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# Optimal chiller loading for energy conservation using a new differential cuckoo search approach

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The electrical energy consumption in a multi-chiller system increases if the chillers are managed improperly, therefore significant energy savings can be achieved by optimizing the chiller operations of heating, ventilation and cooling systems. Recently, optimization methods for optimal chiller loading have been proposed. In general, the aim of the optimization problem is to minimize chillers energy consumption keeping the cooling demand satisfied. As an efficient optimization method, the CSA (cuckoo search algorithm) has been proposed for solving continuous parameters optimization problems. CSA is based on the obligate brood-parasitic behavior of some cuckoo species in combination with the Lévy flight behavior of some birds and fruit flies. Preliminary studies show that it is promising and could outperform existing algorithms. This paper proposes a new CSA approach using differential operator (DCSA) to solve the optimal chiller loading design problem. The results of optimal chiller loading are analyzed on three case studies taken from literature to confirm the validity of the proposed algorithm. Simulations using case studies are presented and compared with the best known solutions. The comparison results with the classical CSA and other optimization methods demonstrate that the proposed DCSA (differential CSA) proves to be an effective and efficient at locating promising solutions in terms of minimum energy consumption.



## 1. Introduction

In the HVAC (heating, ventilating, and air-conditioning) system, a multi-chiller system is the central part. This is widely being used in the air-conditioning system of various buildings. It is one of the primary energy consumption units in the HVAC system. Multi-chiller system consists of chillers of varying performance features and capacities. Its advantages include operational flexibility and minimum energy consumption during various load demands [1].

In this respect, the use of computer-based optimization approach in multi-chiller system design is receiving increasing interest. A benefit of this approach is that it often leads to substantial savings in energy consumption. Many studies focus on developing optimization paradigms with validation by optimal chiller loading benchmarks [2–19].

Recently, CSA (cuckoo search algorithm) has shown a promise in solving optimization problems. CSA is a nature-inspired metaheuristic algorithm, developed by Yang and Deb in 2009 [20], based on the brood parasitism of some cuckoo species, along with their Lévy flight behavior. Due to the characteristics such as easy implementation, CSA has drawn more and more attention and different variants have been developed to enhance the optimization ability [21–27].

This paper proposes an improved CSA using a differential operator scheme (DCSA) to overcome the drawbacks of the classical CSA in terms of the local exploration and the premature convergence. DCSA (differential CSA) is applied to solve the chiller loading

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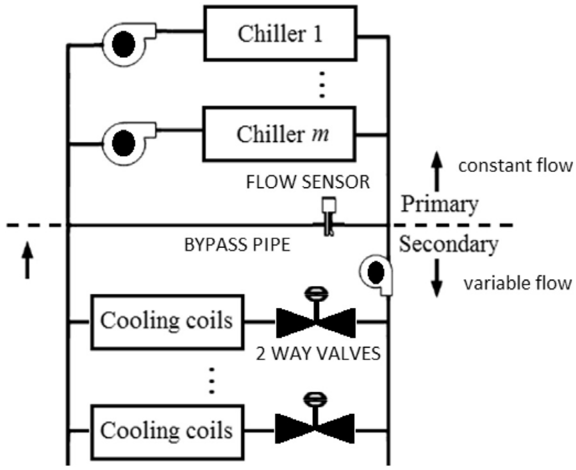


**Fig. 1.** A decoupled system of a multiple-chiller system.

problem by minimizing total energy consumption in multi-chiller loading subject to satisfying some constraints.

In order to validate the effectiveness of DCSA, we choose three chiller loading case studies. Furthermore, the results using DCSA are compared with the traditional CSA approach and recent results reported in the literature.

The remainder of this paper is organized as follows. Section 2 provides the fundamentals of the multiple-chiller system. The description of CSA and DCSA approaches is introduced in Section 3. In Section 4, a description of the three case studies is presented. Optimization results are reported and discussed in Section 5 followed by conclusions and direction for the future work in Section 6.

## 2. Problem formulation

A multiple-chiller system consists of two or more chillers connected in parallel or series piping to a distribution system [1]. Fig. 1 shows the structure of a typical decoupled chilled water system [4,12].

In a multiple-chiller system with all-electric cooling, the best performance is obtained when the sum of energy consumption of each chiller is minimized while satisfying load demand. The PLR (partial load ratio) is defined as the ratio of the chiller cooling load to the chiller power consumption. In this paper, the power consumption of a centrifugal chiller is expressed as [2]:

$$P_i = a_i + b_i \cdot \mathrm{PLR}_i + c_i \cdot (\mathrm{PLR}_i)^2 \quad \text{(first case study)} \tag{1}$$

or

$$P_i = a_i + b_i \cdot \mathrm{PLR}_i + c_i \cdot (\mathrm{PLR}_i)^2 + d_i \cdot (\mathrm{PLR}_i)^3, \quad \text{(second and third case studies)} \tag{2}$$

where $a_i$, $b_i$, $c_i$ and $d_i$ denote the coefficients of interpolation for consumed power $P$ versus PLR of $i$th chiller. In this paper, the adopted lower and upper limits of PLR were 0 and 1, respectively.

The optimal chiller loading problem is to find a set of chiller PLR which does not violate the operating limits while minimizing the objective function (OF) given as follows [2]:

$$\mathrm{OF} = \sum_{i=1}^{m} P_i \tag{3}$$

The objective function is the sum of the power consumed power by each chiller, where $m$ is the total number of chillers and $P_i$ refers to power consumed by $i$th chiller. The optimal chiller loading has to be attained by minimizing Eq. (3), subject to the balance equation must be satisfied simultaneously. This constraint can be expressed as follows:

$$\sum_{i=1}^{m} \mathrm{PLR}_i \cdot RT_i = \mathrm{CL} \tag{4}$$

where $RT_i$ is the capacity of $i$th chiller and $CL$ is the demanded cooling load. The constraint given by Eq. (4) is a condition that must be satisfied for the design to be feasible.

In the next section, the CSA and DCSA are described to optimize the PLR parameters of the chillers.

## 3. Fundamentals of cuckoo search algorithm

In the next subsections first, a brief overview of the classical CSA is presented; and finally, the proposed DCSA is explained.

### 3.1. CSA (Cuckoo search algorithm)

The CSA is a computational and behavioral metaphor for problem solving that originally took its inspiration from some cuckoos species. CSA uses the following three idealized rules: i) each cuckoo lays one egg (i.e., a design solution) at a time, and dumps it in a randomly chosen nest; ii) the best nests with high quality eggs (i.e., better solutions) will carry over to the next generations; and iii) the

```
Begin
  Step 1:  Generate initial population of  n host nests ; x_i  for all i=1...n
  Step 2:  Initialize the generation's counter, t = 1

  While t < Maximum of generations (MaxGen)
    Step 3:  Get a cuckoo i randomly by Lévy flights and evaluate its quality by OF values
    Step 4:  Choose a nest among the host nests (say, j) randomly
    Step 5:  If the objective function OF_i < OF_j (minimization problem) then replace j by the new
             solution
    Step 6:  A fraction (p_a) of worse nests is abandoned and new ones are built
    Step 7:  Keep the best solutions (or nests with quality solutions) and rank the solutions
    Step 8:  Find the current best
    Step 9:  Update the generation's counter,  t = t + 1
  End while
End
Postprocess results
```

**Fig. 2.** Pseudo code of the CSA.