Energy and Buildings 155 (2017) 414–424

Contents lists available at ScienceDirect

Energy and Buildings

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

Long-term field investigation and modeling of electricity end-use patterns in hotel guest rooms

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ARTICLE INFO

Article history:
Received 5 July 2017
Received in revised form
11 September 2017
Accepted 15 September 2017
Available online 18 September 2017

Keywords:
Hotel electricity end uses
Weather normalization
Occupancy normalization
Regression analysis
Inverse Modeling Toolkit (IMT)

ABSTRACT

This paper presents the results of a long-term, detailed electricity end-use analysis of hotel guest rooms in order to provide a better understanding of the electricity use patterns in guest rooms and their explanatory factors. To accomplish this, a one-year of sub-hourly electricity measurements for an entire floor and major electricity end uses of fourteen guest rooms in a case-study hotel in Washington, D.C. were analyzed along with coincident weather and occupancy data collection. A regression analysis was performed on the monthly and daily end-use electricity data to identify key variables affecting different electricity end uses of the guest rooms. As a result, it was found that a regression model with a single temperature variable did not fully describe the electricity use behaviors of hotel guest rooms. The addition of the occupancy variable significantly improved the model fit for both monthly and daily total floor electricity use and was statistically significant. A review of the electricity end uses showed strong correlations between outdoor temperature and the electricity end uses for space conditioning, especially the DOAS unit and the VRF outdoor unit. However, for other end uses such as plug loads, lighting, and the VRF indoor units, the observed correlations to outdoor temperature were not significant but were moderately correlated to occupancy.

1. Introduction

Hotels are part of the lodging sector as defined in the Commercial Buildings Energy Consumption Survey (CBECS) by the U.S. Energy Information Administration (EIA). In the 2012 CBECS survey, the lodging sector was responsible for 8.1% of total building energy use in the U.S., which ranked the fifth largest energy use [1]. Hotels have a wide variety of energy end uses that serve different purposes. On average, about 27.5% of the energy is consumed to provide space conditioning, including heating (12%), cooling (7%) and ventilation (9%). Other energy end uses include hot water (24%), cooking (12%), office equipment (9%), lighting (7%), refrigeration (6%), and other unidentified sources (15%) (Fig. 1). Some of this energy is used in common areas with different functions such as lobbies, restaurants, swimming pool, and offices that have predictable occupancy schedules, while other energy is used in guest rooms that have variable occupancy. However, limited information or data are currently available on detailed energy end-use patterns in the guest rooms and its relationship with occupancy to identify potential opportunities for energy savings, including Occupancy-Based Climate Control (OBCC) technology.

Numerous studies have previously examined the energy use in hotels. However, most studies have focused on establishing useful benchmarks for energy performance of hotel buildings based on simple indices such as annual whole-building Energy Use Index (EUI) in various tourism-intensive regions of the world, including Hong Kong [2–5], Singapore [6], Taiwan [7], Vietnam [8], China [9,10], New Zealand [11], Nigeria [12], Europe [13–16], Canada [17], and USA [18]. In general, these studies collected one-year of monthly energy use data from dozens or hundreds of sample hotels along with other pertinent information. Using the collected monthly energy use data, the annual whole-building EUI normalized for building size (e.g., floor area, number of guest rooms) or occupancy (e.g., guest-nights sold) were then calculated and analyzed statistically in order to identify key variables affecting the energy use in hotels. For example, these studies have investigated the relationship between annual energy use at a whole-building level and the relevant independent variables (e.g., climate, building size, occupancy, and other functional or operational characteristics) using statistical techniques such as regression analysis, correlation analysis, or cluster analysis.

Several studies provided a comparison of average EUIs (kWh/m^2/year) reported in many of these papers [7,12,14,16]. A

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http://dx.doi.org/10.1016/j.enbuild.2017.09.039
0378-7788/

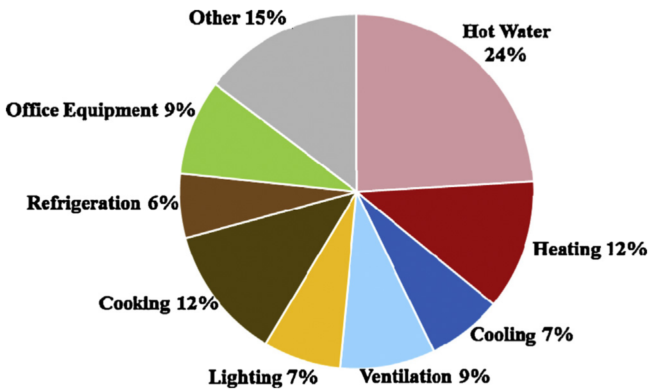

Fig. 1. 2012 CBECS Energy End Use Breakdown for Lodging Facilities [1].

noticeable variation was observed in the average EUIs not only across different regions but also within climatically similar regions. This may indicate there are other explanatory factors for energy use in hotel buildings beyond the existing floor area normalization (i.e., energy use per unit area), including fluctuations in occupancy levels or the services offered by the hotel. However, it is hard to determine the exact reasons for these observed differences based on the simple whole-building approach used in these studies (i.e., annual whole-building EUI) that does not represent the significant variations in services and facilities offered within the hotel. In one study, Bohdanowicz and Martinac [14] reported that the presence of energy-intensive and water-intensive services in a hotel (e.g., food services, in-house laundry services) is one of the key influential factors affecting the energy use in hotels along with total hotel floor area and the number of guest-nights sold based on a multiple regression analysis. Therefore, there is a need for more detailed information to accurately access energy end uses in hotels beyond a building's overall EUI, including disaggregated energy use data for different space uses that have quite different energy use and occupancy patterns (e.g., common service areas vs. guest rooms).

