Advancing Elevator Energy Efficiency

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January 2015
Report A1501

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Acknowledgments

This report was made possible by a grant from United Technologies Corporation, which asked ACEEE to consult with a wide spectrum of industry experts and provide guidance to the industry and the program and policy communities. We were asked to review the global industry's remarkable advances in technology as background, and focus on ways to accelerate adoption of these technologies.

We are greatly indebted to our external advisors and reviewers: Jeff Boldt (principal and director of engineering, KJWW, Madison, and chair of the ASHRAE SPCC 90.1 elevators working group), James W. Bos (Sustainable Elevator Consulting), Joe Busse (chief corporate engineer, Fujitec America, Inc.), Robert S. Caporale (editor emeritus, *Elevator World* magazine), Richard Fargo (systems engineering fellow, Otis Elevator), Kai Kügler (VDI 4707 committee member, TÜV SÜD Industry Services Germany), John Mandyck (UTC Building & Industrial Systems, Farmington, Connecticut), Korinti Recalde (UTC Building & Industrial Systems), Larry Schoen (Schoen Engineering Inc., Columbia, Maryland), and Alan Taylor (principal and vice president, HKA Elevator Consulting, Laguna Hills, California). Their efforts kept us grounded and shaped our report. Of course, their reviews do not imply their agreement or endorsement.

We thank Ethan Rogers, senior manager of the ACEEE Industry Program; Jennifer Amann, director of the ACEEE Buildings Program; and Steve Nadel, executive director of ACEEE, who were our internal reviewers. They helped assure that our work could be understood and used by the policy and program communities. We also thank Fred Grossberg for skilled guidance in shaping our thoughts, Kate Hayes and Roxanna Usher for editing, and Patrick Kiker for helping to launch this report into the world.

Executive Summary

Elevators and escalators (vertical transportation) annually use about 1/3 to 1/2 quadrillion Btus (quads) of primary energy in the United States, comparable to U.S. commercial building electricity consumption for space heating and cooling in 2003, exclusive of ventilation (CBECS 2003). That is about 2–5% of the energy required for most buildings covered by ANSI/ASHRAE 90.1 (ASHRAE 2013). A single modern 14-story elevator in New York City can draw as much as 90 kW—and can employ regeneration to substantially offset this (Bos et al. 2013).

Several factors coalesce to offer a significant opportunity to reduce elevator loads 40% or more. First, new elevator components, systems, and controls improve performance, save energy, and offer a better user experience (such as reduced wait times). These advances include machine-roomless (MRL) designs that eliminate elevator penthouses and their costs. Advanced gearless drive systems, generally with permanent magnet motors, facilitate better control, save energy, and can be commercially configured with line regeneration instead of heat dissipation. LED lighting can improve visual comfort while saving energy.

Elevators are now addressed as regulated loads in ANSI/ASHRAE/IEC 90.1-2013. As a first step, 90.1-2010 directly addresses elevator cab lighting and ventilation, but designers can use performance paths to take advantage of the very large improvements from new technology and controls. This highlights the opportunity and allows building codes to follow technological progress and cost-effective best practices in the marketplace. Adding to this, new international elevator efficiency standards (VDI 4707 and ISO 25745) establish usage classes, and provide methods to calculate expected energy use or directly measure it.[1]

These usage classes brought visibility to a key opportunity: No matter what the usage class, almost all elevators are idle far more than they are moving, and for the lower usage classes, standby energy dominates energy use while moving. Thus, reducing standby power, which can be relatively inexpensive in many cases, can dramatically cut total energy use.

Another factor is that in the eyes of owners and architects, the elevator is an extension of the lobby, a powerful symbol of building quality. Improved mechanical, illumination, and control features can improve perceived quality. Many of these improvements also save construction time and costs.

Finally, manufacturers and advocates are working to increase the visibility of efficiency opportunities through voluntary efficiency programs and other vehicles.

In this paper, we recommend actions by manufacturers, ASHRAE, public benefits programs (including utility incentives), voluntary labeling programs, and government to encourage further innovation. Options include further energy code features and a suite of voluntary

[1] Part 2 of the ISO 25745 standard is not yet completed. It can be tracked at http://www.iso.org/iso/catalogue_detail.htm?csnumber=60951

programs that could include labeling of advanced products, product selection guidance, and incentives such as tax credits or more widespread utility programs.

The core of the industry path we recommend is adopting an efficiency rating system as the basis for an industry-owned premium product label (and rating). We consider this to be the easiest, most cost-effective, and most direct route to generating customer benefits that will position the industry for recognition through voluntary programs (e.g., ENERGY STAR® and LEED), and to open the door for standardized utility incentives—or even tax credits.

Introduction

Elevators account for about 1/3 to 1/2 quadrillion Btus (quads) of primary energy use annually in the United States (Kwatra, Amman, and Sachs 2013). This is comparable to U.S. commercial building electricity consumption for space heating and cooling in 2003, exclusive of ventilation (CBECS 2003). That is about 2–5% of the energy required for most buildings covered by ANSI/ASHRAE 90.1 (ASHRAE 2013). A single modern 14-story elevator in New York City can draw as much as 90 kilowatts (kW)—and regenerate up to 35 kW—during a single day (Bos et al. 2013). U.S. elevator energy use is comparable to the total energy use of Connecticut, Utah, Ireland, or Denmark.

Worldwide, the installed base is probably more than 6 million units. The elevator market is dominated by China, with about half a million installations per year. Europe installs about 100,000 per year, mostly residential, and the United States about 15,000–20,000. Elevators are very long lived, but cabs, controls, safety features, and (often) hoist mechanisms have historically been upgraded every 20–25 years. The pace of technology introduction argues for a quicker cycle.[2] Since the U.S. installed base is about 900,000 units (NEII 2014)[3], a 20-year upgrade cycle implies that the upgrade opportunities in existing U.S. buildings are much larger than in new construction. Indeed, if the modernization cycle were actually as long as 25 years, this would require about 40,000 modernizations per year, or twice as many as new installations.[4] Thus it is critical that any program to accelerate uptake of more efficient elevator technologies must address the needs of existing buildings and their owners.

To the industry, the elevator is an extension of the lobby, a powerful symbol of building quality. This means that features such as look and feel that enhance the user experience are valued. Conversely, because energy use has been perceived as relatively small (less than the cost of the service contract), it has not been historically a matter of great concern. Further, the intersection of elevators, energy use, and public policy has been almost invisible. Swiss and German bodies led early efforts to systematize energy use, leading to the VDI 4707 (VDI 2009) standard followed by the broader ISO-25745 standard activities.

The emergence of potentially cost-effective routes to substantial savings has increased awareness of elevator energy use. This paper is intended to further raise the visibility of the opportunity. Although elevators use less energy than lighting or heating, ventilation, and air conditioning (HVAC) in most buildings, new technologies, including controls, promise savings of 40% or more across many or most applications. These savings can be cost effective in many cases.

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[2] Alan Taylor suggests that the earliest MRL (machine roomless) elevators, unless very well maintained, are ready for modernization, 15 years after entering service (AT, personal communication December 2014).

[3] http://www.neii.org/presskit/pressmaster.cfm?link=7

[4] Jim Bos, personal communication, December 2014

Earlier reviews included simulations with an advanced traffic model (Enermodal 2004); technology reviews and policy recommendations, particularly for voluntary programs (Sachs 2005); and the measurement of elevator energy use for 35 lifts in 22 buildings (Gifford 2010). Gifford offers an excellent primer on technologies, and was early in pointing out that modern drives and controls can reduce the energy needed for lifting to levels below what is required for lighting and ventilation (Gifford 2010).

ASHRAE 90.1-2010 added provisions limiting ventilation energy (0.33 watt/cubic feet/minute at maximum speed) and lighting power (35 lumens/watt). It also requires that elevators turn off cab interior lighting and ventilation when they are unoccupied for over 15 minutes. Elevator energy use was not treated in earlier 90.1 versions. ASHRAE 90.1-2013, Section 10.4.4 requires that escalators reduce speed to the minimum allowed when not conveying passengers (ASHRAE 2013).

