# *MultiEnergySystem*: A Modelica Library for Dynamic Modeling and Simulation of District Heating and Gas Networks

Marcelo Muro[1] Guido Sassaroli[1] Riccardo Lazzari[1]

[1]Materials and Generation Technologies Department, Ricerca sul Sistema Energetico RSE S.p.A., Milan, Italy
{marcelo.muro, guido.sassaroli, riccardo.lazzari}@rse-web.it

## Abstract

This paper presents the *MultiEnergySystem* Library (MESL), an open-source Modelica library designed for the dynamic simulation of integrated district heating and gas/hydrogen networks. MESL introduces a fully equation-based formulation of fluid properties, ensuring model interpretability and enabling compatibility with control and optimization applications. The library includes dedicated models for hydrogen blending studies and supports gas quality indicators such as Wobbe Index (WI), Higher Heating Value (HHV), and Specific Gravity (SG). District heating models have been experimentally validated using data from a real-world test facility, and these datasets are provided to support reproducibility. While MESL currently focuses on thermal and gas domains, planned expansions include a more comprehensive electrical package and experimental validation of hydrogen components. The paper describes the library's design and validation strategy, concluding with illustrative case studies and ongoing development plans.

*Keywords: Modelica library, District Heating, Natural Gas, Hydrogen Blending.*

## 1 Introduction

In recent years, the increasing complexity and integration of various energy systems—such as district heating and gas/hydrogen networks—driven by decarbonization objectives, have motivated the development of sophisticated modeling and simulation tools. Aligned with this context, one of the primary activities of our research department at RSE S.p.A. is the development of precise models to study phenomena within and across different energy systems, facilitating both operational and control analyses.

We are currently involved in two research projects that, while not directly correlated, share similar objectives. The first project focuses on applying novel operational and control approaches to integrate thermal and gas energy vectors with the electrical network, using detailed models that can be experimentally validated at the RSE Distributed Energy Resources Test Facility (DER-TF) (Gandolfi et al. 2022). The second project is dedicated to studying the integration of biogas and/or hydrogen into gas distribution networks, with particular attention to understanding the main dynamics of this phenomenon and its impact on gas quality. Both projects highlight the critical need for precise models and share the gas/hydrogen vector as a common energy domain, demonstrating the value of a unified modeling approach.

The Modelica programming language has emerged as a key modeling tool due to its a-causal, multi-domain, object-oriented nature, enabling dynamic and modular modeling of interconnected systems. Indeed, the use of Modelica for studying multi-energy networks has grown significantly. This growth has led to the creation of modeling libraries tailored for these applications, each offering different levels of complexity and focus.

Focusing on open-source Modelica libraries, the *DistrictHeating* library (Giraud et al. 2015) stands out for its emphasis on accurate and reliable District Heating and Cooling (DHC) simulations. More recently, the open-source *AixLib* library (Maier et al. 2024) has proven valuable for simulating large-scale district heating systems and their interaction with building energy systems. However, both libraries focus solely on DHNs and do not include gas or hydrogen modeling, limiting their applicability to multi-energy system studies.

The *ThermoPower* library (Casella and Leva 2006) instead, is one of the most established Modelica libraries for dynamic modeling of conventional thermal power plants. It contains models from multiple energy domains, including thermal and gas, and has been widely used over the past two decades (Casella and Leva 2024). The *TransiEnt* library (Senkel et al. 2021) is a more recent development designed for transient simulations of coupled energy networks, integrating district heating, gas, and hydrogen networks into a unified framework.

Despite their strengths, these libraries rely on external fluid property backends, either via the Modelica Standard Library or through compiled libraries such as *TIL-Media* (GmbH et al. 2025). While these tools are effective for simulation, they limit symbolic manipulation, making them less suitable for applications involving control design, optimization, or sensitivity analysis, where full access to model equations is essential. Furthermore, these libraries lack dedicated tools for modeling hydrogen blending and gas quality indicators, such as Wobbe Index (WI), Higher Heating Value (HHV), and Specific Gravity (SG)—parameters that are central to assessing hydrogen integration feasibility and regulatory compliance. Finally, although many libraries have undergone theoretical validation, they often lack publicly available experimental datasets that allow direct comparison with real-world measurements. To address these needs, and inspired by previous libraries, we developed the *MultiEnergySystem* library (MESL).

MESL provides a comprehensive framework for simulating the dynamic behavior of integrated energy systems, focusing primarily on thermal and gas domains. A key feature of the library is its fully equation-based formulation of fluid properties, implemented entirely in Modelica. Unlike existing libraries such as *ThermoPower* or *TILMedia*, which rely on external function calls (e.g., C-based backends) for fluid property calculations, MESL uses symbolic equations to compute thermodynamic properties. This approach improves customizability, interpretability, and compatibility with symbolic-based applications such as optimal control.

The library also offers dedicated models for hydrogen blending studies, including the ability to compute gas quality indicators—such as WI, HHV, and SG—which are essential for evaluating the technical feasibility and regulatory compliance of hydrogen integration into gas networks. While the initial focus is on gas distribution systems where ideal-gas behavior is often assumed, MESL also incorporates real-gas models (e.g., Papay equation (Papay 1968)) to support advanced studies on transmission networks and gas mixing phenomena.

