport and short to medium-term storage. These features support low-demand density supply, which is an urgent need in the view of nearly-zero energy buildings. Furthermore, other services such as cooling and drying can be offered based on the same network, which provides an economic benefit for the network structure.

The research is part of the project "H-DisNet - Intelligent Hybrid Thermo-Chemical District Networks" recently selected for funding in the EU H2020 collaborative research program. The main objective of the project is the utilization of residual heat at low temperature levels from industry and from renewables to reduce primary energy consumption. Short overview on the project will be included in the presentation.

Then the presentation will focus on application scenarios of thermo-chemical district networks. This includes the smart integration with conventional water-based district networks as well as other network types, such as electric and gas networks. The economic perspective as well as the technological perspective is discussed and benefits of the integration of thermo-chemical technology in smart networks examined. The basis of this examination are business case scenarios that serve to demonstrate technological feasibility and economic and environmental benefits of the thermo-chemical technology.

Dmytro Romanchenko is a PhD student at Chalmers University of Technology, Sweden. He holds an MSc. in Sustainable Energy Systems and an MSc. in Electromechanics. The aim of his research is to increase the understanding of how the Swedish building stock can contribute to the development of a sustainable energy system. The project includes analysis of the supply and the demand side.

Thermal energy storage in district heating systems: A case study of Göteborg, Sweden

Dmytro Romanchenko*, PhD student, dmytror@chalmers.se, Mikael Odenberger, Assistant Professor, Lisa Göransson, Post Doc, Filip Johnsson, Professor.
Department of Energy and Environment, Energy Technology, Chalmers University of Technology, S412 96 Göteborg, Sweden

Keywords: District heating, energy storage, building stock, modelling

The objective of this study is to evaluate and compare how a centralized hot water storage tank and thermal inertia in buildings, utilized for thermal energy storage (TES), can influence operating strategies of a district heating (DH) system. DH systems typically consist of a mix of production units including combined heat and power (CHP) plants and heat pumps, which harvest waste heat that can provide certain flexibility in terms of generation and consumption of electricity. The inherent flexibility of using the DH system piping as a mean to buffer energy, smoothening out variations in heat generation, can be further improved by the presence of a TES, in this work either a centralized hot water storage tank or thermal inertia in buildings. The analysis is performed using a mixed integer programming (MIP) model, which generates a cost optimal dispatch of heat production units. Utilization of MIP allows a detailed representation of heat production units and storage options, including such properties as: limitations on minimum and maximum output levels, ramping limits, start-up and shut-down performance, minimum up/down times and variable power-to-heat ratio in CHP plants. The DH system of Göteborg is considered as a case study.

The results from the modelling show that utilization strategies of the centralized hot water storage tank and the short-term TES in buildings are found to be similar. Yet, the main differences between storage options are: utilization of short-term TES in buildings requires space heating, it is limited by the minimum outdoor temperature and the total investment cost for all dispersed control systems for short-term TES in buildings is much lower than for centralized hot water tanks. However, hot water tanks in a DH system allow energy storage over longer time frames compared to short-term TES in buildings. It is found that both types of storage investigated increase the number of full load hours and, correspondingly, the heat production from base load units, resulting in decreased use of peaking load boilers. In addition, inclusion of storage can decrease number of start-ups for all heat production units and make consecutive periods of constant heat output longer. Yet, the results also indicate that availability of storage in the investigated DH system results in decreased electricity production from CHP plants and simultaneous increase in electricity consumption by heat

pumps. Finally, the results indicate that utilization of both types of energy storage will lead to a decrease in the operating costs of the DH system.

Daniel Rohde has worked at SINTEF Energy Research for three years, mostly on power production from low-temperature waste heat sources. He started as a PhD student at the Norwegian University of Science and Technology two years ago. His research focuses on dynamic modelling of thermal energy supply systems for buildings.

Hanne Kauko has a PhD in physics from the Norwegian University of Science and Technology (NTNU), and has since 2014 worked with waste heat utilization, heat pumping systems and thermal grids.

Thermal Storage Control of a Local Energy Supply System Acting as District Heating Prosumer

Daniel Rohde[1], Trond Andresen[2], Natasa Nord[1], <u>Hanne Kauko</u>[2]*
daniel.rohde@ntnu.no, hanne.kauko@sintef.no
[1] *NTNU, Norwegian University of Science and Technology, Department of Energy and Process Engineering, Kolbjørn Hejes vei 1A, 7491 Trondheim, Norway*
[2] *SINTEF Energy Research, Kolbjørn Hejes vei 1B, 7491 Trondheim, Norway*

In this study, the control of a thermal energy supply system in Norway was investigated. The system was integrated into a building complex of different building types with a total area of 38 000 m². The system delivered energy for space heating, domestic hot water (DHW) preheating, space cooling and product cooling. The aim was to reduce annual operating costs by adapting controller setpoints to the variable heating and cooling demands and energy prices. The main parts of the energy system were heat pumps with 1 MW total cooling capacity, solar thermal collectors as well as water tanks and boreholes for thermal energy storage. The system was also connected to the local district heating network.

The system was modeled in Dymola/Modelica. Analyses on decreasing the temperatures of the local district heating network were performed. In that way the system could export heat and become a prosumer. Heat from the solar collector tank could be exported to the district heating supply line (65-80°C) and excess heat from the heat pump condenser could be exported to the return line (40-50°C). The net annual operating costs under varying electricity price were analyzed with the dynamic system model.

The developed model had one large heat pump. A cold water storage tank on the evaporator side was used as buffer for the space cooling and product cooling demands and a hot water storage tank was used as buffer for space heating and DHW preheating. The required temperature lift for the DHW after preheating came from the solar collector loop or from district heating. Borehole thermal energy storage (BTES) was used as seasonal energy storage. The BTES was charged during summer with excess heat from the heat pump condenser and the solar collectors and was used as heat source during winter. The control of the thermal storages was found to be crucial for operation of the energy system.

Different temperature control strategies for the thermal storage water tanks have been investigated and discussed. For the base case, the temperatures of the cold and hot storage tank were kept constant at 5°C and 50°C, respectively. To reduce operating costs, advanced control strategies were developed. These adapted the temperature setpoints according to the variations in both heating and cooling load and electricity price. The control strategies also included a prediction of these variables to reduce the high costs during periods of peak demands. Weighting factors for the influence of load changes and electricity price as well as prediction horizons from two to twelve hours were tested and their influence on the net annual operating costs were investigated.

Jens Carlsson is a master's thesis student from Chalmers University of Technology. His studies range from chemical engineering to neural networks, and he wishes to combine traditional HVAC knowledge with machine learning techniques to optimise energy distribution systems.

Control of buildings utilised as thermal energy storage

_Jens Carlsson_* B.Sc., Johan Kensby Tkn. Lic., Anders Trüschel Ph.D.
Division of building Services Engineering, Department of Civil and Environmental Engineering,
Chalmers University of Technology, Sweden
cjens@student.chalmers.se
Dr Sydows Gata 16, 41324, Gothenburg, Sweden

The heat demand in district heating networks naturally exhibits large variations, usually with one or two significant peaks per day. In cities like Gothenburg, whose heating network is supplied by multiple sources, these variations in demand are also associated with variations in cost and environmental impact, as less favourable energy sources have to be activated to meet the peak demands. It is therefore of great interest to device a system which allows an even energy production to supply an uneven demand. Tanks for storing hot water have been successfully used for this in the past, but their applicability can sometimes be limited for practical reasons and alternative solutions are of interest.

A potential alternative method is to utilise the thermal inertia of a subset of the buildings connected to the district heating network. It has been shown that thermal comfort is largely unaffected by indoor temperature variations of up to 1°C. Many older residential buildings in Sweden have a core of concrete, and therefore have a significant heat capacity. A previous study, made in conjunction between Chalmers university of Technology and Göteborg Energi, showed that allowing a select 10-30% of buildings connected to the Gothenburg district heating network to be used as energy storage with a 1°C daily variation restriction could significantly reduce daily heat load variations.

In this research project, the expected performance of relatively simple building-side control methods was estimated. A simple dynamical model of the energy storage of buildings was constructed from previously collected data. The buildings were then simulated with varying control methods which were evaluated on their ability to maintain a stable indoor climate while minimising the total production-side cost of heating, based on the marginal heating cost of the entire network. The control systems have some self-adaptive elements, so that the same algorithm could be quickly implemented in a wide variety of buildings.

Preliminary results are in line with previous research showing that significant energy savings with increased thermal comfort are possible by installing a control system that maintains a stable low temperature. However allowing a slightly higher average temperature and controlling building heat load based on marginal production cost or environmental impact can be even more favourable from a system perspective. Therefore it might be in the interest

of both district heating providers and residential building owners to ensure that, if an older building is being retrofitted with a new temperature control system, the new system is capable of receiving external signals and being reprogrammable for implementation of routines similar to the ones discussed here.

Dr. Roland Baviere is currently a researcher in CEA, the French Alternative Energies and Atomic Energy Commission. He has worked for more than ten years in the field of thermal-hydraulic simulation and he is currently involved in several research programmes dedicated to the development of smart control systems for the district heating sector.

Presentation of an innovative thermal loop combining phase change material thermal storage, solar energy and demand-side management

Dr. R. Baviere*[1], Dr. M. Vallee[1], Dipl.-Ing. C. Paulus[1], Dipl.-Ing. F. Bentivoglio[1], Dipl.-Ing. E. Le Goff[2], Dipl.-Ing. N. Giraud[2]
[1]CEA, LITEN, 17, Rue des Martyrs, F-38054 Grenoble, France
[2]CCIAG, 25 Avenue de Constantine, 38036 Grenoble, France
roland.baviere@cea.fr

The Grenoble district heating network ranks second by size in France, with an annual heat delivery of 800 GWh. The network is currently powered by 55 % of recovery and renewable energy, 30 % of coal and 15 % of gas and heating oil resulting in a CO_2 content of 140 g per kWh. Within the FP7 City-Zen project the Grenoble district heating operator namely CCIAG and CEA will develop and demonstrate an innovative network extension with the aim of improving this figure.
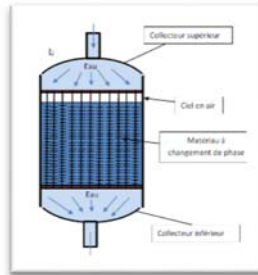
For this purpose, we are designing a new low pressure and medium temperature (70°C – 40°C) loop supplying heat to 380 dwellings and to 11,000 m^2 of tertiary activity buildings. The innovative loop is mainly fed by the current Grenoble heating network. To limit the use of energy when peak generators are operated, the loop will firstly be equipped with a 500 kWh phase change material heat storage module. To increase peak-shaving opportunities and to improve operational flexibility we are implementing advanced control solutions based on simulation, model predictive control and linear optimization. One goal is to take advantage of building thermal mass for modulating space heating demand while guaranteeing comfort. Finally, CCIAG will install and operate thermal solar panels connected to the loop. Depending on the total panel surface, it may be possible in summer conditions to fulfill the demand by optimally combining the available solar energy and the use of the heat storage module.

The purpose of the present paper is to report on the design phase of the demonstrator. We firstly show a virtual dynamic simulator has been established using a new MODELICA model library called _DistrictHeating_, which provides accurate results in limited computation time. The innovative modules and the connected buildings have all been represented. On the other hand, we have developed a first version of an advanced control strategy including heat load forecasting and demand-side management. We have finally simulated the system on a yearly time-basis in order to assess the overall performance of the proposed demonstrator. Future

steps of the present work will consist in preparing the actual implementation, building the system and finally monitor its actual performance during the 2017-2018 heating season.

Buildings connected to innovative loop   Thermal storage module

Session 17: Future district heating production and systems

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

Session Keynote:

District heating - a key element in a fully balanced renewable energy system

Louise Trygg*
Department of Management and Engineering, Linköping University, SE - 581 83 Linköping, Sweden.

Humanity is facing its greatest challenge ever – the transition of society towards sustainability. Increased system efficiency and reduced climate impact are important parts to rapidly change our energy systems.

The transition towards sustainability means that we will meet energy systems with a high share of renewable energy sources and electricity prices that are both volatile and low. To reach a fully balanced and renewable energy system it is vital to have a system perspective where supply and use of energy are equally respected. The aim of this study is to show how efficient use of electricity and conversion of non-electricity specific processes are important foundations in the shift towards less climate impact, and in the same way the importance of designing policy instruments that support the transition towards a more sustainable society.

Several studies have shown how it is possible to convert both industrial processes and space heating from electricity to district heating. In order to change our energy systems towards less climate impact the use of electricity might need to increase in some areas which means that it is even more vital to free electricity from areas that are not electricity specific. In Sweden a high share of domestic heating is still supplied with electricity, even though regional and municipal district heating systems are well expanded. When considering a system with combined heat and power production, converting to more use of district heating also gives a basis for further electricity production.

Combined heat and power production and district heating are important parts to achieve a fully balanced and renewable energy system. Our current energy systems are based on large-scale power generation, but to meet the development of renewable energy technologies our energy systems needs to adapt to handle also small-scale electricity producers.

Lisa Brange is a PhD student at Lund University whose main study field is district heating networks. She has studied prosumers and their technical and environmental impacts on district heating networks and is now studying bottlenecks and how to address these. She often uses network simulations in her work.

Bottlenecks in district heating networks and how to eliminate them

Lisa Brange* MSc, Jessica Englund MSc, Patrick Lauenburg PhD
Department of Energy Sciences, Lund University, Box 118, Lund, SE-221 00, Sweden,
lisa.brange@energy.lth.se

The fourth generation district heating (4GDH) is described as essential for the development of district heating (DH) in a less carbon intensive energy system. One of the main attributes of 4GDH is lower supply temperatures. The 4GDH is predicted to entail many advantages, such as less heat losses, better possibilities for utilisation of excess heat sources with low temperature heat and an economic adaption to the future low-energy buildings. Older buildings with a higher heating demand will however probably still be a part of the energy system for many years to come. If nothing except the supply temperature is changed, 4GDH will thus result in bigger flows in the pipes according to thermodynamic laws. This may result in too small differential pressures and hence an inability to deliver enough heat to the DH consumers. In this paper, inability to sufficiently support DH consumers with heat due to too narrow pipes/too large flow velocities is called bottleneck problems. Such problems are already present in many district heating networks. To deal with this problem, there are many techniques and methods to use. This paper aims to evaluate these and in which situations the different techniques are more advantageous.

The calculations of the technical parameters in the DH network were mainly performed in NetSim, a commercial simulation programme for both district heating and cooling. Simulations were performed on a fictive DH area developed from an existing DH area with bottleneck problems in Malmö in southern Sweden. The maximum heat power demand of the area during the dimensioning outdoor temperature (-16°C) was 10 MW. All bottleneck elimination measures were tested for a winter case with an outdoor temperature of -16°C and an ambient ground temperature of 3°C and a for a summer case with an outdoor temperature of 21°C and an ambient ground temperature of 8°C. In the winter case, the inlet differential pressure (dp) was 602 kPa, the supply temperature was 109°C and the mean temperature difference between the supply temperature and return temperature was 43°C. The same numbers were for the summer case 198 kPa, 75°C and 17°C. The lowest dp in the network was 0 kPa for both cases. The measures for bottleneck elimination tested were: higher supply temperature, bigger pipe area, better cooling performance in substations, more pump work, distributed heat supply (DHS) and demand side management (DSM). The goal for the bottleneck elimination measures was to achieve 100 kPa at the DH consumer

with the lowest dp, to ensure that all customers could be supplied with enough heat. A brief economic analysis was also performed.

