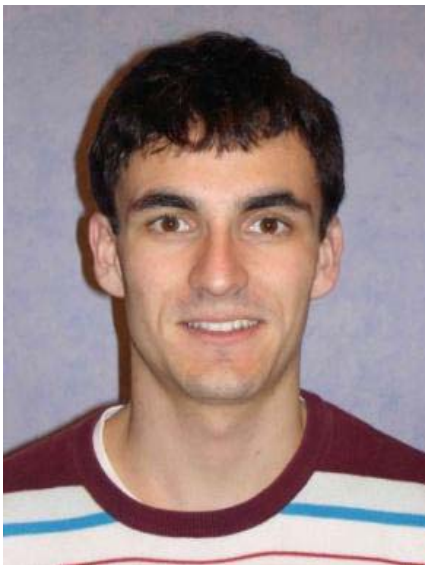


Vita

Loïc Giraud

PhD Student

CEA/LITEN INES

Loïc Giraud joined CEA/LITEN* in April 2013 for a six months internship. Then followed a 3 years period devoted to the preparation of his PhD thesis with the financial support of ADEME** and CCIAG***. His current research activities deal with dynamic modelling and operational optimization of district heating systems.

Prior to that, Loïc studied at INSA Lyon (France) and Lappeeranta University of Technology (Finland) to obtain a Master's degree in Energy and Environmental Engineering.

Loïc has developed skills in multi-domain modeling using the Modelica language and a strong expertise in operational optimization of complex district heating systems.

Email address: loic.giraud@cea.fr
Tutor contacts: roland.baviere@cea.fr
cedric.paulus@cea.fr

* CEA: French Alternative Energies and Atomic Energy Commission
* LITEN: Laboratory for Innovation in New Energy Technologies
** ADEME: French Environmental and Energy Management Agency
*** CCIAG: District Heating operator of the city of Grenoble

A control method of DH systems based on production and distribution optimization

Loïc GIRAUD

ines
INSTITUT NATIONAL
DE L'ENERGIE SOLAIRE

liten
cea tech

20 April 2016, Frankfurt

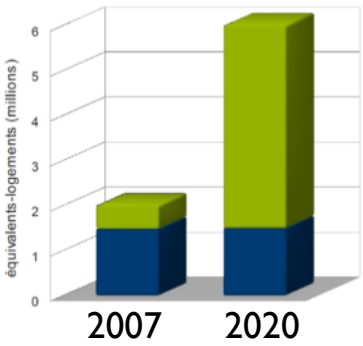
En+Eff - 22nd International Trade Fair and Congress

En+Eff
HEATING | COOLING | CHP

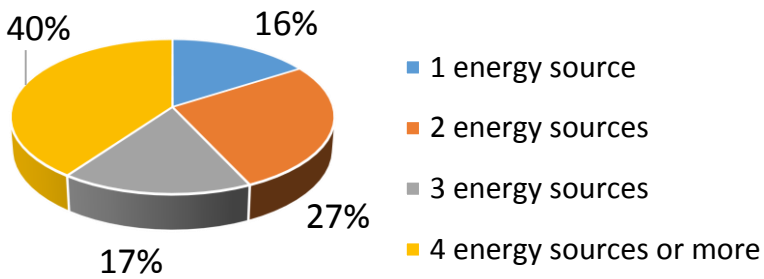
DHC+
TECHNOLOGY PLATFORM

Context

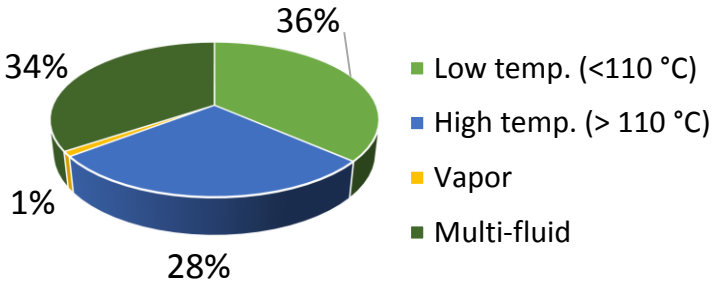
- **French context**
  - ✓ DH systems supply only 6 % (80TJ) of the French total heat demand
  - ✓ Policy of DH development to reduce the carbon emissions
    - Integration of renewable energy sources (biomass, solar…)
    - Construction low temperature DH systems
    - **Operational optimization of DH systems**
  - ✓ Why is operational optimization a key factor ?