Another distinctive feature is the library's emphasis on experimental validation. MESL includes a set of district heating models that have been validated against real-world measurements obtained from a scaled-down District Heating Test Facility (DHTF) (Anderis, Muro Alvarado, and Lazzari 2024). These validation datasets are publicly available and integrated with the library, enabling reproducibility and fostering trust in simulation-based studies. Finally, MESL is released as an open-source Modelica library, ensuring accessibility for the research community and encouraging collaborative development.

Despite these features, some limitations remain. MESL currently includes includes only basic electrical modeling, allowing basic electric power calculations of components such as electric pumps, boilers, and combined heat-and-power (CHP) units. A more comprehensive electrical package is still under consideration, with future integration planned alongside existing Modelica libraries. Meanwhile, planned expansions of our DER-TF, which consist of a Gas Test Facility (GTF) implementation, will enable direct experimental validation of gas/hydrogen components; current validation is limited to measuring natural gas mass flow for thermal devices (e.g., boilers, CHP). Once realized, these additions will enhance the library's validated hydrogen models.

The primary goal of this study is to present MESL, describing its design, implementation, and validation, highlighting potential operational and control applications. The remainder of the paper is organized as follows: Section 2 introduces the library's structure, Section 3 explains the validation methodology, Section 4 presents selected study cases, and Section 5 concludes with an outlook on future work.

## 2 Library Overview

The *MultiEnergySystem* Library contains three main packages.
1. **`DistrictHeatingNetwork`**: All core components needed to model a district heating system.
2. **`H2GasFacility`**: Models for studying gas networks, including biomethane and hydrogen injection.
3. **`TestFacility`**: Various systems and plant configurations representative of RSE's test facilities, plus related validation models and data.

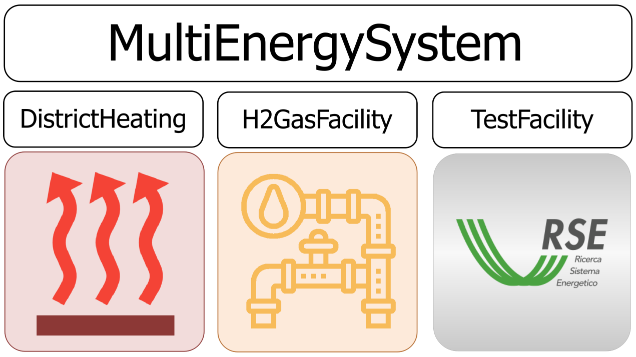


**Figure 1.** Main packages from MESL.

Within `DistrictHeatingNetwork` and `H2GasFacility`, sub-packages are arranged by functionality. For instance,

- `Interfaces` provides the interfaces to use for the specific energy vector.
- `Fluids` defines water for district heating and the various gas mixtures for gas networks,
- `Sources` contains ideal source and sink pressure and mass flow rate models.
- `Components` contains models like pipes, valves, and other thermo-hydraulic elements,
- `Tests` provides models for verifying the functionality of individual components.

These sub-packages appear in both `DistrictHeatingNetwork` and `H2GasFacility` packages, facilitating a consistent approach to component development. The `TestFacility` package, in contrast, follows its own structure, reflecting the setup of RSE's DHTF and related configurations; it also stores validation data and scenarios. Further details about `TestFacility` will be presented later in this section.

In the following subsections, we introduce each main package or MESL in more detail.


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### 2.1 `DistrictHeatingNetwork`

As mentioned previously, this package contains different components that can be used to model a district heating network. Because our focus is primarily on building these models for operational and control purposes, we have chosen certain simplifications. For example, the fluid is treated strictly as liquid water, without phase-change effects. In fact, it is possible to consider a constant specific heat capacity and constant density by the assumption that the system works at low pressures; in any case, it is also possible to find variations of the liquid water model with temperature-dependent specific heat capacity and constant density if the user requires this detail; however, this remains liquid water. Likewise, heat-generation devices such as boilers, CHP or chiller are assumed to be ideal outlet-temperature controlled. These assumptions reduce model complexity while still preserving the key dynamics required for control-oriented studies.

Typical components in `DistrictHeatingNetwork` include:

- **`Pipes/RoundPipe1DFV`**: Pipe model described by the traditional 1D finite-volume approach that implements mass, momentum, and energy balances, used for modeling the RSE's DHTF.
- **`Pipes/BrazedPlateHeatExchanger`**: Allow for heat transfer between heat generation and cooling systems.
- **`ThermalMachines/[ControlledGasBoiler ,ControlledCHP]`**: Idealized outlet temperature-controlled units, including mass and energy balances as well.
- **`TurboMachines/ControlledPump`**: Support simple control modes if needed for optimization tasks (ideal mass-flow or pressure control pumps).

For further details, readers can refer to (Muro Alvarado et al. 2024).

### 2.2 `H2GasFacility`

The `H2GasFacility` package was developed to enable both the integration of gas networks with thermal energy systems and the study of decentralized alternative gas injection in gas networks.

#### 2.2.1 `H2GasFacility/Media`

A key feature of this package is the custom gas model design. Although our primary focus is on gas distribution networks—where ideal-gas behavior is often assumed, we developed our own gas modeling approach to handle both low-pressure distribution networks and high-pressure transmission lines within a single framework. Rather than limiting ourselves to an ideal-gas assumption, we implemented a fully equation-based formulation that effortlessly switches between ideal and real-gas models. This approach enhances portability, interpretability, and compatibility with optimization and control applications, ensuring that the library can support a wide range of research needs, from conventional gas distribution to high-pressure pipelines and hydrogen blending studies.

