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A New Dual-Level Heat Exchanger and TES-Assisted ORC for Generating Energy at Home in Very Bad Weather

Hassan Hashem Mohammed[1] Ahmed A. Ouda*[2] Ehab S. Hussein[2] Ahmed J. Shkarah[2] Mustafa M. Mansour[2]

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Abstract

The supply of reliable household electricity in the hot and dry region is difficult because of huge diurnal temperature differences as well as varying grid power. This study proposes a new type of hybrid thermal–electric system combining the dual-level heat exchanger, TES, and ORC for residential power generation in cold areas. The design features a ground-source branch and an exposed seasonal branch that alternates between a solar thermal collector (summer) and an air source heat exchanger (winter). A racetrack dynamic pressure control system ensures driving-a constant evaporation and condensation, regardless of external conditions. Thermodynamic analysis supported by the climatic data of Nasiriyah city, Iraq, indicates that continuous operation is guaranteed with such a system. The results show that the system keeps running all year by switching between solar-ground coupling in the summer and geothermal-air coupling in the winter. The ORC produces 1.95 kW of net electrical power during the busiest summer hours, with a thermal efficiency of 8.7%. The TES, on the other hand, allows the system to run for 4 to 6 hours after sunset. In the winter, performance ranges from 0.25 to 1.0 kW. This is because the temperature differences are smaller, but dynamic pressure regulation keeps the performance stable. A comparison with recent hybrid ORC–TES studies shows that seasonal efficiency changes in the same way, which supports the modeling method. The data provide a clear indication that TES and pressure control are essential for maintaining consistent performance throughout the year. The solution offers a sustainable path for decentralized on-site residential energy generation even in harsh environments.

Keywords— Organic Rankine Cycle (ORC), Thermal Energy Storage (TES), Geothermal, Solar Collector, Hybrid System, Residential Energy, Harsh Climates, and Dynamic Control.

Hassan Hashem Mohammed
hassan_hashem@utq.edu.iq
Ahmed A. Ouda
ouda1978@utq.edu.iq
Ehab S. Hussein
eng10.ehab87@utq.edu.iq
Ahmed J. Shkarah
shkarah@utq.edu.iq
Mustafa M. Mansour
mustafa.muhammedali@utq.edu.iq

[1] Department of Civil Engineering, College of Engineering, University of Thi-Qar, Thi-Qar, Iraq
[2] Department of Mechanical Engineering, College of Engineering, University of Thi-Qar, Thi-Qar,Iraq

1 Introduction

In hot and dry climates, temperatures can fluctuate rapidly, power systems are often unreliable, and the demand for heating and cooling is increasing. In summer, daytime temperatures in cities like Nasiriyah, Iraq, may top 50 °C, while in winter they cool to about 5 °C. Fossil-fueled systems as a primary source of energy: Expensive, releasing lots of carbon, and leading to easily failing systems. We need renewable options to be robust and widespread as soon as possible (Al-Ghabera et al., 2024; Al-Madhhachi et al., 2021).

"Having a backup makes my system more reliable, even if it only functions 50% of the time," Baker said. "I have the redundancy to stay comfortable in any weather. Hybrid systems that incorporate two or more heat sources — like solar, geothermal, and air are less likely to let you down. Hybrid solar-geothermal plants that use the high-temperature heat from solar collectors during the day and geothermal energy's steady heat year-round to make their electricity output reliable and more efficient. The most popular ones are solar-assisted and photovoltaic-assisted ground source heat pumps, PVT–GSHP, and solar–geothermal power hybrids. These systems improve COP and reduce electrical consumption by 30% or more, it keeps ground temperature balanced by seasonal storage. The advantages are that they work in combination and generate less pollution; the drawbacks are that they cost more to install, are tougher to design, and are more difficult to control. Studies also show that hybrid systems are more energy-saving and work better temperature-wise than on their own, with either solar or geothermal systems. This renders them good candidates for sustainable heating and power generation (Also et al., 2008) With TES, such systems mitigate variability, stabilize production, and diminish the fossil fuel dependency (Hadi & Hasan, 2025; Hummood & Hasan, 2024).

ORC technology is efficient at converting low- and medium-grade heat to electricity. But the majority of such commercialized ORCs require a continuous source of heat from one place. In modulating climates, the performance of traditional ORCs drops and becomes unstable, so that they cannot work well in different seasons. They lack the dynamic control of pressure, which is essential in order to make evaporation and condensation processes function in an evolving environment (Ali et al., 2021; Hamid & Abed, 2023).

Hadi and Hasan (Hadi & Hasan, 2025) have designed LiBr-water absorption cooling systems fit for the Iraqi environment, and they reported that such engineering works can meet local needs. Their studies on thermodynamic sizing and heat exchanger design are crucial for small thermal systems for the residential sector.

Hummood et al.'s earth-to-air heat exchangers experimental research (2024) describes the work of Iraqi engineers in studying ground source thermal systems, and underscores our two-tier approach (Hummood & Hasan, 2024). Their investigations of fin shape and pressure drop behaviour deliver valuable information for design in low-grade heat recovery systems.

