Energy Audits

In Large Commercial Office Buildings

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Office buildings have more floor area (12.2 billion ft² [1.1 billion m²]) than any other building type in the U.S. and have the highest total energy consumption (1.1 quadrillion Btu [1.2 EJ]) of any building type. Furthermore, the largest buildings have a higher energy use intensity (energy consumption per square foot) than any other size of building.[1] This scale creates many opportunities for energy savings. A good place to begin is with an energy audit of the building.

The challenges of energy audits in large office buildings are many. For example, large HVAC plants and controls can be complex for new energy auditors, and even for experienced engineers. High-rise buildings have unpredictable and uncontrolled airflows, driven by interactions among stack effect, exhaust fans, and higher-pressure air-distribution systems. The clients are often seasoned businesspeople, accustomed to hard negotiations who seek to save costs on energy audit fees.

The buildings are large, so energy auditors can be swamped with field data. They often find themselves confused back at the office, unable to remember details about individual HVAC components, details on spaces, and potential improvements. The sheer size of the audit can lead to "audit exhaustion," ending in a limited set of improvements.

Sometimes, the exciting technical challenges of advanced improvements, such as demand-controlled ventilation or chiller plant improvements, or solar energy, will draw the attention of enthusiastic energy auditors, leaving other improvements such as envelope (air sealing, windows, and insulation), lighting, and operation/maintenance inadequately addressed. All of these challenges, led by a concern that building owners might not be willing to pay for comprehensive energy audits, can lead engineering firms to tend towards simpler walkthrough audits.

A consensus increasingly has grown that defines three levels of energy audits: walkthrough, general, and investment grade.[2] However, requirements for each of these levels can still lack detail, leaving decisions to the energy auditor as to what data to gather and which improvements to evaluate. It has been acknowledged that the three levels do not have distinct boundaries.[3] Common mistakes can compound the problems. Simple walkthrough audits can result in a limited set of recommended improvements. Absence of detail in energy audits can lead to unclear recommendations and reports that cannot be easily translated into a work scope or into designs to achieve the energy savings outlined in the audit. A review of 10 comprehensive energy audits identified many common mistakes, including

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overestimation of energy savings and lack of consideration of the latest retrofit technologies.[4]

Opportunities

Although large office buildings present a broad set of challenges, they also bring unusual opportunities. The size of the buildings allows for economies of scale in energy audits and implementation, and energy savings can be large. A single owner, frequently a private entity or individual, can allow for easier decision-making. Repeating space types, from area-to-area and floor-to-floor and building-to-building, can simplify the energy audit: offices, corridors, stairwells, kitchenettes, toilets, first floor/lobby, and conference rooms. A few large loads can offer large energy savings opportunities: ventilation, HVAC plant, HVAC distribution components such as large motors for air handlers and pumps, and adjustments to incorrectly operating HVAC systems. Repeating (often identical) loads also make things easier: computers and peripherals, kitchenette appliances, lighting, and windows. Lighting, in particular, has long hours of use, unlike in many other building types for which occupancy is more sporadic, and so offers greater opportunity for energy savings.

A Comprehensive Approach

A comprehensive approach can be used to leverage the opportunities offered in large commercial office buildings and to minimize the risks presented by their challenges.

This approach, looking at all loads and all equipment, offers the most savings and the biggest selection of improvements from which the owner can choose. Methodical data collection further maximizes savings, makes analysis easier, and documents recommendations in a way that greatly simplifies implementation.

Solid energy modeling and billing analysis can further help and can identify unusual energy losses and opportunities. Calculation procedures should place an emphasis on calibrating the building's energy use with weather-corrected billing data before beginning evaluation of potential improvements. The interaction among improvements should be accounted for to avoid double-accounting for savings between two improvements that affect each other, for example, HVAC plant replacement and space temperature control improvements.

