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A novel H_2O/LiBr absorption heat pump with heat recovery for combined heating and cooling production using renewable energy

O pompă de căldură cu absorbție H_2O/LiBr de tip nou, cu recuperare de căldură, pentru producerea combinată de încălzire și răcire utilizând energie regenerabilă

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Abstract

Absorption refrigeration technology was developed as a response to major challenges, including the energy crisis, rising fuel costs, and the environmental drawbacks of conventional vapor-compression refrigeration systems. Extensive research has focused on developing strategies to enhance the COP of absorption systems, with the aim of making absorption refrigeration technology more competitive compared to conventional compression systems This study investigates a hybrid absorption heat pump integrated with heat recovery combined heating and cooling production to improve the COP of absorption refrigeration systems. The system is based on low- and high-pressure absorber/evaporator pairs, operating with H_2O/LiBr as the working fluid, and driven by a low-temperature heat source. In order to drive the heat pump's heat generator, natural gas (prepared in a boiler) or/and solar energy (prepared in solar panels) was used. The experimental reasearch were conducted on an experimental stand located in the Department of Heat Engineering and Thermal Equipment Laboratory from the Technical University of Civil Engineering, Bucharest. It can simultaneously supply both cooling and heating for preparation of domestic hot water. A performance analysis is carried out through experimental measuring data to calculate the total COP vs. COP for conventional single-effect absorption chiller under the same conditions. In recovery mode, the maximum total COP increases to ***5.446*** *because of heat recovery from condenser and absorber. Nevertheless, the system achieves a temperature of hot water between 33.58–43.92 °C. Notably, the recovery heat mode performance is strongly influenced by the solar radiation during the month, which therefore represents a key design parameter for the proposed system.*

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Key-words: heat pump, heat recovery, H_2O absorbtion

1. Introduction

Considering the global long-term low greenhouse gas Emission Development Strategies based on the Paris Agreement adopted in 2015 [1], measures to reduce carbon emissions by expanding the use of high-energy-efficiency products and promoting renewable energy usage are being proposed. The use of renewable energy sources in buildings is essential. However, renewable energy has two major drawbacks: a low heat-source temperature and an imbalance between the energy supply and demand [2,3]. Therefore, the aforementioned problems must be overcome to increase the utilization of renewable energy for building cooling and heating.

In Europe, the building stock alone is responsible for 40% of total energy consumption and 36% of greenhouse gas (GHG) emissions in the European Union (EU) [4,5].

Decarbonizing the heating and cooling sector is essential to achieving the EU's climate neutrality target by 2050 and the interim objective of reducing net GHG emissions by at least 55% by 2030 [6].

The deployment of heat pumps offers a practical pathway for both buildings and industry to reduce dependence on fossil fuels while accelerating the decarbonization of heating and cooling applications across the EU. The absorption cycle has the advantage of obtaining cooling and heating effects with a low-temperature heat source at 100°C [7].

Heat pumping technologies are commonly designed to provide either heating or cooling, functioning as heaters, refrigerators, or chillers. With an appropriate choice of working fluid (refrigerant) and careful system design, heat pumps can be configured to deliver heating and cooling simultaneously. As examples, there are *hotels* (space cooling and domestic hot water production) [8], *office buildings* (server room cooling and space heating), *sports complexes* (swimming pool heating and ice rink cooling) [9].
Also, industries as *food processing* simultaneous refrigeration, process heating and cooling, and hot water generation [10–12] and other applications like *seawater desalination* combined with space cooling in coastal regions [13].

The earliest AHP cycle configuration proposed for the combined heating and cooling production dates back to the 1980s, using an H_2O/LiBr working pair by Eisa et al. [14]. The thermodynamic design data for the potential combinations of operating temperatures of the absorber (30–50°C), condenser (50–100°C), evaporator (2–15°C), and generator (70–170°C) of the single-effect H_2O/LiBr AHP cycle were obtained using simulation and reported taking into consideration of the LiBr crystallization limit in the absorber and generator. Further, Kumar et al. [15] carried out an experimental study on the single-effect H2O/LiBr AHP for combined heating and cooling production taking advantage of the heat released during the absorption and condensation processes.

