The Smart Cities concept and challenges for heat networks

First Solar District Heating conference - Technical solutions, urban planning and business models, April 9-10, 2013 - Malmö, Sweden

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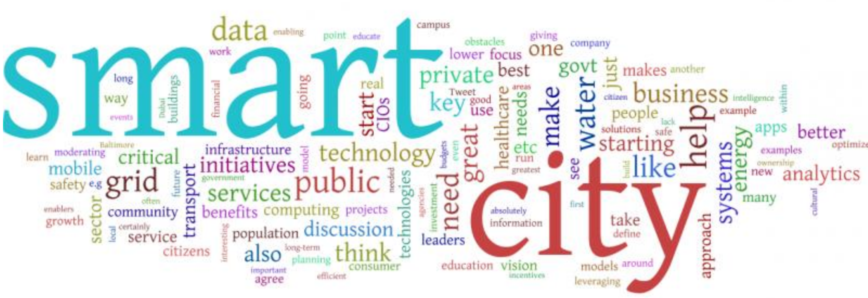
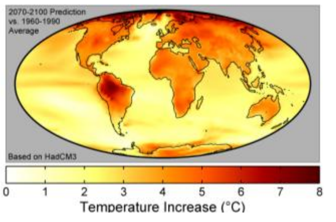
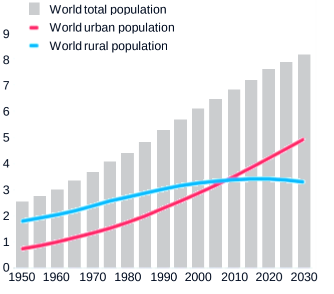


Smart Cities: Drivers and challenges

- Climate change – reduction of CO_2-emissions
- Dependency on fossil energy sources
- Strong coupling of CO_2-emissions to GDP
- Increasing energy demand
  - Growth of population (7 bn in 2011, 10 bn in 2050)
  - Industrialisation
  - Increasing wealth + living standards
- Worldwide trend of urbanisation
  - EU: 2/3 of final energy use in/ around urban areas
- Challenge and chance
  - Urban areas display huge potential for energy efficiency
  - Cities as centres for innovation, policy making, industry and research



http://www.globalwarmingart.com/



Urban & rural population of the world, 1950-2030. Source: UN Population Division.

Smart Cities: New concepts and radical innovations needed

- Considers the city as a whole in all its complexity (**holistic approach**)
- **Focus on energy** and resulting carbon emissions
- **considers interactions** to mobility, water, waste, the quality of life of its citizens and socio-economic conditions within the city.
- Requires intelligent **energy management** on regional & city level
  => ICT & Energy Technologies are merging
- Requires multidisciplinary and integrated **energy and city planning**
  => From a single technology approach to a multi technology approach
  => Understanding and optimizing infrastructure on a system level
- Relies on the **integration of processes, concepts and technologies**
  => including the integration of all relevant stakeholders and the implementation of new business models and new innovation processes

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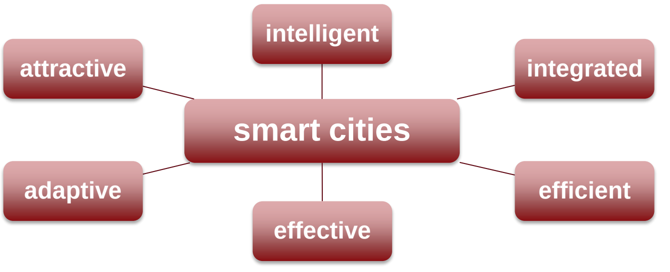
Smart Cities: Properties

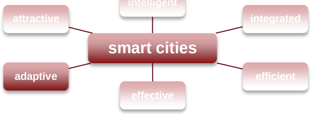
- **Following set of six properties of Smart Cities** is proposed based on
  - a broad review of actual definitions for smart cities,
  - international projects in this field and
  - a consultation process of (Austrian) stakeholder.



⇒ **Filling these terms with content and**
⇒ **deriving implications for thermal networks**

Saringer B., Pol O., et al., *SmartCitiesNet, Evaluierung von Forschungsthemen und Ausarbeitung von Handlungsempfehlungen für „Smart Cities“*, Vienna, April 2012, Project report within the program „Haus der Zukunft“

1. Smart Cities are adaptive

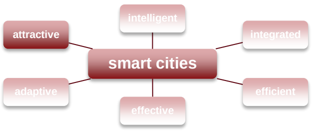


Systems adapt themselves to new framework conditions and keep their functionalities while considering new situations

Implications for thermal networks

- adaptation to an a) increasing fraction of renewables, b) increasing retrofitting rates, c) increasing cooling demand, d) increasing fuels costs
- *short-term:*
  - supply and demand side management (Storages, load shifting …)
- *Medium-term:*
  - adaptation of the temperature level in existing networks
  - Installation of distributed micro-networks connecting a few buildings
- *long-term:*
  - adjusting the network development with urban planning processes
  - “performing the right investments at the right time”

2. Smart Cities are attractive



Attractiveness for citizens and investors leads to increased quality of life and secure perspectives for investors