Fossil and renewable energies share in French DH systems in 2007 and objectives for 2020



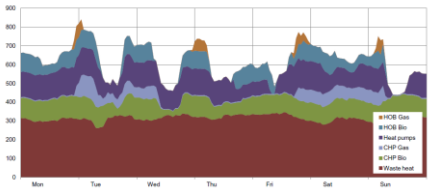
Number of energy sources in French DH systems (SNCU, 2011)

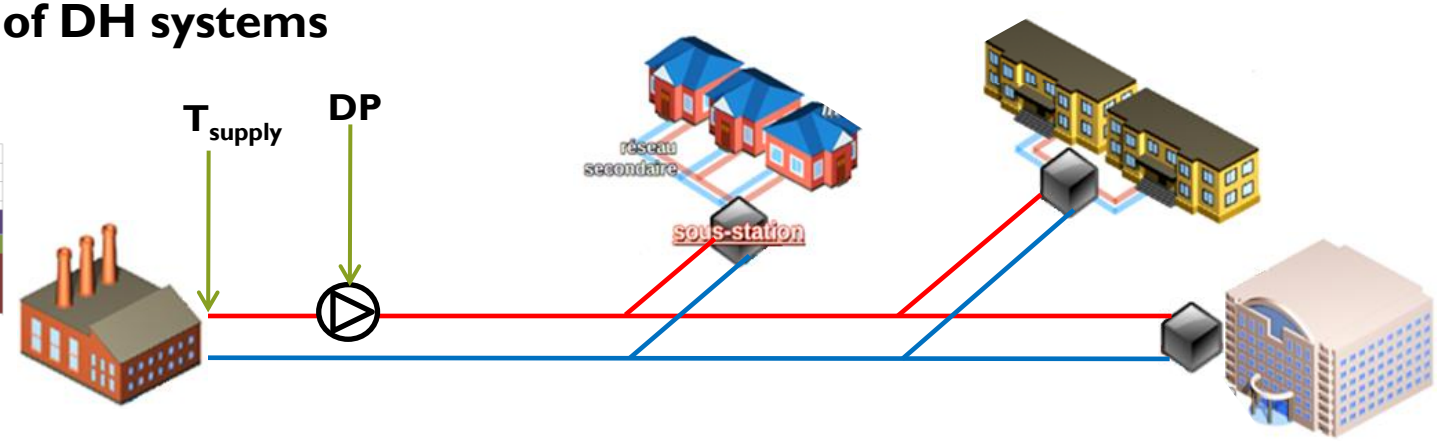


Carrier fluid used in France (SNCU, 2011)

Context

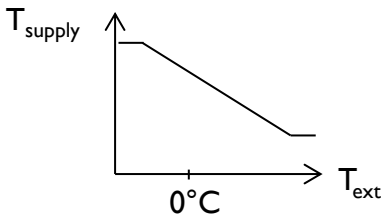
- **Operation of DH systems**





✓ **Empirical laws based on common sense** (if… then…else)

Ex: - Piling method to plan the production
- Determination of T_{supply} with a heating curve



+	-
• Easy to program	• Sub-optimality • Difficulty to implement anticipative strategy

Context

- **Operation of DH systems**
  - ✓ **Model Predictive Control**

Demand prediction → [Model of the system + $\min(costs_{production} + costs_{distribution})$] → Optimal planning of control variables

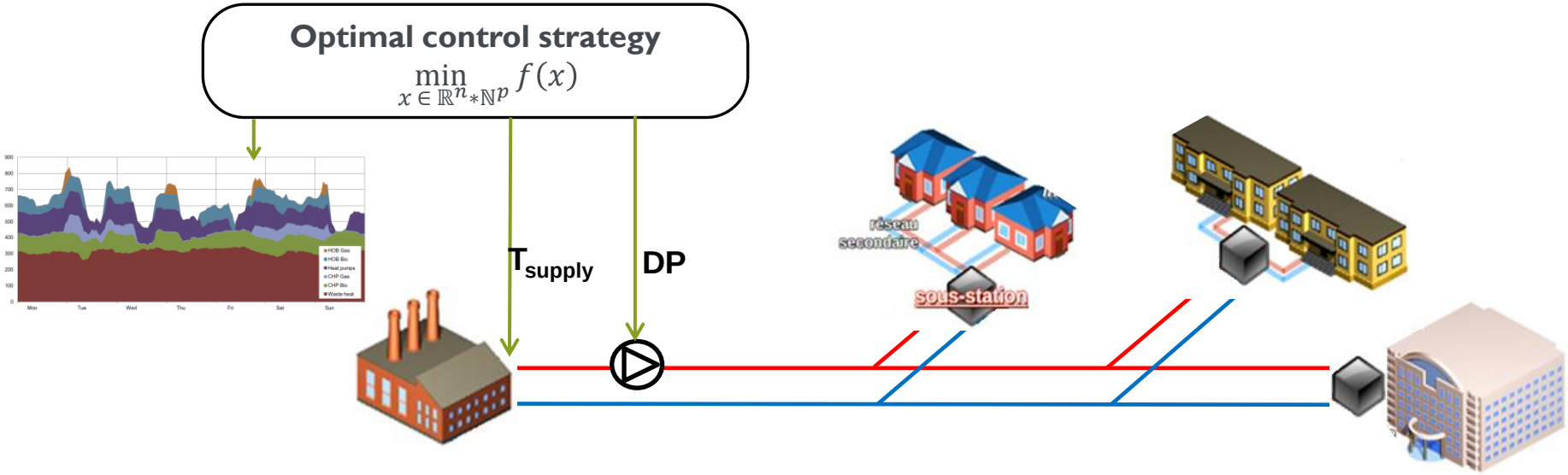
+	-
• Optimal control	• Difficulty to formulate the problem