Prieto et al. [16] carried out a theoretical study on the single-effect H2O/LiBr AHP for combining heating and cooling production to analyze the feasibility of the single-effect H_2O/LiBr absorption heat pump. The cycle is theoretically studied for five different types of applications that require simultaneous heating and cooling: building air conditioning, a 4th generation district heating and cooling network, a sports center with an indoor swimming pool, a hybrid air conditioning system with an absorption heat pump and a desiccant evaporative cooling system, and simultaneous cooling and water purification application for coastal areas.

According to Zhaia et al. [17], the vast majority of the chillers used for air conditioning applications operate with lithium bromide - water solution and use steam or hot water as the heat source. It has been testified that single-effect LiBr-H_2O absorption units using fossil fuels are not competitive from the energy, economic and environmental points of view. They become competitive when using waste or renewable energy.

Although both solar electric and solar thermal systems can be used to produce refrigeration, solar thermal absorption systems are more efficient, specifies Siddiqui et. Al [18]. Such systems can be used in areas where conventional sources of energy are not available or expensive, and also in order to limit the release of the greenhouse gas emissions caused by the usage of the fossil fuels.

Numerous experimental models describing the functioning of a single effect, LiBr-H_2O absorption heat pump at steady conditions were presented in the last years, [19-20]. As a general conclusion, the result shows that experimental and simulated systems which are based on combinations of different types of solar thermal collectors and absorption chillers, have a COP value for the absorption chillers between 0.6 and 0.8 for simulated, and between 0.40 and 0.85 for experimental systems, for generator inlet temperature between 70 and 100 ºC, [21].

The authors have an experience in the study of absorption heat pumps powered by solar energy, [22-23] and in this paper have analysed the operation conditions for cold season, and also the opportunity of using the heat recovered in the condenser and absorber to heat the air in a heating coil, part of an air handling unit.

The experimental results were obtained using an experimental stand located in the Department of Heat Engineering and Thermal Equipment Laboratory from the Technical University of Civil Engineering, Bucharest. The flat plate solar panels, in great measure, cover the heat demand of the heat generator in the hot season. The nominal capacity of the absorption chiller is 17 kW.

2. System description

The proposed absorption heat pump for combined cooling and heating is built on a single-effect H2O/LiBr chiller whose cycle is modified to recover the heat of condensation and absorption at a useful temperature level. By reclaiming this heat, the system reaches higher energy-use efficiency and delivers multiple outputs at the same time, including domestic hot water. The integration shows that the unit can supply cooling and heating simultaneously while improving overall efficiency and sustainability.

Beyond the change in high pressure, the cycle runs at four temperature levels instead of three as in a conventional single-effect H2O/LiBr chiller. The evaporator provides the cooling effect at 6.8 to 12.5°C. The absorber releases heat at 26.3 to 43.8°C, a range that in standard systems is usually rejected to the environment. The condenser also releases heat, between 26.3 and 42.3°C, which becomes available for heating use. The generator receives the driving heat input at 79 to 98.6°C.

In this application the heat from both the condenser and the absorber is fully recovered because the laboratory users require 26/44°C at inlet and outlet, which matches the available temperature levels. Cooling towers are not needed, which simplifies operation and lowers water and energy use. The hybrid system has the thermal power provided by 30 solar collectors with a total area of 66 m^2 and an auxiliary heat source, respectively a 40 kW natural gas boiler as can be depicted from Figure 1.

The water and 30% wt. ethylene glycol solution from the solar collectors fed a heat exchanger with 3 circuits:

- the first circuit where the water-ethylene glycol solution transfers the heat from solar panels.
- the second circuit (for the cold season) where the temperature of chilled water from absorption heat pump is increased by the simulated load.
- in the third circuit (for the hot season) is prepared the hot water which will action the absorption plant's heat generator.