In this paper, we briefly review the industry's baseline and advanced technologies. We then offer a palette of public policy options to accelerate adoption of major energy-saving opportunities. We recommend actions by manufacturers, ASHRAE, public benefits programs (including utility incentives), voluntary labeling programs such as the U. S. Green Building Council (USGBC) LEED, and government to encourage further innovation. Options include further energy code features and a suite of voluntary programs that could include labeling of advanced products, product selection guidance, and incentives such as tax credits or more widespread utility programs.

Basic Elevator Terms and Technology

This section introduces elevator technology. Readers desiring a reference text on this technology are referred to Strakosch and Caporale (2010). Passengers or freight ride in a car that moves in a hoistway. Direct acting hydraulic elevators use a piston to push the car up; traction elevators use wire ropes, bands, or belts to pull from the top.

Hydraulic elevators are relatively inexpensive but limited to low-rise service. In North America, they drive the light-duty, two- to five-stop market.[5] Typical applications include roadside motels, schools, shopping malls, and low-rise office buildings, where the elevators exist for amenity and compliance with the Americans with Disabilities Act (ADA). The lift cylinder can be installed in a well under the shaft, or a telescoping cylinder is installed next to the car. The hydraulic fluid reservoir, pump, and ancillary components may be installed beneath the lowest stop (landing), inside or outside of the hoistway, or in an adjacent closet.

Most hydraulic elevators have very low duty cycles. Standby power dominates total energy use, so improved controls and motor and pump efficiency are not the major focus for saving energy. Most hydraulic fluids are based on mineral (petroleum) oil. The oil's potential to contaminate groundwater if it leaks from the cylinder well has led manufacturers to diverging paths. At least one major manufacturer has discontinued these systems for the

[5] According to K. Recalde, UTC, ASHRAE's 90.1 committee is developing an addendum that would limit hydraulic elevators to three stories or fewer.

European market, whereas another has substituted biodegradable fluids based on vegetable oil for the petroleum-based mineral oils previously employed.

Traction elevators are generally applied for mid-rise (three- to twenty-story) and high-rise (more than twenty-story) buildings. Unlike hydraulics, traction elevators generally have counterweights that weigh about as much as the car plus about 40–50% of its rated load. Traction elevator cars are lifted by ropes (steel or aramid cables) or, more recently, by flat, plastic-coated steel wire belts.

There are two main types of traction elevators: geared and gearless. In geared machines, the electric traction motor drives a reduction gearbox whose output turns a sheave (pulley) over which the rope passes between the car and the counterweights. To maintain a reasonable service life for the ropes, the diameter of the sheave(s) is typically at least 40 times the rope diameter. Smaller diameters would fatigue wires and shorten the service life.

In gearless elevators, the drive sheave is directly coupled to the motor, thus eliminating gear-train energy losses. Gearless designs with large sheaves and wire ropes are used in high-rise buildings where speed is of the essence. During the past decade, multiple firms have introduced alternative approaches that use multiple fine ropes or wire-reinforced flat belts with a DC permanent magnet motor with a small-diameter sheave.

In contrast with hydraulics, modern traction elevators can control speed with regeneration, using the motor as a generator to feed power back to the grid. The gravitational force acting on descending cabs that are heavier than the counterweight and on the descending counterweights when they are heavier than the cab generates power. Power is also generated when the motor brakes the elevator to slow it down (similar to the mechanism in hybrid electric vehicles). In conventional elevator systems, this power was dissipated as waste heat, often in the machine rooms. However, modern regenerative drives can feed this energy back into the building or the electric grid.

Because of the size and complexity of the older controls, safety systems, and power trains, both hydraulic and traction elevators required dedicated machine rooms for motor equipment and controls. Traction elevator machine rooms were above the elevator shafts, generally in penthouses. They have often required additional cooling due to component inefficiency. With advances in motor, control, and rope technology, new installations are now increasingly featuring machine-roomless (MRL) approaches that house the traction motor within the elevator hoistway.

To allow smooth acceleration for departure and deceleration for arrival, acceptable elevator performance requires variable speed capability. Hydraulic elevators generally use an inexpensive constant-speed (AC) induction motor with a simple pump bypass valve to control departure and landing acceleration. In older traction elevators, a grid-powered AC motor drove a DC generator whose power energized an inherently variable-speed DC traction motor. For a century, this was the best available way to smoothly modulate speed. Modulation was achieved by dumping excess power to large resistor banks, thereby wasting energy. Beginning in the 1970s, motor-generator sets were replaced by successive generations of solid-state devices, leading to today's microprocessor-controlled elevators.

Early AC hoist machines were built with induction motors. More recent traction elevators employ permanent magnet (PM) synchronous motors, which are more compact and offer higher efficiency and smoother speed control, using solid-state electronic inverters. These employ regenerative line side converters that do not require the large resistor banks of the early motor-generator systems or AC drives.[6]

For many decades, an operator in the car controlled the elevator, responding to calls for service. In the first half of the twentieth century, operators were gradually replaced by self-service controls that relied on electromechanical relays for dispatch. In turn, these have largely given way to microprocessor-based systems. As in so many other areas, from toasters to aircraft, electronic controls enable a large palette of new features. For elevators, these include adaptive dispatch, utility load control integration, and regeneration of power (with appropriate controls).

Lifting is not the only significant energy use by elevators. In general, the cab requires illumination and ventilation, and includes motor-driven doors for the cab and the landing. Power conditioning requires power. Older motor-generator systems required as much as several kW even in standby, just to keep the AC motor and DC generator spinning to respond to calls for service. Modern systems need at most a few hundred watts, instead of several kW. Controls also require standby power.

The distinction between direct lift energy and other uses leads to another distinction, that between power directly needed for service and standby power that might be reduced or eliminated when the cab is not in motion. The stationary elevator with its doors closed does not require illumination or ventilation. As discussed in the next section of this paper, current efforts to improve elevator efficiency focus on both motion and standby power. For most elevator classes, total annual standby energy use is substantially greater than traction energy. Because so much standby power is not inherent to the core (and expensive) lift function, reducing standby power can be very cost effective. Turning off the ventilation fan after the cab has been idle for some time may be more cost effective than replacing the basic fan with one with a more efficient permanent magnet motor. Similarly, turning off cab lights during standby may be more cost effective than replacing lamps and fixtures.

Opportunities for Energy Savings from Advanced Technologies

HYDRAULIC ELEVATORS

Where permitted, hydraulic elevators are the main solution for low-rise applications because they have generally been less expensive than traction elevators. Elevator manufacturer perspectives on the future of the hydraulic elevator vary. As noted above, there is concern about petroleum-based hydraulic fluids, which can leak and potentially

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[6] DC static silicon-controlled rectifier (SCR) drives started the transition. More recently, insulated-gate bipolar transistor (IGBT) chopper DC drives entered the market and furthered energy efficiency. Microprocessors and software enabled the next generation of drives, with AC variable voltage/variable frequency (VVVF) and IGBT-DC drives. These provided inherently better efficiency and lower energy use (J. Bos, principal, Sustainable Elevator Consulting, pers. comm., December 2014).

contaminate groundwater; this can be addressed by substituting vegetable-based biodegradable fluids. Other concerns include the energy required for hydraulic fluid reservoir heat in non-weatherized installations and the relatively high lift power required for these systems, which have no counterweights. Finally, regeneration is generally cost prohibitive, given the almost universal low-duty cycle (minutes per day) of hydraulic elevators. The best opportunities to save energy lie in cab improvements (lighting, ventilation, door-operating motors), maintaining proper valve adjustment,[7] and sequential standby modes such as identified in the VDI and ISO (draft) standards, for typical applications of hydraulic elevators. Although some hydraulic elevator changes seem modest, the potential exists to reduce hydraulic energy use in the range of 50% with proven, available approaches. Of course, installation of hydraulic elevators in higher use applications, such as shopping malls and airport passenger terminal areas, should be discouraged; traction elevators are generally more appropriate there.

