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A method of selecting cold and heat sources for enterprises in an industrial park with combined cooling, heating, and power

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ABSTRACT

With its continuing socio-economic development, China faces the challenge of meeting the growing energy demand. Industrial parks with combined cooling, heating, and power (CCHP) achieve better comprehensive economic and environmental benefits due to energy cascade utilization. A new enterprise entering an industrial park with CCHP needs to select a reasonable cold and heat source scheme (CHSS). Therefore, this paper presents a method for new enterprises to select an appropriate CHSS. This method is based on comprehensive economic and environmental benefit, using minimal annual average cost in operation optimization mode as a quantitative indicator, and the calculation process uses the improved differential evolution algorithm using the MATLAB software. Finally, a cloud computing center of an industrial park with CCHP in Chongqing is used as a case study to assess the method. Results show that the scheme of lithium bromide absorption refrigerator driven with steam can be accepted by the cloud computing center only steam price below 112.6yuan/t, which can promote energy cascade utilization in the industrial park. This method assists new enterprises entering the industrial park in selecting their energy system scheme. In addition, the method can assist energy supply enterprises to determine energy trade prices and also expand their user base.

1. Introduction

An industrial park with combined cooling, heating, and power (CCHP) has a CCHP trigeneration energy system that directly satisfies the cold, heat, and electricity demands of enterprise users in the park. CCHP technology has been developed for decades, there was a wide range of literature covering the area of CCHP and pointed out its energy-saving and environmental benefit. Wu et al. (2006) summarized in characteristics of different CCHP technologies, the status of utilization and developments. Mago and Chamra (2009) reviewed all literature about performance improvement, performance evaluation, optimization, current research, and development of CCHP systems. Gu et al. (2014) reviewed the modeling, and energy planning and management of a CCHP microgrid from technical, economic, and environmental viewpoints. Lake et al. (2017) summary the district heating and cooling systems on topics including their history, system identification, energy sources, design considerations, environmental impact, economic feasibility, performance analysis and the role of energy policy. Xu et al. (2010) studied the energy efficiency of CCHP technology in China. Cho et al. (2014) studied the operation of CCHP systems under the electric and thermal load strategies, and calculated primary energy consumption, operation cost, and carbon dioxide emissions. Mago et al. (2007), Chicco and Mancarella. (2008a, 2008b, 2009), Wahlund et al. (2004), and Möllersten et al. (2003a, 2003b) demonstrated that CCHP systems could reduce carbon dioxide emissions. Wang et al. (2010) applied three criteria to evaluate the performance of the CCHP system, and used a genetic algorithm to optimize operation from technological, economic, and environmental benefit viewpoints. Methods of evaluating the integrated performance of CCHP systems were based on the weighting method and fuzzy optimum selection theory, which focused on hotels, offices, and residential buildings (Li et al., 2016). All of these researches are focused on energy efficiency, operation mode, carbon emissions and evaluation of CCHP system, but not reported application effect of CCHP in industrial parks.

Nowadays, industrial parks with CCHP are rapidly developing in China. Only few literature reported on design and application of

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Nomenclature

$C_{total,y}$	total annual average cost (yuan)
$C_{capital}$	capital cost (yuan)
$C_{O\&M}$	operation and maintenance cost (yuan)
C_{fuel}	primary energy cost (yuan)
C_{trade}	energy trade cost (yuan)
C_{co_2}	carbon dioxide emissions cost (yuan)
$C_{facility}$	equipment investment cost (yuan)
C_{pipe}	pipe investment cost (yuan)
N_{eq}	equipment number, $N_{eq} = 0, 1, 2 \cdots N(-)$
Inv_{eq}	investment cost per unit capacity (yuan)
Cap_{eq}	capacity of the equipment (kW)
L_i	length of the pipeline (m)
$P_{i,pipe}$	investment cost per unit length (yuan)
$e_{p,t}^{teq}$	. total energy production (kW)
$e_{c,t}^{f,in}$	. total energy consumption (kW)
$e_{gp,t}$	. total electricity consumption (kW)
$P_{f,t}$	time-of-day energy price (yuan/per unit)
$P_{gp,t}$	time-of-day electricity price (yuan/kW)
$e_{tr,t}$	total amount of energy for trading (kW or t)
$P_{tr,t}$	time-of-day energy trade price (yuan/per unit)
$AF_{total.t}$	. total carbon emissions (t)
Tax	carbon tax price (yuan/t)
e_h^{out}	. Energy production of heat (–)
e_c^{out}	. Energy tion of cold (–)
e_p^{out}	energy production of electricity (–)
$D_{h,t}$	energy mand loads of heating (–)
$D_{c,t}$	energy dand loads of cooling (–)
$D_{p,t}$	energy mand loads of electricity (–)
β	load rate of the equipment (–)
β_{min}	minimum load rates of the equipment (–)
β_{max}	maximum load rates of the equipment (–)
N	number of inequality constraints (–)
∂_{eq}	discrete variables (–)
E_{pgu}	primary energy consumption (kW)
E	energy consumption under different load rates (kW)
Q	refrigeration capacity (kW)

