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Article

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Research paper

A new optimized configuration for capacity and operation improvement of CCHP system based on developed owl search algorithm

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ABSTRACT

One of the best ways to optimally consuming fossil fuel thermal energy is to utilize combined cooling, heating, and power (CCHP) systems. In such systems, by recycling heat wasted from hot gases simultaneously generating power, heat, and refrigeration from combustion, as well as water and cooling oil in electricity production systems, the overall system energy utilization efficiency can be increased to more than 85%. Analysis and optimization of the CCHP systems are mostly in accordance to the operating cost reduction without considering the emissions reduction and actual energy utilization. The present study proposes an energy flow for CCHP system to decrease the main power consumption based on a building thermal demand in Kerman area, Iran. The method introduced a developed version of the owl search algorithm to increase the efficiency of the CCHP system in comparison with the separation production system. Final simulations declare well efficient results for the presented method.

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1. Introduction

The issue of pollution is now more than ever considered by different countries and industries, especially as climate changes and water resources decline and rainfall patterns change for the general public (Rostamzadeh et al., 2012; Farmani et al., 2018). The pollution issue has made all companies more concerned about reducing engine emissions and increasing their efficiency (Hosseini et al., 2013). The CCHP system is known as an effective procedure for increasing the efficiency and decreasing the harmful emissions and energy consumption. The CCHP is the simultaneous and thermodynamic generation of different forms of energy from a simple primary source (Gholamreza and Ghadimi, 2018; Yang et al., 2017).

The technology was first used in steam cycle power plants using steam extracted from the cycle for heating purposes in the plant and surrounding units. Although CCHP technology would reduce the efficiency of such power plants, it would save a great deal on fuel consumption. In recent years, the use of CCHP systems, which are highly energy-efficient, has not been confined to steam power plants and has been extended to other power

generators, whether mechanical or electrical, so that any power generating system can be used to any size today. And with each application designed as a single unit, in addition to generating electrical or mechanical power by the device, it makes possible to utilize the heat dissipation of the generator or motor as heat energy. To obtain a high-performance CCHP system, economical savings similar to pollutants emissions should be considered which can be feasible by yielding a convenient design and operation.

There are several research works on increasing the CCHPs' performances in different terms. The literature shows that the best efficiency will be obtained when optimal designing and operating the CCHP system is achieved by yielding primary energy consumption (PEC), carbon dioxide emission reduction (CDER), and operations cost. Different primary movers have been employed in CCHP systems to achieve an optimal configuration, for instance, steam turbine (Gollou and Ghadimi, 2017; Mirzapour et al., 2019), Organic Rankine Cycle (ORC) (Mansour and Ghadimi, 2016; Melika et al., 2018), gas engine (Hua et al., 2018), and gas turbine (Paria et al., 2019).

Non-linear programming and linear programming and are two classic techniques which have been usually used for optimizing the CCHP systems:

Linear programming is a simple, feasible method for optimizing the CCHP system. For example, Kialashaki et al. (Homayoun et al., 2018) proposed a linear programming method for

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Nomenclature

A_i^2	simulated instead of $4\pi D_i^2$
COP_{ac}	COP of the absorption chiller
ATC^{RF}	the annual total cost of RF
CDE^{RF}	CDE value from the RF
$ATCS$	annual total cost-saving
$E_{g,ji}$	hourly demands of the natural gas bought from the electricity
COP_{ec}	Coefficient of performance
F_b	The amount of supplementary fuel energy consumed to the boiler
$C_{ji,e}$	Hourly energy charges of electricity
F_{pgu}	energy consumption of the PGU fuel
$C_{ji,g}$	Hourly energy charges of natural gas
$F_{on-site}$	on-site fuel power consumption
E_{pgu}	produced energy by the PGU
f_{ji}	hourly demands of the natural gas bought from the network
E_{grid}	obtained electricity from the grid
$O_{i,j}$	matrix defines the j th variable of i th owl
E	power consumption of the building
Q_{sb}	boiler supplementary heat
E_p	parasitic electric energy consumption of the CCHP system
Q_{hc}	Heat supplied to the heating coil
E_{ec}	electricity required for compression chillers
Q_{ha}	Heat supplied to absorption chiller
E_p^{RF}	surplus electricity utilize of distribution components
Q_{ac}	generated cool by absorption chiller
k	number of components
Q_{hd}	heat demand for space heating and domestic hot water
L	position of the prey which is achieved by the fittest owl
Q_{wr}	recovered waste heat from the prime mover
n	service life of the component
Q_{cd}	cool demand for space cooling
N_r	random noise
r_i	interest rate
p	power of the installed components
$U(0, 1)$	uniformly distributed random value
R_c	capital recovery factor

Greek symbols

α	uniformly distributed random number
η_{hc}	performance of the heating coil
β	linearly decreasing constant
η_{hr}	performance of the heat recovery system
$\Gamma(\cdot)$	Gamma function

η_b	performance of the back-up boiler
\mathcal{R}	the ratio of electric cooling to cool load
η_G	performance of the distribution and transmission of the power grid
τ	index of the LV mechanism
η_{ge}^p	Performance of the plant generation
$\omega_{co_2,e}$	The factor of the emission conversion for electricity
η_e	performance of the generation in the PGU
$\omega_{co_2,f}$	The factor of the emission conversion for natural gas
w_2	Height of PES
w_1	Height of ATCS
w_3	Height of CDER

Zhu et al. (Hossein et al., 2018) introduced a two-layer programming technique to optimal designing the dispatch problem for a CCHP of a hospital in Chongqing, China. The first layer used non-dominated sorting genetic algorithm-II (NSGA-II) and stochastic selection algorithm (SSA) to minimize the total life-cycle cost and the pollutant emissions. The second layer was to use the mixed-integer linear programming (MILP) algorithm to achieve a dynamic optimal scheduling scheme and achieve the lowest operating costs

Tian et al. (2020) proposed an optimized operation strategy for the distributed system (DES) for a research station in Antarctica. MILP method was used for optimizing the system efficiency and for decreasing the primary energy consumption of the DES over a year. The system was modeled by the GAMS platform. The results showed about a 12% decrease for the optimized primary energy consumption due to the optimization strategy compared with the original operation strategy.

