15TH IEA HEAT PUMP CONFERENCE
MAY 26–29, 2026 | HOFBURG
VIENNA 2026
DECARBONISATION THROUGH INNOVATION

Simulation-based Optimization of Hybrid Absorption Heat Pump Integration in Industrial Process

Emmanuel Hosea Mposola*, Jose Luis Corrales Ciganda

TECNALIA, Basque Research and Technology Alliance (BRTA), Área Anardi 5,20730 Azpeitia, Gipuzkoa, Spain

Abstract

This study investigates a simulation-based optimization of integrating a Hybrid Absorption Heat Pump (HAHP) with solar thermal energy into an agri-food factory in southern Spain, focusing on optimizing energy use and reducing steam consumption. A comprehensive simulation framework was developed to model the existing biomass steam-based heating system and evaluate five integration scenarios. The HAHP, utilizing lithium bromide-water as the working fluid, combines thermal and mechanical compression to enhance efficiency with a focus on dynamic operation based on availability of solar thermal and demand on the heating plant. The model was validated against the measured data showing a 5.11% deviation in steam consumption. Results show that case 4, which utilizes thermal storage in a buffer tank and operates HAHP when solar thermal temperature exceeds 80°C, achieves the highest steam saving of 46.1%. This investigation also demonstrates a balanced use of renewable energy reducing primary energy consumption while maintaining operational efficiency. This study highlights the critical role of buffer tank sizing for storing solar thermal energy to cover the mismatch between solar thermal availability and the demand in the heating and cooling plant.

Keywords: Hybrid Absorption Heat pump; Solar Thermal; Energy optimization;Simulation;Renewable Energy; Steam consumption;Dynamic operation

1. Introduction

As industries seek to improve energy efficiency and reduce environmental impact, innovative thermal energy systems are gaining attention. Especially, integration of renewable energies in appropriate way considering economic and environmental impacts for process which require less than 200°C such as in paper industry, chemical industry or food and dairy. The integration aims to reduce consumption of carbon-based raw materials and electricity consequentially lowering environmental and economic costs. Different innovative energy concepts are available leading to wide range of possibilities, in which their actual implementation and testing require sufficient understanding of the interaction and performances from energy generation, storage to consumption [1]. Due to advancement of simulation tools and computer data processing capabilities, it is possible to analyse the performance of components and complete systems to comprehend the feasibility of their interaction when integrated to the industrial processes, which is a pivotal procedure for global optimization of industrial thermal systems [2].

Recently, the use and development of software for modelling of thermal systems have increased significantly, they include packages that can record and store large number of data which becomes useful in the validation process by evaluation against the monitored data of the physical systems. Commonly used tools like TRNSYS, MATLAB and Dymola can be used for generating models for buildings and HVAC&R systems. Dymola built in modelica language was used due to accessibility and diversity around the subject covered. Modelica is a language for convenient modelling of physical systems available in object-oriented language modelling for complex and heterogeneous physical systems suited for multi-domain modelling from mechanical, electrical, hydraulic, control subsystems, and process oriented applications [3], [4].

*Corresponding author. *E-mail address:* emmanuel.mposola@tecnalia.com

In addition to available renewable energy technologies for heat generation options such as solar thermal using solar collectors, heat pumps have gained increasing attention due to their possibility to utilize low-grade thermal energy or waste heat which is often at the disposal of industrial processes. Absorption heat pumps is a category of heat pumps which uses heat a driving source rather than electricity. However, conventional AHPs have restricted range of operational temperatures and limits their competitiveness in high performance cooling solutions. To address these limitations, a Hybrid absorption-compression system has emerged as a promising variant, by combining the thermodynamic advantages of both mechanical and thermal compression stages. It is worth mentioning that the working fluids most studied in this variant have low environmental impact: in this case Lithium bromide-water(H20-LiBr) used as a solvent integrated with a steam from a compressor (H2O acting as a refrigerant in compressor), can increase the COP from around 22% to 55% depending on the operation of the compressor [5], [6]. Despite their potential, the integration of HAHPs into industrial heating and cooling systems remains challenging due to the complex interaction between process heat demands, waste heat availability and thermodynamic behaviour of the working fluids. Because the price of electrical power and the plant's heat demand fluctuate over time, a wide range of operating conditions can arise. Consequently, it becomes challenging to determine, at any given moment, the operating mode that minimizes the plant's instantaneous operating cost. Simulation-based design and optimization methods help address this complexity by systematically evaluating performance across different operating conditions and configurations [7].

This study explores the integration of HAHP into an agri-food factory in southern Spain, using a Modelica-based Dymola simulation framework. The HAHP, supported by solar thermal energy, is modelled alongside the factory's existing biomass-based heating system. The system is designed to recover waste heat and optimize the use of steam and electricity depending on fluctuating energy prices. A key feature of this integration is the dynamic switching between compressor and steam operation based on real-time economic conditions.