The parameters were measured using the following sensors (table 1):

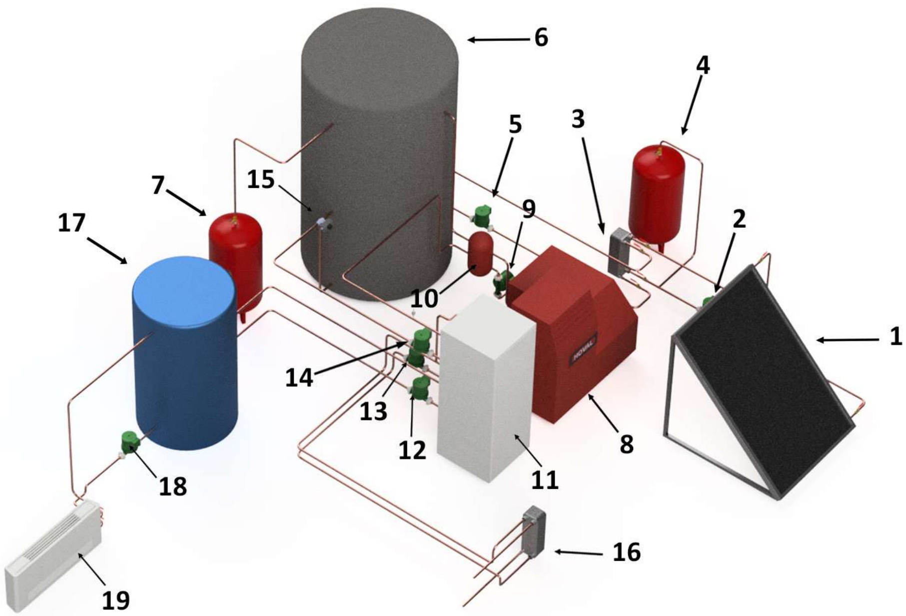
Table 1.

Measured parameters and their uncertainties

Instrument	Measured parameter	Range	Uncertainty (%)
Thermocouples (°C)	ARS inlet temperature	0–100 (°C)	± 0.25 K
	ARS outlet temperature	0–100 (°C)	± 0.25 K
Insulated thermocouple type K NiCr-Ni (Immersion length = 50 mm)	ARS circuits	–20–200 (°C)	± 0.1 K
Flow meter (l/min)	ARS circuit fluid flow rate	4–160 (l/min)	± 0.5…2%

The working principle of the heat pump is as follows: in the solar circuit, the solar collectors deliver the thermal power to a solution consisting of water and 30% wt. ethylene glycol. In the heat exchanger, the water-ethylene glycol solution transfers the heat to a hot water circuit used for driving the generator of the absorption refrigerating machine in the hot season.

The heat absorbed by the water from the condenser-absorber group is recovery using a plate heat exchanger by transferring it to the domestic hot circuit from laboratory. When working as refrigeration plant, the installation prepares cold water in the evaporator, which is used to cool down the air in the fan coil unit.



1 – Solar thermal panel, 2 – Hydraulic kit for solar circuit, 3 – PHE, 4 – Expansion vessel (solar circuit), 5 – Pump, 6 – Domestic hot water storage tank, 7 – Expansion vessel (domestic hot water circuit), 8 – Boiler, 9 – Boiler circulation pump, 10 – Hydraulic separator, 11 – Absorption heat pump, 12 – Chilled water pump, 13 – Cooling water pump, 14 – Hot water pump, 15 – Storage tank recirculation pump, 16 – PHE for recovery system, 17 – Chilled water tank, 18 – Chilled water circulation pump, 19 – Fan coil unit

Figure 1. Experimental stand

3. Methodology

The AHP cycle is modelled using the energy and mass balances on each cycle component. The temperatures and mass flow rate of the external circuits are from experimental data based recorded between May and August 2025.

The experimental performances of the proposed H_2O/LiBr AHP stand are obtained in terms of cooling coefficient of performance (COP_C), heating coefficient of performance (COP_H) and total coefficient of performance (COP_{TOTAL}). The COP_C is defined as the ratio of the cooling output produced by the evaporator (Q_E) and driving heat input in the generator (Q_G):

$$COP_C = \frac{Q_E}{Q_G} \qquad [-] \qquad (1)$$

where the cooling output produced by the evaporator (Q_E) and the driving heat input in the generator are calculated from their respective energy balance equations:

$$Q_E = \dot{m}_w \cdot c_{pw} \cdot (t_{in\ chilled\ water} - t_{out\ chill\ \ water}) \qquad [kW] \qquad (2)$$

$$Q_G = \dot{m}_{hot\ water} \cdot c_{p\ hot\ water} \cdot (t_{in\ hot\ water} - t_{out\ hot\ water}) \qquad [kW] \qquad (3)$$

