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Low-Investment Energy Retrofit Framework for Small and Medium Office Buildings

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Abstract

Small and medium office buildings consume a significant parcel of the U.S. building stock energy consumption. Still, owners lack resources and experience to conduct detailed energy audits and retrofit analysis. We present an eight-steps framework for an energy retrofit assessment in small and medium office buildings. Through a bottom-up approach and a web-based retrofit toolkit tested on a case study in Arizona, this methodology was able to save about 50% of the total energy consumed by the case study building, depending on the adopted measures and invested capital. While the case study presented is a deep energy retrofit, the proposed framework is effective in guiding the decision-making process that precedes any energy retrofit, deep or light.

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Keywords: Retrofit, office buildings, energy, HVAC, plug loads, MELs.

1. Introduction

About 40% of the total primary energy consumed in the U.S. is consumed by buildings. Commercial buildings account for 18% of the energy consumed in the U.S. [1]. Small and medium commercial buildings (smaller than 50,000 sf) account for 95% of the total commercial buildings in U.S. They consume 47% of the commercial

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buildings' energy consumption [2]. According to the Commercial Buildings Energy Consumption Survey (CBECS), the main electricity end uses in commercial buildings are lighting (37%), Heating, Ventilation, and Air Conditioning (HVAC, 30%), and miscellaneous and electronic loads (MELs, 19%) [9]. More than 45% of the total energy consumption of small and medium commercial buildings can be saved by an energy retrofit [3]. However, these buildings' owners usually do not have enough resources or experience to perform a detailed energy audit [3].

A bottom-up methodology is a low-investment alternative for a detailed energy audit. It consists in collecting equipment power consumption data and users' activity patterns to estimate the plug loads energy use for each type of device [4]. When it comes to a retrofit analysis, there are several web-based energy retrofit toolkits. The Commercial Building Energy Saver (CBES) is one of the most comprehensive available toolkits. CBES provides quick and reliable results based on building-specific input data.

The objective of this paper is to develop a low-investment framework for selecting energy retrofit strategies to small and medium office buildings, using a combination of the bottom-up methodology and the CBES toolkit. An office building in Arizona was selected as case study to validate this framework and assess its potential savings. Although relatively simple the methodology is thorough, which increase the reliability of the results.

Miscellaneous and electronic loads (MELs)

The Miscellaneous and Electronic Loads (MELs) include the plug loads (electronic appliances' loads), elevators, cooking, and refrigeration equipment [4]. Plug loads are expected to account for 49% of total electricity use in 2030 [5]. Indeed, in a building with high efficiency systems, the MELs can represent more than 50% of the electricity use [6]. Despite their growing importance, MELs still are not fully understood by researchers. User behavior and power management rates are areas that still carry a high level of uncertainty and need to be better understood [7]. The voluntary labelling program ENERGY STAR, developed by the U.S. Environmental Protection Agency (EPA), is one of the most successful strategies to reduce plug loads. In 2006, ENERGY STAR products saved 4.8EJ of primary energy [8], which corresponds to the total annual energy spent by about one million medium office buildings.

CBES online energy retrofit toolkit

SH Lee et al. (2015) wrote a review on 18 energy retrofit toolkits [3]. Among them, the Commercial Building Energy Saver (CBES) was reported as one of the most comprehensive toolkits. CBES provides a rapid and reliable retrofit analysis. Some of the results include energy costs, retrofit investment and payback in years, a group of suggested Energy Conservation Measures (ECM) based on the user's inputs, and the Indoor Environmental Quality (IEQ) impact for each ECM. In addition, CBES includes the rich database of energy efficiency performance (DEEP), which is compiled from the results of approximately ten million Energy Plus simulations [3]. This study uses CBES for the aforementioned reasons, as well as the applicability of CBES to small and medium commercial buildings.

The case study

To serve as example for this framework, the authors apply it to a medium-size office building in Arizona. Thirty percent of the building is occupied by classrooms. Built in 1966, the building was retrofitted in 2008 and earned a USGBC LEED Silver certification. The retrofit was focused in water and material efficiency measures. The only retrofit energy measure was to install occupancy sensors for the lighting system and add renewable energy systems. Although LEED Silver certified, the case study achieved only 3 out of 17 points in the Energy and Atmosphere category.