Implications for thermal networks

- *Attractiveness for the citizens*: increase motivation to connect:
  - Enable the customer to control their comfort (smart meters) and to
  - participate (business models/ fair, transparent, flexible tariff systems)
  - improving the image of DHC, avoid destructive construction works
- *Attractiveness for investors:* Overcome the barriers for infrastructure investments (long pay back periods) and waste heat utilization (back-up systems, low energy prices, focus on product quality):
  - cost reduction (e.g. via standardization)
  - new business models, legal frameworks for harvesting waste heat
  - channeling the use of public funding, adjusting subsidies, integration with urban planning processes

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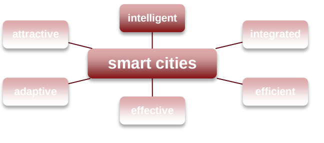
3. Smart Cities are intelligent



Innovative approaches are developed. New information and communication technologies are used

Implications for thermal networks

- *First*, thermal networks need to be intelligently planned or adapted.
  - Including long-term development scenarios
  - Options for topology, typology and operation parameters
- *Second*, thermal networks need to be operated intelligently.
  - real-time metering + control (rarely implemented at substation level)
  - crucial with increasing number of distributed producers/ storages
- *Third*: end-users should access, visualise and interpret consumption data
  - modify temperatures and heating schedules (Smart Metering)
- *Last:* connection of new loads, e.g. white goods as like dishwashers.

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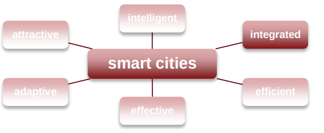
4. Smart Cities are integrated



Synergies are generated through intelligent system integration and cross-links between thematic fields. Expanding system boundaries enables a better understanding of interactions. Intersectoral aspects are also to be understood on a spatial level (e.g. co-operations between cities and their surroundings)

Implications for thermal networks

- *Integration from a* <u>*spatial point*</u> *of view*:

City planning	Energy planning
urban morphology (density, height …), mixed uses, buildings characteristics, socio-economic factors …	heating/ cooling demand, heat losses, active/ passive use of solar energy, occurrence of heat islands …

=> (were) is DHC feasible? In what configuration (micro networks/ city-wide networks or regional heat transport networks)

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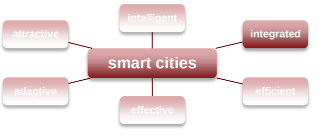
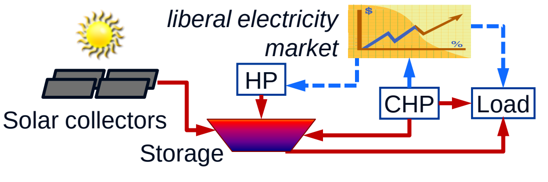


Implications for thermal networks

- *Integration from an* <u>*energy system point*</u> *of view:*
  - Interface to the <u>electricity</u> system



Modified from: Jan Erik Nielsen (PlanEnergi), Smart District Heating, "The Contribution of Renewable Heating and Cooling technologies to the "Smart Cities initiatives" - Workshop February 9th 2011, Brussels

  - Other interface, e.g. to <u>mobility</u> services:
    - electricity demand for the e-mobility => shift ratio between electricity and heating energy => effect on the operation of CHP
    - Increasing battery range by covering thermal demand of vehicles with portable thermal storage in combination with DHC
    - use of alternative fuels in CHP or directly in mobility applications?

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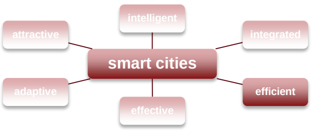
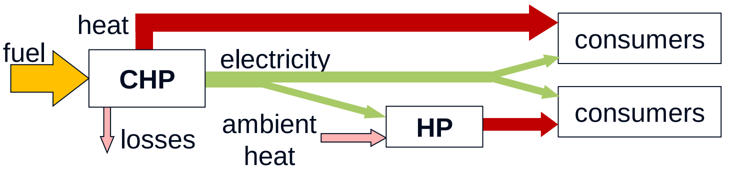
5. Smart Cities are efficient



In comparison to non-integrated approaches, significant efficiency improvements and energy demand reduction levels (in particular from fossil energy sources) are to be obtained. A maximum end-use output is to be obtained from a minimal use of resources

Implications for thermal networks

- A high overall efficiency could be achieved by using a combination of CHP plants and heat pumps (depending on the COP of the heat pump and the thermal efficiency of the gas turbine)



Blackwell, H.: *Looking to the future: CHP, Heat pumps and the best use of natural gas and biomass fuels*, CIBSE Technical Symposium, DeMontfort University, Leicester UK – 6th and 7th September 2011

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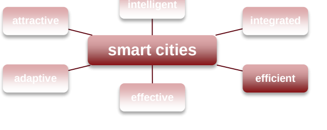
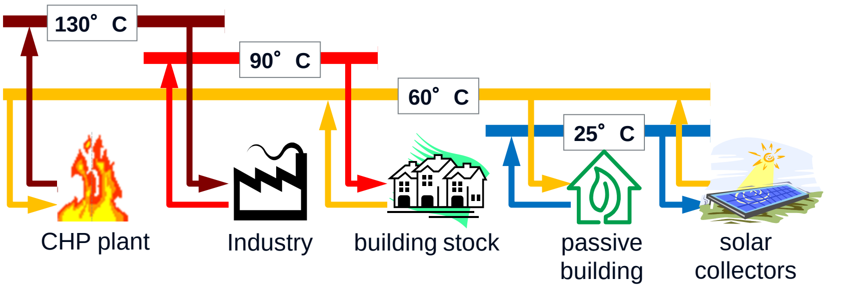
5. Smart Cities are efficient



