Energy and Buildings 153 (2017) 461–475

Contents lists available at ScienceDirect

Energy and Buildings

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

Office building plug and light loads: Comparison of a multi-tenant office tower to conventional assumptions

Isis E. Bennet*, William O'Brien

Department of Civil and Environmental Engineering, Carleton University, Room 3432, C.J. Mackenzie Building, 1125 Colonel By Drive, Ottawa, Ontario, K1S 5B6, Canada

ARTICLE INFO

Article history:
Received 27 April 2017
Received in revised form 2 August 2017
Accepted 17 August 2017
Available online 24 August 2017

Keywords:
Submetering
Commercial building
Multi-tenant
Office
Electricity consumption
Plug load
Light load

ABSTRACT

Pressure to conserve energy in commercial buildings is increasing in order to meet nationwide greenhouse gas reduction targets. In the commercial building sector, multi-tenant buildings are common, where offices often receive yearly electricity bills based on their occupied floor area and not actual electricity consumption. This results in diffused responsibility for electricity consumption and little to no usage feedback or incentive to conserve energy. In this study, two office towers in Eastern Ontario installed submeters to accurately bill tenants for their electricity use. One year of tenant plug and light electricity use gives insights into and valuable high-resolution data for office electricity use across 32 submetered commercial building floors. Results find that commercial tenant electricity use, between tenants, is highly variable; that tenant controlled plug and light loads are lower than ASHRAE design values; and, that tenant plug loads are not fully shut off at night. Electricity use feedback is also assessed anecdotally for its impact on tenant energy use behaviour. The ideal level of submetering is discussed for the purpose of providing useful electricity use feedback to tenants.

1. Introduction

In North America, the consumption of energy in buildings is increasing at a rate of 1.9% per annum [1]. Concurrently, many electricity distributers are in the process of phasing out carbon-intensive generation plants, such as coal burning facilities, to meet the United Nations Framework Conference on Climate Change (UNFCCC) Conference of the Parties 21 (COP21) goal to keep global warming below 2 °C [2,3]. A greater understanding of how this energy is being used can inform designers, operators, tenants and owners on where energy conservation measures will trigger real change.

In Canada, office space has the fifth highest energy use intensity of buildings at 333 kWh/m^2· year, after food stores, hospitals, nursing homes and hotels [4]. Offices can be a strain on the electrical grid, especially in summer with air conditioning driving peak electricity demand, where 78% of Canadian offices use electricity for space cooling, the remaining offices are equally divided between no space cooling and alternative energy sources [4,5]. High plug loads caused by computers, printers, small servers, and kitchen appliances contribute to overall office electricity use and can be a major driver for cooling loads, compounding the need for office energy reduction [6].

Reducing electricity use in offices can be a challenge for individual tenants who may only receive electricity use feedback once per year. Many offices do not have adequate metering to analyze wasted energy, creating a challenge to identifying the most effective energy saving opportunities. Currently, only half of commercial tenants in the US are directly responsible for paying for their electricity use, this is due to the lack of installed submeters, and in some regions, due to electricity billing legislation [7]. Fortunately, regulations that encourage commercial submetering are becoming more widespread; in the US, submetering is required on all federal buildings and in the EU, submetering is encouraged in all new and renovated buildings [8]. Current regulation is transitioning towards mandatory end use metering in all public and private buildings. For example, in Seattle, commercial buildings over 1858 m^2 require metering on all end uses, including tenant light and plug load metering [9].

Research results on typical commercial energy use is highly varied. Office building total energy use intensity has been measured to range by a factor of 10, from 100 to 1000 kWh/m^2· year [10]. Another study, focused solely on high performance buildings found energy use varied by a factor of six in the US and a factor of four in the EU [11]. Occupancy levels are a significant driver of varia-

* Corresponding Author.
E-mail addresses: isis.bennet@carleton.ca (I.E. Bennet), liam.obrien@carleton.ca (W. O'Brien).

http://dx.doi.org/10.1016/j.enbuild.2017.08.050

tion between buildings; at the building level, increased occupancy results in a higher EUI but lower energy per occupant [12]. Office energy use intensity can vary depending on a number of additional factors, including the building's occupied hours, activity type, climate zone, height and size [4]. Climate significantly influences the variance in energy use, a result of space conditioning; this is indirectly controlled by tenants through temperature setpoint requests and hours of operation. Li and Hong [11] found that buildings in a cold climate (ASHRAE climate zones 6–7) on average perform worse at 184 kWh/m^2· year than in a hot climate (ASHRAE climate zones 1–3) with an average of 126 kWh/m^2· year.

Comparing existing research on commercial electricity use can be a challenge due to varying sample sizes, observation periods and granularity of data. Some studies determine electricity use through surveys, calibrating self-reported equipment use patterns [13,14]. Other studies collect electricity use on a few devices or individual offices to generalize [6,15–17]. Manual data collection methods, including spot checking and observing equipment usage can collect only an instance of office electricity use [18,19]. Other studies have large data sets over years, but only have building level energy use that yields little insight to daily office electricity use [4,20]. Some existing research focus on only one type of office, such as academic or government buildings [15].

