A METHODOLOGY FOR REDUCING BUILDING ENERGY CONSUMPTION

Eric Leong
Cooper Union
New York, NY

Gregori John Tayco
Cooper Union
New York, NY

Advised by
Prof. Melody Baglione
Cooper Union
New York, NY

ABSTRACT

Buildings sector comprises a large portion of energy consumption. Internationally, it represents 32% of global consumption 41% of U.S. energy consumption. Therefore it is critical to focus on the reduction of energy usage in existing buildings for reducing global energy consumption. This paper focuses on The Cooper Union's LEED Platinum certified academic building, 41 Cooper Square.

By observing its energy consumption, areas with the greatest potential for energy savings can be monitored to improve operational use and reduce energy usage. This paper examines different methods to characterize energy use and from this propose strategies to reduce consumption. Though this process was applied to 41 Cooper Square, the procedure is designed to be applicable to other building systems.

INTRODUCTION

Internationally, building energy consumption represents 32% of global use and 41% of U.S. use. Similarly, the United Nations Environment Program found that residential and commercial buildings consume approximately 60% of the world's electricity. In addition, the building sector is the largest contributor to global greenhouse gas emissions, another adverse impact of energy production from fossil fuels. And since buildings in developed countries tend to consume more energy than those in developing countries, it is critical for new building construction to be energy efficient.

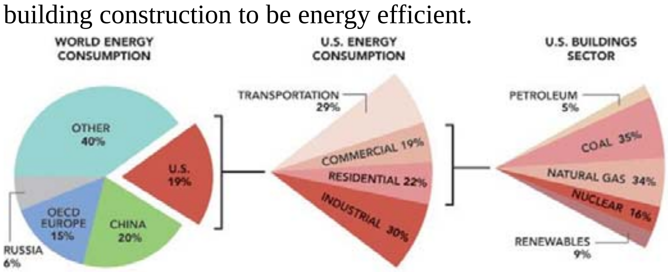


Figure 1 Breakdown of World Energy Consumption

The Leadership in Energy and Environmental Design, or LEED, is a rating system that guides the design, construction, operation, and maintenance of green buildings. Developed as a third-party certification system by the U.S. Green Building Council (USGBC), the system awards credits across different categories that reflect important features of green buildings. The main categories include: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation in Design. Buildings are awarded points for the features that are included in the building's development and are classified by the accumulated credits, the four levels of certification being: Certified, Silver, Gold, and Platinum.

However observing the performance and efficiency LEED certified buildings, 28-35% of LEED buildings actually using more energy than their conventional counter parts. Additionally it was found that LEED buildings had little correlation with their measured energy performance. Though LEED may be influential in the making of green buildings, the LEED system does not account for post-construction operation. To accurately evaluate a building's performance, post occupancy evaluations (POE) are necessary to determine how efficiently energy is consumed by the building. Though energy use within the building was designed with a specific intent, building operation following construction may not have necessarily have been the same.

41 COOPER SQUARE

41 Cooper Square is a LEED Platinum-rated academic and laboratory building located in downtown New York City, and primarily serves as the engineering building of The Cooper Union. Its 187,000 sq ft is composed by nine floors with two lower levels, with a terrace and roof garden on the 8th floor. The building is powered using electricity and natural gas, which feed into the different subsystems that make up the building's demand for energy.

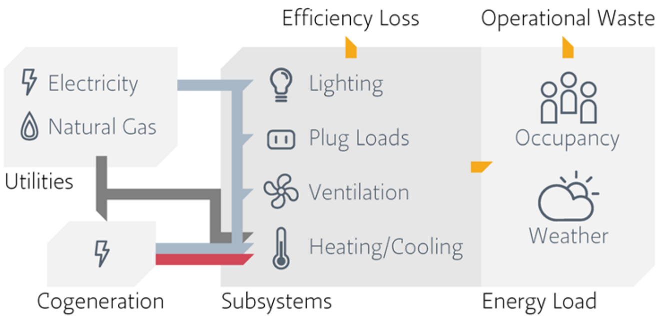


Figure 2 Energy Consumption Breakdown of 41 Cooper Square

Figure 2 shows the general breakdown of energy use of 41 Cooper Square. It is a gas heated, electrically cooled facility with a cogeneration plant. The cogeneration plant uses natural gas to produce electricity for the building, as well as utilizing the waste heat that is also produced. The main components of energy consumption in 41 Cooper Square are lighting, plug loads, ventilation and heating/cooling (HVAC).