Implications for thermal networks

- Thermal networks will enable a maximum exploitation of available energy resources by cascade usage



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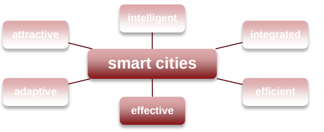
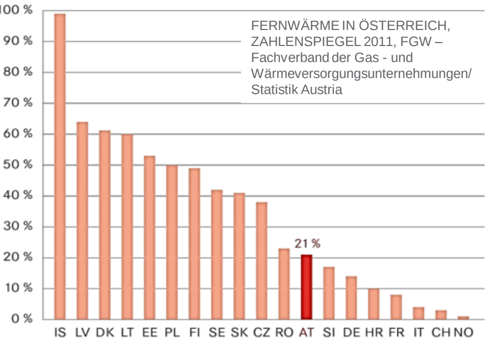
6. Smart Cities are effective



In comparison to non-integrated approaches, significant impacts are to be obtained. The higher effectiveness is to be understood with regard to indicators characterising the future urban and post-fossil society

Implications for thermal networks

- measures have a significant impact on the overall urban energy system efficiency when the broad diffusion of the technology is given.
- any change in the thermal network related production facilities brings environmental benefits to consumers connected



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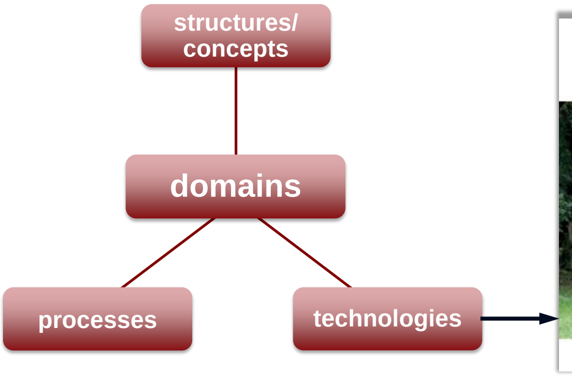
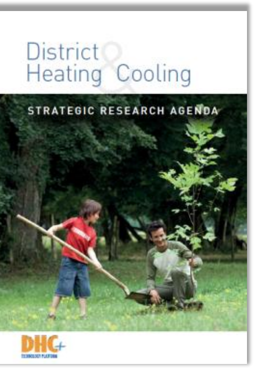
How to enable the transition of thermal networks

- to enable thermal urban networks to support and drive a smart city development, concrete adaptations are necessary in following fields:





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Structures/ concepts I

- **Low temperature networks, cascade usage**
  - *Challenges:* no standard planning procedures, high complexity, no legal framework/ business model for waste heat delivery
  - *Opportunities:* components available, case studies implemented, design methods under development

- **Interface to other networks (CHP and heat pumps)**
  - Challenges: HP as concurrence to DH, development and implementation of HP (high temp.) necessary, impact on CHP operation
  - *Opportunities:* low-temperature networks/ reduced building energy demand enable HP to be used as centralised heating sources

Structures/ concepts II

- **Interface to efficiency measures**
  - *Challenges:* high distribution losses due to retrofitting
  - *Opportunities:* priority areas for retrofitting, low temp. networks

- **Energy management (supply and demand side management)**
  - *Challenges*: hydraulic/ ICT limitations, customer comfort, no legal basis, minor motivation (fixed heat prices/ cheap peal load coverage)
  - *Opportunities*: progresses in metering techniques/ ICT, customers used to ICT, simple control strategies available, potential for large loads

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Technologies I

- **Energy conversion technologies**
  - *Challenges*: flexible and efficient heating & cooling technologies needed
  - *Opportunities:* many technologies available/ in a test phase
- **seasonal storages**
  - *Challenges*: high costs, high heat losses, low awareness
  - *Opportunities:* experience from short term storages, demo sides
- **Components**
  - *Challenges:* out-dated & not easy replaceable infrastructure, disruptive construction/ maintenance works, handicraft production, designed for T > 70° C, bi-directional heat transport,
  - *Opportunities:* low temp. DH enable cost effective installation, multi piping systems, standardisation, non-invasive construction possible

District Heating & Cooling: Strategic research agenda, March 2012, DHC+ Technology Platform

Technologies II

- **Sensors and communication technologies (Smart heat meter)**
  - *Challenges:* costs, legal issues (e.g. data security and privacy)
  - *Opportunities*: ongoing development, spread of ICT (e.g. wireless)
- **Household appliances with DHC connection (e.g. washing machine)**
  - *Challenges:* marked availability, costs, installation costs (new piping)
  - *Opportunities:* application to larger consumers, cooling also possible,
- **Domestic hot water (DHW) preparation in low temperature networks**
  - *Challenges:* removing legionella possible but cost intensive
  - *Opportunities:* DHW production without storage possible

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Processes

- **Planning processes**
  - *Challenges:* innovative concepts not supported/ framework missing, increasing number of stakeholders, limited data available
  - *Opportunities:* easy implementation in new developments, in existing structures, processes have to be developed
- **Business models**
  - *Challenges:* key element for supporting innovative energy infrastructure, regulatory frameworks are often missing,
  - *Opportunities:* different business models (e.g. ESCO, PPP) are existing/ can be derived from experience in electrical networks
- **Implementation process**
  - *Challenges:* adaptation of DHC infrastructure in a transition environment, long term contractual conditions,
  - *Opportunities*: developing small-scale networks (e.g. low-temperature district heating), junction of first micro-networks in future.

