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The Effectiveness of U.S. Energy Efficiency Building Labels

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ABSTRACT

Information programs are promising strategies to encourage investments in energy efficiency in commercial buildings. However, the realized effectiveness of these programs has not yet been estimated on a large scale. Here we take advantage of a large sample of monthly electricity consumption data for 178,777 commercial buildings in Los Angeles to analyze energy savings and emissions reductions from three major programs designed to encourage efficiency: the U.S. Department of Energy's Better Buildings Challenge, the U.S. Environmental Protection Agency's Energy Star program and the U.S Green Building Council's Leadership in Energy and Environmental Design (LEED) program. Using matching techniques, we find energy savings that range from 18% to 30%, depending on the program. These savings represent a reduction of 210 million kilowatt-hours or 145 kilotons of CO_2 equivalent emissions per year. However, we also find that these programs do not substantially reduce emissions in small and medium-sized buildings, which represent about two-thirds of commercial sector building emissions.

Energy supplied in buildings accounted for an estimated 8.8 metric gigatons of CO_2 emissions globally or about one-third of total energy use and carbon emissions (1). The United Nations Environment Program (UNEP) and many energy experts argue that the buildings sector has the largest potential for delivering long-term and cost-effective emissions reductions in both developing and developed countries (2). A recent analysis by the National Research Council contends that the full development of cost-effective energy efficiency technologies in buildings could eliminate the need to construct new electricity-generating plants in the United States (3). A critical question is what kind of programs can catalyze reductions in emissions. This question is especially important given the current lack of global carbon regulation. In the United States, there are three major voluntary information programs aimed at reducing building emissions: The U.S. Environmental Protection Agency's (EPA) Energy Star Program, the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED), and the U.S. Department of Energy's (DOE) Better Buildings Challenge. Participation in these programs has increased rapidly over the last 10 years and has reached 21 billion square feet of floor space (see refs 4-6 and Supplementary Note 1). These programs aim to encourage private investment in energy efficiency. Examples of such investments include structural upgrades for indoor heating, ventilating and air conditioning (HVAC); smart energy management systems; and efficient lighting, sensors and other controls.

Information programs reduce barriers to investment and encourage energy efficiency through two main mechanisms. The first mechanism involves lowering search and information costs for energy planning decisions. This often includes subsidized building audits that provide tailored information about potential savings through available technologies, and benchmarking of best practices through a network of peers. This is a main focus of the DOE Better Buildings Challenge, which provides energy audits to support U.S. commercial and industrial building owners who commit to reducing energy and water consumption in existing buildings by 20 percent or more over 10 years (7). The program provides public recognition for performance but it does not offer a separate certification label. A recent meta-analysis of peer-reviewed studies in energy conservation found that technical audits, such as those provided to many Better Buildings challenge partners, were effective to reduce energy consumption in the residential sector (8).

A second mechanism by which information programs can promote voluntary energy efficiency adoption involves market signaling through a prominently displayed energy efficiency label. Labeling is the focus of both LEED and Energy Star programs, which provide third-party certification for efficient buildings based on a comparative 1-100 Energy Star score. Only those buildings that receive an Energy Star score of 75 (75^{th} percentile or better) compared to similar buildings nationwide are eligible to apply for the Energy Star or LEED certification label in a given year. Unlike Energy Star, which is a government supported label for energy efficiency, LEED is privately supported. The USGBC rates LEED buildings based on a tiered rating scheme, which includes reductions in energy use, but also focuses on improvements such as water use, materials and resources, indoor environmental quality, and sustainable design.

Each program has unique institutional features (see Supplementary Note 1), but largely attracts different segments of the commercial real estate market, with minor overlap in participation. For those buildings not eligible to participate in either Energy Star or LEED certification programs, the Better Buildings initiative provides a market entry point for energy efficiency investment and participation in existing buildings.

These programs are often described as green clubs, in which voluntary participation provides reputation benefits to its members (9). Building owners and managers who participate in these programs often gain recognition for their more efficient buildings through market mechanisms that sometimes includes premiums such as increased asset prices and tenant rents (10-13). These economic returns reflect expectations of lower energy costs for building occupants. However, while the evidence on green premiums has received increased attention, the realized environmental performance of these investments is yet largely undetermined. Definitive evidence on the energy savings or emissions reductions associated with these programs has yet to emerge in the literature.