2. System description

This paper is based on a case study using the existing cooling and heating systems in a dairy plant in Spain as shown in the Figure 1 below as the baseline

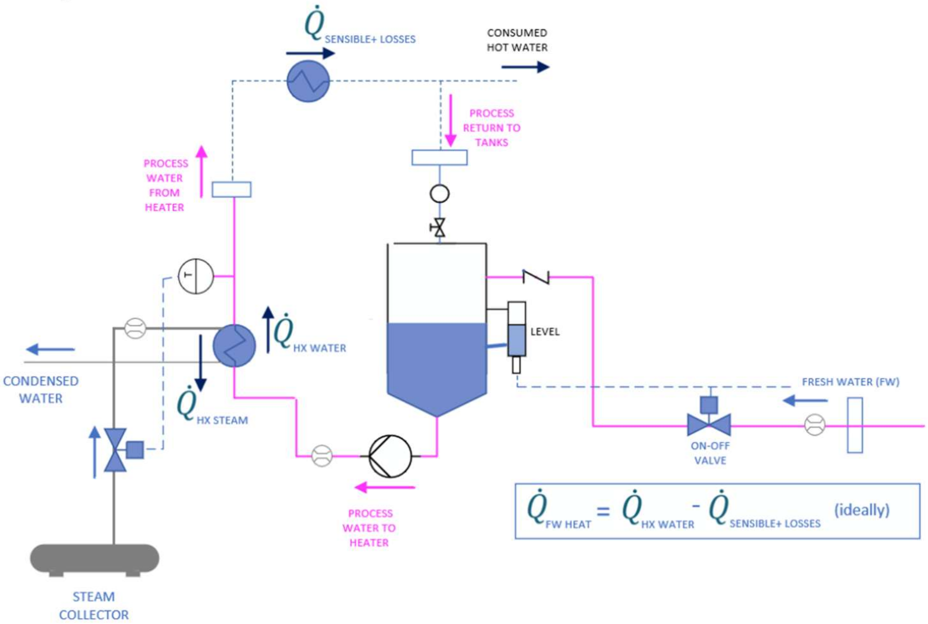

Figure 1.Existing heating plant.

As seen in Figure 1, fresh city water enters the heating plant through a ON-OFF valve into the tank, where it mixes with the return process water. A pump at the bottom of the tank draws mixed water to a steam heat exchanger which heats up water to a set temperature (65°C) ready for consumption. In the consumption side, part of the heat energy is withdrawn as sensible heat and a secondary part as hot water (heat+water consumption). After consumption, the rest of hot water becomes process return to the tanks, with filling levels of the tanks maintained between 55% to 70%. The steam used in this heating plant is fed from biomass.

The cooling plant of the factory is composed of Ammonia chillers as shown in Figure 2.

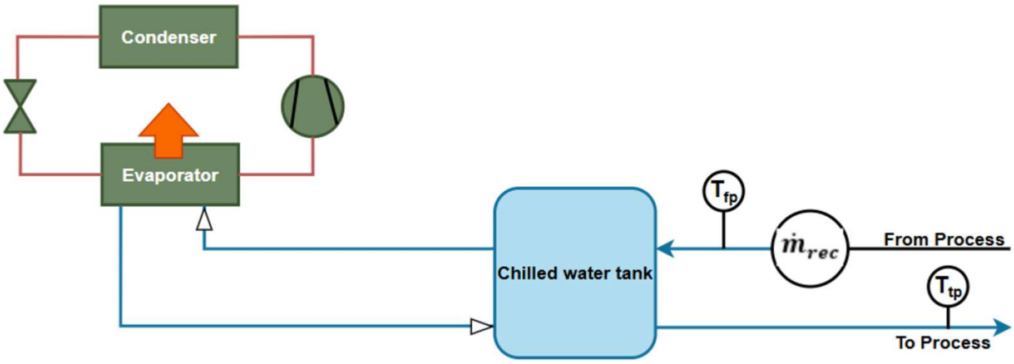

Figure 2. Existing Cooling Plant.

Chilled water produced by the ammonia chiller is stored in the chilled water tank. From there, it is supplied to the process cooling demands. The return flow from the process then re-enters the tank, where it is cooled and stored again. Five proposed solution cases to integrate the studied technologies (solar thermal and HAHP) into the existing heating system to lower the steam consumption

2.1. Case1: Existing plant +Solar collectors

This solution takes advantage of the geographic location of the industrial plant receiving high average solar radiation of 16.4±1.2 MJ/m2 per day [8]. The solar collector field with a surface area of 178 m² designed to supply hot water at 110°C was integrated as shown in Figure 3.