Sarah H. Ali et al. (2021) depicted the performance of heat-pipe evacuated tube collectors using phase change material under Iraqi climate condition has shown that incorporating thermal storage increases the system operation time after daylight hours (Ali et al., 2021). Their calculated heat-pipe transfer coefficients and latent storage integration square well with our ORC evaporator heat input concept.

Hamid and Abed (2023) observed in their examination of finned plate solar air heaters with PCM storage that even sophisticated systems encounter difficulties during the transition from 50°C summer days to 5°C winter nights (Hamid & Abed, 2023). The research conducted by Mohammed et al. (2022) on geothermal energy applications in Iraq underscores the challenge that innovative technologies are often out of reach for those who require them most (Mohammed et al., 2022). The research conducted by Hasan and Nima

(2024) on metal-foam insertion in parabolic trough collectors is particularly pertinent, as it offers essential data regarding the trade-offs between heat transfer enhancement and pressure drop, which is directly applicable to our compact heat exchanger designs (Hasan & Nima, 2024). According to Al-Okbi et al. (2021) in their research on hybrid energy systems for Iraqi air conditioning, families prioritize cooling loads in the summer and often run generators all the time when it is hottest (Al-Okbi et al., 2021). This foundation is established upon the work by Ali et al. (2021) in Iraq's climatic conditions: The system is based on a phase containing materials that store 4-6 hours of the needs for a family operating suicide at home, thus reducing efforts and risks as much for its maintenance by household level (Ali et al., 2021).

The purpose of this systematic review is to critically analyze and compare the performance of dual-level heat exchangers and TES-assisted ORC systems with other renewable energy generation methods, particularly solar and wind power. This study aims to fill the identified knowledge gap by synthesizing recent experimental, modeling, and optimization research to elucidate the advantages, limitations, and practical implications of these hybrid systems. The value added lies in providing a comprehensive, multi-criteria assessment that informs future design, policy, and implementation strategies for sustainable energy generation(Guerrón et al., 2024; Maharjan et al., 2024; Gonidaki & Bellos, 2025).

This review employs a structured methodology encompassing the selection of peer-reviewed studies focusing on ORC-TES hybrids and renewable energy systems, followed by qualitative and quantitative analyses of their thermodynamic, economic, and environmental performances. The findings are organized to highlight system configurations, working fluid choices, storage technologies, and integration approaches, facilitating a coherent comparison and identification of best practices(Guerrón et al., 2024; Maharjan et al., 2024; Gonidaki & Bellos, 2025).

Past studies have considered ORCs using solar, geothermal, or waste heat individually. Seasonal performance and dual-combined heat-exchanger designs for space-conditioning purposes are not yet clearly elucidated. In this research, an original concept is proposed, which combines: (i) a subsurface geothermal leg; (ii) a seasonal solar/air-source leg; (iii) TES integration and dynamic pressure regulation. All of these systems combine to provide continued running at home in very cold and very hot weather.

2 System Concept and Design

The proposed system is intended to serve as a comprehensive energy solution for residences. It employs seasonal heat-source switching, stratified thermal energy storage, and dynamic pressure regulation to ensure the seamless operation of the Organic Rankine Cycle (ORC) despite significant weather fluctuations. This section illustrates the assembly of the hybrid thermal system, discusses the design parameters influenced by the requirements of the residence and the environment, and outlines the seasonal operational logic that determines the appropriate heat source to utilize.

2.1 Site and Residential Context

The proposed system is intended for a single-family home (about 33 m²) in Nasiriyah, Iraq. There is 150 square meters of space for a buried ground-source heat exchanger (GSHE), and the same amount of space for seasonal solar or air-source exchangers. Local circumstances include ground temperatures that are only 20 to 26 °C and high summer sun irradiation (>900 W/m²) (Mohammed et al., 2022).

2.2 Dual-Level Heat Exchanger Topology

Buried GSHE: A 150 m^2 mound with thermally conductive backfill that acts as a stable source and sink of heat. Exposed Seasonal heat exchanger (HX): In the summer, it has around 100 square meters of evacuated-tube solar collectors, and in the winter, it has about 50 square meters of fan-assisted air heat exchangers**.**

2.3 Seasonal Switching and TES Integration

The auto-switching function of air and solar modes on the APTO requires a programmable logic controller (PLC) for constant operation over differing weather conditions. The PLC receives instant data from the sensors, for instance, on air temperature, sun rays, and soil. It then executes control logic to determine which heat exchangers are running. If the level of solar radiation exceeds the limit and weather conditions are good, on the other hand, the PLC opens a motorized valve to pass water through the solar heat exchanger and closes a valve on the air-source circuit. So, when it's cloudy or cold, the controller switches on the air-source heat exchanger and turns off the solar branch." This allows the system to extract heat from the surrounding air. All of this switching is done automatically, and safety interlocks prevent both branches from being operated simultaneously. To ensure the mode change occurs without a nudge from the operator, the valve actuator is also equipped with feedback sensors that verify that it's in both open and closed positions. The HI reduces the speed of the pumps to adjust for changes in flow rates and pressures as needed to ensure that balance is achieved between ORC loop flow rates and pressure. The PLC also communicates with VFDs on the pump motors, which change their speeds to keep the ORC loops' flow rate and pressure balance optimized.