  - ✓ **Existing tools**
    - ✓ Production optimization only
    - ✓ Distribution optimization only

Objectives

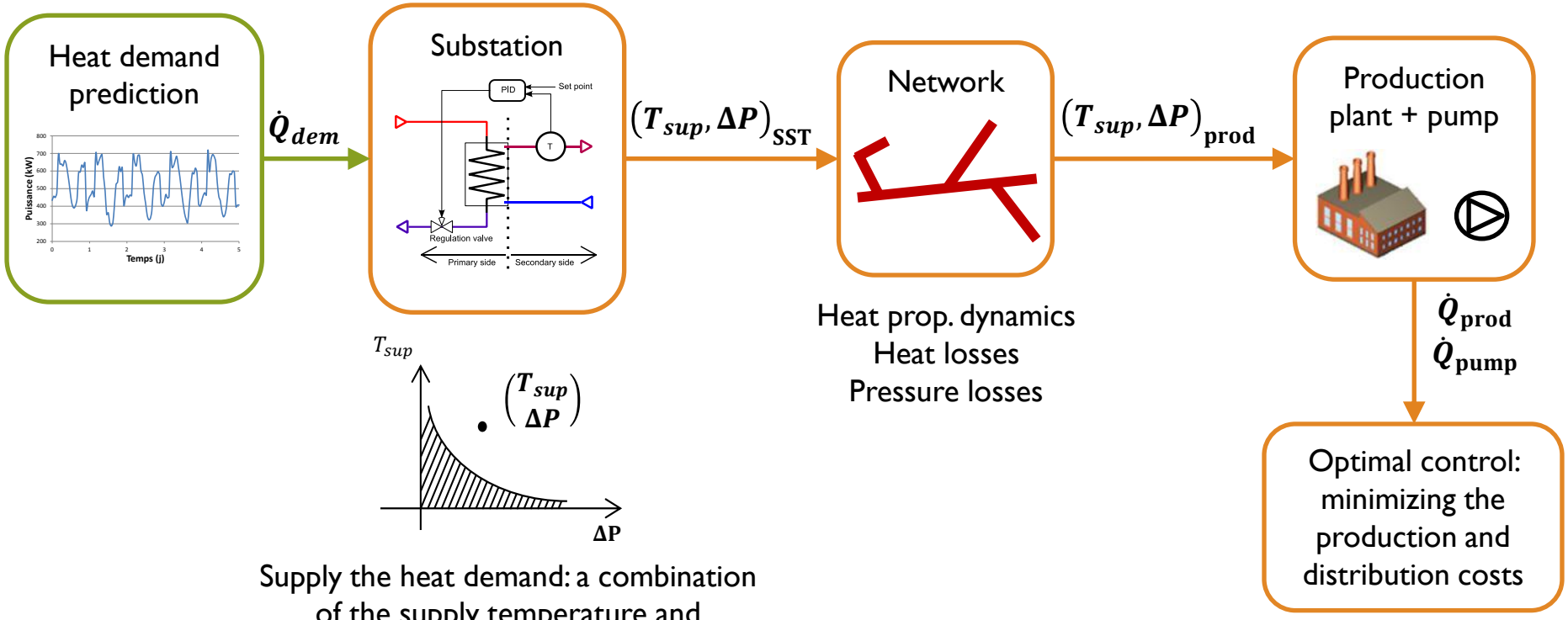
1. Development and validation of component models
2. Dynamic modeling of a DH system
3. Development of an optimal control strategy of DH systems
   - **Simultaneous optimization of production and distribution**
   - Set planning for each control variable

