Proven Energy-Saving Technologies for Commercial Properties

September 1, 2014 — December 15, 2014

S. Hackel, J. Kramer, J. Li, M. Lord, G. Marsicek, A. Petersen, S. Schuetter, and J. Sippel

Energy Center of Wisconsin
Madison, Wisconsin

NREL Technical Monitor: Adam Hirsch

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Subcontract Report
NREL/SR-5500-63807
March 2015

Contract No. DE-AC36-08GO28308
Chapter 4. Efficient Elevators

4.1 Description

Elevators are estimated to account for up to 5% of a building’s annual energy use (Kamm 2006). Choosing newer, commercially available efficient elevators can result in decades-long energy savings.

An elevator in a typical commercial building uses about 7,600 kWh/year (Kwatra 2013), and in a typical office building it uses about 5,800 kWh/year (McKenney 2010).

Traditionally, elevators have used hydraulic, geared traction, or gearless traction systems, depending on building height. Buildings with fewer than seven or eight floors have typically used hydraulic elevators; these represent 75% of installed elevators in the United States. Medium-rise buildings (with 8 to 24 floors) have used geared traction, and buildings with more than 24 floors have used gearless traction (McKenney 2010). Newer elevator designs feature more efficient gearless traction systems with regenerative drives and numerous other efficient components.

Table 7 shows the energy savings values for a new energy-efficient elevator compared to the ASHRAE standard 90.1-2007 baseline, which addresses motor efficiency (and not elevators, specifically).

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Unit</th>
<th>Example (low-rise office, new construction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity saved</td>
<td>kWh/floor (6-floor office)</td>
<td>744</td>
</tr>
<tr>
<td>Gas saved</td>
<td>kBTU/floor (6-floor office)</td>
<td>NA</td>
</tr>
<tr>
<td>Reduction in EUI</td>
<td>kBTU/ft²</td>
<td>0.31</td>
</tr>
<tr>
<td>Utility bill savings</td>
<td>$/floor (6-floor office)</td>
<td>$48</td>
</tr>
<tr>
<td>Typical capital cost</td>
<td>$/floor</td>
<td>Not available</td>
</tr>
<tr>
<td>Typical simple payback</td>
<td>years</td>
<td>Not available</td>
</tr>
<tr>
<td>Capital cost 5-year payback</td>
<td>$/floor</td>
<td>Not available</td>
</tr>
<tr>
<td>Target incentive</td>
<td>$/floor</td>
<td>Not available</td>
</tr>
</tbody>
</table>

4.2 Application

Elevators are generally replaced on a 20- to 30-year cycle (McKenney 2010), meaning that decisions about elevator efficiency will affect building energy use for decades. Options for reducing elevator energy use fall into two general categories: improving elevator energy efficiency (equipment) and reducing elevator use (behavior).

---

6 The estimate was taken from an EIA report from 2006 titled 2003 Commercial Building Energy Consumption Survey, DOE/EIA.
7 About 50% of these, however, are in buildings with only a few floors, so the elevators are not used very much. Many of these were put in to comply with the Americans with Disabilities Act (noted in Kamm 2006, from communication with Rory Smith of ThyssenKrupp).
8 The cost savings are based on national average rates of $0.112/kWh, and $0.81/therm.
9 The values in the table are taken from an unpublished case study of the Bullitt Center drafted as part of the CBP program. Although the authors stated ASHRAE 90.1-2007 was used as the baseline, the standard addresses motor, not elevator, efficiency.
4.2.1 Equipment Efficiency

The relevant factors affecting elevator energy use include:

- Efficiency of the motor and drive components
- Volume of use (number of trips and weight of payloads)
- Efficiency of components that remain powered on when the elevator is not in use
- Ability to go into a standby mode\textsuperscript{10} when not used for some time.

Elevator efficiency has improved over the years so that even within each drive class (hydraulic, geared traction, or gearless traction) the most efficient elevator uses 30\%–40\% less energy than the least efficient (Sachs 2005). Modern efficient elevators use combinations of advanced motor and drive technologies such as variable-voltage VFDs, gearless permanent magnet motors, and regenerative drives (Zogg 2009). They also include efficiency improvements in other components, such as machinery, lighting, fans, and associated controls, and decrease the need for mechanical cooling to condition the mechanical room. Furthermore, choosing new traction systems over older hydraulic systems also opens up the possibility of using regenerative drives.