Solar District Heating: Challenges

- High costs for attaining the **networks temperatures** with solar energy (especially in winter) and **hydraulic conditions**
- Risk of **substituting alternative heat sources** (e.g. industrial waste heat)
- Available **areas for storages** in urban areas limited and costly
- Competition for **space use** (PV, passive solar use and green spaces)
- Missing **awareness of urban planners** for (solar) district heating
- No **business models** for third party access to DHC networks

Solar District Heating: Opportunities

- A carbon neutral heating and cooling supply requires a **maximum exploitation of all available** renewable energy sources
- **Cascade usage** and low-exergy networks will increase the potential of solar thermal energy and the feasibility of thermal networks in general
- Cooling networks open new opportunities for solar thermal energy via **absorption chillers** ("solar cooling")
- Advanced **energy management** strategies (e.g. storage integration and load shifting) will increase the capacities for hosting solar thermal energy
- Many activities fostering **solar urban planning**, creating opportunities for micro DH networks (some pilot systems are already implemented)
- **Business models** can be derived from experience in electrical networks

⇒ Interactions on multiple levels require a **detailed analyses of the individual situation!** (Multi-criteria optimization)

Summary

- Thermal networks can play an important role in the future Smart Cities if they can ensure a reliable and affordable heat and cold supply to various customers with renewable energy carriers and waste heat.
- For this purpose, following main strategic implications for thermal networks were identified:
  - **Temperature adaptation:** cascade usage and increasing the potential of renewable energy resources and reducing heat losses
  - **Supply and demand side management:** enabling adaptation to fluctuating energy generation and reducing peak loads
  - **Optimization of the interfaces to other energy networks** (e.g. via HP and CHP), increasing the efficiency and the system flexibility
  - **Interaction with urban structure and urban planning processes:** aligning planning processes, setup of distributed micro-networks
  - **Introduction of new business models, cost reduction** and technological developments (standardisation, more flexible systems)

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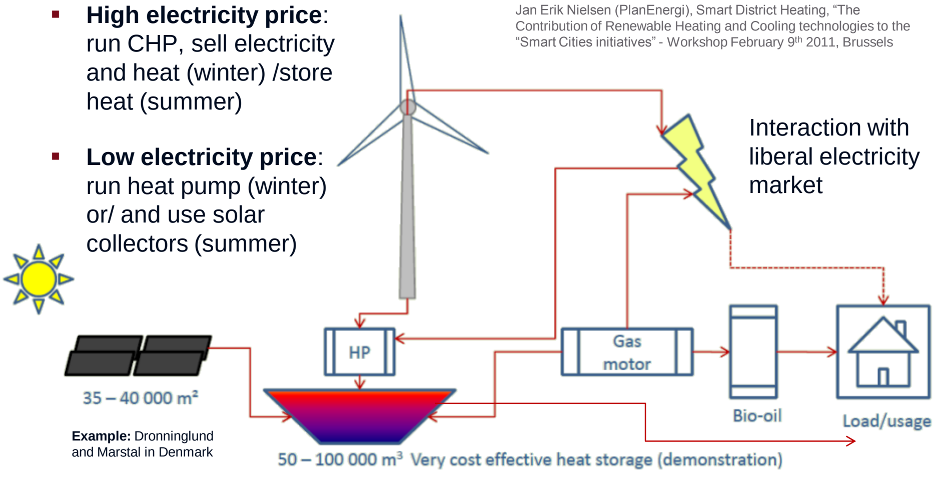
interface to electricity system: integration of renewables

- **High electricity price**: run CHP, sell electricity and heat (winter) /store heat (summer)
- **Low electricity price**: run heat pump (winter) or/ and use solar collectors (summer)

Jan Erik Nielsen (PlanEnergi), Smart District Heating, "The Contribution of Renewable Heating and Cooling technologies to the "Smart Cities initiatives" - Workshop February 9th 2011, Brussels



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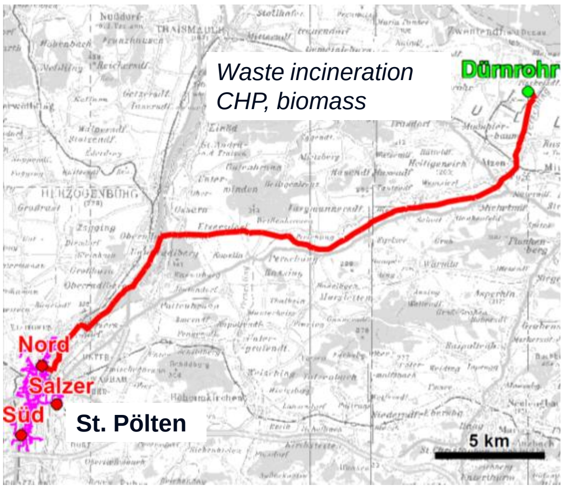
connection to energy sources in surrounding regions

