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Optimum Structure for a CCHP System by Amended Coyote Optimizer

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ABSTRACT

The present study proposes a new optimal configuration of a combined cooling, heating, and power (CCHP) system for annual dynamic simulation. To provide higher efficiency from the CCHP system, a new enhanced bio-inspired algorithm, namely Amended Coyote Optimizer is designed and utilized. The proposed optimal technique is then carried out to a commercial building in Tongchuan, China. The simulations of the suggested method are finally confirmed by the data achieved by the case study which is done to show the method efficacy. Simulation achievements showed that the suggested technique has better effectiveness to provide similar data with the real value.

Keywords: *CCHP; Amended Coyote Optimizer; power generation unit; life cycle cost reduction*

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1. INTRODUCTION

In the early 20th century, the electricity production was in its early days, and majority of industrial units produced all the electricity they needed, often supplying surplus power to neighboring units [1]. These industrial units were in fact the first simultaneous producers [2]. The main primary actuators at the time were reciprocating engines, and low-pressure exhaust steam has been applied for heating utilizations [3, 4]. From 1920s to 1970s, the electricity industry grew rapidly due to increased demand for electric power [5]. Simultaneously with this fast growing, there has been a common decrease in electricity generation and delivery costs, mainly due to economic issues due to size, effective techs, and reduced costs of fuel [6-8]. In this time, most industries forgot their power generation due to the following reasons:

- Power plants reduced their electricity generation rates
- Income tax laws benefited the costs of electricity buyers instead of supporting investment
- Wage costs increased
- Industries were interested in manufacturing rather than in ancillary issues such as power generation
- Advances in techs like power plant (PP) boilers
- Accessibility of gas and liquid fuels at the minimum cost
- No environment-related restrictions

Electrical power needed for industrial sites, residential and commercial buildings is often provided from main PPs in the country. While the demand of heat of all of them is generated at the same location [9-11]. The other technique that already exists and has taken further emphasis these days defined as the combined Cooling, Heating, and Power (CCHP) generation that is the cogeneration of axial power, or electrical power and effective heat by a system [12]. Long ago, this system has been utilized initially in steam cycle PPs, and the steam obtained from the cycle has been utilized to heat the factory and the nearby units [13, 14]. Even though

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this operation rather reduces the effectiveness of the PP, however by supplying the unit's needed heat, prevents the usage of vast quantities of fuel.

This concept has not been restricted to steam PPs, and in recent years, CCHP system that seeks high efficiency of energy, was extended to other power generators. Thereby, besides producing mechanical power or electricity, the wasted heat of the motor or generator can be used as applicable thermal energy.

As mentioned, CCHP technologies have often been designed to generate electricity, cooling, and heating simultaneously. Fuel's chemical energy is released by a main actuator and is converted to mechanical power at the outputted shaft. In these cases, the drive shaft has been combined with a generator and electricity has been produced.

On the other hand, the maximum efficiency available for the primary drive and generator is less than 50%, which means that more than half of the energy of the fuel has been wasted as heating energy. The CHP machine is the most fuel efficient [15]. So that the average efficiency of a power generator is about 32% and the average efficiency of a boiler is 80%. While a CHP system is more than 75% efficient with the production of both of these products [16]. That is, its electrical efficiency is about 30% and thermal efficiency (thermal efficiency is the thermal energy produced to the energy of fuel consumed) is 50%. On the other hand, it consumes about 35% less fuel compared to conventional and similar heat generation systems that are separate [17]. Reducing fuel consumption, reduces the cost of fuel consumed in a single economic basket [18]. Also, from a national point of view, this saving of fuel consumption can be considered as an advantage, either through exports or by providing conditions for more efficient use of fossil fuels. Furthermore, the use of less fossil fuels reduces environmental pollution. CCHP systems not only prevent the release of pollutants such as NOx, CO2, CO and UHC through filters, but also a 35% reduction in fuel in these devices plays a major role in reducing their production.

Several methodologies have been also used to enhance the effectiveness of these systems. For example,

Li et al. [19] optimized the performance of the CCHP system through heat recovery. The use of the integrated CCHP system can significantly contribute to energy security. In this research, they provided a CCHP system through compression heat recovery to supply energy. The advantage of the proposed technique is the use of condensed heat absorption chillers and heat pumps to generate electricity. They also optimized the system for energy savings and cost-effectiveness by the genetic optimization approach. The results showed, the optimal CCHP system respectively increased the initial energy savings by about 5% and the cost-effectiveness by about 6.36% and decreased CO2 production by about 2.74%, compared to this technology.

Deng et al. [20] presented an operating strategy to supply energy using an optimized integrated heat, cooling, and power system using a black hole optimization approach. The purpose of research is to optimize the system to increase the effectiveness of the system to provide power, environmental protection, and improve economic conditions. The results of optimization showed that system proficiency increases by about 4% per year. The optimal system also reduces environmental pollution and reduces the cost of energy production.

Leng et al. [21] designed an integrated optimized cooling, heating, and power to supply electricity. In this research, a hybrid virus colon technique with genetic algorithm optimization approach was used to enhance this system performance. The use of these two techniques improves the process of local and global searching in solving the problem. The achievements of optimal CCHP system showed that power generation by the integrated system will increase by about 94% in warm season and about 92% in cold season. The results indicated that the time of calculation was reduced by the suggested optimal technique.

Wang et al. [22] improved the performance capacity of the CCHP structure by the genetic optimization technique. In this study, the CCHP system current energy and the initial energy consumption were applied to obtain the building's demand of energy. The initial energy saving, yearly entire cost savings, and CO2 declining factors were analyzed to evaluate integrated system effectiveness. The genetic optimization approach was used to increase the integrated system effectiveness. The finding defined the optimization can improve integrated system performance. Also, the optimization reduced CO2 emitted by the system power generation. The results showed that the optimization strategy reduced energy production costs and made energy supply more cost-effective.

