Astérix et le Chaudron, René Goscinny, Albert Uderzo, Darguad
Tools and methods for modelling district heating systems: A comprehensive comparison

Gerald Schweiger, Richard Heimrath, Peter Nageler, Keith O'Donovan, Michael Salzmann, Harald Schrammel, Ingo Leusbrock

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Energy Supply and Energy System Planning

Current
- fossil fuel based
- centrally organized
- mono-directional
- monosectoral
- decoupled
- stationary

Future
EnergySimCity: a modelling toolbox for urban energy systems

- Energy Supply
  - Definition energy sources
  - Simulation energy sources
  - Analysis energy supply

- Infrastructure
  - Network definition
  - Network simulation
  - Analysis energy transport

- Buildings
  - Building definition
  - Building simulation
  - Analysis energy consumption

- Atmosphere
  - Definition of bodies and climate
  - Computational fluid dynamics
  - Analysis temperature and flows

Future energy system
„We also can simulate DH systems with our tool!“
4th Generation District Heating (4GDH)

Integrating smart thermal grids into future sustainable energy systems

Henrik Lund, Sven Werner, Robin Wiltshire, Svend Svendsen, Jan Eric Thorsen, Frede Hvelplund, Brian Vad Mathiesen

4th Generation District Heating

Integration of smart thermal grids into future sustainable energy systems

ABSTRACT

This paper defines the concept of 4th Generation District Heating (4GDH) including cooling, and the concepts of smart energy and smart thermal grids. The motive is to reach a future renewable non-fossil heat supply as part of the sustainable energy systems. The basic assumption is that district heating and cooling will play a role in future sustainable energy systems — including 100 percent renewability. The present generation of district heating and cooling technologies will have to be replaced with new, more efficient technologies in order to be able to cope with the new challenges.

4GDH involves meeting the challenge of more energy-efficient buildings as well as part of the operation of the sustainable energy systems, i.e., integrated smart electricity.
Callenges from 4GDH for simulation & optimisation of DHC systems

Features 4GDH
- Integrated part of smart energy systems
- Combining energy conservation with expansion of district heating
- Intelligent control and monitoring
- Loop layouts
- Renewable heat and waste heat
- Low-temperature district heating for space heating and hot water

Challenges for sim. / opt. tools
- Robustness & calculation speed
- Renewables / storage / prosumers
- Co-simulation
- Loops / rings / meshes
- Zero – Flow / Reverse Flow
- Mixed Integer / Unit Commitment
- Model predictive control
- Dynamic or static?
IL1 It is not clear what you mean with MPC here: You need a (simplified) model for MPC because you need to optimize the model (12-24 hours) and you have limited time (buildings have a MPC timestep 5-30min, DH I would say 15min-1hour). If you need general information about different techniques for MPC tell me and I will send you an overview.
Ingo Leusbrock, 9/7/2017

IL2 This is not a challenge for Simulatino ..Unit commitment (discrete problem) and economic dispatch (continuous problem) are optimization problems. So what you need is a model that you can optimize. (i) gradient based optimization (what we do in JModelica) (ii) derivative free optimization (genetic algo. f.i.) or (iii) simulation based optimization (generally no information about derivatives)...the last one means: simulate the model with free variables (they are called optimization variables) and evaluate the objective/cost function based on that results (f.i. you need the T_supply temperature at the unit for the objective function: So you take the simulation result, evaluate the objective, and simulate again... and again... and again: vary the input/free/optimization variables (supply temperatures, pressure) very smart = a good simulation based method
Ingo Leusbrock, 9/7/2017
Software tools

Dymola (Modelica)
- Equation-based modelling, object-oriented
- Pro's: Reusability, extensibility, adaptability of models, well suited for optimization
- Con's: difficult to go from a mathematical model to numerical solution algorithm

TRNSYS
- Causal modelling, dynamic
- Pro's: Well established, block diagram modelling
- Con's: not well suited for optimization, no parallelization possible

Matlab Simulink
- Causal modelling, dynamic
- Pro's: robust, excellent for control application
- Con's: not easy to read & code, reusability

IDA-ICE
- Equation based modelling, object-oriented
- Pro's: Highly sophisticated models for buildings and HVAC, parallelizable, variable timestep simulation
- Con's: No interface to FM I / Co-sim

STANET
- Stationary, domain-specific
- Pro's: data import, GIS-interface, large networks, visualization of results
- Con's: detailed sim of heat pumps, storages, substations, complex hydraulics/controls
Workflow

General comparison
• Basics
• Features
• Comparison with literature results

Case study
• Pressure drops
• Temperature wave propagation
• Heat losses
• Maximum number of nodes

Evaluation
• Numerics, calculation speed
• Ease of use, Co-Sim
Case study description

- 16 customers
- Evaluation of period 2016/02/01 – 2016/02/14
- Load profiles based on building simulation
- 3 cases
  - Case 1: Standard case, supply temperature 68 °C, return temperature at customer 43 °C, both fixed
  - Case 2: Extension of different lines
  - Case 3: Case 2 + temperature jump of 20K
Case 2: maximum / minimum pressure

<table>
<thead>
<tr>
<th>Software</th>
<th>Maximum pressure</th>
<th>Minimum pressure</th>
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<tbody>
<tr>
<td>IDA-ICE</td>
<td>25.0</td>
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</tr>
<tr>
<td>DYMOLA</td>
<td>20.0</td>
<td>1.7</td>
</tr>
<tr>
<td>STANET</td>
<td>27.87</td>
<td>2.94</td>
</tr>
<tr>
<td>TRNSYS</td>
<td>28.6</td>
<td>2.3</td>
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</tbody>
</table>
Case 2: maximum / minimum pressure – when?