TRACTION ELEVATORS

Traction elevators promise continuing evolution of innovative features, many of which can save energy. Table 1 outlines some important steps in the evolution of traction elevators.

Table 1. Traction elevator technologies

Component	Basic	Intermediate	Advanced
Hoist drive	Motor-generator, or DC with silicon-controlled rectifiers	Pulse-width modulation, geared drives	Permanent magnet, gearless
Car lift	Wire rope	Wire rope	PU-coated belts, multiple rope
Controls	Electromechanical relays, group controller	Microprocessor	Software-defined, e.g., destination dispatch
Lighting, ventilation	Incandescent, halogen	CFLs, efficient fans	LEDs, efficient fans, occupancy sensors
Energy sources	Grid	Grid plus regeneration	Regeneration plus solar
Other considerations	Single operating mode, needs machine room	Standby mode, better power factor	Standby mode, variable door motors, power factor near 1, MRL, quick installation

The new traction approaches (permanent magnet motors, advanced lift ropes and belts) no longer require costly penthouses with significant HVAC requirements. Instead, the modern approach is MRL, with the compact drive equipment generally installed at the top of the hoistway. Advanced drives enable power regeneration (Bos et al. 2013). Modern IGBT component costs have dramatically helped reduce overall regenerative drive price to a cost parity with non-regenerative prices. This trend has been accelerated with regenerative drive

[7] A. Taylor, principal and vice president, HKA Elevator Consulting, pers. comm., December 11, 2014.

production at larger scale to cover not only commercial high-traffic applications but also residential.[8] Additionally, advanced software facilitates features such as destination dispatch, real-time wait-duration control, standby strategies, and grid response.

To date, the underlying VDI, ISO, and other standards efforts have focused exclusively on the individual elevator, without consideration of potential energy savings in controlling elevator groups (multiple elevators serving the same floors in a building). Here, controls can be configured to dispatch only the number of lifts required for a stipulated service level (e.g., maximum likely wait for service). For example, office building usage will be concentrated at the beginning and end of the workday and at lunch, and fewer elevators are required in mid-morning and mid-afternoon. Another innovation is destination dispatch, in which users enter their destination floor at a lobby console, so passengers with the same or neighboring floor choices can ride the same trip. Although sophisticated simulation models can estimate energy usage (Al-Sharif 1997), they are unlikely to be employed except in very tall buildings.

As the case study incorporating some of these technologies demonstrates, it is possible to reduce energy use by about half compared to the base conditions.[9]

CASE STUDY: HOTEL ELEVATOR MODERNIZATION

Table 2 presents an overview of a major elevator modernization project in a 20-story hotel in Hawaii. The hotel had two high-rise elevators dating back to 1974. The modernization involved changing not only the hoisting and control technology but also the cab interiors and lighting. The modernization allowed the hotel to improve ride quality while reducing energy consumption by 56% (Nemeth 2011).

Table 2. Overview of hotel elevator modernization (Source: Nemeth 2011)

	Existing	Upgrade
Motors	Geared	Gearless
Hoist motors	20 HP DC	Permanent-magnet motor
Motor generators	10 kW, 15 HP DC	Not required
Controllers	Relay-logic	Microprocessor controllers with destination-based software and regenerative drive technology
	Group controllers	Not required
Lighting	Incandescent	LED
Cab interiors	Dated	Low VOC, modern

[8] According to an anonymous industry reviewer.

[9] Actual energy savings vary over a wide range depending on the extent of upgrade. For a summary of estimates, see the High Performance Elevators page on the E3T portal managed by Washington State University: http://e3tnw.org/ItemDetail.aspx?id=471.

Current Codes, Standards, and Voluntary Programs

The modern elevator dates to Elisha Otis's 1853 patent for a safety elevator. To prevent falling, the Otis elevator featured a novel automatic brake that immediately stopped the car if the rope broke.[10] Safety is still the first consideration for elevator designers. In the United States, the American Society of Mechanical Engineers A17 Standards Committee is the cognizant safety code-development authority. Most international standards are still primarily focused on safety considerations.[11] However Hong Kong publishes a code of practice that includes minimum design and operating requirements for elevator systems. The Hong Kong EMSD code has stringent requirements for standby mode, including shutting off in-car ventilation within two minutes of cab idleness.

International bodies have worked to develop elevator service categories and energy-use metrics. Success in these efforts will have two important effects for energy use: First, it could eliminate some fraction of the least-efficient products and require adopting better technologies and controls.[12] Second, the code-based minimum efficiency baseline can be used for beyond-code recognition (e.g., USGBC LEED) or incentive payments, such as those provided by many U.S. utilities and other public benefit programs.

For present purposes, the key energy efforts are ASHRAE 90.1-2013,[13] VDI 4707 (a guideline, not a standard), and ISO 25745, each discussed below.

ASHRAE 90.1 Elevator Energy Use Standards Development

ASHRAE has published building energy-efficiency standards for new construction since 1975. ANSI/ASHRAE/IES Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings,* has been the national new-construction minimum energy efficiency standard for commercial buildings since 1992. Prior to the 2010 version of Standard 90.1, the standard focused on five ASHRAE energy end uses: heating, cooling, ventilation, service/domestic water heating, and lighting, with little other equipment except motors. Beginning in 2010, the expanded scope of 90.1 includes additional end uses to help achieve energy efficiency goals. Elevators and escalators are now covered equipment. In particular, 90.1-2010 specifies minimum efficiency levels for cab lighting and ventilation and sets standby-mode requirements for them (table 3).

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[10] In the Otis elevator, the rope was not attached to the cab, but to an arm of the brake. If the rope broke, the arm rotated outward to contact the vertical guide rail and brake the fall.

[11] Examples include: Australia – AS1735, Canada – CAN/CSA B44, Europe – EN 81 series (EN 81-1, EN 81-2, EN 81-28, EN 81-70, EN 12015, EN 12016, EN 13015, etc.).

[12] For consensus-based codes, such as 90.1, a fundamental requirement is that prescriptive requirements (such as elevator features) be cost effective, that is, with life-cycle savings.

[13] Formally *ANSI/ASHRAE/IES Standard 90.1-2013 -- Energy Standard for Buildings Except Low-Rise Residential Buildings.* ASHRAE, Atlanta.

Table 3. Elevator cab efficiency requirements in Standard 90.1-2010 (Section 10.4.3)

Component	Requirement
Lighting	For the luminaires in each elevator cab, not including signals and displays, the sum of the lumens (lm) divided by the sum of the watts (as described in Section 9.1.4) shall be no less than 35 lm/W.
Ventilation power limitation	Cab ventilation fans for elevators without air conditioning shall not consume over 0.33 W/cfm at maximum speed.
Standby mode	When cab is stopped and unoccupied with doors closed for over 15 minutes, cab interior lighting and ventilation shall be de-energized until required for operation

This framework is a just a start, but it has interesting aspects. For example, unlike lighting in other spaces, the elevator metric is not area dependent; it does not limit lm/sq. ft. (brightness), but may affect the technologies used. For example, some low-efficiency incandescent lamps can be used, but only if the total installed illumination gives a calculated efficiency of at least 35 lm/W. Similarly, the ventilation power aspect does not specify a minimum or maximum air exchange rate, either as cfm per passenger or cfm per unit floor area (or cab volume), and it does not specify any rating condition. Presumably, fans are rated with zero external pressure. The standby requirement may be the most important aspect of this code provision.[14] It would be preferable to regulate lighting energy not just in lm/W, but also in W/sq. ft.[15] Finally, display screens (e.g., weather and advertisements) larger than some minimum size should enter standby when the car is in standby.[16]

The 90.1 committee has also addressed escalator and moving walk standby-mode energy use in the 2013 version by requiring that when the units are not conveying passengers, they automatically slow to the minimum permitted speed in accordance with ASME A17.1/CSA B44 or applicable local code.[17] SSPC 90.1 plans to establish reasonable prescriptive minimum requirements for elevator transport efficiency once appropriate test and rating standards for elevator equipment are available from ISO (25745-2), VDI (4707), or others, as discussed below.

