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The performance prediction of ground source heat pump system based on monitoring data and data mining technology

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ABSTRACT

This paper studies the performance prediction of ground source heat pump (GSHP) systems by real-time monitoring data and data-driven models. A GSHP system, which is installed in an office building of Shaoxing (29.42°N, 120.16°E), China, is real-time monitored from Nov. 2012 to Mar. 2015. Data mining (DM) technologies were simultaneously applied to process the monitoring data and find the required inputs for data-driven models. Back-propagation Neural Network (BPNN) algorithm was selected from six classical sorting algorithms to establish the data-driven models. The performance of the GSHP system from Nov. 2012 to Mar. 2015 was evaluated by the monitoring data. And the long-term performance was predicted by the data-driven models. The monitoring results show that the application effectiveness of the GSHP system is unsatisfied because of the high pumping power. Moreover, the relationship between the short-term and long-term performance of GSHP system is investigated for the purpose of predicting the long-term performance of GSHP system by a short-term monitoring data. The monitoring data of different days in several modes are needed to predict the long-term performance of GSHP system under a certain deviation.

1. Introduction

Energy in building is an important part of the primary energy consumption, which accounts for about 35% of the world's total primary energy consumption [1]. And more than 50% of the energy consumed in buildings in China and the United States is for space heating and cooling, and domestic water heating [2]. Ground source heat pump (GSHP) is one of the promising technologies using shallow geothermal energy for heating and cooling applications as well as domestic hot-water. Due to the superiorities of high energy efficiency and environmental friendliness compared to conventional air-conditioning (AC) system, it has attracted more and more attention in the past decades [3].

The main disadvantage of GSHP systems compared to conventional ones is higher initial cost. It is important to ensure the GSHP systems running with higher efficiency to lower its operation cost. However, the practical performance of GSHP systems in actual project may fail to satisfy design expectation due to improper equipment installation, equipment degradation, sensor failures, or inappropriate control sequences [4]. Therefore, accurate assessment of the effectiveness of the practical GSHP system is very important to find out the undesirable problems.

One of the main problems in evaluating the performance of GSHP system is that it's hard to investigate the long-term performance (i.e., the average performance of a GSHP system throughout its service life). Long-term performance of GSHP systems can be affected by many factors such as ground temperature, flow velocity of groundwater and thermal load of buildings. In previous studies, there were mainly three ways to assess the long-term performance of GSHP systems, including experimental researches based on field database [5–11], physics-based models [12–15] and data-driven models [16–41].

Montagud et al. [5] collected monitoring data of a GSHP system in Spain which had been monitored for five years and evaluated the system performance and ground thermal response. In Korea, the cooling performance of a GSHP system installed in a school building was evaluated for one summer [6]. Naili et al. [7] carried out an experiment in a pilot GSHP system for a few days in Tunisia and evaluated the coefficient of performance of the heat pump and the overall system in continuous operation mode. Based on the accumulated data lasting for four years, Luo et al. [8] analyzed the cooling and heating performance of a GSHP system in Southern

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Germany. Michopoulos et al. [9] also conducted the evaluation of a GSHP system installed in Northern Greece which had run normally over eight-years and was continuously monitored. Similarly, based on experimental data, operation performances of a GSHP system in China for both cooling and heating provision with different operation modes are evaluated by Man et al. [10]. Zhai et al. [11] presented a GSHP system that was installed in an archives building in Shanghai. And an increment of about 0.5 °C in soil temperature was observed after one year of operation.

It can be seen that the performance of GSHP systems was generally experimentally evaluated in long-term or in short-term. It is significant to evaluate the system performance in practical project so that the faults in system design and operation can be found and operation of the systems could be improved and optimized. However, it is difficult to validate the GSHP systems operation efficiency in a long-term period using a short-term monitoring or testing data. In general, the service life of a GSHP system is over 20 years and the results of short-term field test may be not representative for the long-term system performance. However, we often need to predict the efficiency and performance of the system in long-term period based a short time data. The other way to investigate performance of GSHP systems in long-term period is physics-based model.

Li et al. [12] used field data and a numerical simulation to examine the long-term performance and environmental effects of a large GSHP system that heats and cools industrial greenhouses in north Japan. The numerical model of the system was developed by Finite Element Subsurface Flow System (FEFLOW) and the simulation results suggest that the system could maintain the heat exchange rate for several years without significantly compromising its performance. Safa et al. [13] used the performance curves obtained from the experimental investigation to simulate the heat pump. And TRNSYS was used to simulate the house as well as the heat pump. Zarrella et al. [14] conducted the long-term analysis of two GSHP systems over ten years by means of a detailed numerical simulation tool. The effects of both axial heat transfer in boreholes and the weather at ground level on the fluid temperature in the boreholes, as well as the energy efficiency of the heat pump, were assessed.