As aforementioned, another method is to use nonlinear programming. for example, Lu et al. (2015) introduced an optimized configuration for buildings energy systems. The optimal scheduling of the case study was performed by an improved nonlinear programming method including a mixed-integer mechanism. For performance evaluation of the proposed scheduling, four scenarios were studied. Finally, the method was applied to a real case study, the Hong Kong Zero Carbon Building. They declared that the presented method can decrease the cost of operation energy, especially in the presence of thermal energy storage.

Huang et al. (2019) proposed a complex hybrid nonlinear integer model to optimize the energy management of a residential area. The method was used for solving the non-convex MINLP to obtain the pseudo-optimal solution. The results showed that using the proposed algorithm gives better results of demand response toward the commercial solver Knitro.

There are also several different methods for optimizing the CCHP systems, like simple tri-generation systems (Ünal et al., 2016), sequential quadratic programming (Shehata, 2017), Karush–Kuhn–Tucker (Shehata, 2017), and Meta-heuristics (Wang et al., 2010; Olamaei et al., 2018). The global searching and fast results of meta-heuristics make them widely used popular methods for different energy problems.

This study introduces an optimized energy flow configuration for the CCHP system. For criteria evaluating, the environmental, the economical, and the technological effects have been considered. Then a newly developed version of the newly introduced meta-heuristic technique, called owl search algorithm has been adopted for optimizing the CCHP operation strategy and its design capacity. The novelty and contributions of propose paper are summarized as follow:

optimized design, sizing, and operation of the CCHP systems. The principal objective was to give an optimal design for the studied system in the presence of absorption and electrical chillers from an economic viewpoint. The results showed a good efficiency by considering the electricity buyback by about 39%.

- Applying a method for the optimal configuration of a residential building with the CCHP system.
- Proposing an improved version of the owl search algorithm.
- Using Lévy flight and circle mapping to improve the algorithm convergence
- Monthly assessment of the received energy from the grid and CCHP.
- Achieving a solution more precise than the other similar methods.
- Analyzing the system using two different scenarios.

In the next section, the mathematical model of the proposed CCHP system has been declared. In Section 3, the method of the proposed developed owl search algorithm is described. Section 4 determines how to use the proposed algorithm for optimizing the CCHP System. In Section 5, the simulation results of the method on a feasible case study have been applied. The results are then analyzed and discussed in Section 6, and Section 7 represents the conclusions of the study.

2. Model of combined cooling, heat and power energy system

The present section explains the governing relationships to model the combined cooling, heat and power energy system.

2.1. The CCHP system energy flow

The CCHP systems utilize waste heat in addition to generating electricity to provide heating and cooling and hot water consumption. Due to their high efficiency and environmental benefits, CCHP systems are a universal alternative to solve energy problems such as increased demand and security of the environmental issues and energy supply. CCHP system includes different components such as a power generating unit (PGU), cooling system, prime mover, control system, power source and heat exchangers for heating purposes. The main drivers typically include a reciprocating internal combustion engine, a gas turbine, a steam turbine, a microturbine, a Stirling engine, and a fuel cell.

The energy flow diagram of the CCHP system is shown in Fig. 1. In a separate generating system (conventional power supply system), the needed electricity for the building is provided by grid electricity. The building's thermal load is supplied by a gas-fired boiler and transmitted to consumers by a thermal coil. The cooling load here is provided by the combination of electric chiller and an absorption chiller because sometimes the extra electricity generated by the CCHP system following thermal demand and the extra power cannot be sold back to the grid. Natural gas is utilized by PGU to generate the building electricity. A supplementary boiler should be considered for times when the heating cannot satisfy the application requirements. It should be noted that when the amount of the energy produced by PGU is not enough, the rest energy is supplied by the local grid.

The operation of PGU will be reduced when enough energy demand is satisfied with the building. Extra generated electricity and heat by the CCHP system will be dissipated from it. For supplying the cooling and heating system in the summer times and the winter times, respectively, the high-temperature exhaust gas of PGU has been recovered to adapt the thermal load. To achieve balanced electrical in CCHP system, the following equation should be considered:

$$E_{grid} + E_{pgu} = E + E_p + E_{ec} \quad (1)$$

where, E_{pgu} represents the produced energy by the PGU, E_{grid} describes the obtained electricity from the grid, E represents the power consumption of the building, E_{ec} is the electricity required for compression chillers, and E_p describes the parasitic electric energy consumption of the CCHP system.

The electrical energy required for the condensing chiller can be evaluated by the equation below:

$$E_{ec} = \frac{Q_{ec}}{COP_{ec}} \quad (2)$$

where, COP_{ec} represents the coefficient of performance (COP) for the electric chiller, and Q_{ec} describes the generated cooling by the electric chiller.

The energy consumption of the PGU fuel (F_{pgu}), is modeled as follows (Wang et al., 2010):

$$F_{pgu} = \eta_e^{-1} \times E_{pgu} \quad (3)$$

where, η_e describes the performance of the generation in the PGU.

The needed heat for the cooling system and heating coil is formulated as follows:

$$Q_{sb} + Q_{wr} = Q_{ha} + Q_{hc} \quad (4)$$

where, Q_{sb} represents the boiler supplementary heat, Q_{hc} is the heat supplied to the heating coil, and Q_{ha} is the heat supplied to absorption chiller such that:

$$Q_{ha} = Q_{ac} \times COP_{ac}^{-1} \quad (5)$$

$$Q_{hc} = Q_{hd} \times \eta_{hc}^{-1} \quad (6)$$

where, Q_{ac} describes the generated cool by absorption chiller, COP_{ac} represents the COP of the absorption chiller, Q_{hd} describes the heat demand for space heating and domestic hot water, and η_{hc} defines the performance of the heating coil (in this study, the domestic transmission performance is assumed η_{hc}).

The recovered waste heat from the prime mover, Q_r , is formulated as follows (Wang et al., 2010):

$$Q_{wr} = (1 - \eta_e) \times \eta_{hr} \times F_{pgu} \quad (7)$$

Where, η_{hr} represents the performance of the heat recovery system.

The cool load balance of the building is formulated as follows:

$$Q_{cd} = Q_{ac} + Q_{ec} \quad (8)$$

where, Q_{cd} describes the cool demand for space cooling.

Therefore, the ratio of electric cooling to cool load can be defined by the following formula:

$$\mathcal{R} = \frac{Q_{ac}}{Q_{cd}} \quad (9)$$

If $\mathcal{R} = 0$, then the absorption chiller is employed by the cooling system, and if $\mathcal{R} = 1$, the electric chiller is utilized to provide the cooling of the building. Otherwise, mixed chillers have been employed by the cooling system.