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[14] Note that European codes discussed below have staged standby requirements, with less standby energy allowed as time since last travel increases, up to 30 minutes.

[15] The 90.1 committee considered this, but decided not to incorporate the parameter in this version (J. Boldt, principal and director of engineering, KJWW, pers. comm., December 11, 2014). For example, glass-walled elevators may have high lighting levels that contribute to ambient levels in hotel atriums.

[16] We do not suggest that essential information displays (landing, emergency instructions) be dark when the car is not in use.

[17] International practice generally allows escalators to stop completely after some interval without passengers.

Another approach to recognizing advanced elevator technologies in 90.1 is through building-simulation modeling using the performance rating method (PRM) in Appendix G of Standard 90.1. Appendix G allows alternative elevator technologies to be compared to a code-compliant baseline building simulation, a feature that is not found in Standard 90.1's Chapter 11, Energy Cost Budget (ECB). Under the Chapter 11 ECB rules, receptacle, motor, and process loads are modeled and estimated based on the building type or space type category and assumed to be identical in the proposed and budget building designs, thus allowing no trade-offs for compliance with the standard.

Appendix G modeling requires that the baseline building design be modeled with the same number of floors and identical conditioned floor area as the proposed design, but it allows more flexibility with compliance trade-offs.

Where the chosen building-simulation program does not specifically model alternative (elevator) systems, spreadsheets or other documentation of the assumptions can be used to generate the power demand and operating schedule of the systems. Use of the Appendix G PRM approach will require building-simulation model inputs for connected loads and performance parameters of these advanced systems, as well as baseline and proposed design operating schedules that reflect how the advanced technology is used on a time-of-day basis. The effort required for the PRM may not be justified except for very large buildings or those whose owners want to show the greatest possible efficiency, so alternative compliance paths should be developed to encourage use of advanced technologies.

There are additional opportunities in the International Green Construction Code (IgCC), which is also a compliance path for ASHRAE 189.1 (ICC 2012). The IgCC includes a prescriptive section outlining the best available elevator technology, from an energy consumption perspective.[18]

INTERNATIONAL STANDARDS DEVELOPMENT

Two major programs, each with two or more parts, attempt to systematically address elevator energy use. The first, VDI 4707 Part 1 (2009) and VDI 4707 Part 2 (2013), began in Switzerland. The publisher, Verein Deutscher Ingenieure (VDI), is the association of German engineers.[19] The purpose of VDI 4707 Part 1 is to provide a simple field measurement or a basis calculation method for standby and hoist energy for lifts. VDI 4707 Part 1 (VDI 2009) defines five usage classes. Usage Class 1 is typified by small apartment or office buildings. At the other end, Usage Class 5 represents structures such as office buildings over 100 meters (~330 feet) and large, tall hospitals.

The first three VDI 4707 classes (very-low- through medium-usage), respectively, have maximum travel time from 0.3 to 2 hours a day, so they are idle (standby) more than 90% of

[18] R. Fargo, systems engineering fellow, Otis Elevator, pers. comm., January 2015.

[19] VDI is not a standards organization, although its technical work is in fact dominated by standardization. VDI standards have the same legal status as DIN (and, consequently, DIN EN and DIN ISO) standards in Germany.

the time. Only the highest VDI usage category reaches a 25% travel fraction. Thus standby (or idle) time dominates elevator service and can be surprisingly high (up to several kW) for some older technologies. Critically, 4707-1 also introduces efficiency classes labeled A (most efficient) through G (least efficient) for both standby and travel.[20] These categories are accompanied by formulas for computing efficiency class from field measurements or calculations, including explicit test lift cycles. Performance is summarized by a label (figure 1).

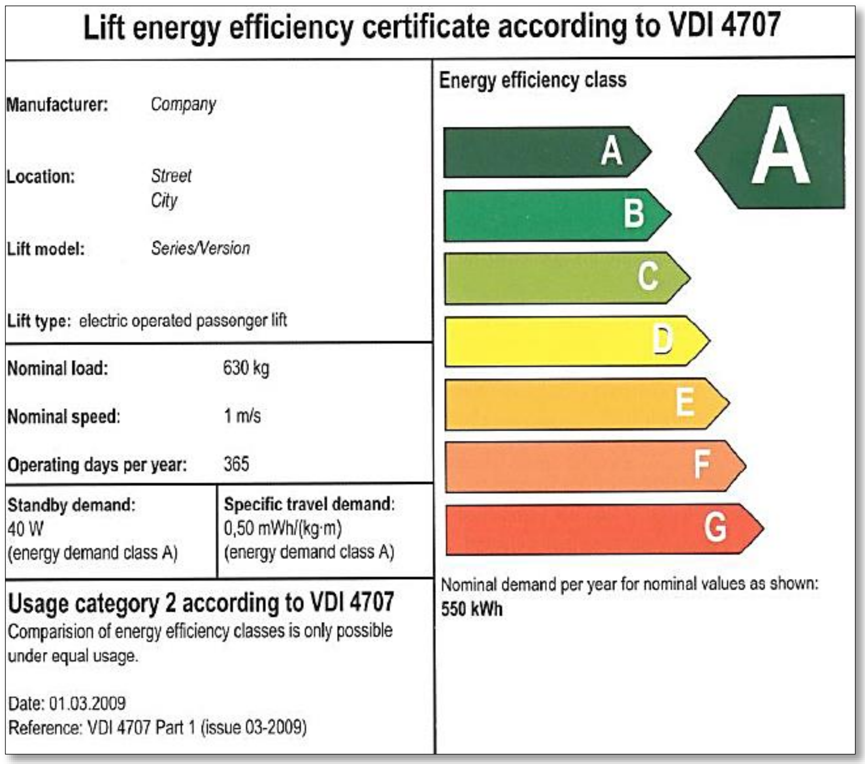

Figure 1. VDI energy efficiency certificate for elevators. *Source:* VDI 2009.

VDI 4707 Part 2 addresses the energy efficiency of lift components. This standard establishes fundamental methods for assessing and classifying the energy demand of lift systems in accordance with VDI 4707 Part 1. It describes the characteristic values to be specified by the component manufacturer and how to calculate them. It also provides an explicit procedure for calculating the energy demand of a complete lift on the basis of the components used. VDI 4707 Part 2 extends the system for determining demand in standby and travel, with four operating mode classes (travel, plus three increasingly long-duration standby modes),

[20] According to VDI 4707 Part 1, an elevator can only be correctly labeled for a given usage category. This means that the same elevator (e.g., one with low standby consumption and high travel consumption) may be energy efficient in a small residential building (because it rarely travels) and poor in a large office building (where it rarely dozes) (T. Wollstein, VDI, pers. comm., January 21, 2015).

and regeneration. Part 2 provides explicit measurement and calculation requirements, including door-operating energy.

VDI 4707 is particularly important because it establishes relatively coherent usage classes and efficiency grades. It is also the only standard available now for global application. Its energy class system approach has been adapted by ISO 25745 (discussed below), but altered in detail.

There are concerns, as would be expected, in at least three respects. Some experts are uncomfortable with using letter grades (A–G) for energy performance instead of actual or simulated energy use (mWh/kg*m). Letter grades are a common European practice for residential appliances, but some feel they oversimplify complex engineered systems such as lifts. Among other concerns, Class G reflects archaic machines, and the future might include much better systems than today's efficiency grade A. Most lift systems purchased today are in energy class C. Class A is commonly reached by elevators employing regenerative drives and permanent magnet synchronous motors with gearless transmissions. Thus Class A is not a technology stretch since higher performance is attainable, in our opinion.

A third issue, limited to multi-lift installations, is that VDI 4707 generally does not consider elevator group energy consumption but only each elevator separately. As a consequence, dispatching systems benefits are not considered, nor is extra energy consumption coming from modern landing fixtures such as low-wattage touch screens installed in recent buildings (two to four per floor).