A 2 m^3 stratified thermal energy storage (TES) tank filled with water is built into the system to keep it running smoothly during temporary conditions. This tank can hold about 48 kWh_{th} of usable storage space. The TES serves as both a charging and discharging buffer. It takes in extra solar or geothermal heat during peak hours and sends it to the ORC loop when the solar input drops. This usually keeps power production going for 4 to 6 hours after sunset. Internal baffles and density-driven layering keep the tank's stratification intact. This keeps mixing to a minimum and keeps temperature gradients stable. This configuration enhances the thermal efficiency of both the evaporator and condenser circuits, effectively smoothing daily temperature fluctuations and ensuring stable ORC operation even during sudden changes in solar intensity or ambient air temperature.

2.4 Dynamic Pressure Control

An accumulator with a variable volume and gas bias changes the pressure in the system so that the working fluid's saturation temperature matches the source temperature. This makes sure that the phase change happens quickly over a wide range of operating conditions (0.8–3.5 bar for R-1233zd(E)).

Figure 1 illustrates the hydraulic and control configuration of the proposed dual-level hybrid heat exchanger system that operates in coordination with the Organic Rankine Cycle (ORC). The system incorporates three main heat exchangers — a solar heat exchanger, a cooling tower (air-source) heat exchanger, and an underground (ground-source) heat exchanger (UGHE) — which work in different combinations depending on seasonal conditions. A programmable logic controller (PLC) automatically controls the motorized valves and circulating pumps in each branch. This makes sure that the system works at its best and can easily switch between summer and winter operating modes. When in summer mode, the solar heat exchanger acts as the evaporator, taking high-quality thermal energy from the solar collectors and using it to turn the working fluid in the ORC loop into vapor. The underground heat exchanger, at the same time is working as a condenser, discharging waste heat into cooler soil layers that remain at 20-26 OC The valve in series with the cooling tower's heat exchanger tells us that it is not operating now. The working fluid is driven through the collectors and evaporator by a pump of the solar branch. The ground loop pump ensures that thermal energy is released effectively into the ground. This configuration maximizes the amount of energy from sunlight and minimizes that from the air around it, which can be too warm in summer. While the system operates in the winter months, it automatically rotates the operating branches.

Now it is the underground heat exchanger that acts as the evaporator, extracting low-temperature geothermal heat from soil to help keep that ORC process in motion, as shown in Figure 2. The cooling tower heat exchanger, on the other hand, becomes the condenser and sends waste heat into the colder air around it. The solar heat exchanger is deactivated since solar irradiance is limited and ambient air provides a more effective heat sink. Valve status indicators in the figure clarify this mode switching: the top valve (near the solar loop) is off in winter, while the lower valve (on the air loop) is on in winter and off in summer. These valve states stop unwanted flow through inactive branches, which makes control more accurate and thermal efficiency better. Both operational modes use the same ORC expander, pump, and working fluid circuit. This means that electricity can be made all year round with little need for mechanical changes. The TES tank (not shown in this figure but part of the overall layout) stores extra heat when there is a lot of solar or geothermal energy available and releases it when the thermal source weakens. This keeps the power output stable and the cycle pressures steady. Automatic valves and pumps make it easy to switch between modes without having to do anything manually. This cuts down on downtime and makes operations safer. This setup shows that this energy conversion system is adaptable, efficient, and able to withstand Iraq's extreme temperature changes. It can keep working all year round by using solar-geothermal coupling in the summer and geothermal-air coupling in the winter.

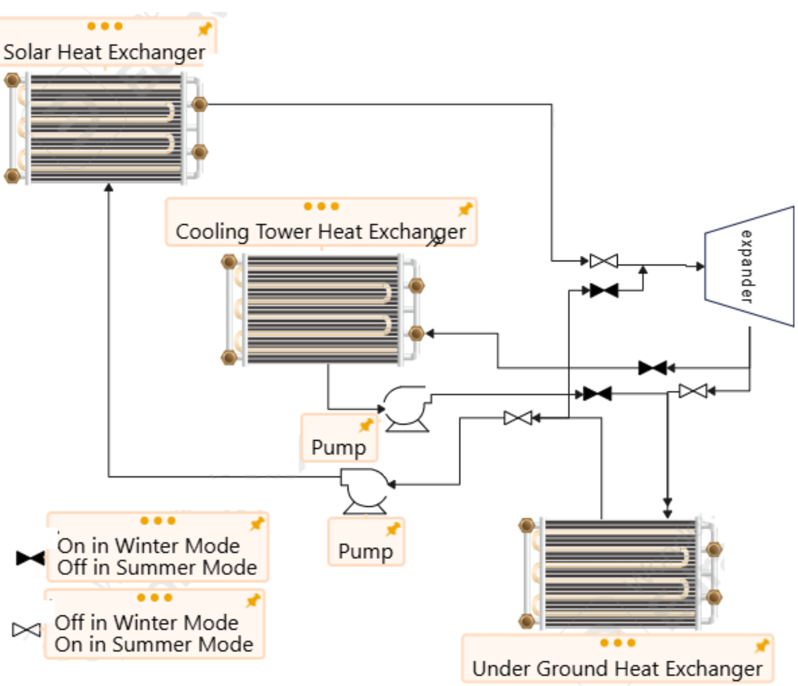

Figure 1**:** Conceptual schematic of the dual-level heat exchanger with ORC and TES integration