At the core of this flexibility is the `PartialMixture` base model, located in the `Media/BaseClasses` sub-package. This foundational model defines essential variables such as pressure, temperature, and mass composition. By extending `PartialMixture`, users can implement custom gas mixture models by specifying the desired thermodynamic equations. The class diagram in Figure Figure 2 illustrates this structure. Each gas mixture model (e.g., `IdealMixture`, `PapayMixture`) defines its own equation of state, enabling tailored simulation of different gas behaviors within the same framework. From these models, users can then define specific gases by setting their composition and other relevant properties, enabling detailed and customizable gas modeling for a wide range of applications.

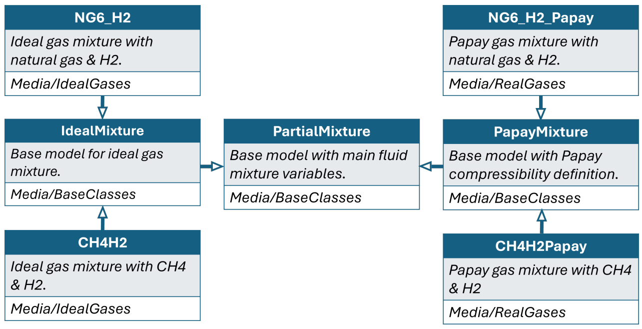


**Figure 2.** Class diagram for fluid models in `H2GasFacility` package.

#### 2.2.2 `H2GasFacility/Components`

The `Components` package contains the fundamental building blocks for modeling gas networks. Among these, two key models stand out:

- **`Round1DFV`**: A detailed 1D finite-volume pipe model that implements mass, momentum, and energy balances, as well as the composition mass balance for gas mixtures. This level of detail is especially useful for research that requires transient or multi-species gas flow analysis.
- **`IdealUser`**: An idealized mass-flow consumer that can be placed within a gas network to represent generic demands or loads.

Additionally, `Components` includes the `Manifold` sub-package, which provides manifold and connector models that can facilitate initialization and improve overall network organization.

#### 2.2.3 `H2GasFacility/Tests`

The `Tests` package contains validation models designed to assess gas quality parameters and the accuracy of component models. In particular, the `Subsystem` sub-package includes test models based on literature examples, ensuring consistency with existing studies on hydrogen blending and gas network behavior. Other sub-packages within `Tests` focus on verifying the functionality of individual components.

#### 2.2.4 Considerations

In addition to predefined test cases, users can construct their own gas network models by combining fundamental components from the `Components` package. A basic gas network can be constructed by connecting an ideal pressure source to one or more `Round1DFV` pipes, then attaching one or more `IdealUser` blocks. All pipe connections must have defined inlet and outlet boundaries—either additional pipes, a gas source, or a user. Figure 3 shows the diagram view of one such medium-pressure gas network from (Cheli et al. 2021). Additional details about this test case will be covered in Section 4.

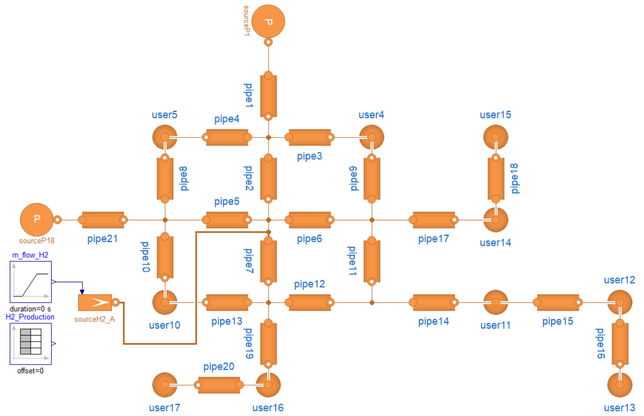


**Figure 3.** Modelica diagram view of medium-pressure gas network based on (Cheli et al. 2021).

In the modeling of extensive gas networks, it is crucial to carefully consider the initial values, especially for pressure. Although exact initialization is unnecessary, the starting pressure values should align with anticipations of network conditions. Poorly selected initial values may lead to initialization issues, potentially impacting the convergence of the model.

To determine feasible initial values, several approaches can be employed:

- Using real measured data from steady-state operation: When available, historical or real-time measurements from the gas network under steady-state conditions provide a reliable basis for initializing pressures and flows.

- Applying a trial-and-error method with iterative refinement: In the absence of reliable data, a manual approach may be adopted, starting with reasonable estimates followed by successive adjustments based on model feedback.

- Performing steady-state simulations using simplified frameworks: Employing less complex simulation tools (e.g., Pandapipes (Lohmeier et al. 2020)) to solve the network under steady-state assumptions can offer a practical way to generate plausible initial values.

#### 2.2.5 Coupling with thermal energy vector

The `H2GasFacility` package can interface with the `DistrictHeatingNetwork` models by incorporating a gas connector into components such as gas boiler and CHP unit. This additional connector represents the fuel inlet (e.g., natural gas or hydrogen blends), enabling direct coupling between gas and thermal domains. This feature is important for conducting multi-vector energy simulations, allowing researchers to analyze the operational implications of hydrogen blending on both gas networks and thermal generation systems.

### 2.3 `TestFacility`

The `TestFacility` package contains models, systems, and full plant configurations that replicate the RSE's DHTF. It also includes the corresponding validation test cases. Because the DHTF is currently implemented while the GTF is still under development, most existing models focus on the district heating side of the library. Nonetheless, for demonstration purposes, a few gas-related study cases are already included. As soon as the GTF is operational, we plan to add experimental data and corresponding models to extend the library's scope on the gas/hydrogen side.