Availability of Class A systems helps us focus on the questions of how to bring higher performance levels to wider acceptance, and whether public policy can or should encourage this market transformation. Some experts have been uncomfortable with specifics of the VDI-4707 approach. In the U.S. context, VDI 4707 is not a consensus standard as defined by the American National Standards Institute (ANSI), as is preferred in the United States.

The second international effort, ISO 25745, also has three parts. ISO 25745 Part 1 (2012) deals with energy measurement for the energy performance of lifts, escalators, and moving walks (like 4707-1 measurement for lifts) (ISO 2012). The draft ISO 25745 Part 2 provides a method for estimating annual energy consumption based on measured values, calculation, or simulation for verification (like 4707-1 as well). It includes three standby modes differing by the elapsed time since the most recent movement (idle, standby after 5 minutes, and standby after 30 minutes). Part 2, in review now, should be completed early 2015. ISO 25745 Part 3 is similar to Part 2, except for escalators and moving walks, and has the classes A+++ through D. It will be completed in early 2015, too.

The ISO and VDI approaches differ in details, such as the number of usage classes (six versus five), and the basis (starts per day versus hours of operation). ISO 25745 Part 2 includes a method to estimate energy consumption on a daily and an annual basis for lifts, and a method for energy classification of new, existing, or modernized lifts. In summary, ISO 25745 and VDI 4707 are broadly similar in structure, but the latter may be more complex in calculation and measurement when finalized.

ENERGY STAR

Building label programs, notably the USGBC LEED and ENERGY STAR® Portfolio Manager programs, are also important today. Many owners—and tenants—value recognition for the aura projected in the market. In general, ENERGY STAR, a U.S. Environmental Protection Agency program, for commercial buildings focuses on whole building energy use,[21] with recognition dependent on evaluation through the Portfolio Manager tool.[22] This program evaluates whole-building performance, as revealed by a comparison of utility bills with a reference set. Buildings that score higher than 75 points may be labeled as ENERGY STAR buildings. With this approach, services like hot water and vertical transportation are not heavily weighted, since they are usually relatively small fractions of the total energy bill. One exception, the ENERGY STAR Multifamily High Rise program, offers a simulation path that includes elevator loads (Section 3.11 of ENERGY STAR 2013). It stipulates appropriate baseline technologies for units of 4–6, 7–20, and 21-plus stories. It also provides default options that can be used to determine total elevator energy consumption without an elevator simulation module. If use is simulated, it is implicit that standby/idle savings can also be claimed. If not included in the simulation, savings from lighting and ventilation in the cab can also be claimed as a separate performance credit based on improvement over the stipulated baseline.

USGBC LEED PROGRAM

USGBC offers the LEED certification program for green buildings.[23] The program is popular because owners and tenants value the prestige associated with earning the label. The LEED certification process requires a building or project to meet certain prerequisites and achieve a number of credit points to qualify for a certification level. Elevators are considered a part of unregulated process loads, and therefore there are no direct credits for installing more efficient systems. However LEED offers a pathway that can credit measures that demonstrate a reduction in process loads, and efficient elevators can apply for these credits. There are also other ways by which elevators can help meet LEED prerequisites as well as achieve credit points. For both new construction and existing buildings, elevators can help increase the levels of building energy performance over the prescribed baseline, such as ASHRAE 90.1 2010, and thus earn points under the Energy and Atmosphere category. The materials used in constructing elevators are important in achieving credit for the Material and Resources and Indoor Environmental Quality categories. For instance, there are options to use recycled steel, aluminum, plastics, glass, and rubber in the construction of the elevator and low VOC materials for the interior. We believe that treating vertical transportation as regulated loads would create further incentive for elevator efficiency upgrades.

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[21] Program resources can be found at http://www.energystar.gov/buildings?s=mega.

[22] For details see http://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager.

[23] We discuss the USGBC program because of its large market share. See www.usgbc.org. There is no intent to discount alternatives such as Green Globes (www.thegbi.org).

Barriers to the Adoption of Energy-Efficient Elevators

Elevators represent only 2–5% of the energy used in a typical building, so their energy consumption has not been a major concern of designers or owners. However a building's elevator energy demand is highly cyclical, depending on the time of the day. Although overall annual elevator energy usage ranges from 2 to 5%, during busy periods (e.g., lunchtime) elevators could account for as much as 50% of a building's energy consumption.

Getting attention requires establishing value. To illustrate, if conventionally designed elevators use 4% of a building's electricity, a 50% reduction cuts that to 2%. That reduces the whole building's energy use only from 100% to 98%, in round numbers. Two percent of whole building electricity savings has real monetary value, but only if service is better, or at least as good. As we discuss below, the industry should leverage these monetary savings to gain recognition from labeling and energy efficiency incentive programs offered by government, utilities, and public benefit organizations.

Although architects and owners care about the elevator experience as an extension of the building's presentation, incremental costs are a barrier (resulting in sticker shock), regardless of payback or return on investment. The challenge is to help customers understand that life cycle costs (LCC) matter much more than first costs. However the payback period on elevator replacement projects can be long, especially for low-rise buildings where trips are relatively few and short, so the total annual energy consumption cost is relatively low.

A further complication is the fact that in most commercial buildings, the cost of elevator energy consumption is bundled with other common-space costs and generally apportioned among the tenants as a pro rata operations and maintenance charge. Depending on lease structure, both the cost of the capital investment required and the proportional energy savings may be passed on to tenants. The overall reduction in costs per tenant is usually not significant enough to motivate an upgrade.

Malfunctioning or end-of-life elevators are usually the chief driving factor for upgrades. In the United States, HVAC and other permanent building systems, including elevators, are depreciated over 39 years, much longer than their service lives, and much longer than the expected refurbishment intervals expected for elevators (Sachs et al. 2012).

Decision makers also under-appreciate benefits, particularly the non-energy benefits. These include smoother, quieter, and faster rides, shorter wait time, and higher reliability with lower service costs. Without personal experience, decision makers do not have a basis for enthusiasm and find too few solid case studies for an analytical approach.

Anecdotally, another barrier is that many of the consultants to owners and architects come from sales backgrounds rather than technical ones. Some may be reluctant to specify novel, advanced technologies for fear of risking their reputation if their advice did not meet expectations.

Europe has exceeded the United States in adopting new technologies, including elevators. The climate for adoption is different in the European Common Market. First, electricity costs much more there. In 2011, average U.S. prices were 12¢/kWh, which can be compared with 20¢/kWh (United Kingdom), 19¢/kWh (France), and 35¢/kWh (Germany).[24] Second, driven by concerns about climate change, Europeans have been open to more aggressive policies for both energy efficiency and renewable energy.

In light of these disincentives, it is clear that the lack of an agreed performance baseline, such as can be developed from VDI-4707 or ISO 25745, is a major barrier to establishing the value of more efficient elevators in the United States.

A Path Forward

ACEEE believes that the elevator industry can transform the market by raising the visibility of advanced technologies as they save energy and have other benefits. Our core recommendation is that the industry adopt an efficiency rating system as the basis for an industry-developed and -owned program to identify and label high-performance elevators. We consider this to be the easiest, most cost-effective, and most direct route to position the industry for recognition through voluntary programs (e.g., ENERGY STAR and LEED), and to open the door for standardized utility incentives, or even tax credits or faster depreciation. The primary feature of the elevator systems included will be exemplary energy performance, which can be roughly defined as performance sufficiently better than baseline equipment to interest voluntary and incentive programs.

DEVELOP AND ADOPT A PERFORMANCE MEASUREMENT YARDSTICK

The first action item is to establish what an efficient elevator is. For each usage class, what performance level (or energy-use band, in VDI terms) uses sufficiently less energy to warrant an efficient product label? ACEEE recommends that manufacturers coalesce around either VDI 4707 or ISO-25745 (or a combination, depending on usage class) to describe the efficiency of new and existing elevators. Given that two rather sophisticated standards sets will soon be available, customers (including incentive providers) will strongly prefer programs that are based on rating methods consistent across the industry. Since both standards sets are performance-based, adopting either would send a strong signal that energy performance matters much more than prescriptive feature lists for incentive programs, whether they are utility rebates or tax credits.

