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UNIVERSITAT JAUME I

Techno-Economic Simulation of a High-Temperature Heat Pump Integrated with Solar Thermal Collectors

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1. Context & Motivation

Industrial sector accounts for **24.7% of global CO_2 emissions**. Heat pumps offer an efficient alternative to fossil fuel boilers, but require complex optimization tools.

Challenge: Design and optimize hybrid systems combining heat pumps, solar thermal collectors, and photovoltaics for industrial applications (80-150 ℃).

Case Study: Industrial laundry ( ) requiring hot water (80 ℃) and pre-steam (150 ℃, 4 bar).

2. MATLAB Simulation Tool Development

Software Architecture:

- **Platform:** MATLAB R2023b + App Designer for GUI
- **Thermodynamic Engine:** CoolProp 7.2.0
- **Input Data:** Hourly weather data (temperature, irradiance), process

Key Features:

- Multi-configuration comparison (8 system types)
- Automatic economic analysis (10-year projection)
- Real-time results visualization

3. Calculation Methodology

Thermodynamic Model:

- Energy balance for each component (evaporator, compressor, condenser, expansion valve)
- COP calculation: $COP = \frac{Q_{cond}}{W_{comp}}$
- Cascade cycle optimization with intermediate heat exchanger (IHX)

Solar Integration:

- Collector efficiency: $\eta = \eta_0 - k_1\frac{T_s - T_e}{G} - k_2\frac{(T_s - T_e)^2}{G}$
- Thermal storage modeling with heat losses
- Photovoltaic generation: $P_{el} = \eta_{panel} \cdot G \cdot A \cdot \eta_{inst}$

Economic Analysis:

- Investment cost calculation (components + installation)
- Operating costs (electricity, gas) over 10 years
- Payback period determination

Simulation Workflow:

