Renewable and Sustainable Energy Reviews 33 (2014) 400–411

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Real-time detection of anomalous power consumption

Jui-Sheng Chou*, Abdi Suryadinata Telaga

Department of Civil and Construction Engineering, National Taiwan University of Science and Technology, 43, Sec. 4, Keelung Rd., Taipei, 106, Taiwan

ARTICLE INFO

Article history:
Received 19 October 2013
Received in revised form
22 January 2014
Accepted 31 January 2014
Available online 5 March 2014

Keywords:
Power consumption
Big data analytics
Anomaly detection
Pattern recognition
Real time detection
Time series prediction

ABSTRACT

Effective feedback can reduce building power consumption and carbon emissions. Therefore, providing information to building managers and tenants is the first step in identifying ways to reduce power consumption. Since reducing anomalous consumption can have a large impact, this study proposes a novel approach to using large sets of data for a building space to identify anomalous power consumption. This method identifies anomalies in two stages: consumption prediction and anomaly detection. Daily real-time consumption is predicted by using a hybrid neural net ARIMA (auto-regressive integrated moving average) model of daily consumption. Anomalies are then identified by differences between real and predicted consumption by applying the two-sigma rule. The experimental results for a 17-week study of electricity consumption in a building office space confirm that the method can detect anomalous values in real time. Another contribution of the study is the development of a formalized methodology for detecting anomalous patterns in large data sets for real-time of building office space energy consumption. Moreover, the prediction component can be used to plan electricity usage while the anomaly detection component can be used to understand the energy consumption behaviors of tenants.

Contents

1. Introduction

The OECD has predicted that global energy consumption will increase 53% from 505 quadrillion Btu in 2008 to 770 quadrillion

* Corresponding author. Tel.: +886 2 2737 6321; fax: +886 2 2737 6606.
E-mail addresses: jschou@mail.ntust.edu.tw, rayson.chou@gmail.com (J.-S. Chou), D9915802@mail.ntust.edu.tw (A.S. Telaga).

http://dx.doi.org/10.1016/j.rser.2014.01.088
1364-0321

Btu in 2035 [1]. Compared to the transportation and industrial sectors, the building sector consumes more energy (approximately 40% of global energy use) and generates 30% more CO_2 [2]. Therefore, a critical step in lowering carbon is reducing energy consumption in buildings. Given the particularly high dependence of Taiwan on imported fossil fuels, developing an economical, low-carbon, and highly efficient green energy system is imperative [3].

Studies performed in the United Kingdom [4] and in the United States [5] show that the growing use of energy-consuming equipment beat efficiency gains in green building technology. The increased energy consumption is mainly due to equipment for maintaining comfort in residential and commercial buildings, such as air conditioners, heaters and other modern appliances [5]. However, energy consumption in commercial buildings is more complex than that in residential buildings [6].

While residential buildings mainly provide a sanctuary for people, commercial buildings have widely varying purposes. Nevertheless, commercial buildings are mainly designed for business activities and expected to generate income for building owners and their tenants. Therefore, energy-saving strategies are needed to reduce operating costs on both sides. Specifically, electricity consumption by commercial buildings is the highest during 9:00–17:00, which is usually the highest price in time-price based schemes. Moreover, Popescu et al. also found that energy-efficient buildings benefit owners by increasing the property values [7].

The building manager is responsible for managing building performance, and one of the main building performance measures is electricity consumption [8]. Additionally, in countries that have recently increased requirements for green building certification, the building manager must minimize energy consumption. Thus, to reduce electricity consumption and CO_2 emissions, building managers must understand energy consumption from the tenant perspective. Therefore, building electricity consumption is both a social problem and a technical problem [5].

Analyzing electricity consumption from the tenant perspective requires very detailed data. To acquire such data, researchers have proposed using sensors for detecting movement [9], thermostats [10], cameras [11] or combinations of sensors that detect light, CO_2, temperature, *etc.* [12]. In practice, however, implementing this approach in commercial buildings is highly impractical. For privacy reasons, some tenants may reject the idea of sensors installed in their offices. Moreover, wiring costs are 45% and 75% of total installation cost for new buildings and retrofitted buildings, respectively [13]. Analyzing data streams from numerous real-time sensors can also be a heavy burden on building energy managers [14].