BUILDING MANAGEMENT SYSTEM

41 Cooper Square has a Building Management System (BMS) that allows the operation and adjustment of equipment from a remote location. 41 Cooper Square's BMS, Siemens Insight workstation, provides information on the weather, building systems such as cogeneration, chilled water, hot water, lighting, ventilation, etc. as well as record the data to monitor past trends. Operational set points can be observed for every sensor, classroom, laboratory, and office.

METHODOLOGY

The number of factors that energy consumption can be analyzed through is daunting, and the goal of this methodology is to define metrics and profiles that reveal inconsistencies in building operation. In an ideal world, a process for reducing building energy usage would be as methodical as a textbook. But in the real world, data is missing, sensors are miscalibrated, and occupants are unpredictable. This project focuses on finding energy-reducing improvements by analyzing relatively easy-to-obtain data from an existing building management system. The process starts with a summary of the entire building, revealing the relative usage between the different subsystems. Then using energy profiles, inconsistencies in energy consumption are explored, which finally leads to a more detailed investigation of troubled subsystems. This process is summarized in Figure 3.

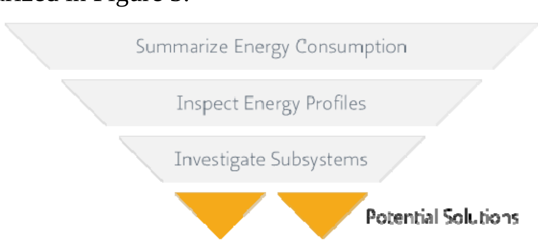


Figure 3 Summary of Methodology

ENERGY CONSUMPTION SUMMARY

In the base level assessment, the total consumption of the building was analyzed. This level looks at overall energy data of the building to give a general idea of how energy is used. In addition, the building can be roughly compared to other buildings, to understand on a basic level how efficiently energy is being used. This assessment addresses two factors in building performance comparison: size and function.

Source Energy Use Intensity (EUI) values for 41 Cooper Square are shown in Figure 4, as compared to the median average of colleges and universities nationally. Figure 4 also indicates a 44% and 54% greater source EUI for 41 Cooper Square in 2012 and 2013, respectively, which suggests that significant improvements in energy efficiency are possible. Though clearly indicated that there is potential savings, a closer analysis on building operation is needed to pinpoint exactly where these savings can be taken from.

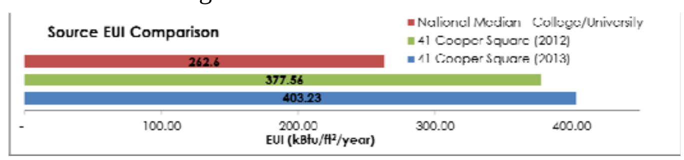


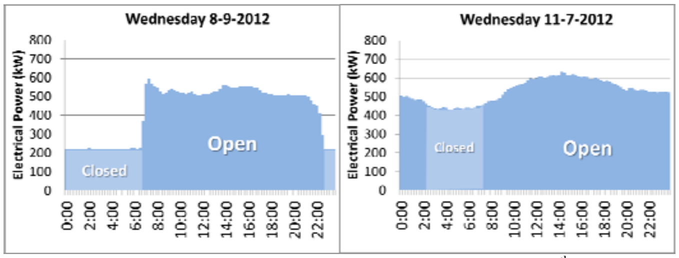
Figure 4 Source EUI Comparison of 41 Cooper Square in 2012 & 2013 to the National Median College/University

ENERGY PROFILE INSPECTION

Secondly, energy profiles of the building were inspected. Energy profiles show how building energy is consumed over varying intervals of time, such as the course of a day, week, month, or year. By monitoring energy profiles, general trends can be observed during the time intervals and can determine if the loads are appropriate for the particular period. Also by observing the profiles, it can be determined what equipment should be operating and why it should be operating, allow the identification of areas of potential waste energy.

DAILY ELECTRIC PROFILES

In Figure 5, the daily electrical use profile (EUP) of 41 Cooper Square shows two distinct periods of energy use: closed and operational building hours. Peak energy use occurs during operational hours 7AM to 9PM, while closed building hours during the other periods of the day. This particular EUP shows that during closed building hours, electrical consumption reduces to about 38% of the peak daily consumption. During closed hours, since the building is unoccupied the energy needed to maintain conditions during operational periods are no longer necessary. Hence the expected reduction occurs. Although there is a large reduction in consumption from closed and operational hours, there is still potential for even greater savings.