All investigated measures have an ability to eliminate bottlenecks, but the results differ between the winter case and the summer case. The supply temperature was needed to be raised 4°C in the winter and 3°C in the summer in order to achieve 100 kPa. If a bigger pipe area instead was used, 649 m of pipe was needed to be replaced by pipes of a bigger size in the winter case and 2693 m was needed to be replaced in the summer case. A better cooling in the substations also had a big impact on the pressure drop. In the winter case, a transition of all mean return temperatures higher than 45°C from consumers to a mean return temperature of 43°C was enough to reach 100 kPa. In the summer case, a change to a mean return temperature of 44°C was enough to reach 100 kPa. If extra pumping power was installed, 5 kW was needed in the winter and 2.2 kW was needed in the summer. For DHS to help reach 100 kPa, 440-650 kW was needed in the winter and 61-228 kW was needed in the summer, depending on location of the DHS. If the heat demand of the four consumers with lowest dp was lowered, 38% in the winter and 66% in the summer was needed to be shifted. The economic results showed that DHS seemed to be the best alternative both for the winter case and the summer case.

The differences in the results for the winter case and the summer case could often be explained by the smaller flow during the summer. The location of the measures taken is also important, as this factor often affected the results.

The results indicate that different bottleneck elimination methods are advantageous for different situations. A general conclusion is however that a well-functioning DH network with sufficient cooling of the DH water in the substations often is very valuable and should the first measure to take. These results may be used by DH planners and companies that have problems with bottlenecks or that for different reasons may get bottleneck problems in the future.

Daniel **Møller Sneum** is conducting his PhD studies within the Energy Economics and Regulation group in the Systems Analysis division at the Technical University of Denmark. His research focus is on flexibility in the energy system, and how this is facilitated through markets and regulation. This research is primarily conducted in the auspices of the Flex4RES project, funded by Nordic Energy Research.

Framework conditions for flexibility options in the district heating–electricity interface: A comparative study of the district heating sectors in the Nordic and Baltic countries

Daniel Møller Sneum*, PhD student, Emilie Rosenlund Soysal, Research Assistant, Klaus Skytte, Head of Energy Economics and Regulation, Ole Jess Olsen, Emeritus, DTU Management Engineering, DTU Lyngby, campus Building 426, DK-2800 Kgs. Lyngby, dasn@dtu.dk
Eli Sandberg, PhD student, NMBU Ecology and Natural Resource Management, elisand@nmbu.no

In order to reach renewable energy policy targets, the share of variable renewable energy (VRE) is increasing in the Baltic and Nordic countries. To accommodate for the variation and uncertainty of the production from VRE there is an increasing need for flexibility in the energy system. While the benefits and relevance of flexible interaction between the electricity system and the district heating (DH) systems are well described in the existing literature, the regulatory framework determining the extent to which DH works as a flexibility provider has so far not been explored in the same detail. As opposed to the integrated European electricity market, the framework conditions for DH are a combination of EU, national and local rules. This article addresses the energy sector regulation influencing the flexibility of DH in the Baltic and Nordic countries, with particular focus on combined heat and power (CHP), power-to-heat (PtH) and heat storage (HS). In these countries, except Norway, DH serves a significant share of the heat demand (50-65 %). Technical barriers are mostly overcome, but despite this, the potential for flexibility in the DH-electricity interface is only partly exploited today. The study has particular significance for regulators, and the work on alignment between regulation and energy policy regarding increased integration between DH and electricity.
To identify the potential, and the drivers and barriers for flexible integration between DH and electricity, a survey has been conducted on the framework conditions for DH in Denmark, Estonia, Finland, Latvia, Lithuania, Norway and Sweden. This provides basis for the comparative analysis applied in the study.
Overall, this study has identified no policy regulations directly aimed at increasing the flexibility of the DH sector. Some of the measures may however, affect flexibility indirectly, and some even counteract flexibility. The survey shows that CHP, particularly when based on renewables, is supported in most of the countries. Subsidy schemes vary between the countries, but none specifically rewards flexibility. _HS in DH is a technology broadly deployed_

in Denmark, Finland and Sweden, while the Baltic countries and Norway has no or limited deployment. The current PtH capacity in the DH systems is currently insignificant in Denmark, Finland and the Baltic countries. At the same time *PtH* draws none or limited policy support. *Furthermore,* regulation provides private-economic incentives for heat-only boilers, compared to the *PtH* technologies. As a very flexible and competitive generation technology, hydropower with reservoirs has historically diminished the utilisation of DH in Norway.

The study concludes that the national policies and regulation regarding DH differ greatly between the surveyed countries and are adapted according to historical developments of the national energy systems, rather than towards a flexible regional one. Choice of technologies depends on the business case in each specific country, which again depends on regulation. Common to all countries is that flexibility has so far not been a concern addressed directly in the regulation of DH. In the Baltic countries, regulation incentivising inflexible, near-baseload operation of CHP is at the same time a barrier for the deployment of HS, thereby doubly limiting flexibility in the DH-electricity interface.

Kristian Fodgaard Christoffersen, **Michel Noaparast**, **Mathias Vestergaard Steenstrup** and **Allan Bjerg** form a group of 6th semester students studying Energy Engineering with thermal specialization at Aalborg University. They mainly work with the design and analysis of thermal systems.

Industrial Waste Heat Utilization for Low-Temperature District Heating

Kristian Fodgaard Christoffersen*, Michel Noaparast, Mathias Vestergaard Steenstrup and Allan Bjerg*, abjerg13@student.aau.dk.
Thermal Energy Engineering (bachelor programme), Aalborg University

This student project investigates the possibility of utilizing the waste heat from the coming Apple data centre for district heating in Viborg. To utilize the waste heat, two types of heat pumps are investigated: An absorption heat pump driven by an external heat source and a mechanical heat pump driven by electricity. Both heat pumps are modelled, and from these models the costs and efficiencies are calculated. The Coefficient of Performance (COP) of both heat pumps is investigated at different district heating scenarios. Supply and return water temperatures have substantial influence on the COP's. Costs are compared for both installation, Operation and Maintenance (O&M) and fuel. Fuel costs are furthermore analysed with respect to taxes.

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

The challenge to integrate the growing fluctuating RES-E power at different vertical entries in the energy system with a focus on DH

Knut Bernotat*, Caroline Lübke
Royal Institute of Technology (KTH). Department of Industrial Economics and Management, 100 44 Stockholm, Sweden, knut@indek.kth.se

District Heating (DH) is embedded within the energy and building sectors and strongly affected by the sectors' present paradigm shifts - firstly moving towards more RES-E with greater fluctuation and secondly the shift towards low energy buildings (LEB). DH researchers have recently defined a concept for DH in the framework of 4th Generation District Heating (4GDH) in which the integration of surplus electricity from wind and solar has been identified as a key subject to be considered.

The task of this paper is to describe various possibilities how peak power caused by fluctuating power production from an increased share of RES-E can be integrated in DH systems and the housing heat market avoiding power shaving, curtailment and dumping of RES-E and possible power blackouts due to a great imbalance of short term power supply and demand.

The shift from mainly large scale power production and the existing grid structure to meshwork structures with distributed generation, an increased fluctuation of power production and forecasting deficits, the managing effort to maintain a stable power grid with a balanced supply and demand becomes more challenging.

The increasing share of RES-E, mainly wind and PV, with immense regional variations leading to fluctuating power production based on wind and solar resources rather than electricity demand is increasing the managing effort and demands mitigation to use access power rather than loose it.

DH has a great potential to integrate this surplus energy potentially reducing the primary energy demand of DH but peak power might also occur in areas without DH where peak power could be used in other parts of the heating sector (e.g. single houses).

The integration is beneficial for DH as well as the single house sector which both have free capacities to be used as power to heat sinks; to integrate the "free energy" when available to replace capacity at later high demand periods, which reduces the use of primary energy resources and by that reduces CO_2 emissions.

The paper shades light on the broad variety of integration possibilities on different system levels but it also shows the complexity of integration as regional and national distinctions influence or limit the alternatives of power integration. The integration demands investment

at different levels of the system which benefits the system as a whole, this raises the question of system responsibility for carrying these costs. The paper also gives an outlook on possible changes of integration in the near future as the power sector is developing dynamically at a vast speed.

Session 18: Energy planning and planning tools

Poul Erik Grohnheit is an economist. Since 1980, he has been working at Risø National Laboratory (now part of the Technical University of Denmark). His main experience is in Danish energy planning and energy-environment-economic modelling for EU research programmes. In the 1990s, he conducted several projects on the development of competitive markets for electricity. Current activities are projects using TIMES models, focusing on electric vehicles, nuclear fusion, and infrastructure for electricity and

Session Keynote:

Modelling district heating infrastructure in global optimisation models

Poul Erik Grohnheit, DTU Management Engineering, Technical University of Denmark, Produktionstorvet, Building 426, DK-2800 Kgs. Lyngby, pogr@dtu.dk.

Keywords: District heating; Optimisation model; Global regions; Archived model results

District heating infrastructure can support a wide range of conversion technologies supplying electricity or heat. These technologies have a prominent role in long-term technology-rich optimisation models, such as MARKAL and TIMES, which were developed under the umbrella of the IEA implementing agreement ETSAP (Energy Technology Systems Analysis Program) since the mid-1970s. Today, numerous teams are working on a wide range of variants of these models. ETSAP meets twice a year in workshops for model developments and results.

An important weakness of these models is that the network infrastructure is seldom properly represented in the optimisation problem. A good network representation may lead to very large and data-intensive models for single nations or small regions. Long-term models for larger regions may use aggregated parameters for network capacities that may be exogenous over time, or optimisation variables that are driven by parameters with arbitrarily assumed values subject to sensitivity analyses.

This paper focuses on the latter option with examples from an archive of results from studies using the global TIMES models, EFDA-TIMES and TIAM during the last decade. The global energy system is divided into 15-17 regions with a common global optimisation until the year 2100. Results are available for each region, e.g. Europe, USA, Canada, China, Russia and South Korea. Regions may be subdivided into single nations or climatic zones with different potentials for district heating.

The paper will discuss appropriate numerical values for selected parameters on the basis of archived model results.

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

District heating and heat savings in the future Danish energy system – insights from TIMES-DTU model

Mr. Stefan Petrović* , Dr. Kenneth Karlsson
Department of Management Engineering, Technical University of Denmark, Produktionstorvet, 2800 Kongens Lyngby, Denmark, stpet@dtu.dk, keka@dtu.dk

As the front runner in the energy efficiency and renewable energy integration, Denmark has committed to very ambitious renewable energy targets - 50 % of electricity production should come from wind power in 2020, power and heat sector should be fossil fuel free in 2035, while no fossil fuels should be used in Denmark starting from 2050. Significant part of the future heating demand is expected to be supplied by district heating. However, traditional district heating based on coal and natural gas CHPs cannot be a suitable solution in the future renewable energy system.

It is clear that the current Danish energy system needs to change over time. No matter how the energy system will develop in the future, consumers need to be supplied by efficient, environmentally friendly and affordable space heating and domestic hot water. The present article analyses a long-term influence of two "experienced technologies" for supplying and reducing heating demand, namely district heating and heat saving measures, respectively.

The analyses are performed by TIMES DTU model until 2050. TIMES-DTU is the only full-foresight optimisation model covering all sectors of the Danish energy system. Three different scenarios are described in the present paper: (i) Base scenario without any policy constraints imposed on the model, (ii) WLP with the constraint that 50 % of electricity production should come from wind starting from 2020, and (iii) WLP-NFE scenario with the constraint that power and heat sector should be fossil fuel-free starting from 2035 and Denmark should be 100 % renewable starting from 2050. In all scenarios, Denmark is constrained to be a net exporter of electricity.

The results imply that in the WLP-NFE scenario around 65 % of residential heating demand in 2050 will be supplied by district heating, while specific heating demand will be reduced by 35 %. The heat saving measures proved to be very important in the older single-family buildings located in areas with low heat density. More than half of district heating production will be based on large-scale heat pumps, while smaller part will come from waste incinerations. Waste heat from bio-refineries and industries will contribute with 15% and 10 %, respectively. This illustrates the importance of integration of power and heat, industrial and fuel production sectors. The transition to large-scale heat pumps leads to the increase of

electricity demand. 85-90 % of electricity will be produced from wind power. The WLP scenario implies less than 1 % higher total system costs compared to the Base scenario, while completely renewable energy system described in the WLP-NFE scenario implies only 4 % higher total system costs compared to the Base scenario.

Pierrick Haurant obtained his PhD degree in 2012. His professional experiences lead him to different topics dealing with thermal and energy systems, solar resource assessment and prediction, thermal solar and photovoltaic modelling and ageing studies. He has begun his second postdoc in 2016, working on smart district heating and communication technologies.

Modelling the effect of the transmitted information quality on the management of 4th generation district heating

P. Haurant*[a], L. Toutain[b], B. Bourges[a] , B. Lacarrière[a]
[a] Department of Energy Systems and Environment, Institut Mines-Télécom - École des Mines de Nantes, 4 rue Alfred Kastler, 44307 CEDEX 3 Nantes, France.
pierrick.haurant@mines-nantes.fr
[b] Department of Networks, Security and Multimedia, Institut Mines-Télécom - Télécom Bretagne – UEB, Rennes, France.

The association of Information and Communication Technologies with energy systems has demonstrated its benefits in the case of electrical smart grids whereas it is still in progress for district heating. Some similarities exist between electricity and heat energy (diversity and number of systems connected to the networks, intermittence of some energy sources, consumers becoming prosumers, coupling with other form of energy grids, storage opportunity...). However, some specificity in the case of heat energy and the associated technologies must be taken into account (time characteristics and inertia, thermal losses, infrastructures costs and constraints...) for a transformation towards 4th generation DH. Moreover the transformation must not be imagined only for future networks but also for existing ones. In particular, communication solutions from and towards substations, energy sources and central communication point, must be robust, easy to implement and at the lowest cost. Such communication solutions (Wi-Fi, LoRa®, SIGFOX, QOWISIO...) already used for many applications related to Internet of Things (IoT) require in-depth study for compatibility of their constraints with required quality of information transmitted in the case of district heating.

The modelling work presented in this paper focuses on impact of quality of information on the management of the different energy systems connected to the network. Hourly heat demand profiles (similar to those which could be monitored at the substations of a given district heating) are studied via time and frequency analysis to identify the lowest level of information necessary for decision making regarding management of energy systems. These signals are degraded in a way that corresponds to limitations of communication technologies (loss of information, transmission capacity, noisy signal...). These demand profiles are used as input of the modelling tool HeatGrid. HeatGrid is a pseudo-dynamic model that simulates hourly optimal use of multi-sources district heating of any size, at each substation. It is based

on oriented graph formalism and linear programming. The tool optimizes heat production mix at each time step by minimizing exploitation costs.

Simulations enable to test the potential of communication technologies for the optimal management of heat sources. They also permit to assess the impact of transmission characteristics on the optimal strategies generated by HeatGrid. Results show that the amount of information, the signal sample frequency as well as information losses are not so restrictive for smart heat grids management than for electrical grids. Low cost communication solutions promising for shifting existing network to 4th generation DH can be considered (LoRa®, SigFox…).

Heinz-Uwe Lewe has a BSc in Environmental and Resource Management from the BTU Cottbus, Germany. He has an MSc in Sustainable Energy Planning and Management from Aalborg University, Denmark. Currently, he is working as a scheduler for Neas Energy.

Combining Monte-Carlo simulation and energyPRO – an approach towards sustainable energy planning

Heinz-Uwe Lewe*, MSc Sustainable Energy Planning and Management, Aalborg University, uwe.lewe@googlemail.com

In my master's thesis I assess the opportunities to combine Monte-Carlo simulation (MCS) and energyPRO for sustainable energy planning. MCS is a common tool within quantitative risk analysis and finds wide applications among Finance and Econometrics. It is a probabilistic approach which assigns probability distributions to a model's input variables and then conducts several 1000 calculations to analyse the frequency of output data. energyPRO is a widely applied tool for techno-economic energy system analysis. It optimizes a system's heat, electricity or cooling production according to pre-defined input variables. Those can include fuels, time series, energy conversion units, fees, taxes, etc. In contrast to MCS, energyPRO is a deterministic tool.