Always with the objective of optimizing the control:
Low computational costs



DEVELOPMENTS

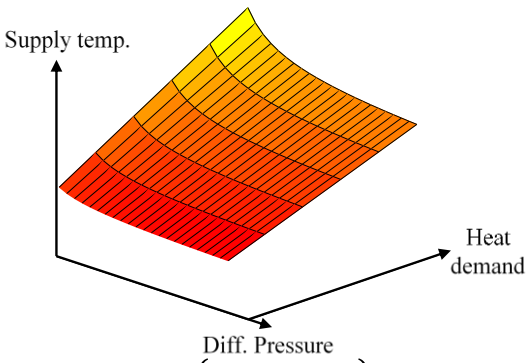
Overview of the proposed approach



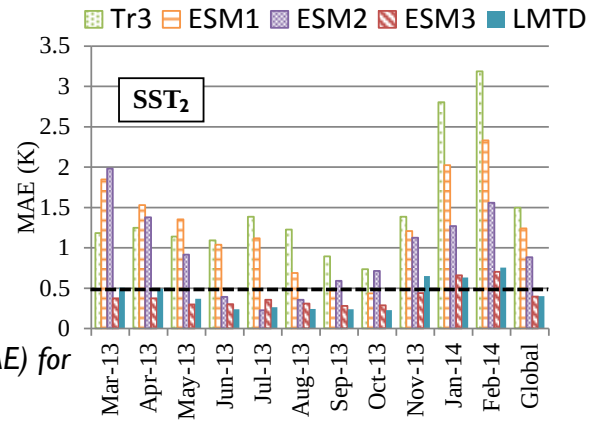
The substation

- **Modelling**
  - **Modelling the substation is essential to consider the consumers' demand**
  - 1 SST = 1 heat exchanger + 1 control valve + 1 controller
  - Development of several models
  - Comparison to experimental data [2]
    - ✓ Several substations
    - ✓ 1 year

➔ Selection of the most appropriate model (ESM_3)



Combination of $(T_{supply}, \Delta P)_{min}$ at a SST to supply the heat demand



Monthly Mean Absolute Error (MAE) for each substation model

The network

- **Modelling**

  ✓ **Representation of the dynamic temperature propagation, heat losses and pressure losses**

  ✓ 2 pipe models developed [3]:
    - The element model (Finite Volume Method)
    - The node model (Method of Characteristics)

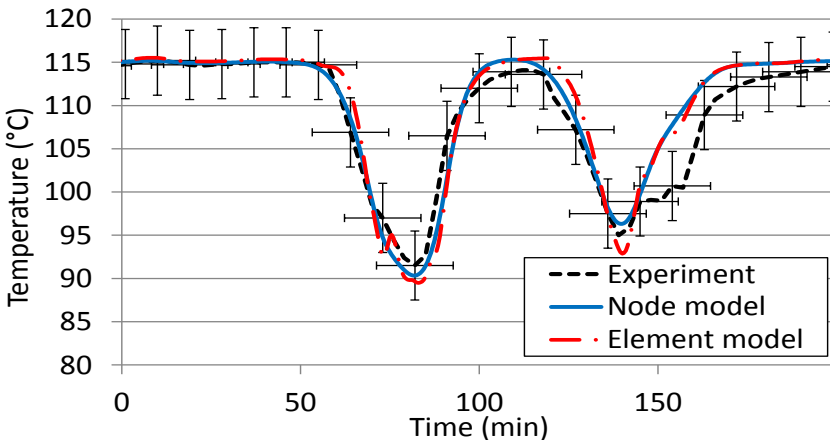
- **Experimental comparison: Grenoble**

  ✓ Accurate representation for both models

  ✓ Computational costs

  $$\text{Node model} \sim \frac{1}{10} \text{ Element model}$$

➔ **The node model is the most appropriate model**



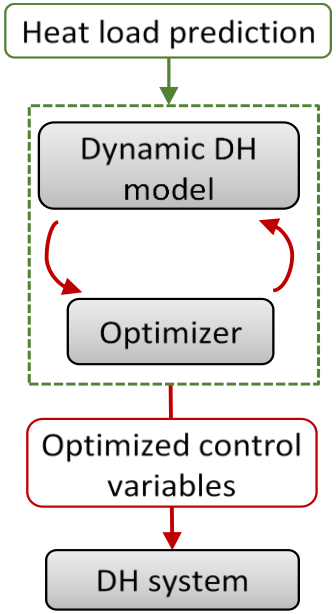
Numerical vs. experimental comparison of the outlet temperatur evolutions on the Grenoble DH system