This package features more complex systems built from the basic models in the other two packages, forming subsystems and complete configurations of the DHTF. Users can find not only the validation tests within the DHTF environment, but also the experimental data employed in these validations. The sub-package `Resources` stores these datasets according to specific plant configurations. At present, most validations concentrate on centralized setups, but future work will incorporate diverse plant configurations to exploit the full capabilities of the DHTF.

Another important sub-package is `FMUExport`, which includes example models at both subsystem and full-plant scales. These classes enable the generation of FMUs for use in external environments like Simulink or Python, supporting advanced control strategies.

### 2.4 Availability & Software Compatibility

The MESL is developed as an open-source project and is publicly available at `https://github.com/RSE-TGM/multienergysystem`. The library has been primarily developed and tested in Dymola 2023, ensuring full compatibility with this Modelica environment. However, the


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DistrictHeatingNetwork package—and models using only its components—have been successfully tested in OpenModelica v1.24.3, demonstrating full functionality in this open-source platform.

On the other hand, the H2GasFacility package currently faces some limitations in OpenModelica. While basic gas models run correctly, advanced test cases involving multi-component gas flow present initialization issues. Future work will focus on improving OpenModelica compatibility to enhance accessibility and usability across multiple platforms.

## 3 Validation

Prior to this work, we had already validated the core district heating components in the DistrictHeatingNetwork package—such as boilers, heat exchangers and water pumps—using the RSE's DHTF. Over a series of experiments, we verified each model's accuracy under diverse operating conditions, measuring temperature, pressure, and flow rates. In the most comprehensive configuration (centralized layout), the models achieved a CVRMSE below 18% and an NMBE below 8%, in accordance with ASHRAE Guideline 14 (Muro Alvarado et al. 2024). These results confirm that the library reliably captures the dynamics in a district heating environment and can thus be extended to other energy vectors.

To enable the interconnection with gas networks, we updated specific models from the DistrictHeatingNetwork main package, by adding an additional gas inlet connector, drawn from H2GasNetwork.Interfaces.Connectors subpackage. In particular, two heat-generation models—the gas boiler and the CHP unit—were extended to calculate gas mass flow rates using Equation 1:

$$w_g = \frac{P_c}{HHV_g \eta_c} \tag{1}$$

where $w_g$ is the gas mass flow (kg/s), $P_c$ is the combustion power (W), $HHV_g$ is the higher heating value of the gas (J/kg), and $\eta_c$ is the combustion efficiency.

For the computation of the gas mass flow rate, the value of $P_c$ depends on the specific component. In the gas boiler, the combustion power is entirely converted into thermal output, so $P_c$ directly depends on the required thermal power. In the CHP model, $P_c$ can be computed based on either the required thermal power or the required electrical power, depending on the selected control mode configuration.

This connector-based approach allows each gas-consuming component to be directly linked to a gas network model, thereby facilitating a coupling between thermal and gas domains.

To validate these hybrid models, we compared simulated results with experimental measurements from the DHTF. Figure 4 illustrates the test model diagram for a gas boiler configuration. The main boundary conditions—inlet temperature and water mass flow rate—were imposed using measured data (Figure 5.a). For evaluation purposes, we focused on two key variables: the outlet temperature of the boiler system, representing the thermal energy vector, and the fuel mass flow rate, representing the gas energy vector. Although Figure 5.b shows the outlet temperature trend, the performance metrics (CVRMSE & NMBE) were computed based on the temperature difference across the boiler (i.e., outlet minus inlet).

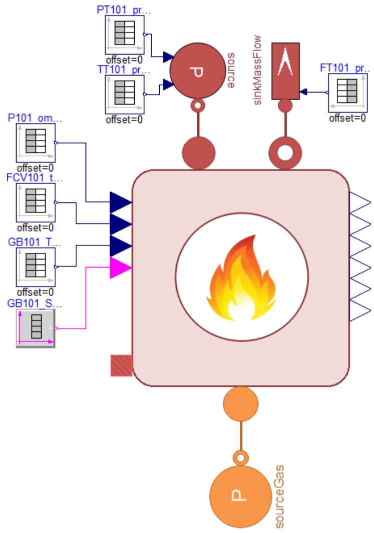
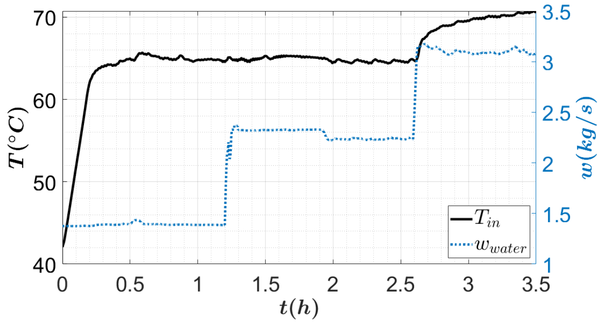



**Figure 4.** Validation test model for gas boiler subsystem.

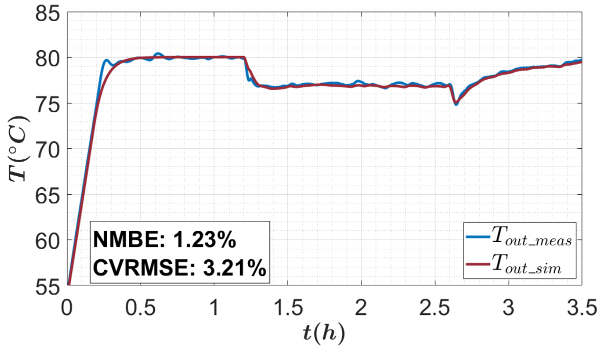
The validation results show good alignment between measured and simulated values: the temperature difference achieved an NMBE of 1.23% and a CVRMSE of 3.21%, while the fuel mass flow rate (Figure 5.c) resulted in an NMBE of -0.14% and a CVRMSE of 2.43%. These results demonstrate both strong accuracy and practical suitability of the model for integrated gas-thermal simulations.