Using the module Interface for energyPRO allows computing iterative simulations in energyPRO with varying input variables, which is the point where MCS comes into play. This tool synthesis is examined using Aalborg's future district heating system as a case study. Aalborg municipality is on a way towards a 100% renewable energy system, which requires future investments. It is presumed that the suggested approach could support such an investment decision and it is analysed whether it generates more valuable results compared to regular energy system analysis.

Wiet Mazairac is a PhD candidate at the Eindhoven University of Technology and the Flemish Institute for Technological Research, where he is developing optimization algorithms for multi-carrier energy networks and smart grids.

Optimization of the Transition Towards a Sustainable Integrated Multi-Carrier Energy Network

Wiet Mazairac*, MSc [a,b,c], Robbe Salenbien, PhD [a,b], Johan Desmedt [a,b], Prof. Bauke de Vries [c]
[a] Flemish Institute for Technological Research (VITO), Boeretang 200, 2400 Mol, Belgium
[b] Energyville, Dennenstraat 7, 3600 Genk, Belgium
[c] Eindhoven University of Technology (TU/e), Den Dolech 2, 5612 AZ Eindhoven, The Netherlands
wiet.mazairac@vito.be

The energy sector faces numerous challenges, for example the environmental impact resulting from the use of fossil fuels and the limited amount of fossil fuels available. These challenges call for a fundamental change with respect to our energy supply. This fundamental change implies a transition from fossil fuels as primary energy source towards renewable energy sources such as solar, wind and geothermal energy. Most renewable energy sources depend on the availability of natural resources like sun and wind. These dependencies can be a cause for irregularities in production over time. In contrast to the situation in which few sources provide all energy required, renewable energy sources such as photovoltaic panels and wind turbines usually come in large numbers and are distributed over a large area.

Existing networks do not have the quantitative and qualitative capacity to facilitate the transition towards distributed renewable energy sources. Irregular production of energy over time at different locations will alter the current patters of energy flow, necessitating the implementation of short- and long-term changes in the energy distribution network. These changes result in a multi-carrier energy distribution network, in which energy can be exchanged between carriers and which enables consumers to choose a carrier based on availability and energy prices.

To determine the transition from existing energy networks towards future multi-carrier energy networks, an optimization model is currently under development. This model not only combines geographical data, energy demand and energy availability to generate an optimal transition plan. It also takes into account economic life of existing energy systems, future energy demand and technical developments. When current energy reserves and future economic resources are known, meaningful results are obtained from this model.

Subject to technical and economic circumstances the model determines if and when existing energy systems should be decommissioned and when future energy systems should be build. If, for example, it is known that in the near future an existing factory will increase its production and therefore its (waste) heat output, then, in the vicinity of that factory, investments in heat pumps are decreased and investments in a district heating network are

increased as suggested by the outcome of the model. To cope with the intermittency of renewables, energy can be stored to be used in case of a shortage, and energy can be converted from another source. In general, economic resources are limited, and therefore the optimization model decides between investing in storage systems or investing in conversion systems. This model determines if and when energy systems should be decommissioned and constructed to optimize the transition towards a sustainable, integrated multi-carrier energy system.

Session 19: Low-temperature district heating and buildings

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

Session Keynote:

Transformation of conventional district heating system to mid-temperature district heating system using model-predictive control

Sam van der Zwan MSc, Deltares Department of Industrial Hydrodynamics, P.O. box 177, 2600 MH, Delft, The Netherlands, Sam.vanderzwan@deltares.nl
Dr. Ivo Pothof*, Deltares Department of Industrial Hydrodynamics
Paul Stoelinga Msc, Deerns Nerderland B.V.
Renske Kind Msc, Deerns Nerderland B.V.
Roman Aalbers Msc, Deerns Nerderland B.V.
Prof. Dr. Chris Hellinga, University of Technology Delft

Delft University of Technology (DUT) is striving to become a prime example of an academic campus that displays energy efficiency measures and sustainably sourced power. The campus has energy related targets to reduce energy use by up to 30% by 2020 relative to 2009, to source 50% of all energy from sustainable sources by 2020, and to become 100% CO_2 neutral by 2020 (TU Delft, 2012).
One of the items investigated is the production and supply of heating via the district heating system (DHS) at the DUT-campus. DUT-Facility Management and Real Estate (FMVG) has started a range of projects to support a transition from a conventional DHS (120 – 80°C) to a medium temperature DHS (80 – 40°C). Part of this project is to investigate and implement a smart district heating control system, which enables the system to run at a low temperature. One driver for going to a lower temperature regime is to increase the full loading hours of the two CHP units. Another driver is the possibility of implementing a geothermal source, which supplies heat at approximately 70°C.
To enable this, a model predictive control (MPC) system is required, which determines the minimum supply temperature and optimal usage of the different sources. The basis of this MPC system is two simulation packages. The first is LEA (Low Energy Architecture) developed by Deerns, which can be used to minimize the supply temperature while ensuring a comfortable climate inside the building. The second package is Wanda of Deltares. Wanda can be used to simulate hydraulic and thermal transients in pipeline systems, like a DHS. Wanda is used to determine the source usage and required supply temperature based on the results of the LEA simulation for each building. Next to this an overall system optimisation (including peak shaving) has been performed in which the source usage has been optimized

to minimize the carbon dioxide output. The LEA and Wanda model have been used as verification platform for this overall system optimisation.

This paper will discuss the result obtained for the design of the MPC system based on simulations performed for a standard climate year. These results show that the supply temperature of the buildings can be reduced, even without major modifications to the building envelopes. This leads to a lower return temperature at the CHP-units and the full loading hours of these two units can thus be increased. With the most optimal scenario an increase of 20% of the full loading hours of the CHP-units can be reached. This leads to a CO_2 production reduction in the order of 10%.

Jeroen Soenens, MSc Eng, is a consultant on energy projects and sustainable buildings at Ingenium.

Step-by-step design for a low-temperature network at the Schipperskaai in Ghent

MSc Eng Jeroen Soenens*
Nieuwe St. Annadreef 23, 8200 Bruges, Belgium
jeroen.soenens@ingenium.be

Schipperskaai is planned as a new residential area of 50,000 m² in the harbour in Ghent. This residential area has the objective to achieve CO_2 neutrality, which is in line with the sustainability ambitions of the City of Ghent. An important element in the energy concept is the low temperature heat network, which will make use of waste heat from the adjacent soap factory. By means of a step-by-step design approach, all the actors involved in the project will become convinced of the technical and economic feasibility of the district heat network, whose temperature regime (55°C/25°C) will be up to 20°C lower than classic heat distribution in Flanders (75°C/45°C).

A methodological approach is used to convince all the relevant actors of the feasibility of low exploitation temperatures. This approach involves the following project steps:

1. Bottom-up analysis of the available market technology: mixer taps, substations, delivery systems.
2. Analysis of the local regulations: legionella, heat invoicing.
3. Dynamic simulation of the heat demand: a combination of space heating and sanitary warm water; year profile per 15 minutes.
4. Pre-design of the heat network: distribution system and insulation.
5. Dynamic simulation of the heat network: necessary bypass streams, temperature regime in outlet and return pipes.
6. Coupling of residual heat and back-up heat provision.
7. Usefulness of extra buffering.

Working through the above project methodology in a step-by-step manner shows that the heat network in Ghent can be designed on the basis of a 55°C/25°C design regime. The heat production must nevertheless take account of periodic higher return temperatures of up to 40°C. Higher return temperatures have a negative influence on the use of waste heat of the factory.

The project is currently in the design phase. The project will be implemented from the end of 2016 onwards.

Kasper Qvist is an Energy Planner at Sweco Danmark in Aarhus. He has an MSc in Sustainable Energy Planning and Management from Aalborg University. He is primarily working with low and ultra low-temperature district heating, heat pumps and strategic energy planning.

Increasing District Heating efficiency with Ultra Low Supply Temperature (35°C)

Kasper Qvist*, Energy Planner[1], Christian Nørr Jacobsen, Energy Engineer[2] and Johnny Iversen, Chief Advisor[2]
[1] _Sweco Danmark A/S, Dusager 12, 8200 Aarhus N, Denmark, Kasper.Qvist@sweco.dk_
[2] _Sweco Danmark A/S, Glostrup, Denmark_

The trend of District heating (DH) is to move towards low-temperature district heating (LTDH) or 4th generation district heating. Not only do lower network temperatures reduce system losses they are also one of the keys to effectively integrating more renewable energy sources in the heat production and utilizing the substantial low-grade heat source potential worldwide.

Through a project funded by the Danish Energy Technology Development and Demonstration Programme (EUDP), an individual consumer substation with an integrated heat pump with domestic hot water (DHW) priority (microbooster) has been developed in a joint collaboration between several companies led by Sweco Danmark A/S. If necessary, the heat pump can boost DH water to 55°C, which is then stored in a storage tank on the substation's primary side, thus preventing legionella contamination. 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. By separating the link between the DH supply temperature and DHW temperature, this concept makes it possible to use DH supply temperatures as low as 30°C all year round.

The microbooster concept has shown very promising results through several tests, most recently from December 2014 to April 2016 in the village of Geding near Aarhus, Denmark, where all of the 25 village houses have been converted to the microbooster concept. Results from this test show that the microbooster concept has made supply temperatures as low as 30°C possible in the summer months while still maintaining the same level of consumer comfort. Over the test period, the micro booster units operated with an average annual COP of 4.5 and it was possible to reduce system losses by almost 40 %. Measurements also show that a supply temperature of approximately 65°C is sufficient during the winter even in old and poorly insulated buildings. A similar concept is currently being tested in a rather new apartment building with floor heating in Kokkedal in Northern Seeland. This makes it possible to maintain low network temperatures all year around. The DH to the building is taken from the return pipe in the traditional network and it is possible to raise the temperature by supplying hot water from the supply pipe or reducing the temperature further by shunting chilled water from the return pipe from the apartment building.

In new residential areas with low energy buildings, ultra-low-temperature district heating could be the best solution for a fossil free heating application. Development efforts are therefore currently put in to optimising investment and operation costs for the distribution network and the consumer substations (DH units). On top of this comes the analysis of the optimal heat production technology, which could be a central heat pump (project specific heat sources to be utilized), solar heat, biomass or any combination hereof. The low district heating temperatures not only allow low temperature heat sources to effectively contribute to the heating supply. A lower district heating return temperature also contributes to a higher efficiency at traditional heating and CHP plants by improved flue gas condensation (by utilising wet fuels) and improved electricity production on back pressure steam turbines.

Rasmus Lund is a PhD fellow at Aalborg University conducting research on 4th generation district heating with a focus on energy scenarios for Denmark. This includes the characteristics of future heat sources and conversion technologies for district heating supply in a holistic energy systems perspective.

Energy System Benefits of Low-Temperature District Heating

Rasmus Lund*[1], PhD fellow, Dorte Skaarup Østergaard[2], Xiaochen Yang[2]
[1] _Aalborg University, Department of Development and Planning, A. C. Meyers Vænge 15, DK-2450 Copenhagen, Denmark, rlund@plan.aau.dk_
[2] _Technical University of Denmark, Department of Civil Engineering, Brovej Building 118, DK-2800 Kgs. Lyngby, Denmark_

Lower temperature levels in district heating systems is a promising improvement of the wide spread heat supply concept. This can, of course, reduce the heat losses from the pipes, but several other benefits can as well be identified. Especially, in the transition towards 100% renewable energy reduced temperature levels will have some significant strengths. Of here can be mentioned increased efficiency of heat pumps, since this depends on a low difference between the heat source and the district heating supply temperature, and this will be improved with lower supply temperatures. Several district heat production units can as well increase their heat output with lower temperatures, such as solar thermal, geothermal, industrial waste heat and biomass boiler plants.

The improved system efficiency should be held against the additional costs of implementing lower temperatures in the district heating systems, which are mainly increased investment costs in the buildings for more advanced substations for preparation of domestic hot water. At very low temperature levels, introduction of direct electric heating for maintaining a minimum temperature of the domestic hot water may be needed at certain times to avoid the risk of legionella. This electricity consumption is important to take into account as well, when assessing the total system benefit of the reduced temperatures.

The benefits and costs of low temperature district heating has never been analysed in an energy system analysis including all energy sectors (electricity, heating and cooling, industry and transport). Previous studies have analysed reduced heat losses, reduced fuel consumption in a single district heating system and influence on types of heat supply units, of reducing temperature levels. This study includes all identified and significant impacts on an integrated energy system of implementing reduced temperature levels in the district heating, using Denmark as a case. In the discussion of the societal importance of low temperature district heating, this study is important because it quantifies the potential savings in systems costs and fuel consumption. Here, different levels of district heating temperatures are assessed to indicate how low temperatures it makes sense to aim for.

The study comprises a quantification of the effect of the different identified energy and economic impacts of reduced temperatures. For example it is assessed how the efficiency of heat pumps are affected by temperature reduction of the required supply temperature. Furthermore the costs and changes in demands caused by the new installations in buildings are thoroughly investigated and quantified. These are put into a model of the Danish energy system applying different sets of temperature levels. The analysis is performed in the EnergyPLAN energy system analysis tool, in an hourly analysis where the specific changes in electricity and heating demands, resulting from the reduced district heating temperatures, forms the starting point.

Maksym Kotenko is a PhD fellow of the 4DH Research Centre at The Department of Energy Technology, Aalborg University. The focus of his research is on minimization of losses in low-temperature district heating. Maksym Kotenko received his MSc in Energy and Environmental Technology from Telemark University College, Porsgrunn, Norway, in 2014.

Drag reducing additives in low-temperature district heating

Maksym Kotenko*, PhD fellow, Carsten Bojesen, Associate Professor
mko@et.aau.dk, Aalborg University, Pontoppidanstræde 101, 9220 Aalborg, Denmark

Keywords: Drag reducing additives; surfactant, pressure loss, DHN (district heating network)

Drag reducing aditives can reduce the pressure losses in the distribution system of DHN. Also they are called surfactants and can be used for costless increase of the flowrate for maintaining the same amount of heat delivered to the customer in low temperature district heating. DRAs can lead to higher flexibility of the system and facilitate extension of any type of district heating because of the increased distances of heat transportation using the same amount of pumping stations.

Drag Reducing Additives were investigated starting from 80-s. Initially polymers were used for that purposes. However, surfactants have the ability to recover damaged bonds unlike polymers. The surfactants are already used in different applications such as oil-field pipes, home care products, personal care products. One of the famous applications of DRAs in the oil industry is the Trans-Alaska Pipeline System. With the help of surfactants the total energy savings of TAPS reach 40%. Previous studies of surfactants added to water shows following savings in pumping power: up to 80% in straight pipes and 40-50% in complicated heating networks. The efficiency of surfactants depends on different factors like concentration and operational temperature. The drawbacks of DRAs can be the following: environmental problems and heat transfer reduction in heat exchanger because of decreased turbulence of the flow.

Tests of different surfactants which are believed to be environmentally friendly will be made at Aarhus University in cooperation with other companies. Five different types of DRAs will be tested. The general procedure for the tests will be the following. The first test will be done with clean water in order to define the reference pressure loss in the test system, to calibrate sensors and do final adjustments. Afterwards each of 5 DRAs will be examined at 5 different concentrations. Each concentration will be investigated at 4 different temperatures and each temperature regime will include 4 different flows. In total the experiment will include 400 tests with different parameters. The approximate time for testing one DRA at one concentration is 2 days. After first two days of experiment initial evaluation of the surfactant will be done in order to outline if it works properly. After finishing the experiment of one DRA type, a total cleaning of the test rig is required, which can take up to one day. Therefore the total length of the experiment including data analysis after each surfactant will be around 21-22 weeks.

Potential results from DRA test is reduction of the power consumption by pumps up to 80% and simultaneous reduction of heat losses due to decrease of turbulence. Current phase of lab facility is in the finalization stage. A few preparations remains before the test can start. Several uncertainties and problems appeared on the way to finish the test rig. The last problem to be solved is data acquisition which will be presented by NI DAQ.