The amount of supplementary fuel energy consumed to the boiler is modeled as follows:

$$F_b = \frac{Q_{ha} + Q_{hc} - Q_{wr}}{\eta_b} \quad (10)$$

where, η_b describes the performance of the back-up boiler.

Based on the above cases, the on-site fuel power consumption is achieved as follows:

$$F_{on-site} = F_b + F_{pgu} \quad (11)$$

And hence,

$$F_T = \frac{E_G \times S}{\eta_G \times \eta_{ge}^p} + F_{on-site} \quad (12)$$

$$S = \begin{cases} 1, & E_G \geq 0 \\ 0, & E_G < 0 \end{cases} \quad (13)$$

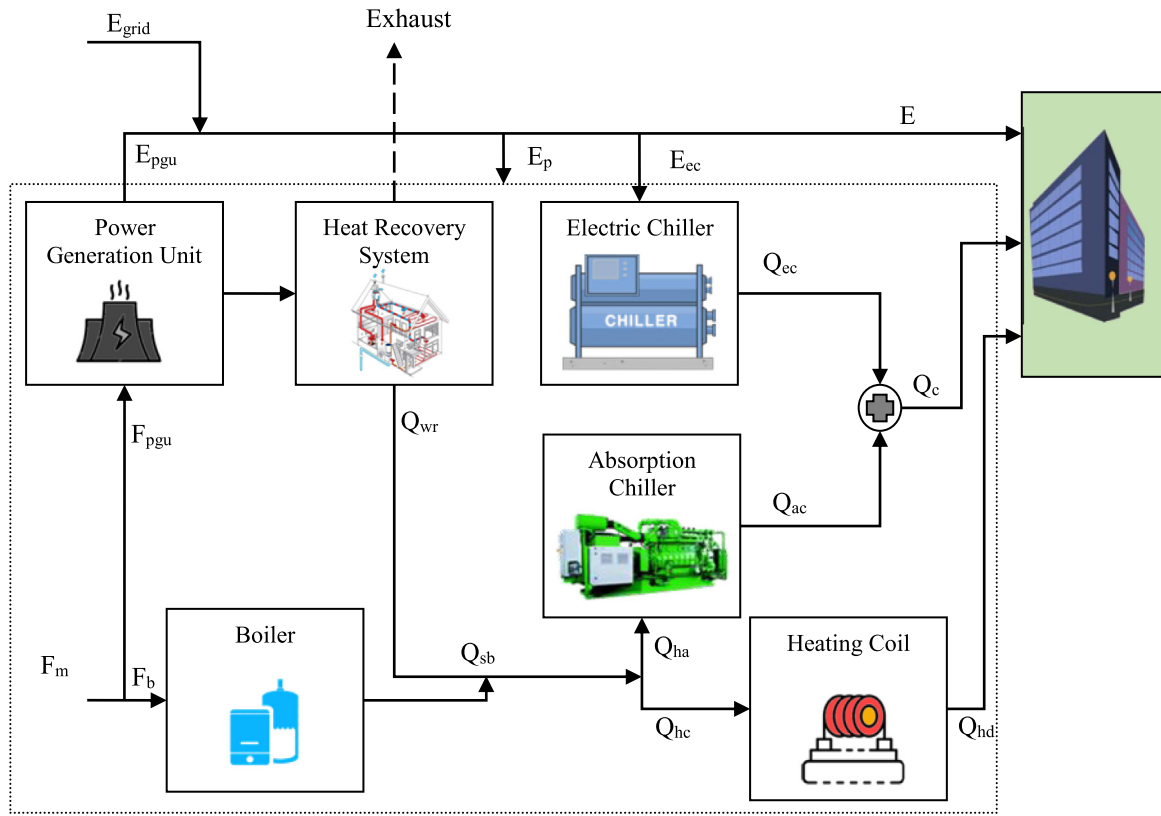


Fig. 1. The diagram of the energy flow for the CCHP system.

where, η_G describes the performance of the distribution and transmission of the power grid, and η_{ge}^p represents the performance of the plant generation.

By considering the maximum input fuel energy of the PGU (F_{max}), the test function has been selected as follows:

$$\frac{(1-R)Q_{cd}}{COP_{ch}} + Q_{hc} \geq F_{max} \times (1 - \eta_e) \times \eta_{hr} \quad (14)$$

Such that:

$$\left\{ \begin{array}{l} F_{max} + \frac{E_G \times S}{\eta_G \times \eta_{ge}^p} + \frac{(1-R) \times Q_{cd}}{COP_{ch}} + Q_{hc} \geq F_{max} \times (1 - \eta_e) \times \eta_{hr} \\ \text{if test function} = \text{true} \\ \frac{E_G \times S}{\eta_G \times \eta_{ge}^p} + \frac{(1-R) \times Q_{cd}}{COP_{ch}} + Q_{hc} < F_{max} \times (1 - \eta_e) \times \eta_{hr} \\ \text{if test function} = \text{false} \end{array} \right. \quad (15)$$

where,

$$\left\{ \begin{array}{l} E_G = E + E_p + \frac{R \times Q_{cd}}{COP_{ec}} - F_{max} \times \eta_e \text{ if test function} = \text{true} \\ E_G = E + E_p + \frac{R \times Q_{cd}}{COP_{ec}} - \frac{(1-R) \times Q_{cd}}{COP_{ch}} + Q_{hc} \times \eta_e \\ \text{if test function} = \text{false} \end{array} \right. \quad (16)$$

For characterizing the proposed method, this study works on optimizing two different scenarios with different configurations. The first one is the fixed ratio of electric cooling to cool load adopted in the operation stage (\mathcal{R}) to provide a simple operation strategy. Indeed, if the value of \mathcal{R} varies over time, the operation

mode will be too hard and needs a stronger control system and the second case is the selected PGU capacity in the design stage ($F_{max} \times \eta_e$) which is a principal term due to the importance of the sizing of the CCHP plant for achieving the capital cost and the operation mode. By assigning the capacity of PGU, the capacity of some other parts such as the boiler and heat recovery system have been also specified. To keep the generation efficiency of PGU at a specified value, a new improved meta-heuristic technique called a developed owl search algorithm has been used. The optimization process has been applied by considering some assumptions:

- The surplus electricity generated by the CCHP cannot be sold back to the network.
- The reliability of the CCHP system is assumed by 100%.
- The minimum technical constraint of the CCHP system is neglected.
- All the components of the CCHP system operate from in the range 0% and 100% of their rated capacity.