Figures 5 & 6 EUP for August 9th, 2012 & November 11th, 2012

In contrast, the EUP for November 11th in Figure 6 shows a different profile. Though the operational hours shift to 7AM to 2AM, during the closed building hours, electrical use only reduces to about 70% the peak daily consumption. Though the window is much smaller, there is still the ability to heavily reduce consumption (as seen in Figure 5), and indicates there is possible waste and a large potential for energy savings. Though it may not be a significant amount over the course of a day, there is large impact over time. Generally, 41 Cooper's daily EUPs are fairly irregular and show little correlation with the building operational hours.

WEEKLY ELECTRICAL USE PROFILE

After observing how energy is consumed hourly over the course of a day, the next step is to observe energy use daily over the course of a week. Figure 7 shows daily electric consumption of 41 Cooper Square for 5 weeks starting from Sunday September 9th, 2012. As seen by the figure, weekdays are differentiable from the weekends by larger and smaller facility accesses, respectively. Further, it also shows a weak correlation between electrical usage and occupancy. Specifically, though electrical usage generally varies with occupancy during the weekdays, during weekends though occupancy reduces electrical consumption remains high.

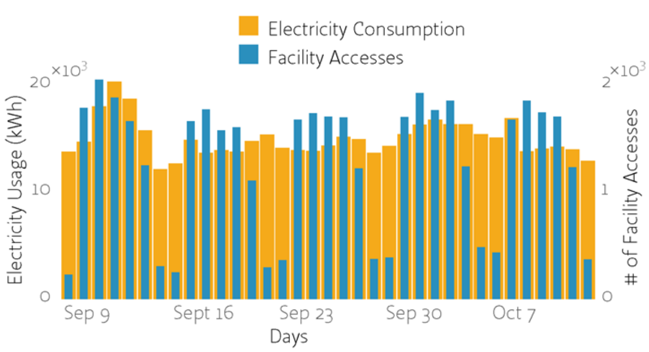


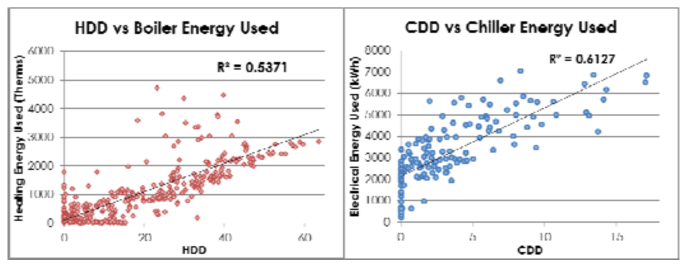
Figure 7 EUP for Weeks of September 9th to October 7th, 2012

Like the previous example showing there is large consumption of energy during low occupancy periods (closed building hours), again there large consumption though the low occupancy period focuses on weekends where there are fewer occupants within the building. Again similar to the previous example, this high usage can be attributed to the operational level of a fully occupied building run at a low occupancy period. Both examples of daily and weekly energy use profiles show there is a large potential for energy savings by reducing consumption during periods of lower occupancy.

WEATHER NORMALIZATION

In addition to observing energy usage with respect to building occupancy hours, another important factor that drives building consumption is the outdoor air temperature. As previously mentioned, a large portion of building energy is used for HVAC to maintain the Indoor Environmental Quality (IEQ).

Degree days help to relate daily temperature to the demand for energy to heat or cool a building. To calculate a Heating Degree Day (or Cooling Degree Day), the average of the day's high and low temperature is subtracted (or added) to a reference of 65 degrees F. Figure 8 shows the correlation between Heating Degree Day (HDD) and energy used for heating. Figure 9 shows the correlation between Cooling Degree Day (CDD) and energy used for cooling in 2013.



Figures 8 & 9 Daily HDD/CDD Correlation to Heating/Cooling Energy Consumption 2013

As shown, when comparing daily HDD/CDD to the daily energy used for heating/cooling 41 Cooper Square, there is little correlation. In Figure 9, the daily CDD analysis shows a better overall correlation, though in Figure 8, the daily HDD analysis has a general linear trend with a few outliers that show greater heating energy use. Overall, a daily HDD/CDD analysis of 41 Cooper Square shows relatively dispersed data points implying the difference in air temperature weakly influences the energy used for temperature control of the building. However using a broader time scale analysis helps average outliers to better correlate data. Seen in Figure 10, HDD are better represented using weekly reporting, though week CDD analysis shows little correlation as with daily CDD analysis, in Figure 11.