Session 20: Organisations, ownership and institutions

Ralf-Roman Schmidt has worked at AIT since 2009, where he is responsible for the field "District Heating and Cooling". After finishing his studies in production engineering at the University of Bremen, he received his PhD degree in the field of thermo-fluid dynamics. Ralf-Roman Schmidt is vice chairperson of the European DHC+ Technology Platform and active in a number of IEA Annexes.

Session Keynote:

Tackling key challenges of Austrian district heating networks within the STRATEGO project

Ralf-Roman Schmidt*[1], Petra Schöfmann[1], John Johnsson[2], Erik Larsson[3]
[1]AIT Austrian Institute of Technology GmbH, Energy Department, Giefinggasse 2, 1210 Vienna, Austria, Ralf-Roman.Schmidt@ait.ac.at,
[2]Profu i Göteborg AB, Götaforsliden 13, nedre, SE-431 34 Mölndal, Sweden
[3]Svensk Fjärrvärme AB, Olof Palmes Gata 31, SE-101 53 Stockholm, Sweden

Keywords: Technical and non-technical solution options, heating and cooling supply concepts, integrating alternative heat sources, return temperature reduction, business models

In Austria, more than 2,400 heat networks exist (among them a large number of small biomass based networks) with a total share of 24% on the low temperature heating marked. Currently, half of the total district heating supply is from biomass, waste incineration, industrial waste heat and other sources; the other half is based on fossil fuels – most of it via CHP plants [1].

Although there are still some potentials for network extensions/ densifications untapped [2], a number of crucial challenges have been identified within some national stakeholder processes [3], [4]. They are including for the systems in general: unstable energy prices, reduction of the specific energy demand and competition to other heating systems; and for the integration of alternative heat sources: high system temperatures and unsuitable legal, organizational and economical boundary conditions.

The STRATEGO project (http://stratego-project.eu/) aims at supporting national and local authorities from Belgium, Austria, Czech Republic, Croatia, Romania, Germany, Italy and the United Kingdom to develop enhanced heating & cooling plans. This is including a coaching scheme for 23 regions/cities for mapping heating and cooling potentials, the identification of priority areas for intervention, barriers and solution options on different levels as well as initiation of concrete projects.

This presentation will describe the results of the coaching for the two biggest cities in Austria (Vienna and Graz) and for two small biomass based district heating networks that are representative for many others (Großschönau and Maria Laach im Jauerling). This is including the discussion of technical and non-technical solution options and possible realisation projects in following areas:

- integrating alternative heat sources such as waste heat and large scale heat pumps
  - technical system integration
  - new and innovative market design, price and business models
- reduction of return temperature and low-temperature networks
  - technical aspects
  - legal aspects
- accompanying measures (information and education)

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Tina Lidberg has been an industrial PhD student within the research school Reesbe since 2013. Her work focuses on energy efficiency improvements of multi-family buildings within district heated areas and how different refurbishment strategies influence the district heating system from an economical, environmental and resource perspective.

Techno-economic contradictions of energy efficient refurbishment investments within a district heated area

PhD student T.Lidberg [a], professor T.Olofsson [a,b], professor L.Trygg* [c,d]
[a] _School of Technology and Business Studies, Dalarna University,791 88 Falun, Sweden, tlb@du.se._
[b] _Department of Applied Physics and Electronics, Umeå University, 901 87 Umeå, Sweden._
[c] _Department of Technology and Environment, University of Gävle, 801 76 Gävle, Sweden._
[d] _Department of Management and Engineering, Linköping University, 581 83 Linköping, Sweden, louise.trygg@liu.se._

The European housing and service sector faces a considerable need for improved energy efficiency in buildings to meet the 2030 climate targets. This will require extensive investments in refurbishment projects for the existing building stock and as for all investment projects, profitability for the real estate owner is crucial also when it comes to improving energy efficiency projects. It is important to consider a system perspective when introducing energy efficiency measures in an energy system to prevent sub-optimization. This is essential when it comes to saving energy and decreasing climate impact, but also when it comes to the business economics of the energy system.

In Sweden, 92 % of the energy used for space heating and domestic hot water in multi-family buildings is based on DH (district heating). A common situation in Sweden is that the municipality owns the DH producing energy company as well as the distribution network for district heating. It is also common that a municipal housing company owns a significant part of multi-family houses as well as commercial buildings and facilities within the DH supplied area. In reality, this means that both these businesses are owned by the same organization group and therefore gets their capital from the same organization.

In this study a multi-family building area situated in the municipality of Borlänge, Sweden, was used as a case study. Four different refurbishment packages were applied to a case study building model. The results from the building model simulations were scaled up to enable the possibility to analyze the consequences of refurbishing including the entire multi-family building area. The impact on the municipal housing company's and the municipally owned energy company's common economy were analyzed. The investment costs due to the refurbishment are compared to the reduced operation costs for both the housing company and the DH company as well as to the costs of historical investments made in the system.

The results show that the overall savings of the refurbishment cannot cover the investment costs when calculating with a payback method and a short-term perspective. The DH production cost consists largely of capital costs due to investments made in the DH system and these will not be reduced when reducing the heat load.

Contradictions appear when new investments are made within a system that is counterproductive compared to the historical investments that are already made within the same system and the same organization group. When the heat load is reduced it will be harder to finance the capital costs for the energy system. The savings made from reducing the heat load are in the same time supposed to cover the costs of the energy efficiency investments.

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. He works with the economic conditions for 4th generation district heating with a main focus on the integration of electricity and heat markets in the context of a 100 % renewable energy system.

Allocation and coordination in the transition to a 100 % renewable energy system

Søren Roth Djørup, PhD fellow, Aalborg University*
Department of Development and Planning, Skibbrogade 5, 9000 Aalborg, Denmark
djoerup@plan.aau.dk

The transition to a 100 percent renewable energy system requires institutional facilitation and adaption. This requirement is rooted in the allocation and coordination related challenges that are associated with a smart energy system. These challenges arise in the technological shift from stored fossil energy reserves to fluctuating renewable energy supply. The main questions concern the need of integrating wind and solar energy across energy sectors while dealing with the scarcity of biomass resources. The present institutional arrangement is shaped by the energy system of the past and is not addressing the physical premises characterising a renewable energy system. In order to provide an efficient allocation of renewable resources, institutional reforms are therefore needed.

As a technological first mover, Denmark is one of the first countries to confront the task of maintaining organisational efficiency in a changing technological regime. This task demand institutional innovation. The present work will take point of departure in the Danish district heating sector and address the contemporary problems surrounding this infrastructure. Since the electricity sector has already undergone significant technological change, the district heating sector is pushed to respond; status quo is not an option. From the literature in technical system analysis, it is already known what main characteristics the district heating system should possess in order to create positive synergies as an integrated part of the overall energy system. However, these characteristics would only be developed if the necessary investments are made. Contemporary investment decisions are shaping the technological direction of the district heating sector and thereby also the overall efficiency of the energy system.

First, the present work will describe the allocative challenges and coordination failures that characterise the current development of the district heating sector. Second, the determining institutional parameters for economic decision making are identified. Third, the effects of the concrete institutional structure on investments are analysed. Fourth, principles for alternative institutional configurations are proposed which could improve resource allocation and thereby underpin the pursuit for a 100 percent renewable energy system.

Kerstin Sernhed is an assistant professor at Lund University. She has a broad research interest in district heating and the development of energy-efficient systems, demand side management, marketing strategies for district heating and electricity, development of energy services, as well as maintenance and status assessment of district heating networks.

Customer preferences on district heating price models

Kerstin Sernhed*[1], Henrik Gåverud[2] and Annamaria Sandgren[3]
[1] _Lund University, Department of Energy Sciences, PO-Box 118, Lund, S-221 00, Sweden,_
  Kerstin.Sernhed@energy.lth.se
[2] _Sweco Energuide AB, PO-Box 2909, Malmö, S-212 09, Sweden_
[3] _IVL Svenska Miljöinstitutet, Anckargripsgatan 3, Malmö, S-211 19, Sweden_

Within the framework of the district heating business, district heating must have a price in the heating market that must be competitive against the customer's options and also give the supplier a desired return on investment in district heating system. Pricing for district heating is a topical issue in Sweden right now where many district heating companies are reviewing their pricing models. Earlier Swedish studies on district heating price models highlights that the pricing model should reflect the company's costs of production and distribution of heat, in order to diminish economic risks. The share of the variable energy price (price per MWh) should not be too high in relation to the total price, the energy prices should be differentiated according to seasons and customer costs should be more fairly distributed in the customer community (i.e. one customer group should not subsidise another customer group). In many cases, incentive-based components are included in the pricing model, such as peak load components or flow components. These are designed to affect customer behaviour and load profiles, and to make customers more apt to see to that their substations are operating effectively.

There are many benefits from a business perspective to develop district heating price models in this way; district heating companies' hedge their income regardless of the weather and reduce the risk of non-repayment of their investments. If incentive-based components can help controlling customers' consumption patterns and which efficiency measures that will be made by the customers, this is also positive from a business perspective. But from a customer perspective, it is not as obvious that a pricing model that lays out the economic risks at the customer level, and that includes many different components, is preferred.

This study has been designed to highlight customer's perspectives on current trends in the pricing of district heating. If the design of price models leads to a large customer dissatisfaction, this can become a competitive disadvantage for district heating and customers may look for alternative heating options – thus this is not only an important question for the customers themselves, but also for the district heating business. Six focus group interviews were conducted in 2015 with clients of three Swedish district heating

companies with different price models. Three of the interviews were conducted with larger customers, mainly representatives of major private and municipal real estate companies. The other three focus group interviews were conducted with representatives from housing associations, community associations and residential customers. Interviews were also made with representatives on different positions at the three district heating companies to explore how the work with the design and the launching of the pricing model was implemented, as well as to explore the representative's views on the customer response to the new price models.

The results show that customer requirements on district heating price models are not congruent with the prevailing view of how a good pricing model should look like from a business perspective. The most important quality that a good price model for district heating should have - from the customer's perspective - is that the price should be responsive to the customer's behaviour and that customers want energy efficiency measures to pay off. This means that price models with large fixed share are not particularly popular among the customers. Price models with multiple components become complex for customers to understand. Especially, peak load components seem to be difficult to understand and it seems to be a plethora of ways in which the district heating industry charges for peak load. Large customers with businesses in several towns ask for an industry-standard way to pay for peak load. Components that provide unpredictable costs are causing concern among customers and make it difficult for customers to present a budget.

Dr Tanja Groth is a Decentralised Energy Manager responsible for projects in the field of decentralised energy, including distributed heat and community energy. At the Carbon Trust, Tanja currently leads on eight decentralised energy projects and provides ad hoc support for a further five projects across a combined portfolio value of over £200k. **Ian Manders** is a consultant advising the Danish Embassy on UK local energy policy.

The PipeCo: an alternate approach to financing heat networks

Dr Tanja Groth* and Ian Manders
The Carbon Trust, 4th Floor, Dorset House, 27-45 Stamford Street, London, SE1 9NT, United Kingdom, tanja.groth@carbontrust.com

A variety of different funding models for heat network schemes already exist in the UK, for example the Energy Service Company (ESCO) model, in which a single or majority owner of the network commits to providing a cost of heat lower than an agreed, market-based alternative, an approach which is especially popular for new developments. Other models include community ownership and finance-build-operate schemes, which are especially prevalent for smaller schemes and equally applicable to retrofit and new build.

However, the allocation of £300 million public support to help unlock up to £2 billion in private investment by 2025 requires an exponential growth in the sector, meaning the existing funding models must be supplemented by additional methods of driving investment. Additionally, cost of financing is frequently cited as a significant barrier in the sector, as most of the existing financing sources are bound by high return on investment requirements.

The PipeCo model works on the basis of splitting the investment in a new district heating scheme into the expensive heat distribution network, which lasts for 50-60 years before refurbishment, from the energy generation plant and ancillaries, which have a lifecycle of 15-20 years before replacement. This structure follows the recommendations from the CIBSE Heat Networks Code of Practice, which recommends assessing multiple governance models for potential heat networks, including splitting up a network into generation (GenCo), distribution (DistCo) and retail (SupplyCo).

Where this model is uniquely suited for the UK market is that is also facilitates refinancing of the expensive, long-term distribution asset by third-party investors – for instance by creating a portfolio of heat network investments of a sufficient scale that would appeal to pension funds and other capital investors interested in low-risk long-term investments.

This refinancing will benefit the initial heat network developer, regardless of whether they are public sector or private sector, as a substantial portion of the initial investment cost can be recouped shortly after commissioning of the network.

Creating a portfolio of distribution infrastructure across the UK will further de-risk refinancing of the asset from the view of an external investor. And by attracting investors who prefer low-risk, long-term investments, the financial viability of heat networks with a sub-

commercial IRR is not compromised by requiring costs to be fully recouped in a fraction of its lifetime. This might lead to larger projects being delivered which can achieve economies of scale.

To our knowledge, at least one form of PipeCo already exists in the utility world (connected to property development) and one major player in the UK district heating market is seriously considering setting up a PipeCo. However, this will not provide the capacity to cope with the portion of the 200 heat networks coming to the commercialisation stage this year and next.

We are currently working with UK government, investors and the UK heat network industry to develop this concept into a working model to catalyse investment into the UK heat market – a model which could potentially be replicated across heat network and cooling network investments in major cities across the globe.

We would welcome the opportunity to present the progress made on this concept at the 4DH conference in Aalborg in September 2016, and invite the opportunity for feedback from the researchers and experts from industry and businesses that will be present at the conference.

Session 21: Smart Energy Systems

Anders Bavnhøj Hansen, **Loui Algren** and **Rasmus Munch Sørensen** work in the department of Energy analysis at Energinet.dk (TSO for power and gas in Denmark). The 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 (MSc) from Aalborg University, Denmark**.**

Session Keynote:

A Smart Energy System designed to be compliant with COP21 visions for fast CO$_2$ reduction

Anders Bavnhøj Hansen*, MSc[1], Loui Algren, MSc[1] and Rasmus Munch Sørensen, MSc[1],
Brian Vad Mathiesen, Professor, PhD[2]
[1] Energinet.dk, Tonne Kjærsvej 65, DK-7000 Fredericia, Denmark,
abh@energinet.dk, loa@energinet.dk and rms@energinet.dk
[2]Aalborg University, bvm@plan.aau.dk

The international global climate meeting "COP21" in Paris outlined a very ambitious target for the global reduction of climate gas emissions for the coming decades. A target for keeping the global temperature "Well below 2 degrees" was agreed upon by 195 nations. This target calls for an average global energy related emission below 2.5 ton/capita in 2035. For Denmark the energy related CO$_2$ emission (2014) is 7.8 ton/capita. Energinet.dk has analyzed a number of different scenarios for the Danish energy system towards 2030, 2035 and 2050. This paper deals with was of optimising a 2035 scenario, ultimately leading to an energy system with an energy related CO$_2$ emission below 1.5 ton/capita in 2035. This scenario is compliant with the COP21 agreed ambition if used globally, and is therefore analyzed both technically and economically.

To obtain this significant reduction towards 2035 a Smart Energy system is imperative. The strategies presented in Energy Concept 2030 (1) and CEESA (2) and Energi 2050 vindsporet (3) are essential in this scenario.

The scenario is not solely based on renewables, but depends on an annual consumption of 80-90 PJ natural gas in an average (nominal wind/solar/hydro) year, used for peak power capacity, industrial process energy and heavy transport sector in 2035.

The balancing of the power system and need for grid reinforcement has been analyzed as a part of Energinet.dk grid planning work (Netudviklingsplanen)

Some of the findings in the analysis are:

Boundary conditions for countries around Denmark are based on European ENTSO-E scenarios. There is a need for more analysis of the European energy system in future scenarios. Also where Smart Energy System integration strategies are implemented across Europe.

