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A multi-level energy performance diagnosis method for energy information poor buildings

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ABSTRACT

A thorough assessment and diagnosis is critical for understating and enhancing building energy performance while most buildings cannot provide sufficient energy use data for a detailed diagnosis. This paper presents a multi-level energy performance diagnosis method for energy information-poor buildings where very limited energy use data are available. A simplified monthly energy performance calculation method based on basic energy balances within a building is developed. It provides sufficient energy performance data of a building at multiple levels (i.e., building, system and component levels) while only requiring monthly energy bill data and few in-situ measurements of the HVAC system. The energy performance level then can be determined by comparing the estimated performance data with the benchmark data. A customized benchmarking method using the “relative performance factor” is proposed to indicate the relative difference between the current performance and the expected performance, and to estimate the energy saving potentials. The developed multi-level energy performance calculation method is validated in a super high-rise building in Hong Kong. A case study on illustrating how to apply the proposed diagnosis method for identifying the poor performance areas and the causes behind as well as estimating the energy saving potentials is also presented.

1. Introduction

The building sector has been the largest energy consumer in most countries. For instance, buildings account for about 40% of the total energy consumption in the EU (European Union) and over 90% of the total electric energy consumption in Hong Kong [1,2]. Excessive amounts of energy are often wasted in existing buildings because they often fail to operate as intended. Theoretical studies and field investigations demonstrated that energy saving potentials of the most investigated buildings can reach up to 20%–50% of the total consumption [3]. Improving energy efficiency in buildings is a major priority worldwide [4]. Building energy performance assessment and diagnosis, which can help to identify the amount of energy waste, the degree of efficiency deterioration and the probable causes behind, plays an important role in improving building energy efficiency and reducing building energy consumption.

Many studies on the development and application of energy performance assessment and diagnosis methods can be found in the existing literature. Hernandez et al. developed energy performance benchmarks and building energy ratings for non-domestic buildings in Irish [5]. Chung et al. performed a study on benchmarking energy efficiency in commercial buildings using the multiple regression analysis [6]. A method for assessing building energy efficiency using both simulation and experiment approaches has been developed by Pisello et al. [7]. Lee and Yik developed simplified models for use in the assessment of HK-BEAM (Building Environmental Assessment Method) as an alternative to the detailed simulation method [8]. Participants of Energy Performance of Buildings Directive (EPBD) in EU have developed various energy certification methods for compulsory assessment of new and existing buildings [9,10]. The IEA (International Energy Agency) also has launched two Annex projects (Annex 46 and Annex 53) to promote the energy efficiency of existing buildings by developing and applying appropriate energy performance assessment methods for different types of buildings [11].

Methods for building energy benchmarking and assessment can be categorized into white box method, gray box method and black box method [12]. A white box method is also termed as first principle based method, which begins with a description of the building system or component of interest and defines the building being

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modeled according to its physical description. These models may be described as either simplified or sophisticated, depending on the complexity and scope of the mathematical model. Sophisticated models, such as DOE-2 and EnergyPlus, generally require a large number of inputs and as a result are often difficult to calibrate. Simplified models, such as SBEM (Simplified Building Energy Model) and modified bin method, generally require fewer inputs and as a result are easier to calibrate [13]. 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 [12]. ANN (Artificial neural network method) and SVM (support vector machine method) are examples of black box method [14]. A gray box method has the features of white box and black box models, which combines both physical knowledge of the system and data fitting techniques to derive a useful energy model. RC network models and Degree-day methods are typical examples of gray box method [15,16].

Energy performance assessment schemes and methods are established mainly for two purposes: energy classification and energy performance diagnosis [9]. Energy classification is often used by regulators as a “macroscopic level of performance assessment for a group of buildings”, which aims to distinguish buildings with different energy performance levels and encourage owners to improve energy efficiencies of their buildings [17]. Typical energy classification programs include whole building benchmarking tools, building certification methods and environmental assessment schemes [9,18]. Energy Star and Cal-Arch are two well-established whole-building benchmarking tools in USA [19,20]. In addition to aforementioned energy performance certification methods developed by EPBD participants, similar certification and rating systems can also found in US including the ASHRAE's bEQ (Building Energy Quotient) program and the DOE AR (energy asset rating) program [21,22]. Typical environmental assessment schemes include Leadership in Energy and Environmental Design (LEED) in USA [23], Building Research Establishment Environmental Assessment Method (BREEAM) in UK [24] and HK-BEAM (Building Environmental Assessment Method) in Hong Kong [25].