In addition to the routine analysis of repeating loads and equipment, the energy auditor should treat each building as unique, not as a commodity, and should look for anomalies in use, wearing the hat of a building scientist or diagnostician to identify building-specific energy efficiency opportunities. Gathering actual HVAC operational data, such as temperature trends, equipment use, and flow rates, can augment the understanding of building-specific problems and energy savings opportunities.

Lighting offers an example of the methods that can be used. *Tables 1* and *2* show an example of a data sheet from an actual commercial office energy audit.[5] Lighting measurements are taken in every room. Note the dramatic variations in light levels in the small sample of offices, ranging from 55 to 115 footcandles (592 to 1238 lux). Some offices are highly overlit and so offer opportunities for reducing lamps or fixtures. As data is taken while still in the building and before leaving each room, the energy auditor formulates a variety of recommendations. The end result is a customized energy audit with specific recommendations and multiple improvements possible for each room and with a report that provides sufficient detail for the owner to proceed with implementation.

An example of a specific office further illustrates the potential approaches and savings. A 120 ft^2 (11 m^2) executive office was found with two light fixtures, each with four lamps. A simpler walkthrough energy audit might have noted that the existing lamps are T8, and the ballasts are electronic, and so would not have made any recommendations. A comprehensive energy audit measured light levels at 150 footcandles (1615 lux), far above the IES-recommended range of 30 to 70 footcandles (323 to 753 lux) for offices. The audit recommended removing four of the eight lamps and replacing the single toggle switch with a dual switch (one switch for each of the two fixtures) and an occupancy sensor and photocell integrated into the switch. A tenant education program helped the office occupants learn how to use the new double switch and switch-integrated photocell and occupancy sensor effectively. The results are savings of more than 70%, since only two lamps are used most of the time (instead of the original eight); savings accrue when the occupancy sensor or photocell turns off the lights. Note the multiple improvements (delamping, controls, tenant education) made possible by a comprehensive and room-specific approach.

What is meant by "comprehensive energy audit"? A comprehensive energy audit includes evaluating all energy loads and equipment in a building: the HVAC plant (in a commercial office building, typically chillers and boilers); the HVAC distribution systems; envelope improvements (walls, windows, roof, foundations, insulation); lighting; plug loads such as appliances and computers; operation and maintenance improvements; tenant education; and more. The energy audit should capture room-specific opportunities and document recommendations in the audit report to allow for clear implementation of improvements. Improvements should focus not only on equipment efficiency, but also ensuring that the equipment meets the required load. For example, do not just replace T12 lamps with T8; also measure light levels to make sure that each space is not overlit. Another example: Do not merely change the boilers to high-efficiency; also make sure that the new boilers are not oversized.

The trend towards comprehensiveness in energy audits likely started in residential buildings more than 10 years ago. On-site measurement of HVAC plant efficiency, such as combustion testing for furnaces and boilers and even advanced testing of air conditioners and heat pumps, are becoming increasingly common. Analysis of distribution systems, for example through duct leakage testing, has arrived. Evaluating the replacement of plug loads, such as appliances, has become commonplace. Diagnostic tools, such as blower doors and infrared thermography, have allowed advanced analysis of the building envelope. Advanced techniques for retrofit insulation, such as spray foam