There is a need for market solutions that can efficiently manage volatile prices in power, gas and heat systems. Furthermore, market solutions and control strategies that can optimize system operation at transmission and distribution level (TSO/DSO) are also mandatory to operate the system cost efficiently and to obtain system stability and security of supply.

The economic and technical analysis is based on forecasted parameters from "Technology data catalogue" (4) and IEA WEO fuel and CO2 prices (5). The results show that a system competitive with fossil solutions towards 2035 is possible for most types of energy services, given the technological development presented in (4).

The findings from the study are used as input for planning of a future resilient and robust system and as input for R&D strategies.

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Olatz Terreros holds a master´s degree in Industrial Engineering from the Technical University of Bilbao (Spain). She has been working for the AIT (Austrian Institute of Technology) in the field of sustainable thermal energy systems since 2014. She is currently involved in national and international projects related to district heating networks in smart cities.

Operational and design optimisation of a hybrid energy grid case study

MSc Olatz Terreros*, MSc Daniele Basciotti, DI. Sawsan Henein, DI Dr. techn. Edmund Widl, DI Dr. Tarik Ferhatbegovic, DI Dr. Ralf-Roman Schmidt
Austrian Institute of Technology GmbH, Energy Department, Giefingasse 2, 1210 Vienna, Austria
olatz.terreros@ait.ac.at

Distribution energy grids (electrical, gas and thermal - district heating and cooling (DHC)) face several challenges when it comes to the integration of a significant share of renewable energy sources. A hybrid energy grid is an energy system operated across different domains, where energy can be transformed between the grids (e.g. via power-to-heat/power-to-gas processes and combined heat and power plants (CHP)). For the specific case of electrical networks, coupling the thermal and the electrical grids via power-to-heat processes is a promising solution for an efficient management of temporary photovoltaic energy surplus. The cooperation between different energy grids contributes to increase the integration of decentralized renewable energy sources, improving demand balancing, as well as energy savings, and reducing the overall CO_2 footprint.

However, the connection, integration and efficient operation of hybrid energy grids has been barely investigated. Analyses of individual components (e.g. optimisation of CHP operation (1)), besides possible control strategies (2), have been accomplished hitherto, although they lack a thorough research in the real impact and benefits of hybridisation. One of the difficulties of the investigation of hybrid energy grids, compared to the analysis of individual energy grids and components, is the absence of tools which enable cooperative simulation on multiple grids (3). It should be noted, though, that a comprehensive study on hybrid energy grids control and cooperation is currently carried out in the framework of the European project OrPHEuS (4). It includes the development of a co-simulation methodology in Ptolemy simulation environment (5), which allows the usage of the state-of-the-art domain-orientated simulation tools, but final results are not yet fully available.

This study, introduces a co-simulation based approach to develop and evaluate optimisation control strategies for a future hybrid grid case study in Innsbruck (Austria), and enable optimal design of the components in the grid. For the co-simulation, the individual simulation models are set up for each energy grid included in the case study. The model of the electricity grid is implemented in the simulation environment DIgSILENT PowerFactory consisting of the distribution grid, photovoltaic plants and a biomass CHP plant for the electricity generation,

loads from office buildings and a large scale battery. The modelling of the district heating system is developed in the simulation environment Dymola/Modelica. The model includes producer units (the biomass CHP, gas boilers, biomass boiler and heat pumps), heat storages, thermal building models and the local distribution network. The electric and thermal domains are then coupled by the co-simulation approach, which enables a detailed analysis of the synergies between both domains and the integration of a seamless control strategy. The hybrid control strategy of the case study optimises the operational performances in the analysed hybrid grid by maximizing local energy generation (PV and biomass usage) and distribution among the grids. Additionally, further analyses are carried out on several pre-defined design variations (e.g. size of the thermal storage) in order to find optimal components layout based on a multi-objective optimisation approach, which considers as objective functions operational costs and CO_2 emissions of the overall hybrid grid.

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Marta Kierek is a Research Assistant at the Department of Distributed Energy of IMP PAN. She obtained an MSc Eng. from Gdansk University of Technology in 2012. She attended a course in energy auditing of buildings at GUT and was nominated a Certificated Auditor. Currently, she is working in the subjects of smart energy management, renewable sources of energy and different aspects of energy systems.

Influence of the capacity of heat storage on identifying an optimal mix of heating technologies using a research centre building in Poland as a case

Marta Kierek*[1], Sebastian Bykuć[1], Anders Andersen[2,3], Poul Alberg Østergaard[2] and Patryk Chaja[1]
[1] Department of Distributed Energy, Institute of Fluid-Flow Machinery, Polish Academy of Sciences, ul. Fiszera 14, 80-231 Gdańsk, Poland, martakierek@imp.gda.pl
[2] Department of Development and Planning, Aalborg University, Skibbrogade 5, 9000 Aalborg, Denmark
[3] EMD International A/S, Niels Jernes Vej 10, 9220 Aalborg Ø, Denmark

This paper focuses on the influence of heat storage on identifying an optimal mix of different heating technologies using the Energy Conversion and Renewable Sources Research Centre (KEZO), Poland, as a case. It is a unique building because it is not only a complex of laboratories but it is also, if not mainly, a living energy laboratory. All of the locally available sources (sun, wind, geothermal energy, biomass) are used there to produce energy (heat, cold, electricity) and produced energy can be stored in different types of energy storages. This paper examines what is the influence of the capacity of heat storage on the cost of using the building, concentrating on two questions: What is an optimal, from the economic point of view, mix of heating technologies in the case building? How is the optimal mix of heating technologies depending on the capacity of heat storage? In order to answer these two questions KEZO Research Centre with all of its equipment was modelled in the energy systems simulation software energyPRO. Through the undertaken analysis, mainly by using energyPRO, it was identified which solution is the best, from an economic point of view, for the case building. It was also found that an optimal mix is not the same for different capacities of heat storage.

Benedetto Nastasi is an Architectural Engineer and Energy Planner. His research is focused on the role of Eco-Fuels in transition towards a low carbon city and society, in a new relation between urban and rural environments in the energy planning field. He is an expert of Sustainable Energy and Climate Action Plans, renewable energy technologies and their integration into urban and agricultural planning.

Power-to-Gas and Power-to-Heat interaction in the transition towards future Smart Energy Systems

Benedetto Nastasi*[1], PhD, Gianluigi Lo Basso[2], PhD
[1]Department of Sustainability Engineering (DIS), Università degli Studi Guglielmo Marconi, Via Plinio 44 - 00193 Rome, Italy, benedetto.nastasi@outlook.com
[2]Department of Astronautics, Electrical and Energy Engineering, Sapienza University of Rome, Via Eudossiana 18 - 00184 Rome, Italy, ing.gianluigi.lobasso@gmail.com

The mid-term and long run climate change-driven energy roadmaps are promoting the use of renewables as low or zero carbon energy sources. Yet, their integration in current energy systems calls for solving balancing, security and matching issues. In this framework, energy storage is meant as a mitigation strategy in the transition towards Future Smart Energy Systems and it is often considered the "solution" for RES capacity firming. Yet, the so-called Power-to-X (P2X) is the current dilemma in energy management strategies. Indeed, Power-to-Gas (P2G) and Power-to-Heat (P2H) show strengths and weaknesses depending on the National energy systems features where those solutions could be applied. Among the variety of applications classified in the aforementioned technologies, synthetic fuels production and electricity-driven heater are considered the most promising ones, respectively. As regards the P2G, electrolysers are the technological driver for balancing the penetration of electrical renewables in energy systems as the main part of synthetic fuels production. Whereas, referring to P2H, Heat Pumps represent the most efficient solution owing to their high efficiency but they require a temperature level control to meet the end-user demand quality. The authors investigated on different national energy scenarios at RES share increase in the energy mix to highlight strengths and weaknesses of the P2G and P2H applications. To do so, a Demand side Power-to-Heat Ratio (PTHR) was defined as the ratio between the Electricity demand and the Heating one for building, district and national scales. The results of the energy analysis were analyzed with the objective function of Primary Energy Consumption (PEC) and carbon emissions to address the IPCC targets.
A fundamental resource for each choice is the well-established respective Grid: the Natural Gas (NG) pipelines are capillary so as to promote the P2G-based synthetic fuels while, the Heat Grid such as District Heating is widespread so as to allow the P2H-based thermal energy production.

The results indicate that such scenarios, in current energy transition, should be promoted depending on the current energy mix and the presence of well-established energy infrastructures.

Tomasz Z. Kaczmarczyk, PhD, Eng., is employed as a Research Associate at the Turbine Dynamics and Diagnostics Department, the Szewalski Institute of Fluid-Flow Machinery PAS, in Gdańsk. Main areas of his scientific activities include: heat and mass transfer, heat exchangers, pool boiling of nanofluids, design and construction of steel structures, RES and ORC systems.

The impact of changes in the geometry of a radial microturbine stage on the efficiency of the micro CHP plant based on ORC

Tomasz Z. Kaczmarczyk*, Grzegorz Żywica, Eugeniusz Ihnatowicz
The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Department of Turbine Dynamics and Diagnostics, Gen. J. Fiszera 14 st., 80-231 Gdańsk, Poland
tkaczmarczyk@imp.gda.pl; gzywica@imp.gda.pl; gieihn@imp.gda.pl

In the last decade, the EU's climate and energy policy has paid a great attention to renewable energy – mostly in the context of promotion of the RES-based technologies. Such an approach is aimed at reducing the consumption of fossil fuels, restricting the emission of environmentally harmful gases into the atmosphere and increasing energy efficiency. That is why novel power devices such as CHP and CCHP units producing heat, cold and electricity have entered the market. The strategic importance will be systems which can use low-temperature (below 200 °C) waste heat. The majority of CHP systems available on the market need to be fuelled with high-energy fuels (e.g. natural gas, LPG or other petroleum products) or high-temperature heat sources that can be used more efficiently in other heating or electrical energy production systems.

The employees of the Szewalski Institute of Fluid-Flow Machinery PAS in Gdańsk, have designed and built a micro CHP plant based on ORC technology, which allows conversion of low-temperature waste heat into electrical energy. The prototypical multi-fuel boiler (fired with biomass in the form of wood pellets) was used as heat source for research purposes. The ORC installation consists of heat exchangers, circulation pumps, industrial fittings and the expansion device – prototypical, radial four-stage vapour microturbogenerator that is characterized by the following nominal operating parameters: rotational speed $24000 \div 25000$ rpm, electric power 2-3 kW$_e$, flow rate of the working medium HFE7100 0.17 kg/s, working medium temperature 160°C, supply pressure approx. 10 bar. The microturbogenerator is located in a hermetic enclosure and requires no additional lubrication thanks to the use of gas bearings lubricated with the working medium. The HFE7100 is a non-flammable, non-explosive and odorless fluid with low toxicity and it has no ozone depleting potential which is of crucial importance from an environmental point of view. Given that the expansion device efficiency has a fundamental influence on the cogeneration unit efficiency, it was decided to modify the microturbogenerator's flow system in order to improve energy efficiency of the cogeneration unit.

The paper presents the impact of modification of the first microturbogenerator's stage on the following efficiencies: exergetic, Carnot, thermal of the ORC system and isentropic of the microturbine. Thermal and flow characteristics were introduced for the heat exchangers (that is, for the condenser, evaporator and regenerator). Moreover, current, voltage and power curves of the microturbogenerator were shown, which were obtained during its operation in the regenerative ORC system using the low-boiling medium HFE7100. The measurements of microturbine body vibration were performed during this research and they aimed to monitoring of the machine and the early detection of potential dynamic problems or defects. The results of these measurements in the form of distributions of frequency of vibration velocity RMS were included in this paper.

Session 22: Future district heating production and systems

Marcus Thern is an associate professor at Lund University. His main research interests are engineering thermodynamics and cycle analysis. He works with the design and modelling of different thermal cycles by means of Heat and Mass Balance Programmes (HMBPs) and the evaluation of gas turbine performance with these heat balance programmes.

Session Keynote:

Impact of local renewables on power plant performance in district heating mode

Marcus Thern, associate professor, Kerstin Sernhed, associate professor, and Magnus Genrup, Professor*
Lund University, Department of Energy Sciences, PO-Box 118, Lund, S-221 00, Sweden,
marcus.thern@energy.lth.se

Keywords: Power plant, district heating, low-temperature district heating, flexible power and heat

Today's smart grids and future district heating solutions will require intelligent power plants. This study describes a flexible power solution that allows both low and high flow temperatures in district heating network. Flexibility in heat and power production is becoming increasingly important as a result of European Union imposing 20-20-20 target. This means that the EU wants 20 % renewable in power generation, 20 % reduction in carbon emissions and 20 % reduction in energy use in the EU. The word renewable implies a handful of different energy sources such as wind, hydro, biomass and solar power. Common to solar and wind is that this generation is very volatile in nature. A large proportion of this capacity in the network means that power plants must be much more flexible than is the case today. It may be mentioned that Germany in 2008 had 25 GW of wind power installed in the network, resulting in a daily reserve capacity of (10-20) GW. To cope with this, plants need to be able to follow load with daily start and stop on the plants. Today's smart grids and future district heating solutions will therefore require intelligent power plants.
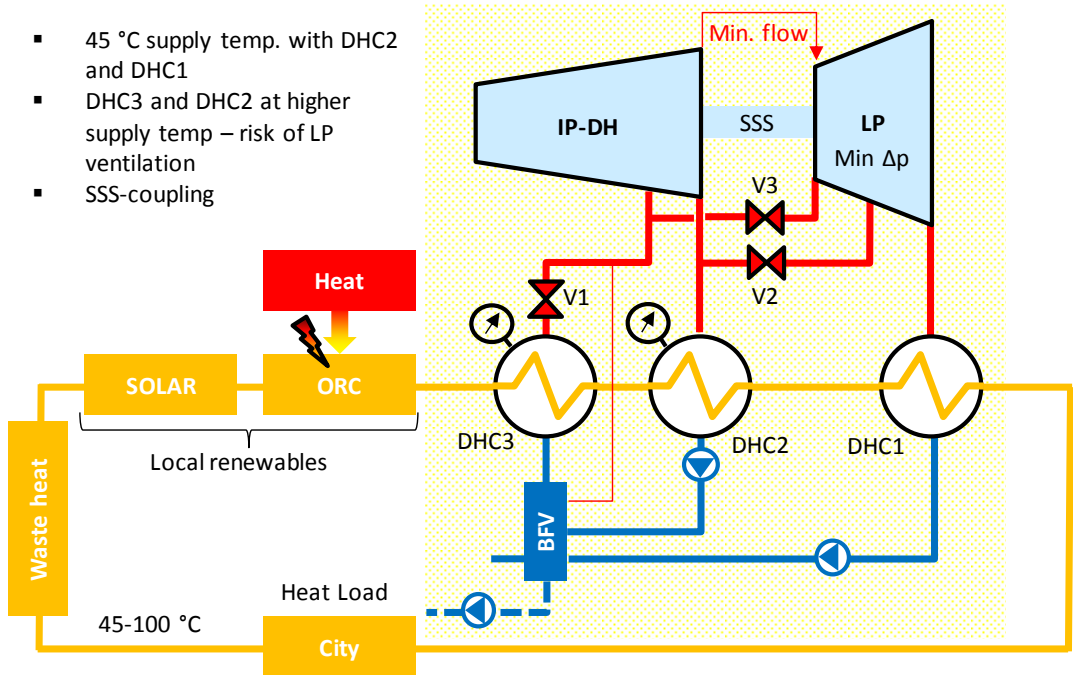
Figure 1: New flexible power plant scheme

The plant is used in addition to two heat condensers, HC1 and HC2, a third heat condenser, VK3. By running one heat condenser and heat condenser 2 power plant can produce hot water at a temperature of around 45 °C. Would then a warmer temperature required can also heat condenser 3 is connected to so as to ensure a supply of (70-100) °C to district customers.

