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

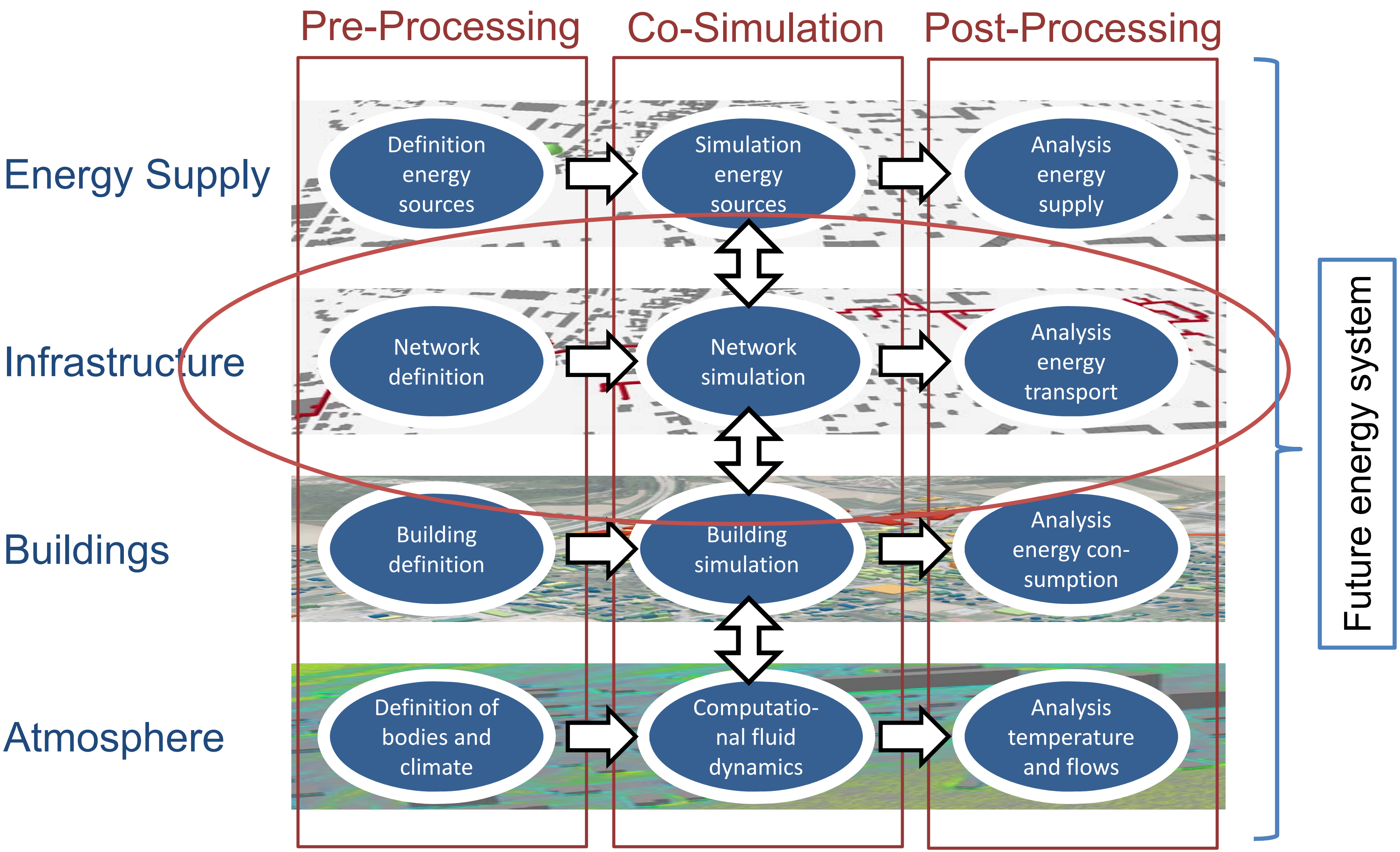
AEE - Institute for Sustainable Technologies (AEE INTEC)
8200 Gleisdorf, Feldgasse 19, AUSTRIA

Energy Supply and Energy System Planning

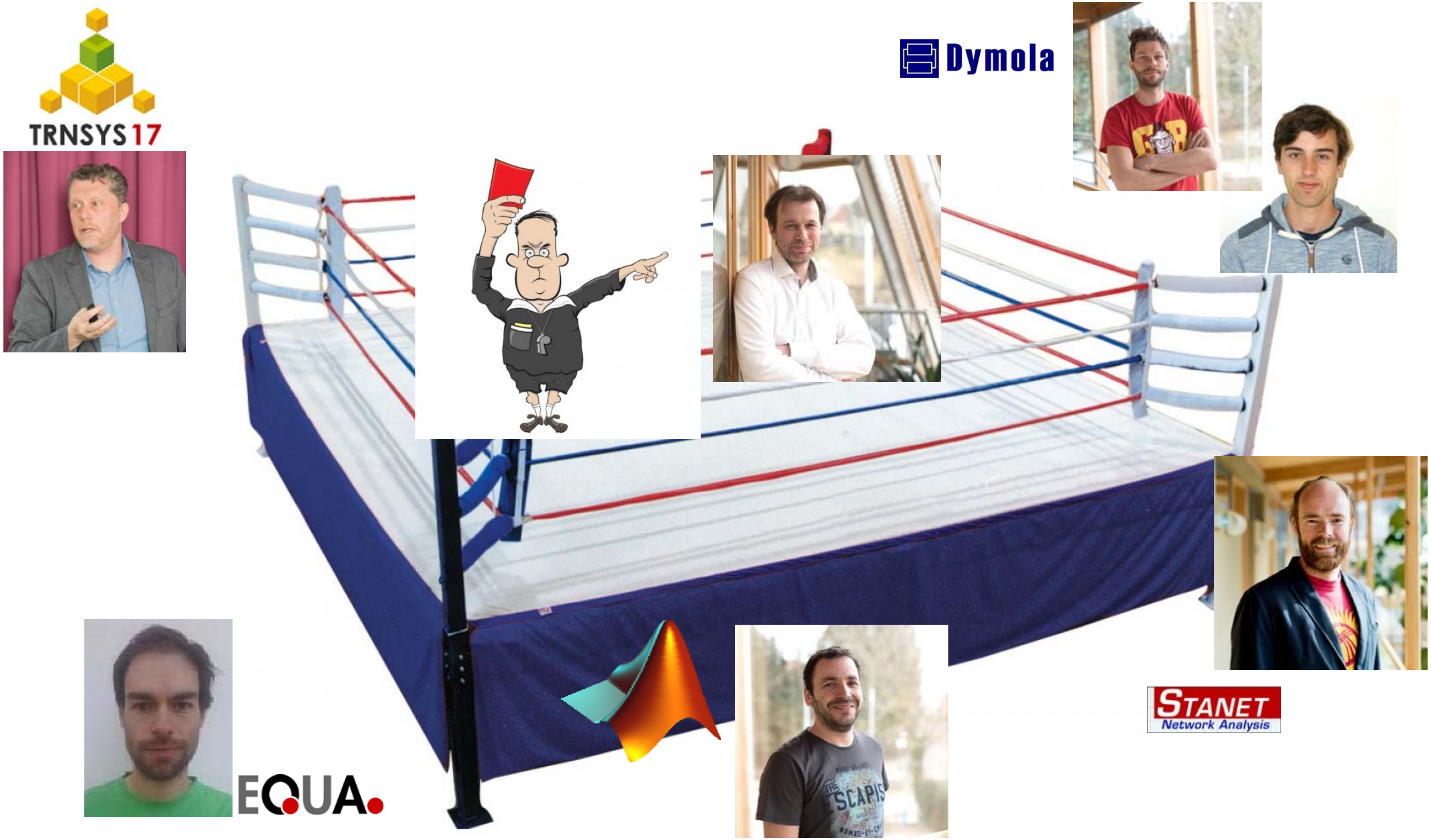
Current

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

EnergySimCity: a modelling toolbox for urban energy systems



„We also can simulate DH systems with our tool!“



4th Generation District Heating

Energy 68 (2014) 1–11

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

ELSEVIER

Review

4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems

Henrik Lund [a,*], Sven Werner [b], Robin Wiltshire [c], Svend Svendsen [d], Jan Eric Thorsen [e], Frede Hvelplund [a], Brian Vad Mathiesen [f]