Optimization of the control

- **Objectives:**
  - ✓ Determine optimal planning for each control variables
  - ✓ Minimize the production costs:
    - Heat production costs
    - Pumping costs
    - Starting costs
  - ✓ Supply the heat demand of each consumer ➔ $> (T, \Delta P)_{min}$
  - ✓ Consider several technical constraints (ex: Generators operating range)

- **Methods:**
  - ✓ Model Predictive Control
  - ✓ Mixed Integer Linear Programming
  - ✓ Iterative method between the dynamic model and the optimizer

➔ More details in [4]

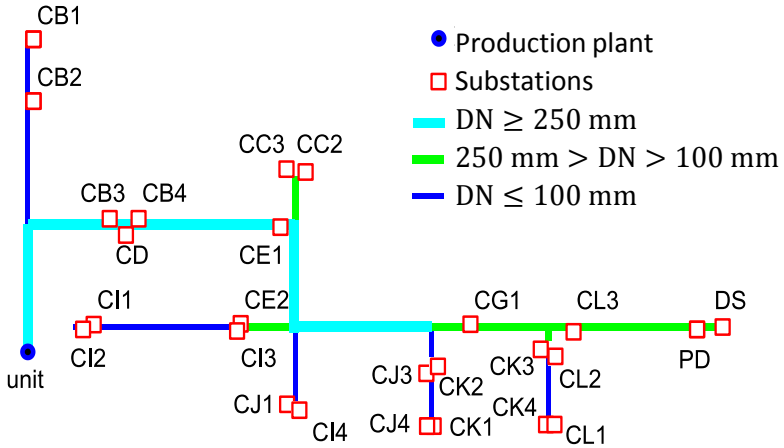


Proposed algorithm to control DH systems

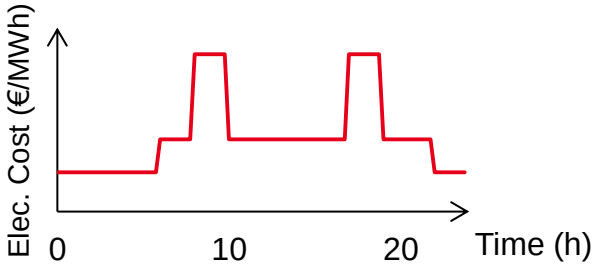
CASE STUDY

Case study

- **Description**
  - **Created with the developed and validated component models**
  - **Representative of a district area of Grenoble**
    - ✓ Liquid pressurized water
    - ✓ 15 heat generators (5 energy sources)
    - ✓ Real heat demand from the Grenoble DH
    - ✓ Real SST and generator parameters



Layout of the DH case study



Daily evolution of the electricity cost

PERFORMANCE ANALYSIS OF OUR CONTROL METHOD

Performance analysis of our control method

- **Comparison of 3 control methods**

Characteristics of each control method

	Production	Distribution
Empirical laws	Piling method	Heating curve
Production optimization	Optimization	Heating curve
Global optimization	Production + distribution optimization	

