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UNIVERSITÀ DEGLI STUDI DI ROMA

SCERG

PAPER TITLE

# MODELING AND PERFORMANCE ASSESSMENT OF AN HT-PEMFC-BASED CHP SYSTEM FOR RESIDENTIAL ENERGY COMMUNITIES


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# INTRODUCTION

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Renewable Energy Communities

HT-PEM Fuel Cells

Energy Sector Transformation

Hydrogen

FRAMEWORK & AIM

# INTRODUCTION – The FlexBIT project



### Smart Buildings

Optimizing residential energy use

### Adaptive Industries

Flexible manufacturing processes

### Connected Energy Communities

Shared energy resources and and benefits

We envision a future where homes, businesses, and industries adapt their energy use in real time supporting supporting the grid and accelerating decarbonization.

# INTRODUCTION – The FlexBIT project



## The Project Approach

### AI Forecasting
Predicting energy needs with machine learning

### Digital Twins
Virtual replicas of physical energy systems

### Blockchain Transparency
Secure, verifiable energy transactions

### Platform Integration
Seamless interoperability between systems

FlexBIT

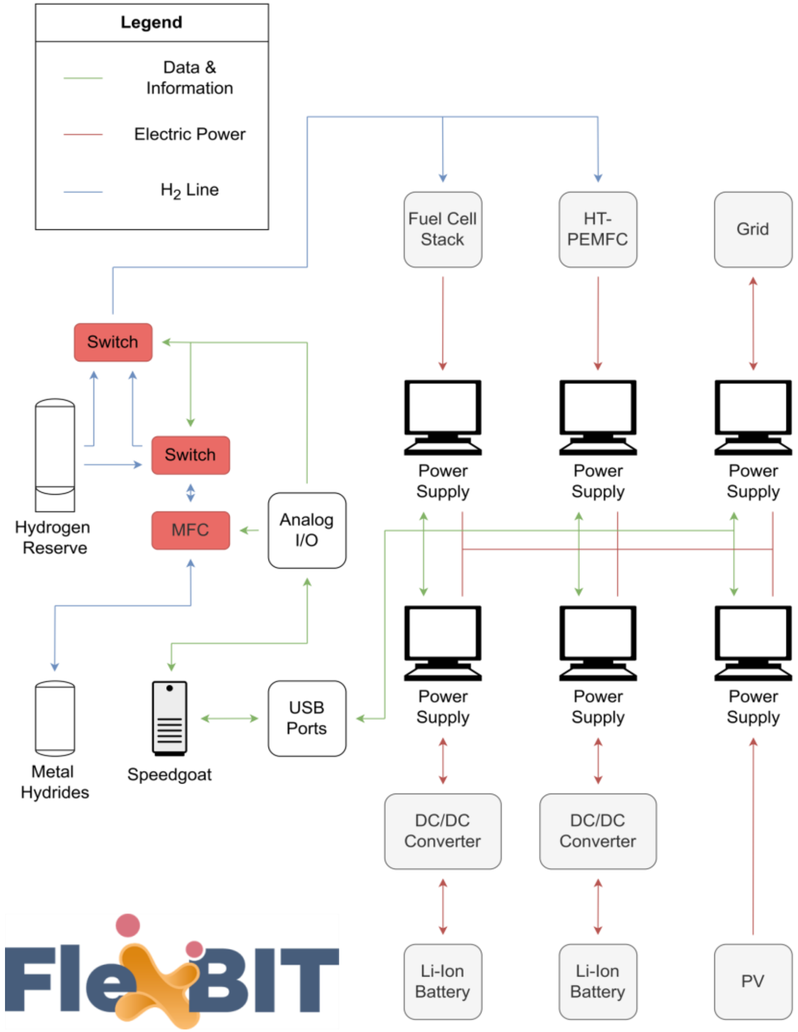
# FRAMEWORK & AIM

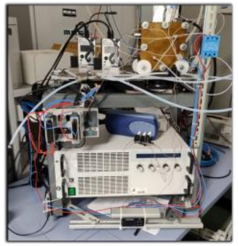
- Our research focuses on integrating **hydrogen technologies** into **Renewable Energy Communities** (RECs) to support self-sufficiency and sustainability.

- Mixed **numerical-experimental approach** with the development of a **lab-demonstrator** for integration of **new technologies** and the **FlexBIT platform**.