2. Methodology

This paper presents an eight-steps low-investment methodology for identifying energy retrofit opportunities in small and medium commercial buildings. We illustrate the effectiveness of this method using a medium office building as a case study. The method is intended to be simple enough to be used by either architects, engineers, project managers, and building owners with no necessary background in programming or specific software. The data analysis requires Excel Spreadsheets and the CBES online retrofit toolkit for energy conservation measure (ECM) suggestions and costs.

3. The Framework

Before the analysis: collect the data you need

The first step is collecting reliable data about the current condition of the building to be retrofit. The more reliable the data, the fewer the assumptions that will have to be made, and thus, the results will be more reliable too. The facility manager (or the building's owner) will provide information such as the operational schedules of the building, the year of construction, gross and net area, and the energy bills. If the floor plans are available and represent the current building's condition, they will provide information about the building materials and fixtures. Retrospective energy data helps in the analysis of the trend of building energy consumption over time and identify unusual behaviors. All the other data can be collected for a one-year period, covering the previous calendar year.

The next step for data collection is collecting field data (not provided by the floorplans – e.g. the number of electric appliances in the building and their power consumption). The HVAC equipment consumption data can be found on the "nameplate" that documents relevant information about the equipment. After collecting field data, an important stage is to collect data from similar buildings in the same region. Publicly available databases can be used for this purpose. In the U.S., the Commercial Buildings Energy Survey (CBECS) includes the average energy data for commercial buildings by region [9]. Though CBECS was used in this case study, the latest available data is from 2003, and the numbers likely have changed since that data was collected. The CBECS 2013 is to be published soon. The most important information to get from these databases is: 1) The Energy Use Intensity (EUI), the Electricity Energy Intensity (EEI), and the electricity consumption by end use.

Sometimes, due to time limitations, it is not possible to collect individual power consumption data from each electric appliance in the building. When this is the case, it is possible to refer to public databases. The best option is to get as much data as possible from a single and reliable source. The U.S. Department of Energy (DOE) publishes the Building Energy Data Book, which averages the existing data for each equipment type [10]. If the building has ENERGY STAR appliances, the ENERGY STAR website is also a reliable data source. For equipment that is not listed in the Building Energy Data Book, a good option is to search into the manufacturers' website.

The next sections present the eight steps for the analysis of the data collected. Ideally, the steps should be followed in the order presented to maintain the logical flow of analysis. However, the order can be altered if data collection constraints arise. All data collected and analysed should be documented in an Excel (or similar software) spreadsheet with linked information between different tabs. This linkage allows the outputs to be readily modified in case an input changes. For the case study, the collected data correspond to the past four years of energy bills (2011-2014). Floor plants were not available.

Step 1: Compare your building with similar buildings

The first step for this data analysis framework is to collect general data about the building and compare it to similar buildings or to an average provided by a public database. The most important data in this step is the Energy Use Intensity (EUI) and the Electricity Energy Intensity (EEI). Comparing the EUI and EEI with the average EUI and EEI of commercial buildings of the same type in the same region can identify retrofit needs: if the building whether it consumes much less energy than similar buildings, it likely will not need retrofit. If the building consumes more energy than its peers, or if the building is about average in terms of EUI and EEI, the building is likely a good candidate for retrofit.

Table 1: Building's summary and comparison with similar buildings in the neighbourhood. Data from 2014.

Information	Case Study	Building A	Building B	Building C	CBECS 2003 (U.S. West)
Year	1966	1950	1969	2005	
Gross Area (sf)	51,742.00	44,203.00	94,717.00	163,959.00	
Net Area (sf)	25,896.00	25,650.00	52,672.00	78,245.00	
% classrooms	29%	36%	25%	0%	
% office	70%	52%	64%	65%	
% research	0%	0%	2%	0%	
% class lab	0%	0%	6%	0%	
EEI (KWh/sf/year)	21.05	7.93	14.20	11.82	15.40
EUI (KBtu/sf/year)	173.35	48.03	65.82	51.41	93
Electricity (KWh) %	20.73%	33%	41%	37%	
Heating (mmBTU) %	26.62%	-	2%	-	
Cooling (tonHrs) %	52.66%	67%	57%	63%	

Both the EUI and EEI of the case study largely differ from the CBECS data and from similar buildings in the same university (Table 1). Also, the percentage of heating energy consumption of the case study is markedly inconsistent both with the other buildings' consumption and with the hot climate of Arizona. Given the clear opportunity for savings, the next step is to perform a deep investigation of the building's energy consumption.

