

Chapter 38

Performance Prediction and Optimization of Solar Water Heater via a Knowledge-Based Machine Learning Method

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ABSTRACT

Measuring the performance of solar energy and heat transfer systems requires a lot of time, economic cost, and manpower. Meanwhile, directly predicting their performance is challenging due to the complicated internal structures. Fortunately, a knowledge-based machine learning method can provide a promising prediction and optimization strategy for the performance of energy systems. In this chapter, the authors show how they utilize the machine learning models trained from a large experimental database to perform precise prediction and optimization on a solar water heater (SWH) system. A new energy system optimization strategy based on a high-throughput screening (HTS) process is proposed. This chapter consists of: 1) comparative studies on varieties of machine learning models (artificial neural networks [ANNs], support vector machine [SVM], and extreme learning machine [ELM]) to predict the performances of SWHs; 2) development of an ANN-based software to assist the quick prediction; and 3) introduction of a computational HTS method to design a high-performance SWH system.

INTRODUCTION

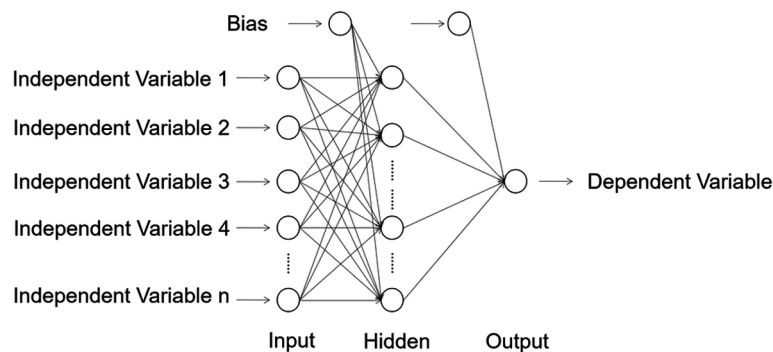
Predicting the thermal performance of solar energy systems is of huge challenge due to the complexity of the internal structures. In fact, the measurement of thermal performances of a typical solar energy system (e.g., solar water heater (SWH)) requires a lot of time, economic costs and labors. Due to the

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complicated structures, conventional physical and mathematical models usually fail to estimate their thermal performances. These problems not only dramatically hinder the acquisition of the thermal performances of solar energy systems, but also block the possibility of optimizing their thermal performance.

In the past decades, scientists have come up with a powerful prediction method to address these problems. People found that a knowledge-based machine learning model can help precisely predict the performances of some energy systems utilizing some simple independent variables as the computational inputs. With a proper machine learning algorithm, people only need to acquire a sufficient experimental database as well as perform the model training and testing, and then a predictive model can be acquired. During the training process, machine learning can “learn” the non-linear relationship between the independent and dependent variables via a “black box” fitting, and subsequently perform the predictions. The research group of Prof. S. Kalogirou, from Cyprus University of Technology, has conducted a majority of the pioneer application research on the prediction of thermal performances for energy systems (Kalogirou, 1999), leading to huge positive engineering impacts during the last two decades. Subsequently, relevant studies have become increasingly popular all over the world. Meanwhile, there are more and more new or revised machine learning algorithms developed. Among various machine learning approaches, there are some most widely used algorithms, such as artificial neural network (ANN) (Kalogirou, 1999), support vector machine (SVM) (Suykens & Vandewalle, 1999) and extreme learning machine (ELM) (Huang et al., 2006). ANN is the most prevalent algorithm due to its long history and powerful predictive capacity. The general schematic structure of an ANN model is presented in Figure 1.

Figure 1. General schematic structure of a typical ANN model. The empty circles represent the neurons. All the neurons interconnect with other neurons in the adjacent layer(s). Each neuron in the input layer represents an independent variable. The neuron in the output layer represents the dependent variable. Reproduced with permission from Reference (Li, Liu, Liu, & Zhang, 2017).



So far, despite the great progress of machine learning, engineering and industrial requirements have been rising in recent years: how to cost-effectively design and optimize a solar energy system by utilizing machine learning? Now, machine learning is a proven powerful tool for varieties of numerical predictions, and people are trying to make full use of its predictive power, as well as provide a good optimization strategy in order to acquire higher performances. Nevertheless, to the best of the authors’ knowledge, very few research reports have mainly focused on the relevant studies (Peng & Ling, 2008). Recently, the authors have found that with a sufficiently large experimental database, the machine learning models are

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