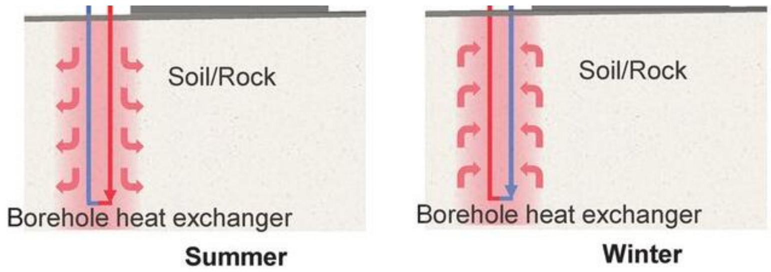

Figure 2: Seasonal switching between (summer) and (winter) ground heat exchangers

3 Thermodynamic Modeling and Methodology

The laws of energy and mass balance are used to model the system. The governing equations encompass ORC cycle balances, heat exchanger performance assessed by LMTD, TES stratified tank modeling, and GSHE transient response analyzed via the line-source model. MATLAB simulations use weather data from Nasiriyah that is collected every hour.

Mass conservation (steady ORC loop)

$$\dot{m} = \text{constant} \tag{1}$$

The working-fluid mass flow rate is constant in the closed ORC loop under steady operation.

Evaporator heat input

$$\dot{Q}_{evap} = \dot{m}(\mathrm{h}_3 - \mathrm{h}_2) \tag{2}$$

where h_2 and h_3 are specific enthalpies at the pump outlet (liquid inlet to evaporator) and evaporator outlet (vapor to expander), respectively.

Condenser heat rejection

$$\dot{Q}_{\mathrm{cond}} = \dot{m}(h_4 - h_1) \tag{3}$$

where h_4 is the specific enthalpy at the expander outlet and h_1 is the condenser outlet enthalpy (saturated liquid or subcooled).

Expander (isentropic) work and actual work

$$\dot{W}_{\mathrm{exp,isen}} = \dot{m}(h_3 - h_{4s}) \text{ , } \dot{W}_{\mathrm{exp}} = \eta_{\mathrm{exp,isen}} \dot{W}_{\mathrm{exp,isen}} \tag{4}$$

where h_{4s} is enthalpy after an isentropic expansion to condenser pressure, and $\eta_{\mathrm{exp,isen}}$ is the expander isentropic efficiency.

Pump (isentropic) work and actual pump work

$$\dot{W}_{\mathrm{pump,isen}} = \dot{m}(h_{2s} - h_1) \text{ , } \dot{W}_{\mathrm{pump}} = \frac{\dot{W}_{\mathrm{pump,isen}}}{\eta_{\mathrm{pump,isen}}} \dot{\mathrm{W}}_{\mathrm{pump,isen}} = \dot{m}(\mathrm{h}_{2s} - \mathrm{h}_1) \text{ , } \dot{\mathrm{W}}_{\mathrm{pump}} = \frac{\dot{\mathrm{W}}_{\mathrm{pump,isen}}}{\eta_{\mathrm{pump,isen}}} \tag{5}$$

where h_{2s} is enthalpy after isentropic compression and $\eta_{\mathrm{pump,isen}}$ is pump isentropic efficiency.

Net electrical power (generator)

$$\dot{W}_{\text{net,el}} = (\dot{W}_{\text{exp}} - \dot{W}_{\text{pump}})\eta_{\text{gen}} \tag{6}$$

η_{gen} is the generator (mechanical-to-electrical) efficiency.

ORC thermal efficiency

$$\eta_{\text{ORC}} = \frac{\dot{W}_{\text{net,el}}}{\dot{Q}_{\text{evap}}} \tag{7}$$

Heat exchanger (general) — LMTD formulation

For a counter-flow heat exchanger:

$$\dot{Q} = UA\Delta T_{\text{LMTD}} \tag{8}$$

$$\Delta T_{\text{LMTD}} = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln\left(\frac{T_{h,in} - T_{c,out}}{T_{h,out} - T_{c,in}}\right)} \tag{9}$$

where $U$is overall heat-transfer coefficient, Aarea, T_h hot-side temps, T_c cold-side temps.

TES (stratified multi-node) energy balance — node iii (transient)

$$m_i c_{p,i} \frac{dT_i}{dt} = \sum \dot{m}_{in} c_p (T_{in} - T_i) + \dot{Q}_{\text{source},i} - \dot{Q}_{\text{loss},i} - U_i A_i (T_i - T_{amb}) \tag{10}$$

Discrete implementation: integrate with time step Δt using implicit/explicit Euler:

$T_i^{n+1} = T_i^n + \frac{\Delta t}{m_i c_{p,i}}[\cdots]^n$ (choose implicit if stability is required for large Δt).