One principal limitation of such analyses has been the lack of access to longitudinal high-resolution building energy performance data (14-15). Another difficulty for program evaluation arises in the fact that participating firms in voluntary programs seldom constitute random samples. We also never directly observe the alternative states among participants in which an investment or participation decision is not made, making it difficult to construct valid control groups for program evaluation (16). Further, cross-sectional analyses of programs can be misleading because of endogeneity issues, which can be due to a number of reasons including technology adoption, pricing and consumer preferences, all of which potentially limit our ability to make causal inferences.

Increases in the availability of data have opened new research horizons in the social and behavioral sciences (27). In this article, we perform a comparative analysis of the effectiveness of energy efficiency labeling strategies in the Better Buildings Challenge, Energy Star and LEED programs in the commercial buildings sector, enabled by access to monthly electricity consumption data for all commercial buildings in Los Angeles from 2005-2012 (28). We find that all these programs deliver high magnitudes of energy savings that range from 18% to 30%, depending on the program. These savings represent a reduction of 210 million kilowatt-hours (kWh) or 145 kilotons of carbon dioxide equivalent (CO_2e) emissions per year. Due to the long lifespan of buildings and retrofits, these savings are likely to persist, particularly in larger, more energy-intensive buildings. However, due to eligibility rules and participant self-selection, we find that current information programs do not substantially target emissions reductions in small and medium sized buildings, particularly in the 75th percentile and below by consumption, which represents up to 2/3 of commercial sector building emissions and the long tail for greenhouse gas mitigation efforts from building efficiency improvements.

Program evaluation overview. Our dataset includes 178,777 buildings with 16.5 million panel observations.

The dataset consists of the universe of all commercial buildings in the Los Angeles Department of Water and Power (LADWP) service territory from 2005-2012. This includes 16,536,241 observations of 178,777 buildings in the City of Los Angeles and 56 neighboring cities. We also acquired detailed building stock characteristics from CoStar, the premier commercial real estate database. CoStar provides building level information including physical building and occupancy characteristics and various measures of building quality.

Because participation is not randomly assigned, we use matching strategies to compare the performance of participating buildings against similar buildings that are not part of these programs. In this way, we control for overt sources of bias due to systematic differences between participating and non-participating buildings, which affect evaluation outcomes, and then we test the sensitivity of our estimates to hidden bias. Matching strategies mimic randomization by identifying a comparison group of buildings that is statistically similar to treated buildings, based on observable characteristics. We use computational advances in matching algorithms to match buildings on a more comprehensive set of characteristics than previous literature. In doing so, we quantify an important source of evaluation error when estimating emissions reductions.

Los Angeles is an ideal setting to study energy efficiency for three reasons. First, unlike many other cities that may be at earlier stages of adoption, we can already observe significant participation in these 3 programs simultaneously during this period for a total of 192 million square feet of commercial floor space in 254 buildings. Second, Los Angeles is the largest market in the U.S. for green building investments and is often considered a model for other cities (29). Third, we have access to high-resolution data at the building level, which allows us to go beyond simulations or predictive modeling to assess emissions reductions (30).

Characteristics of building participants. Participating buildings for Better Buildings Challenge, Energy Star and LEED certified buildings in Los Angeles are generally larger, more energy intensive (in kWh per month and kWh per square foot) than non-participating buildings. Participating buildings are also more likely to have been renovated, which is to be expected as building owners and managers often consider capital investments for energy efficiency during periods of renovation. These differences are significant both in means and distributions from the general population (Supplementary Table 1). Thus, a simple comparison of mean outcomes for participating and non-participating buildings is unlikely to yield accurate estimates of the causal effect of program participation. For example, during the period from 2005-2009, participating buildings are significantly more energy intensive (1.134 kWh per sq. ft) than an average non-participating building (0.893 kWh per sq. ft). Participating buildings are also commonly designated as Class A buildings, the more coveted and higher quality real estate assets, and to a lesser extent, Class B or Class C buildings, which indicates positive selection. Buildings may be classified as A, B, or C in descending quality based on such parameters as desirability of location, age of building, building infrastructure and maintenance. Building class designations are subjective ratings used by real estate professionals to gauge building quality and may vary from market-to-market. For example, Class C buildings are only about 2% by square footage in participating buildings (Table 1). However, Class C buildings, which most often represent smaller, aging buildings, still account for a substantial 36.3% of commercial sector emissions or 583 kilotons of CO_2 emissions in Los Angeles. These baseline differences suggest that counterfactual strategies based on a comparison group of average non-participating buildings would be ineffective reference groups versus more rigorously matched controls.