- We assess the feasibility of embedding a **High-Temperature Proton Exchange Membrane Fuel Cell (HT-PEMFC)** within a **Combined Heat Power (CHP)** unit tailored for residential use.

- The study contributes to the development of **decentralized, multi-vector energy systems**, combining renewable generation with dispatchable and efficient technologies.



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# Combined Heat Power System

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### HT-PEMFC

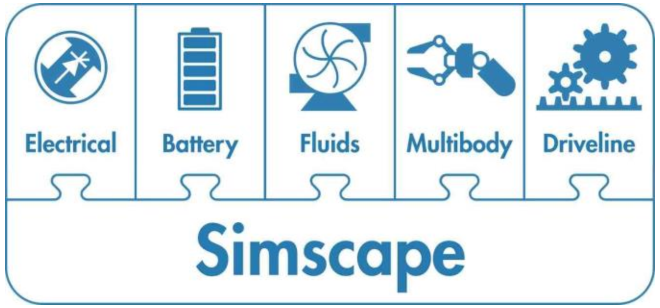
- 140-180 °C
- 20 000 h
- Allowed Impurities
- Imported Load Profiles
- No Humidifier

### Balance of Plant

- Compressors
- Heat Exchangers
- Pumps
- Thermal circuit
- Valves

### Thermal Management

- Electric Heater
- PI Dynamic Modulation
- Included RASHP
- Three-Way Valve





**Reference**

J. Wang *et al.*, "Effect of cooling surface temperature difference on the performance of high-temperature PEMFCs", *Int J. Hydrog. Energy*, vol. 48, no. 44, pp. 16813–16828, May 2023, doi: 10.1016/j.ijhydene.2023.01.125.

# MODEL VALIDATION

- Model validation was performed through the analysis of the **polarization curve**.
- A **standardized current profile** was applied, with current density ranging from 0.1 to 0.9 A/cm$^2$.
- Voltage decreased progressively with increasing current, reflecting a **typical fuel cell behavior**.
- **The model slightly overestimate voltage** due to reduced activation and ohmic losses representation.

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J. Wang *et al.*, "Effect of cooling surface temperature difference on the performance of high-temperature PEMFCs", *Int J. Hydrog. Energy*, vol. 48, no. 44, pp. 16813–16828, May 2023, doi: 10.1016/j.ijhydene.2023.01.125.

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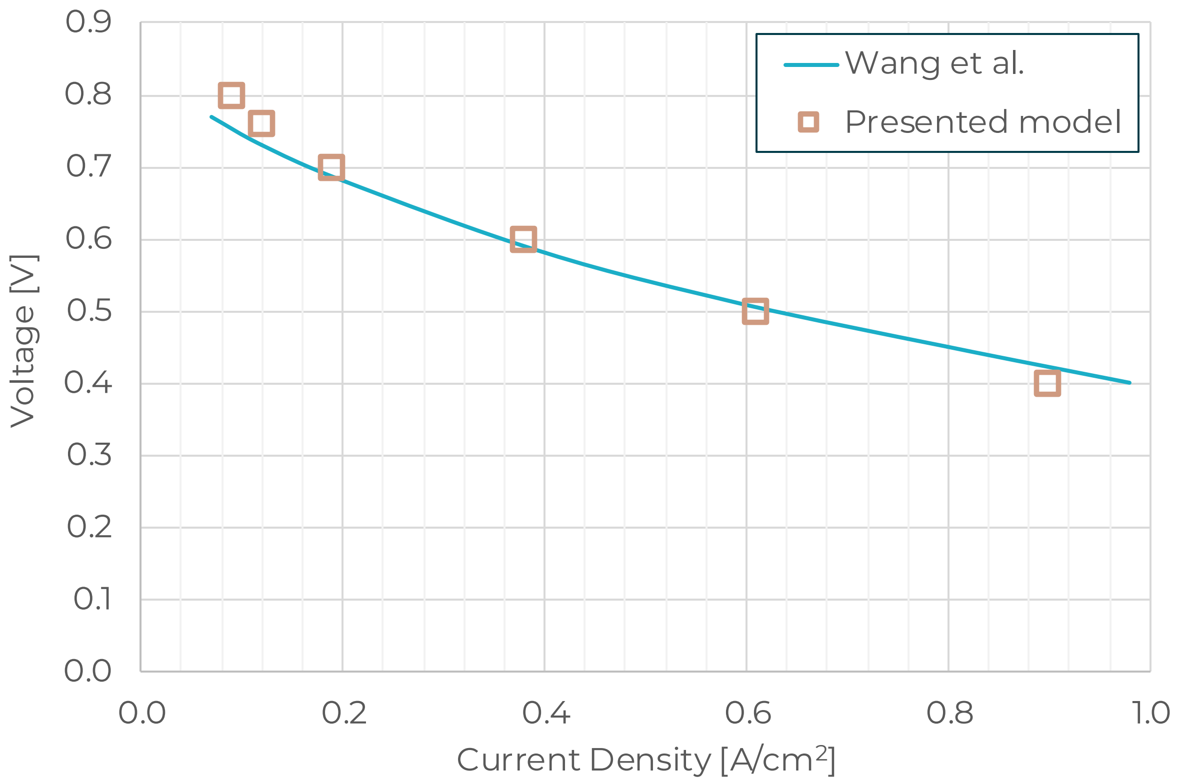