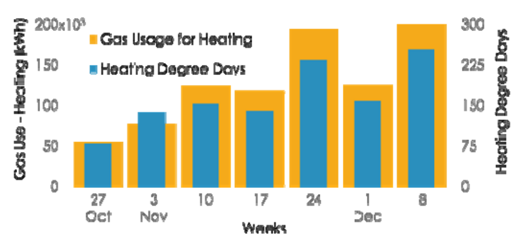


Figure 10 Weekly HDD Correlation to Heating Energy Consumption

Figure 11 Weekly CDD Correlation to Cooling Energy Consumption

WEATHER-OCCUPANCY NORMALIZATION

To better correlate weather data, occupancy data was also considered and analyzed simultaneously. This metric, "degree occupant days," accounts for both thermal and occupant loads in a single analysis. The data from Figure 7 was used for a daily CDD – occupant analysis. The results in Figure 12 show better correlation when analyzing daily electrical consumption of weekdays and weekends separately. The data from the weekdays and weekends shows strongly correlated data between electrical energy used per degree for every occupant, better than correlation of just degree days. Most importantly, weekend data shows a greater amount of electricity being used per degree per occupant as compared to weekdays, due to the few occupants distributed throughout the building.

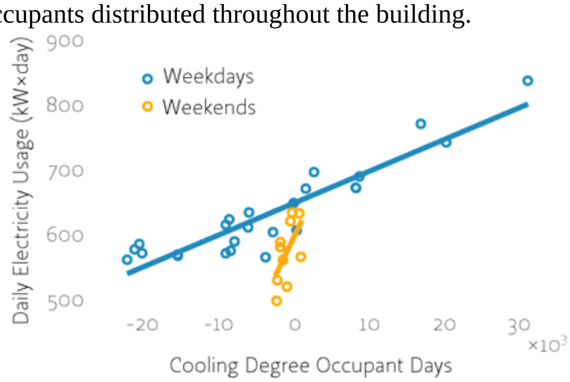


Figure 12 Cooling Degree Occupant Day Analysis

METHODOLOGY

Finally individual subsystems were analyzed to ultimately determine where energy consumption can be improved. Using the information gathered from the previous analyses, the ventilation system was observed to be a large portion of the energy usage by the air handlers located on the subcellar and roof, as noted in Figure 13

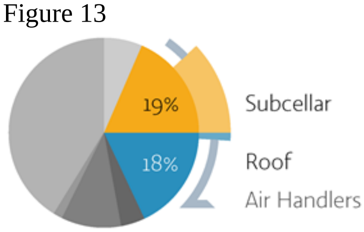


Figure 13 Energy Breakdown by Location of 41 Cooper Square

Observing the daily EUP of the air handlers over a 12 month period shows relative constant use of energy throughout the day, as seen in Figure 14. However, what was also observed were operations for air handler 03, which provides ventilation for the offices and classrooms for the basement and floors 1 and 2. Figure 15 shows that in middle of November 2013, air handler 03 was able to shut off operation during closed building hours and continue functioning as such through the rest of December, though in January 2014, operation becomes mainly constant once again. Knowing some of the air handlers can function at this level shows that closed building hour operation is generally left the same as open building operation and that there is in fact a large potential savings that is possible to extract.