[a] Department of Development and Planning, Aalborg University, Vestre Havnepromenade 9, DK-9000 Aalborg, Denmark
[b] School of Business and Engineering, Halmstad University, PO Box 823, SE-30118 Halmstad, Sweden
[c] Building Research Establishment (BRE), Bucknalls Lane, WD25 9XX Watford, UK
[d] Department of Civil Engineering, Technical University of Denmark, Brovej, Building 118, DK-2800 Kgs. Lyngby, Denmark
[e] Danfoss District Energy, DK-6430 Nordborg, Denmark
[f] Department of Development and Planning, Aalborg University, A.C. Meyers Vænge 15, DK-2450 Copenhagen SV, Denmark

CrossMark

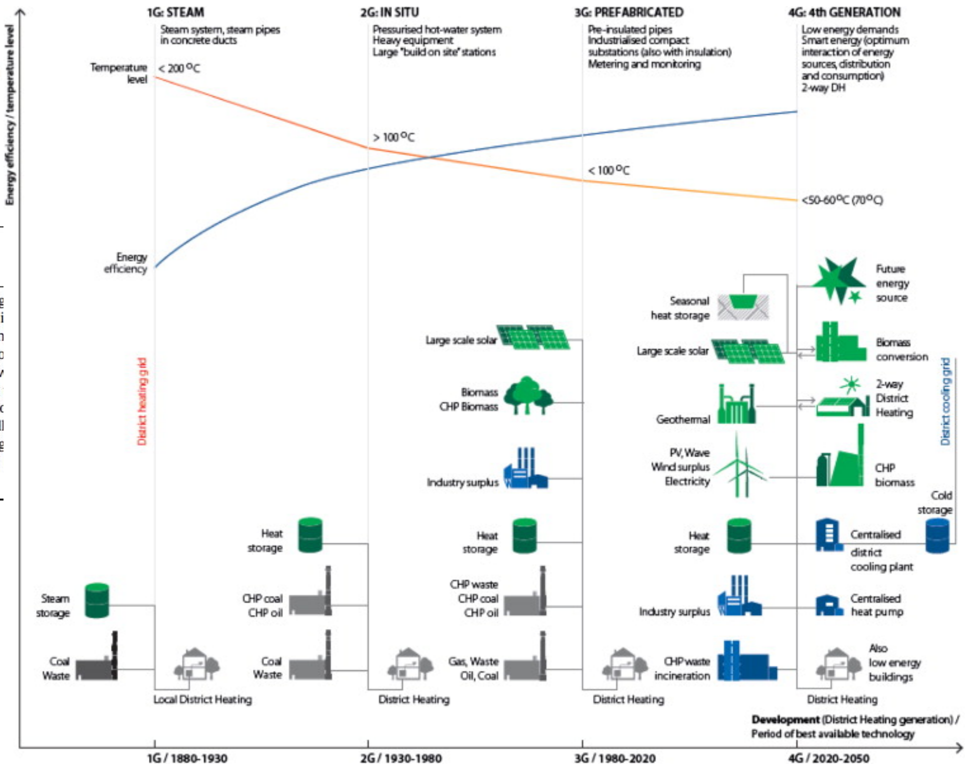
A R T I C L E I N F O

Article history:
Received 24 January 2014
Accepted 23 February 2014
Available online 31 March 2014

Keywords:
4GDH
District heating
Smart thermal grids
Smart energy systems
Sustainable energy systems
Renewable energy systems

A B S T R A C T

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 i challenges of reaching a future renewable non-fossil heat supply as part of the im sustainable energy systems. The basic assumption is that district heating and co role to play in future sustainable energy systems – including 100 percent renew but the present generation of district heating and cooling technologies will have into a new generation in order to play such a role. Unlike the first three generatic 4GDH involves meeting the challenge of more energy efficient buildings as well part of the operation of smart energy systems, i.e. integrated smart electricity, g



Callenges from 4GDH for simulation & optimisation of DHC systems

IL1

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?

IL2

Slide 7

IL1 It is not clear what you mean with MPC here: You need a (simplified) model for MPC because you need to optimze 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 (continiuos problem) are optimiization 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 evalute the objective/cost funciton based on that results (f.i. you need the T_supply temperature at the unit for the objective function: So you takte the simulation result, evaluate the objective, and simulate again.. and again.. and again: vary the input/free/optimizatino 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

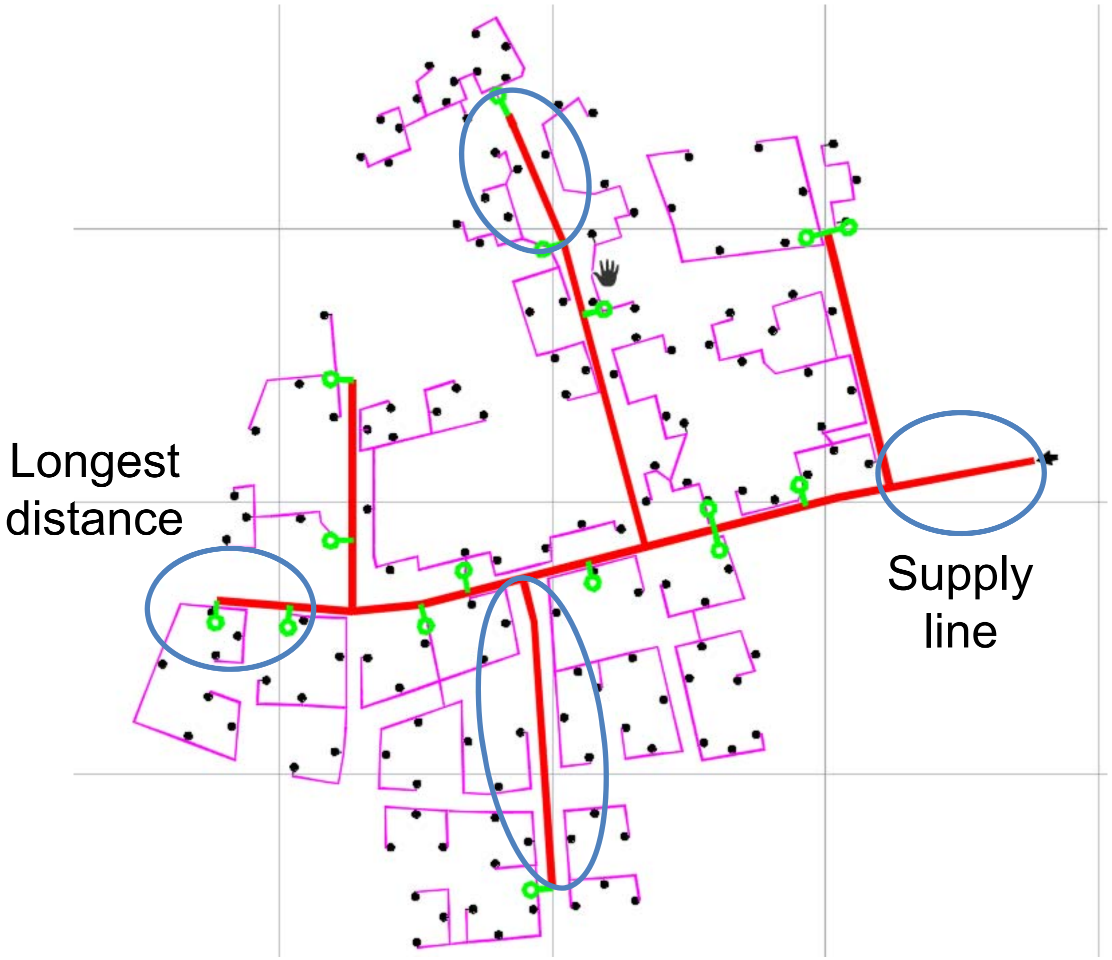
STANET
- Stationary, domain-specific
- Pro's: data import, GIS-interface, large networks, visualization of results
- Con's: detailed sim of heat pumps, storages, substations, complex hydraulics/controls