Regarding gas network modeling, one of our primary goals is accurately capturing gas quality parameters (e.g., Wobbe Index) when hydrogen is blended into natural gas networks. We reference (Cheli et al. 2021) for such scenarios, which, although focused on quasi-steady operating conditions, provide a sufficient number of hourly data points to validate our model's compositional calculations. Figure 6 illustrates a representative comparison, showing minimal deviations from the reference data. While (Cheli et al. 2021) does not explore fast transients, our simulation framework allows for the generation of continuous hydrogen injection profiles. This feature becomes particularly useful for investigating faster ramping conditions and transient behaviors beyond the temporal resolution of the reference data.

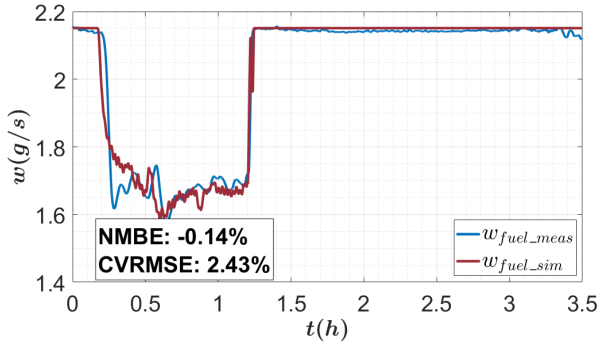
For more rapid transients (seconds to minutes), we have compared the library's performance with other validated tools—such as the Modelica Standard Library (Fritzson 2011)—yielding negligible discrepancies. Once the




**(a)** Main boundary conditions for the test




**(b)** Outlet gas boiler temperature.




**(c)** Fuel mass flow rate.

**Figure 5.** Measured and simulated profiles in a gas boiler subsystem validation test case.

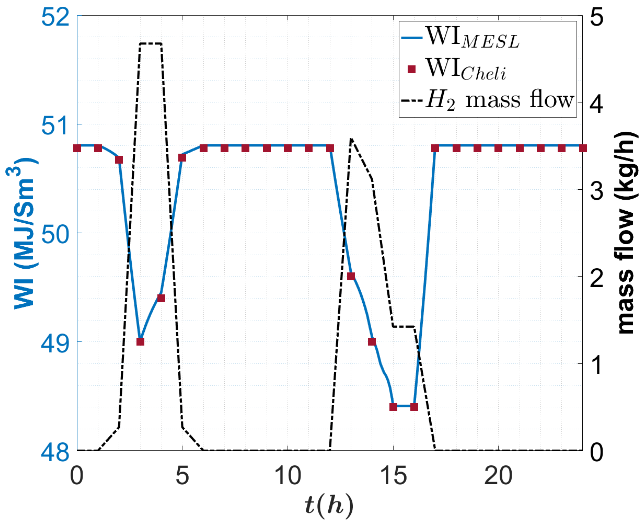


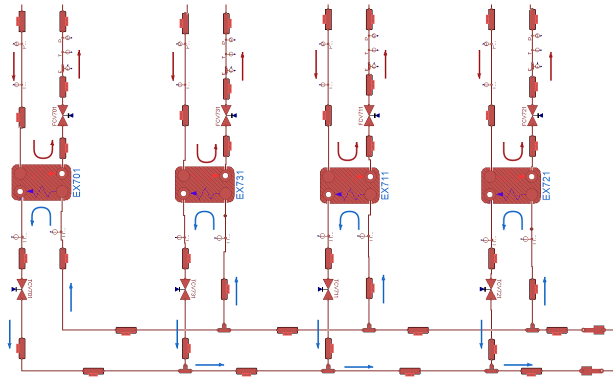

**Figure 6.** Comparison with (Cheli et al. 2021).

RSE's GTF is fully implemented, additional experimental validation will be performed to improve confidence in these models under dynamic hydrogen blending scenarios.

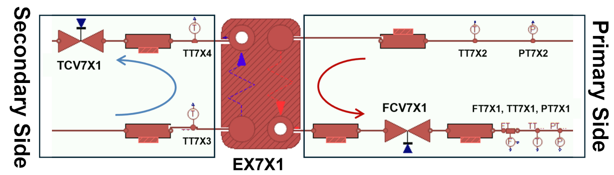
# 4 Case Studies

## 4.1 DHN application

One of the first applications of our library was the development of a decentralized control system for the load section of the DHTF. The load system consists of four heat exchangers (each representing a user in a DHN), connected on one side to a centralized heat distribution system (primary side) and on the other to a cooling system (secondary side) (Figure 7.a). Each user is equipped with pressure, temperature and flow sensors on both the primary and secondary sides, as well as two controllable valves: a flow control valve on the primary side and a temperature control valve on the secondary side (Figure 7.b). By adjusting these valves, the system emulates different heat demand profiles, closely replicating real DHN user behavior.




