Small office buildings are often old houses, such as this one in Ithaca, N.Y. (circa 1954 at right, present day at left).

Energy Audits, Improvements In Small Office Buildings

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Large commercial office buildings[1] tend to be homogeneous in size and shape, but small offices come in a variety: old walkups, converted strip malls, newer single-story buildings, old schools, houses, and more. My hometown even has an old jail that was converted into a small office building, appropriately and fondly still called, "The Old Jail."

And while large commercial office buildings get a good bit of attention, small office buildings run the risk of being overlooked and underserved for energy improvements because of their size. But taken as a group, small office buildings are significant. If we loosely treat 25,000 ft^2 (2323 m^2) as the upper limit of "small," more than 90% of office buildings (by count) are small, representing 34% of all office floor space.[2]

Common traits between small and large offices include their main space types: primarily desk/office space, but also conference rooms, storage/filing, kitchenettes and break rooms, bathrooms, corridors, stairwells, copy/print areas, and computer rooms.

But with all the common traits, small offices are very different from large offices in their energy characteristics. Small office buildings tend to be envelope-dominated, with little interior core space, so envelope deficiencies and associated energy opportunities should not be overlooked.

Small office buildings typically do not have energy management systems, so control improvements need to be examined in a different way than for big buildings. Small office buildings also often use residential HVAC equipment, or small commercial equipment such as packaged rooftop units, almost all of which are direct-expansion cooling systems.

Chillers are virtually non-existent, and boilers are rare. This is the almost exclusive domain of small forced-air systems. Ventilation and economizer mode free-cooling tend to be a challenge for the very smallest equipment, as smaller unitary equipment (such as

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residential split systems that are so common in small offices) often do not integrate these functions.

Small buildings typically do not have specialty loads such as elevators or on-site transformers, and they have very few large motors.

There are operational and structural differences as well. Small buildings usually do not have on-site maintenance personnel who might be tending to energy systems. Buildings below 5,000 ft^2 (465 m^2) cannot be benchmarked in EPA Portfolio Manager, so tracking of energy costs may be less common. Almost all (more than 90%) small office buildings are one or two stories in height, whereas more than 50% of large commercial offices buildings are three stories or higher.

Small offices also often tend to be integrated as part of a mixed-use building, for example, as one floor of an apartment building, or as one section of a strip mall. Small offices are also often just old houses, with features such as pitched roofs and basements. This brings us back to the importance of envelope energy losses and improvement opportunities, as well as to the important emerging improvements relating to reducing distribution losses.

The energy audit challenge for small office buildings is simply that the small size makes for poor economy of scale. It is difficult to get in and out of a small building, and do a good job in the time needed to keep the energy audit cost down to a reasonable ratio of the annual energy costs of the building. We need to find cost-effective ways to serve these buildings. At least this is the perception.

In reality, a 5,000 ft^2 (465 m^2) building with \$15,000/year in energy costs probably warrants something better than a quick walk-through audit. But a small 1,500 ft^2 (139 m^2) building certainly is a challenge to serve cost effectively. This needs to be kept in mind as we develop energy audit approaches. And, just because small offices are small, does not mean that engineers are not involved in energy audits. In New York, audits for the state's program for small commercial buildings are done by a group of engineering firms, with the same firms also doing large commercial and industrial energy audits.

Let us look at available energy improvements in small office building energy audits, and then look at a case study where energy use was reduced by 60% in a small office building. What is possible? What is cost-effective?

Improvement Mix

A first group of improvements sounds similar to those for large office buildings: High-efficiency HVAC, controls, and high-efficiency lighting. Nothing new, right? Well, no, but it turns out we need to make a few adjustments for small offices.

To evaluate HVAC improvements in small offices, it is helpful to familiarize oneself with the classes and energy efficiency terminology of residential and small unitary HVAC equipment, such as seasonal energy efficiency ratio (SEER) and annual fuel utilization efficiency (AFUE). High-efficiency HVAC replacements can be an excellent and often simple improvement.

For small forced air furnaces, replacement with condensing furnaces is usually straightforward, and offers added benefits such as integrated variable-speed blower motors, typically referred to as electronically commutated motors (ECMs). Packaged rooftop systems still do not have integrated condensing furnaces, although we are seeing some development activity in that direction. Variable speed motors are now common in even small rooftop units. High-efficiency cooling also is an option, although less cost effective in the heating-dominated climates of the North, just as heating replacement is less cost effective in the cooling-dominated South.

For controls, the opportunities are also similar to those for large office buildings. As a building class, offices have extremely low hours of operation, averaging only 55 hours per week. So setback of temperatures during heating and cooling are critical. Without an energy management system, this is typically evaluated on the basis of savings with a programmable thermostat.