Li et al. [23] analyzed the optimization strategy in the integrated CCHP system. designed an optimized CCHP system for maximum power generation with minimal cost for a commercial building. Particle swarm optimization (PSO) metaheuristic technique has been applied to improve. The results of the designed system showed that besides improving the system efficiency to generate electricity, optimization also improved the economic and environmental performance of the system.

From the previous researches, various methods have been suggested to improve the effectiveness of the suggested structure. Herein, and due to the fact that metaheuristics showed better effectiveness achieve this, a new enhanced bio-inspired algorithm is applied.

2. MODEL DESCRIPTION

Due to complicated structure of the CCHP, proper modeling of this system is too hard, therefore, using classic methods for solving these kinds of problem is too hard. A better way for modeling CCHPs is to use soft computing and metaheuristics. In this study, to provide a simple way and optimal modeling, metaheuristic-based method with the following assumptions for the CCHP has been considered:

- With assumption that the legislation is local, there is no permission to sell back the additional generated power by the customers. This means that there is no economical/environmental gain for the excess power [24].
- The CCHP is assumed dependable [25].
- The maintenance cost is ignorable [25].
- The performance of the absorption chiller (AC) is assumed stable [15].
- Energy storage system is neglected to simplify the assessments [26].

Constant value gas been assumed for the parameters of the generation plus system

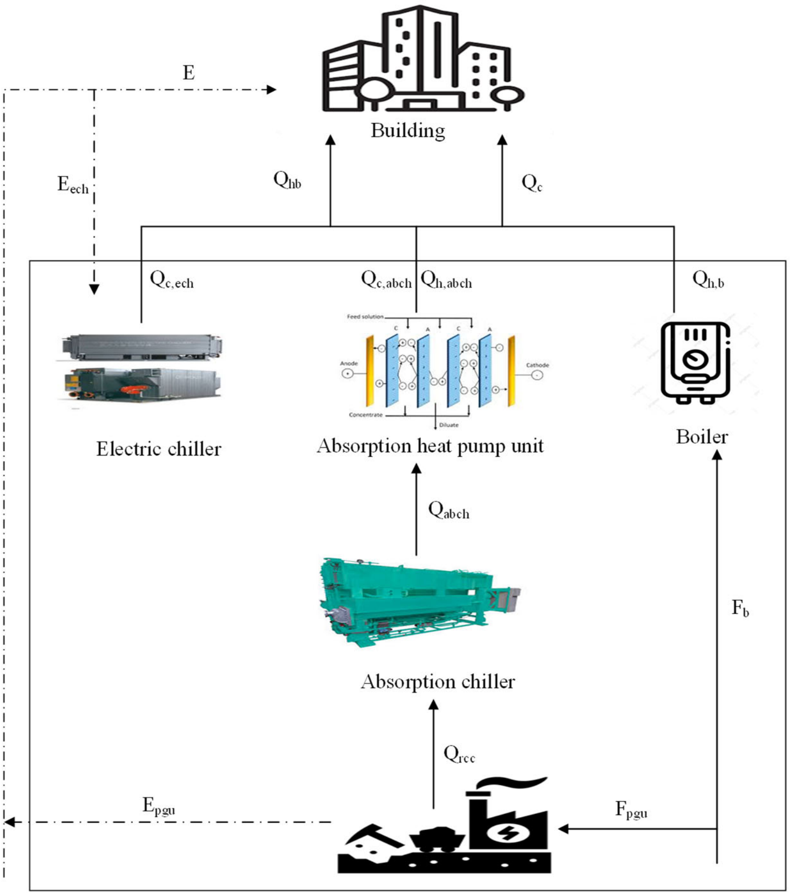


Fig. 1. Total structure of the studied CCHP

performance during the annual system life cycle so that the system can be optimized by a year approximated from the total life cycle as time passes. Fig. (1) depicts the total structure of the investigated CCHP.

By the parameters defined in Fig. (1), by considering the following equation [27]:

$$e \times t + E_{ac} = E_G + E_{PGU} \tag{1}$$

where, e specifies the load, t describes the time elapsed during the simulation, E_{ac} defines the employed electricity by the electric chiller, E_G describes the power generated by the network, and E_{PGU} describes the employed electricity by the engine electricity grid.

the over-all power consumption has been achieved by the following equation:

$$F = F_b + F_{PGU} \tag{2}$$

where,   specifies the fuel use of the boiler and F_{PGU} describes the power generation fuel consumption which can be obtained as follows:

$$F_{PGU} = C_{PGU} \times t + Q_{rec} \tag{3}$$

where, C_{PGU} signifies the produced power value based on the power generation unit, and Q_{rec} is the residual heat. The C_{PGU} can be achieved as below:

$$C_{PGU} = \eta_e \times F_{PGU} \tag{4}$$

where, η_e specifies the performance of the electricity achieved by the power production system.

In this study, the additional heat which is employed to be used in absorption chiller (Q_{rhac}) is as follows:

$$Q_{rhac} = \eta_{rhu} \times Q_{rec} \tag{5}$$

where, η_{rhu} defines the performance of the additional heat.

Furthermore, the system cost of operation can be obtained as defined below:

$$R = F \times P_{ng} + E_G \times P_e \tag{6}$$

where, P_e and P_{ng} represent the cost of the electrical power and the cost of the natural gas.

$$Q_{c,ac} + Q_{c,rhac} = L_c \times t \tag{7}$$

where, L_c defines the cooling load, $Q_{c,rhac}$ specifies the cooling energy supplied by AC, and $Q_{c,ac}$ expresses the cooling energy supplied by electric chiller.

To achieve $Q_{c,rhac}$, the following equation can be assumed:

$$Q_{c,rhac} = COP_{rhac} \times E_{ec} \tag{8}$$

where, COP_{rhac} defines the efficiency coefficient of the absorption chiller.

and is achieved by the following

$$Q_{c,ac} = COP_{ec} \times E_{ec} \tag{9}$$

where, COP_{ec} and E_{ec} represent the coefficient of electric chiller efficiency and the consumed electricity by electric chiller, respectively.