Workflow

General comparison

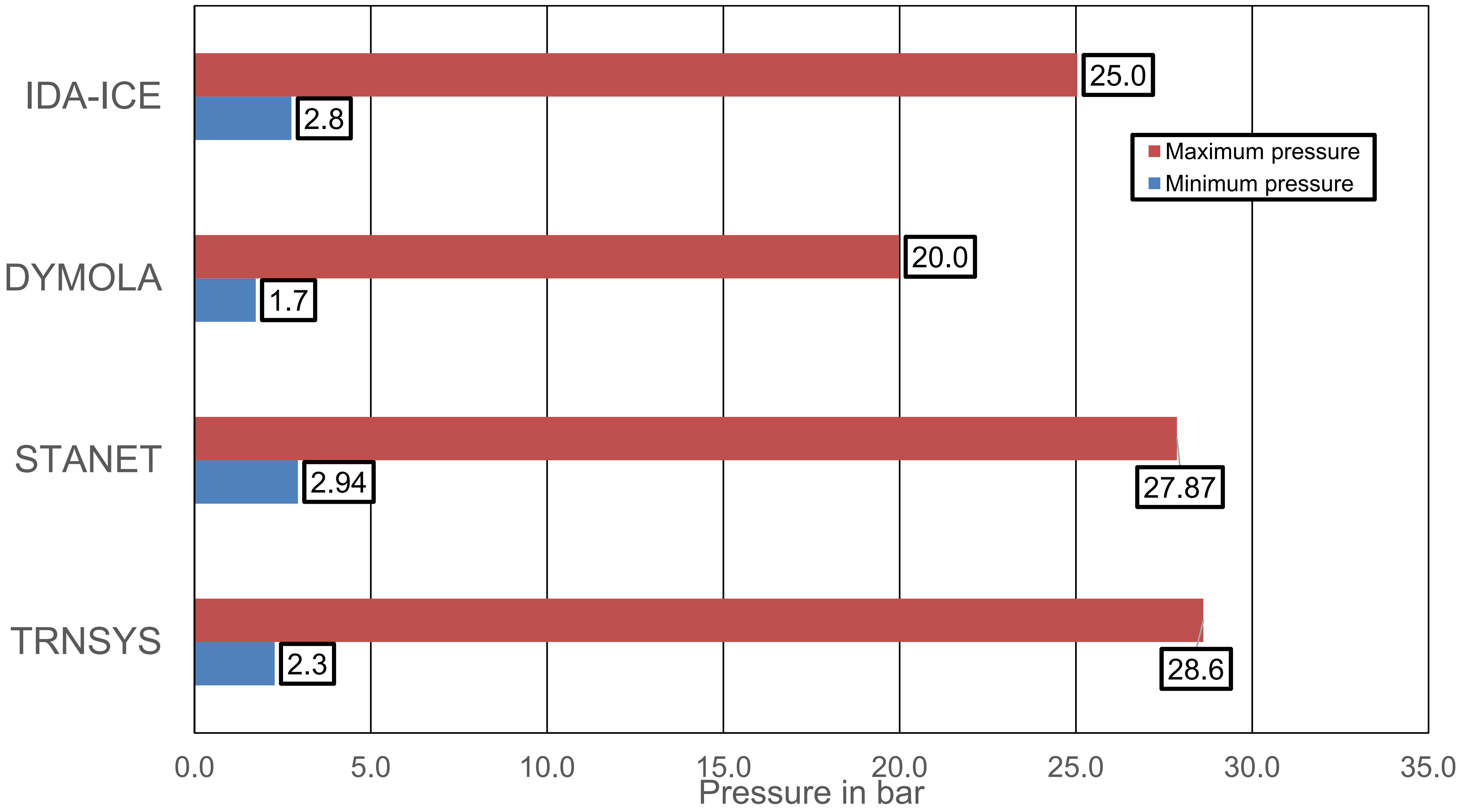
- Basics
- Features
- Comparison with literature results