# RESULTS

The following results focus on the system's behavior across multiple operating conditions, highlighting trade-offs in efficiency, responsiveness and energy contribution.

### CHP System
HT-PEMFC unit integrated in a hybrid residential microgrid.

### 3 Control Strategies
Load Following, Fixed Power, Maximum Efficiency.

### Use Case
10-apartment building in Rome, with realistic demand profile.

### 15-Day Dynamic Simulations
Capturing transient and daily thermal and electric trends.

### Key Performance Indicators
Quantitative metrics for assessing system behavior.

### Efficiencies
Electrical and thermal energy conversion.

### Thermal Demand Coverage
Fraction of building heating needs covered.

### Delivered Net Power
Net electricity supplied to the user, accounting for auxiliaries.

# RESULTS – Electrical power output

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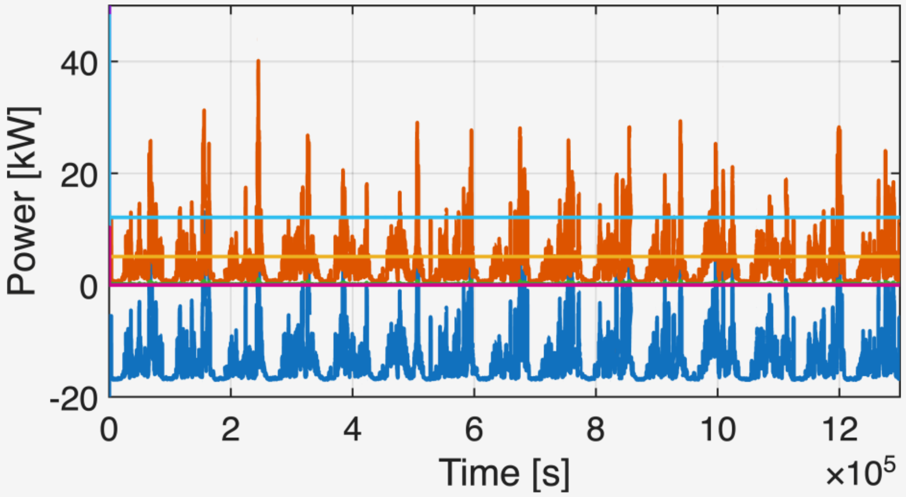
## Load Following

- The system **closely tracks** the building's real-time electricity demand.
- Transient loads and fixed auxiliaries can yield **zero or negative net power**.




## Fixed-Power

## Maximum Electrical Efficiency

**Legend**

| | |
|---|---|
| Blue | Net power gain |
| Green | Hydrogen heater |
| Light Blue | Air heater |
| Orange | FC gross electrical output |
| Red | MultiTherm 503 heater |
| Violet | Coolant pump |
| Yellow | Air compressor |