In addition, there was disagreement among different studies regarding the relationship between energy use and occupancy. For example, Wang [7] reported a strong correlation between energy use and number of total guests of 200 hotels in Taiwan with a high R^2 coefficient of 0.93. However, Priyadarsini et al. [6] reported a poor correlation between energy use and occupancy (i.e., number of occupied rooms) in 29 hotels in Singapore with a low R^2 coefficient of 0.58, which possibly indicated the energy savings potential of improved cooling system controls during unoccupied periods. Deng and Burnett [2] also described no clear relationship between annual EUI normalized for floor area and hotel occupancy rate of 16 hotels in Hong Kong. They analyzed this was partially affected by prevalent space conditioning practices in many of the hotels in Hong Kong where the cooling system was not turned-off even when the room was not occupied in order to prevent potential discomfort or odors. However, it is hard to justify these observations without a more detailed analysis of energy end-use data of the guest rooms at shorter time interval along with concurrent occupancy data.

A few studies have performed detailed analysis of hotels using energy use data with higher temporal and spatial resolution [19,20]. Noren and Pyrok [19] developed typical energy use load shapes for hotels in Sweden using measured energy use data from nine sample hotels, but no efforts were made for sub-metering major energy end uses or energy use by space use. Thus it was hard to determine statistically how the major energy end uses or different space uses contributed to the total energy use or how the energy use was related to occupancy. Placet et al. [20] collected sub-hourly energy end-use data from one case-study hotel for a wide range of building systems, including both public spaces and 32 guest rooms. Although this study provided useful information to better understand the more detailed energy end-use patterns in guest rooms, the study neither measured nor analyzed the relationship between occupancy and the energy use of the guest rooms. Therefore, further studies are needed to better understand how occupancy affects energy use in hotel guest rooms.

Therefore, this paper presents the results of a long-term detailed, electricity end-use analysis of hotel guest rooms in order to provide a better understanding of the electricity use in guest rooms and their explanatory factors. One year of sub-hourly electricity use for one floor of fourteen guest rooms in the hotel and major end uses in fourteen guest rooms were collected along with coincident weather and occupancy data. A regression analysis was then performed on the collected monthly and daily end-use electricity data to identify key variables affecting the different electricity end uses of the guest rooms. The information presented in this study is expected to provide deeper insights into how electricity is used in guest rooms at a higher level of detail, which was not addressed in the previous publications, in order to identify potential opportunities for electricity savings in hotel guest rooms.

2. Methodology

This study collected one-year of detailed electricity use data from fourteen guest rooms on the sixth floor of the case-study hotel in Washington, D.C. from June 2015 to May 2016 along with coincident outdoor weather from the nearby National Oceanic and Atmospheric Administration (NOAA) weather stations and coincident occupancy data. The analysis closely followed the methods and procedures outlined in the ASHRAE Guideline 14-2014 [21] and the 2010 ASHRAE/CIBSE/USGBC Performance Measurement Protocols (PMP) for Commercial Buildings [22].

2.1. Case-study hotel

The ten-story, case-study hotel is located in Washington, D.C. The building was first built in 1966 and underwent a full renovation in 2013. The conditioned floor area of the building is 7297 m^2 (78,545 ft^2) with a window-to-wall ratio of 32%. There are a total of 121 guest rooms in the hotel, each with a fully-equipped kitchen. The construction of the building is metal frame with an R-value of 3.35 K m^2/W (19 h ft^2 °F/Btu) batt insulation and an R-value of 1.48 K m^2/W (8.4 h ft^2 °F/Btu) continuous insulation. Operable double-pane, low-e windows with a U-factor of 1.93 W/m^2 K (0.34 Btu/h °F ft^2) and a solar heat gain coefficient of 0.60 are used in all rooms.

The guest rooms are conditioned with individual Variable Refrigerant Flow–Heat Recovery (VRF-HR) units. The VRF outdoor unit serving the fourteen guest rooms on the sixth floor of the case-study hotel has a cooling capacity of 60,278 W (206 kBtu/hr) and a heating capacity of 67,778 W (231 kBtu/hr). The efficiency of the VRF system is 3.16 COP for cooling and 3.30 COP for heating.

A card-key based automatic climate control system is used for temperature set-backs of the VRF units in the guest rooms when the rooms are unoccupied. When the room is unoccupied or unrented, the room temperature is set back to 15.6 °C (60 °F) during the heating season and 26.7 °C (80 °F) during the cooling season. To activate the mechanical air-conditioning and lighting systems in a guest room, a guest inserts their card key into the card slot located inside the entryway of the room, which triggers the occupied mode. When a guest removes their card key from the card slot prior to exiting the room, both the mechanical air-conditioning and lighting systems automatically return to the unoccupied mode that includes a temperature setback.