Case study description

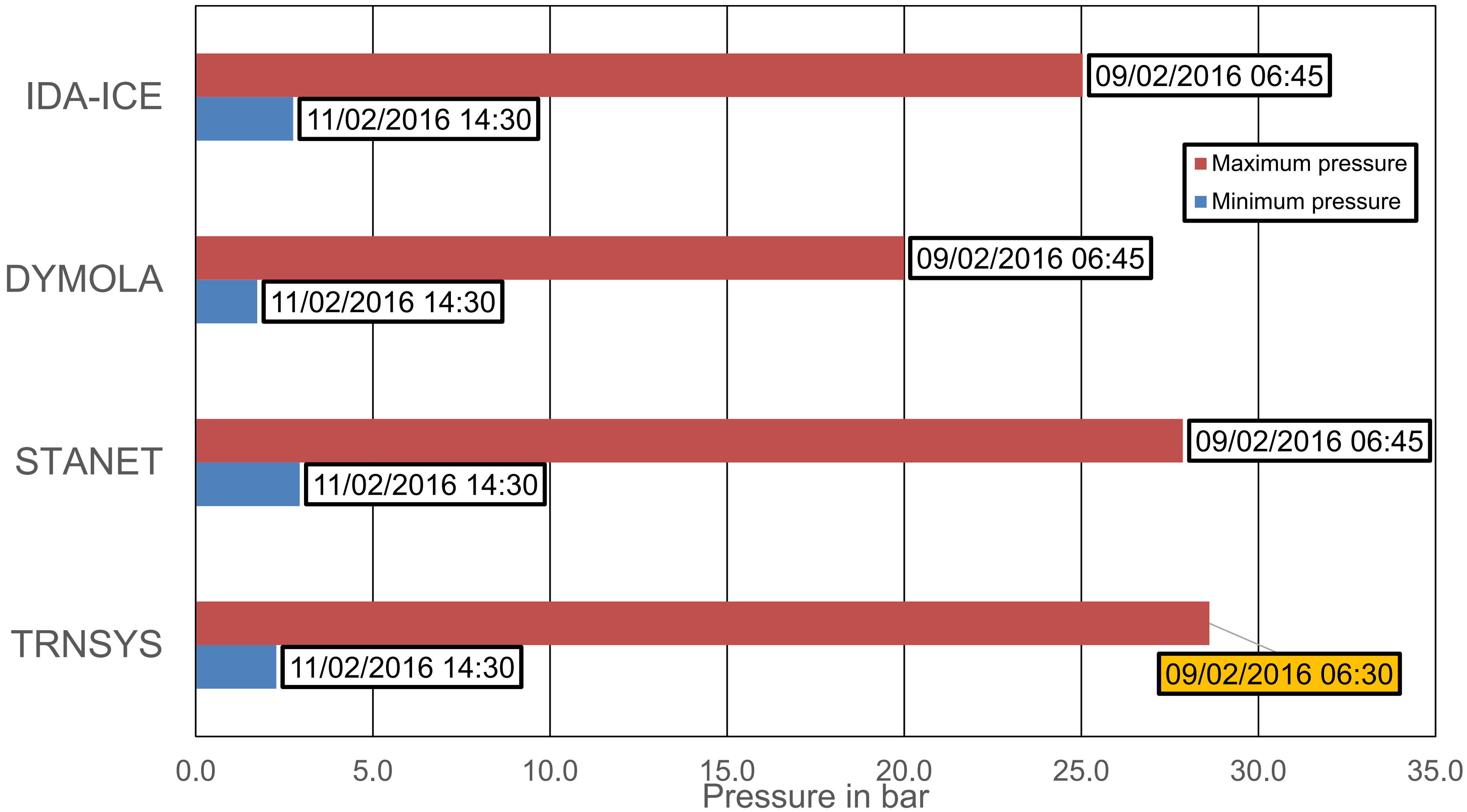


- 16 customers
- Evaluation of period 2016/02/01 – 2016/02/14
- Load profiles based on building simulation
- 3 cases
  - Case 1: Standard case, supply temperature 68 °C , return temperature at customer 43 °C, both fixed
  - Case 2: Extension of different lines
  - Case 3: Case 2 + temperature jump of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

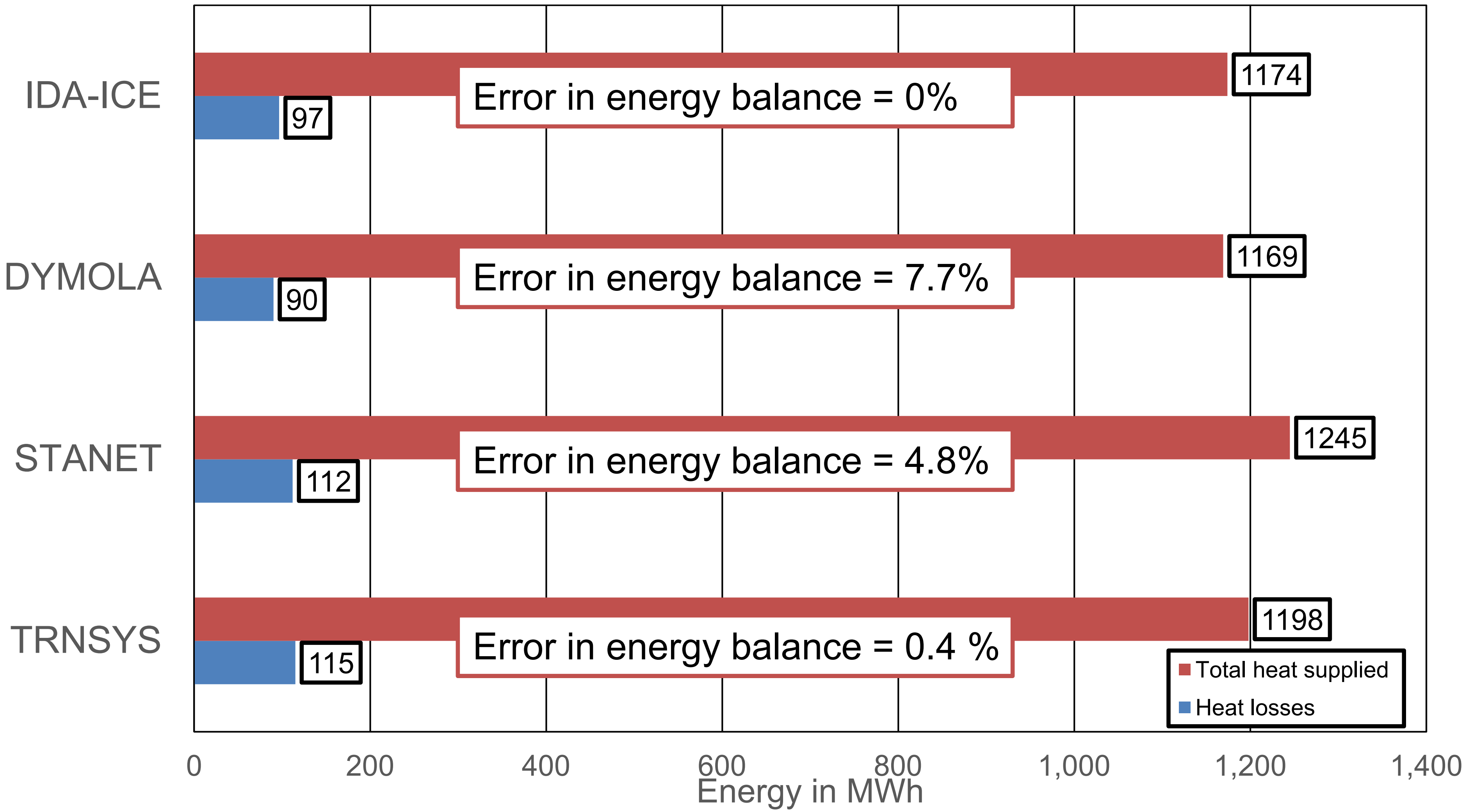
Case 2: maximum / minimum pressure



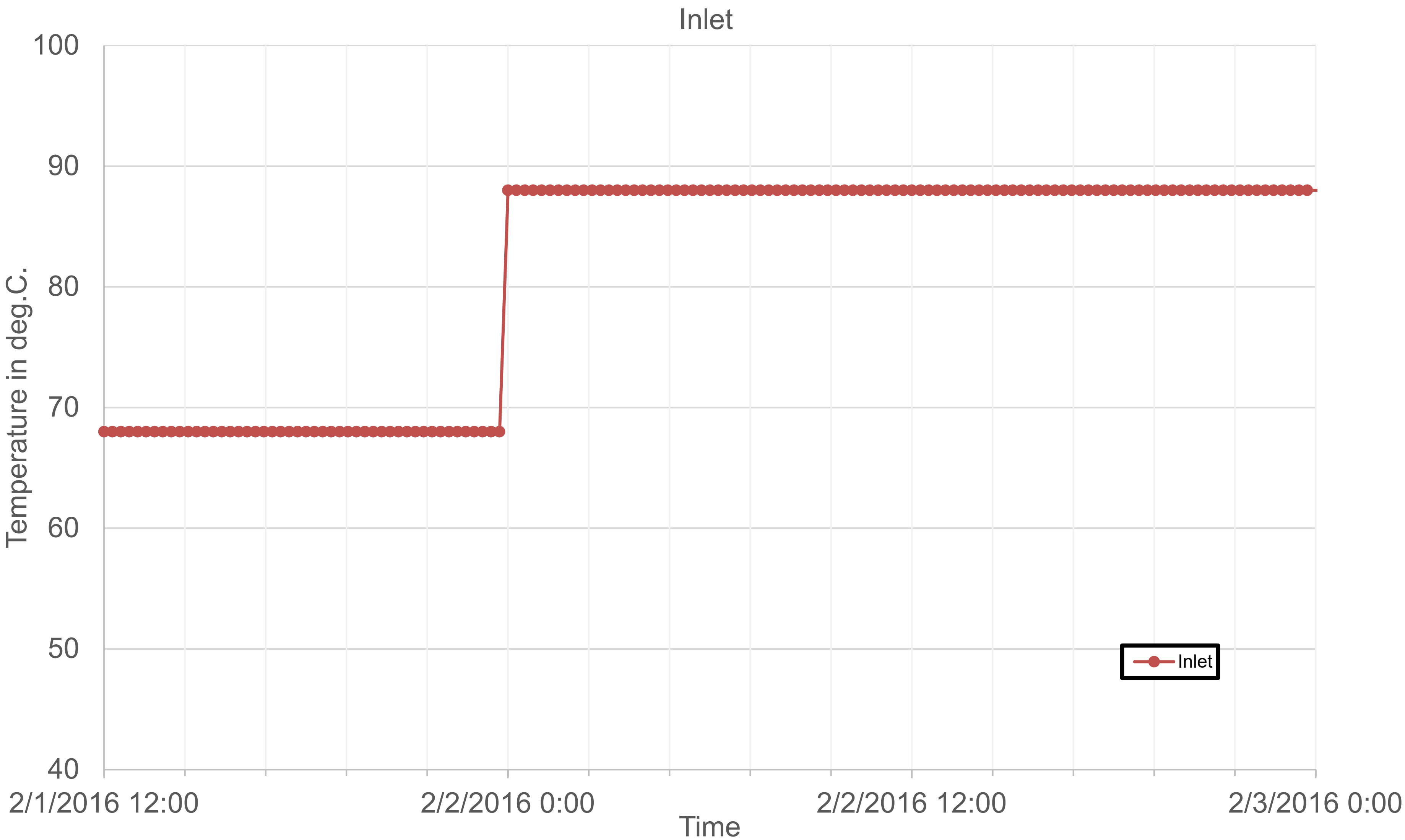
Case 2: maximum / minimum pressure – when?