When we combine the low operating hours with the fact that offices have the highest occupant density of the any of 13 CBECS commercial building classifications (at 434 ft^2/person (40 m^2 per person), compared to 501 to 2,306 ft^2/person for the other 12 classifications [health care, food service, etc.]), we absolutely need to evaluate demand-controlled ventilation (DCV). For example, a small 3,600 ft^2 (330 m^2) office building with four occupants might need only 260 cfm (123 L/s) ventilation, according to ASHRAE Standard 62.1, but annual energy cost savings more than \$400/year still accrue if DCV is used. Therefore, the cost of DCV controls may be merited despite the building's small size.

For those small office buildings which rely on windows for ventilation, we're out of luck, but this will lead to a discussion of tightening the envelope, adding ventilation, and then applying DCV to the ventilation (increasingly called "build tight, ventilate right"). For rooftop units, DCV is often an off-the-shelf or retrofit option.

High-efficiency lighting is a solid improvement to evaluate, and generally follows the same methods as for large buildings. Start with 24/7 corridor and stairwell lighting, and move right on to the office lighting. But do not assume lighting that uses T8 with electronic ballasts means there are no opportunities for lighting improvement. Check lighting power densities on a room-by-room basis.

Take advantage of the full range of IES lighting recommendations of 30 to 70 footcandles (320 to 750 lux) for offices,[3] and see what lighting power density is possible down at that lower 30 footcandle (320 lux) level (which is more than adequate for offices where people are sitting at computers). (We really need a better term for reduced lighting power density. "Reduced lighting power density" just does not roll off the tongue, or speak to building owners. "De-lamping" is not bad, but still sounds like we are taking something away from the building, as does "Reduced overlighting." How about "right-lighting?")

Consider evaluating task lighting at one lamp per desk. A lighting evaluation is not done without full evaluation of lighting controls. A typical two-desk office with two or more light fixtures should have at least two light switches. There is no need for all the lights to be on in a partially occupied office.

Occupancy sensors (for example, integrated with bilevel fixtures) make sense for stairwells and corridors. Vacancy sensors (occupancy sensors that only turn a light off, but require a person to turn them on) are appropriate for print/copy areas, kitchenettes, conference rooms, and other areas where the lights do not need to turn on with every occupancy or where we do not want the lights to come on when people are just walking by the space.

Occupancy sensors also make sense in bathrooms and utility rooms such as filing and mechanical rooms. Occupancy sensors often work for outdoor lighting when used in combination with photo-sensors, so lights are kept off during the day.

Differences between large and small office buildings really get amplified when it comes to the building envelope. In small buildings, wood-frame operable windows dominate, compared to the typical metal-frame fixed windows in large offices. In small buildings, wood-frame walls dominate, compared to concrete and metal in large offices. And in small buildings, pitched roofs are frequent, and with pitched roofs come all the complexities of attics, and a set of energy losses which simply do not exist in flat-roof buildings. Finally, small office buildings often have basements, also with their own significant set of energy losses and improvement opportunities.

The good news is that small office buildings are small enough to use blower door tests to examine infiltration. Already common in residential energy audits, we need to take advantage of this great tool in small office buildings.

Blower door tests are good not only for measuring infiltration, but also for finding out where the infiltration is, and for guiding air-sealing, and for quality control on the finished project. A typical blower door test only takes an hour. Count two hours if more advanced diagnostics are done for harder to find air leaks. I predict that government and utility programs will start requiring blower door tests for all projects under 10,000 ft^2 (929 m^2), as has become standard for residential energy audits, because the information gained is so valuable.

Likewise, infrared scans, widely used in residential energy auditing, have a great place in energy audits for small office buildings. Infrared scans are useful not only for identifying conduction losses, but can also contribute to finding air leakage as well. Insulation is a major improvement for small office buildings, where it can be installed in uninsulated walls, attics, and basements.

Almost all offices have kitchenettes, and almost all kitchenettes have refrigerators, most of which are residential refrigerators. Evaluating replacement refrigerators is readily done with online databases of consumer refrigerators (e.g., www.kouba-cavallo.com/refmods.htm). For example, a typical old 1,200 kWh/year refrigerator can be replaced with an ENERGY STAR refrigerator rated below 400 kWh/year for under $500, with a simple payback of under five years. When evaluating refrigerators, it is important to pay attention to the size and number of refrigerators. Are all refrigerators needed? Can smaller refrigerators be used in the place of large refrigerators?