Example EVN:

- Heat transport line from power plant **Dürnrohr** to the city of **St. Pölten** (52.000 inhabitants)
- Total length: **31 km**
- Diameter: 0.4 / 0.45 m
- Heat delivered: ab. **200 GWh** per year
- **Coverage of 2/3 of the heat demand of St. Pölten**



Oberhammer, A.: Die längste Fernwärmeleitung Österreichs, Bericht über die Planung, den Bau und die Qualitätssicherung, Vortrag anlässlich der Fernwärmetage 2010, 17.–18. März 2010 http://www.gaswaerme.at/de/pdf/10-1/oberhammer.pdf

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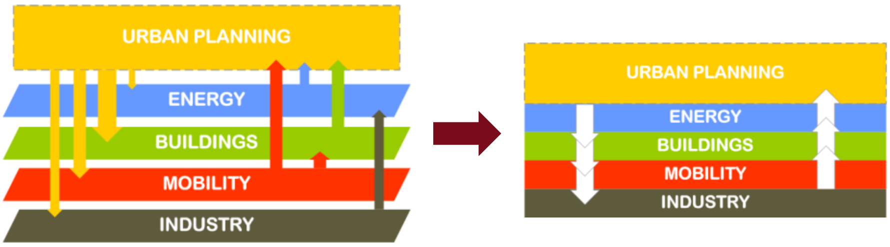
Integrated Smart Infrastructure Development

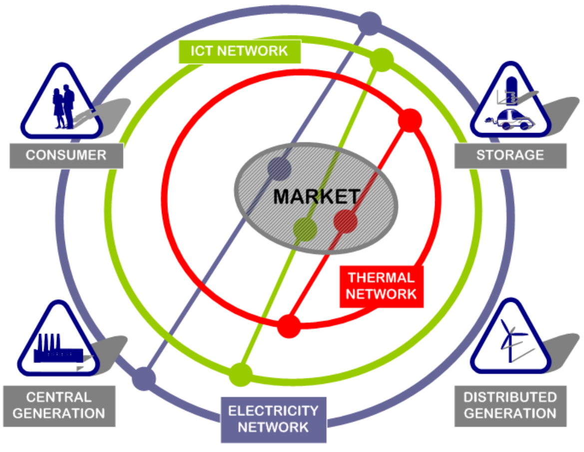
- **Understanding + optimising infrastructure on a system level …**
- **….**by developing methods and concepts which focus on a comprehensive approach targeting all energy related aspects



Smart Grid

Requirements on the ‚Smart Grid'

- Many decentralized producers
- Power Grid combined with IT network
- New decentralized storage to compensate consumption and production
- Customers adapt their behavior: Smart Meters



Important factors for energy planning

Urban morphology: density, height, building typology	heat losses, natural lighting, passive/active use of solar energy, wind flow, district heating feasibility, heat islands, energy for pumping and lifts …
Mixed uses: area required +proximity for different uses	Energy system configuration (e.g. heating system/ cooling) and design (e.g. load profiles)
buildings characteristics: physics, applications characteristics	Energy demand, source of energy, energy system (design)
Socio-economic factors: education, income, gender, …	size of apartments and their equipment, user typology (influence on operation)

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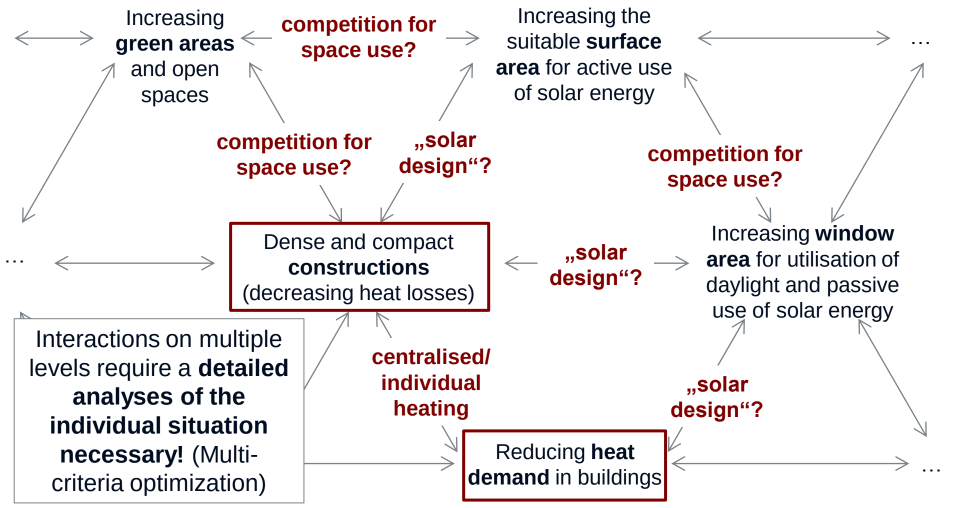
Interactions between aspects of energy and city planning