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Location	Existing Condition					De-Lamp		Replace Bulbs or Fixtures			New Ballasts?	Recommended Controls						SIR
	Bulb Model	Number of Bulbs Per Fixture	Number of Existing Fixtures	Hours/Day (Average)	Average Light Level (Footcandles)	Number of Fixtures to Remove	Number Bulbs/ Fixture to Remove	Replacement Bulb Model	Number of Fixtures to Modify	New Number of Bulbs/Fixture		Number of Timers	Number of Photosensors	Number of Motion Sensors	Number of Bi-Level Fixtures	Number of Fixtures Controlled	New Hours/ Day (Average)	
106 Hallway	EXITINC20	1	1	24	0			EXITLED2	1	1								5.6
133 Boiler Room	F32T8	4	8	8	18							1		2		8	3	1.7
134 Transformer Room	F40T12	2	8	8	25			F32T8	8	2	X	1		1		8	3	1.7
204 Office	F32T8	4	2	7	55								1			2	3	2.2
205 Office	F32T8	4	2	7	65								1			2	3	2.2
206 Office	F32T8	3	4	7	115								1			4	3	3.3
207 Hallway	EXIT INC20	1	1	24	0			EXITLED2	1	1								5.6
211 Office	F32T8	2	3	7	55								1			3	3	1.6
213 Main Lobby	FLOOD65	1	2	8	58								1			2	3	3.2
213 Main Lobby	F32T8	2	6	8	58								1			6	3	3.8
213 Main Lobby	F32T8	4	4	8	58								1			4	3	5.1
213 Main Lobby	FLOOD65	1	3	8	58	2												22.2

Table 1: Existing conditions and recommendations (from an actual commercial office energy audit).

and dense-pack cellulose, have largely been developed in the residential field, but are not yet common in commercial building retrofits. In addition to these technologies, advances in modeling have made common the use of hourly energy models and interactive calculations among energy improvements. Technician accreditation is widespread, as are energy auditor training programs. There is broad dissemination of best practices and extensive ongoing applied energy conservation research. A national energy audit standard has recently been adopted.[6] Evaluating "the building as a whole" has become a mantra in the residential energy field, but is not at all common in commercial buildings. Comprehensiveness has been almost universally recognized and adopted in residential energy audits. Anything short of comprehensiveness is often frowned upon.

How is the room-by-room aspect of a comprehensive audit conducted in commercial office buildings? At a minimum, light levels and lighting inventories should be taken on a room-by-room basis, along with occupancy levels and schedules for occupancy and lighting use. Room-specific HVAC issues, such as distribution problems or mistaken temperature control setpoints, also can be noted. In addition, information on plug loads, such as computers and office kitchen appliances, can also be inventoried on a room-specific basis. Field data sheets should be structured to allow energy auditors, as they are standing in each room, to check off exactly what improvements will be evaluated for each particular room. Although measurements in all spaces might appear to be time-consuming, they can be completed quickly, even in large buildings, if data input is well-organized. There are time-savings during analysis, because much of the analysis can be automated.

Room-specific data collection allows more accurate calculations to be performed, and, more significantly, the recommendations can be made in a fashion that guides implementation. Rather than providing general recommendations that are difficult to implement ("Replace all lighting, delamp to meet IES standards, and install photosensors on fixtures close to windows."), room-specific recommendations allow a work scope to be given by the owner to maintenance staff or to a contractor. Tables are provided such as the ones in the previous example, which give sufficient information that might translate as: "Office 201: Replace two four-lamp fixtures with two two-lamp T8 fixtures with high-efficiency electronic ballasts, and add a second light switch to allow the fixtures to be controlled independently, with a photosensor for the fixture close to the window, and an occupancy sensor to turn lights off if no occupants are detected."

Detailed reports reduce duplication of effort, as the energy auditor's descriptions of improvements are conveyed in detail to those responsible for implementation, whether design engineers, architects, contractors, or construction managers.

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Location	Recommended Change			Savings Analysis				
	Lighting Changes	De-Lamping	Control	Annual Energy Savings, kWh/Yr	Annual Cost Savings, $/yr	Cost of Retrofit	Simple Payback, Years	SIR
106 Hallway	Replace EXIT			166	$28	$115	4.1	5.6
133 Boiler Room			Occupancy Sensor Plus Timer	1,754	$167	$1,166	7.0	1.7
134 Transformer Room	Replace Bulbs, Ballasts		Occupancy Sensor Plus Timer	1,635	$178	$1,225	6.9	1.7
204 Office			Light Sensor	376	$36	$194	5.4	2.2
205 Office			Light Sensor	376	$36	$194	5.4	2.2
206 Office			Light Sensor	564	$54	$194	3.6	3.3
207 Hallway	Replace EXIT			166	$28	$115	4.1	5.6
211 Office			Light Sensor	282	$27	$194	7.2	1.6
213 Main Lobby			Light Sensor	279	$17	$194	11.3	3.2
213 Main Lobby			Light Sensor	658	$62	$194	3.1	3.8
213 Main Lobby			Light Sensor	877	$83	$194	2.3	5.1
213 Main Lobby		Remove Fixtures		431	$36	$91	2.3	9.2