**(a)** Full Load system model.




**(b)** Single Load model.

**Figure 7.** DHTF Load System using MESL.

Traditionally, centralized DHN controllers regulate the secondary-side outlet temperature to ensure user comfort (Buffa et al. 2021). However, in this study, we adopt a different approach, prioritizing thermal power control at each heat exchanger. This strategy enables more precise energy demand regulation, allowing predefined load profiles. Moreover, it aligns with advanced control methodologies such as Model Predictive Control (MPC), where load thermal power profiles serve as key inputs for optimizing supply temperatures and mass flow rates from the heat generation side. A secondary objective is return temperature regulation on the primary side, ensuring compliance with the operational constraints of heat generators. Consequently, the primary variables of interest are the *thermal power exchanged* at each heat exchanger and the *return water temperature* on the primary side.

To achieve these objectives, we designed a decentralized control system. We used our library to develop an open-loop analysis of the load system in a centralized configuration and verified that (i) Primary-side valve control is best suited for thermal power regulation since mass flow directly governs power exchange, (ii) Secondary-side valve control is better for regulating primary-side return temperature and (iii) the system can be decomposed into independent Single-Input Single-Output (SISO) loops, allowing a decentralized control strategy. For simplicity, the detailed analytical steps of this analysis have been omitted from this paper.

The decentralized control system for the load system, developed using MESL, was validated both in simulations and experimentally in the DHTF. As shown in Figure 8, the final design consists of:

- Four independent PI controllers for return temperature control (secondary-side valves).
- Four cascade controllers for thermal power control (primary-side valves), with a PI controller in the primary loop and an integrator in the secondary loop.

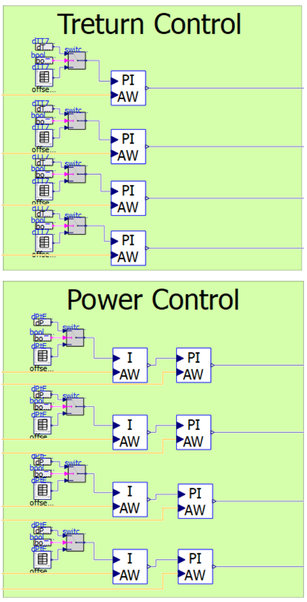
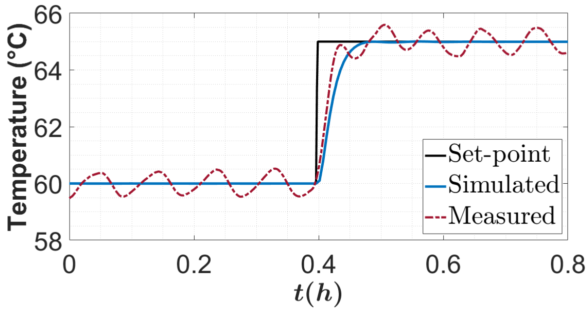
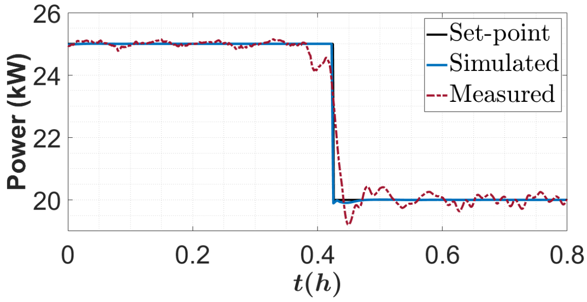



**Figure 8.** Controller diagram in Modelica.

A comparison between simulated and experimental results for a single load is shown in Figure 9. Trends for both return temperature (Figure 9.a) and thermal power (Figure 9.b) demonstrate the control system's ability to regulate desired variables effectively. While the overall response is well captured, some discrepancies appear, particularly in the return temperature dynamics. These deviations are primarily due to the cooling system's chiller: in real operation, the chiller follows an on/off control




**(a)** Return temperature.




**(b)** Thermal exchanged power.

**Figure 9.** Example of the controlled variables of one load.

approach, whereas in the simulation, an ideal temperature control assumption was used for simplicity. Despite these differences, the experimental results confirm that the control system successfully regulates the load dynamics, demonstrating the effectiveness of MESL in developing and validating customized control strategies for district heating applications.

Beyond the decentralized control implementation described above, the package *DistrictHeatingNetwork* has also been used in the design and experimental validation of a MPC strategy for district heating networks. In that study, MESL was employed to simulate the DER-TF environment and support controller tuning. For further details, see (Nigro et al. 2025). This application reinforces the suitability of the library not only for dynamic simulation but also to support advanced control design.

## 4.2 Integration of Thermal and Gas Domains

As mentioned previously, the gas models within our library have not yet been experimentally validated in the DER-TF. However, given the satisfactory simulation results obtained so far with academic results, we aim to showcase the potential of integrating district heating and gas networks using the developed tools. Specifically, we demonstrate how thermal and gas systems interact and how simulation-based approaches can help predict key network parameters in scenarios involving hydrogen injection.

To illustrate this, we constructed a study case that couples an existing system from the DHTF—the gas boiler system (previously introduced in Figure 4)—with the gas distribution network model described earlier (Figure 3).