✓ Heat demand prediction is supposed ideal for each control method

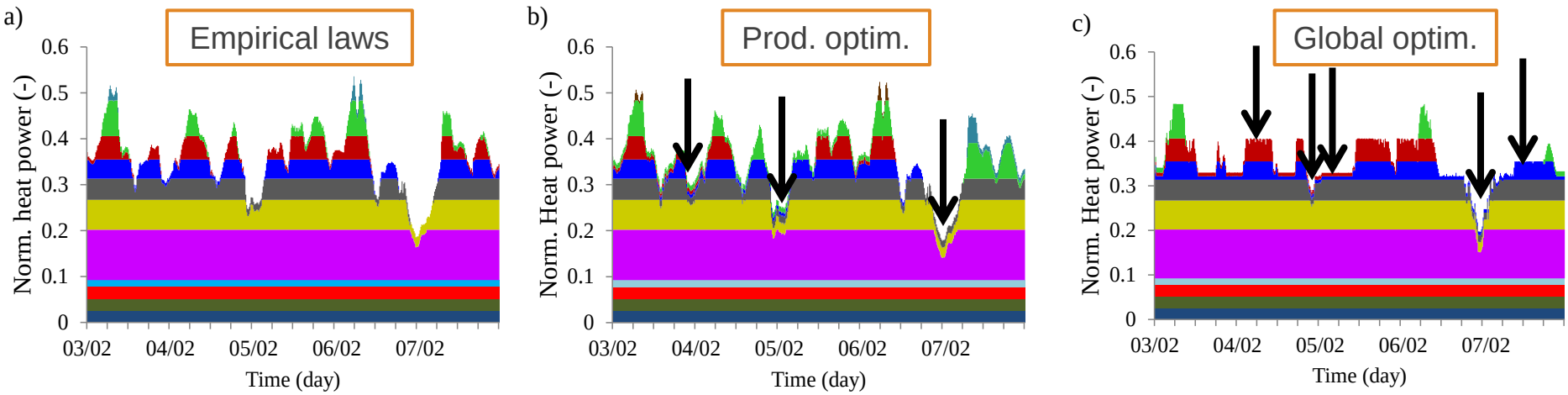
- **Times of the simulation**

✓ Simulation horizon: Heating season 2013 / 2014

✓ Time step: 15 minutes

Performance analysis of our control method

- **Zoom on 5 days of the production planning**



- **Global results**

	Empirical laws	Prod. optim.	Global optim.
Production costs	**100 %**	**93,59 %**	**91,74 %**
Produced energy	100 %	100 %	98,34 %

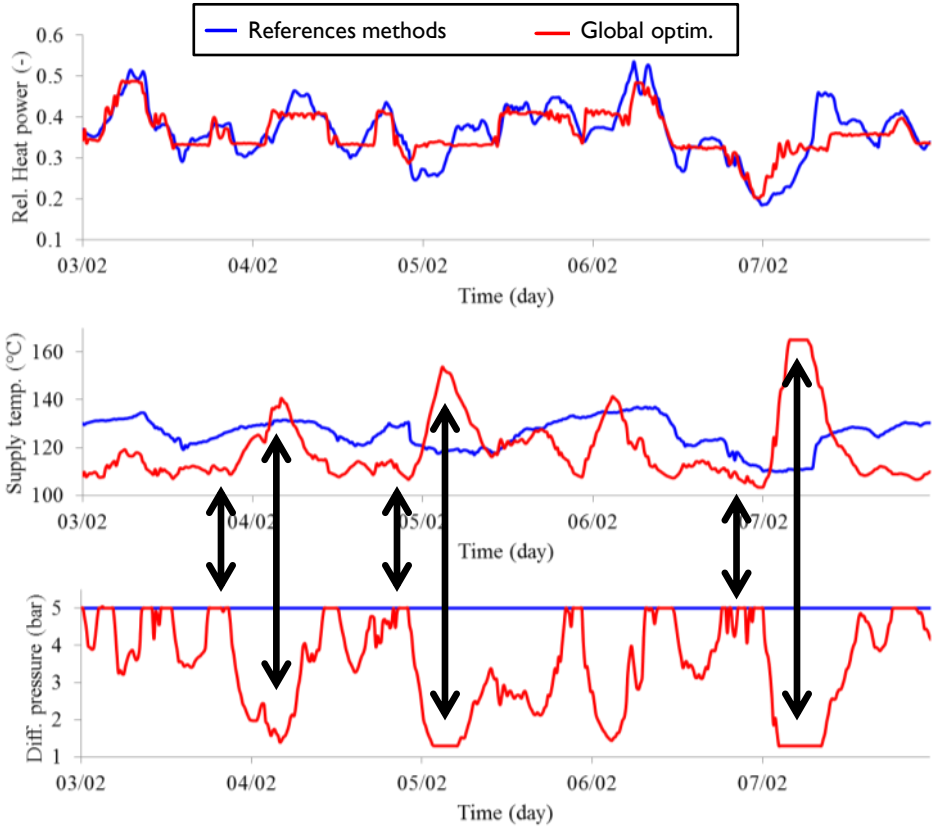
➔ Reduction of the generator starts

➔ Reduction of the produced energy

➔ Use the network as storage

Performance analysis of our control method

- **How does our method reduce the energy and use the network as storage?**



- Reduction of the produced energy:
  - ✓ Minimization of the supply temperature
  - ✓ Maximization of the differential pressure
  - ➔ Reduction of the heat losses

- Heat storage in the network:
  - ✓ Increase of the supply temperature before a peak demand
  - ✓ Decrease of the differential pressure
  - ➔ Constant produced power