Table 2: Lighting results (from an actual commercial office energy audit).

The Improvement Mix

What improvements are best suited to commercial office buildings? The occupancy-driven nature of office spaces make occupancy-based controls attractive, such as demand-controlled ventilation, programmable temperature controls, and variable capacity distribution systems (VAV air handlers, variable speed pump drives, etc.). Large office spaces often result in interior/core spaces with an associated high cooling demand, so economizers make sense in many climate zones, as do systems that recover core heat for use on the perimeter, such as water loop heat pumps. High-efficiency replacement HVAC is also always an option. Significant savings often can be achieved through operational adjustments to HVAC controls.

Reducing overlighting is a frequently missed improvement, so a light meter in the toolkit is essential. While energy codes typically require a maximum of 1.0 to 1.1 W/ft^2 (0.09 to 0.10 W/m^2) for office lighting power density,[7] and existing buildings often consume much higher than even these levels, 0.75 W/ft^2 (0.07 W/m^2) or lower are easily obtainable and should be used as a goal; these levels can be further reduced on a time-average basis through task lighting, daylighting, and occupancy-based lighting. These lighting savings are amplified by a reduction in air conditioning use in such typically core-dominated buildings. Installing pendant lighting fixtures in spaces with tall ceilings will also reduce lighting power densities. Energy savings are often accompanied by improvements in visual quality as well. In corridors and stairwells, 5 to 10 footcandles (54 to 108 lux) are adequate, and typical existing 24-hour use merits both reducing lighting to this level, in addition to occupancy sensors to turn off lights when the corridors and stairwells are not occupied, and photo controls for lights near windows. Low-level lighting can be maintained for safety and security.

Plug loads, such as computers and kitchenette refrigerators, contribute substantially to electricity use and can be replaced with high-efficiency substitutes through purchasing policies, or used more efficiently, such as by setting display screens to turn off, or implementing policies regarding turning off screens and computers. Plug loads require engaging tenants in energy efficiency, which is a good thing.

For engineers, who often feel most at home in the boiler room or looking at the chiller and air handler, envelope improvements often seem foreign. What can we do with the envelope in a high-rise office building? Stack effect and associated infiltration losses can be reduced through weather stripping of windows and caulking window frames, and by compartmentalization of the building interior (such as weather stripping of stairwell doors) and other air-sealing (plumbing chases, roof penetrations, and more). Such improvements will also dramatically reduce discomfort caused by airflow induced at the entrance to the building and on lower levels. Window replacements and storm windows can reduce heat loss in winter by half or more and similarly reduce heat gain in summer. Creative improvements, such as interior or exterior shades, can further reduce loads and reduce glare in offices. Even wall and roof insulation should not be ruled out.

Two Examples

Comparing two actual energy audits, a walkthrough audit and a comprehensive energy audit, provides insight into the difference between these approaches. *Table 3* summarizes these two audits.

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The comprehensive energy audit identified savings of 46%. Interestingly, the predicted energy savings appear to have been exceeded by those improvements, which were implemented by the owner. Natural gas savings were measured at 53%, following replacement of the boilers, window replacement, installation of summer boilers for service hot water, and separation of the heating plant into multiple zones.[5]

Meanwhile, the walkthrough audit in a different large commercial office building identified savings of only 7%. Sometimes presented as a preliminary audit, or a precursor to an in-depth audit, the walkthrough audit runs the risks of delivering small savings, satisfying the owner's need to make energy improvements, allowing "greenwashing" claims, giving the false impression that significant savings are not possible, preventing the owner from considering comprehensive work, and deferring in-depth improvements for years into the future.