By considering:

$$L_h \times t = Q_{h,b} + Q_{h,rhac} \tag{10}$$

where, L_h specifies the heating load, and $Q_{h,b}$ and $Q_{h,rhac}$ represent the boiler supplied heating, and supplied heat by the absorption chiller, respectively.

The mathematical formulation for $Q_{h,b}$ and $Q_{h,rhac}$ are given below, respectively:

$$Q_{h,b} = F_b \times \eta_b \tag{11}$$

$$Q_{h,rhac} = Q_{rhac} \times \eta_{rhac} \tag{12}$$

where, η_b and η_{rhac} describe the heat efficiency of the boiler and the absorption chiller, respectively.

3. METHODOLOGY

The operational methodology for the proposed CCHP system to supply the load profile is significant. The profiles of the load don't match the relationship between heating and generating of the CCHP system, so the operational methodology for the PGU and other auxiliaries dispatching to meet the demand provides a direct impact on the primary economic, environmental benefits, and energy ratio. There are two well-known operational methodologies for this purpose: Following Electric Load (FEL) and Following Thermal Load (FTL). Based on the [28], if the electric load is smaller than thermal load, using FEL methodology by the

CCHP system is a better way. In contrast, if the electric load is relatively larger than thermal load, using FTL methodology will be a good way for the system. This makes FTL so applicable to consider the efficacy of energy consumption [29]. Even though, the additional electric power production is not considered in the model [30]. By considering hourly simulation for the system, the device will be boots up during the business season. After extending the open-air temperature between $10°C$ and $15°C$, transit season has been considered. Afterward, based on the of the cooling and heating load size, the season (which can be summer or winter) has been defined.

In winter season, to supply the heating of the places, heating condition has been utilized, although, if there is need for the cooling, the cooling condition has been activated [31]. The heating not only is for heating the air conditioning, but also, it is used for supplying the hot water for the load [32]. Next, the methodology decides if the made cooling or heating by the absorber chiller satisfies the building heat/cool demand load [33]. In the event that the required cooling has not been satisfied, the electric chiller cools the residual cooling load.

In the event that the building load requirement has not satisfied, the system uses boiler heating. And finally, the produced electricity by the power production unit satisfies the electrical power of the building [34]. So, in the event that the load demand cannot 0be satisfied by the generated electricity, extra electricity will be supplied from the grid. All of the explanations are briefly shown in Fig. (2).

As can be shown in Fig. (2), the system is first shut down (mode 1). Based on the explained discussions and formulations before, the consumed energy in the system and the separation energy in the generation system are considered consistent, i.e.,

$$R_{Tfc} = \frac{L_h \times t \times P_{ng} + \eta_b \times (P_e \times e \times t)}{\eta_b} = R \tag{13}$$

$$F_{Tfc} = \frac{\eta_b \times e \times t + L_h \times t \times \eta_G \times \eta_e^{Tfc}}{\eta_b \times \eta_G \times \eta_e^{Tfc}} = F \tag{14}$$

where, η_G and η_e^{Tfc} represent the performance of the grid, and separation electricity generation system in the power generation unit, respectively, and R_{Tfc} and F_{Tfc} represent the hourly operating

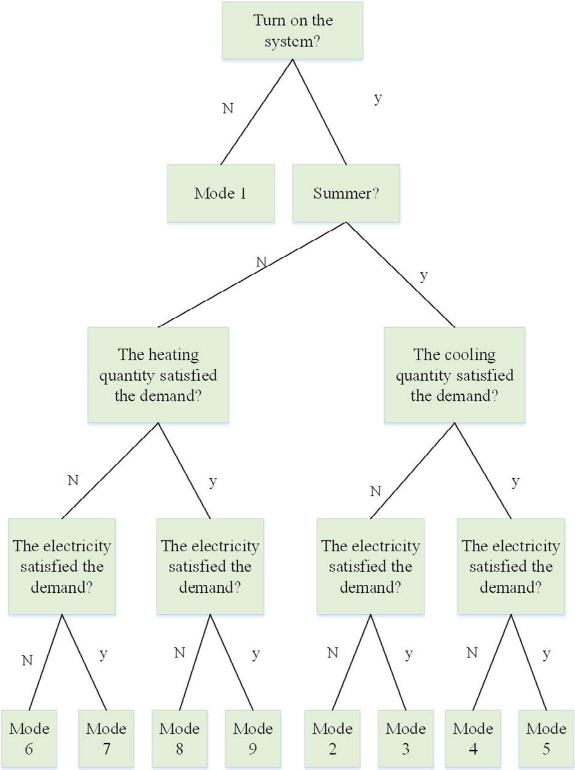


Fig. 2. Diagram flowchart of the proposed methodology

cost of the separation system and total fuel consumption for the separation generation unit.

By assuming mode 2, neither cooling, nor electricity are satisfied for the load demand in summer, so a certain heating load has been still present. In this condition, a complement of the grid and the electric chiller provide enough load demand for the system, and boiler is used for covering the required heating, in other words,

$$R=\left(\frac{\left(\eta_b\times F_{pgu}+L_h\right)\times P_{ng}}{\eta_b}+\frac{(l_c-k\times L_c^{max})\times t\times P_e}{COP_{ec}}+e\right) \tag{15}$$

$$F=F_{PGU}+\left(\frac{e-\eta_e\times F_{PGU}}{\eta_e^{Tfc}\times\eta_G}+\frac{L_h}{\eta_b}+\frac{\frac{l_c-k\times L_c^{max}}{COP_{ec}}}{\eta_e^{Tfc}\times\eta_G}\right) \tag{16}$$

$$F_{Tfc}=\left(\frac{e}{\eta_e^{Tfc}\times\eta_G}+\frac{L_h}{\eta_b}+\frac{\frac{l_c}{COP_{ec}}}{\eta_e^{Tfc}\times\eta_G}\right)\times t \tag{17}$$

$$R_{Tfc}=\left(\frac{L_c}{COP_{ec}}+e\right)\times t\times P_e+\frac{L_h}{\eta_b}\times t\times P_{ng} \tag{18}$$

where, L_c^{max} and k represent the building's highest cooling load and the cooling of the absorption system to the highest ratio of cooling load, respectively.