Regenerative drives allow the elevator to generate electricity whenever it is braking (lifting a load lighter than the counterbalance weight or lowering a load heavier than the counterbalance weight). The regenerative drive can generate usable electricity equal to about 25\% of the overall energy used by the elevator system (KONE 2013). Elevators with regenerative drives can be 70\%–75\% more efficient than hydraulic systems, and 50\%–60\% more efficient than traction two-speed drive systems (KONE 2013; Otis 2014).

The three modes of elevator energy use and estimates for the U.S. elevator population (Zogg 2009) are listed in Table 8.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Load (kW)</th>
<th>Hours/ye</th>
<th>Energy Use/year (kWh)</th>
<th>Options To Conserve</th>
</tr>
</thead>
<tbody>
<tr>
<td>In use</td>
<td>10</td>
<td>300</td>
<td>3,000</td>
<td>Upgrade drive/reduce use</td>
</tr>
<tr>
<td>Ready</td>
<td>0.5</td>
<td>7,146</td>
<td>3,573</td>
<td>Efficient lighting/controls for fans and lights/occupancy sensors</td>
</tr>
<tr>
<td>Standby</td>
<td>0.25</td>
<td>1,314</td>
<td>329</td>
<td>Efficient lighting/controls for fans and lights/occupancy sensors</td>
</tr>
</tbody>
</table>

Elevator efficiency can be increased further when packages include LED fixtures and occupancy sensors that can put the elevator in standby mode when it is not in use. As shown in Table 8, elevators are in ready mode but not in use nearly all the time. Standby mode uses half the energy that ready mode does; thus, converting more of that time to standby mode would save energy. Adjustments in usage patterns and improvement in component efficiencies may be needed to maximize energy savings.

\textsuperscript{10} ASHRAE 90.1-2010 includes a section specific to elevators that requires de-energizing lighting and ventilation during standby mode when the elevator is unoccupied with doors closed for more than 15 minutes. Jurisdictions adhering to this standard will require this feature in new elevator installations.
4.2.2 Shifting Usage Patterns
Building occupants who are able to use stairways take the elevator because it is easy to use and socially acceptable. Taking the stairs is a healthy alternative that can be encouraged through a culture of sustainability reinforced by building design. Figure 11 shows a design using a modern efficient elevator with a regenerative drive and an open, inviting stairway, compared to conventional designs typically seen in office buildings today.

![Figure 11. Efficient gearless hoist elevator with open stair versus conventional design](image)
(Courtesy Jason Sippel, Energy Center of Wisconsin)

Stairways can be designed to be more prominent than elevators if they are the first things building occupants encounter at the building entrance. Their entrances can be open and inviting, instead of hidden behind closed doors. Glazing that allows users a view of the outside could also increase their appeal.

4.2.3 Nonenergy Benefits of Modernizing Elevators
A modern efficient traction elevator instead of a lower cost hydraulic system provides nonenergy benefits such as:
- Avoided need for a control room (typically placed on the roof or taking up usable building space)
- Reduced maintenance
- Improved rider experience (lower noise, less vibration, shorter cycle time)
- Improved options for use of space near the elevator controls due to reduced noise
- Avoided need for hydraulic fluid and constant fluid heating.

4.2.3.1 Low-Rise Office Building

Efficient elevators with regenerative drives promise great savings when replacing traditional hydraulic systems used in low-rise office buildings. Manufacturers claim the new systems are 70%–75% more efficient than hydraulic systems.

4.3 Real-World Considerations

Multiple established elevator manufacturers use proven technologies in a competitive market for efficient and regenerative drive elevators.

Actual energy savings achieved for elevators is highly dependent on users. As described in Section 4.2.2, stairways could be designed to be more inviting; however, the effectiveness of strategies to modify usage patterns is difficult to predict and is likely very situation specific (i.e., dependent on age, fitness level and inclination of the occupants, the stairwell design, and the number of floors people usually need to travel).

4.3.1 Financial Incentives

Few, if any, state or utility programs specifically target efficient elevator purchase. In some locations, this measure could qualify for financial incentives as a “custom” EEM. Examples include:

- **Hawaii State Commercial Energy Efficiency Rebate Program**. Provides incentives for custom efficiency projects based on projected energy and demand savings for new construction and retrofit projects. Projects are evaluated case-by-case and require preapproval.