Using heat pump to recover waste heat from thermal power plants for district heating

Haichao Wang* [a,b], Risto Lahdelmaa [a]
a Department of Mechanical Engineering, Aalto University School of Engineering, P.O. BOX 14100, FI-00076, Aalto, Finland, haichao.wang@aalto.fi
b Institute of Building Environment and Facility Engineering, Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian 116024, China

China is now undergoing a fast urbanization, increasing the total district heating (DH) demand. DH systems are gradually expanded and the size of individual system is dramatically growing, leading to a problem of insufficient heat production. Meanwhile, the excess and waste heat of power plant cooling water is not recovered and used efficiently but discarded into the atmosphere. This part of waste heat contains a large amount of energy, for example, Beijing has 6 big combined heat and power (CHP) plants with DH capacity of 4128MW, but they can generate excess heat of 1240MW in the cooling water; the DH production can be increased by 30% if this the excess heat would be recovered.

Although heat pump (HP) technologies are mature in using the low-grade heat sources, the application in power plants is just in the beginning stage. In 2005, the total capacity of coal-fired thermal power plants in China is 3.9×10^8 kW, among which about 86% is not supplying DH. This means that the cooling towers in those pure thermal power plants are not connected to DH network. The heat loss from cooling towers is equivalent to about 3.4×10^8 t standard coal. This amount of coal is equivalent to 15% of the total energy consumption in China or 36% of the building energy consumption in China in 2005!

The cooling water in the power plants contains a majority of the excess heat and it is better than other low-grade heat sources because of: 1) huge excess heat amount; 2) good water quality; 3) obvious environment protection effect. The means for using excess heat from power plants are: 1) Increase the heat supply without major investment in new heat plants and additional emissions; 2) Solve the heat transportation problem and increase the capacity of DH network; 3) Increase the energy efficiency of power plants and contribute to energy savings.

This paper is dedicated to evaluate the different HP technologies for waste heat recovery from thermal power plants and CHP plants, and then find out the most promising scenarios

theoretically considering the heat recovery and the connection to DH networks. Different HP technologies will have different connection strategies to DH network, and different operating requirements as well as constraints. The HP technologies studied in this paper include already existing absorption heat pumps, compressor heat pumps and heat pumps under development in laboratory.

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

Performance evaluation of utility plant and booster heat pumps in ultra-low-temperature district heating system at varying flow temperatures of the network

Torben Ommen*, postdoc, Wiebke B. Markussen, associate professor, and Brian Elmegaard, associate professor, Technical University of Denmark, Department of Mechanical Engineering, Nils Koppels Allé, Bygning 403, 2800 Kgs. Lyngby, Denmark, tsom@mek.dtu.dk

The use of ultra-low temperature (ULT) district heating (DH) networks has been proposed as an approach to increase district energy performance. Opposite to the low temperature DH, the ULT systems utilize booster units for fractions of the end-consumer heat demand according to the required temperature level of the service. Efficient booster units are designed to enable the highest possible direct heat transfer between the DH and the service. By utilizing heat pumps (HPs) for the booster service, the electricity consumption of supplying the remaining fraction is reduced, and the DH return may be lower than what is possible for direct heat exchange. By controlling the return temperature of DH from the booster unit, an additional degree of freedom is obtained in the network, which can be utilized to adjust the return temperature of an area to an optimal range.

The topic of ULTDH has received attention in a number of recent publications. The use of the technology has been proposed for two quite different energy scenarios:

- Expansion of existing DH networks, where troublesome capacity constraints are addressed, which is achieved by connecting ULTDH consumers at remote positions by utilizing the return flow. This may be done without interfering with consumers requiring DH at traditional temperature levels.
- The design of new or updated systems with better performance of utility units according to the production temperatures and lower losses in DH network. A key aspect of lowering DH temperature is the increased performance for renewable technologies at lower forward temperatures.

The focus of the current study is the newly designed urban systems. The proposed technology may be relevant in new areas of cities, where waste heat from electricity production is not abundant, and where the average consumption of space heating is low.

Especially three advantages are worth mentioning for systems with lower temperatures in the network: the possibility for decreased DH heat losses, improvements in performance of combined heat and power (CHP) plants, and improvements in performance for renewable heating technologies, either by direct utilization (e.g. solar thermal collectors) or by use of HPs. On the other hand, the ULTDH has lower temperature difference between forward and

return lines, and is thus subject to increased investment and/or pump work due to larger volume flow of DH media for a fixed heat delivery.

Two possible heat production technologies for the DH network were analyzed in terms of performance and interdependencies, namely CHP-plant and central HPs. The analysis focusses on the characteristic heat demands of multi-story buildings and the results are based on the ratio of the individual demands compared to the total. It was found that the optimal return temperature is dependent on the forward temperature and the heat consumption profile. For typically proposed consumption profiles, the optimal return varies from 21°C to 30°C. The return temperatures correspond to forward temperatures from 35°C to 50°C. When using a central HP to supply the DH system, the resulting coefficient of system performance (COSP) is in the range 3.8 (-) to 4.2 (-) for equipment with realistic component efficiencies and effectiveness, when including the relevant parameters such as DH system pressure and heat losses.

Susana Paardekooper has a background in economics and engineering, and is now a research assistant in the Sustainable Energy Planning Research Group at Aalborg University in Copenhagen. There she focuses on decentralised and renewable energy systems modelling and analysis, including the Heat Roadmap Europe 4 project.

Heat pumps in British cities – assessing optimal scales of implementation

Ms. Susana Paardekooper*
Department of Development and Planning, Aalborg University, AC Meyers Vænge 15, DK-2450 Copenhagen, Denmark, susana@plan.aau.dk

Linking the thermal and electricity sectors is increasingly being recognised as a key part of integrating renewables into the thermal sector, and achieving an energy transition at large. This research aims to understand in what manner heat pumps could best be used in cities to contribute toward these aims. Using geographic heating and cooling demand data, 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 to varying degrees. This also allows for an assessment of the potential levels of district heating in combination with large-scale heat pumps in cities. Specific cities are used as case studies for the analysis and the scenarios are assessed based on cost, energy efficiency and ability to integrate intermittent renewable energy into the system; security and the urban space are also considered where appropriate.

The optimal extent of the large-scale heat pumps in combination with district heating is dependent on the heat density demand, which is combined with geographical data to indicate potential areas. The large-scale heat pump systems are roughly equally fuel efficient to individual-scale heat pumps, and very well suited to the urban environment. This is because losses in the grid are offset by higher, more dependable COPs. While both heat pump scenarios show significantly higher fuel efficiency than gas alternatives and achieve the integration of energy sectors, the individual-scale heat pump scenario is considerably more costly than both the gas boiler and large-scale heat pump scenario. Costs are significantly lower for the large-scale heat pump scenario per year than both gas-based and individual-scale heat pump scenarios, although high up-front investments are required. This provides a strong impetus for change from the suboptimal gas boiler scenario to a district heating network supplied by heat pumps in the denser areas. Planners can use this modelling to understand the different scales at which energy efficiency and renewables can be used in their cities, and work towards more efficient, secure, affordable and sustainable energy solutions.

Hans-Christian Gils studied physics at the Universities of Konstanz, Padua and Hamburg. He joined the Systems Analysis and Technology Assessment department of DLR in 2010. In 2015, he received his PhD from the University of Stuttgart. His main fields of scientific interest are energy system modelling and development of future energy supply scenarios, with a special focus on demand response and linkage of energy sectors.

Potential contribution of advanced district heating and electric heat pumps to the integration of renewable power generation in Germany and Europe

Dr. Hans-Christian Gils, Institute of Engineering Thermodynamics, German Aerospace Center (DLR), Wankelstraße 5, 70563 Stuttgart, Germany, hans-christian.gils@dlr.de*

Balancing of intermittent power generation from renewable energy (RE) is one of the central challenges within the system transformation towards a more sustainable supply. This paper addresses the potential role of an improved linkage between power and heating sector in meeting increasing balancing needs in Europe. It is particularly focused on the impact of a reorientation of district heating combined heat and power plants (DH-CHP) and electric heat pumps (HP) from a heat-controlled to a power-controlled operation, achieved by a decoupling of demand and production of heat using thermal energy storage (TES).

The analysis relies on an upgrade and application of the cross-sectoral REMix model, which is designed for the assessment of energy supply scenarios based on a system representation in high spatial and temporal resolution. REMix is a deterministic linear optimization program minimizing the system costs in the overall investigation area during one year of operation.

In order to evaluate the least-cost configuration of enhanced DH-CHP and HP systems in different countries and RE supply scenarios, REMix is applied in two case studies for Germany and Europe. Both case studies focus on supply systems with high share of fluctuating RE power sources as they might be realized by the year 2050.

The first case study is focused on Germany and evaluates different scenarios of RE, electricity storage and grid capacity development paths (1). The REMix results show that substantial capacities of TES are installed in HP and CHP supply systems if they are available as investment option. Overall TES capacities in Germany reach up to 281 GWh and are only to a minor extent influenced by the RE supply structure, as well as by the availability of hydrogen fuel production, hydrogen storage and grid extension. Specific TES capacities are highest in DH-CHP and industry, whereas they are lower in building supply with CHP and HP. During the year, between 1% and 12% of the heat production is stored, corresponding to a TES input between 5 TWh and 17 TWh. Additional benefit can be created by integrating up to 15 GW of electric boilers in CHP systems, which are used to avoid RE curtailments in times power generation exceeds demand. The installation of both TES and electric boilers are correlated to the wind power supply share: they are particularly high in the wind power regions of northern and eastern Germany.

Increased operational flexibility of CHP proves to be a very effective measure for the reduction of VRE curtailment in Germany: the amount of wasted electricity can be cut by up to 21 TWh, around half of which is used for electric heat production. Furthermore, power-controlled operation of CHP and HP reduces the demand for additional power generation capacity by up to 3.6 GW. Optimized power plant operation, reduced capacity demand and higher VRE integration achieved by power-controlled heat supply enable a reduction in system costs by up to 1.5 billion euro.

In additional model runs, different heat supply scenarios for Europe will be evaluated concerning their contribution to the integration of high share of fluctuating RE into the power sector. In doing so, the least cost design of linked power and heat supply systems primarily based on RE are determined.

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Session 23: Energy planning and planning tools

Romanas Savickas has a doctoral degree in Energy and Thermal engineering (2007). He is an energy professional with an uncommon combination of scientific work experience (from 2007 associated professor) and professional business/industry experience (from 1998: Engineer-Project manager- Head of technical division-Head of Engineers analysts group, etc.). He is the author of the Interactive Actual Energy Consumption Class map.

Session Keynote:

Smart 4th generation energy management: online interactive building actual energy consumption class map

Dr. Romanas Savickas*, romas.savickas@gmail.com,
Vilnius Gediminas Technical University, Veolia Energy, Šaltinių g. 22-10, Vilnius, Lithuania
Prof. Vytautas Martinaitis, Vilnius Gediminas Technical University
LL.M. Lauryna Savickiene, Vilnius University

Keywords: Smart metering, Smart energy management, energy consumption, actual energy consumption, energy efficiency, strategic energy planning, low temperature heating, heat meters, 2012/27/EU Energy Efficiency Directive, Interactive Actual Energy Consumption Class (AECC) Map

The global energy consumption annually increases, so the energy efficiency means must be found and implemented. The 2012/27/EU Energy efficiency Directive provides to decrease energy consumption for every final energy consumer by 1.5 % annually, but does not define how these targets can be achieved by each member state. Usually a typical final customer cannot identify the scope and level of energy consumption. The analysis of different countries shows that customers usually measures and compares energy consumption level according to the percentage from gross domestic product or income level in a country. Therefore, the final customers in low-income countries usually state that they consume a lot of energy even in cases they consume relatively small amount of energy comparing with the same type of identical buildings. In opposite case the final customers in high-income countries usually state that they consume a small amount of energy even in cases they overheat buildings and consume relatively high amount of energy compared with the same type of identical buildings. Empowering consumers with information about actual energy consumption and energy consumption comparison with the same type of identical buildings increases awareness of consumers about energy consumption and the main question in heads of consumer arises – why does my building, being the same type or identical project type as other few hundreds or thousands of buildings, consume much more energy? We obtain the main factor to increase energy efficiency - the motivation factor of a customer. Later it is only the selection of corresponding means to obtain that. Therefore, as a great American statistician, professor, author, lecturer and consultant William Edwards Deming (October 14, 1900 – December 20, 1993) has stated "You can't manage what you can't

measure", first of all we must measure it (energy consumption). To measure and rate energy consumption is not an easy task. Energy consumption in buildings can be evaluated by the help of energy performance certificate, energy audit, according to bills for heat energy, other scientific methodologies but not all of them present clear and right information. Energy performance certificates show only theoretical energy consumption and performed analysis shows that actual energy consumption may differ even in 30-50 % comparing with values in certificates. Energy audits are performed in detailed way but it takes too long time to audit all buildings in a whole city. For example, all Lithuanian audit experts can audit a whole capital of Lithuania - Vilnius city (~600'000 inh.) only in 3-5 years. We need information right here and right now. Bills for energy also are not very precise and are not suitable for detailed analysis, so the special methodology must be defined. To compare energy consumption of different buildings, various influencing factors must be eliminated: different heating areas, hot water consumption, number of heating days, outside air temperature, etc. After the main influencing factors have been eliminated, finally we got a heat amount to increase 1 m^2 of premises temperature by 1°C per 1 day. According to such criterion can be compared different types of buildings by different heating seasons. So there is defined the separate criterion for an evaluation, showing actual energy consumption in a buildings and which can be comparable – Actual Energy Consumption Class (AECC). According to that, all buildings are divided into 15 classes: 1 – most effective, 15 – worst. All different buildings can be compared – from smallest to largest. Can be compared buildings of the same project type, can be analysed, does a new building consume too much of energy due to a bad maintenance or does an old building consume too small amount of energy it should to use, does the consumption of building correspond to consumption of such type of buildings. All buildings are divided into different project types – Vilnius has 330 different project types and 740 different modifications. On a basis of this information have been performed different analyses. Analysis of individual metering for every final customer shows that the saving potential is 25 %. All this energy consumption information of every customer has been placed on a GIS platform and is shown in Vilnius City municipality page as an Interactive Actual Energy Consumption Class (AECC) map (http://www.vilnius.lt/stendas/siluma.html). This tool can be used also as a strategic energy efficiency plan for a whole city to identify districts suitable for low temperature heating, for buildings reconstruction (insulation), district heating development, etc. This interactive AECC map has won a first place for an Innovation in Energy among all Europe Cities in "Eurocities" organisation in 2014.

Kevin Vervuurt is a Senior Consultant in the Planning and Computation team of the Arup Amsterdam office and is mainly involved in long-term sustainable urban resource planning. His academic degree focused on studying urban models and gaining insight in the materialization of the built environment from a socio-economic perspective. Kevin is experienced in employing a multidisciplinary approach for urban re-development projects and has worked on different aspects of urban planning, energy planning and water management, while taking into account the social, environmental and economic value. He is specializing in energy planning, integrated resource management and climate change strategies for cities.

FP7 Ecodistr-ICT tool: a model for sustainable energy retrofit at district scale

Kevin Vervuurt, MSc, Laurens Tait, MSc, Ir. Peter Mensinga, Veronika Heidegger, MSc*
Arup, Naritaweg 118, 1043CA, Amsterdam, the Netherlands, Kevin.vervuurt@arup.com

The Ecodistr-ICT project, a collaboration of 11 partners, aims at developing an integrated decision support tool that facilitates decision making on the retrofitting and renewal of existing districts and its composing buildings. It connects the main decision makers in urban district transformation programs, acting from different perspectives, with different time scales, to reach a coordinated approach that joins building retrofitting with district renovation. This coordinated approach adds the benefits of the economies of scale on a district level and allows for optimization and prioritization of decision-making. The tool provides trustworthy insights on retrofitting and renewal projects, the associated costs and benefits during the life cycle of the buildings and the impacts of these on resource efficiency, social aspects, indoor and outdoor quality of buildings and districts, and environmental concerns.