Descriptive statistics also reveal significant differences in building characteristics between programs (see Supplementary Table 2). For example, building construction year, renovations and quality ratings all differ substantially between programs. These differences in participant profiles before matching reveal both different targeting strategies by program managers and administrators, and self-selection into the respective programs. See Supplementary Note 2 for a more detailed discussion on observable bias.

Matching algorithms. A few studies evaluating building performance data have used matching procedures based on propensity scores to control for overt bias, or the fact that the treatment and control groups differ in ways that matter for the outcomes under study (10, 31). These studies typically use a single covariate based on building location (e.g. proximity, or linear distance) to enable comparisons between buildings (31). The main identification assumption, although largely unproven, is that buildings close to each other are more similar to buildings that are far away. However, matching buildings on a single distance measure does not address two important potential sources of selection bias. The first is due to remaining imbalances in other relevant covariates, which can bias estimates; and the second is due to the lack of sampling density in the region of the common support, which is often prevalent in finite samples (16). In our review of the literature, few published studies report the degree of covariate imbalance in matching studies with observational data, and none that we are aware of in the energy efficiency literature.

In our analysis, we match on an expanded set of covariates than previously available in the literature. We use several matching strategies to enable performance comparisons—including genetic matching, which uses a search algorithm to automatically find the optimal covariate balance in the reference group (32-35). See Methods for more detail. Our reference group consists of the universe of all commercial buildings in the service territory of the Los Angeles Department of Water and Power (LADWP), the nation's largest municipal utility. This includes 56 neighboring cities and 1.4 million customers. We match buildings on 12 characteristics found in the literature to affect building energy consumption (Table 2). These include: location (climate zone); physical building characteristics (square footage, year built, year renovated); occupancy (percent leased, tenant type); building use type (property type); industry characteristics (SIC industry code, utility customer class); building operating expenses (average rents, taxes per square foot); and building quality (building class). We also include the CoStar analyst ratings (scored from 1-5) to mitigate hidden bias and capture other unobserved characteristics quantitatively. The CoStar rating is a national rating scheme for commercial buildings that considers a combination of factors typically unobserved by evaluators such as building amenities, construction quality, architectural attributes, management, location/accessibility, systems standards and specifications, detailed property specifics and market factors. Using this approach, we believe that we substantially reduce observable bias arising from participant selection.

Energy savings of information programs. To evaluate the impact of participation in information programs on building energy savings (measured as the percentage energy change in kilowatt-hours (kWh) per square foot), we implement matching procedures and then conduct post-matching regressions to adjust for time variation on building energy use. In post-matching regressions, we include important seasonality and time controls such as heating and cooling degree-days, in order to adjust for weather variation and any calendar shocks on consumption. See the Methods section for details. In Table 3, we report the final estimates of energy savings for each program in the City of Los Angeles. The estimates are robust to several matching procedures and specifications, which yield quantitatively similar results, and we report the most conservative estimates. The energy savings from the Los Angeles Better Buildings Challenge (LABBC) program is -18.69%, significant at the 10% level. These savings are the result of building technology upgrades identified through LABBC audits in 91 participating buildings totaling 35 million square feet of floor space. The most common building upgrades include HVAC systems (72%), lighting and controls (14%), and improvements in building envelope (6%). Other upgrades (8%) include deep renovations in pumping, ventilation and sensor technology. These building efficiency upgrades are primarily structural, although a few implemented projects include behaviorally informed changes such as data server optimization and computer power management. The savings for Energy Star and LEED programs are -19.31% ($p<0.02$) and -29.99% ($p<0.06$), respectively over the period 2005-2012. We find that building efficiency investments across all 3 programs show significant progress towards long-run environmental policy goals of 20% savings over 10 years.

Across 125.9 million square feet of total participating floor space in the 3 programs, this is an annual reduction of 210.2 million kWh of city energy use. Using EPA (eGrid2012) emissions factors based on LADWP's local electricity mix, the savings amount to 145 kilotons of non-baseload CO_2 emissions per year. To put these numbers in context, the savings from Los Angeles commercial sector building improvements are the equivalent of burning 70.6 kilotons of coal each year. We contrast the magnitudes of these savings from capital upgrades versus behavioral intervention programs commonly employed in the residential sector, which yield significantly lower percentage savings by an order of magnitude ranging from 2-3% for the highest-quality studies (8).