Smart meter use can reduce the required number of sensors and eventually reduces data stream volume. A smart meter is an electrical meter that records electrical energy consumption at intervals of an hour or less and sends the information back to the utility center for monitoring and billing purposes [15]. Therefore, smart meters provide more information compared to conventional meters, which only provide data for billing purposes [15]. Moreover, a smart meter management system is needed for an efficient smart grid system [16]. Finally, customers benefit from improved reliability of utility networks [17] and improved responsiveness of services, which eventually improve and sustain the customer relationship [18].

Additionally, smart meter data can be utilized to provide power quality (PQ) information to customers and utility companies. As the quality is susceptible to any disturbance in power transmission network, PQ is an important measure for customers [19]. Particularly, for the buildings that use electricity from different companies, the companies could develop PQ index [20] to provide fair information to customer and use the index to monitor any disturbance in power quality production. Consequently, for a fairer energy price, the price can be adjusted in terms of power quality [21].

Smart meters can provide detailed data for the electricity consumption of a customer in real-time or near real-time. Further, in-home implementations combining smart meter and enabling technologies such as in-home display have shown that smart meters can reduce energy consumption [22]. Studies show that the highest reductions occur when people are already at home at 17:00 (5 pm), which indicates that, with the right feedback, people can reduce their electricity consumption [23]. For example, a study by the Energy Saving Trust in 2009 showed that feedbacks that had the largest contribution to smart meter use were those that helped to reduce electricity use [24].

Anomalous electricity consumption data can help tenants identify extraordinary consumption patterns [25]. In commercial buildings, anomalous consumption may also result from activities such as over-lighting [6], inefficient equipment or overtime work. Therefore, anomalous feedback data can be further used to warn tenants to minimize electricity use and to help them identify ineffective equipment or over-lighting in office spaces. However, extracting meaningful information from smart meter data is a formidable task [26].

Although several anomaly detection methods have been researched, the primary objective has been detecting anomalous consumption in automated building systems such as heating, ventilation, and air conditioning (HVAC) systems [14,26–28]. However, the building must also support random use of office equipment, lightings, heating, and air condition. Since HVAC systems consume almost 50% of energy in a building [8], reduction of energy use by non-HVAC systems can potentially reduce total consumption by 50%. Office equipment consumes 15% of the total energy consumed by an office. By 2020, this figure is expected to increase twofold [29]. Therefore, potential savings in electricity consumption by office spaces are also large.

Because no studies have considered anomaly detection in office spaces, this study performed an experiment to develop a real-time system for detecting anomalous electricity consumption in an office space from the perspective of occupant activities. All experimental data were retrieved from smart meters used to monitor electricity consumption in an office space in a university building. The main objective was to develop an anomaly detection methodology that is applicable in large data stream of smart meter data and real time environment. Therefore, the research results have potential applications in a web-based early warning system. Notably, the results application is not only limited to building energy consumption domain, but also applicable to any anomaly detection system that use time based sensor data as input. Furthermore, the potential application includes gas flow detection, water flow detection, and comfort level detection. The main contributions of this research are the following:

- A formalized methodology for detecting anomalous patterns in large real-time datasets for building office space energy consumption.
- The method is performed in two stages. The prediction stage helps building managers plan their electricity demand while the anomaly detection stage helps building managers identify tenant consumption patterns. In the case of a building that generates its own electricity and has abnormally low energy consumption, the building manager can connect to a smart grid and sell the excess electricity to gain profit.
- Anomaly detection benefits tenants by helping them understand how their office activities consume energy. They can then modify their anomalous activities, analyze energy consumption costs and benefits, and eventually reduce their wasteful activities.

The remainder of this paper is organized as follows. Section 2 briefly introduces the study context by reviewing related