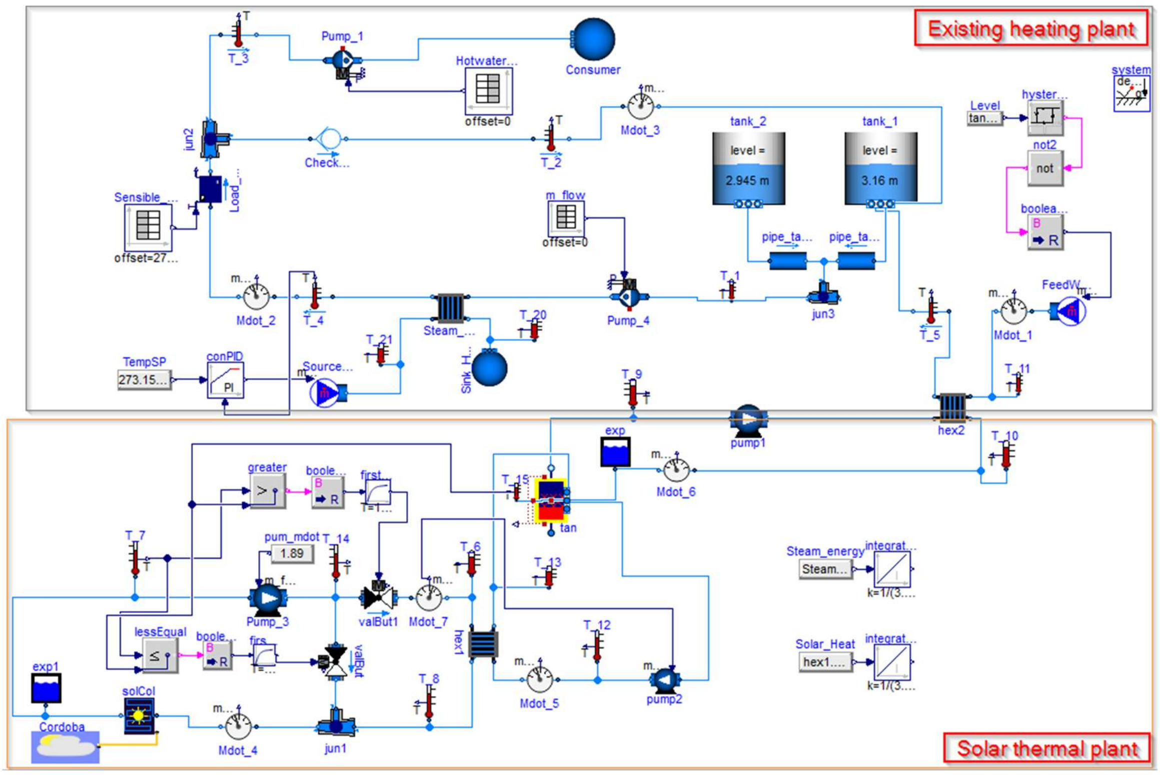

Figure 3.Schematic layout for case 1 in the model.

2.2. Case 2: Existing plant +HAHP

In this case, a hybrid absorption heat pump installation was designed to supply hot water at 60 °C with a return temperature of 15 °C to the absorber, while also providing cooling with an inlet temperature of 10 °C and an outlet temperature of 7 °C at the evaporator. A steam/water heat exchanger heats up the driving heat stream that enters the desorber of the heat pump with 100°C and leaves it with 90°C. The compressor operates with a nominal pressure ratio (PR) of 1.5. The schematic of this case is shown in Figure 4.

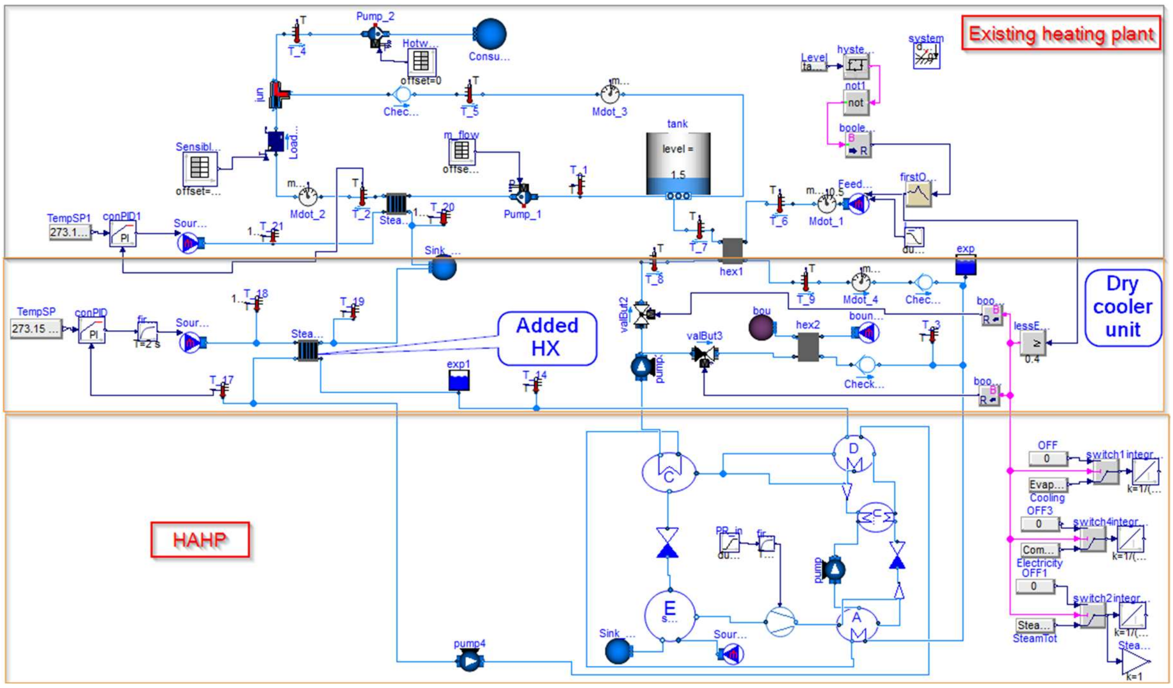

Figure 4.Schematic layout for Case 2 in the model.

In Figure 4, a dry cooler is included as a safety measure for periods when no fresh water enters the heating plant (when the tanks are full), resulting in non-solar hot water consumption. This ensures that the absorber inlet temperatures remain within the required limits to prevent simulation failure. During these periods, the absorption heat pump will be switched off.

2.3. Case 3: Existing plant +HAHP+Solar thermal plant

In this case, a combination of HAHP and Solar thermal plant is installed. Heat is provided to the desorber of the HAHP primarily from Solar thermal. For periods when the solar thermal tank could not supply 100°C, a steam heat exchanger covers the deficiency. As shown in Figure 5, a dry cooler unit is also included in this case. Steam consumption to the HAHP is only accounted for when fresh water enters the heating plant otherwise switched OFF.

2.4. Case 4: Existing plant +HAHP+Solar thermal plant (utilize thermal storage in the buffer tank)

Case 4 shares the same schematic layout as case 3 in Figure 5. However, when no fresh water enters the heating plant and steam consumption for the HAHP is turned off, the HAHP continues to operate, provided the temperature in the solar thermal buffer tank remains above 80°C. If the tank temperature drops below this threshold, the HAHP turns off, but heat exchanger hex4 (taking heat from buffer tank to the existing plant) remains in operation until the buffer tank temperature falls below 65°C.

