Applied Energy 124 (2014) 325–334

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Methods for benchmarking building energy consumption against its past or intended performance: An overview

Zhengwei Li *, Yanmin Han, Peng Xu

College of Mechanical Engineering, Tongji University, Shanghai, China
Institute of Advanced Study, Tongji University, Shanghai, China

HIGHLIGHTS

- This paper reviews up to date methods for building energy benchmarking.
- This paper summarizes the major characteristics of these methods.
- This paper recommends a flow chart for reader to choose a proper method.

ARTICLE INFO

Article history:
Received 10 December 2013
Received in revised form 6 March 2014
Accepted 14 March 2014
Available online 4 April 2014

Keywords:
Building
Energy benchmarking
Overview

ABSTRACT

Building sector consumes a significant portion of energy worldwide. One of the reasons is that the performance of building and its components degrades over the years. It is found that by improving the performance of existing systems through continuous commissioning, significant energy saving can be achieved. In a continuous commissioning process, energy benchmarking is extremely important for tracking, monitoring and detecting abnormal energy consumption behavior of a building. In this paper, up to date methods and tools available for energy benchmarking purpose are reviewed. It is hoped that with this paper, researchers and building operators are more confident in choosing a proper method (or tool) during the commissioning process.

© 2014 Elsevier Ltd. All rights reserved.

Contents

* Corresponding author at: College of Mechanical Engineering, Tongji University, Shanghai, China. Tel.: +86 021 65989750.
E-mail address: zhengwei_li@tongji.edu.cn (Z. Li).

http://dx.doi.org/10.1016/j.apenergy.2014.03.020
0306-2619/© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Building sector consumes more than 30% of the total energy worldwide [1]. An efficient way to alleviate global warming and improve environmental sustainability is to enhance building energy efficiency. However, many causes lead to a decrease of building energy efficiency for most buildings over the years, such as degradation of HVAC system components [2].

Continuous commissioning (CC) is an emerging technology to improve energy efficiency. Essentially, a CC is to conduct commissioning continuously throughout the life cycle of a building. It aims at assessing, improving and optimizing the performance of building systems [3]. A CC project launched in Texas A&M University between 1995 and 2000 is estimated to bring a total cost saving of as much as $10 million [4]. According to the Federal Energy Management Program (FEMP) in United States, CC has produced typical savings of 20% with payback under three years (often one to two years) in more than 130 large buildings [5]. To assess the energy consumption performance of a building, energy benchmarking is a necessary step. Energy benchmarking is defined as 'a macroscopic level of performance assessment, using metrics to measure its performance relative to other building or its previous performance' [6].

In the past, various methods for energy benchmarking have been developed. These methods can be categorized into white box method, gray box method and black box method. A white box method is also termed as first principle based method, which embeds physical constraints into the modelling of building components, and thus requires large amount of design documentations. Examples of this type of method include modified bin method and detailed energy simulation method [7,8]. On the contrast, a black box method uses data fitting techniques rather than physical knowledge, therefore requires a pre-selected statistical model and training data. Examples of black box method include artificial neural network method (ANN) and support vector machine method (SVM) [9]. The principle of gray box method lies in the middle between white box method and black box method, it combines both physical knowledge of the system and data fitting techniques to derive a useful energy model. Degree day method and its variants are examples of gray box method [10].

Benchmarking methods can also be categorized based on their corresponding types of baselines. Four types of baselines can be calculated by existing benchmarking methods: previous performance of comparable buildings, current performance of comparable buildings, previous performance of the same building, and intended performance of the same building [11]. While the first two types of baselines are often used by regulators and released to public, to encourage owners to improve energy efficiencies of their buildings [12], the rest are often used internally for energy tracking and monitoring purpose. In the context of this paper, benchmarking methods to calculate the latter two types of baselines are focused.

Overviews of building energy benchmarking methods have been given by several researchers [9,10,13]. Al-Homoud [10] introduced characteristics of mainly three methods: degree day based method, modified bin method, and detailed energy simulation method, which lie in the white box and gray box category. Holcomb [9] compared performance of three black box methods: multiple linear regression (MLR), artificial neural network (ANN) and support vector machine (SVM). It is found that ANN has the worst prediction accuracy compared to the other two methods. Zhao [13] investigated major characteristics of engineering methods (namely white box methods in this paper), statistical methods (namely regression based black box methods in this paper), neural networks, support vector machines, and grey models, with a conclusion that the neural network method and simplified engineering method have the highest accuracy.

To have a systematic view of up to date energy benchmarking methods and their performance levels, a literature review is conducted in this paper. It is hoped that with this paper, researchers can choose an appropriate benchmarking method based on the detail level of available information and required prediction accuracy. The content is organized as the following: first, the principles and characteristics of various benchmarking methods are introduced; second, the application cases of these methods and their performances are presented; finally, discussion section and conclusion remarks are given.

2. Energy benchmarking methods

As mentioned above, current energy benchmarking methods can be categorized into black box method, gray box method, and white box method. In this section, main methods in each category are briefly reviewed.

2.1. Black box method

In the category of black box method, multiple linear regression (MLR), bin method (BM), support vector regression (SVR), artificial neural network (ANN), and Gaussian process regression (GPR) are the most popular methods for energy benchmarking purposes.

2.1.1. Bin method (BM)

In this method, historical loads are grouped together into a bin if their associated variables (such as hour of week, temperature, and humidity) are close and fall into the same interval categories. The average value of the bin is then used to predict load with similar associated variables.

2.1.2. Multiple linear regression (MLR)

MLR method relates the predicted variable (baseline energy consumption) to multiple input variables. Typically, ambient

Download English Version:

https://daneshyari.com/en/article/242836

Download Persian Version:

https://daneshyari.com/article/242836

Daneshyari.com