An enormous diversity of operators is involved in the built environment who play a role in the decisions taken to design, build, occupy, renovate or renew buildings and districts. Currently, many of these stakeholders have their own decision making processes, which are not or only partially integrated. The Ecodistr-ICT tool can help to align all stakes and decisions to reach a mutually supported vision, based on comprehensible data.

As part of the Ecodistr-ICT tool an energy module is developed to compare different supply technologies. The module provides the stakeholders with an insight of the carbon emissions, costs and return rate of different supply options. The stakeholders can investigate three alternatives; (i) the conversion of existing individual heating systems to a collective heat network, (ii) transitioning an existing high temperature heat network to low carbon sources and (iii) for new developments supply a new network with low carbon sources. The supply technologies that can be tested in this model include primarily: Individual gas boilers, Individual Heat Pumps, Collective gas CHP, Collective Heat Pumps (GSHP).

The data input can be from generic average buildings to accurate and district-specific data level. One of the objectives is to gather and process a massive amount of data on properties of the district and especially the properties of individual buildings and building components. The value of the Ecodistr-ICT tool is that it delivers the innovation necessary to enhance the district retrofitting process. It focuses on the harmonisation and interactive operation of well-selected and validated knowledge and tools. By combining relevant tools intelligently, essential innovation is established on the level of combining scales (building/district), time (phases of the decision process) and multiple impacts.

Agris Kamenders is a docent at Riga Technical University performing research and lectures in energy efficiency in buildings and industry, district heating systems and renewable energy sources and cost optimality. Agris Kamenders has followed a large number of projects dealing with the implementation of energy efficiency improvement measures and the installation of energy efficiency technologies and renewable energy systems and has developed energy demand mapping procedures for municipalities.

Energy efficiency in buildings and impact on heating energy demand in Latvia

Agris Kamenders*, Dr.Sc.Ing., Kristaps Kass, MSc, Janis Ikaunieks, MSc, Marika Rosa, Dr.Sc.Ing., and
Dagnija Blumberga, Dr.Sc.Ing.
Riga Technical University, Institute of Energy Systems and Environment, Latvia
agris.kamenders@rtu.lv

In Latvia, district heating is widely used and overall district heating presents potential to utilize low quality energy sources, integrate flexible renewable resources, improve air quality, improve overall system efficiency, possible to use excess electricity produced from renewable ect. To utilize those all different possibilities district heating system should be developed and investments planned in advice. But taking into account that residential sector is the main energy consumer and majority of the Latvian building stock needs to be renovated it is possible that energy demand for heating could drop dramatically. Beside energy efficiency measures in residential sector medium-sized cities throughout Latvia are experiencing depopulation, aging of population and low birth rates. However very often during energy planning process feasibility studies are based on existing energy demand or even growth-oriented scenarios. Therefore very often such scenarios lead to false conclusions and inadequate measures for future DH development. Very often it leads to DH system inefficiencies and increase of costs per energy unit provided. Therefore the main question studied during this study is how the heating energy demand will change in a future and how existing DH systems could adapt.

During the article comprehensive easements covering the heating demand, based on measured data and energy consumption benchmarks for different types of buildings are given. For heating demand at sectorial breakdown and forecast of how this demand will evolve is given for years 2020 and 2030.

During the study questioner for DH companies have been developed and data collected to analysed energy demand and energy consumer supplied by DH. For energy consumers not connected to the DH grid, energy consumption was obtained based on building types and energy consumption benchmarks. For the most common types of buildings (office buildings, schools and multi-apartment buildings) energy consumption benchmarks have been obtained from the Central Statistical Bureau, while for the other types of buildings heat

consumption benchmarks values were based from local Sustainable Energy Action Plans (SEAP) and results from energy audits carried out in different type of buildings. Beside energy demand structure and energy consumption changes questionnaires allowed to obtain information about DH network and boiler technical characteristics.

Data summarized for each city and municipality - data about existing boiler capacities, fuel and heat consumption, boiler efficiency, installation year and existing heating demands. Based on building types and corresponding areas future energy demands forecasted for the years 2020 and 2030.

Line P. Pedersen has performed this study as a master's thesis. She has graduated as MSc in Sustainable Energy Planning and Management from Aalborg University.

The Socio-Economic Perspective of Conversion of Individual Heating to District Heating

Line P. Pedersen, lpp@niras.dk*
Sustainable Energy Planning and Management, Aalborg University, Denmark

The present abstract is based on a master's thesis as the end of the study Sustainable Energy Planning and Management at Aalborg University.

This thesis examines how the Danish heating sector can contribute to the transition to a fossil neutral society. District heating is considered to play an important role in the future Danish energy system and it is often discussed to expand district heating. However, there are conflicting conclusions in the existing research to whether the district heating sector should be extended or not, i.e. whether it is socio-economically feasible. This project therefore analyses the socio-economic perspective of converting individual heating to district heating. Unlike previous research, this thesis analyses a specific case: four potential district heating areas in the area of Aabybro in Northern Jutland.

The individual heating in the areas that are analysed in the thesis is mostly individual natural gas. In order to convert natural gas areas to district heating, it has to be the most socio-economically feasible project according to Danish law. The feasibility calculations have to be based on the guidelines by the Ministry of Finance and the Danish Energy Agency, hence this is also part of this thesis. Since the thesis is based on the theory of Choice Awareness, developed by Henrik Lund, the research question is also preserved by a more institutional socio-economic analysis, developed by the author of the thesis. In order to find the most socio-economically feasible project, several scenarios are developed. This is done by performing interviews with different stakeholders representing either natural gas or district heating, in order to get their view of the subject; including district heating in the future. The modelling of the scenarios is done in the program energyPRO.

Almost all scenarios in the thesis conclude that CO_2 emissions can be reduced by expanding district heating. The thesis also concludes that a significant amount of fossil fuels are saved in all of the scenarios. Using the guidelines by the Ministry of Finance and the Danish Energy Agency, the conclusion is that it is not socio-economically feasible to expand district heating in Aabybro. When using the alternative socio-economic model, the conclusion is that it is socio-economically feasible to convert to district heating at a discount rate of 0%. The most feasible scenario is district heating based on geothermal energy. It is also feasible if the individual consumers are supplied by district heating produced by solar heating combined with pit storage. At a discount rate of 2%, and if the socio-economic fuel costs are based on the prerequisites from December 2014 instead of on the prerequisites from April 2016, it is also socio-economically feasible to convert to district heating. The conversion is furthermore

shown to have a positive employment effect for the area. The fact that the current prerequisites do not support a conversion from individual heating to district heating is deemed to be contrary to the Danish policy objectives of reducing fossil fuels, since it is shown that a conversion will actually contribute to this.

Ashreeta Prasanna is an energy engineer with a background in mechanical engineering. She has more than four years of work experience in the area of energy research and consulting and has worked on model-based assessment of reliability, self-sufficiency and the environmental impact of renewable energy systems (heat and electricity) in the urban environment. She currently works on modelling and evaluation of advanced district energy concepts.

Modelling, design and assessment of a decentralised energy system in Switzerland

Ashreeta Prasanna and Viktor Dorer*
Empa, Urban Energy Systems Laboratory, Überlandstrasse 129, 8600 Dübendorf,
ashreeta.prasanna@empa.ch

The design, dimensioning and operation of decentralized energy systems which include renewable energy sources on the site/quarter/community level are complex tasks. In this paper we evaluate a low energy district in Switzerland. We use monitored data for heat demand as an input to a mixed integer optimization model and solve for minimum total costs or carbon emissions. This initial model is verified by comparing the optimisation results of electricity demand of equipment to measured data. We then include additional buildings and additional or alternative technology options which include increased heat and electricity storage (PV and battery, replacement of PV with PVT). The results of the optimisation of costs and emissions enable us to understand to what extent total heating energy can be supplied on site (through renewable or low carbon generation), if heat fluxes in the low temperature district heating network can be balanced, and what the benefits and drawbacks of the various options are.

Session 24: Low-temperature district heating and buildings

Professor **Dagnija Blumberga**, PhD student **Ieva Pakere** and master's degree student **Raimonda Soloha** are representing the Institute of Energy systems and Environment of Riga Technical University. Research of DH systems is continuing in the direction of expanding the solar energy share in existing 3rd generation on the way to 4th generation district heating.

Session Keynote:

Some aspects of low-temperature DH systems: solar energy share and integration of historical buildings

Dagnija Blumberga*, Raimonda Soloha, <u>Ieva Pakere</u>
Institute of Energy Systems and Environment, Riga Technical University
Azenes street 12/k1 – 605, LV1048, Riga, Latvia,
dagnija.blumberga@rtu.lv

Solar energy is an important renewable energy source for the transition from fossil fuel towards renewable based district heating (DH) system. In this case thermal energy storage (TES) system that is connected to the district heating network plays an important role. TES gives important benefits for the overall system operation as heat stored in summer can be used to cover peak loads during heating season.

Therefore, heat consumers are an important part of the system as they determine the energy supply. Heat load variations depend on the climate, social habits, behavior and other aspects. As for now it is important to analyze the district heating system parameters in existing buildings which have been designed for the high temperature heating carrier. By carrying out energy efficiency measures, for example energy management and thermal insulation of buildings, it is possible both to reach energy consumption reduction and reduce supply temperature of the heat carrier.

The paper describes the methodology and algorithm which allows evaluation the possibility to integrate solar energy in DH for space heating and domestic hot water supply as well as to optimize solar energy share in case of step by step introduction approach.

Methodology tested on district heating system analysis in municipality in Latvia with 20 thousand inhabitants. The existing DH system operation data are processed for use of analysis and optimization. The results show the main benefits and problems which need to be solved for the successful operation of the system.

Leif Gustavsson has more than 30 years of research and work experience. His main field of research is systems analysis from a bottom-up perspective linked to sustainable development, especially building construction, energy efficiency, renewable energy, forestry and the interaction between these fields. The aim of his research is to increase understanding of how resource- and cost-efficient systems with low environmental impact can be designed, analysed and implemented. **Nguyen Le Truong** has a PhD in Building Technology from Linnaeus University and a MEng in Energy Technology from Asian Institute of Technology. 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.

Energy efficient building blocks and low-temperature district heating

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

Keywords: Energy efficient building, renewable energy supply, low temperature district heating, climate change impact

There is great potential to build new energy efficient building blocks combined with energy efficient and renewable energy supply systems. Such a development contributes to achieve the national energy and climatic goals as well as the overall aim for a sustainable development. In this project, we analyse cost, carbon dioxide and primary energy efficiency for heating new building blocks with low temperature district heating and compare such heating with conventional district heating and heat pumps. We analyse the impact of climate change on heat and cooling demands, how cooling demands may be avoided, and if electricity instead of district heating can be used for local tap water heating during summer. The energy performance of the buildings is cost optimized and compared to those designed to fulfil the Swedish building code, passive house criteria or zero energy buildings. The results can be the basis for the planning and design of new building blocks and their energy supply systems to reduce primary energy consumption and increase the use of renewable energy in the built environment. An increased use of renewable energy allocated to efficient energy chains and energy efficient buildings will help to achieve the national energy and climate objectives and the overarching objective of sustainable development.

Rasmus Aaen has more than 13 years of experience in the energy and environmental industry and has developed a wide range of skills on project management and development and on procurement and construction within the energy sector. He has extended expertise on the design, planning and establishment of energy-producing plants and district heating networks. Rasmus has comprehensive knowledge of the different processes involved in development and construction projects, going from idea and visualisation to realisation and operation.

Energy + Communities

Rasmus Aaen, Chief Consultant at AAEN, part of NIRAS*
AAEN A/S, Nordre Strandvej 46, 8240 Risskov, Denmark, ra@niras.dk

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Buildings are built or renovated for increased energy efficiency which is putting traditional thermal energy supply under pressure. New building standards such as "passive houses" and "plus energy houses" are constructed alongside traditional buildings creating a complex mix of energy demands. In this future are communal energy systems eligible?

Research shows that B2020 standard buildings are not performing as expected, and energy usage is much higher than the designated design values. Furthermore, energy need and energy availability is seldom in balance in these new buildings. How can this imbalance be balanced?

Moving towards a low temperature future research indicates that communal energy systems may have a future, not as energy supply systems, but as energy balance systems operating in Energy + Communities.

It is the goal of the project to investigate options, strategies, challenges and synergies associated with the development of Energy + Communities.

Pedro Pattijn is a consultant and business manager on energy projects and sustainable buildings at Ingenium.

LATENT: low-temperature energy grid evaluation tool

Eng Pedro Pattijn*, Msc, business unit manager energy & sustainability, Ingenium
Raf Schildermans, IF Tech, Tom Feyaerts, Hydroscan, Kathleen Markey, Efika
pedro.pattijn@ingenium.be, Nieuwe St.Annadreef 23, 8200 Brugge, Belgium

Keywords: Low temperature, energy grid, evaluation tool, geothermal energy

The acronym LATENT means "LAge Temperatuur EnergieNet evaluatieTool" or "Low Temperature Energy Grid Evaluation Tool".

The project LATENT is a research project and examines the operational and legislative conditions to realize a collective energy grid on very low temperature.

The energy supply and systems for industry and buildings is traditionally and most commonly considered as an individual and privately owned system. Collective energy systems and grids are an interesting alternative. But why are they not considered in Belgium?

The current generation of highly insulated buildings requires a low heat demand and as a consequence they have a growing demand for cooling. Heat grids and heating systems should therefore be adapted to these new building conditions. They should make it possible to distribute and exchange energy on very low temperatures (5 to 30°C) in order that can be cooled and heated as well. The very low temperature energy grid uses natural energy sources (i.e. surface water as river, lakes, canal, sea… or ground water/energy by open or closed geothermal energy systems) or waste heat at very low temperature (i.e. sewage water or waste process water). It also offers the opportunity for exchange of energy between the users linked to the same low temperature energy grid.

The criteria for a LATENT energy concept:
1) The source temperature should be lower than 40°C
2) Energy supply (heat or cold) by energy grid to multiple end-users

We made an inventory of representative projects and concepts. Based on the inventory we identified several energy concepts for low temperature energy grid. They are mainly based on ground source systems with heat or cold buffering in combination with surface water as additional source.

We defined a roadmap and developed a quickscan-evaluation tool as a first step in this process. The evaluation tool is based on newly developed maps. One map shows the ground characteristics for energy supply by geothermal energy systems in Belgium. The map was developed by IF Tech. Another map shows the surface waters (rivers, canals…) in Belgium and was developed by Hydroscan. Both maps are used to identify the potential as an energy source for low temperature energy supply.

The evaluation tool is based on both a quantitative and qualitative evaluation. It gives a quick and short evaluation of the options and advises on further steps in the process.

The LATENT project is developed by 4 partners (Ingenium, IF Tech, Hydroscan and Kathleen Markey). It was started in October 2014 and finished in April 2016. The info which is available for public can be found on www.latent.be

Tommy Rosén is a PhD student with an MSc in engineering and with industrial background from the steam turbine industry. He conducts research at the division of Energy Systems at Linköping University on improvements in district heating and steam turbine plants and enhanced system integration for better energy efficiency.

Active management of heat customers towards lower district heat return water temperature

Tommy Rosén*, Louise Trygg
Division of Energy Systems, Linköping University, SE-581 83 Linköping, Sweden
tommy.rosen@liu.se

Keywords: District heating, system perspective, low-grade district heating, return water temperature

In the ongoing process of moving towards a more energy efficient society that reduces its CO_2 emissions and lowers its use of fossil fuels, district heating can play an important role in the improvement of regional energy systems.