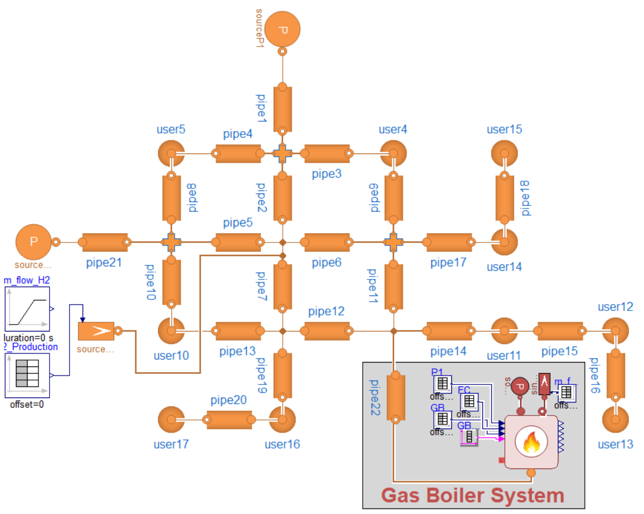



**Figure 10.** Diagram View of gas boiler system model from the DHTF, integrated in the case study based on (Cheli et al. 2021).

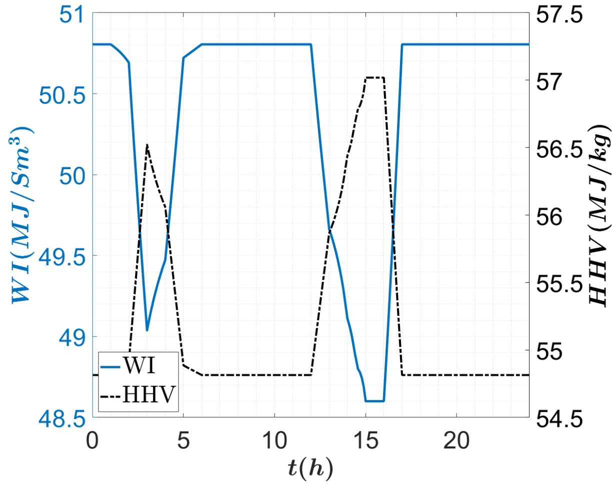
In this scenario, the gas boiler system is treated as an additional user in the gas network, alongside the existing users. The diagram of this configuration is described in Figure 10. The goal is to assess how the gas composition and flow characteristics evolve when the same hydrogen injection profile used in Figure 6 is applied.

The initial fuel composition consists of 97.20% $CH_4$, 1.80% $C_2H_6$, 0.30% $C_3H_8$, 0.10% $C_4H_{10}$, 0.10% $CO_2$, and 0.50% $N_2$ (vol%). The nominal fuel mass flow rate required by the gas boiler system, once connected to the network, is 7.41 kg/h. As hydrogen injection occurs throughout the day, this mass flow rate dynamically adjusts in response to the changing gas mixture composition, according to Equation 1.

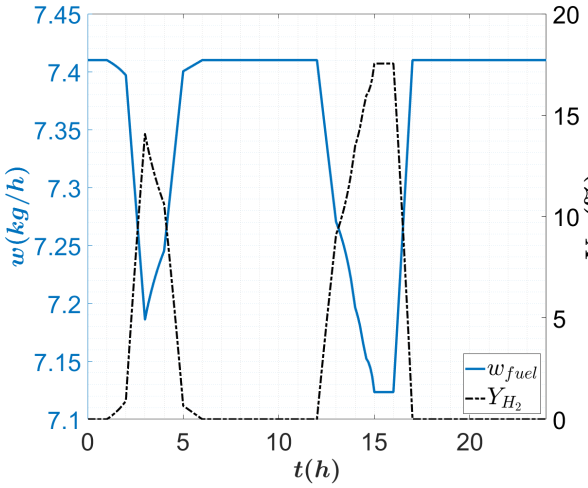
Figure 11 illustrates the impact of hydrogen injection on fuel consumption. As hydrogen enters the system, the fuel mass flow rate decreases (Figure 11.b, blue line), which is expected since the HHV of the gas mixture increases (Figure 11.a, black line). At hour 15, the hydrogen volume fraction in the gas mixture reaches approximately 17.5% vol(Figure 11.b, black line), remaining within the manufacturer's specified limit of 20% vol. In this hypothetical scenario, the gas boiler operates safely within its design constraints despite the hydrogen injection.

This simulation not only provides insights into how hydrogen blending affects gas demand, but also highlights potential operational constraints—not only for the pipeline network but also for end-user equipment, which must be evaluated for hydrogen tolerance and performance limitations.

Complementary to this case, the *MultiEnergySystem* library has also been used in a separate study focused specifically on decentralized hydrogen injection in natural gas distribution networks (Sassaroli, Muro, and Casamassima 2025). That work leveraged MESL to develop a detailed dynamic model that captures transient effects in




**(a)** Gas quality indexes.




**(b)** Fuel flow and hydrogen content.

**Figure 11.** Time evolution of key gas quality and fuel flow variables.

pressure, temperature, and gas mixing, including hydrogen and biomethane injection scenarios. The case study used a real-world Italian gas distribution network, further demonstrating the flexibility and applicability of the library to current and future hydrogen integration challenges.

## 5 Conclusion and Future Work

This paper presented the *MultiEnergySystem* Library, a Modelica-based library for modeling, simulating, and analyzing district heating and gas network. The library includes experimentally validated district heating models and a gas modeling approach capable of handling ideal (and potentially real) gas formulations for the study of hydrogen blending.

