Managing Energy Retrofits

Matthew Dahlhausen, The Pennsylvania State University

Mohammad Heidarinejad, The Pennsylvania State University

Jelena Srebric, The Pennsylvania State University

Seeking Energy Savings

Commercial buildings are major energy consumers, accounting for 19% of U.S. primary energy[1] consumption and 36% of electric use[2]. Globally, commercial buildings are responsible for 10% of energy-related greenhouse gas (GHG) emissions[3,4]. Retrofitting existing commercial buildings to use significantly less energy is an essential strategy for climate mitigation and energy security.

For the past several years, IFMA has partnered with Johnson Controls to assess the status of energy efficiency in the building industry. The market has significantly expanded in recent years and many facility managers and building owners are installing energy efficiency measures (EEMs) to reduce energy use in their buildings. This is primarily driven by a desire to save on energy costs, and EEMs are subject to a short investment payback period of 3-5 years. As a result, priority is given to the easiest and highest payback measures - lighting, control setpoints and schedules, building management systems, and HVAC system replacements[5].

The first bit of energy savings in buildings is highly lucrative, especially if it is the first time that a building's energy use has been scrutinized. Through simple measures like proper temperature setpoints for control systems, calibrating sensors, and lowering or shutting down equipment output during unoccupied hours, office buildings can easily reduce their energy use by up to 20%[6]. However, as energy savings targets become more stringent and easy measures exhausted, it becomes more expensive to get further energy savings[7]. At this point, professional experience is brought in, usually in the form of an energy audit, to determine further courses of action.

Professional energy audits are expensive, prohibitively so for the majority smaller commercial buildings, where the price of an audit can exceed the energy cost savings from the first year. Professional audits measure and savings costs are often inaccurate and inconsistent between different auditors. Audits are a "snap-shot in time" that will become obsolete as the building undergoes energy retrofits, changes in operating characteristics, and changes in building management.

A new generation of software tools has been developed to fill the need for measure identification without an audit and to assist auditors in measure selection. The intent of these tools is to increase adoption of EEMs to enable savings for individual building owners and contribute to long term societal efforts to curb GHG emissions. These software tools are typified as energy benchmarking tools, which compare a building's energy use to a set of similar buildings and make recommendations from what is known about that type of building, and energy audit tools, which help a facility manager or auditor to better determine

---

[1] U.S. Energy Information Administration. (2012). *Annual Energy Review 2011.*

[2] Urge-Vorsatz, et al. (2012). *Global Energy Assessment - Toward a Sustainable Future.* International Institute for Applied Systems Analysis, Laxenburg, Austria.

[3] U.S. DOE. (2012). *2011 Buildings Energy Data Book.*

[4] World Resources Institute. (2005). *World Greenhouse Gas Emissions: 2005.*

[5] Johnson Controls, Inc. & International Facility Management Association. (2011). *2011 Energy Efficiency Indicator IFMA Partner Results.*

[6] Pacific Northwest National Laboratory. (2011). *Advanced Energy Retrofit Guide:Office Buildings.*

[7] McKinsey & Company. (2009). *Unlocking Energy Efficiency in the U.S. Economy.*

EEMs to implement. While these tools are rigorous and robust for comparing and ranking buildings in relation to the current building stock, most don't consider the technically achievable potential of energy savings that may be important in the decision making process for building energy retrofits.

Thinking for the Future

In order to get greater energy savings, many energy efficiency experts have adopted an integrative design approach, called *deep* or *advanced energy retrofits*[8]. The strategy is straight forward: spend a lot on measures that reduce the need for heating, cooling, and ventilation in a building, and then recoup the cost through being able to significantly downsize the equipment needed to meet those loads.

In office buildings, internal gains such as lighting, equipment, and plug loads contribute to well over half of the cooling load, with sun shining in from the windows contributing to the rest[9]. In the heating season, these internal gains help offset the need for heating significantly, however, heating can be provided much more efficiently by other means. Heating loads are usually dominated by heat loss through windows and walls. Air infiltration can be significant as well, typically 30% of the peak heating load in heating climates[10]. The importance of various components of heating and cooling loads is highly dependent on the climate and type of building.

For some EEMs, reducing loads first is critical. Condensing boilers are an example. Condensing boilers extract extra heat out of combustion by condensing the water vapor in the exhaust gas, achieving thermal efficiencies over 95%, compared to 80% for a standard boiler. However, to be able to do this, the water returning to the boiler must be much cooler than is typical in a standard system. This lower water temperature reduces the capacity of radiators and heating coils that serve a space, meaning that the condensing boiler must run in the standard efficiency range to provide water at a high enough temperature to meet the peak heating load. While this effect is only important for a small proportion of operating hours, and may not be a problem given that systems are frequently oversized, it shows that possible energy savings can be lost by failing to consider how the building operates as a whole system.