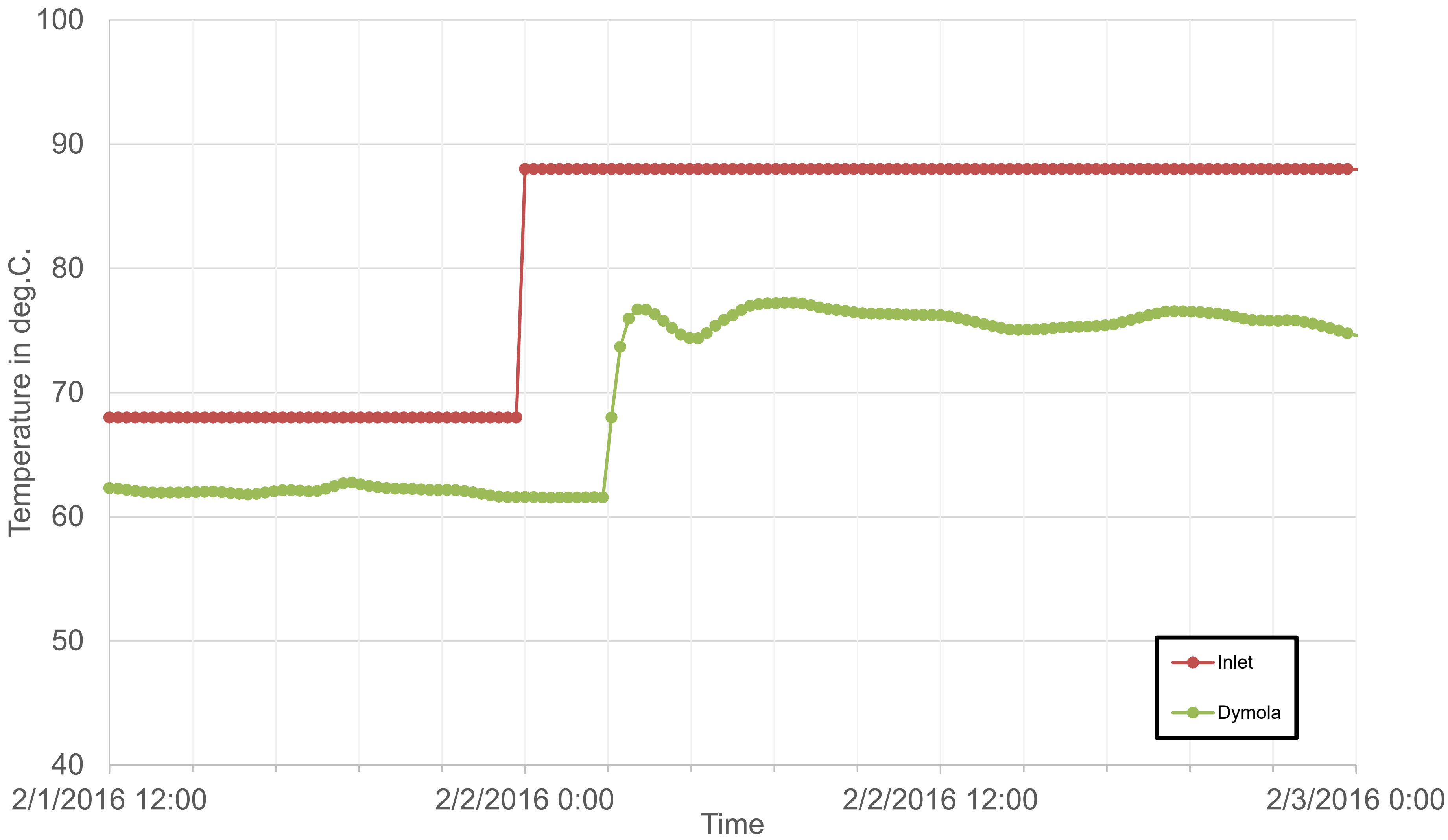
Case 2: Heat supply, total heat losses and error energy balance



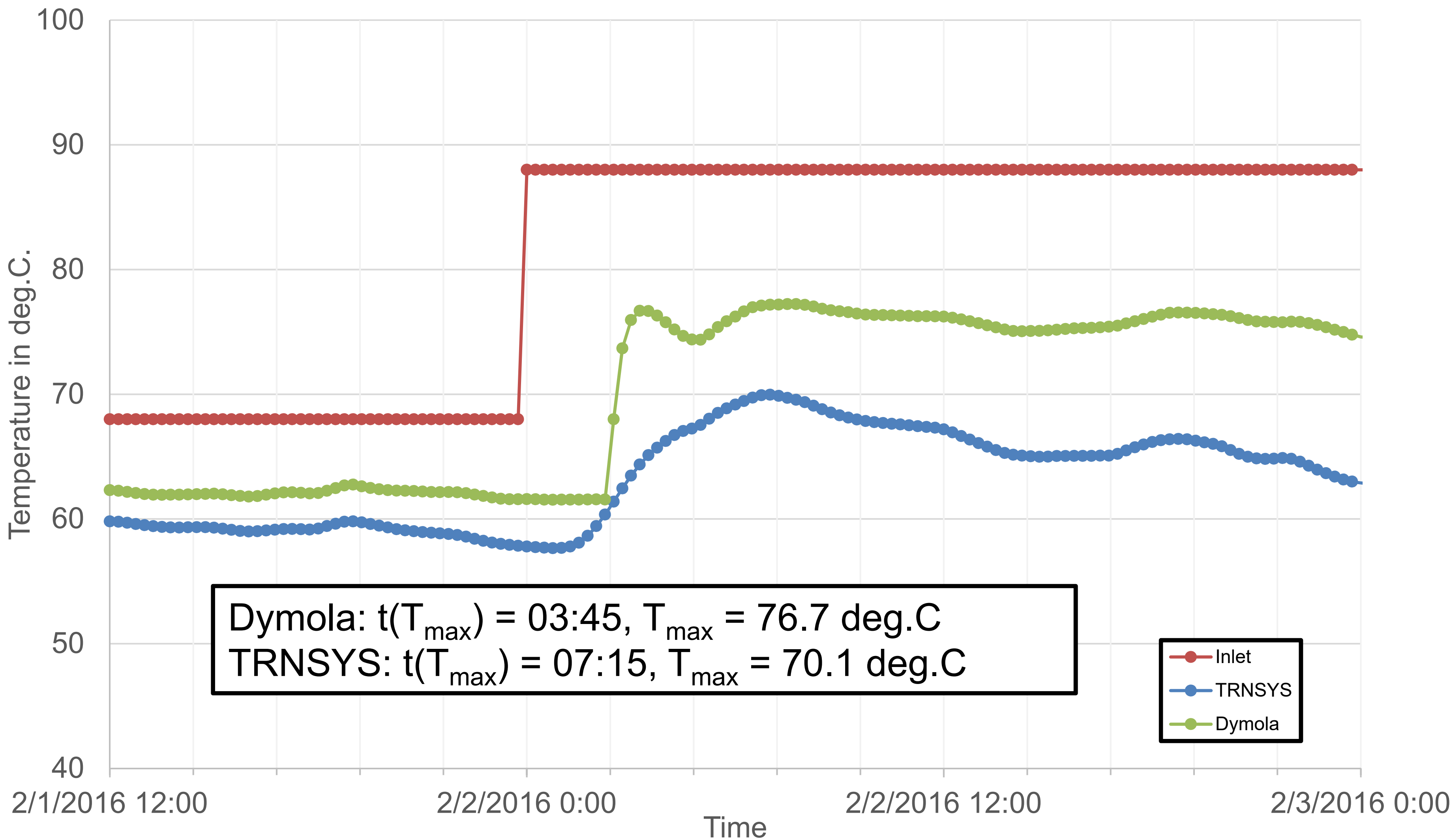
Case 3: Temperature wave propagation → temperature jump