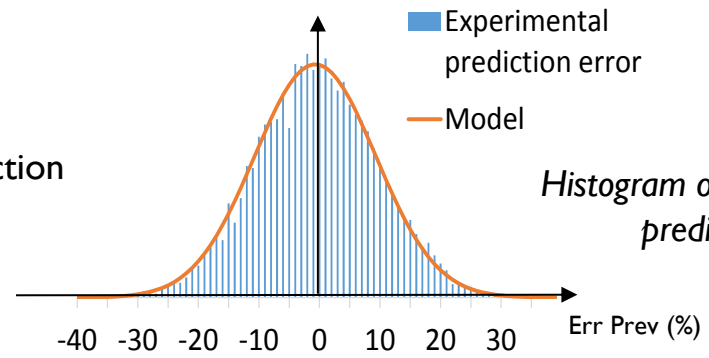
CONTROL IN REAL CONDITIONS

Control in real conditions

- **What are real conditions?**

  ✓ Uncertainties on the demand prediction

  ✓ Gaps with the set-points



Histogram of the error on the demand prediction over a season

- **Robustification of our method (on going)**

  ✓ Unexpected events are considered in our control method

  ✓ How to supply the heat demand and minimize the costs?

  - Minimize the simulation times
  - Control ΔP in reactive when necessary
  - Margin on the supply temperature and available power

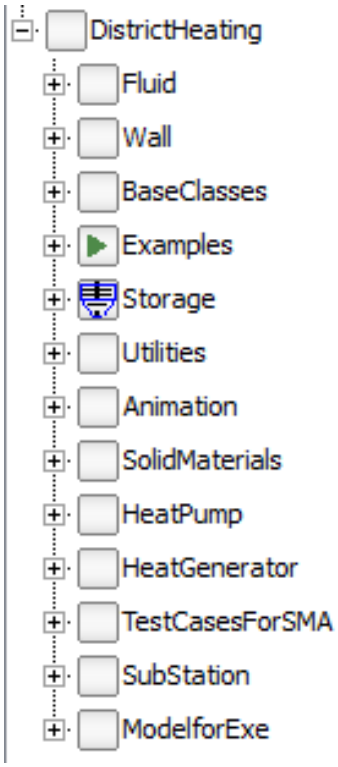
CONCLUSIONS

Summary

- Development and validation of several component models
  - ✓ The substation
  - ✓ The network
  - ✓ The production plant
  - ✓ The pump
  - ✓ …And others gathered in a Modelica library, *DistrictHeating*

- Development of a new control method for global optimization using:
  - ✓ A dynamic DH model
  - ✓ A linear optimizer

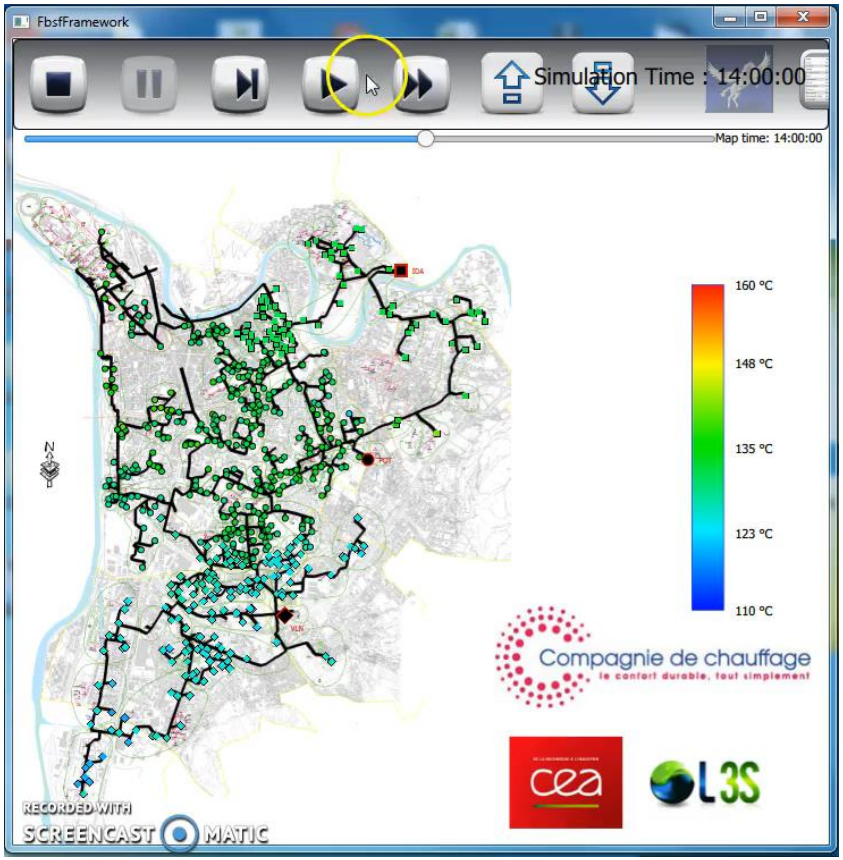
- Compared to an empirical control strategy, **the production costs are decreased of about 8 %.**