Step 2: Analyze the energy bills

The building's energy bills provide information on the electricity consumption and other sources of energy, such as natural gas. The case study uses natural gas for heating purposes. The data collected from the case study's bills showed a very unusual consumption pattern. For instance, the building consumed 81.39mmBTU ($1,033.66) of natural gas for heating purposes in August 2012, when the outside temperatures in Arizona are higher than 100ºF (37.8ºC). In fact, the building consumed a total of 315.4mmBTU ($4,005.60) for indoor heating in the summer of 2012. In the last four years, the natural gas consumption sums up to 6,406.72mmBTU (more than $80,000.00), or approximately 1,600mmBTU/year.

In the case of an obvious issue with unknown cause like this, understanding energy consumption trends requires a qualified energy professional that will analyze the HVAC system and investigate the possible causes of unusual behaviors. For the case study, an energy manager listed possible causes for the peculiar natural gas consumption pattern: 1) Simultaneous heating and cooling (first cooling the air, then heating up again); 2) Overcooled spaces due to design issues (e.g., overestimated occupancy, overestimated amount of outside air); 3) Leaking chilled water valve; 4) Defective zone dampers; 5) Defective steam valve; 6) Defective steam traps; and/or 7) Defective steam metering. Five out of these seven possible causes are due to equipment maintenance issues. In fact, the HVAC system of the case study is almost fifty years old and would require frequent maintenance. In this case, replacing one single valve may save about $20,000 dollars a year.

Step 3: Analyze the HVAC equipment's electricity consumption

Besides the primary energy consumed for heating and cooling purposes, the HVAC equipment (e.g., motors) also consume electricity to operate. The motor's description label provides all information needed for finding the motor power consumption in Watts. Although an online converter can do the calculation in seconds, the equipment wattage can be obtained by the equation: P(W) = 1.732 x PF x I x V, where: P (W) = Power in Watts; PF = Power Factor; I = current (Amps); and V = line-to-line voltage in volts. Once the power is determined, the next step is to analyze the HVAC operational schedule data to calculate the total annual electricity consumption of the AHU (in kWh). In our case study, the single Air Handling Unit (AHU) has the power equivalent to 76.48KW and works during 5,022 hours a year, so its annual electricity consumption is 384,082.56 KWh.

Analyzing the HVAC operational schedule can also help to find some inconsistencies. In the case study, for example, it was noticed that twice a week the HVAC system started to work three to four hours ahead of the building's use schedule. This earlier operating hours were discussed with the energy manager, who explained that there is a need to start the HVAC early twice a week to reach comfortable temperatures for occupancy, due to the building's thermal mass issues. If his assumption is correct, a comparison between the costs of a retrofit on the thermal isolation systems and the energy saving costs is recommended. In the case study, these earlier hours summed up to almost 30,000 KWh (or $3,000.00) a year. Moreover, the HVAC system had no operational schedule specific for weekends, when the activities are reduced. Developing an appropriate weekend HVAC operating schedule for the case study can save up to 80,000KWh (or $8,000.00) a year.

As a result of the age of the HVAC system, the lack of adequate maintenance, and the lack of efficiency of the building's thermal mass, the HVAC equipment's annual electricity consumption is accountable for 70% of the building's total electricity consumption in 2014. This value is more than two times the average of commercial sector (30%) in the U.S. West Mountain region according the CBECS 2003.

Step 4: Analyze the lighting system's electricity consumption

Calculating the electricity consumption of lighting fixtures begins with collecting data on the number of fixtures, lamps per fixtures, individual lamp power consumptions, and lighting schedule (which can be assumed based on the building's operating schedule). The case study had occupancy sensors on the lighting fixtures; thus 30% of savings were assumed. Table 2 shows the calculation results for the case study.

Table 2. Electricity used for lighting purposes.

