Energy and Buildings 78 (2014) 165–175

Contents lists available at ScienceDirect

Energy and Buildings

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

Comparison of building energy use data between the United States and China

Jianjun Xia[a], Tianzhen Hong[b,*], Qi Shen[a], Wei Feng[b], Le Yang[a], Piljae Im[c], Alison Lu[b], Mahabir Bhandari[c]

[a] Department of Building Science, Tsinghua University, Beijing, China
[b] Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA
[c] Oak Ridge National Laboratory, Oak Ridge, TN, USA

ARTICLE INFO

Article history:
Received 11 January 2014
Received in revised form 18 February 2014
Accepted 13 April 2014
Available online 29 April 2014

Keywords:
Buildings
Comparison
Data analysis
Data model
Energy benchmarking
Energy monitoring system
Energy use
Retrofit

ABSTRACT

Buildings in the United States and China consumed 41% and 28% of the total primary energy in 2011, respectively. Good energy data are the cornerstone to understanding building energy performance and supporting research, design, operation, and policy making for low energy buildings. This paper presents initial outcomes from a joint research project under the U.S.–China Clean Energy Research Center for Building Energy Efficiency. The goal is to decode the driving forces behind the discrepancy of building energy use between the two countries; identify gaps and deficiencies of current building energy monitoring, data collection, and analysis; and create knowledge and tools to collect and analyze good building energy data to provide valuable and actionable information for key stakeholders. This paper first reviews and compares several popular existing building energy monitoring systems in both countries. Next a standard energy data model is presented. A detailed, measured building energy data comparison was conducted for a few office buildings in both countries. Finally issues of data collection, quality, sharing, and analysis methods are discussed. It was found that buildings in both countries performed very differently, had potential for deep energy retrofit, but that different efficiency measures should apply.

1. Introduction

Worldwide, the building sector is the largest emitter of carbon dioxide (CO_2) and the main contributor to climate change [1]. Buildings account for 72% of U.S. electricity use and 36% of natural gas use, and U.S. buildings currently contribute 9% of the world's CO_2 emissions [2]. In 2007, China's building sector consumed 31% of China's total primary energy [3]. China is also the second largest building energy user in the world, ranking first in residential energy consumption and third in commercial energy consumption [4]. In both developed and developing countries, buildings are responsible for more than 40% of global energy use and one-third of global greenhouse gas emissions [5]. In 2011, buildings in the U.S. and China consumed 41% and 28% of total primary energy in both countries, respectively. Furthermore, China's percentage is on the rise.

Better understanding of and improvements to building energy performance and operation are critical steps toward sustainable development and mitigation of global climate change. In the building sector, two distinct scenarios apply: Buildings in China have lower design efficiency levels [6] but also lower needs in terms of energy use; buildings in the United States have higher design efficiency levels but also higher needs for energy use. As a result, U.S. buildings use much more energy than those in China. This is mainly driven by essential differences between building operation and occupant behavior in both countries: Chinese buildings typically operate in a part-time, part-space mode—only occupied spaces during occupied time are conditioned, while U.S. buildings typically operate in a full-time, full-space mode—the whole building is conditioned most of the time including unoccupied hours with thermostat setback [7]. Therefore while buildings in the world's two largest economies have large energy savings potential, different energy savings measures will be needed.

Good building energy data are the foundation for research and building energy efficiency policy making. Energy monitoring, data collection, and analysis play crucial roles to support the design and operation of low energy buildings. Several studies, including a National Institute of Standards and Technology (NIST) report, show

* Corresponding author. Tel.: +1 510 486 7082; fax: +1 510 486 4089.
E-mail addresses: xiajianjun@tsinghua.edu.cn (J. Xia), thong@lbl.gov, hongtz68@yahoo.com (T. Hong), sqbeengineer@gmail.com (Q. Shen), weifeng@lbl.gov (W. Feng), yljjw_911@126.com (L. Yang), imp1@ornl.gov (P. Im), alisonlu007@gmail.com (A. Lu), bhandarims@ornl.gov (M. Bhandari).

http://dx.doi.org/10.1016/j.enbuild.2014.04.031
0378-7788/

that energy feedback devices can provide real energy savings by motivating building occupants to modify behavior, and while the level of savings varies, typical energy reductions on the order of 10% can be expected [8]. Moreover, a commissioning study shows that problems of building energy performance are pervasive and well known [9].