4.VFITNESS FUNCTION

The main purpose here is to provide an optimum structure of CCHP system by assuming the thermodynamic index, environment-related index, and economic index, i.e., our purpose is to provide a multiple-criteria optimization problem for optimal CCHP configuration. The Life cycle Cost Reduction (LCCR) is the first Cost function which is used for this purpose. The LCCR contains the life cycle of the primary investment and the operating cost and the system primary investment. The Life cycle Cost Reduction is mathematically defined as below:

$$LCCR=1-\frac{LCC}{LCC^{Tfc}} \tag{19}$$

where,

$$LCC=T_b+T_{rhac}+T_{PGU}+T_{ec}+\frac{\left(r_i+1\right)^n-1}{r_i\times\left(r_i+1\right)^n}\times R_c \tag{20}$$

where, n defines the service life of the devices, interest rate is specified by r_i, the factor for capital recovery is defined by R_c, the initial investments of the system components are T_b, T_{rhac}, T_{PGU}, and T_{ec}, are the system components initial investments.

The primary investment of the power generation unit in this condition is as follows:

$$T_{PGU}=C_{PGU}\times A_e\left(1+U_e\right) \tag{21}$$

where, A_e defies the PGU unit price, and U_e describes the additional rate of expense proportional to the civil structure cost, auxiliaries, and labor.

Another term for Primary Energy Saving (PES) is the rate of the CCHP system that can be obtained as defined below:

$$PES=1-\frac{F}{F^{Tfc}} \tag{22}$$

The environmental index in the CCHP system aims to direct it to a poor-carbon economy which makes the CO_2 Emission Reduction (CDER) index important. The CDER index is mathematically modeled below:

$$CDER=1-\frac{CDE}{CDE^{Tfc}} \tag{23}$$

where,

$$CDE=\mu_{CO_2^f}F+\mu_{CO_2^e}E_G \tag{24}$$

where, CDE and CDE^{Tfc} describe Co_2 emission of the CCHP and the classic separation generation system, respectively. $\mu/_{CO_2^f}$ and $\mu_{CO_2^e}$ represent the CO emission factors for the fuel and the electricity, respectively.

Finally, the main cost function can be achieved by a multiplied summation of the explained cost functions, i.e.,

$$Cost=\alpha_1\times\frac{LCCR}{LCCR^{max}}+\alpha_2\times\frac{CDER}{CDER^{max}}+\alpha_3\times\frac{PES}{PES^{max}} \tag{25}$$

where, α_1, α_2 and α_3 describe the weight of $CDER$, PES, and $LCCR$ performance indexes.

As mentioned in the literature, different kinds of optimization methods are introduced for CCHP configuration. However, the metaheuristic-based methodologies provide more efficient results. Therefore, in this study, an amended version of Coyote Optimization Algorithm has been proposed for providing more better results during the configuration optimization.

5. AMENDED COYOTE OPTIMIZER

5.1. Conception

Coyote optimizer is one of the meta-heuristic algorithms that is based on population. This is inspired by the can is latrans kinds. In the suggested optimizer, the compatibility of coyotes to their surroundings and their social behavior is defined. The gray wolf optimizer (GWO) and the coyote optimizer (COA) are completely different, so that in the gray wolf algorithm, the process of attacking the prey is fully described, but in the coyote algorithm, social behavior and the experience of coyotes are expressed.

In the suggested algorithm, N_p groups of the population are created and all group contains N_c coyotes. The fitness function cost was expressed by the social behavior of the coyote and the candidate's solution to the coyote. Coyote social behavior is presented at a given time (and in group p with the following equation:

$$soc_c^{p,t} = y = \left(y_1, y_2, \ldots, y_D\right) \tag{26}$$

The compatibility of coyotes to their surroundings is regarded the cost of fitness function. By creating random coyotes in the solution space, the procedure of optimizing the coyote algorithm begins.

$$soc_{c,j}^{p,t} = LB_j + r_j\left(HB_j - LB_j\right) \tag{27}$$

the lower and higher borders of the design variable j are indicated by HB_j and LB_j. r_j is a amount randomly between 0 and 1. The equation presented below express the fitness function of all coyote:

$$fit_c^{p,t} = f\left(soc_c^{p,t}\right) \tag{28}$$

At the beginning of the algorithm, the coyotes were entangled in flocks while occasionally moving from their flock to other groups. This is associated with a probability P_L, that can be prepared as follow:

$$P_L = 0.005.N_c^2 \tag{29}$$

The exchange of coyote culture between groups is done by the suggested mechanism. The coyote that best acclimates to its surroundings is regarded as the alpha coyote or leader coyote, and the formula given below relates to this coyote.

$$alpha^{p,t} = soc_c^{p,t} \ for \ minfit_c^{p,t} \tag{30}$$

Information is collected between groups by coyotes, and culture is transmitted within the group and between coyotes. The following formula expresses cultural orientation:

$$cul_j^{p,t} = \begin{cases} o_{\frac{N_c+1}{2},j}^{p,t}, N_c \ is \ odd \ Number \\ \dfrac{\left(o_{\frac{N_c}{2},j}^{p,t} + o_{\frac{N_c+1}{2},j}^{p,t}\right)}{2}, otherwise \end{cases} \tag{31}$$

the ranked social circumstances of the coyotes of the design variable j. at a time t is expressed by $o^{p,t}$.