	Walkthrough Audit	Comprehensive Audit
Percent Savings	7%	46%
Room-by-Room	No	Yes
Number of Improvements	8	12
Lighting Improvements	No	Yes
HVAC Plant Improvements	No	Yes
HVAC Consolidation/Reduction	No	Yes
Controls Improvements	Yes	Yes
Health/Safety/Comfort Improvements	No	Yes
HVAC Distribution Improvements	No	Yes
Demand/Purchasing Recommendations	Yes	Yes
Motor Improvements	No	Yes
O&M Recommendations	No	Yes
Service Hot Water Improvements	Yes	Yes
Tenant Education Recommendations	No	Yes
Envelope (Insulation, Air Sealing) Improvements	Yes	Yes
Plug Load Improvements	No	No

Table 3: Comparison of two example commercial office energy audits.

Further risks derive from the possibility that energy savings estimated in an energy audit can easily be eroded between the energy audit and final implementation. These risks are illustrated in *Figure 1*. Beyond the risk of energy savings not materializing because the audit itself is not clear or because the auditor missed energy measures, there is the risk of the owner choosing not to implement all the savings, the risk of contractors making mistakes or substituting less efficient products, the risk of inadequate commissioning of energy conservation installations, and the risks of poor operation and maintenance. All of these can erode the originally recommended savings. Comprehensiveness is the best hedge against the erosion of these savings between energy audit and closeout of implementation.

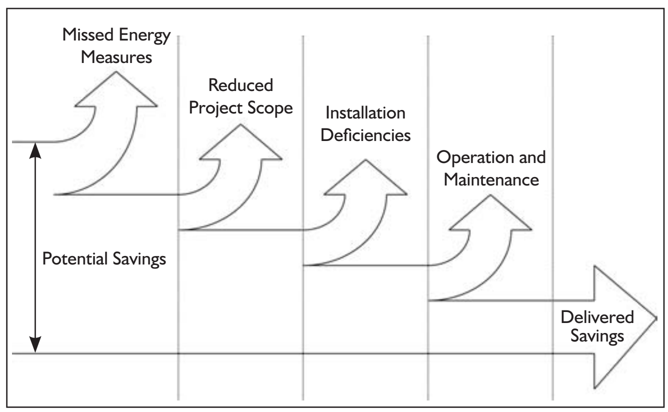

Figure 1: Erosion of energy savings.

Finally, projected savings as small as 7% present a high risk of actual savings not being measurable, as real savings are lost in the "noise" of fluctuating energy use in a building.

Case Study

A different example points to audit costs and projected savings of a comprehensive audit.[8] A 77,000 ft^2 (7154 m^2) office building in upstate New York has annual electricity costs of $130,000, and annual gas costs of $210,000, for total annual fuel costs of $340,000. A comprehensive energy audit identified 14 improvements, all of which meet a positive life-cycle cost test (savings-to-investment ratio greater than one). The recommended improvements include HVAC plant (new high-efficiency boilers), HVAC distribution (new VAV system, premium efficiency motors, pipe insulation), HVAC controls, ventilation (new energy recovery ventilation system), envelope (door weather stripping, storm windows), lighting (extensive delamping, relamping, and controls), and appliances (replace an oversized ice-maker, intelligent power control on vending machines).

Projected annual savings are $125,000 per year, or 37%. The cost of the audit was approximately $27,000. The ratio of estimated audit cost to annual energy costs savings is 0.22. In other words, the energy savings will pay for the audit in 0.22 years, or approximately 2.6 months.