Vending machines are another common plug load in office buildings. Replacement ENERGY STAR vending machines are available, along with controls which can be retrofit to allow occupancy sensors to turn vending machine lights and compressors off. The EPA reports that high-efficiency vending machines are 50% more efficient than standard machines, and can save more than 1,700 kWh/year. Again, like refrigerators, go one step further and ask the owner if all vending machines are needed. Many small office buildings can simply use the existing refrigerator to cool drinks, and dispense with the vending machine, pun fully intended.

An interesting load in small office buildings is the domestic hot water. If the building only has bathroom and kitchen sinks, this load can be very low, in fact hot water is rarely used. So, instantaneous (and even point-of-use) water heaters can make a lot of sense.

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Case Study

A case study gives us some insight into what does and doesn't work with energy audits and actual improvements in a small office building. 109 South Albany Street, Ithaca, N.Y., was built around 1910 as a 1,625 ft^2 (151 m^2) single-family house. It was converted to an office building around 1980, serving as a doctor's office, as offices for a general contractor, as offices for a credit union, as the offices for our firm from 2002 to 2009, and currently as a multi-tenant professional office building, with offices for a diverse set of tenants: several environmental not-for-profits, an acupuncturist, a solar energy company, and a vet who does house calls.

	Electric Savings (kWh/yr)	Gas Savings (therms/yr)	Installed Cost	Annual Cost Savings
Insulate Walls, Air-Sealing, Storm Windows	163	326	$9,440	$514
Duct Sealing	134	267	$2,110	$421
Furnace Replacement	363	124	$4,980	$240
Duct Insulation	57	113	$980	$178
Attic Insulation and Air Sealing	41	82	$6,250	$129
Ductless Air Conditioning	510	0	$12,500	$77
Instantaneous Water Heater	0	49	$3,040	$74
V-Strip Window Weatherstripping	21	43	$550	$67
Lighting Improvements	715	–29	$950	$64

Table 1: Energy improvements at 109 South Albany Street.

The foundation is a full basement with poured concrete walls. The building has its original wood-frame windows, although most have aluminum storm windows. Interestingly, the house originally had gas lighting, as evidenced by abandoned gas lighting pipes. The building is heated with a forced-air gas furnace, and cooled with a residential split system air conditioner.

Energy renovations were made to the building over 10 years, from 2002 to 2012. What is interesting is that many of these energy renovations were made separately, and so we can examine the energy savings impact of these improvements separately. Through the energy renovations, the building's character and historic features were maintained, and this resulted in the building receiving an award for historic preservation in 2011.

The energy improvements began in October 2002, when our engineering firm moved into the building, replacing about 10 incandescent lamps in the lobby and two offices, changing lighting in one small office from eight to four T8 lamps, and installing an ENERGY STAR refrigerator.

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In August 2003, a multisplit ductless air-conditioning system was installed, to replace the central ducted split system. Indoor units are typically wall-mounted, just below ceiling level. There are two separate systems—one for each of the two floors.

In February 2004, an old standing-pilot residential gas storage water heater was replaced with an electronic-ignition instantaneous gas water heater. In the fall of 2004, we were visited by a local gas utility representative. He had come to investigate why our gas meter had failed. But the gas meter had not failed! Our summertime gas usage had simply dropped to nearly zero because hot water is rarely used in the two bathroom sinks or kitchen sink, and so the instantaneous water heater rarely fires.

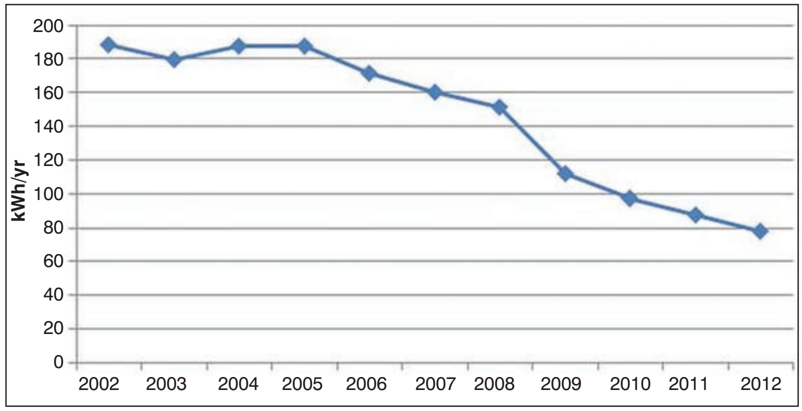

Figure 1: Total energy use at a small office building at 109 S. Albany St.

From 2005, we adopted a policy to purchase ENERGY STAR computers. As a trend toward using notebook computers increased, it was offset a bit by a trend for some people to use two monitors. One person even started using three monitors. With our growth came an increase in server power use.