Location	**Qty fixtures**	**Qty lamps**	**KW**[1]	**Hours/ Year**[2]	**KWh**	**%**
Conference Rooms	46	92	0.015	1,560.00	2,152.80	4
Classrooms	75	150	0.015	2,880.00	6,480.00	12
Common Areas	239	478	0.015	3,160.00	22,657.20	42
Office areas	257	514	0.015	2,880.00	22,204.80	42
Total (KWh)					53,494.80	100
Savings in KWh (occupancy sensors, 30%)					16,048.44	
Total consumption with savings (KWh)					**37,446.36**	

[1] The case study has T8 (15W) fluorescent lamps. The building to be retrofitted may have several different types of lamps. In this case, a percentage of the total quantity should be calculated or assumed for each type of lamp.
[2] The hours/year are divided by each building location type (conference, classrooms, office, common areas), because each has its own schedule.

Step 5: Analyze the MELs' electricity consumption

Similar to the lighting fixtures, the MEL's need to be separated by location types (e.g., conference rooms, classrooms, common areas, and office areas), according to each operation hours. Figure 1 shows the comparison between the electricity consumption of each office appliance. Collecting data both for the active power mode and low power mode (or stand-by) improves the results' reliability. Based on the building users' behavior, it is possible to make assumptions about the percentage of time each appliance stays in each power mode. In this study, the assumptions were based on a survey made with the users' occupants.

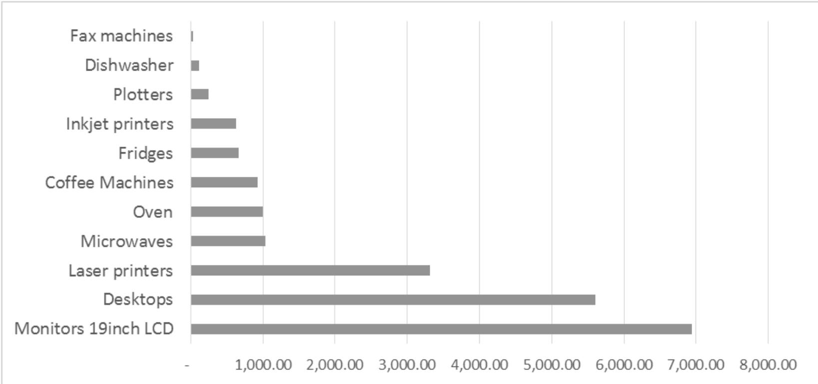

Figure 1. Comparison between office appliances individual annual consumption (KWh) for the case study.

Step 6: Measure the overnight loads (or phantom loads)

Whether there is a possibility to collect short interval data on electricity consumption or not, the overnight loads, also called phantom loads, should be measured or estimated. Some overnight loads include the elevators (in stand-by mode), fridges, HVAC equipment (if there is any stand-by loads), and other equipment not turned off at the end of the day. The measuring can be made during some days a year, enough to look for inconsistencies or potential for savings. Power management strategies can be very effective to reduce them. In the case study, overnight loads were accounted for approximately 86,000 KWh (or $8,600) a year.

Step 7: Summarize the total electricity consumption by end uses

As an example for this step, Table 3 summarizes the electricity consumption by end uses for the case study. The office areas were responsible for the largest part of the building consumption, as expected (offices account for ~70% of the building's floor area).

Table 3. Electricity consumption by end uses for the case study (2014).

MEL	**KWh**	**% total**	**CBECS 2003[8]**
office	20,449.39		
classrooms	2,970.02		
common areas	9,207.81		
conference rooms	1,354.51		
Total	33,981.73	6%[9]	16%
Lighting	**KWh**		
office	22,204.80		
classrooms	6,480.00		
conference rooms	2,152.80		
common areas	22,657.20		
Savings	30%		
Total	37,446.36	7%	31%
HVAC system	**KWh**		
AHU	384,082.56	70%[9]	40%
Overnight loads	**KWh**		13%

Total	86,215.38	16%	
Others	**KWh**		
Total	3,410.37	0.6%	
Total consumption (KWh)	**545,136.40**	**100%**	**100%**

[8] Data from the Tempe Climate Zone (Zone 5).
[9] Most of the MELs are ENERGY STAR certified, and most of the users turn off their appliances after work.
[10] The overconsumption of the HVAC system undermines the comparison of the other fractions with the CBECS data.