The life period of coyotes is regarded in this algorithm. The coyote parents' social behavior includes the time of their birth, randomly chosen in the solution space plus an environmental element. The following formula describes this life occurrence:

$$Pup_j^{p,t} = \begin{cases} soc_{r_1,j}^{p,t}, rand_j < p_s \ or \ j = j_1 \\ soc_{r_2,j}^{p,t}, rand_j \geq p_s + p_a \ or \ j = j_2 \\ R_j, otherwise \end{cases} \tag{32}$$

Random coyotes in the group p is expressed by r_1 and r_2, p_a and p_s are the association and scatter probabilities, j_1 and j_2 indicate two random design variables, $rand_j$ is between [0,1]. The diversity of coyote cultures is expressed by these probabilities, and the formulas given below relate to the values of these probabilities.

$$p_s = \frac{1}{D} \tag{33}$$

$$p_a = \frac{\left(1 - p_s\right)}{2} \tag{34}$$

The dimension of design parameters is indicated by D. Given that the probability of death of newborn coyotes is ten percent, the proposed algorithm for synchronization of death and birth is presented with Optimizer 1.

```
Algorithm 1
Define $\omega$ and $i$
If i=1
Pup lives and coyote in $\omega$ dies
Else if $i > 1$
Pup lives and oldest coyote in $\omega$ dies
Else
Pup dies
End if
```

The new social behavior is replaced the prior one if its better.

Where the coyotes that have worst solutions is indicated by ϖ and the number of coyotes in the group is indicated by i.

In Coyote optimizer algorithm, α_1 and α_2 factors represent the interaction of culture in groups. where α_1 describes the culture distinction of a random coyote (cr_1) and flock's leader coyote and α_2 describes the culture distinction of a random coyote (cr_2) and the flock's culture propensity. The following equation represent this behavior:

$$\alpha_1 = alpha^{p,t} - soc_{cr1}^{p,t} \tag{35}$$

$$\alpha_2 = cul^{p,t} - soc_{cr2}^{p,t} \tag{36}$$

Then the updated behavior of the coyote under the influence of the group and by the coyote leader can be defined as below:

$$nsoc_c^{p,t} = soc_c^{p,t} + r_1\alpha_1 + r_2\alpha_2 \tag{37}$$

Where r_1 and r_2 indicate randomly amount between 0 and 1. The value of the new fitness of coyote is estimated according to following formula:

$$nfit_c^{p,t} = f\left(nsoc_c^{p,t}\right) \tag{38}$$

$$soc_c^{p,t+1} = \begin{cases} nsoc_c^{p,t}, nfit_c^{p,t} < fit_c^{p,t} \\ soc_c^{p,t}, otherwise \end{cases} \tag{39}$$

In the last stage of this procedure, the best solution is the behavior that is best suited to the environment. An exact pseudo-code of the suggested optimizer was noted as Optimizer 2:

```
Algorithm 2

Start the optimization procedure by initialization of $N_p$ and $N_c$
Verify the coyote compatibility by (28)
While iteration < max number of iterations for all groups
Define alpha by (30)
Define culture tendency by (31) for all coyote of the group
Update social behavior by (37)
Define the new fitness value by (38)
Do compatibility by (39)
End
Develop birth and death life cycle by (7) and algorithm 1
End
Shuffle among group by (29)
Update the coyotes ages
End
Select the best coyote
```

5.2. Amended Coyote Optimizer (CO)

The original *CO* has the capabilities of a simple operation, good optimization effect, and few parameter settings, but it easily stocks into the local optima and it has a premature phenomenon during the optimization [35]. Numerous researches are presented to recompense of this problem [36]. This study uses two improvement mechanisms to resolve this issue in Coyote Optimization Algorithm.

One improvement is to utilize pseudo-opposite learning that can help to enhance the efficiency of the exploration term [37]. By proposing this methodology, each candidate has been compared with opposite values and the best ones based on the objective function to enhance the algorithm's exploration term, which is accomplished by performing an individual $y_{i|i=1:D}$ as a actual value in the search space being defined between and σ. The opposite value of a candidate y is achieved as follows:

$$\widetilde{y_i} = \gamma_i + \sigma_i - y_i \tag{40}$$

$$i = 1, 2, \ldots, D \tag{41}$$

where, the opposite mechanism of the candidate y is showed by $\widetilde{y_i}$.

Based on the description of the opposite mechanism, the quasi-opposite is achieved by the following formula:

$$\hat{y}_i = rand\left(\frac{\gamma_i + \sigma_i}{2}, \widetilde{y_i}\right) \tag{42}$$

where, $\hat{y}_i$ describe the quasi-opposite value of the candidate y.

The other modification to enhance the efficiency of the optimizer is based on chaos theory. This can be used to enhance the convergence problem in the optimizer. By generating pseudo-random values that are related to each other, rather than using random amounts, this mechanism enhances the convergence speed in the algorithm. Here, we used logistics map for chaotic improvement:

$$\beta_{\mathrm{o,n}}^{\mathrm{q+1}} = 4 \times \beta_{\mathrm{o,n}}^{\mathrm{q}}\left(1 - \beta_{\mathrm{o,n}}^{\mathrm{q}}\right) \tag{43}$$

where, n is the number of population, q represents the number of iterations, o defines the system generators value, β_{n} specifies the chaotic mechanism which is between 0 and 1. As stated by the above explanations, the new candidates for the next iteration are achieved as below:

$$r_n^{it+1} = \beta_{o,n} \times r_n \tag{44}$$

5.3. Algorithm confirmation

For confirming the effectiveness of the suggested Amended Coyote Optimizer, it can be verified by performing to some test functions. We utilized Sphere, Schwefel2.22, Rosenbrock's, and Quartic as standard benchmark functions and its achievements are then put in comparison with several different algorithms to show its better effectiveness toward them. Table 1 indicates the definition of the studied functions and their optimum values.