After some of these early energy improvements were made, we decided to do an energy audit in 2008 to see what good improvements still remained. We proceeded to implement the audit recommendations and continued examining actual energy savings.

In January 2009, dense-pack cellulose insulation was blown into the walls, some air-sealing was done including weather-stripping three doors, approximately five storm windows were installed over single-pane windows, and the old furnace was replaced with a high-efficiency condensing furnace with a variable speed motor and downsized from 120,000 Btu/h to 60,000 Btu/h (35,200 W to 17,600 W).

In March 2009, the ducts were sealed manually using mastic. In July 2009, lighting improvements were made: four T8 lamps were removed (two each in two offices), one old T12 fixture was

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replaced with a T8 fixture, several vacancy sensors were installed in spaces such as the kitchen, and a photo sensor was installed on a small front porch light. In December 2009, the basement ducts were insulated with 2 in. thick fiberglass insulation.

In January 2011, the attic floor was air-sealed (after removing the existing insulation), the attic insulation was increased from approximately R19 to R50, and an unused fireplace on the first floor was sealed.

In September 2011, the ducts were sealed using an aerosol sealing technology. Interestingly, more than 350 cfm (165 L/s) in duct leakage was measured before the aerosol duct sealing, even though the ducts had been sealed with mastic two years earlier. The mastic clearly had not effectively sealed the ducts. The aerosol duct sealing reduced leakage to below 30 cfm (14 L/s). In February 2012, the windows were weather-stripped using vinyl V-strip weather-stripping.

The number of occupants changed over time. In 2002, when we moved in, there were about six people in the building. When we moved out, in 2009, there were about 13 people in the building. We were replaced in 2009 by several tenants who work part-time, reducing the occupancy to about three full-time equivalents.

Results of this work are shown in *Table 1*, Page 18. Installed costs and annual cost savings have been adjusted to 2012 dollars. Almost all savings are actual measured savings that are adjusted with weather corrections. For some of the smaller improvements, for which savings could not be seen in the noise of the utility bills, the audit-predicted savings are shown. In one case where two improvements were made simultaneously, furnace replacement and wall insulation, the actual savings were prorated by the estimated savings from the energy audit. Likewise, almost all installed costs were actual contractor costs, with a few exceptions where costs were not tracked, in which case energy audit estimates were used. *Table 1* combines results for the two duct sealing improvements into one improvement.

The energy audit was accurate with some predictions, and inaccurate with others. For example, the energy audit predicted 216 therms/year (6,330 kWh/year) savings for duct insulation, and measured savings were 113 therms/year (3,310 kWh/year). The energy audit calculation relies heavily on an assumption of furnace run-time, and so we presume the audit overestimated the runtime. The energy audit predicted 58 therms/year (1,700 kWh/year) savings for duct sealing, and measured savings were 267 therms/year (7,820 kWh/year). This difference can likely be explained by high duct leakage found in testing. A "panned return" (return duct formed by adding one side of sheet metal to the space between floor joists) had heavy air leakage in a large space between a joist and the floorboards above.

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The energy audit predicted 353 therms/year (10,350 kWh/year) savings for wall and floor insulation, matching reasonably well against actual savings for a slightly different improvement (wall insulation, air sealing, and a few storm windows), which were measured at 326 therms/year (9,550 kWh/year).

Note the significant envelope savings (insulation and air-sealing), comprising 40% of the overall annual cost savings. The air-sealing improvements involved in-depth work, not just window and door weather-stripping, by contractors certified in building energy improvements, and guided by blower door diagnostics. Distribution improvements (duct sealing and duct insulation) are also large, equal to 34% of the overall annual cost savings. Note also the impact of lighting improvements (controls and "right-lighting") even though the building primarily already had T8 fluorescent fixtures with electronic ballasts before the project began.

The total reduction in energy use is significant: a 60% reduction over the 10 years, on a basis of total energy usage (*Figure 1*, Page 20).

Conclusion

Along with the dramatic reduction in energy use, tenants repeatedly report the building is much quieter after the energy improvements, despite a new busy city bus route on the street outside. Comfort is also improved, primarily due to the multi-split air conditioners with thermostats in each office.

With the 60% reduction in energy use, our plan now is to shoot for net zero. A 6.7 kW solar photovoltaic system is being installed this summer, and we are mulling converting to an air-source or geothermal heat pump. With a little luck, we will have made "100% to net zero in 10 years."

Small office buildings are a wonderful mix of sizes, shapes, and diverse occupants. Substantial energy savings are possible if attention is paid to detail. Energy audit prioritization of cost-effective measures should include evaluation of envelope improvements and HVAC distribution improvements, in addition to the more standard lighting and high-efficiency HVAC plant improvements.

Acknowledgments

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