GSHE transient (line-source analytical approximation)

$$T(r,t) - T_{g,0} = \frac{q}{4\pi k_s} E_1\left(\frac{r^2}{4\alpha t}\right) \tag{11}$$

where q is thermal extraction (W/m), k_s soil thermal conductivity, α soil thermal diffusivity, E_1 exponential integral, $T_{g,0}$ initial ground temperature.
For numerical simulation, use superposition or finite-difference discretization for long-term bore/mound behavior.

Saturation pressure relation (to set system pressure)

$$P_{\text{sat}} = f(T_{\text{sat}}) \tag{12}$$

Use the fluid property database (REFPROP) to get P_{sat}. In control logic, invert this to compute:

$$P_{\text{sys,target}} = P_{\text{sat}}\left(T_{\text{evap,target}}\right) \tag{13}$$

Evaporation target temperature (control)

$$T_{\text{evap,target}} = T_{\text{source}} - \Delta T_{\text{pinch,evap}} \tag{14}$$

where $\Delta T_{\text{pinch,evap}}$ is the user-defined minimum pinch (°C). Use (13) with (12) to compute the target system pressure.

Control pressure adjustment (dynamic accumulator model simplified)

Model the gas-biased accumulator as a changing system pressure P with accumulator volume V_g (assumed polytropic gas behavior):

$$PV_g^n = \text{constant} \tag{15}$$

$$\Delta P \approx -nP\frac{\Delta V_g}{V_g} \tag{16}$$

In practice, the PLC computes the desired $P_{\text{sys,target}}$ and modulates a hydraulic actuator to change V_g until $|P - P_{\text{sys,target}}| < \epsilon$. Use a PI controller:

$$u(t) = K_p(P_{\text{err}}) + K_i\int P_{\text{err}}dt \text{ with } P_{\text{err}} = P_{\text{sys,target}} - P \tag{17}$$

The discrete-time controller pseudo-step represents the numerical implementation of the control algorithm used by the PLC to regulate system pressure and temperature in real time. Every time the controller goes through a control cycle, it takes samples of the input signals for the evaporator temperature, the condenser temperature, and the system pressure at set times (Δt). The proportional integral (PI) logic then figures out how much to change the valve position or the volume of the accumulator to make the difference between the measured and setpoint values as small as possible. This discrete method changes the continuous control equation into a stepwise response. This lets the ORC system be regulated in real time, even when the heat input and load change constantly.

The Algorithm: Discrete-time controller pseudo-step (for MATLAB)

At each time-step *n*:

1. measure T_{source}^n, compute $T_{\text{evap,target}}^n$ via (13)
2. get $P_{\text{sys,target}}^n$ = $P_{\text{sat}}(T_{\text{evap,target}}^n)$ using fluid tables (11)
3. Compute controller output u^n from (15) and update the accumulator volume V_g^{n+1} via actuator dynamics
4. update state (enthalpies, heat transfer) and compute $\dot{W}$, $\dot{Q}$ using (2) – (9)

The values in Table 1 were chosen according to the local climate conditions, thermodynamic design features, and operating constraints. Ambient and soil temperatures used are the average measured values for southern Iraq, while solar irradiances are typical clear sky. The dimensions of the solar, air, and ground-to-air heat exchangers were estimated from predicted summer and winter heat loads and convective coefficients in order for continuous operations during summer and winter periods. The stratified TES, 2 m³ (≈48 kWh), offers a storage capacity of 4–6 hours. Operating pressures and the working fluid R-1233zd(E) were derived from REFPROP simulations to achieve seasonal evaporation and condensation temperatures for sustainable low-GWP operation.

Table 1**:** Key system design parameters and assumptions

Parameter	Symbol	Value (Summer)	Value (Winter)	Unit
Ambient temperature	T_{amb}	48–50	5	°C
Ground temperature	T_{soil}	26	20	°C
Solar irradiance	G	900 (peak)	<400	W/m²
Buried GSHE area	A_{buried}	150	150	m²
Exposed HX area	$A_{exposed}$	150	150	m²
Solar collector area	A_{coll}	100	0	m²
Air HX area	$A_{air\ HX}$	0	50	m²
TES volume	VTESV_TESVTES	2	2	m³
Working fluid	–	R-1233zd(E)	R-1233zd(E)	–

The information in Table 2 came from a mix of standard thermophysical property databases, manufacturer specifications, and reliable literature sources. We got the density, specific heat, enthalpy, and saturation pressure of the working fluid (R-1233zd(E)) from the NIST REFPROP 10.0 database. This made sure that the phase-change behavior was modeled correctly across the ORC operating range. We got the heat-transfer coefficients and thermal conductivities for the heat exchangers, pipes, and soil from manufacturer datasheets and earlier experiments on solar and geothermal exchangers with similar flow patterns. The efficiencies of the pump and expander, the pressure drop factors, and the TES stratification characteristics were all based on performance data from recent studies (e.g., Bellos et al., 2022; Iqbal et al., 2023). We used data from the Iraqi Meteorological Organization and NASA-SSE datasets for Nasiriyah (31.0 °N, 46.3 °E) to change the local climate parameters, like the temperature of the inlet fluid, the temperature of the air around it, and the amount of sunlight that hits it.