2.5. Case 5: Existing plant +HAHP+Solar thermal plant (utilize steam for cooling)

Case 5 uses the same schematic layout as case 3 in Figure 5. In this scenario, when no fresh water enters the heating plant and steam consumption for the HAHP remains on, the HAHP continues to operate using the dry cooler. This setup is designed to compare the operational costs of cooling production using biomass derived steam plus electricity in the compressor versus pure electricity cooling during periods when the hot water tanks in the heating plant are fully charged.

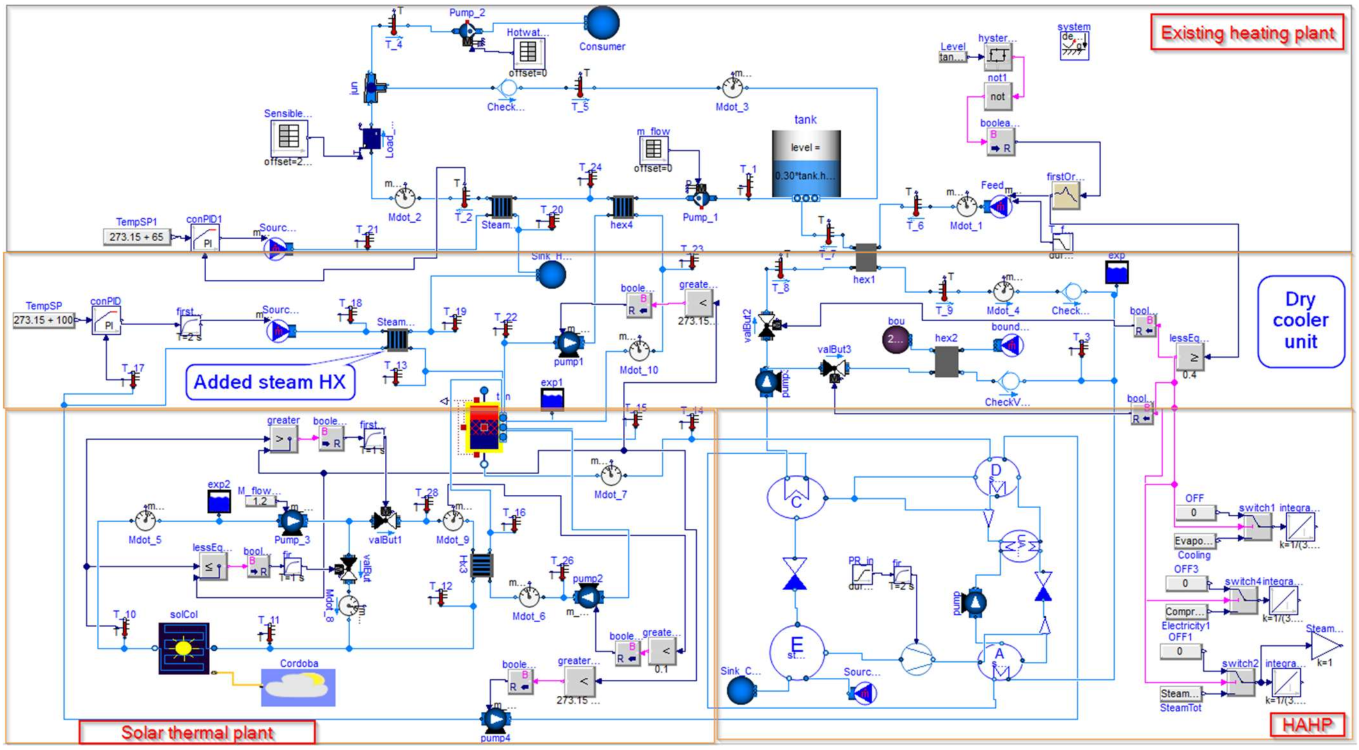

Figure 5.Schematic layout for case 3 in the model.

3. Model validation and Results

3.1. Model validation

The results obtained with the model of the existing system were compared with the measured data of the actual monitored heating plant of the factory. In Figure 6 , *Tank 1fl_exp, Tank 1fl_model* represent the level of water in the tank in the measured data and in simulation respectively, similarly, *Tank 2fl_exp, Tank 2fl_model* represent the level of water in tank 2 in the measured data and in simulation respectively.

Q_st_exp, *Q_st_model* refers to the Heat supplied for hot water preparation by steam heat exchanger in measured data and simulation respectively, *Q_load_exp, Q_load_model* refers to the heat dissipated in the process and in the pipes due to insufficient insulation in the measured data and simulation respectively.