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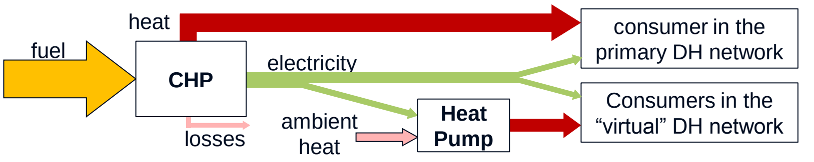
interface to electricity system: coupling CHP + heat pumps

- What is optimum production of heat (& cold) & electricity?
- Heat pumps coupled to e.g. CCGT CHP can offer a higher overall system efficiency
- Existing district heating networks should be used but extension of networks (especially in built up areas) is costly and intrusive
- „virtual“ extension of an existing district heating/cooling network by decentralised production of heat and distribution via micro-grids

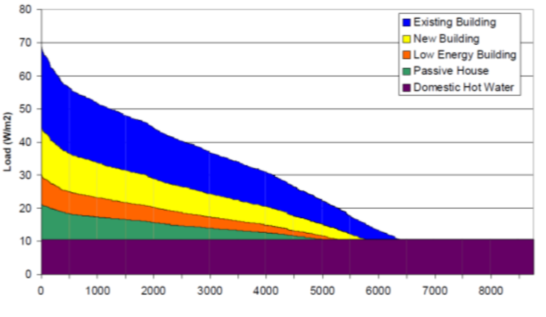


- Similar options with district cooling networks possible

Pierluigi Mancarella: Distributed Multi-Generation Systems: Energy Models and Analyses, Nova Science Pub Inc (August 2008)

Motivation for low temperature networks

- space heating in traditional residential buildings is often generated based on radiation heat transfer via radiators at about 60° C.
  - Distribution losses in district heating pipes are in the range of 10-30%
- Reduced heat demand of buildings (due to thermal insulation) decreases cost effectiveness of district heating networks
  - Also valid for sparsely populated areas

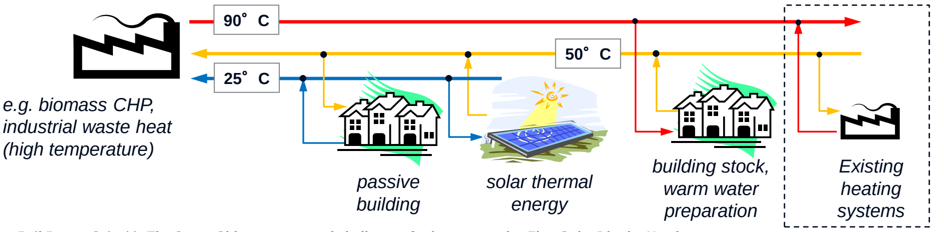


Load profiles of different building types

Kari Sipilä: VTT: District Heating for Energy Efficient Building Areas, 31.08.2009, Tuusula, FI

Low temperature district heating

- Low supply temperatures (30-40° C) are sufficient to gain comfortable room temperatures in buildings with suitable heating systems (e.g. floor heating, concrete core activation)
- Advantages of low supply temperatures:
  - lower distribution heat losses due to lower temperature gradient
  - lower invest costs possible (cost effective installation of flexible plastic pipes)
  - Increasing the potential of renewable resources like solar thermal energy and low temperature waste heat (that is in general removed by cooling towers)
- E.g. integration of passive buildings in the return line:



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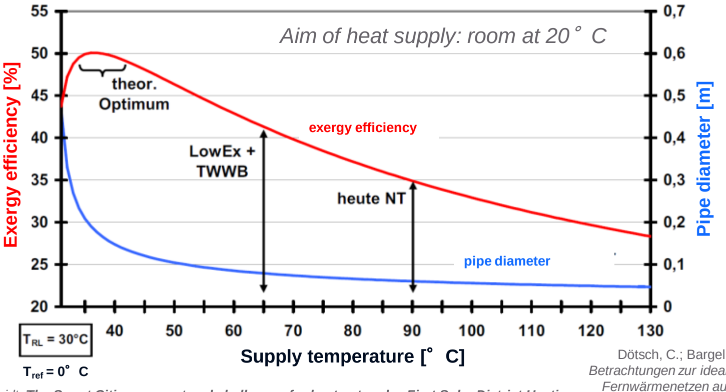
Option for new DH systems connected to existing buildings

Exergetic evaluation of district heating supply temperatures

- Exergy is a measure of the actual potential of a system to do work. Whereas electrical (and mechanical) energy consists of 100% exergy, the exergy of thermal energy depends on its temperature related to a reference system.
- Simulation results for an example network:



Dötsch, C.; Bargel, S.: *Theoretische Betrachtungen zur idealen Temperatur in Fernwärmenetzen auf Grundlage einer exergetischen Bewertung*, Vortrag auf dem LowEx Symposium in Kassel, 28-29 Oktober, 2009

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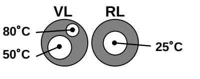
Low supply temperatures: domestic hot water preparation

