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Comparative analysis of optimal operation strategies for district heating and cooling system based on design and actual load

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HIGHLIGHTS

- Optimized operation strategies for DHC system were offered based on economic rule.
- Based on design load and actual load, different strategies were analyzed.
- The allocation of energy supply and operation cost of sub-systems were analyzed.
- Using actual load in developing DHC operation strategies is more reasonable.

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ABSTRACT

Computational load significantly influences energy and cost savings when developing an operation strategy for a district heating and cooling system. In this study, a model was identified to study the effects of the difference between design load and actual load on an optimal operation strategy. The established model is strongly dependent on the economy principle, and the proposed optimal strategy could achieve a dynamic balance between the users' load and the system energy supply. This model was validated at 30% load rate, which demonstrated an obvious cost saving of 63.6% under the actual load and 42.2% under the design load. Based on the current strategy, the optimal strategy at different load rates was analyzed with respect to two characteristics of each sub-system: energy outputs and operation costs. Furthermore, in the optimal strategy, changes in total operation costs and cost savings rates under different load rates are also discussed. The results showed that, when the load rate was changed from 30 to 75%, the savings rates based on the design load were 42.2, 17.9, 2.5, and −12.6%, and the savings rates based on the actual load were 63.6, 49.8, 34.3, and 25.7%, respectively. Based on the actual load, the energy savings advantage of the optimal operation strategy could be maximized, in particular, during the initial stage of project construction. Furthermore, the commercial software MATLAB was used for programming and calculations. The simulation results indicated that the application of the combined cooling, heating, and power system could significantly improve the cost-effectiveness.

1. Introduction

With the rapid urbanization, the phenomenon of clusters of buildings has become popular in China. Heating and cooling demands of building clusters are higher than those of a single building [1,2]; therefore, a unified planning of large scale heating and cooling systems is urgently required. A district heating and cooling (DHC) system generates thermal energy centrally and distributes it by circulating water or low-pressure steam through a net of underground piping [3,4]. DHC systems could improve energy efficiency and are economically viable. Besides that, DHC systems provide stable and resilient supply, high quality service, and mid-to-long term adaptability of the system. DHC systems have been used in recent years and have the potential to reduce carbon dioxide (CO_2) emissions, primary energy demands, and operation costs [5–7]. Moreover, energy savings technologies, such as combined cooling, heating, and power (CCHP) systems and high-efficiency chillers have been successfully used because of their large capacity and stable energy supply [8]. Furthermore, a DHC system can provide an ideal platform for using natural and renewable energy sources [9–11].

The design and operation of a DHC system are traditionally based on

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Nomenclature

DHC	district heating and cooling
CCHP	combined cooling heating and power
HVAC	heating, ventilation, and air conditioning
TMY	typical meteorological year
PV	photovoltaic
EC	electrical chiller
AC	absorption chiller
GSHP	ground source heat pump
TES	thermal energy storage
ICE	internal combustion engine
PGU	power generation unit
TEST	thermal energy storage tank
PHE	plate heat exchanger
COP	equipment coefficient of performance
EER_{sys}	system energy efficiency ratio
C	operation cost (CNY)
Q	cooling capacity (kWh)
W	energy used (kW)
PP	power price (CNY/kWh)
RC	rated cooling capacity (kW)
FTL	following thermal load
ALCS	actual load current strategy
ALOS	actual load optimal strategy
DLOS	design load current strategy
N	gross operation time (h)

Superscripts

Day	daytime operation
Nig	nighttime operation
P	chilled water pump
S	cooling capacity remained in TES system (kWh)
T	cooling water pump
*	optimal strategy without CCHP
τ	category of sub-system

Subscripts

o	tested condition
k	device ID
i	time (h)
j	sub-system ID

Greek symbols

η	PGU's efficiency
δ	the minimum excess cooling capacity (kWh)
ε	heat loss coefficient of TEST
β	percentage of dispatched cooling capacity
γ	output percentage

calculated heating and cooling loads of buildings. A commonly used calculation method is the load index method [12,13]. It is based on recommended parameters from literature, such as design requirements and heating, ventilation, and air conditioning (HVAC) design guidelines and standards [5,12,14]. However, the load index method cannot reflect the hourly change of the load. The harmonic response method and the cooling load factor method have often been used to calculate the hourly load taking into consideration factors such as building envelope, typical meteorological year (TMY) data (ambient temperature, solar radiation, etc.) equipment parameters, and inhabitants [15]. In recent years, the hourly load of the DHC system has been calculated with computer simulation methods, using software such as TRNSYS or DeST [14–18]. However, considering the uncertainties and real-time feedback in the operation of a DHC system, the actual load is often different from the calculated data, and this brings into question the accuracy of the calculation results [5,19]. When it comes to energy supply to building clusters, the actual load is often different from the design load [14] in peak value and trends, because of the factors such as building completions, real-time meteorological data, and occupancy rates [20–23]. Therefore, the two key issues for optimizing a DHC system involve optimizing the allocation of DHC equipment based on the actual energy load, and addressing the extensive decrease in the deviation between the energy demand and supply.

Extensive research efforts are required for studying the optimal operating strategy of the DHC system. Compared to a single style of energy supply to one building, a DHC system often involves the selection of several types of cold and heat source equipment for building clusters [24–28]. Thus, there are several achievements in the combined operation strategy of multiple types of energy equipment [24–26]. Existing boilers and chillers have been successfully integrated with CCHP and photovoltaic (PV) units. Following the optimization of the capacity and operating condition of the equipment, the combined system achieved 40.8% energy cost reduction compared to the conventional system [24]. A hybrid heating system was tried by combining a sewage source heat pump system with a gas boiler. Compared to a traditional gas-fired boiler heating system, a hybrid system can achieve 45.2% energy savings and 13.5% operating costs savings [28]. A CCHP system with an internal combustion combined boiler, an electrical chiller (EC), and an absorption chiller (AC) has also been used. Based on simulation and comparison among different models, an optimized operating strategy formulated based on a detailed model can reduce daily operation cost by 2.5% [27]. In these studies, the economy is a common criterion in analyzing the operation of a hybrid system. It is important to consider regional differences when selecting heating and cooling sources. Because of different local energy price policies, it is better to use economy as the criterion for the operation of a DHC system.

Moreover, the gross cooling or heating energy supplied by a DHC system could meet users' load requirements most of the time. However, the study on the sub-systems of heat or cold sources focused only on energy efficiency of a single sub-system [6,15,27], and did not consider the cooling or heating capacity distribution of each sub-system in actual operation. In a few cases, some results were simply presented [16,29], and the allocation of the energy supply and operation costs of the sub-systems were hardly obtained, in particular, for a DHC system following a changing energy price policy.

The regional heating and cooling load is influenced by characteristics of the building cluster and changes in meteorological factors. Therefore, in the operation of a DHC system, different energy equipment should be completely utilized to operate efficiently and to maintain a good dynamic balance between the users' load demand and the system capacity. Optimizing a DHC system is affected by the difference between design load and the actual load of the served district. In this study, based on the actual energy consumption and cost data from the summer of 2014 for one energy station, that of Tianjin Eco-City, optimal operation strategies of this DHC system in summer were analyzed. Economy was selected as an evaluating criterion and an optimal running model was developed. Moreover, the effect of the proposed strategies relied on design load and actual load was explored. Further, the potential cost savings ability of the DHC system was studied under different load rates with a detailed allocation of the energy supply and operation costs of each cooling sub-system. It is expected that this research can provide a scientific and quantitative dispatching strategy for actual operation of the DHC system, and provide a guidance and reference for optimizing the operation of an existing regional energy