Program cost effectiveness. We are able to calculate program cost-effectiveness for Los Angeles Better Building Challenge participants, for which we have financial data reported to us by program administrators. We find a program cost of 5.54 cents per reduced kilowatt-hour (kWh), which includes both public and private expenditures. This cost-effectiveness ratio compares favorably with prior estimates of returns to demand side management programs (37-39) commonly used for government policy analysis, in which private spending is typically unobserved. This figure, however, does not include benefits in the form of higher property values and tenant rents. Total public expenditures of US$4.2 million for the LABBC program through 2012, include: $3.5 million in direct costs for conducting the audits and approximately US$700,000 in administrative costs. Private expenditures include an estimated US$74 million in building efficiency investments by building owners and managers. In qualitative interviews with commercial building owners and managers, the most cited reasons for participating are: savings with utilities, lower operating and maintenance costs, recognition from tenants, access to technology providers and local support. Unfortunately, financial operating data for specific properties participating in Energy Star and LEED programs are not disclosed as part of the certification process. As project implementation costs are proprietary and kept confidential by individual owners and managers, we are not able to generate cost-effectiveness estimates for these programs in the current study. From an evaluator's perspective, this is important future work. The estimated mitigation cost of 5.54 cents per reduced kWh in commercial buildings is comparable to the 5 cents per kWh previously estimated for behavioral energy conservation R&D programs most commonly employed in the residential sector (18), keeping in mind however, that capital upgrades are subject to much larger investment hurdles and criteria.

Discussion and Policy recommendations. Commercial building owners and managers face steep investment hurdles. For the 91 initially enrolled buildings in the Los Angeles Better Buildings Challenge, total project costs for implementing the recommended energy conservation measures in 35 million square feet of floor space are an estimated US$82.81 million in 2012 dollars. The minimum investment levels per building range from US$136,000 up to about US$8.4 million for the largest buildings, net of available rebates and incentives. We observe a 30-40% project implementation rate in the LABBC program. This compliance rate following energy efficiency audits is consistent with previous studies (40). Although the magnitude of these required investments may easily be justified for larger investors who own and operate larger Class A or Class B buildings; we note that even a 10% rental premium would be hard to justify financially in smaller, aging infrastructure such as in Class C buildings. Investor strategies by asset class could partially explain the dominant participation among premium Class A buildings and the weaker participation among Class B or Class C buildings. However, weak participation at the lower end of the market is also structural. For instance, even for highly motivated Class C investors, only a fraction of buildings with net leases, e.g. where tenants share in utility costs (as opposed to gross leases where tenants face zero marginal costs for utilities), have the ability to pass along investment costs to tenants. This suggests that a large share of the market becomes inaccessible to major private investment due to principal agent problems. Thus, the fact that participation and investments are primarily observed in larger commercial buildings (i.e. 50,000 sq. ft. and above) suggests that more effort might be required to attract smaller, capital constrained investors.

Targeted information programs are needed to address both investment inefficiencies and energy use externalities (41-44). Barriers to investments in energy efficiency still remain. For example, the evidence suggests that individual building owners and managers appear to be more sensitive to total implementation costs rather than to actual energy savings (40, 45). Research also shows that top management support (46) and the sequencing of recommendations can affect individual adoption decisions at a portfolio level (47). When managers decide to invest, we show that structural upgrades are effective at reducing energy intensity in commercial buildings at an impressive performance level consistent with long-run emissions and energy reduction goals. These structural investments in building technologies are cost-effective versus demand side management or new generation, but require major capital outlays, albeit at a lower level than investing in new capacity. For every public dollar invested in the community-based Los Angeles Better Buildings Challenge, this yielded an estimated return of US$17.6 in private infrastructure spending through 2012. Given the limits to public finance in funding capital upgrades in existing buildings and infrastructure, public-private partnerships aligned towards grand challenges may serve to extend the traditional boundaries of the public sector and increase directed innovation toward meeting societal goals.

Voluntary energy efficiency labeling programs are effectively targeting the most energy-intensive office buildings at the high end of the market. This is because existing programs and incentives currently result in positive selection—larger premium office space under professional management and owned by investors who seek rental and asset price premiums. From an emissions reduction point of view, the need for broader participation in energy efficiency is particularly relevant for building owners and managers in the least efficient three quarters of buildings, particularly those buildings ineligible for energy efficiency labeling. These non-participating buildings tend to be smaller Class B and Class C buildings, but they are greater in number and in aggregate represent a significant 2/3 of greenhouse gas emissions inventories in the commercial building stock (Table 1).