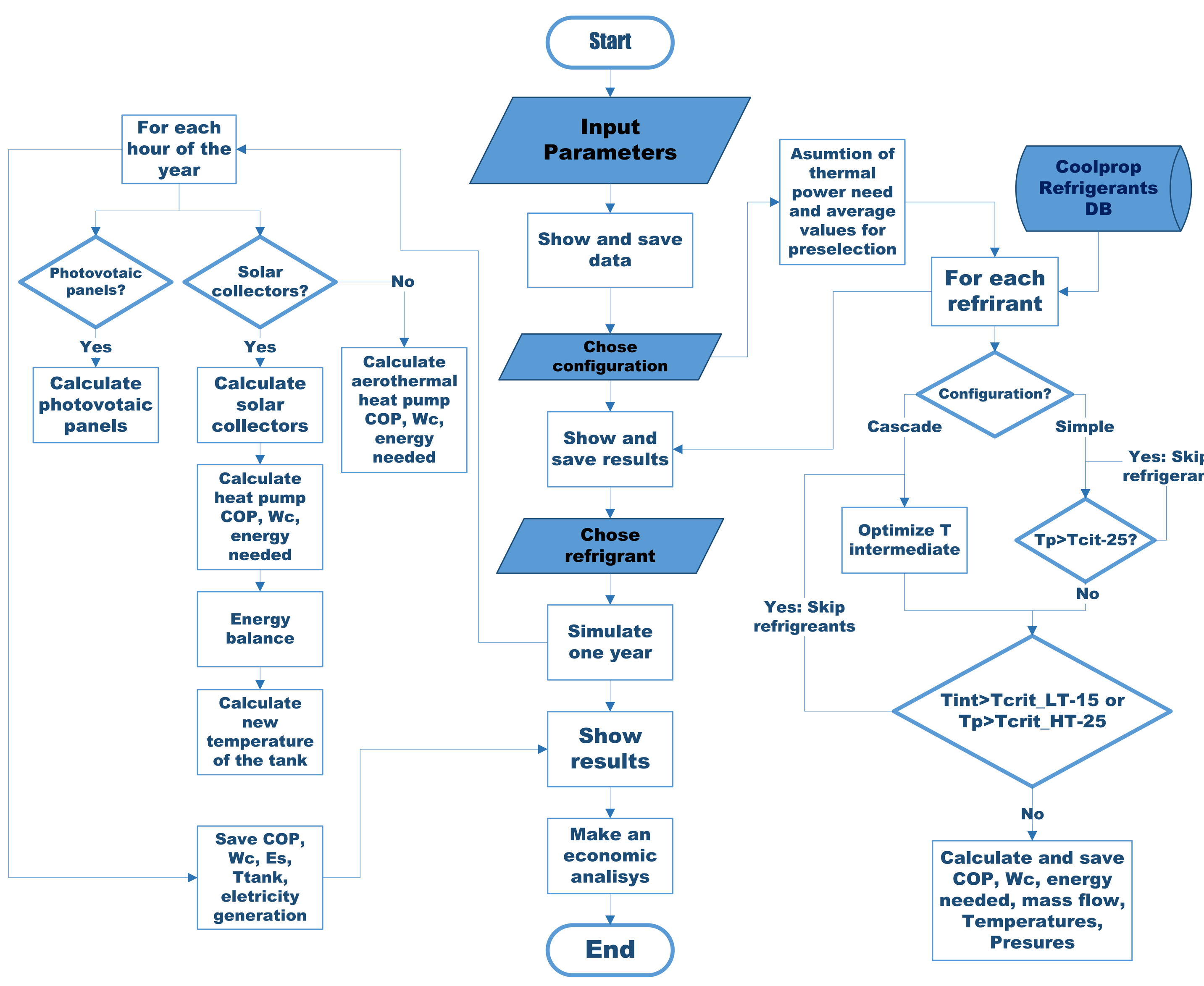

Fig 1. Software calculation flowchart showing the complete simulation process.