Both VDI-4707 and ISO-25745 have representative usage and efficiency classes, although they differ in many details. ACEEE takes no position on which of these is better, but notes that ease of use for marketing and customer decisions matter. Our opinion is that the differences are smaller than the potential for increased sales and energy savings from adopting either, or a successor that bridges the gaps. For example, the successor might offer

[24] http://theenergycollective.com/lindsay-wilson/279126/average-electricity-prices-around-world-kwh.

both continuous and categorical options for disclosing energy use. [25] Or, under foreseeable circumstances it might make sense to adopt one of these for lower-usage (or lower-lift) elevators that use less energy and cost less, and the other for the larger, more heavily used, and more expensive elevators that warrant deeper analysis by owners' consultants.

In any case, early consensus of what should be used in North America would be our first action item. Indeed, the core of our recommendations is adopting an efficiency rating system as the basis for an industry-owned premium product label (and rating).

Support ASHRAE Efforts To Establish a Minimum Elevator Efficiency Metric

Next, ACEEE recommends that the elevator industry strongly support ASHRAE's efforts to establish credible minimum efficiency levels for different lift categories. In the construction industry, energy codes such as ASHRAE 90.1 specify minimum acceptable efficiency levels. They are limited to considering and adopting technologies and practices that are well established in the relevant sector, with multiple sources, and cost effective by an agreed measure.[26] Establishing cost effectiveness can be challenging, particularly because advanced energy-efficiency technologies are often bundled with other premium features and priced accordingly. However other highly competitive industries, such as commercial HVAC equipment, have managed to meet this challenge.[27]

ACEEE's industry interviews suggest a good likelihood that it will be possible for ASHRAE 90.1-2016 to include a reasonable usage-based elevator classification, and to specify maximum standby and (daily or annual) travel energy with reasonable, if not perfect, calculation or measurement-based methods. Of the two, for most elevators, standby is the dominant energy dissipater and the easier to specify, with 30-minute (or somewhat longer) measurements.

Since ASHRAE 90.1 is the principal model energy code for commercial and certain residential properties, if ASHRAE adopts minimum standards from either VDI 4707 or ISO-25745 (or a combination), those performance requirements will become a reasonable minimum performance baseline. This would conform to long-standing incentives practice for HVAC equipment, for which the baseline has been the relevant legal minimum federal minimum energy standard.[28]

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[25] A continuous scale uses numerical values, e.g., kWh/day. A categorical scale has discrete classes, such as the A–G efficiency labels in VDI 4707. A dichotomous classification, as used by ENERGY STAR, is a special categorical variety with only two classes, such as pass/fail.

[26] Building codes generally cannot require a performance level that can only be met by one product or provider.

[27] In the case of commercial HVAC, there is some calibration from DOE's independent analyses in the determination analysis carried out to substantiate energy savings in successive versions of 90.1.

[28] The path differs between "federal equipment," such as most residential appliances, and equipment for which ASHRAE sets standards. These become federal minima following a formal federal determination of savings. In turn, this is followed by adoption by the authorities having jurisdiction (AHJs), typically state or local bodies.

Our assumption is that technology-based simulations for each usage class would be sufficient. For example, an online calculator used by the industry could allow owners and consultants to quickly calculate baseline energy from usage class and number of stops. This would lay down a marker of what minimum efficiency levels are acceptable as cost effective for new elevator installations, whether in new construction or retrofits covered by the code.

A new version of ASHRAE 90.1 is published every third year.[29] Following publication, the Department of Energy's determination process evaluates the energy savings attained. After that, states begin considering adoption but often lag behind ASHRAE by more than six years. In the meantime, the new version of 90.1 is still an effective tool for establishing that more efficient elevators have value to the customer.

We do not fear that adoption of a standard in ASHRAE 90.1 will reduce headroom for selling much more efficient products. The conservative cost-effectiveness criterion and the need to show that multiple firms can meet the standard leave substantial headroom to market even more advanced (and/or specialized) technologies and systems that reduce energy use further and offer additional customer benefits. There are also additional opportunities, particularly for voluntary programs, if ASHRAE 189.1 (ASHRAE 2014) adopts higher performance standards.[30]

DEVELOP AN INDUSTRY PROGRAM TO IDENTIFY AND LABEL EFFICIENT ELEVATORS

An industry-developed program to identify efficient elevators could be the next key step. An old ENERGY STAR program rule of thumb might be a starting point: If the spread of efficiencies available in the market is small, there is no program opportunity. That is clearly not the case for elevators. A further rule is that a program is not warranted until efficient products are common enough that customers can easily find them. For mass-produced products in the ENERGY STAR program, that usually means that 20–25% of the models offered (not sales) would meet the proposed criterion, and that the ENERGY STAR product was about 10% more efficient than the baseline or legal minimum efficiency. Finally, some measure of cost effectiveness for the customer is needed.

The latter requirements are clearly not appropriate for elevators. Elevators are generally built to order, not mass produced, so the concept of "model" is quite different. Prices are only revealed through bids. But, there is a wide range of available efficiency levels. So, the job of a consensus process is to discover acceptable performance criteria that can be met cost effectively and that are well differentiated from the baseline products.[31] ACEEE believes that

[29] In between, addenda are published as they are ready, and presumably can be adopted individually by AHJs.

[30] Formally "ANSI/ASHRAE/IES/USGBC Standard 189.1-2014, Standard for the Design of High-Performance Green Buildings."

[31] From reviewer comments, qualification might need to be based on a multi-parameter criteria sum or other process to weight various factors that contribute to efficiency in specified elevator classes.

elevator manufacturers active in the North American market will be able to agree on performance-based criteria for a "Premium Elevator" label.[32]

A prescriptive approach that requires specific technologies, such as permanent magnet motors (lift, ventilation, doors, or all) is relatively easy to document from product cut sheets, maintenance manuals, and similar documents. Unfortunately, it is frozen, locking out alternative technologies that may yet be introduced. And it might be subject to gaming, for example, by using a primitive, inefficient controller on a permanent magnet motor of barely adequate design. Thus we prefer a performance-based efficiency-class proposal, such as the VDI-4707 Part 1 approach in its Table 5, which accounts for both standby and travel power for each efficiency class A–G and each usage class 1–5. The goal is an efficiency rating method that is good enough for comparisons and flexible enough to encourage rather than impede innovation.

ACEEE suggests that an industry elevator efficiency program could be loosely modeled on the NEMA Premium® motor specification and the Motor Decisions Matter program, rather than on ENERGY STAR (NEMA 2014; Elliott 2007). The parallels with the NEMA Premium program are not exact but worth outlining. We believe such a program could be faster, more certain, and better adapted to the needs of the industry and its customers than ENERGY STAR.

Electric motors used more than half of all electricity in the United States, and larger motors tend to be installed where the cost of the motor is lower than the value of the first year's power it uses. These factors combined to create powerful incentives for manufacturers, customers, utilities, advocates, and government to work together for improved efficiency. After EPACT 1992[33] set standards for most integral horsepower motors (1–200 hp),[34] industry and the efficiency community created the voluntary NEMA Premium Motors Program (NEMA 2014)[35], with an efficiency specification table.[36] This specification was addressed to industrial applications for 600 V or lower motors rated 500 hp or less, operated more than 2,000 hours per year at greater than 75% of full load.[37]

To encourage use of the specification NEMA, efficiency advocates and others launched a public awareness campaign called Motor Decisions Matter, which is managed by the

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[32] ACEEE is not recommending "Premium Elevator" for the label. What to call it is a topic for marketing professionals, but (if you will excuse the exercise) the label should be uplifting.

[33] http://thomas.loc.gov/cgi-bin/query/z?c102:H.R.776.ENR:

[34] For a succinct introduction to the motor efficiency levels, see www.me.ua.edu/me416/s09/pdf/nema_**epact1992**.pdf.

