A smart controller for small-scale district heating and cooling networks: development and testing

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Heating and Cooling networks efficiently distribute thermal energy at **different scales**
There are significant advantages also at **small-scale level** compared to single boilers...

- Flexibility
- Integration of renewables
- Energy efficient buildings
...but, together with opportunities, these multi-source networks introduced new challenges

- Flexibility
- Integration of renewables
- Energy efficient buildings

- Load allocation
- Management of the system
- Real-time control
Today, energy systems are managed through day-ahead schedule, rule-based or, in the best of cases, adaptive strategies
But, in order to face extreme climate conditions and to achieve optimal management of the system, predictive control strategies are necessary.
Model Predictive Control uses a model to predict the future behavior of the system and compute optimal control sequence.
Each time-step, time horizon is moved one step forward, model variables are updated and optimization is repeated (receding time horizon)
Each optimization problem is solved through a **Dynamic Programming algorithm** previously developed.

\[
\hat{T}_{\text{ext}} \neq T_{\text{ext}}
\]

\[
T_{\text{actual}} \rightarrow \hat{T}_{\text{future}} \rightarrow \hat{u}_{i} \leftarrow \hat{u}_{\text{optimal}} \rightarrow T_{\text{future}}
\]

A Model-in-the-Loop platform is used to test and compare different control strategies.
A conventional controller (baseline) and the innovative **Model-based Predictive** controller are implemented.
The **detailed model** of the real system is built with the components of a library and used as test bench.
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**MPC-model ≠ Detailed MiL-model** since it must be simplified for **real-time optimization**

**System model**
The **standard components** of energy systems has been modeled...
...and collected in a **library** with a **modular approach** ideal for the application to **different layouts**

*Cadu et al. Energy Procedia 2018;148:352-359*
The **preliminary test** has been performed on the heat distribution network of a single end-user.
This first case study has shown promising results in terms of **energy efficiency**
This first case study has shown promising results in terms of **energy efficiency**.
The controller has been applied to more complex energy systems according to a **multi-agent hierarchical strategy**.
In each branch, an **MPC** controller minimizes the energy required for each user...
...while another MPC controller optimizes the production side starting from the optimal demands calculated downstream.
The case study is a district heating network supplied by an **ORC** and a **thermal energy storage tank**

**Diagram:**

- **Legend:**
  - 1. Expansion vessel
  - 2. Pump
  - 3. Boiler
  - 4. Heat exchanger
  - 5. Thermal energy storage
  - 6. Splitter/mixer node
  - 7. Building
  - 8. Three-port valve
  - 9. Two-port valve
  - 10. Electric power

**Fuel:**
- Hot water
- Cold water
- Control signals
- Set point
The case study is a district heating network supplied by an ORC and a thermal energy storage tank.
After its development and demonstration, the controller has been exploited in real case studies...
...demonstrating its **effectiveness** and **reducing** the energy consumption substantially
...demonstrating its **effectiveness** and reducing the **energy consumption** substantially.
Our project **DISTRHEAT** proposes a scalable MPC for district heating networks and will start at the end of the year.

**DISTRHEAT** ➔ Digital Intelligent and Scalable conTrol for Renewables in HEAting neTworks

**Duration:** 01/11/2019 – 31/10/2022

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In future developments, the presented approach will be replicated in **multi-source smart energy networks**.
The MPC controller is implemented on a standard workstation and the communication is set up from sensors to actuators.