Applied Energy 126 (2014) 90–106

Contents lists available at ScienceDirect

Applied Energy

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

Data and analytics to inform energy retrofit of high performance buildings

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HIGHLIGHTS

- High performance buildings can be retrofitted using measured data and analytics.
- Data of energy use, systems operating and environmental conditions are needed.
- An energy data model based on the ISO Standard 12655 is key for energy benchmarking.
- Three types of analytics are used: energy profiling, benchmarking, and diagnostics.
- The case study shows 20% of electricity can be saved by retrofit.

ARTICLE INFO

Article history:
Received 4 January 2014
Received in revised form 28 February 2014
Accepted 22 March 2014
Available online 24 April 2014

Keywords:
Analytics
Data model
Energy benchmarking
Energy use
High performance buildings
Retrofit

ABSTRACT

Buildings consume more than one-third of the world's primary energy. Reducing energy use in buildings with energy efficient technologies is feasible and also driven by energy policies such as energy benchmarking, disclosure, rating, and labeling in both the developed and developing countries. Current energy retrofits focus on the existing building stocks, especially older buildings, but the growing number of new high performance buildings built around the world raises a question that how these buildings perform and whether there are retrofit opportunities to further reduce their energy use. This is a new and unique problem for the building industry. Traditional energy audit or analysis methods are inadequate to look deep into the energy use of the high performance buildings. This study aims to tackle this problem with a new holistic approach powered by building performance data and analytics. First, three types of measured data are introduced, including the time series energy use, building systems operating conditions, and indoor and outdoor environmental parameters. An energy data model based on the ISO Standard 12655 is used to represent the energy use in buildings in a three-level hierarchy. Secondly, a suite of analytics were proposed to analyze energy use and to identify retrofit measures for high performance buildings. The data-driven analytics are based on monitored data at short time intervals, and cover three levels of analysis – energy profiling, benchmarking and diagnostics. Thirdly, the analytics were applied to a high performance building in California to analyze its energy use and identify retrofit opportunities, including: (1) analyzing patterns of major energy end-use categories at various time scales, (2) benchmarking the whole building total energy use as well as major end-uses against its peers, (3) benchmarking the power usage effectiveness for the data center, which is the largest electricity consumer in this building, and (4) diagnosing HVAC equipment using detailed time-series operating data. Finally, a few energy efficiency measures were identified for retrofit, and their energy savings were estimated to be 20% of the whole-building electricity consumption. Based on the analyses, the building manager took a few steps to improve the operation of fans, chillers, and data centers, which will lead to actual energy savings. This study demonstrated that there are energy retrofit opportunities for high performance buildings and detailed measured building performance data and analytics can help identify and estimate energy savings and to inform the decision making during the retrofit process. Challenges of data collection and analytics were also discussed to shape best practice of retrofitting high performance buildings.

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http://dx.doi.org/10.1016/j.apenergy.2014.03.052
0306-2619/

1. Introduction

In 2010, the U.S. accounted for 19% of the global energy consumption – more than any other country except China [1]. The buildings sector is responsible for about 41% of the U.S. primary energy use and 8% of the world's CO_2 emissions [2,3]. Globally the buildings sector consumes more than one-third of the world's primary energy. It has been demonstrated that most existing buildings operate with various levels of deficiencies, and the problems of building energy performance are pervasive and well known [4]. Thus it is important to identify and realize energy saving opportunities in the buildings sector to reduce energy use and carbon emissions.

Currently, more and more attention is drawn to high performance buildings (HPBs), aka green, sustainable, and low energy/carbon buildings, discussed in many studies [5–7]. HPBs are buildings receiving higher rating scores under various building performance rating and labeling systems. Though such buildings are designed to be more energy efficient than other buildings, more efforts and retrofits are needed to maintain their high performance status [8,9]. Whether there exists any deeper energy savings for HPBs and how to identify such opportunities become an important concern for not only the government, but also the building owners and facility managers.