To analyze the criteria of the CCHP system, it is compared with an existing reference (Rf) system. for the Rf system, the electrical energy of the building is provided by the local electricity grid, the building heating system is distributed to the users by heating coils which are provided by a gas boiler, and the electric chiller has been employed by the cooling system. The primary energy consumption by the Rf system has been achieved by the following:

$$F^{RF} = \frac{(E + E_p^{RF})}{\eta_e^{RF} \times \eta_{grid}} + \frac{Q_c}{COP_e \times \eta_e^{RF} \times \eta_{grid}} + \frac{Q_{hd}}{\eta_b^{RF} \times \eta_h^{RF}} \quad (17)$$

where, E_p^{RF} describes the surplus electricity utilize of distribution components such as fans and pumps in an RF system, and η_b^{RF} and η_h^{RF} determine the performance of the boiler and the heating coil, respectively.

To the environmental and economic analysis of the proposed CCHP system in comparison with RF, three evaluation criteria have been adopted. The first criterion is the annual total cost-saving (ATCS). The ATCS contains the annual capital cost and the annual energy based on the following equation:

$$ATC = R_c \times \sum_{i=1}^k p_i \times c_i + \sum_{j=1}^{365} \sum_{i=1}^{24} (E_{g,ji} \times c_{ji,e} + f_{ji} \times c_{ji,g}) \quad (18)$$

where p describes the power of the installed components and c describes the initial capital cost of the components, k describes the number of components, f_{ji} and $E_{g,ji}$ describe the hourly demands of the natural gas bought from the network and electricity, respectively and $c_{ji,e}$ and $c_{ji,g}$ represent the hourly energy charges of electricity and natural gas, respectively and R_c determines the capital recovery factor which can be achieved as follows:

$$R_c = \frac{r_i \times (r_i + 1)^n}{(r_i + 1)^n - 1} = 1 - \frac{F}{F^{RF}} \quad (19)$$

where, r_i represents the interest rate and n describes the service life of the component.

The values of r_i and n is assumed to equal to all kinds of components. In addition, the criterion ATCS is achieved as follows:

$$ATCS = \frac{ATC^{RF} - ATC}{ATC^{RF}} = 1 - \frac{ATC}{ATC^{RF}} \quad (20)$$

where, ATC^{RF} describes the annual total cost of RF.

The next criterion is the primary energy saving (PES). The PES declares the saving energy ratio of the CCHP system for the energy consumption of the RF system. PES is formulated below:

$$PES = \frac{F^{RF} - F}{F^{RF}} = 1 - \frac{F}{F^{RF}} \quad (21)$$

By considering the carbon dioxide emission (CDE) as follows:

$$CDE = \omega_{co_2,e} E_G + \omega_{co_2,g} F \quad (22)$$

where, $\omega_{co_2,e}$ and $\omega_{co_2,g}$ describe the factor of the emission conversion for electricity and natural gas from the network, respectively.

By considering the conception of the ATCS and PES, the third criterion, CDER of CCHP system in comparison with RF is evaluated as follows:

$$CDER = \frac{CDE^{RF} - CDE}{CDE^{RF}} = 1 - \frac{CDE}{CDE^{RF}} \quad (23)$$

where, CDE^{RF} describes the CDE value from the RF.

3. Developed Owl search algorithm

There are different types of nature-inspired algorithms that mimic different phenomena from natural reactions (Arif and Wang, 2019; Holland, 1992; Mousavi and Soleymani, 2014) to social behavior (Aliniya and Mirroshandel, 2019; Atashpaz-Gargari and Lucas, 2007; Hosseini et al., 2012; Razmjoooy et al., 2011, 2013, 2017b) and human competitions (Razmjoooy et al., 2016; Bandaghirri et al., 2016; Razmjoooy et al., 2017a, 2018). An important part of these techniques is their ability for escaping from the local optimum point. Recently, Jain et al. (2018) introduced a new nature-inspired method using the owl’s idealized hunting behavior. The barn owl (scientific name: Tyto alba) has the highest prevalence among owls and even other species of birds. Barn owls are found almost everywhere except for poles and deserts, including the Alpine Belt, much of Indonesia, and the Pacific Islands. Other names have been given to the owl’s appearance, location, and flight (Grothe, 2018). The barn owls

have a great potential to find and to locate the prey which is because of their anatomical characteristics of the auditory system by a vertical asymmetry of ears. This prominent feature is utilized for achieving the sound in one ear before the other for precise locating of the prey (Stemmler et al., 2018). The prey sound is processed using two parts of the owl’s brain, the interaural time difference (ITD) and the interaural level (loudness) difference (ILD) that are employed for providing the auditory map of the prey location (Jain et al., 2018).

3.1. Owl search algorithm (OSA)

The owl search algorithm starts with n number of random population, called owls which are the initial guesses for the problem solutions. In OSA, the forest is considered as a d dimensional search space in this algorithm. By considering the owls in the forest, the initial position for owls is stored in $n \times d$ matrix, i.e.

$$O = \begin{bmatrix} O_{1,1} & \cdots & O_{1,d} \\ \vdots & \ddots & \vdots \\ O_{n,1} & \cdots & O_{n,d} \end{bmatrix} \quad (24)$$

where, the component $O_{i,j}$ in the matrix defines the j th variable (dimension) of i th owl.

The initial owls have been then normalized to give a uniform distributed position by the following formula:

$$O_i = O_l + (O_l + O_u) \times U(0, 1) \quad (25)$$

where, $0 \leq U(0, 1) \leq 1$ describes a uniformly distributed random value, and $O_i \in [O_l, O_u]$.

The cost for the position of the owls in a forest is evaluated based on a cost function and stored in a matrix as follows:

$$f = \begin{bmatrix} f_1([O_{1,1}, O_{1,2}, \dots, O_{1,d}]) \\ \vdots \\ f_n([O_{n,1}, O_{n,2}, \dots, O_{n,d}]) \end{bmatrix} \quad (26)$$

The cost value of the position for the owls directly depends on the intensity information received through the ears. Therefore, maximum intensity is achieved by the best owl as it is more close to prey. The normalized intensity value information of the i th owl is employed to update the position as follows:

$$I_i = \frac{f_i - f_m^l}{f_m^h - f_m^l} \quad (27)$$

where,

$$f_m^h = \max_{m \in 1, \dots, n} f_m \quad (28)$$

and,

$$f_m^l = \min_{m \in 1, \dots, n} f_m \quad (29)$$

Then, the distance information for the owl and prey population is achieved as follows:

$$D_i = \sqrt{\sum_i (O_i - L)^2} \quad (30)$$

where, L describes the position of the prey which is achieved by the fittest owl.