The $COPH$ is defined as the ratio of the heating provided by the condenser (Q_C) and the absorber (Q_A) to the driving heat input in the generator (Q_G) for the applications where the absorber heat is dissipated to the ambient:

$$COP_H = \frac{Q_C + Q_A}{Q_G} \quad [-] \quad (4)$$

where the heating provided by the condenser (QC) and the absorber (Q_A) are calculated from their respective energy balance equations:

$$Q_C = \dot{m}_w \cdot c_{pw} \cdot (t_{out\ cooling\ water\ condenser} - t_{in\ cooling\ water\ condenser}) \ [kW] \quad (5)$$
$$Q_A = \dot{m}_w \cdot c_{pw} \cdot (t_{out\ cooling\ water\ absorber} - t_{in\ cooling\ water\ absorber}) \ [kW] \quad (6)$$

Where
$\dot{m}_w$ – mass flow rate of water (kg/s)
c_{pw} – specific heat of water (kJ/kg·K)

Finally, the combined COP (COP_{TOTAL}) is calculated by considering both the heating and the cooling outputs of the AHP cycle, which is defined as:

$$COP_{TOTAL} = COP_C + COP_H \quad [-] \quad (7)$$

In these calculations, the pumps (chilled water pump at evaporator P_1, cooling water pump at condenser and absorber P_2, hot feed water pump at generator P_3 and H_2O/LiBr solution pump) and fans (at cooling tower) consumption is included in equation 5.

In the conventional installation at cooling towers, the heat removed from condenser and absorber, as latent heat, will be discharged into the environment in the form of water vapour carried by the outgoing current of air, whose humidity will thus be higher than that of the intake air, normally to the point of saturation. The proposed solution form this study is based to recovery heat from condenser and absorber using for domestic hot water in laboratory from Faculty of Building Services Engineering.

4. Result and discussion

In this research project, the feasibility of a new experimental test bench configuration for an H_2O/LiBr absorption heat pump (AHP) is investigated for the combined production of cooling and heating under different operating conditions. Thus, the new system can be integrated into several types of end-use applications. A numerical model of the thermodynamic cycle for the AHP was developed, and the operational limits of the cycle in terms of temperature were identified; therefore, the results can be used to determine suitable potential applications for the proposed configuration. Based on the available literature, there is a lack of information regarding heat recovery from the condenser and absorber of an absorption refrigeration system entirely powered by flat-plate solar collectors or by a bivalent system (flat-plate solar collectors + gas-fired boiler).

The experimental dataset includes nine channels. *Channel 0* records the chilled water supply temperature at the evaporator, and *Channel 1* records the chilled water return temperature at the evaporator. *Channel 2* measures the hot water supply temperature at the generator, while *Channel 3* measures the hot water return temperature at the generator. *Channel 4* tracks the cooling water supply temperature to the condenser and absorber. *Channel 5* tracks the cooling water return temperature from the condenser, and *Channel 6* tracks the cooling water return temperature from the absorber. *Channel 7* logs the absorber cooling water flow rate, and *Channel 8* logs the condenser cooling water flow rate.