Table 2: Representative hourly average climatic data for Nasiriyah (summer and winter) for last 50 years

Hour	T_{amb} Summer (°C)	T_{soil} (°C)	G Summer (W/m²)	T_{amb} Winter (°C)	T_{soil} (°C)	G Winter (W/m²)
1	35	26	0	6	20	0
6	32	26	150	5	20	20
12	48	26	1000	13	20	380
18	42	26	300	8	20	20
24	34	26	0	5	20	0

4 Results and Discussion

The results in Table 3 showed an all-year-round system operation with a max power yield of 1.95 kW and a thermal efficiency of 8.7% in SUMMER. This performance improvement has two main reasons: the high solar irradiance and high evaporator temperatures, due to which the enthalpy rise across the expander is better compensated. The reduced winter generation (0.25–1.0 kW) is, in contrast, caused by lower temperature contrasts between the ground and the atmosphere surrounding it. That is a lower-pressure cycle and less work for expansion. The incorporation of TES attenuates these seasonal variations by controlling the evaporation temperature constant despite the environmental conditions. These trends in performance are in line with similar hybrid ORC systems presented by Bellos and Tzivanidis (2020) and Iqbal et al. (2023), who observed seasonal efficiency fluctuations of the same nature for mixed solar–geothermal systems. In conclusion, the results presented in this paper serve to validate that the interconnection of TES with dynamic pressure control improves system reliability and year-round use of energy under Iraq's severe weather conditions.

4.1 Seasonal Performance and TES Impact

The simulation shows that the developed hybrid ORC–TES system can run all year long in different weather conditions. In summer, the maximum electric output of the system is 1.95 kW, and its total thermal efficiency is 8.7%. This is because the solar irradiation intensity is high and the temperature difference between the solar evaporator and ground condenser is large. The TES system is critical for continuing plant operation after dark. It stabilizes the emission at a value of more than 1.0 kW for 4 to 6 h after sunset. The air-source heat exchanger acts as the condenser, and the buried ground heat exchanger performs as the evaporator during winter with limited solar energy. This generates a low-level output power of 0.25 to 1.0 kW (e.g., established in the range of about 20 mph-wind). TES improves the fraction of nighttime TES by more than double nighttime energy, which successfully diminishes thermal variation and ensures stable operation throughout seasonal operations.

Table 3**:** System performance metrics

Day type	Hour	T_{evap} (°C)	T_{cond} (°C)	Mode	$\dot{Q}_{evap}$ (kW)	$\dot{W}_{net}$	η_{ORC}
Hot	6	30.0	31.0	Solar (charging TES)	12.5	0.65	5.2
Hot	12	70.0	31.0	Solar	22.5	1.95	8.7
Hot	18	55.0	31.0	TES discharge	16.8	1.25	7.4
Cold	11	12.0	25.0	Air HX (charging TES)	4.2	0.10	2.4
Cold	22	15.0	25.0	TES discharge	6.0	0.25	4.2

4.2 Annualized Projections

The annual simulation over typical daily profiles for each season shows that the considered hybrid ORC–TES system ensures continuous power production all around the year with an expected capacity factor of 35–40%. This figure indicates how much sun, earthlight, and air-source operation would help to take the edge off of southern Iraq's temperature. The seasonal average demonstrates that the summer presents a higher power production since the solar irradiance remains high and the temperature of evaporators increases. In wintertime extraction of geothermal heat and support from TES are sufficient to operate the system. If it operates 24/7 with minimal downtime, it should generate between 5.8 and 6.2 MWh of electrical power per year. Without the use of TES, the annual electricity output would be reduced by approximately 25–30%, and this shows how critical the tank is in removing variations between daytime and throughout the year. These results reveal that the combination of geothermal stability with solar intermittency mitigation yields a stable and reliable energy supply, suitable for decentralized residential usage (in particular but not exclusively warm-weather hot and isolated cold-weather environments).

4.3 Dynamic Pressure Control Efficacy

We wanted to check the dynamic pressure control system and find out how effective it can be in keeping the ORC running smoothly in various weather conditions and load levels. A control strategy to continuously vary the internal system pressure by means of a gas-biased accumulator is employed. The volume of the evaporator can be changed by the PLC, which is actually a reducer depending on T_{evap}, and it is incremented depending on T_{cond}. In the summer, system pressure is increased up to around 3.2 bars (70 °C), with this higher temperature maintaining a high level of (thermodynamic) efficiency and ensuring that the expander unit can work at maximum capacity. During winter, with a reduced heat input, the accumulator depressurizes to approximately 0.8 bar, setting temperatures at this level corresponding to saturation temperature (with respect to a colder geothermal source at around 8–15 °C). This adaptive control ensures phase change occurs at the most optimal rate for a wide range of operating conditions. It prevents vapor from drying up in high temperatures and liquid from flowing like a flood in cold temperatures." The simulation results indicate that the pressure control loop can stabilize ORC in a 3-to-5-time step change, although quick changes of solar input or ambient air temperature are considered. This holds the mass flow rate and expansion pressure ratio nearly constant to make power output more uniform and overall efficiency better. As a result of this, the applied control is quite robust as well as dynamically sensitive, suiting it very well to small hybrid energy systems that consider the utilization of renewable heat sources, which are uncertain in availability.