The assumption in the algorithm is that there is only one prey as the global optimum in the forest. During the hunting process, owls flights silent towards the prey such that the intensity changing for the i th owl can be considered as follows:

$$C_i = \frac{I_i}{A_i^2} + N_r \quad (31)$$

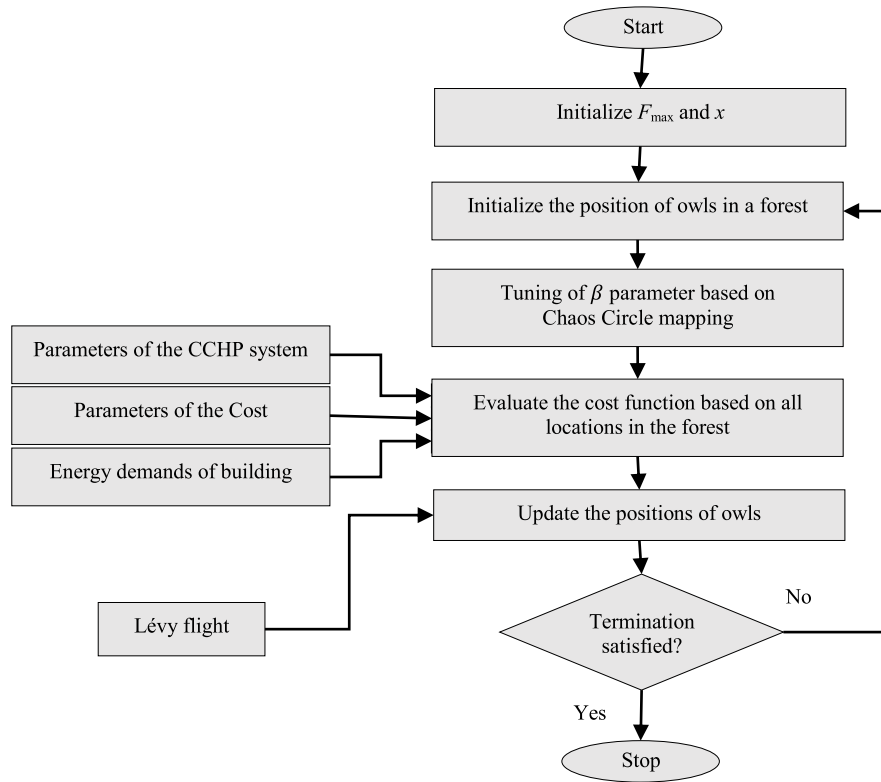


Fig. 2. The diagram flowchart of the proposed DOSA.

where, A_i^2 represents the simulated instead of $4\pi D_i^2$, and N_r describes the random noise.

As it is clear, the owls should change their position silently based on the prey movements. The OSA algorithm model the prey movement based on probability as follows:

$$O_i^{t+1} = \begin{cases} O_i^t + \beta \times C_i \times |\alpha L - O_i^t|, & p_{pm} < 0.5 \\ O_i^t - \beta \times C_i \times |\alpha L - O_i^t|, & p_{pm} \geq 0.5 \end{cases} \quad (32)$$

where, p_{pm} represents the prey movement probability, $0 \leq \alpha \leq 0.5$ describes the uniformly distributed random number, and $0 \leq \beta \leq 1.9$ is a linearly decreasing constantly.

The coefficient β contains the exploration term of the algorithm in the search space that makes it so reliable than the other bio-inspired algorithms.

3.2. Developed Owl search algorithm (DOSA)

In recent years, plenty of chaotic maps have been discovered by scientists in several domains of human activities. A large number of these mechanisms have been applied to different algorithms to solve multiple real-world problems like optimization.

As before mentioned, the parameter β in OSA is a random value in the algorithm in which using it in each iteration makes the algorithm premature converging. The present study gets help from a chaos mechanism (circle mapping) to solve the premature converging. The circle mechanism maps the unknown parameter β into a regular formulation as follows (Hilborn, 2000):

$$\beta_{i+1} = \beta_i + \rho - (\alpha - 2\pi) \sin(2\pi \beta_i) \bmod(1) \quad (33)$$

where, a chaotic time series $\beta_i \in [0, 1]$ are generated by $\alpha = 0.5$ and $\rho = 0.2$.

In this study, the Lévy flight (LF) procedure is also used for increasing better convergence. LV is a widely used mechanism that is also employed in nature-inspired optimization algorithms

(Choi and Lee, 1998). LV models the random walk for controlling the local search as follows:

$$Le(w) \approx w^{-1-\tau} \quad (34)$$

$$w = \frac{A}{|B|^{1/\tau}} \quad (35)$$

$$\sigma^2 = \left\{ \frac{\Gamma(1+\tau) \sin(\pi\tau/2)}{\tau \Gamma((1+\tau)/2) 2^{(1+\tau)/2}} \right\}^{\frac{2}{\tau}} \quad (36)$$

where, $\Gamma(\cdot)$ Determines Gamma function, $0 \leq \tau \leq 2$ is the index of the LV mechanism (here, $\tau = 3/2$ (Li et al., 2018)), $A \sim N(0, \sigma^2)$ and $B \sim N(0, \sigma^2)$, w is the step size, $A/B \sim N(0, \sigma^2)$ means that the samples generated from a Gaussian distribution in which mean are zero and variance is σ^2 , respectively.

By considering the LV mechanism, new positions of the owls can be obtained by the following equation:

$$O_i^{t+1} = \begin{cases} O_i^t + \beta \times C_i \times |\alpha L - O_i^t| \times Le(\delta), & p_{pm} < 0.5 \\ O_i^t - \beta \times C_i \times |\alpha L - O_i^t| \times Le(\delta), & p_{pm} \geq 0.5 \end{cases} \quad (37)$$

4. Optimizing CCHP system based on DOSA

As before mentioned, the principal objective is to design an optimal configuration for the CCHP system. The efficiency of the CCHP system is analyzed and improved in comparison with the RF system. To environmental and economical maximizing the CCHP system efficiency, the following cost function should be minimized:

$$\min cf = \frac{1}{w_1 \times ATCS + w_2 \times PES + w_3 \times CDER} \quad (38)$$

where, w_1 , w_2 , and w_3 describe the weights of ATCS, PES, and CDER.