In our participant interviews with major capital investors, we asked whether the future of investing in commercial energy efficiency would likely come from their portfolios of non-certified buildings—to which one investor replied: “The current programs are not targeting poorer performing buildings.”

We argue that potential policy responses may be needed not only at city or regional level, but also at the state and federal level. For example, mandated information disclosure programs, which would require all commercial buildings to measure and disclose their energy use, might help to broaden participation and motivate poorer performers. First, they provide all performers with benchmarking information about relative consumption. Gathering building energy use data for the entire building population establishes a performance baseline that allows building owners to compare their buildings to similar buildings, but also to evaluate the magnitude of potential energy savings. Second, market pressure created by consumers and investors might create incentives for building owners to reduce their energy use when such information is shared throughout a city or industry. However, practical implementation may require significant investments to integrate information systems between utilities and jurisdictions for secure uploading and information management.

In summary, our study shows that increases in the availability of data can allow evaluators to become more accurate in societal accounting of energy and emissions reductions. Tracking these investments in the private sector presents challenges not just for evaluation efforts, but also for attributing its underlying causes. Without careful research design, when private investments in energy efficiency are made, we cannot be sure whether these investments are the result of strategic community policies, or whether they result merely from private considerations at the individual building or project level. The answer is that both of these considerations may be necessary to accelerate new investment. While energy savings are a primary outcome of building energy labels, we suggest further research into other outcomes, such as rental prices, vacancies and contracts. This will help clarify strategies that support long-run benefits, which could help broaden participation.

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AUTHOR CONTRIBUTIONS

O.I.A. and M.A.D. contributed equally to this study.

COMPETING INTERESTS

The authors declare no competing financial interests.

FIGURE LEGENDS

Figure 1. Bias reduction in matched samples for the three energy programs. Reducing observable bias by nearest neighbor matching with replacement for a) LABBC Buildings b) Energy Star Buildings and c) LEED buildings.

Figure 2. Comparison of site Energy Use Intensity. EUI distribution of Los Angeles commercial buildings (black) versus a national dataset from the Building Performance Database (BPD) assembled by the Lawrence Berkeley National Lab (grey).

TABLE LEGENDS

Table 1. Annual Building Emissions by Building Class (2005-2012)

	Number of buildings	Square Footage (in million sq.ft)	Metric Tons of CO_2	Percentage of Building Emissions	Square footage in Energy Star, LEED or LABBC (in million sq.ft)	% of Square Footage in Energy Star, LEED or LABBC
Class A	456	107.7	585,410.71	36.4	66.98	91.04
Class B	3452	125.5	437,936.05	27.3	4.77	6.48
Class C	14698	238.3	582,999.95	36.3	1.82	2.47
Total	18606	471.5	1,606,346.71	100	73.57	100

Buildings located in Los Angeles Department of Water and Power territory

Table 2. List of Balancing Characteristics Used in Matching

Observable Building Characteristic	Data Source
Physical Building Characteristics	
Year Built	Costar/Public record
Year Renovated	Costar
Building Location/Climate	
Climate Zone	Public utility/NOAA
Occupancy Characteristics	
Rentable Building Area (Sq. footage)	Costar/Public record
Property Type	Costar
Occupancy Rate (Percent leased)	Costar
Building Quality	
Building Class	Costar
CoStar Rating [a]	Costar
Industry Characteristics	
SIC Industry Code	Public record
Utility Customer Class	Public utility
Building Operating Expenses	
Average Rent	Costar
Taxes per sq. ft.	Costar

[a] The CoStar building rating system is a national rating system for commercial buildings, which captures a number of characteristics including architectural attributes, structural and systems specifications, amenities, site and landscaping treatments and detailed property type specifics. Ratings reflect commercial real estate quality as valued by investors.

Table 3. Program Energy Savings

Program	Average Treatment Effect	Std. Err. (Abadie-Imbens)	p-value	N matched observations
LABBC	-18.69	10.95	0.09	35,939
LEED certified	-29.99	12.06	0.06	35,439
Energy Star	-19.31	5.81	0.02	35,416

Estimates using matching procedures with weather and time controls