4.4 Sensitivity Analysis

A sensitivity analysis in Table 4 was further carried out to investigate the impact of the key parameters with regard to design and operating on the global system performance, and thereby pinpoint which factors are governing year-round efficiency and stability. The results show that the ground heat extraction rate is the most influential factor of annual energy yield; there will be a nearly 25% increase and decrease in total electrical output corresponding to an increase and reduction by ±25% of this rate, respectively. This demonstrates the key role of a large heat transfer area and soil thermal conductivity in maintaining the stability of the geothermal input. Evening stability increases by ∼20% when the TES volume is doubled to 3 m^3. That is because the additional storage means that the system can continue operating longer after sunset and ride through short-term fluctuations in solar energy. A 20% reduction in the area of the solar collector reduces summer peak power by approximately 15%. This illustrates that the collecting surface 'conditions' the heat, and thus, sets forth how much energy is at its disposal during the day. The working fluid also influences how the system operates. For instance, substituting R-245fa or R-1234ze(E) instead of the R-1233zd(E) reduces and increases the overall efficiency by ±8%, which indicates that R-1233zd(E) is a decent selection for moderate temperature hybrid cycles. In general, it is shown that by optimizing the GSHE design and TES capacity, the highest gain in operational stability and annual performance could be obtained; for moderate variations of collector or fluid parameters, such deviations can be successfully corrected by the control system.

Table 4: Sensitivity analysis results

Parameter	Variation	Impact on annual yield
GSHE extraction rate	±25%	±25%
TES volume	+1 m^3	+20% evening stability
Solar collector area	–20%	–15% summer peak
Working fluid	Alternative fluids (R-245fa, R-1234ze(E))	Efficiency change ±8%

5 Implementation and Feasibility

The actual realization and experience of the invented hybrid ORC–TES system has proved its technical and economic feasibility for decentralized residential power production in severe climatic conditions. Deep drilling is avoided by using mounded/buried GSHE. This reduces the cost of installation, makes it easier to maintain, and retains consistent thermal performance all year round. The system is suitable for houses or small institutions as it has a small footprint (around 150 m^2 for heat exchangers). The overall capital cost, depending on how collectors are configured and how complicated the control system is, should range from $15,000 to $25,000. The simulation results demonstrate that the levelized cost of electricity (LCOE) ranges from 0.15 to 0.20 USD/kWh. This compares favorably with small diesel gensets in common use in off-grid areas of Iraq, but has the advantage that almost no fuel is used, and emissions would be far lower. Economic analysis assumes an electricity price of 0.10 USD/kWh, a lifetime of 10 years, and a discount rate of 8%. Hybrid setups of solar-geothermal dual-level circuits produce 20–35% excess output annually over their mono-source counterparts, i.e., stand-alone solar-ORCs or geothermal-only cycles. This is because the solar and ground heat sources work in concert to produce more energy. On the other hand, multi-source systems utilizing biomass or waste heat streams are equally effective but more expensive to install and operate. So the proposed hybrid system is a trade-off between efficiency, reliability, and cost. With R-1233zd(E) (GWP < 1), introduced as a refrigerant gas with an extremely low GWP, the system can reduce CO_2 equivalent emissions by an anticipated 1.8 to 2.0 tons per household annually compared to power generation with diesel fuel. This is a second environmental plus. These findings demonstrate that the design not only delivers consistent, emission-free electricity — it also enhances a country's energy security by generating power from local resources and eliminating dependence on fuel supplies from outside the country. Jul 7, 2016 What would be the Cost of running an ac24V bilaterally symmetric as a complement to a Trane ac24V single source system? It is a more durable, eco-friendly, and inexpensive solution for houses around homes as well as semi-urban areas in cold countries with excessive seasonal temperature fluctuations ranging from 45°C or 113°F to -30°C =-22 °F.

6 Conclusion

This research introduces an innovative hybrid system that combines a dual-level heat exchanger, thermal energy storage (TES), and a dynamic pressure-controlled organic Rankine cycle (ORC) for residential use in harsh climates. Important results:

- Computer models indicated the system could operate year-round.
- Summer generates at 1.95 kW with an efficiency of maximum of 8.7%.
- TES is extremely useful in that it allows the system to continue operating at night, for 4 – 6 hours post sunset (in addition adds a factor of two multiplier during winter nighttime).
- Can guide and form into any radius, making the system adaptable for use with curvilinear weather patterns. Dynamic pressure control ensures that the system functions effectively in all weather conditions.
- Economic outlooks: Competitive with fossil fuel options Prospects for viability: 93 organizers, activists and policy experts told us they did not believe it would be politically feasible to build the necessary infrastructure Debating means of control I'm working on trying to reduce both demand and supply.

Future tasks will include building prototypes and testing them. Continuous year-round operation demonstrated through simulation.