- **Illinois ComEd - Smart Ideas for Business Efficiency Program**. Provides incentives for custom efficiency projects of up to $0.07/kWh saved annually.

- **Duke Energy Smart Saver Incentive Program (North Carolina)**. Provides incentives for custom efficiency projects of up to 75% of the incremental cost. The projects must be preapproved and have a payback period of more than 1 year.
The Bullitt Center found a creative way to acquire incentives for its unique energy-saving measures. It partnered with the local utility, Seattle City Light, on a novel variation of a traditional power purchase agreement. The heart of the Metered Energy Efficiency Purchase Agreement is a metering system that estimates the energy savings from the Bullitt Center’s energy efficiency features relative to a dynamic baseline, and the utility pays for the amount of electricity it doesn’t have to deliver because of these improvements. The building investors, not the building owner, sell the efficiency to the utility, and the investor makes rental payments to the owner to use the building as a host for efficiency generation (as a wind power company might pay farmers to put wind turbines on their land). The 20-year purchase agreement treats efficiency like power generated from more traditional sources. It gives the building investor incentives to maintain or increase the efficiency of the building, and the utility remains financially whole despite delivering less electricity to the building. For simplicity, the energy generated from the Bullitt Center’s solar roof is not included in this agreement.

4.4 Project Results

Developers of the new Bullitt Center in Seattle, Washington, participated in the CBP program. The building design included an efficient elevator with a regenerative drive as part of its plan to be designated a Living Building through the International Living Future Institute’s Living Building Challenge. Figure 12 shows the Bullitt Center building.
The building design made the elevator less prominent and required that tenants use a key card to access it. The building also includes a prominently displayed “irresistible stairway,” which offers an attractive design, artwork, and views of the city. Cost information about the elevator and stairway was not available (see Table 9).

### Table 9. Efficient Elevator in the Bullitt Center

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building size (ft²)</td>
<td>50,070 ft²</td>
</tr>
<tr>
<td>Project description</td>
<td>6-story commercial office building, new construction project seeking Living Building status</td>
</tr>
<tr>
<td>Energy-efficient regenerative elevator</td>
<td>Regenerative elevator as part of a suite of EEMs</td>
</tr>
<tr>
<td>Expected annual energy savings (kWh)</td>
<td>4,461</td>
</tr>
<tr>
<td>Expected annual energy cost savings</td>
<td>$290</td>
</tr>
<tr>
<td>Expected reduction in EUI (kBtu/ft²)</td>
<td>0.31</td>
</tr>
<tr>
<td>Annual carbon emissions avoided</td>
<td>3 metric tons CO₂e₁¹</td>
</tr>
</tbody>
</table>

### 4.4.1 Elevator Features

The Bullitt Center deployed a modern energy-efficient elevator to serve the six-story office building. In addition to using a regenerative drive system, the elevator also includes an auto-off technology that initiated standby mode during inactive periods (McManus 2012).

---

₁¹ Greenhouse gas reductions are given in terms of CO₂e. For electricity, 0.000692 metric tons CO₂e/kWh are assumed to be avoided. For natural gas, 0.006418 metric tons CO₂e/therm are assumed to be avoided.
4.4.2 Diversionary Measures

The Bullitt Center’s “irresistible stairway” was designed to entice occupants to use the stairs rather than the elevator to travel between floors. The design team did not include estimates of diverted traffic from the elevator in its energy use projections.

Preliminary data on stairway use suggest about 70% of the ascents to the sixth floor from the entrance (second) floor are made via the stairway, and 75% of vertical traffic overall (initiated at the entrance floor) is accomplished using the stairway (Burpee 2014). This is compared to about 25% of vertical ascents that use the stairway in a conventionally designed building (Olander 2011).

The Bullitt Center has an unusual group of tenants who are all sustainability focused and are further incentivized to conserve by green leases and energy budgets. However, the approaches pioneered there and the lessons learned can be applied more broadly across the industry.
4.5 Modeling Efficient Elevators

Elevators use about 3%–5% of electrical energy in a typical building, but they are often overlooked in energy modeling (ASHRAE 2010). Thus, considering elevators in the building energy model, especially for taller buildings or healthcare applications, is important. In addition to their primary power consumption, they typically add heat, which must be removed by the HVAC system. Elevator power includes the elevator motor and associated lights, fans, and controls.