Case 3: Temperature wave propagation: Dymola



Case 3: Temperature wave propagation: Dymola & TRNSYS



Workflow 2.0

General compari-son

- Basics
- Features
- Comparis on with literature results

Validation

- Single pipe measure-ments on lab scale
- Small DH network KU Leuven

Case study

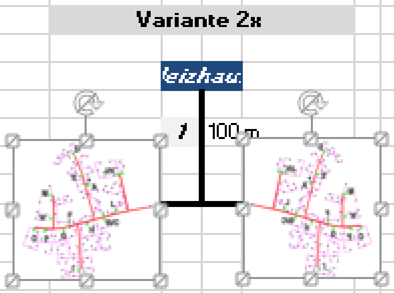
- Pressure drops
- Tempera-ture wave propaga-tion
- Heat

Evaluation

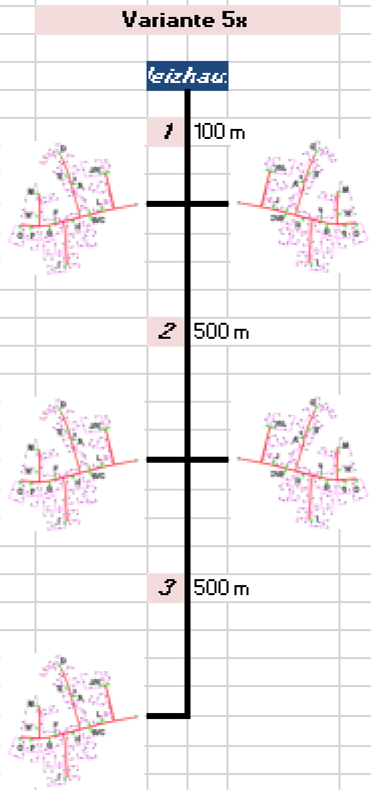
- Numerics, calcula-tion speed
- Ease of use, Co-Sim

Case 1: Maximum number of nodes

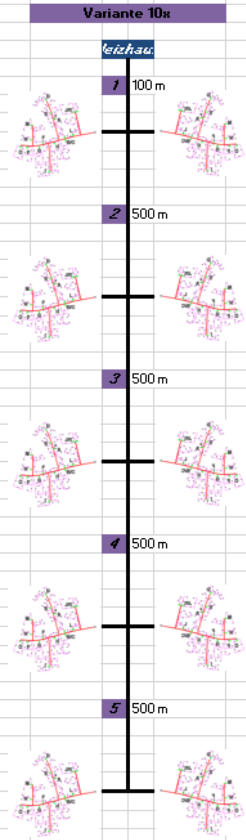
- Simulation of one year



Länge		
#	m	DN
1	100	200



Länge		
#	m	DN
1	100	300
	500	250
	500	200



Länge		
#	m	DN
1	100	400
	500	400
	500	350
	500	300
	500	250

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

IL4
IL5

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

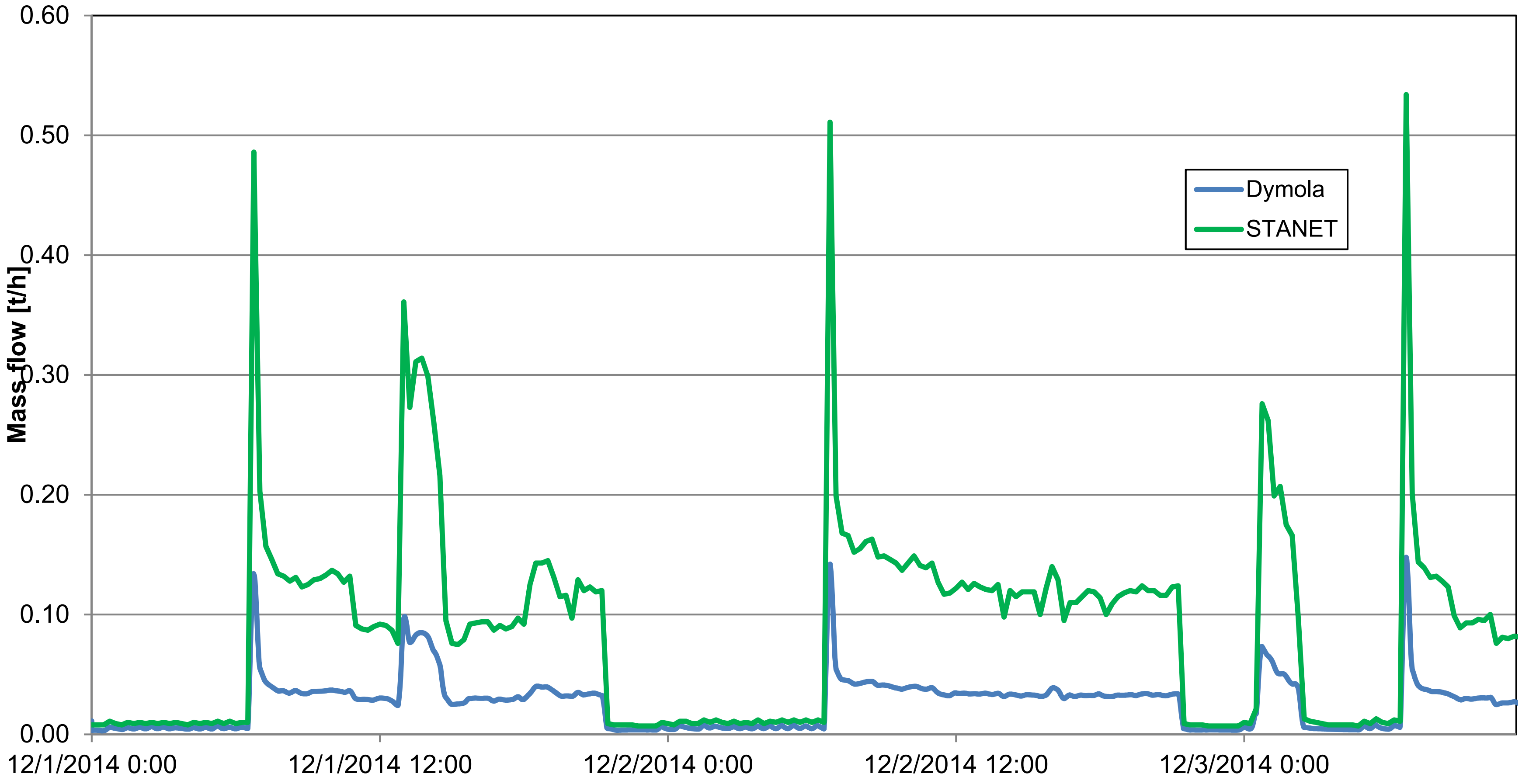
Slide 20

IL4 Basak has nice results that show that we dont really need dyn. for a lot of applications
Ingo Leusbrock, 9/7/2017