# RESULTS – Electrical power output

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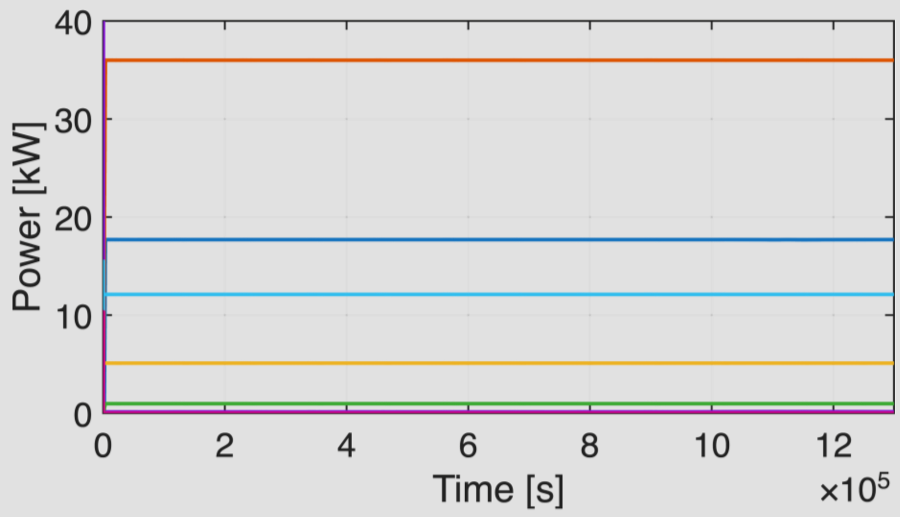
Load Following

Fixed-Power

- A **constant operating point** is maintained, selected to match the average building and auxiliary load.
- **Stable net power output**, with positive values sustained for most of the simulation period.




Maximum Electrical Efficiency

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# RESULTS – Electrical power output

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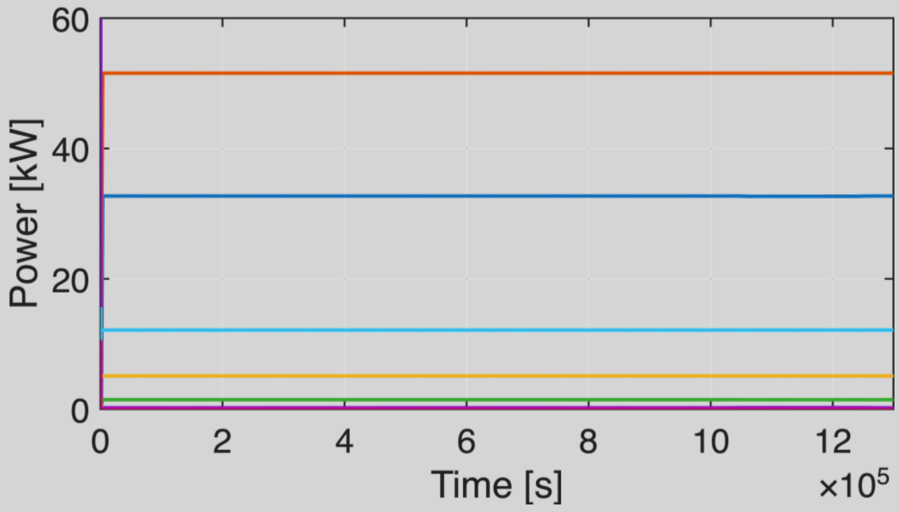
Load Following

Fixed-Power

Maximum Electrical Efficiency

- This scenario offers the **best net output performance**.
- The stack is operated at the **highest efficiency** (51.56 kW).
- Minimization of hydrogen consumption to delivered energy ratio.
- **Electrical efficiency** of 45%, **thermal efficiency** above 70%.

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# RESULTS – Covered Thermal Demand

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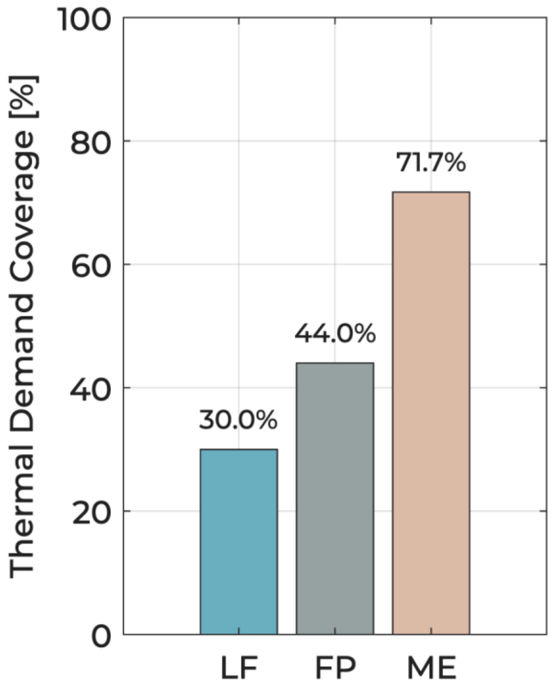
- **HT-PEMFCs** generate high-grade heat, suitable for **domestic hot water and space heating**.
- In **Load Following mode**, thermal output remains relevant despite limited electrical contribution.
- **Fixed Power operation** provides stable heat recovery.
- The **Maximum Efficiency scenario** showcase strong **cogeneration performances**.
- Optimal results are achieved when **electrical and thermal conversion** are balanced.