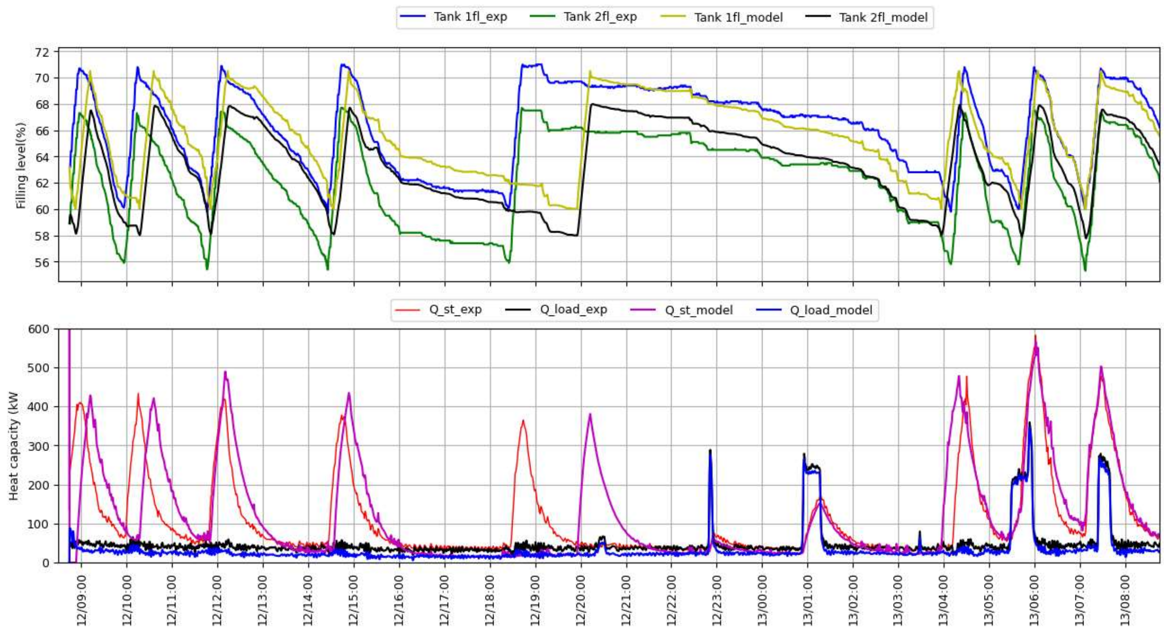

Figure 6. Comparison of water level (top) and Heating (down) in measured data vs simulation for the existing heating plant.

The pattern of fluctuation of water level in the tanks, heat supply and demand in the simulation is similar to the pattern in the measured data with deviations in magnitude and timing this can be due to reaction of controllers in the model is different compared to the actual controllers in the heating plant. This comparison on data for 24 hours.

In Figure 7, $E_{steam-exp}$, $E_{steam-model}$ refer to the steam consumption in the measured data and simulation respectively, and the comparison in made for 15 days as can be seen the model estimates steam consumption with a deviation of 5.11% to the steam consumption in the measured.

The deviation was calculated using Eq. (1) with 33.35 MWh in simulation vs actual consumption of 31.73 MWh

$$deviation = \frac{Model\ estimation - Measured}{Measured} * 100 \tag{1}$$

With these deviations, the model was hence forth used as a baseline for comparison of other scenarios simulations.

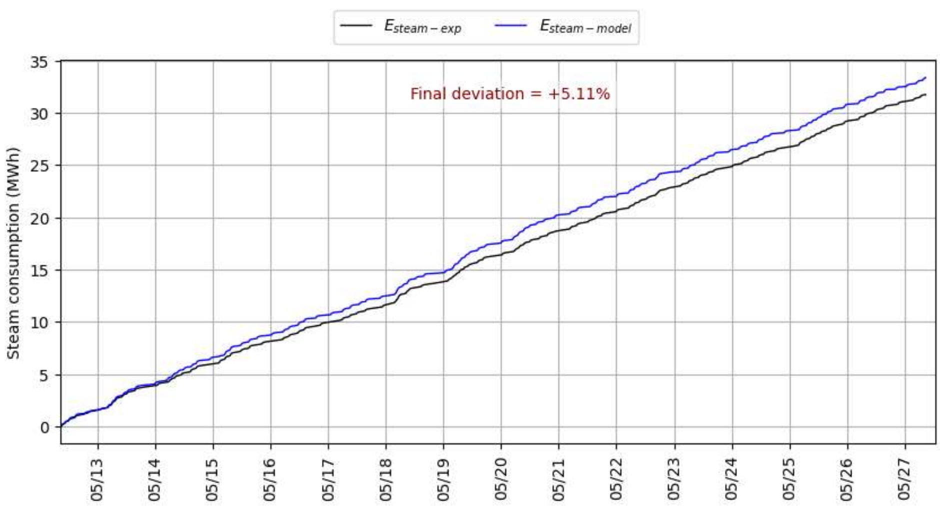

Figure 7.Comparison of measured vs simulated steam consumption for the existing heating plant.

3.2. Results and Discussions

3.2.1. Performance of scenarios

The comparison of performance of scenarios vs baseline was made for 15 days. In Figure 8, the highest steam consumption of 33.4 MWh corresponds to the baseline (only steam used for heating), followed by case