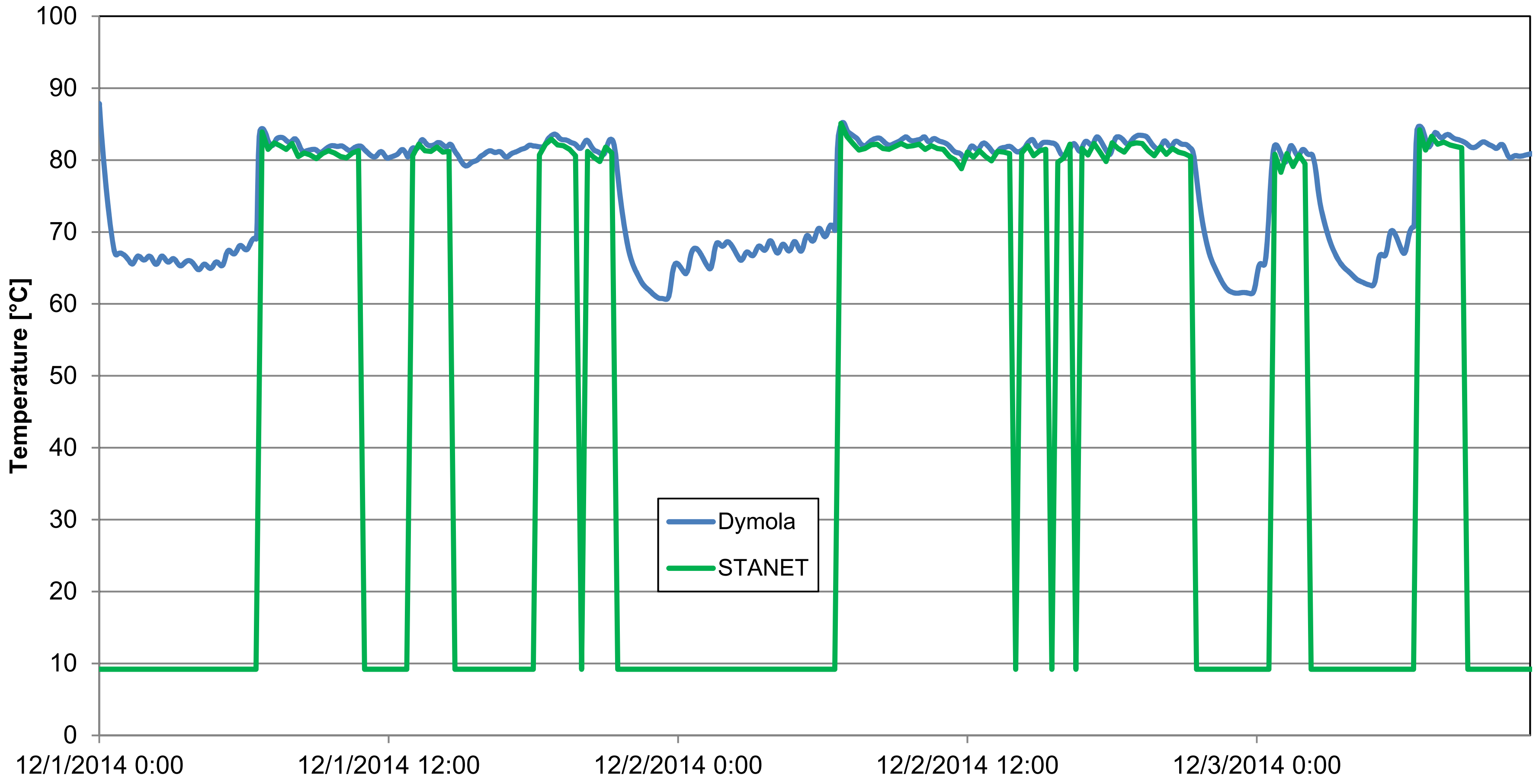
IL5 I worked on conceptually define: What do we do with our models, what accuracy is relevant... I called it "the myth of accuracy" based on a presentation at the conference I saw. I can send you the ideas or we can discuss this the next days (skype??)

It would be great if you could "provozieren" the community. The colleague from Leuven is doing this at the croatian conference (I convinzed him haha).
Ingo Leusbrock, 9/7/2017