The comparative algorithms include Biogeography-Based Optimizer (BBO) [38], Supply-Demand-Based Optimization (SDO) [39], Billiard-based Optimization Algorithm (BOA) [40], and the original Coyote Optimization Algorithm [41]. Table 2 shows the complete information about the algorithms' set parameters.

The simulation has been established by considering similar values of maximum iteration and population number equal to 120 and 60, respectively. Furthermore, the optimizers were independently run 30 times to provide consistent and fair results. The computer configuration for this study is given in Table 3.

Table 4 reports the comparative analysis of the suggested Amended Coyote Optimization Algorithm toward the other studied algorithms. four indicators that are highest amount (Max),

Table 1. Definition of the studied functions and their optimum values

Function Name	Function	Dim	Range	F_{min}
Sphere	$F_1(x) = \sum_{i=1}^{n} x_i^2$	30	[-100,100]	0
Schwefel2.22	$F_2(x) = \sum_{i=1}^{n} \lvert X_i \rvert + \prod_{i=1}^{n} \lvert x_i \rvert$	30	[-10,10]	0
Rosenbrock's	$F_3(x) = \sum_{i=1}^{n-1} [100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2]$	30	[-30,30]	0
Quartic	$F_4(x) = \sum_{i=1}^{n} ix_i^4 + random[0,1)$	30	[-128,128]	0

Table 2. Complete information about the algorithms' set parameters

Algorithm	Parameter	Value
SDO [39]	MaxIteration	200
	MarketSize	40
	FunIndex	1
BOA [40]	No. of pockets	22
	w	0.7
	ES	0.3
BBO [38]	Habitat modification probability	1
	Immigration probability bounds per gene	[0,1]
	Step size for numerical integration of probabilities	1
	Max immigration (I) and Max emigration (E)	1
	Mutation probability	0.005

Table 3. Computer configuration in this study

Name	**Setting**
Hardware	Intel® Core™ 2 Duo
CPU	2.67 GHz
RAM	4 GB
Frequency	2.66 GHz
Operating system	Windows 7
Programming software	MATLAB R2016b

lowest amount (Min), mean amount (Med), and standard deviation value (STD) are utilized for this purpose. Since all of the employed functions are minimization problems, the best algorithm should have the ability to provide almost minimum value of all terms as much as possible.

Based on the achieved results, the suggested Amended Coyote Optimization Algorithm with almost minimum value in all terms provides the best results. The minimum value for min and med indicates its better precision for solving the problems. the lowest amount of the Max, or in other words, minimum space between Min and Max shows its better distribution in solving the problem, and finally, the lowest amount of the STD indicates its better capability to provide the highest reliable results for the problems.

6. RESULTS AND DISCUSSIONS

The technique was then carried out to a practical CCHP studied case for validating its efficiency. The case study is a commercial building in Tongchuan, China which contains restaurant, shopping, and entertainment parts. The operation body of the building is from the first floor to the eighth floor. Natural gas is considered as initial mover of the proposed CCHP system in the building that can be used for supplying the heating, cooling, and electricity of the building. Information is extracted by the *approach of setting hourly load factor* [42].

To provide the installation capacity, coefficient of power consumption, and the coefficient of concurrent application of the systems, site inspection has been utilized. Fig. (3) indicates an example for a special day for the case study.

Table 4. Comparative analysis of the suggested Amended Coyote Optimization Algorithm toward the other studied algorithms

Metaheuristics	SDO [39]		BOA [40]		BBO [38]	
Function	Average	SD	Average	STD	Average	STD
F1	9.251-4	13.344e-4	10.462e-5	15.533-5	5.262e-6	8.633e-6
F2	12.681e-4	16.613e-4	11.561e-5	25.371e-5	9.176e-6	10.521e-6
F3	11.628	8.182	7.164	5.183	6.289	5.421
F4	1.631e-5	2.521e-5	1.0048	0.0033	0.0022	0.0020

Metaheuristics	COA [41]		ACOA	
Function	Average	STD	Average	STD
F1	9.614e-7	15.287e-7	4.614e-8	19.829e-8
F2	7.754 e-6	10.627e-6	15.222e-7	17.246-7
F3	4.263	3.051	2.961	2.0015
F4	0.0017	0.0012	0.0006	0.0004

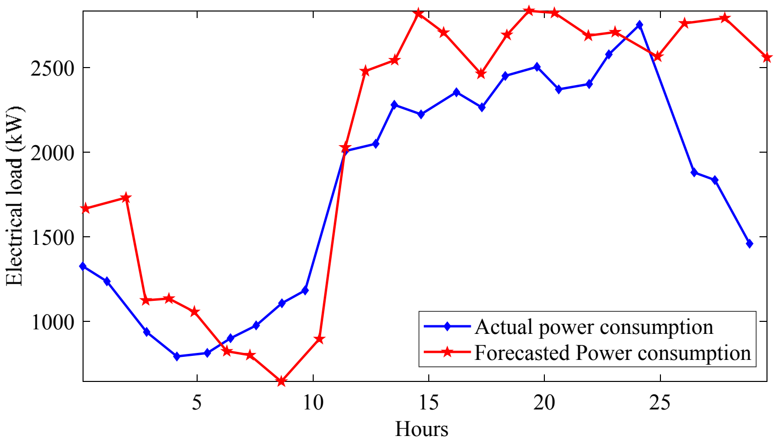


Fig. 3. Example for a special day for the case study

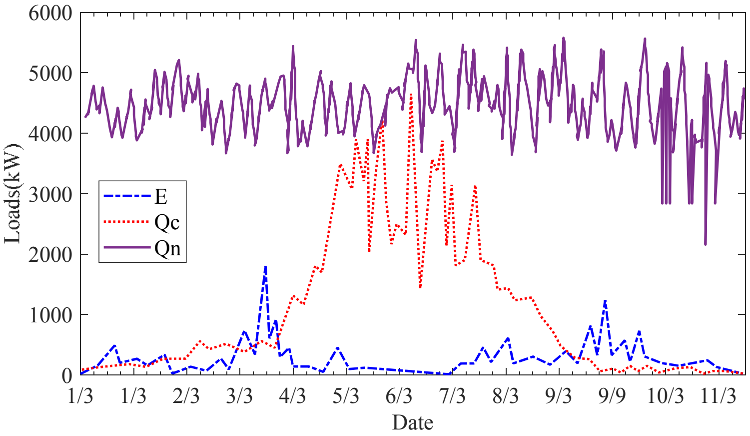


Fig. 4. Heating, electrical, and cooling loads of the building

Table 5. parameters information about the studied CCHP system [22]