[35] http://www.nema.org/Policy/Energy/Efficiency/Pages/NEMA-Premium-Motors.aspx.

[36] http://www.nema.org/Standards/Pages/General-Specification-for-Consultants-Industrial-and-Municipal-NEMA-Premium-Efficiency-Electric-Motors.aspx

[37] This would be analogous to starting an elevator program with the higher usage classes, instead of all at once, and may be worth considering.

Consortium for Energy Efficiency.[38] For numerous reasons, particularly the enormous effect on manufacturing of the recent severe recession, this program may have reached a penetration plateau at about 20% where it has been actively promoted. Sophisticated customers responded, but customers who were primarily driven by first-cost considerations continued buying less-efficient motors—when they did not just rewind the old ones, often further decreasing their efficiency.

Clearly, elevators are not equivalent to motors. Motors are less customized, although many are built to order. For industrial and many commercial motors, efficiency is a very important customer concern. Motors are bought to meet specific needs. In contrast, elevators are sold, and efficiency has generally been just an ancillary benefit of premium look and feel, or building user experience of the elevator as extension of the lobby.

On the other hand, we believe that the market will respond well to proposed VDI or ISO usage classes. Experts need to decide what performance levels identify the efficient product. This can be based on meeting or bettering a specific VDI energy grade, or having particular energy use associated with the ISO process (per usage class, of course). We recommend that the first industry program identify a level that clearly is associated with less energy use than the proposed ASHRAE minimum efficiency baseline (as discussed above), and is likely to be attractive for users with investment horizons comparable to elevator renovation intervals, roughly 20 years.

Product performance can be labeled in at least three ways. Basic ENERGY STAR labels are dichotomous: Either a product meets the ENERGY STAR criteria, or not.[39] If a product meets the criteria for program participation, it can carry the label in the market. European guides, in contrast, are categorical, with multiple efficiency grades represented (see figure 1 above). This gives consumers an easy gauge of relative performance. In contrast, U.S. EnergyGuide labels give continuous values, such as kWh/yr, with a guide bar (or thermometer) indicating relative performance.

If the goal is simply differentiating better products, the dichotomous ENERGY STAR label demonstrably works in the market but does not help those purchasers who want even better or the very best. In this context, the European categorical grades A–G are helpful, certainly for most household products. Again, elevators are different from washing machines in that they are individually specified, complex, engineered products whose energy use is highly dependent on many technology choices, including their controls. Thus a continuous measure (e.g., total energy/day), may be important, at least as a basis for any kind of incentives. This can, of course, lead to categorical ratings, as used in VDI 4707.

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[38] http://www.motorsmatter.org

[39] The ENERGY STAR Most Efficient program "recognizes products that deliver cutting edge energy efficiency along with the latest in technological innovation. " It is also a pass-fail program, but with much more stringent criteria. See http://www.energystar.gov/index.cfm?c=partners.most_efficient_criteria.

The key task of the program is to establish that very efficient elevators are available, affordable, and easily purchased: The bid specification or purchase documents simply require an efficiency-rated and labeled product. Experience suggests that this kind of label can be owned (trademarked) by a trade association or an ad hoc group.

LEVERAGE ACCEPTANCE OF HIGHER PERFORMANCE LEVELS

The industry program can leverage acceptance of higher performance levels in stretch codes like ASHRAE 189.1 and IgCC, and possibly encourage acceptance of an ENERGY STAR elevator system efficiency label. Some elevator industry participants have advocated an ENERGY STAR program as a way to differentiate premium products. Figure 2 compares national vertical transport energy use with that of some ENERGY STAR products, establishing that elevators are comparable in annual energy consumption.[40]

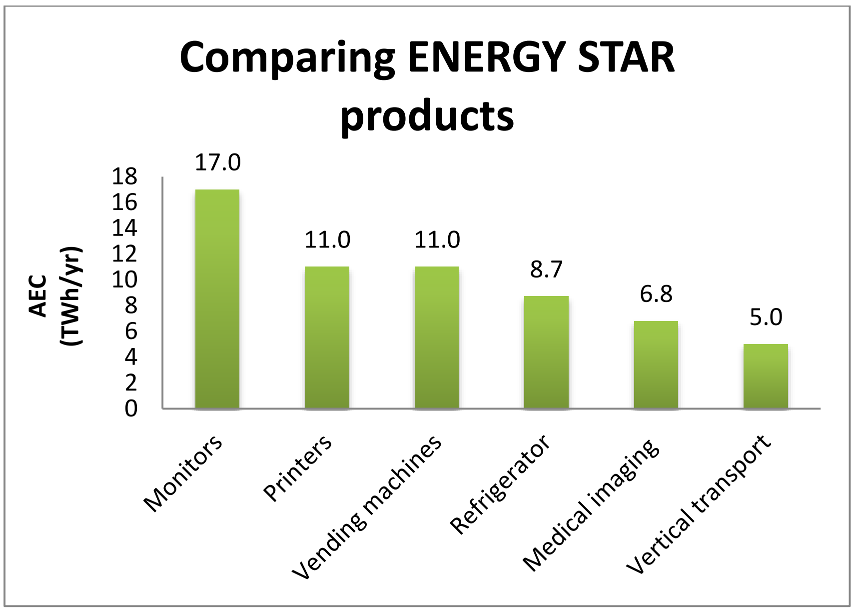

Figure 2. Energy use of select ENERGY STAR products. Specification for medical imaging is currently under development. *Source:* Kwatra, Amman, and Sachs 2013.

This suggests that industry could make a case for an elevator ENERGY STAR program based on an industry-developed premium specification.[41] There is also an opportunity beyond an ENERGY STAR label to differentiate even more efficient elevators. This is, of course, one of the values of the VDI-type categorical label, a model that has been so successful for simpler products. ACEEE suggests that an actual energy-use guide level (like the VDI label in figure 1) would encourage further innovation and support industry efforts

[40] Vertical transport includes the smaller contribution of escalators.

[41] We note that ENERGY STAR programs have not been limited to appliances and equipment for which there are federal rating methods and standards. One early example was ceiling fans, for which the program responded to manufacturer requests for a program by stating that they needed a reproducible method of test. Industry developed an acceptable one, just as the elevator industry is now with VDI 4707 and ISO 25745.

to improve image and actually save money for customers. This can also be accomplished with the energy-use values of the ISO-25745 approach, which is similar to the yellow EnergyGuide efficiency labels used for regulated residential products in the United States.

Include Elevators in Energy Efficiency Incentive Programs

ACEEE believes that utility and other demand-side incentive program operators will provide financial incentives for better elevator performance that save energy, if (and only if) they have a reasonable, easy-to-use, and verifiable basis for estimating savings and their monetary value.[42] An accepted and verifiable elevator efficiency label will go a long way toward meeting these requirements.

Utilities and other program operators routinely offer financial incentives to customers who adopt energy efficiency measures, including installing more-efficient equipment.[43] The financial incentive itself sweetens the pot enough to sway decisions in many cases, by reducing payback period. The credibility of the utility's commitment can also help decision-influencers sell a project internally, so it moves from the facility side of the firm to the financial side.

Utility and other demand-side programs spent $7 billion to $8.0 billion in 2013 (CEE 2013; Gilleo et al. 2014).[44] As of August 2014, 24 states had fully funded policies in place that established specific energy savings targets that utilities or non-utility program administrators had to meet through customer energy efficiency programs.[45] Utilities are actively seeking prudent ways to increase savings, since these energy efficiency resource standards are binding, and many states are setting increasingly aggressive savings targets. A well-founded elevator program should be welcome.

Incentive programs have traditionally stimulated sales of widgets such as compact fluorescent light bulbs. Even for HVAC equipment, they have emphasized high-efficiency "boxes" or units rather than system performance. On the other hand, the better programs are increasing emphasis on systems and on concepts such as retrocommissioning and comprehensive commercial retrofits (Kwatra and Essig 2014). That is why establishing the performance level of the elevator system is so important: owners and consultants want to be able to evaluate the savings from this integrated system as easily as for an air conditioner.

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[42] See http://energy.gov/eere/femp/energy-incentive-programs for an introduction to utility incentives by state; see http://www.pge.com/en/mybusiness/save/rebates/ief/index.page for one approach to custom rebates for energy and demand savings. The basic concept, introduced by Lovins (1990), is that efficiency should always be purchased when its levelized (life-cycle) cost is less than the full cost of generating electricity, including the purchase of new power plants when needed. Many utility regulators both require and reward such efficiency investments.

[43] In some states, these programs are operated by the government itself or third parties on behalf of the utilities.

[44] http://www.cee1.org/content/2013-report-deepens-picture.

[45] http://www.aceee.org/topics/eers (policy brief). Note that Indiana and Ohio have rolled back or frozen their programs through legislation.

The key to unlocking the incentives bank is giving the agencies that offer incentives assurance that the promised savings will be achieved. For all but the largest or most prominent projects, incentive programs need simple procedures to determine eligibility and to calculate (life-cycle) savings to calculate incentives.[46] This requires projecting savings beyond the defined baseline so they can be monetized and incentivized.[47] At the program level, the savings must somehow be verifiable. This is necessary so the public utility commission that regulates utility rates can justify recovery of the utility program costs and its incentives.

In some cases, field studies of usage and direct measurements of energy savings can be used to compute deemed savings. For example, if we know the difference in rated energy use of an average gas water heater and an ENERGY STAR water heater, and number of water heaters incentivized, we can calculate energy savings and their value for each year a program operates. At the other extreme, utilities are comfortable with spreadsheet calculations for industrial and commercial buildings, if done by standard methods.

Labeling makes incentive programs easy to administer. The engineer of record submits the bid documents with information on the usage class. The manufacturer certifies that his laboratory measurements or simulations justify the energy-use assertions for the specific product, both for the baseline unit and a unit eligible for incentives. The potentially verifiable performance of the installed equipment, as compared with the agreed baseline, is the basis for calculating saved energy, its value, and thus the value of an incentive.

Determining the baseline may not always be simple. ASHRAE 90.1 will provide a performance baseline for new construction and the substantial retrofit of commercial buildings. Its efficiency level may not be the right one for other situations. In particular, consider an end-of-service-life elevator modernization contract. If the 90.1 version that is in use in the local Authority Having Jurisdiction (AHJ) is not current, and might not even have any elevator requirements, then many utilities would consider the appropriate baseline for calculating savings to be the least efficient elevator that could be procured today as a replacement, on the assumption that this is what the customer might buy instead of an efficient one. This could be interesting.

For major modernizations, the baseline also requires either actual measurements of energy use of the old lifts (e.g., by methods of VDI 4707 Part 1), or a generalized data table by installed technologies, usage class, and number of stops, such as can be derived from VDI 4707 Part 1). Which to use is debatable. If a building owner proposes to accelerate modernization, that is, to retire old mechanisms and their controls before the end of their useful life (or depreciation), then the building owner could argue that the baseline should be the actual performance of the installed equipment, even if it dates back to motor-generator

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[46] For very large or very prominent buildings, the cost of detailed simulations might be justified.

[47] "Monetized" and "incentivized" are ugly terms, but they are part of the jargon used in the utility programs. Using them (properly) helps market the concepts. We apologize.

levels. On the other hand, the incentive provider could take the perspective that the owner would install most commonly installed technology level, or something even worse.

Thus we need both solid estimates of both new and replacement baseline products, and robust estimates of the new elevator's energy use. The outcome of this process would be recognition that some energy efficiency class (A–G in the VDI process) would represent the baseline energy consumption for incentive programs, absent site-specific data. That can be easily applied across the board, for all usage classes—or an authority responsible for a program might decide that a different letter efficiency class is suitable for each usage class, in an extreme case. We envision this as a performance table based on VDI or ISO usage classes, which can be expressed in metrics such as watt-hours per stop per day. The alternative, post-installation energy-use measurement would be the gold standard, but it is generally too expensive for all but very large projects and large incentive payments to justify.

FIRST STEP: CONVENE AN INDUSTRY WORKING GROUP

The preliminary step is bringing together industry leaders to develop and adopt a road map that establishes a both a consensus goal and a path to that goal. All manufacturers must be encouraged to participate. In addition, there should be an open call to others, and some specific groups with relevant experience should be invited to participate. These would include elevator contractors, ASHRAE, USGBC, Green Buildings Alliance, utilities (such as the California IOUs),[48] and efficiency advocates whose early involvement helps with acceptance of policies involving government (such as utility regulators). The process might start with a short briefing paper and meeting invitation, calling for discussions at a facilitated workshop lasting one or two days.[49] The goal of that workshop is to agree on a road map comprising steps, sequences, and timing. There should be discussion of whether a more formal nonprofit is even required, or any staffing (or secretariat) to keep to the agreed schedule.

We suggest including the Consortium for Energy Efficiency (CEE) and leading utilities in the proposed workshop to launch an industry efficiency marketing process. CEE is dedicated to developing standard North American qualification levels for products that would receive incentives from individual regional or local program operators to minimize confusion in the market. Often, they establish multiple tiers, which we might call "efficient," "even better," and "best of the best." For elevators, such tiers could readily be an overlay on VDI-type efficiency steps, or ISO-type energy consumption levels. Industry adoption of standard ways to estimate savings is critical for incentives that track value.

Conclusion

The technology revolution of the past few decades has been remarkable, if largely invisible to the passenger. In this, elevators are like automobiles, which have seen a similar

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48 Investor-owned utilities, notably Pacific Gas & Electric, Southern California Edison, and San Diego Electric.

49 The present paper might be helpful as background for the workshop invitation/briefing memo.

reinvention. Advanced elevators today use less energy, respond more quickly, accelerate more smoothly, are quieter, and are more attractive. They need less service and break down less often.

Ultimately, the customer for elevators is the building owner. In practice, a number of parties affect the owner's choices: architects, engineers, specialized consultants, and manufacturers all come readily to mind. As with nonresidential HVAC today, labels and incentives could also be powerful influences.

We believe that elevator efficiency made visible by labels and/or ratings could be a potent symbol of quality, one that helps customers grasp the full value package of better controls, improved performance, quietness, and comfort. Consensus descriptions that differentiate performance levels are one key to this recognition. Both VDI 4707 and ISO-25745 are huge steps forward.

By itself, efficiency will not make advanced technologies into market preferences. Still, it is increasingly important. Efficiency is a major component of greenness, as witnessed by the success of USGBC's LEED program. LEED is now a requirement for many government procurement programs, and it is highly valued for the better grades of office buildings. Further, energy-conscious jurisdictions are considering and adopting green codes such as ASHRAE 189-2014 (ASHRAE 2014) and the IgCC (ICC 2012).[50]

Even if it is not used as a tag in the cab, an efficiency label makes energy use visible. Thus energy use can be used as a decision criterion alongside other features being marketed. Every manufacturer who uses the label increases awareness of the availability and value of energy-efficient elevators. Indeed, efficiency can become an attribute that is strongly associated with higher quality, helping everyone sell better products instead of commodity-level units. That is part of the value proposition of the ENERGY STAR label: it becomes part of the quality proposition for customers.

As reduced energy consumption becomes a conspicuous part of the value package, it will increase the fraction of customers who recognize and seek the benefits associated with a high rating or low electricity consumption. Adding to this, with a consistent rating method available, manufacturers can build credible energy savings into case studies and their marketing plans, which will increase customer understanding of the savings potential of more efficient elevators.

Given the work ahead, manufacturers who would make the investments must answer one question: Are the potential benefits and profits from accelerated replacements and sales of premium products for new construction worth the investment over time that will be required to launch and sustain a program?

[50] ASHRAE 189-2014 is a compliance path in the IgCC, also.

An affirmative answer will draw in help from efficiency advocates and utility incentive programs to help transform the industry to new levels of performance—by any measure.

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