- IDA-ICE: Maximum pressure on 09/02/2016 06:45, Minimum pressure on 11/02/2016 14:30
- DYMOLA: Maximum pressure on 09/02/2016 06:45, Minimum pressure on 11/02/2016 14:30
- STANET: Maximum pressure on 09/02/2016 06:45, Minimum pressure on 11/02/2016 14:30
- TRNSYS: Maximum pressure on 09/02/2016 06:30, Minimum pressure on 11/02/2016 14:30

Pressure in bar:

- 0.0
- 5.0
- 10.0
- 15.0
- 20.0
- 25.0
- 30.0
- 35.0
Case 2: Heat supply, total heat losses and error energy balance

ID-A-ICE
- Total heat supplied: 1174 MWh
- Error in energy balance = 0%

DYMOLA
- Total heat supplied: 1169 MWh
- Error in energy balance = 7.7%

STANET
- Total heat supplied: 1245 MWh
- Error in energy balance = 4.8%

TRNSYS
- Total heat supplied: 1198 MWh
- Error in energy balance = 0.4%

Legend:
- Red: Total heat supplied
- Blue: Heat losses
Case 3: Temperature wave propagation → temperature jump
Case 3: Temperature wave propagation: Dymola
Case 3: Temperature wave propagation: Dymola & TRNSYS

Dymola: $t(T_{\text{max}}) = 03:45$, $T_{\text{max}} = 76.7 \text{ deg.C}$

TRNSYS: $t(T_{\text{max}}) = 07:15$, $T_{\text{max}} = 70.1 \text{ deg.C}$
Workflow 2.0

General comparison
- Basics
- Features
- Comparison with literature results

Validation
- Single pipe measurements on lab scale
- Small DH network KU Leuven

Case study
- Pressure drops
- Temperature wave propagation
- Heat

Evaluation
- Numerics, calculation speed
- Ease of use, Co-Sim
Case 1: Maximum number of nodes

- Simulation of one year

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<tr>
<td>2</td>
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</tr>
<tr>
<td>3</td>
<td>500</td>
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</tbody>
</table>
Case 1: Maximum number of nodes

- Simulation of one year
- TRNSYS
  - 10x possible
  - Tedious process to generate larger networks
- STANET
  - 100x possible
  - Even larger networks possible
- IDA-ICE
  - 80x possible, after that crash
- Dymola
  - 20x possible, but calculation time 80 hours

- 10x: 160 customers, ~50 km net length
- 100x: 1600 customers, ~500km net length
Do we need dynamic simulations?

- Temperature wave propagation
  - static simulations capture general profile, but delay time can be significantly off depending on distance

- Static simulations do not capture pipe cooling patterns during longer periods of zero or close to zero flow events
IL4  Basak has nice results that show that we don't really need dyn. for a lot of applications
Ingo Leusbrock, 9/7/2017

IL5  I worked on conceptually define: What do we do with our models, what accuracy is relevant... I called it “the myth of accuracy” based on a presentation at the conference I saw. I can send you the ideas or we can discuss this the next days (skype??)

It would be great if you could "provozieren" the community. The colleague from Leuven is doing this at the croatian conference (I convinced him haha).
Ingo Leusbrock, 9/7/2017
Zero-flow events
Zero-flow events: supply pipe temperature
Zero-flow events: heat Loss in Consumer Supply Pipe

Heat losses in STANET: 3.11 kWh
Heat losses in Dymola: 7.04 kWh
Difference: 126% over 2.5 day period
Do we need dynamic simulations?

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- Static simulations do not capture pipe cooling patterns during longer periods of zero or close to zero flow events

- 4GDH components (storage, P2H, prosumers) experience high fluctuations in temperature which cannot be captured from static simulations

- Complex systems, control strategy

- But: Dynamic simulations are however significantly slower (for obvious reasons) and more complex
  - Use static when possible, use dynamic when necessary?
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Conclusions and outlook
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- All tools show comparable results for standard situations
  - No need to develop new tools for DH modelling as Annex 60 pipe model / Carnot toolbox is open source
- More advanced situations need dynamic simulations
  - Tradeoff: increased complexity, calculation speed
- Static simulations may under- and/or overestimate certain effects
- Validation to be finalized
  - Conclusions then possible for error of indivual programs
- 2 papers in preparation
  - Validation
  - Case studies

Thank you for your attention

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TRNSYS types
Need for improved pipe flow models, now in development

Problem encountered while simulating Time modulation case:
Time delay during temperature change is too simplified.

What we want to see (plug flow):

Old model, low complexity:
Wrong time delay behavior

Old model, high complexity:
Time delay okay, but numerical diffusion and high computation time