Here, DOSA is utilized to minimize the determined cost function (cf). The method of CCHP system optimization based on DOSA is shown in Fig. 2.

Table 1

The parameter's value adopted for the CCHP system and separation generation system (Hosseini et al., 2018; Wang et al., 2010).

Parameter	Value
The efficiency of the Boiler (η_b) (Wang et al., 2010)	0.7
The efficiency of the Waste heat recovery System (η_{hr}) (Wang et al., 2010)	0.7
The efficiency of the Heating coil (η_{hc}) (Wang et al., 2010)	0.8
The performance of the PGU of CCHP system (η_c) (Wang et al., 2010)	0.4
The efficiency of the PGU of the separation production system (η_{ge}^p) (Wang et al., 2010)	0.5
Transmission Efficiency of the Grid (η_G) (Wang et al., 2010)	0.89
CO ₂ emission ($\mu_{CO_2,f}$) (Hosseini et al., 2018)	220
Conversion factor (g/k Wh)($\mu_{CO_2,e}$) (Hosseini et al., 2018)	968
COP of Electric chiller (COP_{ec}) (Hosseini et al., 2018)	3
COP of Absorption chiller (COP_{ch}) (Hosseini et al., 2018)	0.7

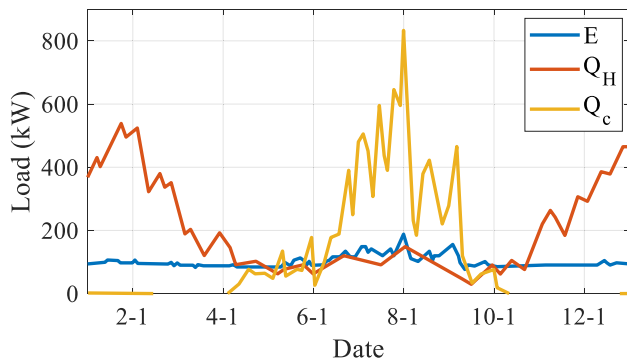
**Fig. 3.** Daily loads of the building in Kerman.

Table 1 illustrates the parameter quantity for the components of the employed CCHP system. The values for the table have been obtained from (Hosseini et al., 2018; Wang et al., 2010)

Table 2 illustrates the initial unit cost for all components of the CCHP system. The values for Table 2 have been achieved by (Hosseini et al., 2018; Wang et al., 2010)

Table 3 illustrates the parameter value of the DOSA which is selected after trials and errors (Jain et al., 2018).

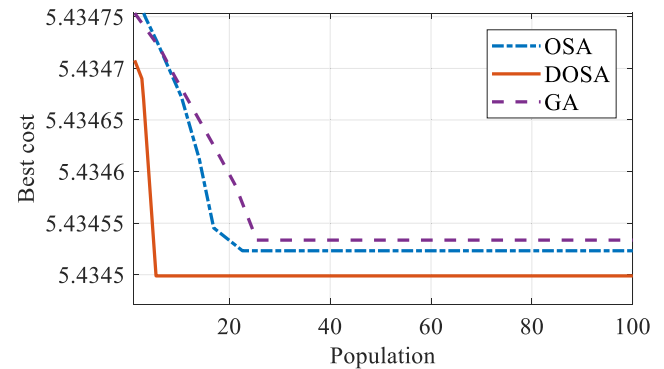
After determining the CCHP system and the DOSA, the system has been simulated. To do so, the cost function is calculated. During the optimization in the search space, the operational strategy is analyzed and the annual energy charge is calculated based on the general relationship among system efficiency characteristics, the general energy balance of the system, and the load demands. Therefore, after selecting the parameters of the algorithm, the search is turned back to the cost evaluation until a satisfying optimal criterion is reached.

5. Simulation results

To implement the DOSA method for determining the capacity of the designed CCHP system and the electric cooling to cool load ratio, a residential building in Kerman has been considered. The area of the floor in the building is 8500 m² and the average height for its ceiling is 3.6 m. The favorable temperature of the building is considered close to 25 °C and the oscillation of the daily cool load and heat load is higher than the daily electricity demand. The stability of the electricity demand is well and the heat and cool load have a higher value than it.

The building hourly energy load is approximated by the software DesignBuilder (d. builder) and the results for annual daily CHP loads of the building are shown in Fig. 3.

It should be noted that the peak value for the cool load is higher than the maximum value of the heat load which is due to the hot climate of Kerman and the energy demands for CHP are alike in autumn and spring. During the simulation, the

**Fig. 4.** The optimal process of the proposed system for the objective function.

DOSA parameters are important for optimal processing and better convergence. This is the reason that leads to the design of a developed version of OSA by decreasing the random value generation of the algorithm. By applying the proposed method to the system, the optimal values of capacity for PGU and ratio of electric cooling to cool load are achieved [F_{max}, \mathcal{R}] = [500, 0.69]. In other words, the capacity of PGU of the CCHP system is 500 kW with 48% of the cool load of the building which is achieved using absorption chiller and electric chiller in heat from the boiler or recovery system. The results of the best cost for the optimal process of the system based on the proposed DOSA compared with the traditional OSA and GA are shown in Fig. 4.

It is observed that the fast convergence for the cost function is achieved by the proposed DOSA by only 5 iterations. Then, the traditional OSA and GA have the next optimal values in 22 and 25 iterations that show the proposed DOSA methods' fast convergence that is made by the improvement.

However other meta-heuristics can be also employed for the optimization, each of them has its own shortcomings. For example, as can be seen from the results, GA as the most popular and widely used optimization algorithm a slow convergence among the other algorithms. It also needs several Fine-tuning for its parameters, such as elitism percentage, mutation rate, fitness normalization/selection parameters, and crossover parameters that is often achieved by trial and error. While the proposed method has the minimum number of parameters for handling and its convergence speed has been increased due to the Lévy flight and circle mapping.