Keeping in mind the importance of monitoring and building energy performance management and to further the understanding of building operations, an Energy Information Handbook, published by Lawrence Berkeley National Laboratory (LBNL), is part of a DOE sponsored project to educate commercial building owners, facility managers, and operators [10]. The importance of this field is also emphasized by the fact that International Standards Organization (ISO) is developing a Standard 12655 [11], to standardize the data model used to represent measurement and performance data across all buildings and participating nations. DOE is also working on a building performance database to provide engineering and financial practitioners with a decision-support platform that enables them to evaluate energy efficiency products and services in commercial and residential buildings. The IEA's Energy Conservation in Buildings and Community Systems (ECBCS) Annex 53, also aims to develop new methods and tools to better understand and predict energy use of buildings [12].

Several cities in both countries are actively installing online measurement and monitoring platforms, which mostly measure electricity consumption, cooling loads, indoor air temperature, etc. Electricity consumption measurements include not only total use, but also each major end use, subcircuit branch use, and large power equipment use. However, most of these building energy monitoring platforms are relatively isolated and lack a common data structure. This makes communication and exchange of building energy performance data difficult. One of the challenges in comparing the performance of a set of buildings that have different data acquisition systems, data output formats, and energy analysis platforms is the lack of a common platform for data analysis. To make the communication and exchange of building energy consumption information seamless across all monitoring platforms and building automation systems (BAS), a standard and uniform building energy use description and a definition of minimum measured data requirements are urgently needed. Furthermore, most monitoring systems are separated from existing BAS, which leads to incomplete data collection and places extra burden on building owners and operators to run and manage both systems. Data analysis capability is also limited in providing actionable information for key stakeholders and decision makers to achieve energy savings.

To better understand building energy performance and improve building operations to reduce energy waste and increase efficiency, and more importantly to investigate the discrepancy in building energy use between the U.S. and China, a study of buildings in both countries with different climatic conditions and occupant cultural differences can play an important role. This paper presents outcomes from a joint research project under the U.S.–China Clean Energy Research Center for Building Energy Efficiency. The project aims to create knowledge, tools, and guidance to support the development of a standard methodology for building energy data definition, collection, presentation, and analysis; apply the developed methods to a standardized energy monitoring platform, including hardware and software to collect and analyze building energy use data; and compile offline statistical data and online real-time data in both countries to fully understand the current status of building energy use. A dozen buildings with online measurement and monitoring platforms were selected across the several climatic conditions in both countries. To gain a detailed understanding of building performance, measurements included three types of data at one-hour or 15-minute intervals: (1) building energy use, including building totals and a breakdown into major end uses for various fuel types; (2) operating conditions of HVAC systems and equipment; and (3) indoor and outdoor environmental conditions. The collected data were analyzed for three main purposes: (1) energy profiling—annual and monthly end uses, weekly and daily use patterns; (2) energy benchmarking—comparison of annual and monthly energy end uses among selected buildings to identify and understand driving factors of high performance buildings and demonstrate good design and operation practices; and (3) energy diagnostics—analyzing the performance of HVAC systems and the central plant to identify potential energy and operating issues and recommend retrofit measures.

This paper first reviews and compares several popular existing building energy monitoring systems in the U.S. and China. System structure, function, and performance are compared for each monitoring system, and the common field and basic functions of these monitoring systems are discussed. Next a standard energy data model for building energy monitoring is presented. Then a detailed building energy data comparison was done for a few selected office buildings in both countries. Finally, issues of data collection, quality, sharing, and analysis methods are discussed.

2. Building energy monitoring systems

Granderson et al. [10] reviewed and summarized the characteristics of more than 20 building energy information systems (EIS), as well as their differences with building management systems (BMS) and energy management and control systems (EMCS). The study covered key EIS characteristics: data collection, transmission, storage and security, displays and visualization, energy analysis, advanced analysis, financial analysis, demand response, remote control and management, and other general management issues.

In general, building information tracking can be categorized as system tracking and energy tracking, as shown in Fig. 1. System tracking focuses on building systems (such as lighting and HVAC) performance, including basic building automation control, fault detection and diagnostics (FDD), and continuous system optimization. Energy tracking focuses on building energy consumption. Based on customer needs and metering strategies, energy tracking can further be divided into utility tracking and benchmarking, meter visualization, and EIS. Utility tracking and benchmarking takes a whole building's portfolio and looks at its energy performance. Meter visualization is used to analyze more detailed building submetering information and calculate building end-use energy.

Some systems offer comprehensive solutions and a generic application programming interface (API) for both energy and system tracking. These systems require secondary programming to meet each user's needs. This offers great flexibility to energy and system tracking, allowing users to build a system topology and embed different algorithms for data processing and analysis.

Various monitoring systems were used in the selected buildings. All the systems share some characteristics, such as a centralized database, data acquisition module, and a data visualization GUI. Most systems can provide good support on technical features, data analysis, and fault detection, but each has different capacities in terms of data analysis and fault detection. Some in-house-developed systems have relatively simple GUI and user-customized functions, while some commercialized platforms often offer better GUI and more comprehensive data processing capability.