The benefits of an integrative design approach are enormous, especially when done as riders to building renovation projects. Most of the building industry is focused on building renovation, accounting for 86% of the market, but little of that goes to energy efficiency projects[11]. Only 2.2% of building renovations included significant energy savings measures[12], meaning there is extraordinary energy and monetary savings potential that is current underutilized. It is worthwhile to have long term energy management plan so that EEMs are known in advance of deferred maintenance and renovation projects, to avoid missing the potential for significant energy and cost savings.

It can be cumbersome and tedious to deciding which EEMs to implement as part of a long term energy management plan, and often the savings are not assured. Here, energy simulation software provides a valuable means of testing retrofit options. Energy simulation is mostly used in the integrative design of new buildings, as it is especially useful to quickly test the impacts from changing building shape, materials, and systems. It can likewise be applied to plan energy retrofits, especially when combined with hourly energy data from a utility company to match what is happening in the building. Several simplified energy simulation interfaces are in development at the Energy Efficient Buildings Hub[13], sponsored by the U.S. Department of Energy, to assist architects, auditors, energy managers, and building owners in

---

[8] Pacific Northwest National Laboratory. (2011). *Advanced Energy Retrofit Guide: Office Buildings.*

[9] Huang, J., & Franconi, E. (1999). *Commercial Heating and Cooling Loads Component Analysis.* Lawrence Berkeley National Laboratory.

[10] Emmerich, S., McDowell, T., & Anis, W. (2005). *Investingation of the Impact of Commercial Building Envelope Airthightness on HVAC Energy Use.* NIST.

[11] Pacific Northwest National Laboratory. (2012). *Commercial Building Asset Rating Program Market Research.*

[12] Olgyay, V., & Seruto, C. (2010). Whole-Building Retrofits: A Gateway to Climate Stabilization. *ASHRAE Transactions, 116*.

[13] Energy Efficient Buildings Hub <http://www.eebhub.org/>

energy management. A key benefit of the simplified interfaces is that they do not require a professional energy auditor to be able to plan and track EEM performance over time, though that capability is there for those with such expertise. This also allows building owners and managers to easily incorporate energy planning as part of their building or portfolio management, allowing them to intentionally stage energy efficiency projects over a period of several years.

There are several advantages to intentionally staging energy efficiency projects instead of pursuing only best-payback measures first, or a one-off advanced energy retrofit:

- Realize greater energy savings over the long term
- Realize great peak electric load reductions
- Reduce the capital cost of major heating, cooling, and ventilation equipment if and when it needs to be replaced
- Avoid the need to remove obsolete building systems before end of their life
- Ability to meter data over time to measure actual building loads to allow for right-sizing building heating, cooling, and ventilation systems
- Open up the possibility for alternative, smaller HVAC systems, especially ones that may allow for more individualized control, as well as freeing-up space
- Avoid the capital intensive all-at-once retrofit to achieve best available technology, if such reductions become necessary

The major drawbacks of the staging approach are:

- Non-optimal short-term monetary payback for energy efficiency measures initially
- Near-term energy consumption remains higher than maximum achievable near-term reduction

A Case Study for Staging

An example of a staged retrofit through energy simulation shows the advantage of this approach. The building is a 50,000 ft^2 office building in Baltimore, MD (Climate Zone 4A), with pre-1980s building systems and equipment. For details, see *U.S. Department of Energy Commercial Reference Building Models of the National Building Stock*[14]. The building undergoes three energy efficiency measures:

1) Upgraded lighting fixtures, reducing the lighting power density to match current energy code, ASHRAE Standard 90.1 - 2010[15]. Further reductions are possible with daylight harvesting, dimming, and occupancy sensors, though these measures are not included in this case study.

2) Replaced windows constituting 33% of the building wall area with best practice windows used in new construction for the climate[16].

3) Replaced the cooling equipment to be more energy efficient, to efficiency standards recommended for new construction for the climate[17].

---

[14] Deru, M., et al. (2010). *U.S. Department of Energy Commerical Reference Building Models of the National Building Stock.*

[15] American Society of Heating, Refrigeration, and Air Conditioning Engineers. (2010). ASHRAE Standard 90.1-2010 - Energy Standard for Buildings except Low-Rise Residential Buildings.

[16] ASHRAE. (2011). *Advanced Energy Design Guide for Small to Medium Office Buildings.*

The goal of this example is to show the benefit from pursuing load reduction first, therefore measure costs are not considered. The measures installed are the same, so it is a matter of when, not if the measures are installed. If the reader wants costing estimates, the U.S Department of Energy's Advanced Energy Retrofit Guide for Office Buildings has cost figures for some measures[18].