If multiple elevators in a building have roughly similar usage patterns, they can be modeled as a single elevator. The power input for the modeled elevator would equal the sum of the values for the real elevators. Guidance for modeling elevators in EnergyPlus is provided in Appendix B.

4.6 Ensuring Performance

4.6.1 Installation and Commissioning

Elevator installation and commissioning are specialized practices performed by licensed installers who are often affiliated with the manufacturers. Chapter 1 provides information about the general commissioning process.

4.6.2 Controls Programming

The building owner and engineer should consider the parameters for control settings (such as putting fans and lights into sleep mode when not in use) and discuss these with the installer for proper programming. Facilities staff should monitor these controls to ensure they continue to function correctly over time.

4.6.3 Measurement and Verification

Because elevators are somewhat isolated from other building systems, an isolated metering approach is often used to verify efficient elevator energy savings. Because elevators can affect HVAC energy consumption, a more comprehensive M&V approach should also include whole-building calibrated simulation.

4.6.4 Recommended Monitoring Points

If multiple elevators in a building have the same setup, only a few need to be metered. Understanding the energy consumption of elevator carriages involves evaluating power input to the following components: motor, fan, lighting, and associated controls. Elevator components are typically on their own dedicated electrical circuits, simplifying the metering process.

4.6.5 Inexpensive, but Less Accurate, Approach

Current transducers installed on individual electrical circuits serving elevators enable continuous monitoring of the electricity current. The voltage and power factor of these circuits should be spot checked during installation, and occasionally thereafter, to confirm their values. Estimates of electrical power and energy may then be calculated from the measured current, as well as spot (one-time) measurements of voltage and power factor.
4.6.6 More Complex and Expensive, but Accurate Approach

Power meters installed on individual electrical circuits serving elevators enable direct monitoring of real electrical power. This method is more costly and time-consuming to install, but is more accurate because it accounts for the full waveforms of the electrical power. Real power meters should meet the following criteria:

- Sampling interval of 30 seconds
- Designed for the type of circuit to be metered (e.g., 480 Volt, 30 amp, 60 Hertz)
- Ability to accurately meter loads; rated to meet the load per phase (e.g., 0–10,000 Watts)
- Internal clock that timestamps each data point
- UL listing
- Compatibility with the BAS.

4.6.7 Guidance for Analysis

Chapter 1 provides information about data management for M&V efforts. Analyzing the data and determining verified energy savings involves different approaches for existing and new construction projects.

4.6.7.1 Existing Buildings

For existing buildings, energy performance both before and after replacing the elevators may be measured explicitly. Energy use is then normalized by factors that affect energy performance, such as changes in hours of operation and building occupant density. Once energy use is normalized, the energy savings from this EEM is determined by taking the difference between energy consumption before and after the strategy was initiated.

4.6.7.2 New Construction

For new construction projects, the energy performance baseline is less clearly defined, because no measured baseline data are available for comparison; therefore, a theoretical baseline energy consumption must be estimated from other available data. One potential source of baseline information is an existing building used by the people who will be occupying the new building. For the existing building to be a good baseline case, it must be generally the same type of facility and have the same number of floors, because elevator usage varies greatly among different building types. It must also have an elevator system design that is still common today and that could have been implemented in the new building. The elevator power in the baseline building can be monitored before completion of the new construction project. An alternative, and somewhat simpler, option is to develop a baseline energy model by combining manufacturer data for “standard” efficiency elevators with site-specific assumptions about usage patterns.

If possible, energy use should be normalized using the same hours of operation and building occupant density. Once energy use is normalized, the energy savings from using efficient elevators are determined by taking the difference between the energy consumption of the baseline system and that of the efficient system.
4.6.8 Occupancy Sensor Failures

If the elevator usage appears high during unoccupied periods, the first item to check is how the lights and fans are controlled. If the lights are controlled by occupancy sensors, the sensor function should be verified. Occupancy sensors fail in the “on” mode, meaning that the lights controlled by them will remain on if the sensors faulty.

4.7 References and Other Resources