Energy performance diagnosis is usually used by building owners as a performance inspection tool, which aims to identify faults and poor energy performance areas and causes in a building so that useful information and recommendations can be provided for fixing these faults and problems. Energy performance diagnosis can be conducted in a building at different levels. According to the inspection scope and examination details in a building, all diagnosis methods can be categorized as whole building diagnosis, system level diagnosis and multi-level diagnosis. Whole building diagnosis, which typically only addresses the overall performance of a building and does not require large amounts of information regarding the operation of the building, is the most commonly used diagnosis method in practice. Shao and Claridge proposed a quality control method using “Energy Balance Load” for verifying whole-building energy-use data [26]. Different from the HB (heat balance) method for load calculation [27],“Energy Balance Load” is a parameter derived from the first law of thermodynamics based on a whole-building energy analysis, which is mainly used to detect building level faulty energy use data [28]. PACRAT (Performance And Continuous Re-commissioning Analysis Tool), the WBD (Whole Building Diagnostician), and the ABCAT (Automated Building Commissioning Analysis Tool) are three well-recognized whole building diagnosis tools [13]. These tools can help identify a building with poor energy performance (e.g., the measured building consumption is larger than the predicted data) or faculty energy data while they are difficult to explain the performance and identify the causes of poor performance. For provided a more detailed diagnosis, a system level diagnosis that can make clear the energy performance of each individual system is necessary. Lee et al. proposed a method for assessing the energy performance of a complex building at system level, by which the energy consumption of main central systems are calculated using a bottom-up estimation method [29]. Yan and Wang proposed a simplified method for assessing the energy performance at the building and system levels [30]. This method can effectively break down the energy bill data into three individual systems without using sub-meters. In addition, building cooling load is also included in the assessment, which can help to differentiate whether a high level of energy use in a building is caused by intensive cooling demands or by inefficient cooling systems.

The most detailed diagnosis method is multi-level diagnosis, which extends the examination of energy performance from building level to system, subsystem and/or component levels, and consequently can provide the most useful performance information and the most specific and targeted recommendations for enhancing the performance. For example, Field et al. proposed a hierarchical performance tree comprised of various energy performance indices of different types of end-use for assessing the building energy performance at multiple levels [31]. The detailed end use data can be either provided by sub-meter systems or calculated based on detailed usage information such as the rated power, the usage time and the usage factor through in-site surveys. This method has also been adopted by Energy Assessment and Reporting Methodology-Office Assessment Method (EARM-OAM), which is a progressively detailed multi-level assessment method, consisting of three stages, i.e. initial stage, intermediate stage and advance stage [32]. More detailed and useful information about the energy performance can be provided when more time and efforts are increasingly taken for data survey and monitoring stage by stage.

However, the current studies or applications of multi-level assessment and diagnosis are still very limited due to the problematic availability of energy use information in most existing buildings [33]. A detailed diagnosis is usually dependent on sufficient energy use data (e.g., end-use data) and/or detailed energy performance data. Energy use data are the most important information for understanding the energy performance of building energy systems. Most existing buildings are energy information-poor buildings in which very few or even no sub-meters are installed [34]. As a result, only the total energy use data of the whole building are available from monthly energy bills. Without the detailed energy use and performance data of individual systems, the energy performance could not be diagnosed at system level, not to mention at component level. Installing a comprehensive sub-metering system is a possible solution while it is usually considered as too expensive for practical applications [35]. Using calibrated simulation tools might be, in principle, the most powerful methods by providing abundant and detailed outputs. However, even though a simulation tool is carefully calibrated at the whole building level (i.e., the simulated energy use of whole building fits well with the utility bill data), the reliability and accuracy at system and end-use level still cannot be guaranteed [9]. In addition, the use of calibrated-simulation usually needs to spent much time and efforts to collect a large number of performance data and system parameters, which is also not cost-effective in practice, particularly in buildings with poor data availability.

In order to resolve the dilemma that most buildings need a detailed diagnosis while few buildings can provide sufficient energy use data, this paper therefore presents a multi-level diagnosis method specially for energy information poor buildings (i.e., buildings with limited energy use data). This method can assess and diagnose energy performance of a building at different levels and then provide sufficient information for decision making even though there are very limited energy use data available in the