Plug load electricity is variable in an office setting and typically accounts for a significant portion of end use, from 13 to 44% [21]. In a study on small offices, plug loads accounted for 23% of the total office energy use, and of this, 69% is computers, 17% equipment, 9% monitors and 5% other [22]. When analyzing individual private offices, Gunay et al. [15] found that plug loads varied by a factor of 40, between 10 individuals, due to chosen equipment and usage patterns. In an office setting, individual electricity use patterns can differ wildly, but when individual behaviours are aggregated, load profiles converge towards a consistent usage schedule [17]. During typical office hours (9:00-17:00), there is low load diversity, where individual electricity consumption occurs simultaneously, and instantaneous electricity use nears peak demand [23].

When approximating office electricity use, building modellers typically use an average plug load equal to or less than 10.8 W/m^2 [14]. The 10.8 W/m^2 plug load is recommended by ASHRAE for offices, but this value is considered high to allow for future changes in space use [24,25]. Research has suggested that this recommended plug load could be more than double observed plug loads [26]. Simply by having ubiquitous laptop use, the peak plug load could be as low as 2.7 W/m^2 [24].

In a study on energy modelling professionals and researchers, 44% of participants believe that discrepancies between modelled and actual building electricity use can be attributed to occupant behaviour [27]. A better understanding of office plug and light loads through post-occupancy evaluation (POE) can narrow the difference, to 6%, between modelled and actual use [28]. However, for building design, such detailed studies cannot be performed prior to construction if tenants and their equipment are undefined.

Occupancy schedule and behaviour is a major variable influencing plug and light loads [28]. In recent years working hours have become less consistent, with a quarter of employees working from home part-time, resulting in less predicable office load schedules [29]. Adding to the difficulty of estimating office plug loads, servers can now be found in over half of commercial office spaces, and they are often included with submetered plug loads [20]. However, such servers are often served by their own cooling system (separate from the main equipment). Thus, servers should not be included when using plug load predictions to size main building cooling equipment.

There are many energy saving opportunities in offices. One of the simplest is reducing plug loads during unoccupied hours or simply reporting the unoccupied end use fraction [30]. These unoccupied loads can be as high as 75% of total plug load electricity [15]. Encouraging occupants to turn off computers can result in energy reductions in some offices, where 20–40% of computers do not get turned off, but for some employees this would interfere with remote desktop use [13,15,18].

Energy use behaviour can be identified with non-intrusive monitoring systems that determine the load type and behaviour based on electricity use patterns [31]. These monitoring systems can identify energy saving opportunities, for example, if equipment is being left on when not in use. In an office with plug load meters on all office equipment, 90% of interactions with these appliances were correctly predicted through automated interpretation the interval data [17]. Recording occupancy data through sensors or Wi-Fi can give further insight into electricity use, but can infringe on occupant privacy [32,33]. If the metering data is increasingly coarse then these systems have greater difficulty producing useful information [31]. To identify individual office equipment use, data sampling at one minute intervals may be required, with reduced accuracy at 10 min intervals [34]. In addition, these systems must provide electricity use data as actionable items for office managers in order to effectively reduce energy [35].

Metering a whole building at the individual outlet level can be expensive and understanding every action in a workplace may be excessive when looking for significant energy reducing interventions. Metering at too low of a spatial resolution (e.g. building level) does not provide enough information or insight into energy use behaviour.

The objective of this paper is to provide new insights on predicting plug load schedules, magnitudes, and peak loads for use by building modellers, energy managers, and property managers – using a comprehensive high-resolution dataset from 32 office building floors. First, the methodology outlines the available data, submetering layout and high-level analysis methods. The results compare the case study buildings to the existing research and the discussion section makes further analysis based on anecdotal observations. This study provides new insights on whether existing plug load models reflect current office electricity use patterns and makes recommendations on the appropriate level of submetering for a commercial application.

2. Methodology

Commercial tenant electricity consumption was collected for a period of one year (01-01-2016, 31-12-2016) by Measurement Canada-certified meters (ensuring accuracy and reliability) located in two multi-tenant commercial buildings. Electricity consumption was recorded at 15-min intervals and analyzed with both 15-min and one-hour interval data.

2.1. Case study buildings

Energy use data was collected from two commercial office towers in Eastern Ontario, Canada. These office towers have 43 tenants including: financial institutions, engineering firms, marketing companies, TV broadcasting stations, law firms, accounting firms, technology companies, embassies and other office types. Both towers are certified LEED Gold for existing buildings, BOMA BEST Gold (formerly Level 3) and achieved an ENERGY STAR score of 96 in 2015. Due to these certifications, the base building load in this study is expected to be lower than other buildings of the same size. The building certifications do not directly affect the individual tenant electricity consumption, although it is possible that there is self-selection bias where a disproportionate number of environmentally conscious tenants choose to lease within Tower A and B.