Four cases are shown:

A) Baseline

B) Cooling equipment is replaced first, followed by lighting and window improvements, so the initial larger size equipment remains in place

C) The lighting and windows are replaced before the cooling equipment is replaced, so the equipment can be downsized to the reduced cooling load

D) The lighting and windows are replaced before the cooling equipment is replaced, and the equipment is right-sized to 10% excess capacity, rather than 33% assumed in the standard model

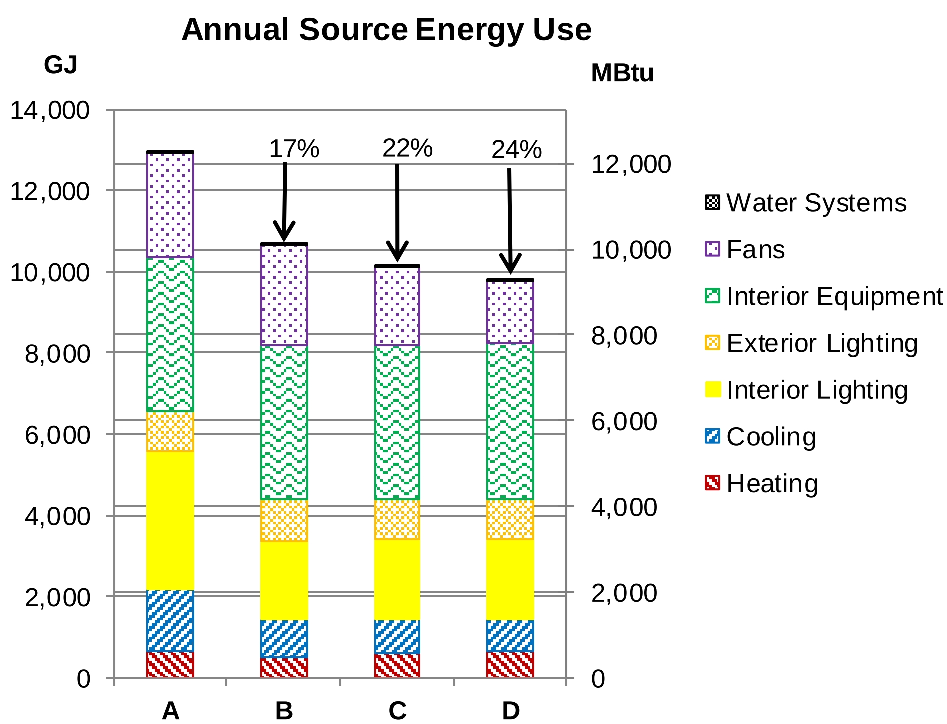

Figure 1 – Annual source energy use of the reference building. Source energy refers to the total energy consumption of the building, including all the energy it takes to deliver energy to the site as a result of electric grid generation, transmission, and distribution inefficiencies. Source energy is preferred over site energy, as it is more representative of energy cost and environmental impact.

[17] ASHRAE. (2011). *Advanced Energy Design Guide for Small to Medium Office Buildings.*
[18] Pacific Northwest National Laboratory. (2011). *Advanced Energy Retrofit Guide: Office Buildings.*

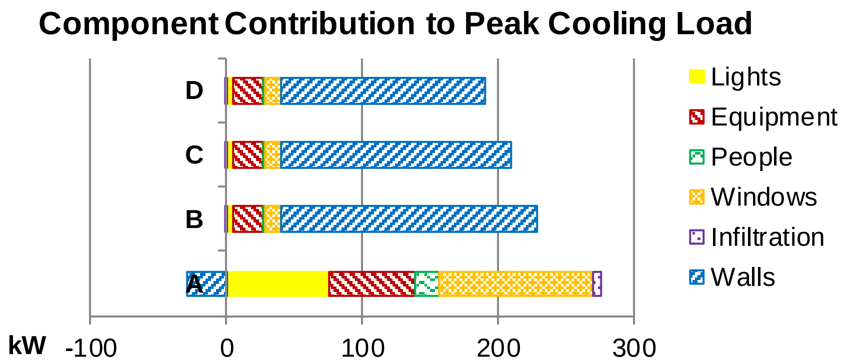

Figure 2 – Peak cooling load for the reference building. The window and lighting measures cause the peak cooling to shift from early afternoon on August 4th to early morning on June 26th in the simulation, thus the significant difference in component loads, especially wall conduction. This does not affect the design cooling load calculation, which occurs on July 21st.