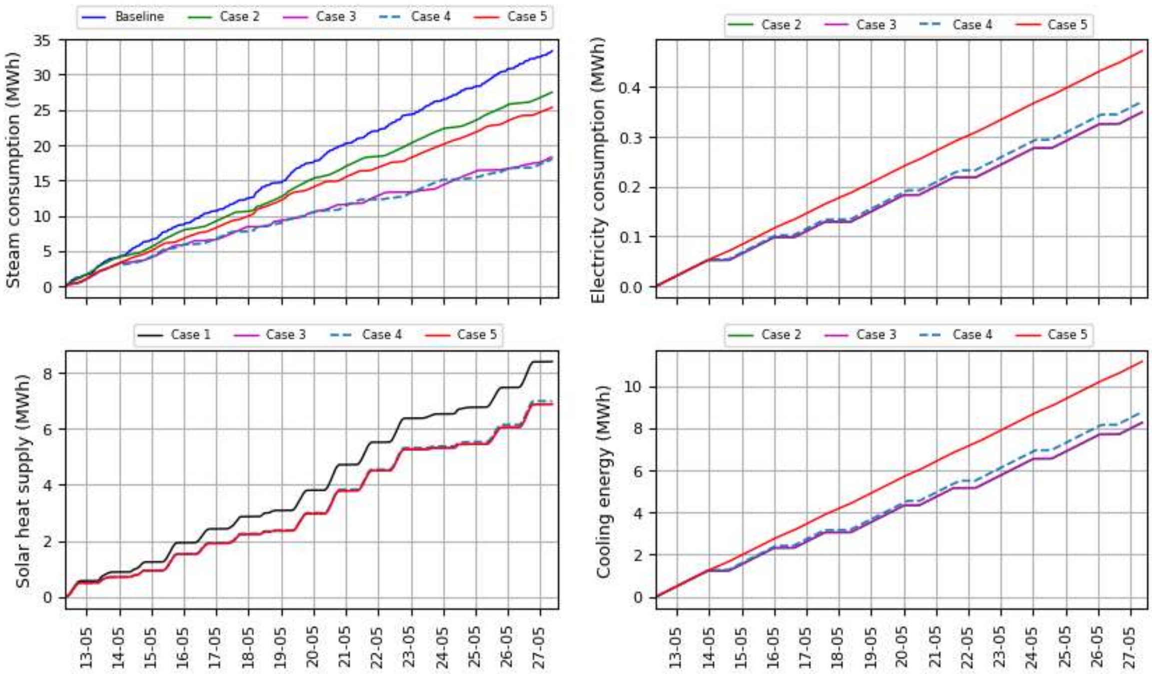

Figure 8.Performance of scenarios vs baseline.

2 with 27.5 MWh (steam used for heating and running HAHP) and least in case 4 with 18 MWh .The electricity consumption was highest in case 5 with 0.5 MWh and least in case 3 with 0.35 MWh, because the heat pump was used full time in case 5, but switched off immediately when tank was full and insufficient heat (<100°C) to the generator in case 3. The supplied cooling energy was highest in case 5 with 11.2 MWh and least in case 2 and 3 with 8.3 MWh. The solar heat supplied was higher in case 1 with 8.4 MWh and lower in case 3 to 5 with 7 MWh, because case 1 utilized solar heat at low temperatures for heating fresh water entering the heating plant from 15°C, compared to case 3,4 and 5 where solar heat was useful above 80°C. Due to the full-time operation of HAHP in case 5, it had the highest electricity consumption and cooling energy production. Figure 9 shows that steam consumption is highest in baseline compared to other cases, highlighting that renewable energy mix minimizes primary energy consumption [9], [10]. In cases 3,4, and 5, the supplied cooling energy reduced the overall demand to the cooling plant in Figure 2 at the cost of electricity consumption in the compressor in magnitude of 0.3 to 0.5 MWh.

It is vivid that case 4 shows balanced benefits of renewable energy mix as seen in Figure 9, with relative steam savings up to 46.1%, 8.8 MWh cooling energy supplied, and utilization of solar thermal hence, case 4 was selected as a best case for further study.

In Figure 10, Q_sol - solar heat from collectors, Q_solp - heat from buffer tank (tan) in Figure 5 to process water, Q_HAHP-Heat supplied by HAHP. As water in tank decreases, the steam consumption increases due freshwater entering with low temperatures in the tank. Q_sol only available in the days, however, the tank is sometimes full in days, hence the solar heat was stored in the buffer tank storing heat from solar and remaining heat from generator.

Figure 11 shows the variation of water temperatures for fresh water, water from solar collectors, ambient air temperature, and water level in the tank. Water temperature from solar collectors reaches up to 110°C during day times while average temperature of 15°C fresh water was used.

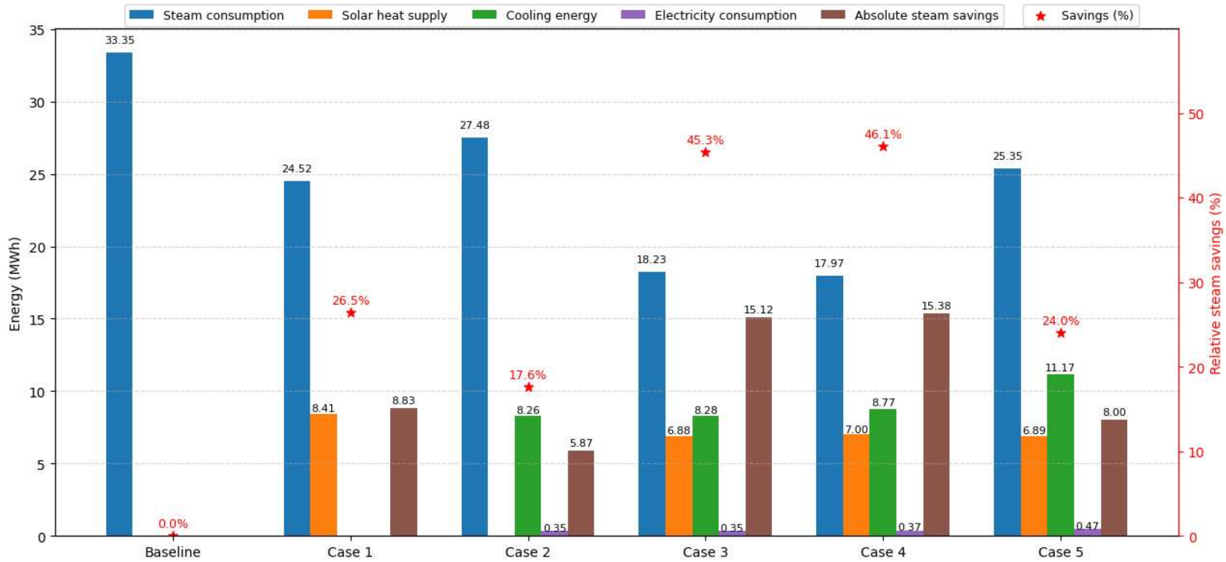

Figure 9. Overall comparison of scenarios vs cases for simulation period of 15 days from May 12 to 27- 2025.