In February 2011, President Obama announced the Better Buildings Initiative to make commercial and industrial buildings 20% more energy efficient by 2020 and accelerate private sector investment in energy efficiency [10]. In this aspect, California has been a leader since the inception of the Building Energy Efficiency Standards – Title 24 [11] in 1978. California buildings also received higher Energy Star scores compared with the national stock [12]. Further, more energy codes and savings targets were set in subsequent state policies, such as the Energy Action Plan [13], Assembly Bill 32 – Global Warming Solutions Act [14] which sets California's target of reducing GHG emission to the 1990 level by 2020, and Assembly Bill 758 – Comprehensive Energy Efficiency Program for Existing Buildings [15]. On the other hand, owners and managers of HPBs can also benefit from improving building operation and maintenance, reducing energy cost, extending equipment life span, and improving indoor environmental quality and employee productivity.

However, it is not easy to find out the specific energy savings potential and related retrofit measures for HPBs which already employ energy efficient technologies and design strategies to reduce energy use – no low hanging fruit in this case. Although building simulations can be used to analyze energy performance and estimate savings potential of building technologies [16–21], creating and calibrating energy models is a time-consuming effort. The other approach is to measure and analyze performance of buildings. Since energy savings may lie in some specific end-uses or equipment, traditional analysis methods, based on the whole building's total energy use data from monthly utility bills, are far less adequate. Though some new approaches have been studied and implemented in real projects for a long time, such as energy benchmarking, building energy simulation, building energy monitoring, and fault detection and diagnosis, there is a lack of holistic and uniform approach for energy consultants or building managers to follow [22]. Besides, due to the lack of comprehensive and detailed monitored data, the previous studies and projects mainly focus on some aspects of the building energy performance, or portion of the building systems. For example, only energy use patterns or system operating efficiency is analyzed, only lighting system or heating, ventilation and air conditioning (HVAC) system is considered [23,24].

There are three main reasons to study the retrofit of HPBs: (1) HPBs do not necessarily consume less energy than normal buildings [25], (2) operational changes and maintenance issues can degrade performance of energy systems [26,27], and (3) building owners or regulations may require further energy savings. In this study, a new holistic approach using measured building performance data and analytics were proposed, for the purpose of identifying energy use patterns, operation deficiencies and then retrofit measures for major energy end-uses in existing HPBs. This study aims to shed some light on energy retrofit of high performance buildings by exploring answers to the following questions:

(1) Are there energy savings in retrofitting HPBs?
(2) What types of measured building performance data is needed to enable the analyses?
(3) What analytics can be used to identify and evaluate energy retrofit measures?
(4) What are the main challenges of using data-driven analytics to inform retrofit of HPBs?

The first section of this paper describes three types of measured building performance data which are needed to enable the analytics. An energy data model based on the ISO Standard 12655 "Presentation of real energy use of buildings" [28] is used to represent the energy use in buildings in a three-level hierarchy. Next, analytics were proposed to analyze energy use in buildings and to identify retrofit measures for high performance buildings. Then, as a case study, these analytics were applied to retrofit of a HPB in California. Finally conclusions and discussion of challenges were provided.

2. Building performance data

As Peter Drucker, a management thinker, said "you can't manage what you can't measure." To fully understand and manage energy use and performance of buildings, good quality measured data from energy monitoring systems, building automation systems, and building energy management and control systems are crucial. Unfortunately for most buildings, only one electric meter and one natural gas meter are usually installed, and only monthly electric and gas use data from utility companies are available. This is far from adequate to tell the details of how, when and where energy is consumed in buildings, leading to a huge information gap in building operations which need detailed performance data and analytics to provide insights to improve operations, inform retrofit, and reduce energy use. It should be noted that in the U.S., smart meters with time interval electric use data are expanding rapidly, which can fill some information gap. On the other hand, data quality is always an issue in most buildings as meters and sensors lack maintenance and calibration, were installed incorrectly, or were purchased with low resolution and quality due to cost considerations.

2.1. Three types of data

There are three types of measured building data that are needed to enable energy analytics for buildings and inform retrofit decisions:

(1) energy use data

Energy use data include whole building total energy use as well as major energy end uses. Whole building energy use includes electricity and fuels like natural gas. The major end uses include indoor and outdoor lighting, plug-loads, data center, kitchen equipment, elevators, domestic hot water, and HVAC equipment such as chillers, boilers, cooling towers, fans, pumps, DX (Direct Expansion) units, and radiators for heating. Energy use data at a time interval