A key aspect of MESL is its ability to bridge district heating and gas domains, facilitating studies on hydrogen injection impacts and coupled energy networks. The library was successfully used in two case studies: (i) the design and validation of a decentralized load control system for the DHTF, and (ii) the integration of a gas boiler system into a hydrogen-injected gas network. These applications demonstrate MESL's versatility for both operational and control-oriented studies.

Despite these advancements, some limitations remain. While district heating models have been experimentally validated, the gas/hydrogen components are still pending validation in RSE's upcoming Gas Test Facility. Additionally, MESL currently lacks a dedicated electrical network modeling package, though electric power parameters can already be estimated for key components such as water pumps, CHP unit, and electric boiler.

Future work will focus on enhancing the library's capabilities. Once the Gas Test Facility is operational, we plan to experimentally validate the gas models, particularly for hydrogen blending effects. Moreover, we aim to expand MESL's electrical modeling, potentially by integrating it with existing Modelica libraries. Finally, the library will be further developed so the models can be used for advanced control applications, exploring co-simulation approaches with tools such as Python or Simulink.

By continuously improving MESL, we hope to provide a comprehensive and open-source simulation tool for multi-energy systems, fostering research and innovation in district heating, gas networks, and hydrogen integration.

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## References

Anderis, Claudio, Marcelo A. Muro Alvarado, and Riccardo Lazzari (2024). "Implementation of an Experimental Facility for District Heating Networks Flexibility Assessment". In: *2024 AEIT International Annual Conference (AEIT)*, pp. 1–6. DOI: 10.23919/AEIT63317.2024.10736713.

Buffa, Simone et al. (2021-01). "Advanced control and fault detection strategies for district heating and cooling systems—A review". In: *Appl. Sci. (Basel)* 11.1, p. 455. DOI: 10.3390/app11010455.

Casella, Francesco and Alberto Leva (2006). "Modelling of thermo-hydraulic power generation processes using Modelica". In: *Mathematical and Computer Modelling of Dynamical Systems* 12.1, pp. 19–33. DOI: 10.1080/13873950500071082.

Casella, Francesco and Alberto Leva (2024). "Modelling and Simulation of Thermal Power Generation Systems with Modelica: 20 Years of Experience with the ThermoPower Library". In: *IFAC-PapersOnLine* 58.13. 12th IFAC Symposium on Control of Power and Energy Systems - CPES 2024, pp. 227–234. ISSN: 2405-8963. DOI: 10.1016/j.ifacol.2024.07.487.

Cheli, Lapo et al. (2021). "Steady-state analysis of a natural gas distribution network with hydrogen injection to absorb excess renewable electricity". In: *International Journal of Hydrogen Energy* 46.50, pp. 25562–25577. ISSN: 0360-3199. DOI: 10.1016/j.ijhydene.2021.05.100.

Fritzson, P. (2011). "The Modelica Standard Library". In: *Introduction to Modeling and Simulation of Technical and Physical Systems with Modelica*. John Wiley & Sons, Ltd. Chap. 5, pp. 157–168. ISBN: 9781118094259. DOI: 10.1002/9781118094259.ch5.

Gandolfi, Chiara et al. (2022). "MISSION Project: Design of MV/LV hybrid AC/DC smart-energy grid". In: *2022 AEIT International Annual Conference (AEIT)*, pp. 1–6. DOI: 10.23919/AEIT56783.2022.9951813.

Giraud, Loic et al. (2015-09). "Presentation, Validation and Application of the *DistrictHeating* Modelica Library". In: *Proceedings of the 11th International Modelica Conference, Versailles, France*, pp. 79–88. DOI: 10.3384/ecp1511879.

GmbH, TLK-Thermo et al. (2025). *TILMedia: Thermophysical Property Library for Modelica*. https://github.com/ClaRaLibrary/TILMedia. Accessed: 2025-06-25.

Lohmeier, D. et al. (2020). "Pandapipes: An Open-Source Piping Grid Calculation Package for Multi-Energy Grid Simulations." In: *Sustainability*, vol. 12, p. 9899. DOI: 10.3390/su12239899.

Maier, Laura et al. (2024). "AixLib: an open-source Modelica library for compound building energy systems from component to district level with automated quality management". In: *Journal of Building Performance Simulation* 17.2, pp. 196–219. DOI: 10.1080/19401493.2023.2250521.

Muro Alvarado, Marcelo Andre et al. (2024). "Development and Experimental Validation of an Open-Source Model Library for District Heating Network Simulation". In: *2024 Open Source Modelling and Simulation of Energy Systems (OSMSES)*, pp. 1–6. DOI: 10.1109/OSMSES62085.2024.10668994.

Nigro, Lorenzo et al. (2025). "Experimental validation and design of nonlinear predictive control and moving horizon estimation for district heating". In: *Proceeding of IFAC Workshop on Smart Energy Systems for Efficient and Sustainable Smart Grids and Smart Cities*. to be published.

Papay, J. (1968). "ATermelestechnologiai Parameterek Valtozasa a Gazlelepk Muvelese Soran". In: *OGIL MUSZ*, pp. 267–273.

Sassaroli, Guido, Marcelo Muro, and Vincenzo Casamassima (2025). "Dynamic modeling and simulation of gas distribution networks with decentralized hydrogen injections". In: *Proceeding of IFAC Workshop on Smart Energy Systems for Efficient and Sustainable Smart Grids and Smart Cities*. to be published.

Senkel, A. et al. (2021). "Status of the TransiEnt Library: Transient Simulation of Complex Integrated Energy Systems". In: *Linköping Electronic Conference Proceedings*. DOI: 10.3384/ecp21181187.