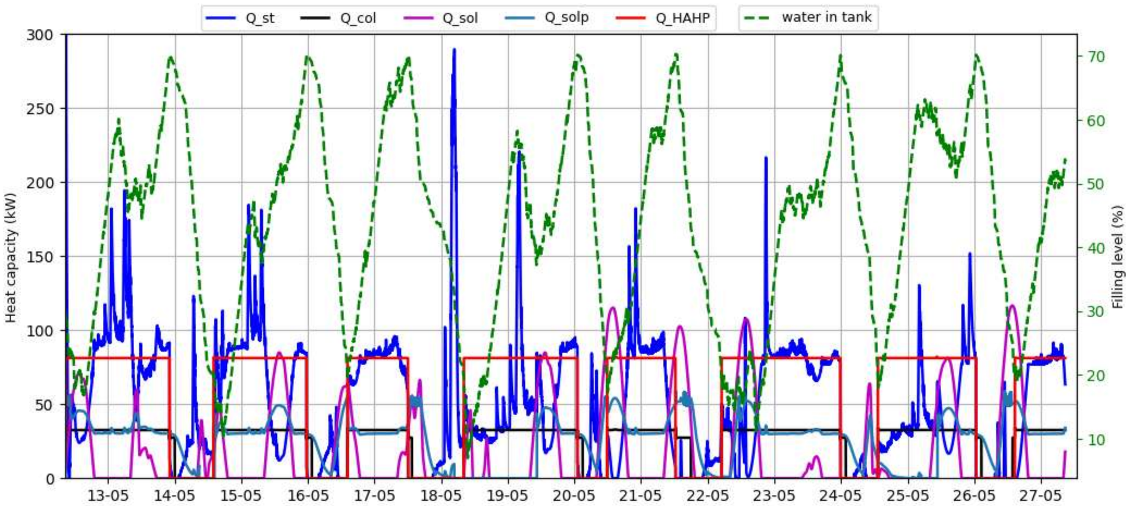

Figure 10. Heating and cooling capacity distribution for case 4 vs hot water filling level in the tank.

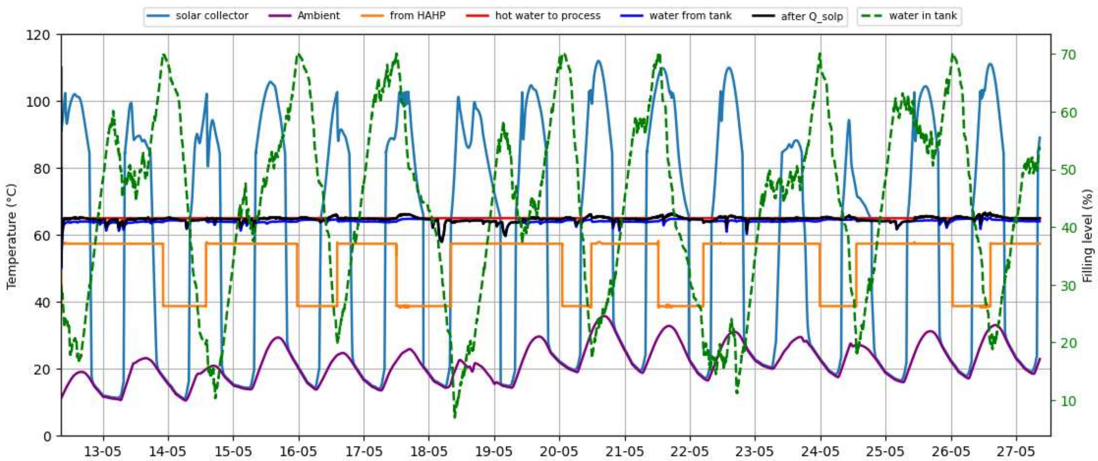

Figure 11. Water temperatures in different components in Case 4 vs filling level in tank and ambient temperature.

.

3.2.2. Performance of HAHP

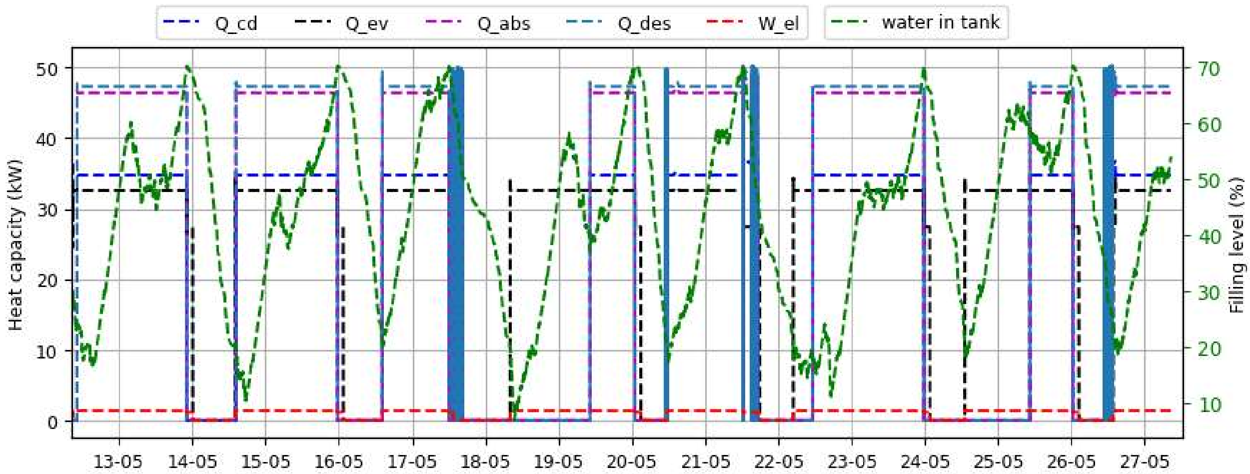

Figure 12.Performance of HAHP in Case 4.