- Depending on national regulations, when storing domestic hot water (DHW) a minimum temperature level has to be kept to avoid legionella
  - E.g. ÖNORM B 5019: in public buildings, 60° C has to be exeeded permanently
- Approaches for low temperature networks:
  - Supply temperatures above 65°C (trade off to traditional systems)
  - direct DHW preparation without storages (high peak loads) – e.g. storage on primary side to avoid peak loads
  - additional heating (e.g. via heat pumps, electric heaters, solar energy…)
    - In distributed heating stations at the consumers
    - In a central heating station and distributed via three-pipe systems

- **These approaches have to be evaluated depending on the available energy resources, network topology, consumer structure …**



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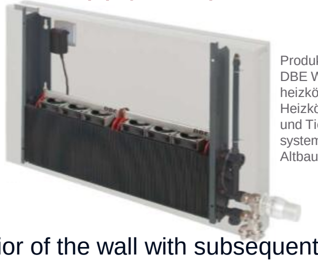
Building retrofitting compliant to low supply temperatures

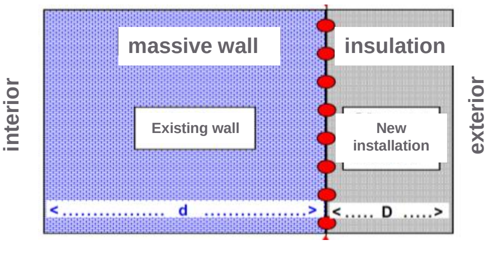
- E.g. exchange of existing radiators with low temperature radiators
  - Efficient heat transfer due to the use of aluminium/ copper, for peak heating periods: enhancement of heat transfer with fans



Produkt -Broschüre Jaga: DBE Wärmepumpen-heizkörper, ECO Heizkörper für Fussboden und Tieftemperatur-systeme, Einsetzbar in Altbau und Neubau, 2011

- E.g. heating system applied to the exterior of the wall with subsequent thermal insulation

Altgelt, Luther, Mahler: Außen liegende Wandheizsysteme für Niedertemperaturanwendungen (LEXU-aWH),
Schmidt, D.: Einsatz von innovativen LowExSystemen für Gebäude und Siedlungsgebiete, LowEx Symposium, Kassel, 28-29 Oktober, 2009



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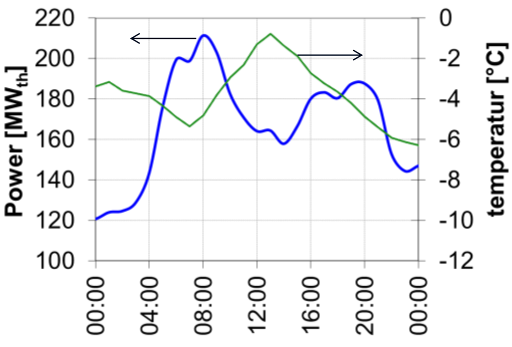
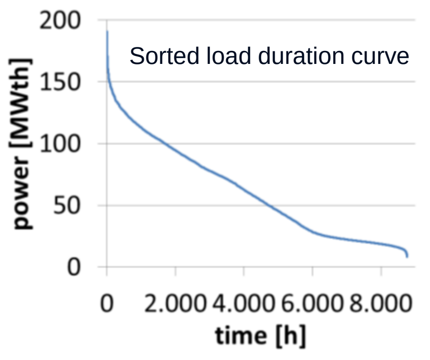
Peak loads in thermal networks





- peak load generation are usually boilers (without combined power generation) based on fossil combustibles (gas, oil).

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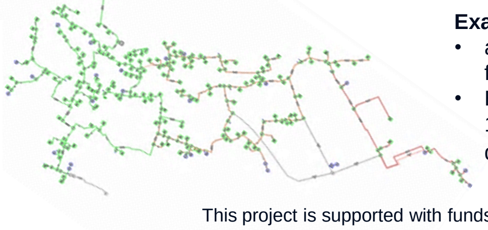
Project example: Smart Heat Networks

- Research project within the Smart Grids Modellregion Salzburg
- National funding, consortium: AIT, Salzburg AG, (municipal DH supplier)
- Aim: analysing and evaluating the potential of Smart Grid concepts for district heating systems, **focus: the reduction of peak loads**
- Method: **Dynamic network simulation** and model calculations are applied to investigate intelligent operation strategies and control mechanisms.
- project start: 01.03.2010, project end: 31.11.2012



Example Network: Altenmarkt (Salzburg)
- ab. 250 buildings connected, many single family houses, some hotels and mixed use
- Biomass heating plant with ORC process, 10 MW connected load, 23.000 MWh heat delivered (2009)

This project is supported with funds from the Climate and Energy Fund and Implemented in line with the "New Energies 2020" programme.

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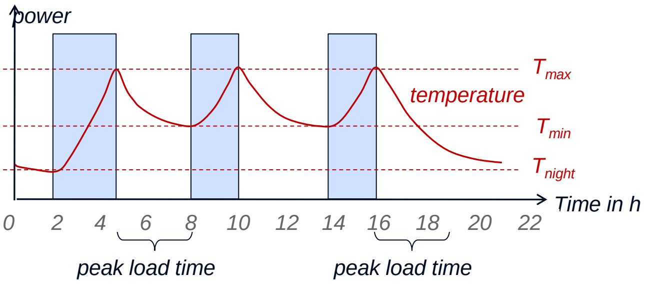
Load shifting in thermal networks

- Shifting controllable loads for
  1. minimisation of peak loads and
  2. adapting to fluctuating energy resources



- Possible loads for shifting: **building mass (e.g. night set back),** storage for domestic hot water, intelligent household appliances with connection to DH, swimming pools ...