To do the better analysis of the system, two different scenarios have been considered. In the first scenario, the capacity of the system is assumed constant in 500 kW while the ratio of the electric cooling to cool load has variant ratios of electric cool to the cooling load. Fig. 5 shows the performance analysis of the CCHP system for the ratio of electric cooling to cool load variation.

Table 2
The unit cost for each component.

Facility	Prime mover	Absorption chiller	Heating coil	Boiler
Price (\$/kW)	960.22	169.45	28.24	42.36
Facility	Electric chiller	Natural gas	Electricity (7:00–22:00)	Electricity (23:00–6:00)
Price (\$/kW)	136.97	0.027	0.14	0.061

Table 3
DOSA parameters (Jain et al., 2018).

Parameter	Value
Owl population	120
No. of iteration	30
α	0.25
The range of forest for capacity	[0, 1000]
The range of forest for Ratio of electric cooling to cool load	[0,1]

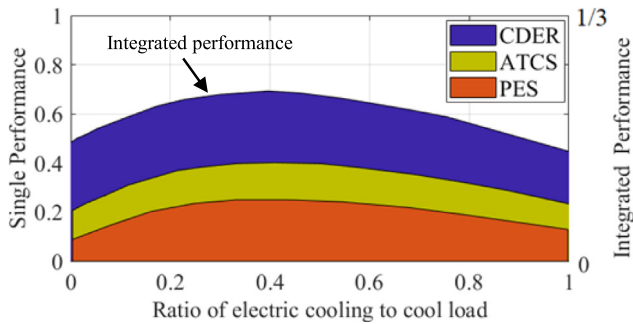


Fig. 5. The performance of the PES, ATCS, CDER of the CCHP system by changing the ratio of electric cooling to cool load.

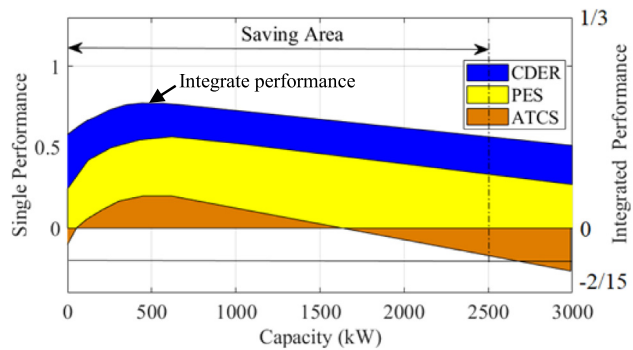


Fig. 6. The performance of the PES, ATCS, CDER of the CCHP system by changing various capacities.

It is observed that the integrated efficiency is a positive value at the top of the curve. After increasing the integrated performance, the speed decreases step by step and reaches the peak value, 19.30%, by increasing the \mathcal{R} when the capacity is less than 0.69 and if it was greater than 0.69, the integrated efficiency starts to decrease. It can be also concluded that increasing the \mathcal{R} makes ATCS, CDER, and PES to be vaulted for the curves. Therefore, the order of ATCS to the integrated efficiency gives the least value and the ability of the CDER for the CCHP system in comparison with RF is the most prominent. The results declare that optimization of the CCHP system for designing and operating, can decrease cost decrease the CDE than the RF and achieve better efficiency to save primary energy.

In the next scenario, consider the efficiency areas of the CCHP system with different capacities when $\mathcal{R} = 0.69$. The results of the simulation are shown in Fig. 6.

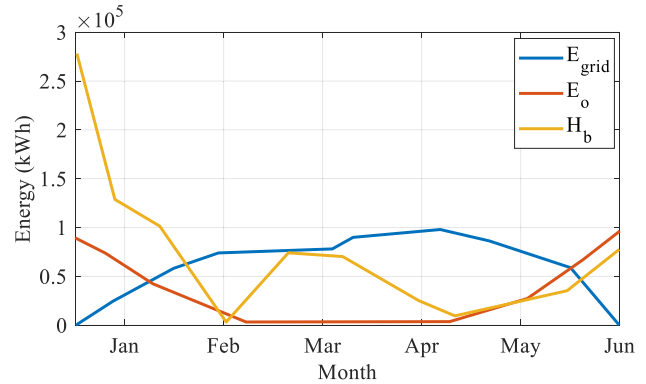


Fig. 7. The monthly received energy from the grid, surplus power of CCHP systems, and supplementary heat for Scenario1.

As can be seen, the weighted integrated efficiency includes the top of the diagram. After increasing the integrated performance with a high value of speed, the speed step down gradually and reaches the peak value, 19.30% at 500 kW and then it reduces step by step by increasing the PGU capacity. In addition, both single and integrated performances are negative during the capacity value of less than about 93kW. This is due to the larger value of the parasitic electric energy consumption of the CCHP system compared with the RF. It is also observed that both the CDER and PES have been increased at first, and after reaching the peak, they have been decreased by increasing the PGU capacity. Finally, ATCS has been increased firstly, and after reaching to the peak value, it has been decreased by increasing the CCHP system capacity with more specifically than CDER's and PES's.

As can be seen from Fig. 6, if the capacity becomes higher than 2700 kW, the annual cost cannot be saved by the CCHP system due to the surplus capital cost. However the CCHP system saves the main energy in comparison with the RF system, it has not the ability to save the cost for the users. Hence, the saving area includes a region in the interval of 110 kW and 2700 kW. From the results, it is observed that proper selection of the CCHP system capacity is a principal part of designing in terms of its efficiency.

6. Discussions

This section analyzes the capacity and the ratio of the electric cooling to cool load to the building in Kerman. Here, two different scenarios have been considered. In scenario 1, the optimal CCHP system has been utilized and in scenario 2, a CCHP system with $\mathcal{R} = 0$ and only absorption chiller has been considered to compare with the optimal CCHP system efficiency. Figs. 7 and 8 show the monthly received energy from the grid, surplus power of CCHP systems, and supplementary heat for the building.