The operation of the HAHP was kept at temperature difference of 10K , inlet at 100°C and outlet at 90°C in generator (driving heat), condenser (heat output) operated at temperature difference of 17K ,40°C inlet, outlet at 57°C, absorber (heat output) kept at temperature difference of 27K , inlet at 17°C, outlet at 40°C and evaporator (input heat / cooling) at 3K , inlet of 10°C and outlet of 7°C and the compressor at PR of 1.5.

In Figure 12 Q_cd - heat capacity from condenser, Q_ev - heat capacity from evaporator, Q_abs - heat capacity from absorber, Q_gen - heat capacity from generator, W_el - eletrical power in the compressor were varying between zero and their respective full capacities with fluctuation of filling level of water in tank. The HAHP was OFF when the tank was full (70% filling level) and switched ON when the lower limit level is reached. During the operation of HAHP, seasonal cooling COP was 0.69, seasonal heating COP was 1.72, and seasonal electrical COP was 23.64.

4. Conclusion

This case study was conducted on an agri-food factory in southern Spain from where the data were measured. The following findings are highlighted from this study.

- The model was validated against the measured data with 5.11% deviation in steam consumption
- Integrating solar thermal (case 1) into the heating plant reduced steam use by 8.8 MWh, while adding HAHP (case 2) reduced it by 5.9 MWh and provided extra 8.3 MWh of cooling. Thus, either option can be selected depending on whether steam savings or cooling production is the priority.
- Combining both HAHP and solar thermal and with appropriate control systems (Case 4), the use of steam can be reduced up to 46.1% plus cooling of 15.4 MWh while, the operation mode of Case 5 would be viable when electricity is priced at over 5 times the cost of steam.
- The sizing solar thermal buffer tank is critical to store the solar thermal available on the day when there is mismatch with demand in the heating plant.
- The use of a compressor improves the heat capacity in the condenser side of the HAHP and cooling capacity in the evaporator.

For further study an algorithm to decide between electricity consumption in the compressor or steam in the generator should be implemented depending on heat demand, solar thermal availability, and electricity price for more optimal energy and cost-efficient operation of the heating and cooling plant

Acknowledgements

This work has been developed under the project “RE-WITCH” funded by the Horizon Europe framework of the European Union, Project No. 101138697. https://re-witch.eu/.

References

[1] M. Lockan and R. Kansara, "Robust optimization of the energy concept of an industrial process w.r.t. uncertain energy costs and environmental conditions," *Journal of Environmental Management,* p. 122023, 2024.

[2] R. Wang, T.-Y. Zhang, Y.-l. Wang, W. Shao, J.-l. Liu, Z. Cui, Y. l. Wang, Q. Chen, . T. Y. Zhang and J. l. Liu, "Multi-scale simulation and optimization on a thermal management system of intermediate circuit and experiment validation," *Case Studies in Thermal Engineering,* vol. 60, p. 104831, 2024.

[3] A. Hernández-Arizaga, A. Picallo-Pérez and J. Sala-Lizarraga, "Procedure for modelling and calibrating operating thermal systems in buildings," *Journal of Building Engineering,* vol. 45, p. 103530, 2022.

[4] M. Otter and H. Elmqvist, "Modelica Language,Libraries,Tools,Workshop and EU-Project RealSim," *Simulation News Europe,* pp. 3-8, 2000.

[5] M. M'madi Hassane, Y. Filali Baba, A. Al Mers, B. Noureddine and M. Bakkas, "Lithium bromide-water absorption chiller with integrated compression for performance enhancement," *EPJ Web of Conferences,* vol. 326, p. 04005, 2025.

[6] J.-I. Yoon, O.-K. Kwon and Y. Yang, "Performance Characteristic of the Compression-Absorption Hybrid Heat Pump Cycles," *Journal of the Korean Institute of Gas,* vol. 3, 1999.

[7] M. Dentice, M. Sasso and S. Sibilio, "Optimum Operation of a Thermal Plant with Cogeneration and Heat Pumps," *International Journal of Thermodynamics,* vol. 4, 2001.

[8] Á. Ramos Ridao, E. Hontoria García, B. Moreno Escobar and M. Zamorano Toro, "Solar energy in Andalusia (Spain): present state and prospects for the future," *Renewable and Sustainable Energy Reviews,* vol. 11, pp. 148-161, 2007.

[9] R. Li, Z. Yang and Q. Wang, "Does renewable energy reduce energy intensity? A matter of income inequality," *Humanities and Social Sciences Communications,* vol. 12, no. Li2025, p. 138, 2025.

[10] S. Yu, J. Liu, X. Hu and P. Tian, "Does development of renewable energy reduce energy intensity? Evidence from 82 countries," *Technological Forecasting and Social Change,* vol. 174, p. 121254, 2022.