Symbol	Parameter	Value	Unit
A_{abch}	Absorption chiller's unite cost	1200	Yuan/kWh
A_b	Boiler's unite	150	Yuan/kWh
A_{ech}	Electric chiller's unite cost	835	Yuan/kWh
$A_{e,Engine}$	Engine's unite	3900	Yuan/kWh
$A_{e,Turbine}$	Turbine's unite	4800	Yuan/kWh
COP_{obch}	Absorption chiller's performance coefficient	1.50	-
COP_{ech}	Electric chiller's performance coefficient	3	-
η_{abch}	Absorption chiller's heat effectiveness	0.80	-
η_b	Boiler's heat effectiveness	0.80	-
η_e^{sp}	Separation production system's electrical efficiency	0.40	-
η_{grid}	Effectiveness of power network	0.65	-
η_{rec}	Residual heat's application effectiveness	0.80	-
P_{ng}	Cost of the natural gas	0.29	Yuan/kWh
P_e	Cost of the electricity	0.90	Yuan/kWh
$\mu_{co_{2},e}$	Electrical power's CO2 emission conversion factor	972	g/kWh
n	Life-cycle	19	year
$\mu_{co_{2},f}$	Natural gas's CO2 emission conversion factor	210	g/kWh
i	Rate of benchmark interest	0.08	-
t	Time steps	1	h
U_{abch}	Absorption chiller's additional price factor	0.25	-
U_b	Boiler's additional price factor	0.20	-
U_{ech}	Electric chiller's additional price factor	0.10	-
U_e	PGU's additional price factor	0.20	-

According to Fig. (3), the suggested method provides a good validation with the actual hourly power consumption that indicates its good precision to model the power load. Also, the building's electrical, cooling, and heating loads were depicted in Fig. (4).

Table 5 tabulates the parameters information about the studied CCHP system. The data has been extracted by [22]

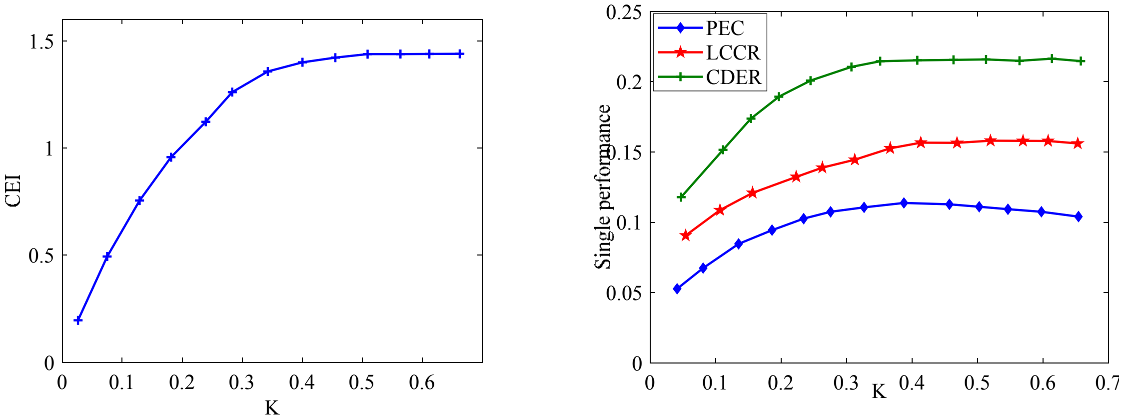
The project has been done by assuming 3800 kW engine installed capacity and 3850 kW absorption chiller. The achievements of the power use in a month in real and simulation is shown in Fig. (5).

According to Fig. (5), in winter, the amount of the actual electric power is lower than the modeled electricity. Although, this value is more than the modeled electricity in in summer. This is because of that the warming system of the personnel and their lighting get less value when the model load is addressed because of less electricity consumption in summer and high-electricity usage in winter. Also, because of the expensive value of the electricity, the following thermal load (FTL) methodology has not been addressed by the owner for yearly operation of the equipment.

Here, the values of all weights are considered equal, i.e., $\alpha_1 = \alpha_2 = \alpha_3$. As mentioned before, the main mover is gas internal combustion engine. The system optimization results are reported in Table 5.

As stated in Table 5, different values of indices deliver different results. The installed PGU capacity is achieved 1167 kW. Fig. (5-A) and Fig. (5-B) define the index changes in the system and the CEI with absorption cooling to the topmost cooling load ratio, respectively.