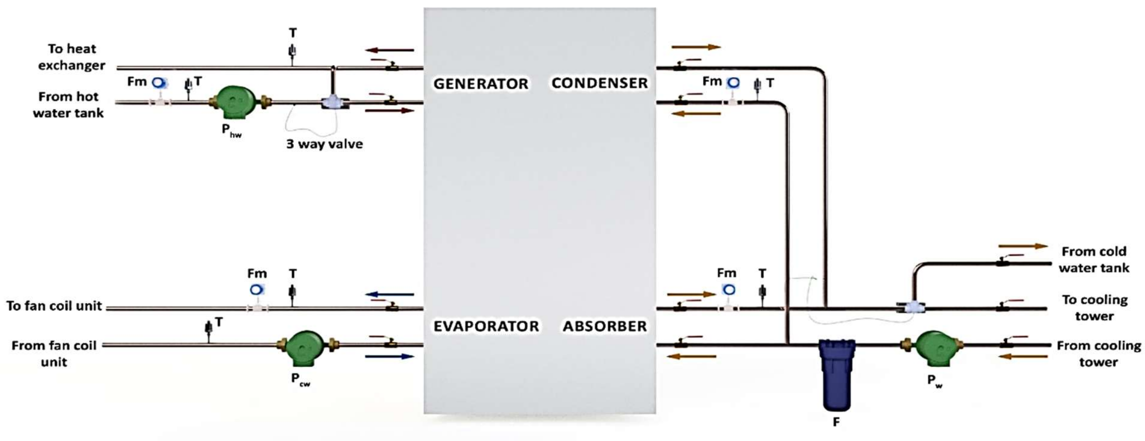


Figure 2. Measurement points schematic of the H_2O/LiBr absorption system

The flow rates were measured with an ultrasonic flowmeter. Chilled water flow rate at evaporator. Each experimental measurement set is recorded every 2 hours from the start-up of the experimental test bench, in order to avoid fluctuations of thermodynamic parameters during long-term operation. For each set, all parameters are measured and logged in real time at 5-minute intervals.

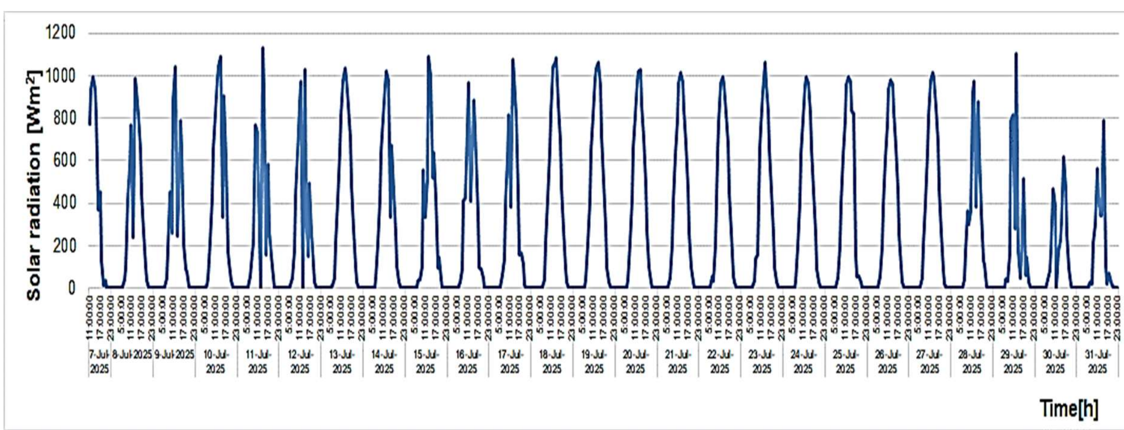


Figure 3. Solar radiation recording for July 2025.

The inefficiency of the flat-plate solar collector before 8:00 a.m. and after 5:00 p.m. makes solar radiation negligible outside this time interval as it can be noticed from Figures 3 and 4. Practically, the solar system does not contribute to heating or generating the thermal load outside these hours, as the flat-plate collector cannot capture enough thermal solar energy to drive the absorption refrigeration system. Initially, the solar system does not contribute to meeting the generator's thermal load **(FNP – Fraction of Net Production = 0).**

As the day progresses, the solar panels continue to operate, and during the period roughly between 12:00 and 15:00, the generator covers **80–95% of the required thermal load.** Experimental recordings on the solar system allowed the determination of precise **FNP values for flat-plate solar collectors (FPST)** depending on the climate in Romania, taking into account: geographical location, climatic data, solar panel model, and operating conditions.