The results show that the electricity from the grid, E_{grid} , in scenario 2 is less than the optimal CCHP system, while supplementary heat from the boiler, H_b , is more than the optimal CCHP system in summer. Furthermore, because the surplus power generated by scenario 2 cannot be sold back to the network, it has been exhausted. Since during using the mix chiller by the optimal

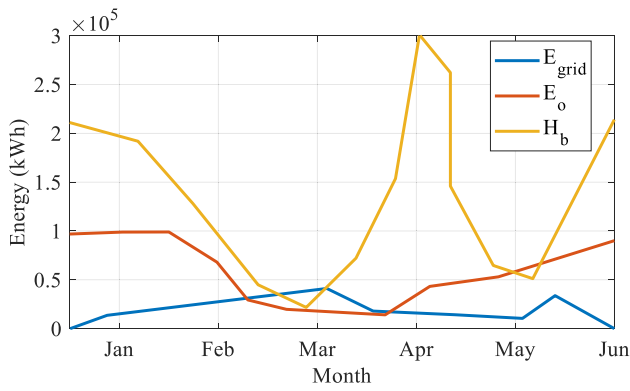


Fig. 8. The monthly received energy from the grid, surplus power of CCHP systems, and supplementary heat for Scenario 2.

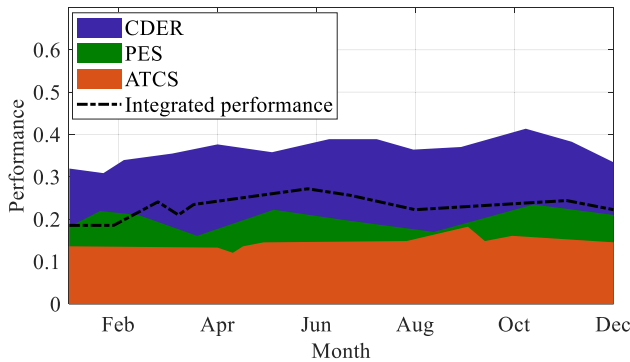


Fig. 9. The monthly performance analysis of CCHP systems for Scenario 1.

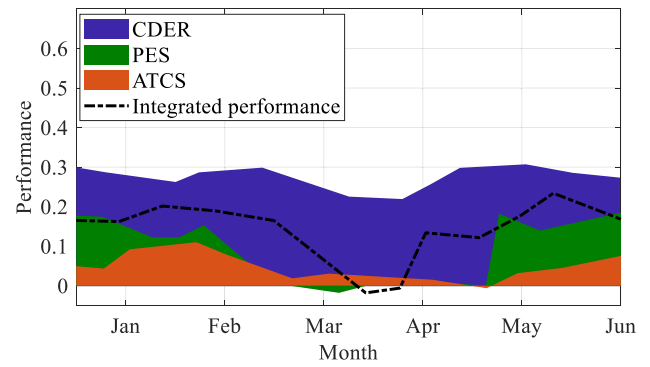


Fig. 10. The monthly performance analysis of CCHP systems for Scenario2.

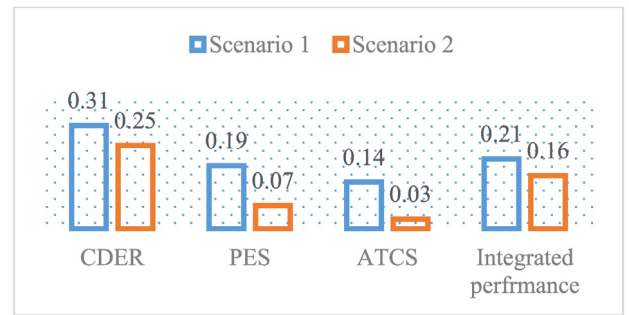


Fig. 11. The annual performance of the carbon dioxide emission reduction, total cost saving, primary energy saving, and integrated performance of the two scenarios: blue for scenario 1 and red for scenario 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

CCHP system, the surplus power is employed in the electric chiller for the cooling process, it prevents the optimal CCHP system from exporting energy, E_o , in summer that saves the primary energy.

The performance analysis of both scenarios is shown in Figs. 9 and 10. The results show that the only difference is about seasons that the building needs cooling. As can be seen, the value of the CDER and PES are close in both scenarios except ATCS. In summer times, because of the surplus power for providing the cooling process, the primary power consumption of the optimal CCHP system has been reduced to a large extent. Accordingly, the carbon dioxide emission of the CCHP system and the annual cost have been decreased. The results also show that the CCHP system in scenario 2 just adopts an absorption chiller that cannot save primary power in the summertime due to the surplus power exhausting. Therefore, the efficiency of scenario 2 can be improved if there are components to store or recover the surplus power. Consequently, more attention has been paid to the application of the surplus power generated by the CCHP system following thermal demand.

Fig. 11 shows the annual performance of the total cost saving, primary energy saving, carbon dioxide emission reduction and integrated performance of the two scenarios. It is observed that carbon dioxide emission reduction of the CCHP system has the most performance compared with other aspects and the next aspects are annual total cost saving and primary energy saving, respectively. The annual integrated performance of the CCHP system in scenario 1 is also 1.3% greater than scenario 2.

7. Conclusions

This study presented a newly developed version of the owl search algorithm based on the Levy flight mechanism and circle

mapping for optimizing the CCHP design capacity and its operation. The new configuration was adopted on a numerical example of the CCHP system for a building in Kerman, Iran and its impact was analyzed. The area of the floor in the building is 8500 m^2 and the average height for its ceiling is 3.6 m. In the proposed system, after increasing the integrated efficiency of the CCHP system, its speed was step down step by step and reaches the top and afterward by increasing the capacity and the electric cooling to cool load ratio, it was reduced. System analysis showed that primary energy saving and carbon dioxide emission reduction of the CCHP system keep the limited value in comparison with the RF system, while the annual total cost saving reduced the capacity and ratio. The system also contained a mixed cooling system to decrease the exhaust of surplus power. By applying the proposed method to the system, the optimal values for the capacity of PGU of the CCHP system are 500 kW with 48% of the cool load of the building that is achieved using absorption chiller and electric chiller in heat from the boiler or recovery system. For better analyzing the system, two different scenarios were considered: in the first scenario, the capacity of the system is assumed constant in 500 kW while the ratio of the electric cooling to cool load is variant ratios of electric cool to the cooling load. In the second scenario, the efficiency areas of the CCHP system are assumed with different capacities when the electric cooling to cool load is 0.69. The simulation results showed that using optimal parameters for the system can increase the efficiency of the components for the principal design of CCHP systems.

Declaration of competing interest

The authors declare that there is no conflict of interest in this paper.

CRedit authorship contribution statement

Yan Cao: Conceptualization, Data curation, Writing - original draft, Writing - review & editing. **Qiangfeng Wang:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing. **Zhijie Wang:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing. **Kittisak Jermisittiparsert:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing. **Mohammadreza Shafiee:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing.

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