4. Results

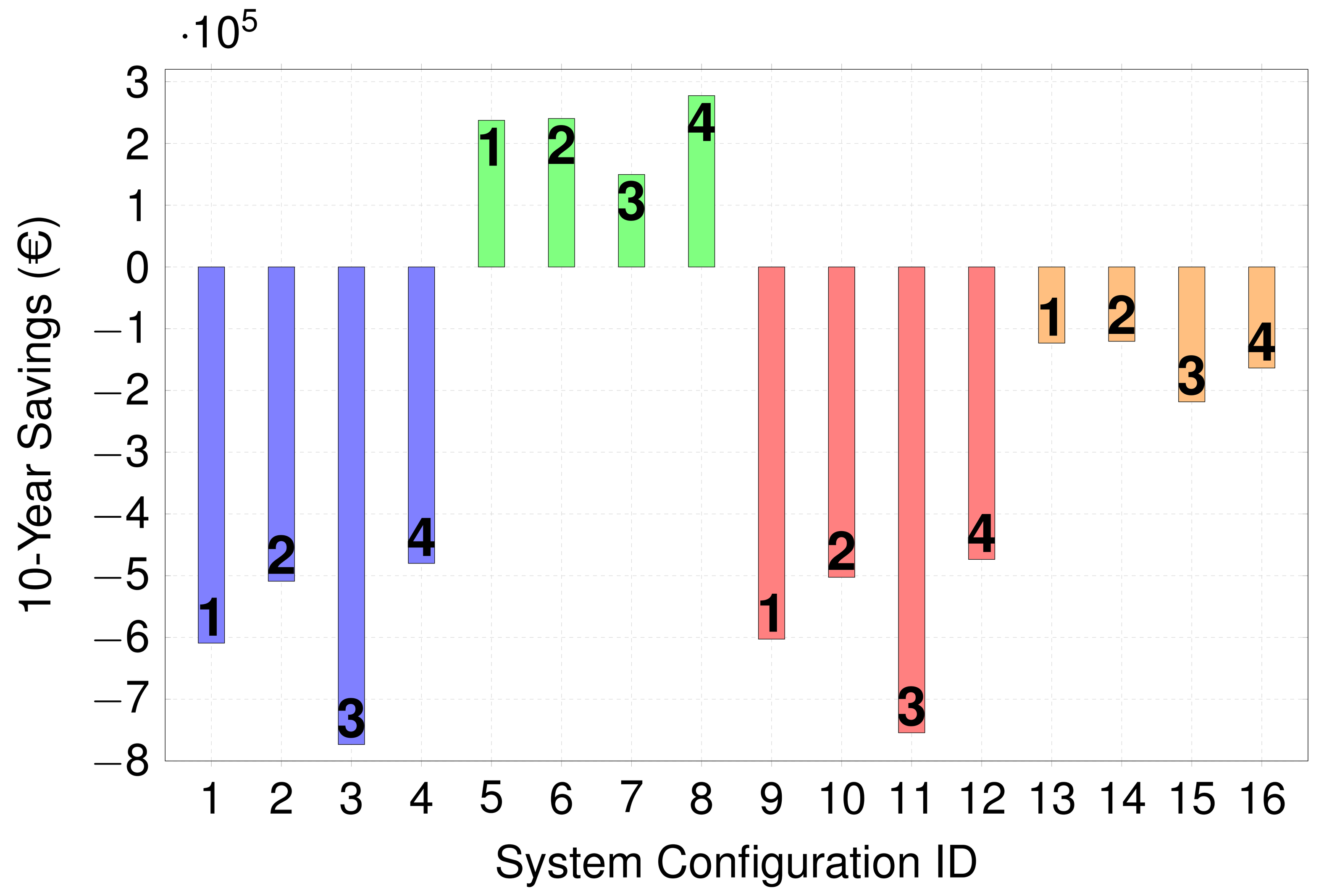

Fig 2. 10-year savings for each heat pump configuration combination. Each bar shows the economizer configuration number (1-4), while the color indicates the hot water heat pump configuration.

Optimal Configuration Selected:

This configuration was selected as it achieves positive 10-year savings while delivering the highest economic performance. The solar collector area has been optimized to maximize cost-effectiveness. Additionally, the selected refrigerants comply with European regulatory standards, offering an optimal balance between low GWP values and excellent thermodynamic performance.

Component	Specification
Hot Water HP	Cascade aerothermal
Refrigerants	R1234ze(E) + R600a
COP	2.87
Economizer HP	Cascade solar-assisted
Refrigerants	R1234yf + R1233zd(E)
COP	1.83
Solar Collectors	180 m²
Photovoltaic	300 m²

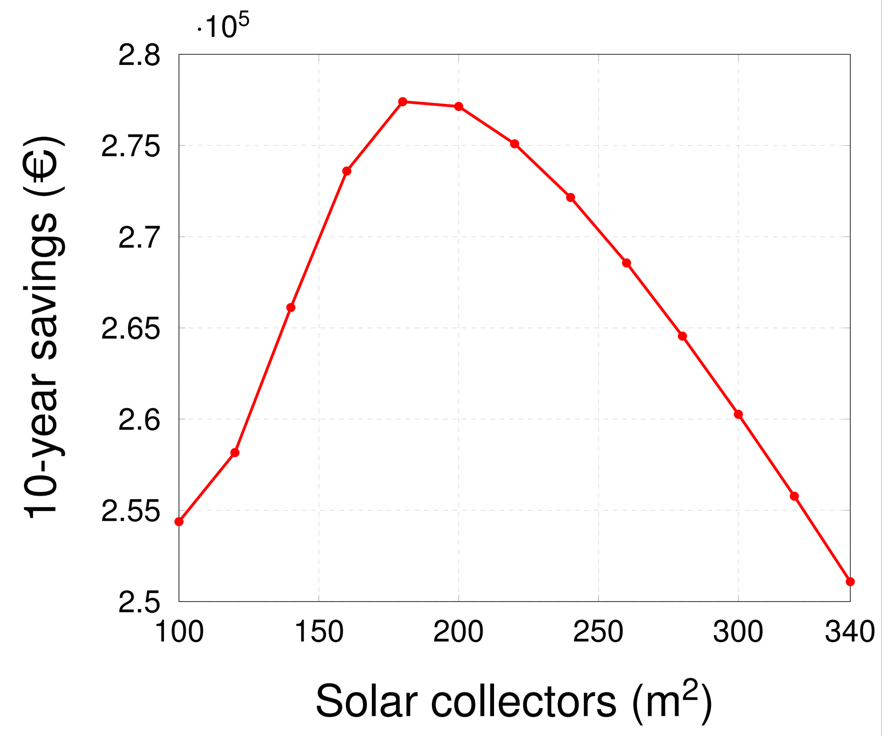

Fig 3. 10-year savings variation with solar collector area optimization.

5. Conclusions

Software Achievements:

- **Comprehensive Tool:** Successfully developed MATLAB application capable of simulating 16 heat pump configurations with full CoolProp database integration
- **Accurate Modeling:** Thermodynamic calculations validated against experimental data and technical literature

Case Study Results:

- **Economic:** Payback 4.22 years, savings 277,400 € (10 years)
- **Environmental (TEWI):** 73.5% CO reduction (3,590 → 950 tons)
- **Technical:** COP 2.87 (hot water), 1.83 (economizer)

Ongoing Development:

- **Compressor Validation:** Experimental validation with real compressor performance maps
- **IHX Optimization:** Enhanced intermediate heat exchanger design algorithms
- **REFPROP Integration:** Extended refrigerant database compatibility

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