## Legend

| | |
|---|---|
| FP | Fixed Power |
| LF | Load Following |
| ME | Maximum Efficiency |

# RESULTS – Contribution to self-consumption

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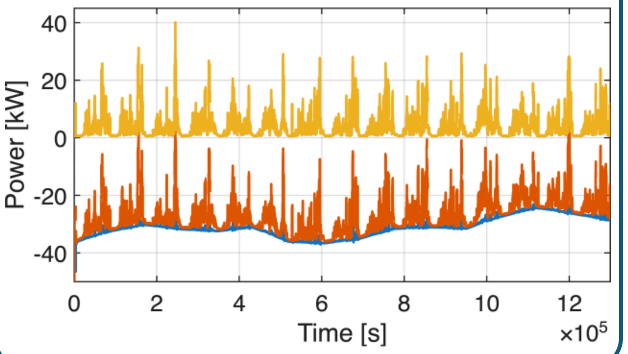
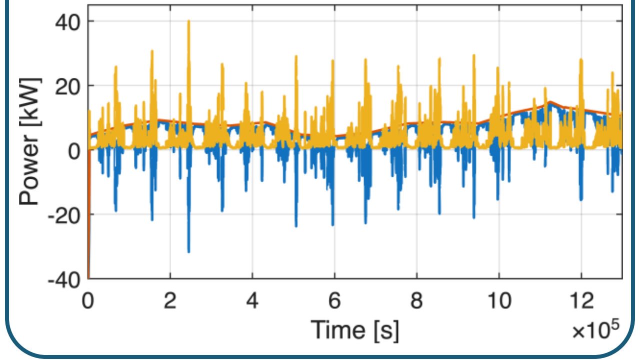
## Load Following

Net electrical output is often negative or near zero, resulting in **very limited contribution** to self-consumption.



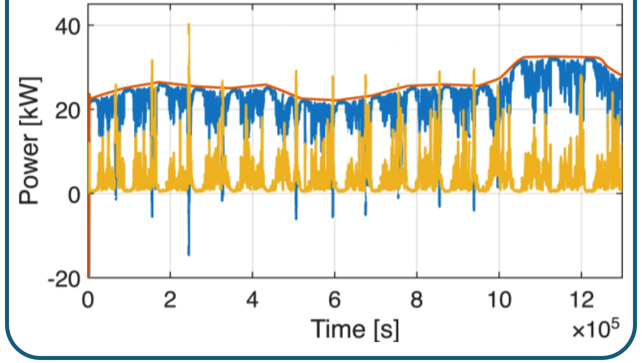

## Fixed-Power

**Stable electrical output**, covering a **larger share** of building demand and improving energy autonomy.




## Maximum Electrical Efficiency

**Highest self-consumption rate**, enhancing **grid independence** and **system resilience**.




## Legend

| | |
|---|---|
| Blue | FC delivered power |
| Orange | Total power supplied by the HT-PEMFC stack |
| Yellow | Building electrical demand |

# CONCLUSIONS

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The energy transition calls for **local, flexible, and low-emission systems** capable of integrating renewable sources and reducing grid dependency.

**Renewable Energy Communities (RECs)** are emerging as a key framework to enable shared generation, self-consumption, and distributed storage.

In this context, **HT-PEMFC-based CHP units** offer high-efficiency cogeneration, combining electricity production with valuable thermal recovery.

The proposed numerical model demonstrated **strong performance in optimized scenarios**.

Results confirm the suitability of HT-PEMFCs for **REC-aligned architectures**, particularly when operated at stable and efficient setpoints.

Next steps include the **integration** of the fuel cell **into a complete hybrid microgrid**.

# THANKS FOR YOUR ATTENTION

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# THANK YOU!

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