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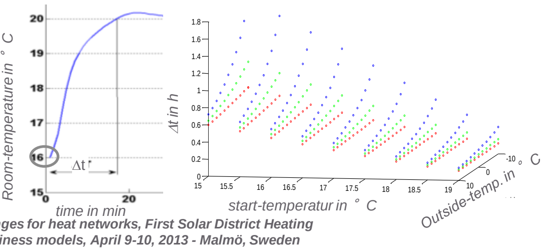
Chosen method to determine load shifting potential

- Selection of a **demonstration DH network** (Altenmarkt, ab. 250 buildings)
  - Survey to determine (missing) building properties
    - Age of the Building
    - Number of (heated) floors,
    - Type of usage,
    - Thermal renovation
    - Pictures of every building

- Analyses of **monitoring data**
- Dynamic **building simulation** to determine the load shifting potential (Δt)
  - Multiparameter variation:
    - Type of walls,
    - Air exchange rate,
    - Outdoor temperature,
    - start temperature,
    - Size of the building,
    - Heating system



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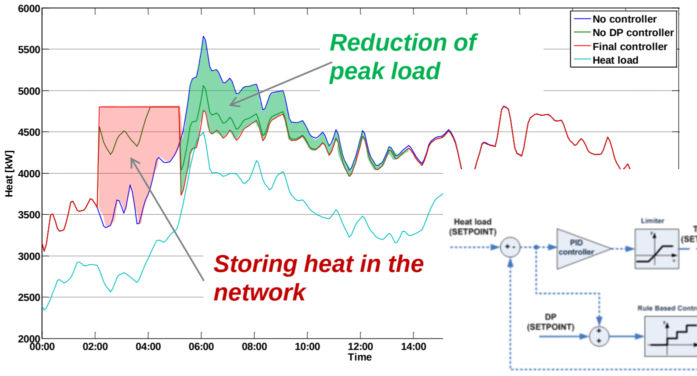
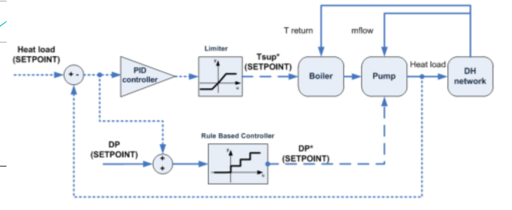
utilizing the capacity of the district heating network as a storage

- The distribution of heat within the network has a high inertia
- the volume of the pipes could be utilised to store heat in off-peak times to reduce peak loads by supply temperature and mass flow variation



PID controller



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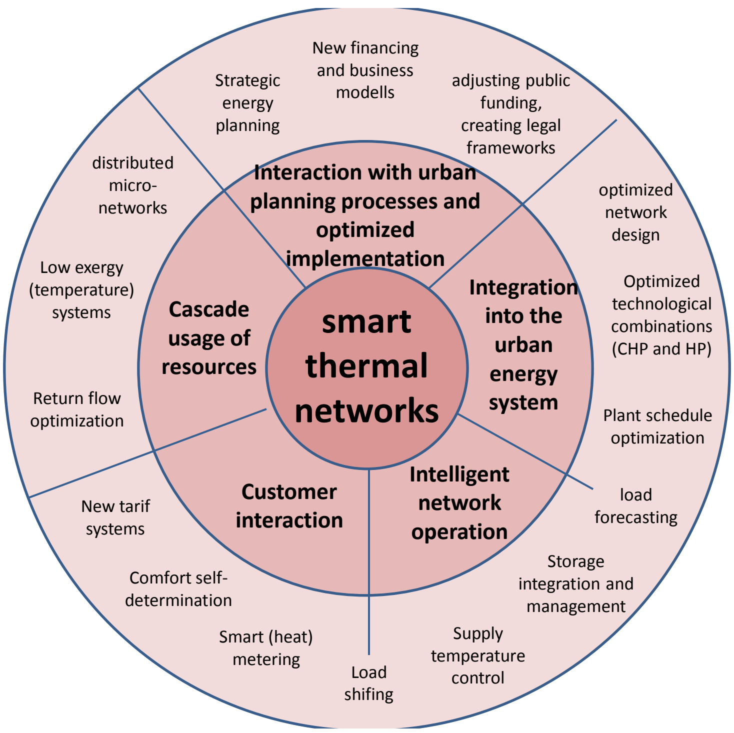

Summary I - properties of “smart” thermal networks

attractive

for citizens: comfort control/ participation, tariff systems for investors: reduce cost, adjusting public funding, creating legal frameworks

intelligent

planning, adaptation, operation, Interaction with end-users, connection of new loads

integrated

optimisation of interfaces to a) city planning, b) the electricity system via CHP and HP and to others (e.g. mobility)

adaptive

Adapt to increasing fraction of renewables, retrofitting rates, cooling demand, fossil fuel costs

efficient

Increasing the urban energy system efficiency by optimal combination of technologies and cascade usage of resources

effective

A broad diffusion of DHC enables a significant impact of measures on the urban energy system

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