Although numerical or analytical models explicitly simulate the mechanism of GSHP systems and ground heat exchangers (GHE) processes in long-term period, we can observe that those models are commonly complex and computationally expensive. The data-driven approach involving DM algorithms is an alternative for modeling GSHP systems. DM is an emerging powerful technology with great potential to discover hidden knowledge in large data sets [16]. Due to its significant superiorities of high prediction accuracy and artificial intelligence in modeling complex, dynamic and non-linear system, DM technology has attracted more and more attention in recent years. In building field, the DM technology had been effectively utilized for building energy conservation [16–22], performance prediction and optimization of heating, ventilation, and air-conditioning (HVAC) system [23–29] and GSHP system [30–38]. There are many popular algorithms for DM technology, such as statistical analysis method, neural network, decision tree method, genetic algorithm. In general, these algorithms can be classified into three categories: sorting algorithms, clustering algorithms and association algorithms.

Decision tree algorithm which belonged to sorting algorithms was applied in Refs. [17], [19] and [22]. Operation performance was optimized to decrease the energy consumption and improve comfort level in these buildings. Clustering algorithm which was used to construct the predicted models was proposed to decrease the prediction errors and computational cost in Ref. [27]. In Refs. [16] and [21], association rule mining was adopted to unveil the associations between power consumptions of main components and influencing factors. Chou et al. [18] used various DM technologies to predict the cooling load and heating load in buildings. Comparison results showed that the ensemble approach (SVR (support vector regression) +ANN) and SVR were the best models for predicting cooling load and heating load, respectively. Artificial neural network (ANN) model was conducted to optimize the control strategy of GHE and cooling tower to improve the thermal performance of GSHP system in Refs. [30,31]. In the work of Esen et al., ANN [32], ANFIS (adaptive neuro-fuzzy inference systems) [33] and SVM algorithms [34] were respectively verified that they can effectively simulate the non-linear GSHP systems. And it was found that SVM has better generalization ability than ANN and ANFIS models. Meanwhile, Esen et al. also used ANN models [35,36] and ANFIS models [37] to predict the performance of GSHP system. The results showed that those trained models can be used as an alternative way to evaluate the performance of GSHP systems. In Esen's latest work, ANN and ANFIS models were simultaneously applied to modeling a solar-assisted GSHP system to analysis its energy performance [38]. The obtained results showed that the ANFIS is more successful than that of ANN for forecasting performance of a solar-assisted GSHP system.

A physics-based model can express a clear relation, but it's difficult to build a physics-based model for the long period performance of GSHP system for the internal structure and character of the system is not very clear. Field monitoring method requires long term monitoring data and is time-consuming while it can supply exact results. The data-driven models operate like "black box" or "gray box" and there is no need to define internal relationship between inputs and outputs. They are simple in modeling process and computation and reliable when the GSHP systems are simulated. And an accurate GSHP system model may be established based on a short-term monitoring database, thus it is not necessary to evaluate the performance of GSHP system by long-term field monitoring. So data-driven models are suitable methods to assess and predict the long-term performance of GSHP system.

Until now there are few researches on performance of hybrid GSHP system (equipped with cooling tower in this study) under different operation modes using data-driven models. And in the system modeling process, it is very necessary to compare the performance of different intelligence artificial algorithms to improve the accuracy of the models. On the other hand, it is significant in projects to understand the long-term performance of GSHP system by data-driven models instead of long-term monitoring database. However, the needed time and situation for conducting short-term monitoring are unclear.

In this study, an actual hybrid GSHP system equipping with a cooling tower, which is installed in an office building of Shaoxing, is real-time monitored from Nov. 2012 to Mar. 2015. Basing on the monitoring data which have been processed by DM technology, a post-evaluation procedure is conducted to evaluate the performance of this GSHP system. The main operation problems in this GSHP system are pointed out. Then this hybrid GSHP system is modeled by a DM algorithm, which is the most appropriate algorithm selected out from six classical sorting algorithms under different operation modes and each operation mode is respectively modeled by optimal algorithm. Follow that, the average long-term performance of this hybrid GSHP system is predicted and evaluated under different operation modes by those data-driven models. Besides that, the relationship between long-term performance and short-term performance of GSHP system is discussed and the major factors which directly affect the results of short-term assessment are analyzed. Finally, the optimal time and number of days when conducting a short-term monitoring with the purpose of predicting the long-term performance of a GSHP system are provided.