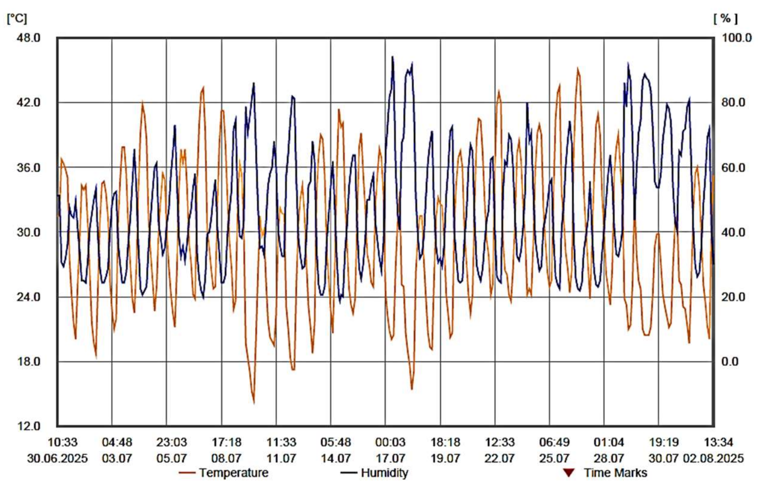


Figure 4. Ambient temperature and relative humidity for July 2025

The absorption heat pump delivers chilled water at 6–7 °C to the air-conditioning system with fan coil units, and hot water up to about 44 °C to the recovery circuit from the condenser and absorber, as reported in Table 2. The measured return temperatures are 6.84–7.04 °C for the chilled water circuit and 33.58–43.92 °C for the hot water circuit.

The heat released in the condenser and absorber during the absorption process is not suitable for space heating, since the supply level, around 35 °C, is below the typical heating requirement of about 50 °C. This residual heat is therefore directed to domestic hot water preparation through a water-to-water heat exchanger, which matches the temperature needs while keeping the cycle stable. This configuration improves performance compared with conventional air-conditioning systems. It recovers heat that would otherwise be rejected, removes the need for a cooling tower, and fits low-temperature hydronic networks such as radiant heating circuits.

Table 2.

Characteristic values of the absorption refrigeration system

Condenser/Absorber cooling inlet water temperature [°C]	Calculated Values					
	Cooling capacity [kW]	Generator capacity [kW]	Condenser capacity [kW]	Absorber capacity [kW]	Relative deviation [-]	COP_{TOTAL} [-]
26.72	17.3	30.36	18.6	28.72	1.04	4.228
32.34	16.1	30.84	18.64	28.50	0.5	5.092
36.70	15.32	28.41	18.45	27.76	3.65	5.262
36.96	12.86	26.43	15.2	22.56	3.9	5.446

5. Conclusions

This paper proposed a novel absorption heat pump (AHP) based on a single-effect H_2O/LiBr absorption chiller, modified to enable the combined production of cooling and heating for domestic hot water**.** Unlike a conventional single-effect absorption chiller, where condensation and absorption heat is rejected to the ambient, the proposed system recovers condensation and absorption heat at a useful temperature level**.** The research focused on introducing advanced heat recovery strategies aimed at improving system-wide heat recovery.

Environmental test of the prototype was performed, and several main conclusions was drawn as follows.

- The experimental stand ran stably to provide 12-17 kW cooling and heating in a wide temperature range from 79 to 98.6°C, with solar thermal ratio of 80-95% in different weather conditions during the period roughly between 12:00 and 15:00

- The COP for cooling (COP_C) full boiler source reached 0.462 to 0.545 for inlet chilled water temperature range 6.8 to 12.5°C and the COP of cooling (COP_C) bivalent source reached 1.992 to 2.285 for inlet cooling water temperature range 26.72 to 36.96°C.

- The total COP (cooling COP_C and heating COP_H) for bivalent source reached 4.228-5.446 with cooling water temperatures reduced from 43.8 to 26.3°C. Advanced systems have been proposed to improve the system performance with heat recovery provide enhanced of COP over the classic AHP cycle when considering cooling or heating propose.

- results demonstrated that the proposed AHP with recovery system mode has significant energy and carbon reduction potential and is an excellent solution for combined cooling and heating in distributed areas.

The future studies involves validation of the AHP in the lab to confirm simulations and tune the design; size new heat-recovery units for the highest achievable temperatures and nominal flows; if reusing an existing unit, verify temperature, flow, and capacity compatibility, since the AHP must not be bound by a legacy system.

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