***DistrictHeating* library**

Conclusions and perspectives

- Possibility to optimally operate DH systems:
  - ✓ Minimize the heat losses
  - ✓ Use the network as storage
- The computational costs are adapted to an in-line utilization.
- **Further steps**
  - ✓ Robustification of the control method in real conditions (on going)
  - ✓ Implement this method on the DH system of Grenoble (in progress)
  - ✓ Consider more control variables



Acknowledgments

Compagnie de chauffage
le confort durable, tout simplement

ADEME
Agence de l'Environnement
et de la Maîtrise de l'Energie

For more details

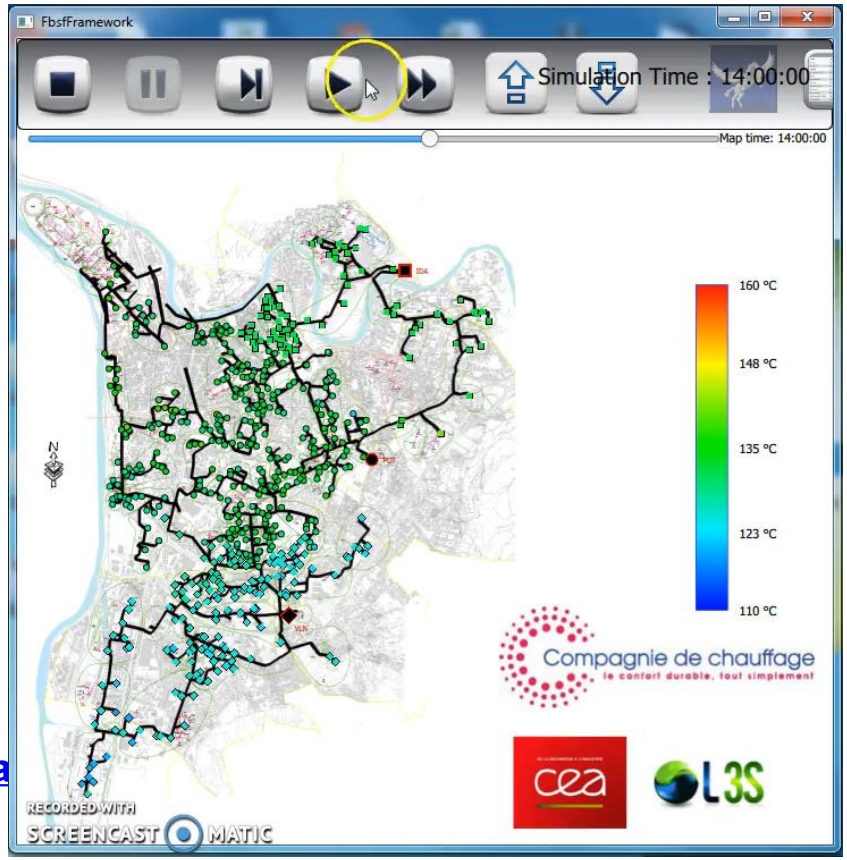
[1] L. Giraud, R. Bavière, C. Paulus, "Modeling of Solar District Heating: A Comparison between TRNSYS and Modelica", Proceedings of EuroSun 2014, Aix-les-Bains, France, 2014.

[2] L. Giraud, R. Bavière, C. Paulus, M. Vallée, and J.-F. Robin, "Dynamic Modelling, Experimental Validation and Simulation of a Virtual District Heating Network," 28th Int. Conf. on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS), Pau, France, 2015.

[3] L. Giraud, R. Bavière, M. Vallée, and C. Paulus, "Presentation, Validation and Application of the DistrictHeating Modelica Library," 11th International Modelica Conference, Versailles, France, 2015, p. 10.

[4] L. Giraud, M. Merabet, R. Bavière, M. Vallée, C. Paulus and C. Schaeffer, "A global linear optimization of District Heating management considering network storage", *Energy*, 2016 (Under Review)

THANK YOU FOR YOUR ATTENTION



CONTACT: loic.giraud1510@gmail.com

TUTORS CONTACT: cedric.paulus@cea
roland.baviere@cea.fr

DHC+ TECHNOLOGY PLATFORM