The final report provides a variety of detail that may be helpful for the owner in proceeding with implementation, including information on all 32 motors to be replaced (location, load description, horsepower, quantity, existing efficiency, recommended minimum replacement efficiency, etc.), 20 pages of lighting data with room-specific recommendations, and more. Much of the scope of work for implementation is already defined in the energy audit.

We estimate that the cost of a walkthrough audit might be $5,000 and provide 7% annual savings, as shown in the prior example, or approximately $24,000 energy cost savings per year if applied to the same building. But a hidden cost is that a walkthrough audit rarely provides sufficient data to describe the scope of work for implementation. Assuming that this work scope development, whether done by an engineer or by a design-build contractor, might cost an additional $5,000, the ratio of audit-plus-work scope costs to annual cost savings is 0.42, or almost one half as cost effective as the comprehensive audit.

Significantly, the comprehensive audit report also presents six improvements that were evaluated and could provide further savings, but that do not meet the positive life-cycle cost test. These include chiller replacement, roof insulation, replacing electric heat in the core of the building with a gas furnace (due to the high cost of electricity relative to gas), and service hot water improvements. While helping to prioritize recommended improvements (on the basis of estimated installation cost, estimated annual savings, estimated useful life, non-cost trade-offs, and more), the comprehensive audit significantly assists the owner in *not* making poor economic decisions by explicitly showing the results for nonrecommended improvements. Meanwhile, the owner is provided with useful information that might tip the scales to proceed with a nonrecommended improvement, if the complete picture that portrays non-cost issues (health and safety, comfort, equipment nearing end-of-life, etc.) along with energy savings for a particular improvement, add up to justification for implementation.

Structured Techniques

A variety of structured techniques can help make energy audits in large commercial office buildings easier.

- Analyze utility bills before doing the field visit. Disaggregate use by season, fuel, building, and meter. Look for anomalies in energy use patterns to guide the search for unusual energy loads and savings opportunities.
- Assign two people for the site visit, each with a walkie-talkie or cell phone. An effective combination of staff can be an engineer familiar with HVAC plant and controls and an energy technician familiar with lighting, envelope, and plug loads.
- Look for incorrectly operating HVAC systems, such as programmable setpoints that have not been correctly set (reset controls for hot and cold water temperatures, space temperatures, ventilation schedules, etc.).
- Come prepared with a data collection plan, including data sheets.
- Schedule adequate time for fieldwork. One day is inadequate for an effective site visit for a large commercial office building, even for a two-person team.
- Bring a small set of useful tools, most of which fit in a small tool bag or even on a belt: infrared thermometer, CO_2 meter, tape measure, reduced scale plans, light meter, lighting ballast checker.
- Involve building staff; ask probing questions about schedules, controls, and suspected energy inefficiencies and savings opportunities.
- After the site visit, immediately write a detailed building description and list the improvements planned for evaluation. This essentially jump-starts the final report; more important, it allows a supervisor or peer to identify possible missed opportunities early on. By identifying all opportunities that need analysis up front, the analysis will not need to be repeated after the report is finished, which is much harder than if missed improvements are identified early.
- Calibrate energy models against utility bills before modeling improvements.
- In modeling, account for interactions among improvements.
- Describe non-cost trade-offs of each improvement, such as health and safety issues, comfort impacts, operation and maintenance, anticipated persistence of savings, etc.
- Use life-cycle costing, such as savings-to-investment ratio on a net present value basis, accounting for the time value of money, as well as the projected inflation of fuel costs. These all account for costs and benefits in a more complete manner than simple payback.

Summary

Large commercial office buildings present a variety of challenges that are specific to the sector. An incremental approach (walkthrough audit first) runs a significant risk of not leading to significant or measurable energy savings. The higher cost of comprehensive audits is well justified by the greater energy savings opportunities identified and by avoiding duplication of effort, as many improvement descriptions, which guide implementation can be provided in the audit. A comprehensive approach using structured techniques can make the work easier and provide a framework for substantial and measurable energy savings.

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