Step 8: Use a Retrofit Toolkit to Analyzing Potential Savings

The final step of the low-investment energy retrofit framework is inputting the collected data in a reliable online retrofit toolkit. For this case study, the Commercial Building Energy Saver (CBES, available at http://cbes.lbl.gov) was the chosen toolkit. Besides is one of the most comprehensive available tools and CBES offers the possibility of a low-investment analysis. In addition, based on the building's Gross Energy Use Intensity (EUI), CBES provides an ENERGY STAR score as a benchmarking tool. Though CBES offers significant benefits, it is still restricted to the California climate zones. The case study is located in a city in Arizona that belongs to the same climate zone as El Centro, in California. The zip code of El Centro was used in the input data.

Table 4 shows the CBES Energy Conservation Measures (ECMs) generated for this case study. The building received an ENERGY STAR benchmarking score of 8. A score of 75 qualifies the building for an ENERGY STAR certification, which confirms that the case study's EUI of 173.35 kBtu/sf is highly inefficient. Four of the five ECMs suggested by CBES are relatively simple and do not require detailed research. The plug load ECM, however, does require additional research, and it is also the most expensive. CBES does not provide an itemization for these final costs. However, this value may consider the replacement of some equipment. Power management strategies are no-cost measures that can reduce plug loads though. If the monitors, desktops, and printers were left on the stand-by mode at the end of the day rather than be turned off, the total MEL's electricity consumption would raise from 20 to 50MWh (250%). On the other hand, if the measures 12, 31, 33, and 36 (see Table 4) were adopted in the case study, a total of 502.28 MWh (26%) could be saved every year after an investment of $23,571.

Table 4. CBES analysis results for low-investment retrofit in the case study.

ECM	IEQ impact	Savings (MWh)	Cost (USD)	Payback (years)
#36 HVAC ceiling fans	The use of ceiling fans can maintain thermal comfort at higher temperature (28ºC or 81ºF, assuming 50% relative humidity).	223.34	10,316	0.3
#31 Lighting controls	Achieving good daylight control can be challenging because of the vast difference in lighting level preference among people. Automatic lighting controls allow occupants to manually override to ensure satisfaction.	107.76	1,784	0.1
#33 HVAC filter	Select low-pressure air filters that have the same or better particle removal efficiency; there are substantial health benefits by reducing indoor particle levels.	89.88	0	N/A
#12 HVAC economizer	Adding an economizer will increase time-average outside air ventilation, often by more than a factor of two. This can improve indoor air quality. In office settings, studies found that more outside air can reduce sick building syndrome (SBS) symptoms, and improve work performance.	81.30	11,471	0.9
#14 Plug loads [9]	-	65.71	25,871	2.4

[9] Efficiency upgrade (25% from baseline).

Finally, because this study has previously examined the detailed energy consumption, it is already known that: 1) some repairs in the HVAC system will lead to significant energy savings, especially natural gas savings (about 1600mmBTU/year), 2) a more efficient HVAC operating schedule will avoid unnecessary weekend hours, saving up to 80MWh/year, 3) investment in thermal isolation systems will reduce the need for the HVAC system in the earlier hours, saving another 30MWh annually, and 4) an investigation of the phantom loads can help to decrease the overnight consumption (86MWh in 2014). In theory, the savings identified by this framework in the case study building can save approximately 1300MWh (including natural gas) for the year of 2014, or 50% of the building's total energy consumption that year. However, some of these savings can be interrelated. For example, repairs on the HVAC consumption can help to reduce the overnight loads. Hence, these savings should not be treated as independent.

4. Conclusion

Performing an energy retrofit can be a great challenge for small and medium office buildings without many energy management resources. The framework presented in this paper allows building owners, project managers, architects, and engineers with no expertise in energy management to maximize energy savings and understand the building's energy consumption though a relatively simple but thorough bottom-up approach. With the assistance of a free online retrofit toolkit (CBES), the 8-step framework leads to significant savings. Although these savings vary depending on the building's specific conditions and characteristics, they can be as large as 50% of total energy consumption, as shown by the presented case study. This framework is recommended for small and medium office building owners who cannot invest in an energy audit or specialized professional. Larger and more resourceful office buildings are recommended to hire an expert team to perform a detailed energy audit and analysis that will lead to the most cost-effective retrofit solutions for the building.

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