The traditional way of managing supply and return water temperatures in district heating systems (DHS) is by controlling only the supply water temperature. The return water temperature then becomes a passive result that reflects the overall energy efficiency in the DHS. A DHS with many poorly functioning district heating centrals (low cooling) will create a high return water temperature and for the overall energy efficiency of the DHS that is negative in a number of ways e.g. lower efficiency in flue gas condenser, higher heat losses in pipes and higher electricity consumption in water pumps. An important secondary effect of lower return water temperature is in many cases a lower supply water temperature, for DHS with combined heat and power (CHP) this will mean higher electricity production.

With strategic introduction of low grade heat customers situated in proximity to central production units (CHP) the return water temperature can be lowered and in some extent controlled. A traditional approach where the DHS is regarded as a production plant connected to heat customers in parallel will only improve return water temperatures in the same pace as customers improve, by improved district heating centrals, refurbishment and introduction of new low energy buildings. Active management of some key customers can probably improve return water temperatures faster and in the long run lead to controlled return water temperature.

With the MODEST energy optimization software the DHS in the municipality of Linköping will be studied. New customers supplied with low grade district heating (DH) in the proximity to the CHP will be introduced and system effects regarding costs and CO_2 emissions will be analyzed.

Session 25: Energy planning and planning tools

Björn Karlsson is a Professor in Energy systems at University of Gävle and Mälardalen University in Sweden.

Session Keynote:

A critical analysis of the current primary energy assessment

Björn Karlsson, Ola Eriksson and Mattias Gustafsson University of Gävle*
bjorn.karlsson@mdh.se

The value of the primary energy resource is defined as the heating value of the energy carrier. This means that the energy quality or the exergy of the resource is not assessed. Table 1 illustrates the results of this definition. Ideal combustion of 2,5 kg of hydrogen, 6,5 kg of methane or 11 kg of coal will all deliver 100 kWh of heat. 100 m^3 of water in a hydro power station with a fall height of 367 meter can deliver 100 kWh of heat. 1000kg of water delivers 100 kWh of heat if cooled 86K. These are considered as identical energy resources. The heating value of a fuel is given by its enthalpy ΔH.

Table 1. Resources with primary heat energy 100 kWh

Resource	Mass	Heating Value
H_2	2,5kg	100kWh
CH_4	6,5kg	100kWh
C	11kg	100kWh
Hydro power, Fall height 367m	100 000kg	100kWh
Heat, ΔT=86K, water	1000kg	100kWh

Use of energy means that the energy is converted and the exergy is consumed. The exergy ε is defined as the ability to perform work or to deliver electric energy. When the energy finally is converted to heat of ambient temperature the exergy is exhausted, ε=0, and the energy cannot do work or heat a building. Table 2 shows that ideal conversion of 3 kg of hydrogen, 7 kg of methane or 11 kg of coal all will deliver 100 kWh of electric energy. 100 m^3 of water in a hydro power station with fall height 367 meter will deliver 100 kWh of electric energy. 417 kWh of heat stored as hot water at 359K can be converted to 100 kWh of electric energy in a Carnot cycle at ΔT=86K. All these resources are considered as identical exergy resources. The exergy content of the fuels is given by Gibbs Free Energy ΔG, which means that electricity is delivered in an ideal fuel cell.

Table 2. Resources with primary exergy 100 kWh

Resource	Mass	ΔG/ΔH, ε	Exergy Value
H_2	3,0 kg	0,83	100kWh
CH_4	7,0kg	0,92	100kWh
C	11kg	1,0	100kWh
Hydro power, Fall height 367m	100 000kg	1,0	100kWh
Heat, ΔT=86K (T_0=273K) water	4166kg	0,24	100kWh

Since fuel cells with this ideal efficiencies do not exist it is suggested that the exergy efficiency is replaced by a practical possible electrical efficiency. The result of this analysis is given in table 3.

Table 3. Resources with primary electric energy 100 kWh

Resource	Mass	Heating Value	Electric Efficiency	Electric Value
H_2	5,0 kg	200kWh	0,5	100kWh
CH_4	13,0kg	200kWh	0,5	100kWh
C	27,5 kg	250kWh	0,4	100kWh
Hydro power, Fall height 367m	100 000kg	100kWh	1,0	100kWh
Heat, ΔT=86K (T_0=273K) water	10 000kg	1000kWh	0,10	100kWh

5kg of hydrogen, 13kg of methane or 27,5kg of coal will deliver 100kWh of electric energy in a power cycle. 100 m^3 of water in a hydro power station with fall height 367 meter will deliver 100 kWh of electric energy. 1000 kWh of heat stored as hot water at 359K can be converted to 100 kWh of electric energy in a power cycle at ΔT=86K. These are considered as identical electric energy resources. We suggest that the current definition of primary energy as given by the heating energy value should be replaced by the electric energy value of the sources. This is as a modified exergy method, which takes into account the quality of the energy source. This means that the current primary heat energy values are weighted by the electric efficiencies in table 3, which define the practical energy quality of the primary energy source.

Nikola Botzov has graduated as a MSc student of Sustainable Energy Planning and Management at Aalborg University. He has carried out various student projects in the areas of district heating, balancing the energy system and integrating large-scale renewable energy. Currently, he works at PlanEnergi, Denmark.

Renewable energy alternatives for small district heating plants

Nikola Botzov*, nb@planenergi.dk
PlanEnergi, Jyllandsgade 1, DK-9520 Skørping

The thesis develops the methodology for assesses the possibilities for supplementing the heat production of small fossil fuel-based district heating plants with renewable energy. The analysis is performed from a technical and business-economic perspective.

Energy-related goals are investigated on the European and national level in Denmark, followed by an assessment of the Danish district heating sector. With the purpose of implementing the methodology for assessment of the feasibility of different technologies, the district heating plant Løgstrup Varmeværk is used as a case.

The operation of the district heating plant in Løgstrup is modelled and simulated with energyPRO. Consequently, three alternative scenarios, consisting of the current system together with solar thermal panels and a ground water heat pump are modelled. The technically optimal operation is calculated with the purpose of determining which technology is more suitable to be integrated.

This is followed by a business-economic assessment of the different scenarios, in order to determine which alternative decreases the heat production price at the plant the most.

Sensitivity analyses of different economic parameters in the main scenarios are conducted, with the purpose of investigating the technologies' robustness to variation of key parameters. This is followed by an optimization of the economic performance of the ground water heat pump.

Finally, the thesis concludes that solar thermal panels are currently more economically feasible for integration in small district heating plants in Denmark. Nonetheless, large scale heat pumps show a great potential for the district heating sector from an energy production perspective. Hence, if their business-economic performance is improved, they would be able to replace a large fraction of the production from natural gas-based units in district heating plants, while also balancing the electricity grid, through the utilization of excess electricity from wind turbines.

Hanne Kauko has a PhD in physics from the Norwegian University of Science and Technology (NTNU), and has since 2014 worked with waste heat utilization, heat pumping systems and thermal grids. MSc Karoline Husevåg Kvalsvik studied process engineering at NTNU. She works with advanced system modelling in Dymola and Comsol Multiphysics, within fluid- and thermodynamics, refrigeration and heat and mass transfer.

Modelling local low-temperature heating grids: a case study for Norway

Hanne Kauko*[1], Karoline Husevåg Kvalsvik[1], Daniel Rohde[2], Natasa Nord[2] and Armin Hafner[2]
[1] SINTEF Energy Research, Kolbjørn Hejes vei 1B, Trondheim 7491, Norway
[2] Department of Energy and Process Technology, Norwegian University of Science and Technology (NTNU), Kolbjørn Hejes vei 1B, Trondheim 7491, Norway
hanne.kauko@sintef.no

Keywords: Low-temperature district heating, thermal system modelling, energy planning

The current district heating (DH) networks in Norway are a mixture of 2nd and 3rd generation systems, with supply temperatures of 80-120°C owing to older buildings and industrial clients with a demand for high-temperature heat. In new developments consisting of buildings with low heating demand, it is desirable to shift to the 4th generation, low-temperature district heating (LTHD), in order to reduce heat losses as well as to facilitate better utilization of renewable heat sources and excess heat available from buildings and industry. In Norway, however, the supply temperature should not be lower than 65°C owing to the regulations directed to avoid the growth of the *Legionella* bacteria.

In this study, the application of a local LTDH grid in a new development, Brøset, that is planned to be built in Trondheim, has been analysed. The new Brøset will consist of residential buildings with a total heated area of 135,000 m², as well as a school, nurseries, an office building, nursing homes and a sports hall. The area additionally includes two large protected historical buildings.

A local heating grid supplying heat to the buildings at Brøset has been modelled in the dynamic simulation program Dymola (Figure 1). The model includes hourly heat demand data for the different type of buildings, an energy plant, a heat distribution network, and a pressure loss model. For the heat demand, actual DH use data from buildings located in Trondheim with building standards corresponding to the building stock to be built at Brøset was employed. Distribution heat losses and pump energy use have been analysed for different supply temperatures, ranging from 55°C to 95°C. A supply temperature of 55°C is applied for instance in Denmark, and this case has been included as a possible future scenario. Firstly, a connection to the municipal DH system via a heat exchanger was simulated for the suggested temperature levels. Further, the model has been extended to include distributed renewable and waste heat sources.

In addition to different supply temperature levels, different scenarios for supply and return temperature control, as well as one scenario with peak load shaving through thermal storage

locally in the buildings, have been investigated. The model includes also estimation for the costs and environmental impact in the form of CO_2 equivalents for the suggested heating grid. The results will serve as a support for the local DH company for designing heating grids for new developments.
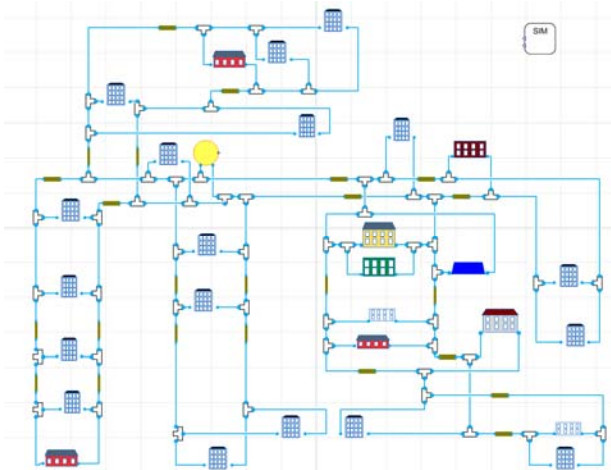

Figure 2: Dymola-model of a heating grid and an energy plant (yellow sphere), supplying heat to the buildings at Brøset.

Sara Ben Amer-Allam holds a MSc Eng. in Sustainable Energy Planning and Management from Aalborg University. Currently, she is employed as a PhD candidate at the Technical University of Denmark researching sustainable cities and the application of energy models for planning urban energy systems.

Modelling of low-carbon municipal heat supply: lessons learnt from a Danish and Czech case

Sara Ben Amer-Allam, Daniel Møller Sneum, Stefan Petrovic and Marie Münster*
Technical University of Denmark (DTU), Management Engineering Department, Systems
Analysis Division, Produktionstorvet, Building 426, 2800 Kongens Lyngby, Denmark
sbea@dtu.dk

Flexibility is an indispensable characteristic of future smart energy systems. Advanced district heating systems should be flexible to be able to cope with increasing share of intermittent renewables, while maintaining secure and affordable heat supply. These requirements often go together with city-level CO_2 emission reduction plans. District heating networks are usually applied in urban areas due to their high heat density, thus municipalities often require the heating system to provide cost-effective low-carbon supply.

This study analyses two cases: Helsingør in Denmark and Litomerice in Czech Republic. Both municipalities are relatively small (60,000 and 25,000 inhabitants, respectively) and have a similar amount of heating degree-days (3,310 and 3,340, respectively). Nonetheless, their coverage with district heating is different, as well as the age of their district heating networks, fuels used for production of electricity and district heating, heating demands of buildings stock, availability of waste heat etc.

The aim of this paper is to assess the prerequisites and consequences of increasing flexibility on a local scale. Using the energy modelling tool energyPRO, we simulate two setups for each municipality: a reference – with existing combined heat and power plants and an alternative – more flexible one. We choose among the following flexibility measures: implementation of renewables such as large-scale geothermal and solar thermal, use of electricity in the form of electric boilers or heat pumps, generation control of heat units, and heat storage. Next, we compare the results of simulations, concerning total (investment, operation and maintenance and fuel) costs, private-economic value of flexibility measures and CO_2 emissions. These indicators will form a framework for assessing flexibility of a district heating system, which can also be applied in other geographical locations.

Our expected results will depict the differences in applicability of flexibility in a Danish and Czech case. We also expect to find out how implementing flexibility measures in a local district heating system influences the techno-economic operation of a plant and, consequently, the local heat prices. Finally, the study will provide reflections on the applicability of the tool (energyPRO) for the purpose and in the specific cases, and, if relevant, suggest improvements of the tool.

Raffaele Salvucci is a PhD student at the Technical University of Denmark at the division of System Analysis. His field of research is energy system modelling and technology optimal integration, focusing on potential district heating, power and transport sector synergies within the Nordic energy system.

Production of future district heating and cooling – applying TIMES models on six European countries

Raffaele Salvucci*[a], Stefan Petrovic[a], Kenneth Karlsson[a], Tobias Fleiter[b], Lukas Kranzl[c], Rasmus Bramstof [a] and Richard Büchele [c]
[a]Department of Management Engineering, Technical University of Denmark, Produktionstorvet, 2800 Kongens Lyngby, Denmark, rafs@dtu.dk
[b]Fraunhofer Institute for Systems and Innovation Research, Breslauer Strasse 48, 76139 Karlsruhe, Germany
[c]Institute of Energy Systems and Electrical Drives, TU Wien, Gußhausstraße 25-29, A-1040 Wien, Austria.

The aim of the ProgRESsHEAT (acronym for integrating policies for renewable and efficient heating and cooling sector on a local, regional, national and European scale) project is to investigate the future heating and cooling sector in six European countries, namely Denmark, Germany, Austria, Czech Republic, Romania and Portugal.

The analyses are going to be performed by six national TIMES (The Integrated MARKAL-EFOM System) models. TIMES models are technology-rich, cost-driven optimisation models, which assume full foresight and perfectly competitive markets.

Traditionally, energy system analysis tools have been developed with a strong focus on the energy production technologies and the supply side. With the growing awareness of the importance of energy efficiency measures and the trade-off between investments in energy production and energy savings, it becomes important to improve modelling of the demand side in energy system analysis tools. In this project, this is done by combining the detailed modelling of the energy demand in buildings with the Invert/EE-Lab tool developed by Vienna University of Technology, and the detailed modelling of energy demand in industries with the FORECAST-Industry developed by Fraunhofer ISI.

Most significant inputs to TIMES models are provided by these two models. In particular, the Invert/EE-Lab is a bottom-up simulation model that calculates energy demand for heating and cooling and simulates energy-related investments in buildings. The calculation of energy demands is based on national standards and includes user behaviour. Energy-related investments are simulated based on a combination of approaches from decision theory as well as diffusion theory. Both investments regarding the building envelope and heating and cooling systems inside the buildings are simulated. Invert/EE-Lab provides the

TIMES models with detailed projections of future energy demands in buildings (electricity, district heating and cooling).

While the FORECAST-Industry model is a simulation based bottom-up energy demand model which represents the entire EU industry on a country level and aims at developing energy demand scenarios for the time range 2020-2050. As the model explicitly considers about 60 industrial processes and additional crosscutting technologies it allows disaggregating heat demand by temperature level. FORECAST-Industry provides the TIMES models with detailed projections of industrial heat demand and waste heat supply.

The main role of TIMES models is to determine the investment and operation path with the minimal cost for the whole energy system. The analysed national energy systems are different in many regards: demands for electricity, heating and cooling as well as national policy targets, existing district heating and cooling infrastructures, renewable energy potentials, etc. Future scenario analyses are performed for each of the countries within a time horizon up to 2050. Results will include optimal investment in electricity, heat and cooling generation technologies, their operation, quantification of emissions and fuel consumption.