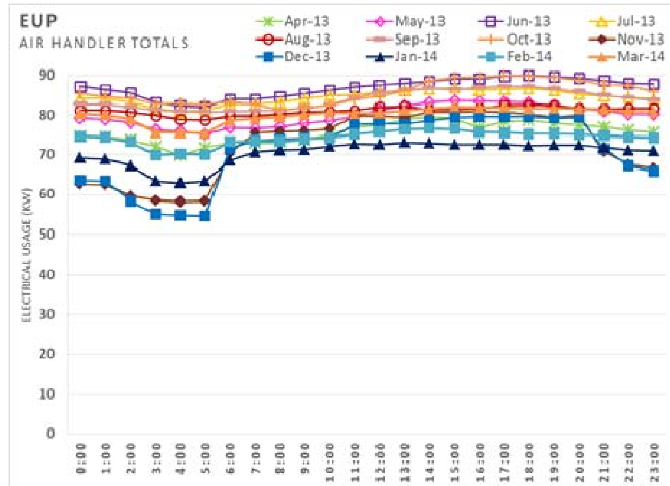


Figure 14 EUP for Total Air Handlers

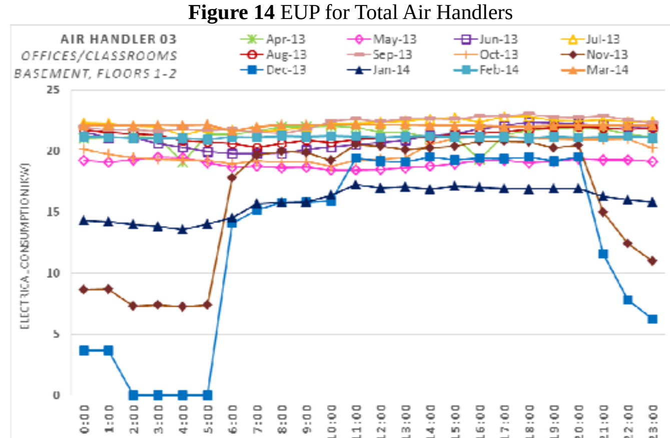


Figure 15 EUP for Air Handler 03

By reducing nighttime consumption to reduced levels discussed previously, as shown in Figure 16, there is potential to save about 23.6% of energy used by ventilation, not including the associated energy from the heating and cooling of the air that is saved. Using this estimate and noting the similar operation of subsystems during the closed building period, this percentage can be used to estimate the savings subsystems which are also operated at a constant use throughout the day.

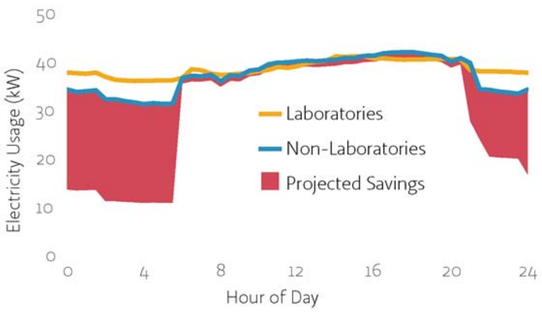


Figure 16 Projected Savings from Ventilation by Adjusting Closed Building Operation

RECOMMENDATIONS FOR IMPROVEMENT OF 41 COOPER SQUARE

The findings from the analysis show that a large level of energy is used during periods of low occupancy, specifically closed building hours and weekends. The recommendations provided detail a strategy to overcome the reported issues.

1) Reduce overall energy demand by modifying set points and adjusting by season and time of day.

By reducing temperature set points (lowering temperatures in the winter / raising temperatures in the summer) the demand on the boiler of chiller system is also reduced, thus reducing overall energy usage. The level of reduction can be determined by slowly reducing set points and determining comfort levels at every reduction so IEQ is still maintained.

Additionally, since IEQ does not have to be maintained during closed building hours, set points can be further reduced during this time period. The level of reduction can be determined through slow, gradual reduction of the set points while still being able to reach operational levels the following day. Similarly for weekends with a smaller occupancy load, energy used for HVAC should gradually be reduced while still maintaining necessary IEQ.

2) Reclassify spaces that aren't used as laboratories to reduce ventilation loads.

Laboratory spaces require constant negative pressure due to safety regulations, requiring large amounts of energy to maintain. However certain spaces provide beyond adequate ventilation and thusly reclassification could set appropriate levels of ventilation and laboratory energy use.

Additionally by reclassifying a space from a standard laboratory, a constant level of ventilation throughout the day may be unnecessary. Thus further reduction in ventilation could be attained during closed building hours, not only reducing energy from ventilation but as well as the associated energy from the heating and cooling of the air. Fume hoods that are not being used should be de-commissioned for further energy savings.

3) Retro-commission the building to operate at levels of design intent.

As stated previously, often facilities often undergo changes throughout its lifecycle and current building operations may differ from the designed operation. Retro-commissioning is a systematic approach to solving building problems relating to maintenance and energy management. Building equipment systems operation is closely examined, similar to the methodology outlined in this analysis, and compared to intended operation and maintenance procedures. A study by Berkeley National Labs study in 2009 found that retro-commissioned facilities resulted in 16% energy savings with payback time of 1.1 years.

By allowing the retro-commissioning of 41 Cooper Square, a more in depth analysis can be taken to find more savings potential in operation and ultimately resolve issues that are found.

4) Monitor energy use actively to avoid operational waste and track improvements.

Ultimately the most knowledgeable people of the facility operation can make the most informed decisions regarding which equipment needs to run and when. By tracking and monitoring energy use closely, especially during closed hours and weekends, facility managers can determine if equipment is operating as expected and if not, determine sources of waste and potential for improvement.

ACKNOWLEDGMENTS

Much of this work was completed in collaboration with other research involving 41 Cooper Square by the Mechanical Engineering Department of Cooper Union under the advisement of Prof. Melody Baglione.

Additionally, the following students are acknowledged—Janet Bulter, Daniel Moreno, Yudi Guo, John Rodriguez, and Polina Smirnova—for their contributions to this project.

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