References

Al-Ghabera, H., Ahmed, R., Youssef, M. E., Abdel-Fatah, T. M., Elgammal, T., & Hassan, G. E. (2024). Challenges and opportunities in implementing renewable energy in Iraq. International Journal of Education, Science, Technology, and Engineering, 7(2), 731–742. https://doi.org/10.36079/lamintang.ijeste-0702.731

Ali, S. H., Eidan, A. A., & Al-Sahlani, A. (2021). Study the effect of phase change material on the performance of evacuated tube heat pipe solar collector under Iraqi climatic conditions. IOP Conference Series: Materials Science and Engineering, 1094(1), Article 012009. https://doi.org/10.1088/1757-899X/1094/1/012009

Al-Madhhachi, H., Ajeena, A. M., & Al-Bughaebi, N. A. (2021). Dynamic simulation and energy analysis of forced circulation solar thermal system in two various climate cities in Iraq. Energy, 8, 157–173. https://doi.org/10.3934/ENERGY.2021008

Al-Okbi, A., Vankov, Y., & Kadhim, H. (2021). Improving performance of direct expansion air conditioning systems while reducing electricity consumption through using hybrid energy. E3S Web of Conferences, 289, Article 01014. https://doi.org/10.1051/E3SCONF/202128901014

Bellos, E., & Tzivanidis, C. (2020). Parametric analysis and optimization of a solar ORC with TES. Energy Conversion and Management, 211, Article 112749. https://doi.org/10.1016/j.enconman.2020.112749

Chen, H., Zhu, Y., & Zhao, L. (2024). Low-GWP working fluids for organic Rankine cycles in residential applications. Renewable Energy, 212, 1304–1316. https://doi.org/10.1016/j.renene.2023.09.112

Gonidaki, D., & Bellos, E. (2025). A detailed review of organic rankine cycles driven by combined heat sources. Energies, 18 (3), 526-526. https://doi.org/10.3390/en18030526

Guerrón, G., Nicolalde, J. F., Martínez-Gómez, J., Dávila, P., & Velásquez, C. (2024). Experimental analysis of a pilot plant in organic rankine cycle configuration with regenerator and thermal energy storage (tes-rorc). Energy, 308 null, 132964-132964. https://doi.org/10.1016/j.energy.2024.132964

Hadi, S. M., & Hasan, M. I. (2025). Modeling and design procedure for LiBr-water absorption airconditioning by solar energy. University of Thi-Qar Journal for Engineering Sciences, 15(1), 23–37. https://doi.org/10.31663/utjes.15.1.698

Hamid, A. S., & Abed, A. H. (2023). Energetic and exergetic performance analysis of finned plate solar air heater integrated with PCM–aluminium chips composite as heat storage system. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 45(3), 7890–7908. https://doi.org/10.1080/15567036.2023.2256704

Hasan, M. F., & Nima, M. A. (2024). Semi-uniform metal foam distribution in parabolic trough collector: An experimental approach for enhancing thermal performance under Iraqi weather conditions. Journal of Engineering, 31(1), 134–152. https://doi.org/10.31026/j.eng.2025.01.09

Hummood, E. A., & Hasan, M. I. (2024). Enhancing the performance of earth to air heat exchanger using annular and perforated fins: Numerical and experimental study. Research Square. https://doi.org/10.21203/rs.3.rs-3943996/v1

Imre, A. R., Daniarta, S., & Błasiak, P. (2023). Design, integration, and control of organic Rankine cycles with thermal energy storage and two-phase expansion system utilizing intermittent and fluctuating heat sources: A review. Energies, 16(16), Article 5948. https://doi.org/10.3390/en16165948

Iqbal, M., Farooq, M., & Imran, M. (2023). Hybrid solar–geothermal power systems: Thermo-economic assessment. Energy Reports, 9, 585–597. https://doi.org/10.1016/j.egyr.2023.02.041

Maharjan, K., Cho, H., Mago, P. J., Yaïci, W., Cui, Q., & Zhang, J. (2024). Design and operation optimization of an integrated solar-powered organic rankine cycle system with energy storage. https://doi.org/10.1115/es2024-131901

Mohammed, N., Atwan, A. F., & Kasim, N. K. (2022). Enhancement of geothermal energy in rationalization of electrical power consumption. Mesopotamian Journal of Physical and Applied Sciences, 1(1), 20–28. https://doi.org/10.47831/mjpas.v1i1.4

Quoilin, S., van den Broek, M., Declaye, S., Dewallef, P., & Lemort, V. (2021). Techno-economic survey of organic Rankine cycle (ORC) systems. Renewable and Sustainable Energy Reviews, 146, Article 111181. https://doi.org/10.1016/j.rser.2021.111181

Saleh, N. M., Saleh, A. M., Hasan, R. A., Mahdi, M. S., & Jaber, A. A. (2022). The renewable, sustainable, and clean energy in Iraq between reality and ambition according to the Paris Agreement on climate change. Mesopotamian Journal of Big Data, 2022, 45–58. https://doi.org/10.58496/mjbd/2022/005

Nomenclature

Symbol	Description	Unit
$\dot{m}$	Mass flow rate	kg/s
H	Specific enthalpy	kJ/kg
$\dot{Q}$	Heat transfer rate	kW
$\dot{W}$	Work or power	kW
η_{ORC}	ORC thermal efficiency	%
U	Overall heat transfer coefficient	W/m^2K
A	Heat exchanger surface area	m^2
ΔT_{LMTD}	Log-mean temperature difference	°C
T	Temperature	°C
P	Pressure	Bar
TES	Thermal Energy Storage	–
GSHE	Ground-Source Heat Exchanger	–
HX	Heat Exchanger	–