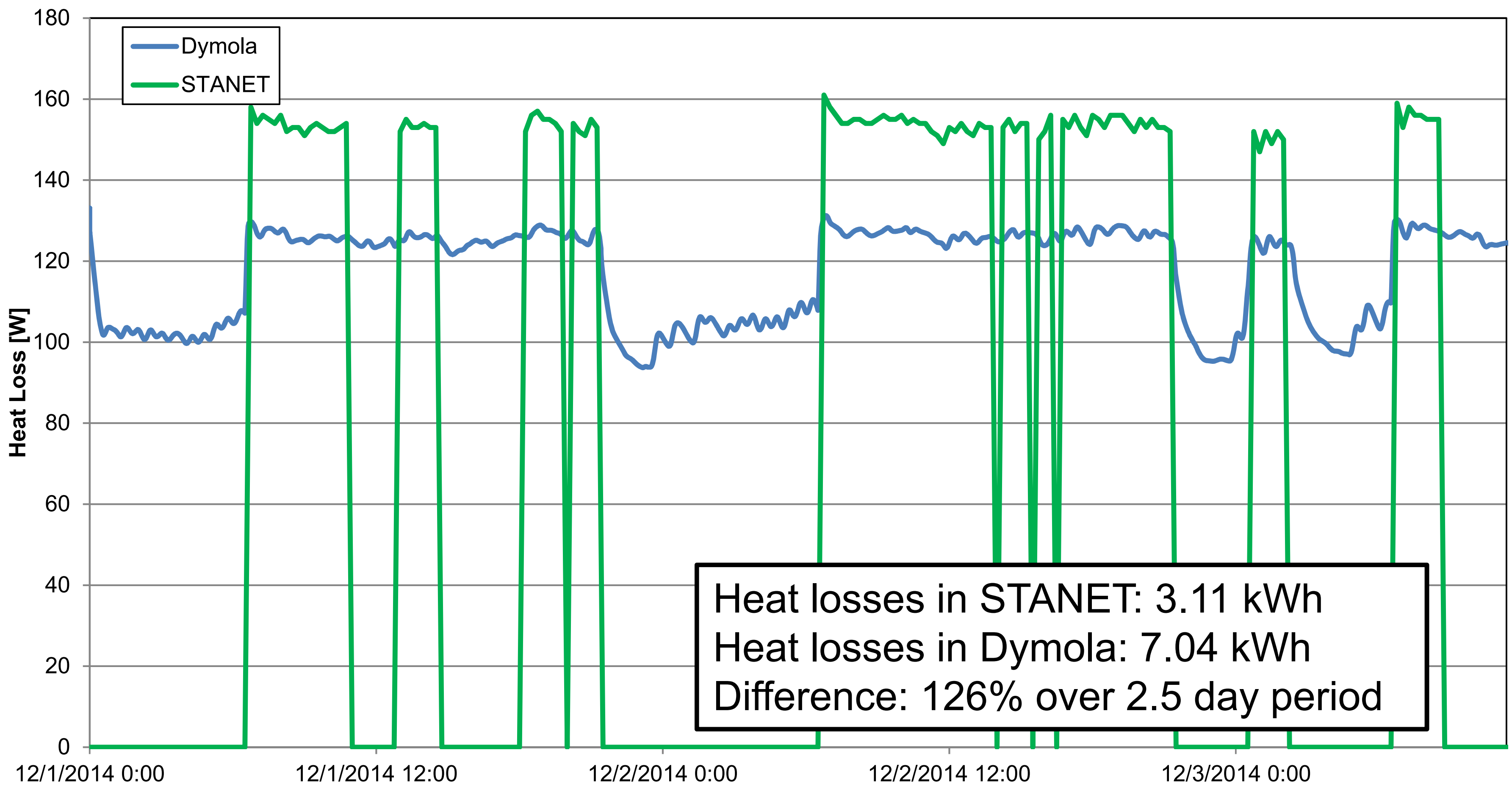
Zero-flow events



Zero-flow events: supply pipe temperature



Zero-flow events: heat Loss in Consumer Supply Pipe



IL4 IL5

Do we need dynamic simulations?

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

Slide 24

IL4 Basak has nice results that show that we dont 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 convinzed him haha).

Ingo Leusbrock, 9/7/2017

Conclusions and outlook

Astérix et le Chaudron, René Goscinny, Albert Uderzo, Darguad

Conclusions and outlook

B. van der Heijde et al., Dynamic equation-based thermo-hydraulic pipe model for district heating and cooling systems, Energy Conversion and Management, https://doi.org/10.1016/j.enconman.2017.08.072

- 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

Ingo Leusbrock
i.leusbrock@aee.at
@leusbrocki

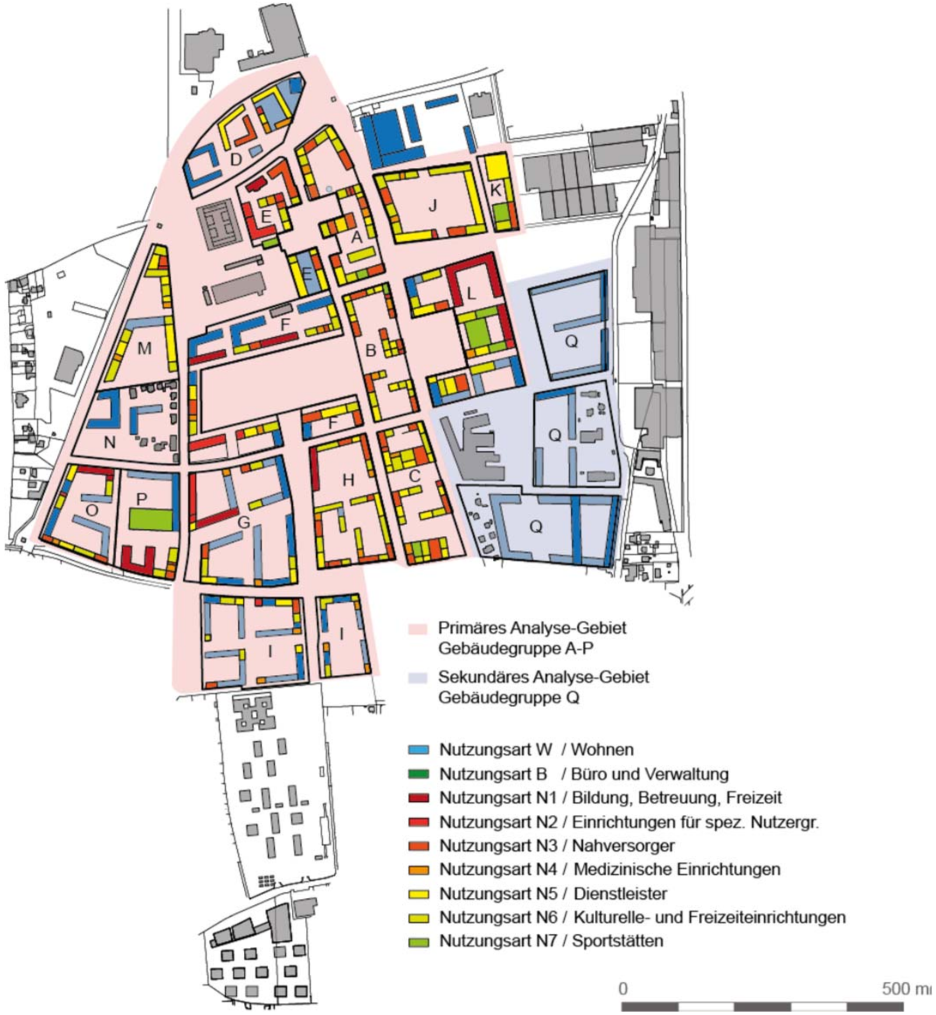
Conclusions and outlook

- 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

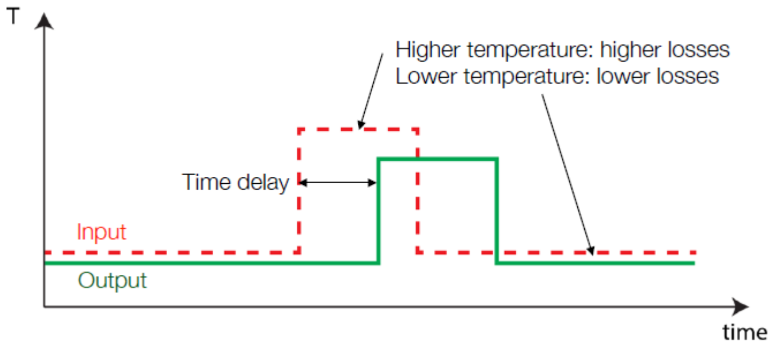
TRNSYS types


D
E
A
J
K
L
Q
M
F
B
N
F
H
C
O
P
G
I
I
Primäres Analyse-Gebiet
Gebäudegruppe A-P
Sekundäres Analyse-Gebiet
Gebäudegruppe Q
Nutzungsart W / Wohnen
Nutzungsart B / Büro und Verwaltung
Nutzungsart N1 / Bildung, Betreuung, Freizeit
Nutzungsart N2 / Einrichtungen für spez. Nutzergr.
Nutzungsart N3 / Nahversorger
Nutzungsart N4 / Medizinische Einrichtungen
Nutzungsart N5 / Dienstleister
Nutzungsart N6 / Kulturelle- und Freizeiteinrichtungen
Nutzungsart N7 / Sportstätten
0
500 m

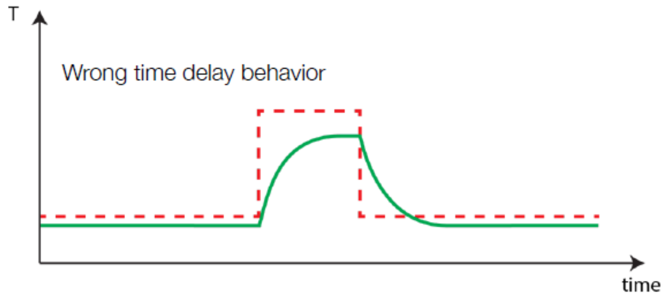
Need for improved pipe flow models, now in development

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:



Old model, high complexity: