Building Performance Defined:
the ENERGY STARä National Energy Performance Rating System

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Introduction – A Knowledge Gap in the Commercial Buildings Market

One constant through the last three years of energy market evolution has been the high level of interest from commercial building owners, operators, and energy managers in understanding the energy performance of a building.[1] Numerous methods exist for measuring the energy performance of commercial buildings. From simple to complex, these methods range from basic energy consumption benchmarking, to engineering audits and analysis, to more sophisticated computer modeling and simulation. While each approach adds valuable information to understanding the whole-building performance, all have significant shortcomings in their practical utility.

On the simple side, annual per-square-foot consumption benchmarking provides a quick and cost-effective first measure of the energy performance of a building relative to its portfolio, regional, or national level peers. Considerable judgement must be exercised when interpreting these results, however, as significant drivers of energy consumption (such as weather, climate, occupancy and operating conditions) are typically not accounted for in this basic evaluation. Comparing the performance of buildings without factoring out the essential functions of the building (occupancy type, hours of operation, number of occupants, location, etc) that are out of the owner's or manager's control tends to restrict accuracy and utility of this method.[2] Communicating a benchmark through typical energy use intensity terms (kWh or kBTU/ft^2/yr) is confusing for non-technical management, and can be misleading if based on site energy terms rather than source or primary energy terms.

Engineering assessments, computer modeling, and simulation yield a more refined indication of a building's efficiency, but only against the building itself, or against a design standard (California Title 24, ASHRAE 90.1). This is problematic to describing a

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[1] Arthur K. Venables, and John Egan, *Corporate Energy Manager Speak Their Minds, Report on the 7th Annual E SOURCE Energy Manager Survey*, ER-02-12, July 2002.
[2] Paul Komor, *Benchmarking: A Tool for Measuring Building Energy Performance*, E SOURCE, TU-98-2, January 1998.

building's energy performance in two ways. First, benchmarking a building against itself provides a baseline indication of the current performance of the building against where it could be, but offers no comparative indicator of performance against other buildings. Relating a building's performance against a building code offers better comparative power, but suffers as the performance baseline is variable subject to the modeler's interpretation of the code or standard. Other drivers of energy consumption not controlled by code, such as thermal massing, building orientation, and plug loads enlarges the gap between the actual performance of the building and its anticipated performance against code.[3] Additionally, while building codes control for the physical equipment in the building, it cannot describe the as-built operational and maintenance factors which contribute significantly to the energy performance of the building. Finally, both of these methods are generally too expensive and time consuming to be used across an organization's portfolio of buildings, further restricting their practical comparative power.

The national Energy Performance Rating system (EPR), as conceived by the U.S. Department of Energy and the U.S. Environmental Protection Agency, was designed to supplement these approaches, improving the commercial building market's ability to measure and communicate a building's energy performance. The EPR, (now administered by the EPA) was created to provide an easy, cost-effective method to compare the efficiency of a building relative to the national building stock, provide a simple 1-100 metric to help communicate that relative performance, and establish a national performance target for excellence. Recognition for buildings achieving excellence (defined as the top 25% of the market) is provided through ENERGY STAR, an internationally recognized symbol for excellence in energy performance. Through this rating system, ENERGY STAR hopes to make understanding building energy performance easier for all parties involved in the design, construction, and operations of commercial buildings. With this knowledge it is hoped that these parties are motivated to identify and pursue mutually beneficial, cost effective solutions which improve the financial performance of their buildings while minimizing their deleterious impact on our energy resources and natural environment.

[3] Jeff Johnson, *Is What They Want What They Get? Examining Field Evidence for Links between Design Intent and As-Built Energy Performance of Commercial Buildings*, ACEEE 2002 Summer Study

This objective of this paper is to introduce the EPR as a metric to measure and communicate commercial building energy performance. Having established a basic understanding of the rating system, a comparative case study between the ENERGY STAR labeled offices and their peers within the national building stock is presented. The energy consumption, physical, and operational characteristics of these buildings are examined to explore the similarities and differences of these buildings compared to their peers in order to identify any common ingredients or attributes of high performing buildings.

The National Energy Performance Rating System

The intent of the EPR is to provide an easy to use, equitable, and accurate benchmark of comparative energy performance within a national context. Unique in its approach to benchmarking, the EPR accomplishes these objectives using the following features; source energy as the energy convention, consideration of the most significant drivers of energy consumption, national data sets for algorithm development, and normalization of weather impacts on energy consumption. Each attribute and its contribution to the objective will be considered in turn.

Two methodologies exist to describe building energy consumption – site energy and source energy. Site energy is the energy that is consumed at the building location. Source energy is equal to site energy plus the energy used to generate, transmit, and distribute the energy to the building. Although site energy is the more familiar and common convention for discussing building energy consumption, it is only useful in comparing groups of buildings with the same fuel mix (e.g. all electric buildings). When making comparisons between groups of buildings with various fuel types, the source energy convention is a far more equitable means of assessing a building's performance. Because different fuel types produce differing air emissions (some by as much as 3 ½ times more than others), and can vary in price (by as much as 4 ½ times), source energy is a more accurate indicator of a building's energy, environmental, and economic performance. As a national program to encourage energy efficiency to achieve profitable pollution prevention, ENERGY STAR uses source energy as the basis for benchmarking building energy performance. National conversion factors for each major fuel type are used to translate site energy to source energy consumption. By their ability to offset the need for source energy, on-site power generation is fully accounted for, as are the use of on-site renewables. As discussed in the forthcoming comparative analysis, this convention is also fuel neutral in identifying high performance buildings; a building is no more or less likely to be ENERGY STAR based on its choice of fuel.

Within any given commercial building end-use market (K-12 schools, offices, convenience stores, etc), annual per-square-foot energy consumption can range between 250-400% between the 10th percentile to the 90th percentile. This broad range suggests that beyond building type, there are numerous variables which influence the energy consumption of a building. The objective of the EPR is to develop a model that includes these variable, accurately describing the distribution of building energy performance within each occupancy type/end-use buildings market. Using step-wise linear regression, national data sets of building characteristics[4] are examined to determine the most significant drivers of source energy consumption. For each identified driver or variable, the regression calculates the mean value (e.g., the average value for the driver) and the coefficient (e.g., the magnitude of the driver). These values were combined to form the benchmarking algorithm that takes user-defined actual values for a given building to compute the energy performance level of that building within the market distribution. After including building size, which explains roughly 65% of the variability in source energy use, the other variables found to have significant explanatory contribution in office buildings are climate, weekly occupancy hours, number of occupants, and number of personal computers. This minimal set of variables, combined with one year of monthly energy consumption by fuel type, keeps the rating system as simple as possible to use while offering the greatest accuracy supported by the available national building consumption and characteristics data sets.

Annual energy consumption in buildings can vary up to 30% depending on local weather. In evaluating the energy performance of a buildings, the EPR removes the impact of weather by determining what the building's energy consumption would be during a "normal" weather year. This weather normalization is accomplished by regressing one year of monthly energy consumption data against actual outdoor air temperatures. Having characterized the building's energy consumption as a function of outdoor air temperature, this model is driven with a year of 30-year average normal air temperatures.

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[4] for the office and school models, the data source is -
Energy Information Administration (EIA). 1998. *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Expenditures*. DOE/EIA-0625 (95). Washington, DC.

With weather resolution to the three digit zip code level, this approach provides a high degree of accuracy in removing the effects of weather on a building.[5]

The ENERGY STAR Label for Buildings

Buildings which score 75 or greater on the 1-100 EPR scale (indicating performance in the top 25% of the national building stock) while meeting the current industry standards for indoor environment quality are eligible for ENERGY STAR certification. This certification requires that a licensed Professional Engineer verify that, in addition to correctly benchmarking their building, the building also adheres to current industry standards for thermal comfort, outside air ventilation, control of indoor air pollutants, and illumination, as specified by American National Standards Institute, and the Illuminating Engineering Society of North America[6]. Once awarded, ENERGY STAR certification is conveyed by a bronze plaque, which is intended to offer immediate recognition of performance excellence to tenants, customers, and other occupants. National recognition is made available through the ENERGY STAR website, and through annual, major media promotion campaigns.

Comparative Evaluation

The ENERGY STAR certification program has been available to offices since its inception in 1999, extended to K-12 schools in 2000, with grocery stores, hotels, and hospitals included by mid-2002. By the end of 2001, 475 offices and 287 schools have been certified. For this comparative evaluation, only office buildings will be examined. While the total number of schools is large enough to merit a comparative evaluation against the market, the concentration of ownership within one-dozen school districts prohibits meaningful comparison against the population.

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[5] Fels, et. Al., Energy and Buildings, Vol. 9, Feb/May 1986, and Kissock, et. Al., ASME Journal of Solar Energy Engineering, August 1998.

[6] American National Standards Institute (ANSI) and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 1992. *ANSI/ASHRAE Standard 55-1992, Thermal Environmental Standards for Human Occupancy*. ISSN 1041-2336. Atlanta, GA.

ANSI/ASHRAE. 1990. *ANSI/ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality*. ISSN 1041-2336. Atlanta, GA.

Illuminating Engineering Society of North America (IESNA). 1993. *Lighting Handbook, 8th Edition*. ISBN 0-87995-102-8. New York, NY.

In the initial phase of the evaluation, energy, cost, and operating characteristics of the ENERGY STAR offices dataset were compared to DOE's *Commercial Building Energy Consumption Survey* (CBECS)[7] and the Building Owners and Managers Association International (BOMA) *Energy Exchange Report 1997* (EER)[8] datasets. Next, a more detailed evaluation of the physical and operational characteristics of a sample of the ENERGY STAR dataset and CBECS was performed to assess the type of building equipment and systems, and management practices. Since building ownership or management for each of these ENERGY STAR Buildings chose to apply for the Label, this dataset must be considered a self-selected sample and, as such, is subject to self-selection bias. What follows, then, are the results and conclusions found in simply comparing offices certified through 2001, to other known national datasets.

ENERGY STAR Buildings Database

Through the applicants requisite use of the internet-based building performance rating tool, building characteristics, energy consumption, and expenditure data was collected for 475 commercial office buildings totaling over 148 million square feet of gross floor space, representing 33 states and the District of Columbia (Figure 1). To be eligible to apply, office buildings are required to:have at least 5,000 square feet of gross building area;

- have at least 50% of its gross building area used as primary use space;
- be in use at least 11 of the previous 12 months; and
- be in operation at least 35 hours per week, on average.

Additional data on HVAC and energy management equipment and systems, management practices, and architectural characteristics were collected through interviews with the building representatives upon earning the ENERGY STAR designation. Of the 475 office buildings that have earned ENERGY STAR through 2001, 270 volunteered to take part in an exit interview typically lasting 15 to 20 minutes. In order to render the ENERGY STAR dataset more physically and operationally comparable to other datasets, 30 of the 475 office building records each having a total gross building area less than 50,000 ft^2 were removed from the dataset.

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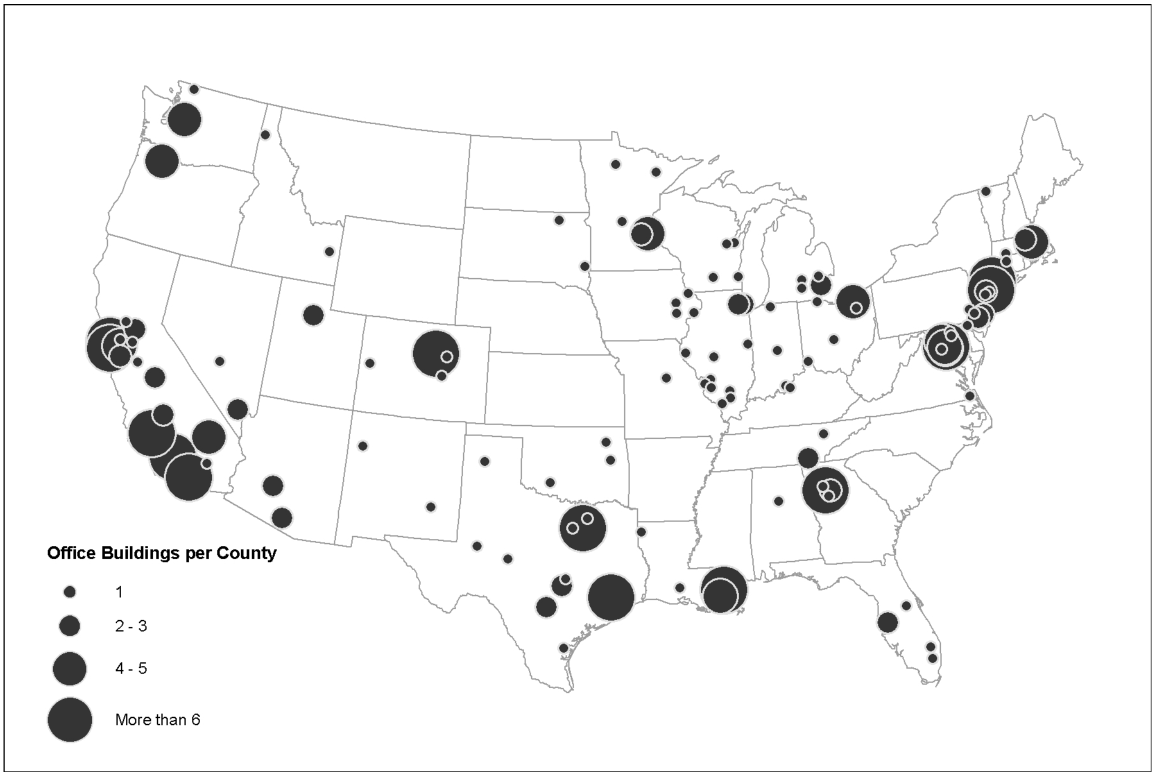
[7] Energy Information Administration (EIA). 1998. *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Expenditures*. DOE/EIA-0625 (95). Washington, DC.

[8] Building Owners and Managers Association International (BOMA). 1997. *BOMA Energy Exchange Report*. ISSN 0738-2170. Washington, DC.

Figure 1 - ENERGY STAR Offices – 1999 to 2001



CBECS Database

The 1995 CBECS contains building characteristics, energy consumption, and energy expenditure data for 5,766 commercial buildings representing all fifty states and the District of Columbia of which 1,228 are U.S. office buildings.[9] The CBECS sample was designed so that survey responses can be used to estimate characteristics of the entire stock of commercial buildings in the United States (EIA 1998; 4). To accomplish this objective, sampling weights were calculated that relate the sampled buildings to the entire stock of commercial buildings. For the comparative analysis contained herein, the sampling weights were applied to the CBECS dataset. To produce a more level comparison, the ENERGY STAR eligibility requirements and screening criteria used to develop the ENERGY STAR benchmarking algorithms were applied to the CBECS datasets. This reduced the total number of office buildings from 1,228 in the raw CBECS data set to 530 buildings in the working data set. The following eligibility requirements were applied:

- Building area > 5,000 square feet;
- Weekly hours > 35; and

- Months in use > 11.

For the purposes of the leveling the comparison, the following screens were also applied:

- Building area > 49,999 square feet;
- Electricity consumption > 0; and
- # of workers > 0.

Additional analysis included evaluations of upper and lower quartile energy performance amongst the 530 CBECS records. Rather than using a simple site or source energy intensity to determine which quartile a record belonged, each of the 530 records was assessed using the same algorithms used in the EPR. This analysis resulted in 144 buildings in the upper quartile of performance (the top 25%) and 125 records in the lower quartile, or bottom 25%.

1997 BOMA Experience Exchange Report Database

The 1997 EER contains tables of operating income and expense data for 3,364 office buildings located in 92 cities in the United States covering over 600 million square feet of office space. Access to the data was derived from the published tables; no direct access to microdata was made public. The EER contains National Cross-Tabulation tables that provide select analyses sorted by building location, age, and size. EER tabulated data is organized by city rather than census region and is therefore not directly amenable to location comparisons.

Results

As shown in Table 1, the energy intensity of the ENERGY STAR buildings was, on average, 39% lower in site terms and 37% lower in source terms than that of the average building stock as represented by CBECS. Similarly, the energy cost intensity of this group was \$0.80/ft^2, or 39% less than the average building stock as represented by CBECS and \$0.88/ft^2, or 42% less than the average building stock as represented in the EER. Site and source energy intensities of the upper quartile of CBECS buildings suggest that this group is outperforming the ENERGY STAR buildings, which is itself a subset of the upper quartile ostensibly.

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[9] The results for the 1999 CBECS survey had not yet been released prior to this paper.

Table 1. Comparison of Office Energy Use Intensity and Energy Cost Intensity

	Site Energy Intensity (kBtu/ft^2-year)	Source Energy Intensity (kBtu/ft^2-year)	Energy Cost Intensity (\$/ft^2)*
ENERGY STAR Offices	61.4	166.2	1.23
CBECS Average	101.1	261.8	2.03
CBECS Top 25%	48.2	113.9	1.02
CBECS Bottom 25%	217.0	511.0	3.51
BOMA EER	--	--	2.11

* 2001 constant dollars

Table 2 provides results of select average building operating characteristics including gross floor area, weekly operating hours, occupant density, personal computer density, and percentage of buildings operating as all-electric in each population. Perhaps the most striking difference between the ENERGY STAR buildings and the other datasets is found in the average building size, where the ENERGY STAR buildings were over twice the average size of the both the CBECS and EER datasets on average. While the reported weekly occupancy hours of ENERGY STAR buildings were less than that of the CBECS average and CBECS upper quartile, the reported occupant density of the ENERGY STAR buildings were significantly greater. Note that EER defines building size based on rentable rather than gross square footage, making occupancy density and size comparisons to this database difficult.

Personal computer density, often used as a proxy for equipment load density, was relatively uniform across each dataset. Although source energy intensity, not site energy intensity, is used as the determinant for ENERGY STAR, the percentage of all-electric buildings earning ENERGY STAR were consistent with the CBECS average and upper quartile populations of 24% and 30% respectively. Based on this observation, we conclude that a building is no more or less likely to be a top performer based on its fuel mix.

Table 2. Comparison of Select Office Building Characteristics

	Size (ft^2)	Operation (hrs/week)	Occupant Density (per 1000 ft^2)	PC Density (per 1000 ft^2)	Vacancy %	% All Electric
ENERGY STAR Office	354,527	69	3.14	3.19	5.4	30%
CBECS Average	129,677	75	2.65	3.31	--	24%
CBECS Top 25%	123,051	79	2.72	3.54	--	30%
CBECS Bottom 25%	119,482	79	2.43	2.73	--	16%
BOMA EER	209,262	--	3.31	--	10	39%

Table 3 provides more detailed building characteristics comparison results of the ENERGY STAR buildings to those found in the CBECS average, upper quartile, and lower quartile. Selected characteristics are categorized by type: construction; HVAC; energy efficiency; management; and amenities. Two noteworthy trends are present within the construction category. First, fifteen percent of the ENERGY STAR buildings reported as having glass as the primary wall construction material. Review of CBECS indicates that buildings having glass as the primary wall construction material are generally more energy intensive; a fact that appears to be born out by the lower incidence of glass in the CBECS upper quartile. Second, the median age of the ENERGY STAR buildings, 1978, is the same as the CBECS average and upper quartile median age, indicating that these sets of data are of a similar vintage and likely subject to similar buildings codes and standards.

Looking at HVAC equipment revealed that the ENERGY STAR office buildings were much more likely to use a chiller for cooling and a variable air volume (VAV) system for comfort air distribution, while buildings in the CBECS average and upper quartile tended to use packaged units. Similar to the ENERGY STAR buildings, buildings in the CBECS lower quartile - the worst performing buildings - tended to use a chiller for cooling and VAV system for distribution. The ENERGY STAR buildings, on average, showed a greater use of energy management systems (EMS), economizers, variable speed drives (VSDs), and motion sensors than buildings found in the CBECS average and upper quartile. Similar to results found with the HVAC equipment, the presence of energy efficiency equipment and systems amongst the ENERGY STAR buildings generally tracked most closely with the buildings in the CBECS lower quartile. This observation is consistent over the last 3 years this survey has been conducted.

This paradox – the apparent similarity of efficient equipment between the lowest and highest performing buildings – challenges a longstanding misconception that building efficiency can be defined by the presence of efficient equipment. Certainly energy-efficient equipment significantly contributes to whole-building performance, however, problems with energy-efficient equipment is frequently a primary source of energy *in*efficiency. Numerous studies support this assertion. In a 60 building study, Lawrence Berkeley National Labs found that 50% of the buildings had control problems, 40% had HVAC equipment problems, and 25% had EMS, economizers, and/or VSDs that were not functioning properly[10]. ESource documents a study which estimates failure rates of economizers of 50% and higher, with the resultant energy waste far exceeding the achievable energy savings from properly working equipment.[11] Other studies on oversizing, poor system integration, operator error, and poor commissioning and maintenance also illustrate the potential energy waste from energy efficient technologies. Just as incorrectly deployed efficient equipment is not the sole cause of a low performing building, efficient equipment alone is not indicator of a high performance one.

In an effort to look beyond technologies as a determinant of high performance, basic information on the management of the ENERGY STAR buildings was collected. The ENERGY STAR office buildings were three times more likely to have had an energy audit conducted within the past three years than the CBECS average and upper quartile buildings, but just over twice as likely as the CBECS lower quartile. Reported operation and maintenance (O&M) was found to exceed 90% throughout each of the datasets. Although not collected by CBECS, 78% of the ENERGY STAR buildings reported having an energy upgrade for a major energy consuming component within the last three years, and 42% reported having had a major renovation over the same time period. Useful to note here is that 72% of these buildings are reported as Class A as defined by the BOMA building classification system as the most prestigious space competing for premier office space users with rents above average for the area. As part of their ENERGY STAR certification, each building has also

[10] PECI, "Summary Report," Second National Conference on Building Commissioning, St. Petersburg Beach, Florida, May 9 – 11, 1994, pp. 34-35.

[11] Lunneberg, T. 1999. *When Good Economizers Go Bad*. E Source Report ER-99-14.

been professionally verified as in conformance with current industry standards for indoor air quality and comfort. Taken together these attributes suggest that an involved and committed management is an important attribute to a high performance buildings. These management characteristics are also exemplified across different types of building ownership; 50% of the ENERGY STAR buildings are investor-owned, 29% are private sector owner-occupied, and 21% percent are owned by the public sector.

Table 3. Building, Equipment, and Management Characteristics of ENERGY STAR Office Buildings and CBECS Average, Upper Quartile, and Lower Quartile

	ENERGY STAR Offices	CBECS Average	CBECS Upper Quartile	CBECS Lower Quartile
# of Records	270	530	144	125
Construction				
Concrete	30%	16%	10%	22%
Glass	15%	15%	12%	20%
Masonry	41%	63%	71%	56%
Year (Median)	1978	1978	1978	1974
HVAC				
Boiler	58%	46%	32%	49%
Chiller	65%	43%	26%	65%
Packaged	31%	59%	70%	47%
VAV	73%	50%	36%	67%
Energy Efficiency				
EMS	84%	43%	23%	56%
Economizer	68%	55%	29%	73%
VSDs	63%	33%	19%	45%
Motion Sensors	61%	16%	8%	21%
Management				
Energy Audit	66%	24%	23%	36%
Regular O&M	98%	96%	92%	98%
Renovation	42%	--	--	--
Equip. Upgrade	78%	--	--	--
Amenities				
Class A	72%	--	--	--

Conclusions – uniquely different, surprisingly the same.

As exemplified by the office buildings earning ENERGY STAR certification over the last three years, the Energy Performance Rating System appears to be successful in identifying high performance buildings both in objective and subjective terms. As compared against the national building stock, ENERGY STAR offices are approximately 40% less energy and cost intensive than average buildings. These buildings have achieved this performance while maintaining indoor environments that have been professionally verified as compliant with current industry standards. Roughly three-quarters of these buildings are considered class A offices, and are maintaining this level of energy performance and occupant service in some of the most competitive office buildings markets in the country.

While they are unique in their energy performance, these buildings demonstrate physical characteristics that are surprising similar to their peers. They are of the same average vintage, use generally the same fuel mix, are found in geographically diverse locations (which subjects them to a wide variety of climates, building codes, energy prices, and access to public-benefit energy management programs). Most importantly these are also not high-end, one-off buildings, but designed to service a variety office occupants - a mix of both the public and private sector, investor-owned and owner-occupied.

Curiously, while the majority of ENERGY STAR buildings understandably use highly efficient equipment, they are most similar to the poorest performing buildings from a technology perspective. Although the implications of this are unclear without further study, this observation does reinforce the need to look beyond technologies and design when defining building performance, and consider building operations and management practices as critical to the realization of a building that performs as well in the ground as it does on paper. In characterizing and communicating the energy performance of buildings based on a relative consumption-based metric, the national Energy Performance Rating system and ENERGY STAR designation hopes to stimulate further motivation to capture the cost-effective energy savings opportunities in this country's commercial building stock.