Superscripts

T_{eq}	Life cycle of the equipment
l	Energy form, including electricity, cold and heat of various grades
f	fossil fuel

Subscripts

y	yearly
eq	equipment
tr	trade
t	running time
I	equipment's annual depreciation rate
h	heating
c	cooling
p	power
in	energy inputs
out	energy outputs
pgu	power generate units

Abbreviations

CCHP	combined cooling, heating, and power
CHSS	cold and heat source scheme
AAC	annual average cost
CEEB	comprehensive economic and environmental benefit
COP	coefficient of performance
KWh	kilowatt-hours

CCHP in industrial parks. The research from Lin et al. (2008) showed that energy cascade utilization in CCHP could make a significant contribution to energy saving in the eco-industrial park. Wang et al. (2016) presented a multi-objective energy planning methodology for regional distributed natural gas (NG) CCHP systems in an industrial park in China, and the multi-criteria decision making (MCDM) method is employed to evaluate their integrated performance. Waste heat utilization saves more primary energy, according to Oluleye et al. (2015). It is very important to prompt utilizing waste heat in industrial parks with CCHP, but not a literature reported how to select cold and heat sources scheme for new enterprises entering the industrial park yet.

Therefore, this paper considers CEEB and presents a method of selecting CHSS for new enterprises to stimulate waste heat utilization from CCHP. The enterprise can use the method to select a CHSS based on CEEB, using AAC as a quantitative indicator. And the method considers energy trade between enterprises in an industrial park. Finally, a case study is applied to evaluate the selection method.

2. Methodology

The method is as follows: a mathematical model, which is an objective function of minimal annual average cost (AAC), is used to select a CHSS for enterprises in an industrial park with CCHP. The AAC is based on the saving-energy mode using an optimal algorithm with MATLAB software.

2.1. Mathematical model of the selection method

The AAC of CHSS contains five aspects: initial investment cost, operation and maintenance costs, energy consumption cost, energy trade cost, and carbon tax. The objective function is as follows:

$$\text{Min } C_{total,y} = C_{capital} + C_{O\&M} + C_{fuel} + C_{trade} + C_{co_2} \quad (1)$$

where $C_{capital}$ is the equipment unit and corresponding pipe cost; $C_{O\&M}$ is the total maintenance cost for energy production and storage; C_{fuel} is the gross cost of electricity and primary energy consumption during energy production; C_{trade} is the trade cost when energy is being traded between enterprises in an industrial park; and C_{co_2} is the cost of the total amount of carbon dioxide emissions. The following is a detailed explanation of each aspect.

2.1.1. Initial investment cost

$$C_{capital} = C_{facility} + C_{pipe}$$
$$= \sum_{eq} N_{eq} \times Inv_{eq} \times Cap_{eq} \times \frac{I}{1-(1-I)^{T_{eq}}} + \sum_i \left[L_i \times P_{i,pipe} \frac{I}{1-(1-I)^{T_i}} \right] \quad (2)$$

where $C_{facility}$ is the investment cost of the equipment; C_{pipe} is the investment cost of the energy pipe network; $N_{eq}$is the equipment number, $N_{eq} = 0, 1, 2 \cdots N$; Inv_{eq} is the investment cost per unit