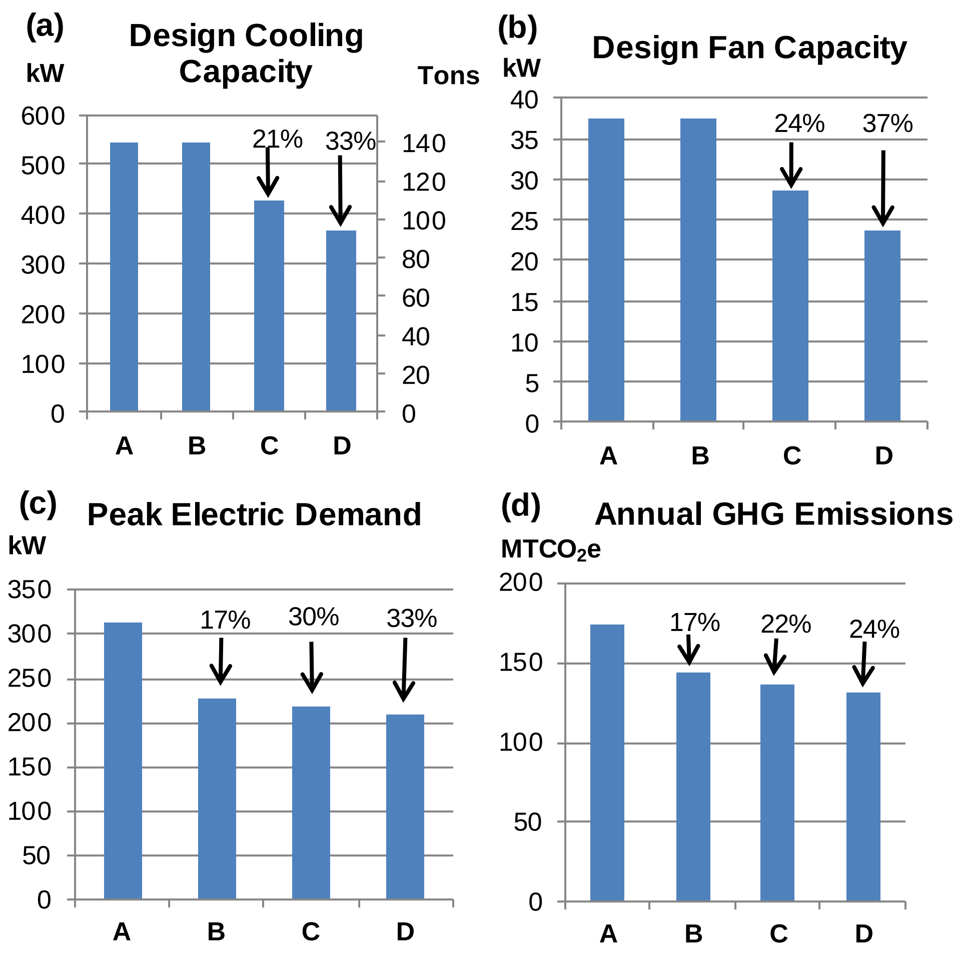

Figure 3 – Design cooling capacity (a), design fan peak rated power (b), peak electric demand (c), and annual GHG emissions (d) for the four cases.

This example shows that pursuing load reduction measures first through a staged approach significantly reduces equipment capacity requirements, especially when equipment is right-sized.

Some key questions to ask when developing an energy retrofit plan are:

- What are the main contributors to heating and cooling load over the whole year?
- Does heating or cooling dictate the equipment design capacity for ventilation equipment?
- What is the capital cost savings from smaller heating, cooling, and ventilation equipment?
- Do load reductions open up options to switch to another type of system entirely?
- How much excess equipment capacity does the building need?
- Will future changes in building use increase the needed heating or cooling capacity?

This case study building would further benefit from changing the ventilation from constant-air-volume (CAV) to variable-air-volume (VAV), and a switch to electric heat pump heating, making it possible to eventually run on renewable energy from the grid. It would also benefit from plug load management and behavior programs to reduce energy use, though those may be unreliable for the purposes of equipment sizing, and are not easily modeled in energy simulation software. Furthermore, energy simulation tools are unable to capture the impacts of operation and maintenance on a building. In reality, there can be significant savings at low or no-cost from simple system checks and commissioning such as changing equipment schedule, calibrating sensors, and quickly diagnosing system failures such as dampers or valves stuck open or coil fouling. A robust maintenance and commissioning program should precede energy efficiency work as it is the cheapest energy savings, and will allow for more accurate estimations of future EEMs.

Conclusion

Staging EEMs as part of an energy management plan can provide significant savings beyond pursuing measures in isolation. In some cases, such as steam systems or space-confined urban centers, planning EEM deployment in advance may be the only way to achieve long-term energy savings and allow for the possibility to switch off of a fossil-fuel source, which is necessary to achieve the order of magnitude GHG emission reductions needed in the next several decades.

Acknowledgements

This material is based upon work supported by the Energy Efficient Buildings Hub (EEB Hub), an energy innovation hub sponsored by the U.S. Department of Energy under Award Number DE-EE0004261.