According to Fig. (5-B), the amount of the Continuous Energy Improvement (CEI) changes satisfies its topmost value with a gentle downward trend. As can be seen the value of CEI increases by growing the capacity of the installed absorption chiller from 0.1 to 0.6. It is observed from Fig. (5-B) that once the maximum value is happened in the PES and CDER, they become saturated. This is due to growing the installed capacity of the absorption chiller which causes unsatisfying results for the demand by the PGU based on the wasted heat. From Fig. (5-B), it is also observed that by receiving the maximum value with the LCCR, it starts to decreasing which is due to growing the installed capacity of the absorption chillers because of growing the primary investment of the system, although, the output is not grown. Fig. (7-A) and



(A) (B)

Fig. 5. (A) the CEI changing with the absorption load ratio by considering 1167 kW of PGU, and (B) LCCR, PES, and CDER changing with the absorption load ratio

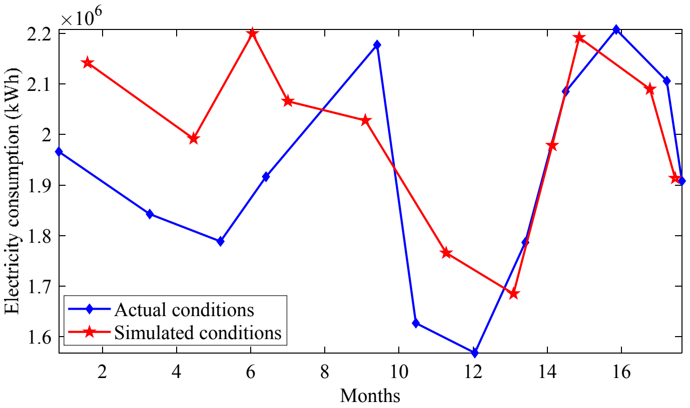
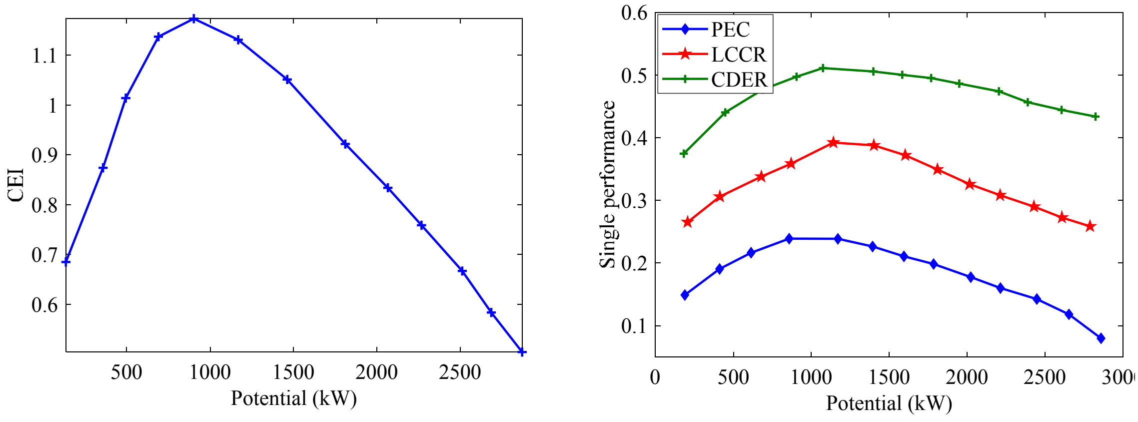


Fig. 5. The achievements of the power use in a month in real and simulation



(A) (B)

Fig. 7. Rate of absorption cooling to the uppermost cooling load for (A) CEI variation, and (B) LCCR, PES, and CDER variations with the PGU capacity.

Table 6. System optimization results

Index	$C_{pgu\,(kW)}$	k	Best operation
LCCR	1065	0.28	0.0591
CEI	1167	0.31	0.6246
CDER	1450	0.46	0.1025
PES	2355	0.52	0.1876

Fig. (7-B) show the single performance of CEI and PES, LCCR, and CDER once the absorption cooling ratio to the highest cooling load is maximum, respectively.

As can be seen, the value of the PES and CDER, are getting to be saturated after reaching their uppermost value. This is done because of growing the capacity of the PGU which increases the operation time of the PGU under part load conditions. This reduces electrical efficiency of the system. The results in Fig. (7-A) show that CEI changes satisfies its topmost value with a gentle downward trend after that. It is clear that the value of CEI increases by growing the capacity of the installed absorption chiller from 0.1 to 0.6. Similarly, increasing the capacity of the installed PGU, an obvious decreasing trend is made due to the life cycle cost reduction. This is done after reaching the maximum value that is because of reducing the electrical efficiency using the primary investment and PGU growing.

Fig. (7-A) displays that changing in the comprehensive evaluation index satisfies its uppermost value with a fast speed and delivers a decreasing trend. It can be seen that the reduction trend of comprehensive evaluation index in this figure is clearer than the Fig. (5-A) which is because of the incessantly reduction of the PES and CDER to satisfy their topmost value. Smaller value for the unit price in the absorption chiller against the PGU, makes its decreasing in life cycle cost clearer in Fig. (7-B) toward in Fig. (5-B).

7. CONCLUSIONS

The system of combined cooling, heating, and power (CCHP) is a set that has the ability to simultaneously generate cooling, heating, and electricity. The major characteristic of the CCHP set is the application of wasted energy, which includes forms of hot water, exhaust, and steam in power plants (PP) and different industrial units. The heat wasted from power generators, which are gas turbines and diesel generators, is as, hot water and exhaust forms is also produced in diesel generators by a converter. Moreover, in some industrial units and PPs, a major waste steam exists that this waste energy should be utilized as heat resources in absorption chillers. Although, the defining of the power generation unit (PGU) and chiller capacity is one of the main problems for optimal CCHP systems designing. Herein, a new optimum configuration of the system of CCHP was proposed for energizing a commercial building in Tongchuan, China. Different operating conditions were assumed for the output of the part load in the power generation unit (PGU). To provide optimal configuration of the CCHP with the best installed capacity, a new enhanced bio-inspired algorithm, namely Amended Coyote Optimizer was designed ad utilized. The achievements of the suggested technique have been then confirmed by the data of the actual CCHP system to show the method accuracy. The achievements indicated better effectiveness of the suggested method toward the real value. An interesting part of the suggested technique is that the weights of the objective function ca be changed based on the considered purpose using the decision makers.

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