Energy Benchmarking of Commercial Buildings: A Low-Cost Pathway toward Energy Efficiency

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ABSTRACT

US cities are beginning to experiment with a regulatory approach to address information failures in the real estate market by mandating the energy benchmarking of commercial buildings. This paper estimates the possible impacts of a national energy benchmarking mandate through analysis chiefly utilizing the Georgia Tech version of the National Energy Modeling System (GT-NEMS). Through a Monte Carlo statistical analysis keyed to a comprehensive literature review, we identify and adjust input discount rates for customers modeled in GT-NEMS. This produces a 4.0% reduction in projected energy consumption for seven major classes of equipment relative to the reference case forecast in 2020, rising to 8.7% in 2035. Further discount rate reductions spurred by benchmarking policies yield another 1.3–1.4% in energy savings in 2020, increasing to 2.2–2.4% in 2035. Benchmarking would increase the purchase of energy-efficient equipment, reducing energy bills, CO_2 emissions, and conventional air pollution; these effects vary in each of the nine census divisions and in the eleven building types modeled by GT-NEMS. Achieving comparable CO_2 savings would require more than tripling existing US solar capacity. Our analysis suggests that nearly 90% of the energy saved by a national benchmarking policy would benefit metropolitan areas. While implementation issues were highlighted in an informal survey of early adopters of this policy, the policy's overall benefits would outweigh its costs, both to the private sector and society broadly.

Introduction

Understanding how a commercial building uses energy has many benefits; in particular, it helps building owners and tenants focus on poor-performing buildings and subsystems, and it enables high-performing buildings to participate in various certification programs that can lead to higher occupancy rates, rents, and property values. However, in many cases, the recipient of energy information does not have the incentive or the ability to improve energy performance. In fact, commercial buildings often suffer from the principal-agent problem, also known as the split incentive problem, where one party (the agent) makes decisions in a given market, and a different party (the principal) bears the consequences of those decisions (Prindle, 2007). Information asymmetry and split incentives are further worsened by high discount rates used by commercial consumers, which lead to fewer purchases of high-efficiency equipment (Frederick, Loewenstein, and O'Donoghue, 2002; Train, 1985).

Mandated benchmarking focuses on giving building owners access to baseline information on their building's energy consumption. This could be accomplished by requiring utilities to submit energy data in a standard format to a widely used database, such as ENERGY STAR Portfolio Manager, which currently maintains information on hundreds of thousands of buildings in the U.S., submitted by building owners and managers.

In this paper, we discuss an approach to benchmarking that requires utilities to submit whole building aggregated energy consumption data for all tenants in electronic form to

EPA Portfolio Manager, and develops a national registry of commercial buildings, with each building receiving a unique Building Identification (BID) number, analogous to the VIN number for automobiles. If implemented, better building energy data would be available to owners, tenants, and utilities, addressing some of the information barriers that currently hinder energy efficiency in commercial buildings. Benchmarking also prepares building owners and utilities for implementation of smart grid and demand response programs. There is also a noted lack of information about building locations, another issue that this policy option would address. Lastly, this policy would lay the groundwork for future information, financial and regulatory policy options, such as mandated disclosure and on-bill financing. EPA and the American Council for an Energy-Efficient Economy (ACEEE) both suggest that savings up to 10% can be made under a benchmarking program at little or no cost to building owners, but these savings frequently go overlooked (Dunn, 2011; Nadel, 2011).

Background

Policy Experience

The U.S. and Canada are collaborating on a common platform for benchmarking commercial building energy consumption (EPA, 2011). The federal government also benchmarks its buildings as a result of Section 432 of the Energy Independence and Security Act of 2007. However, policy experience with benchmarking in the U.S. is largely tied to mandated disclosure policies at the state and local level. The States of Washington and California lead the rest of the nation by having a mandated disclosure policy for the commercial sector. Nine other states have either benchmarking or mandated disclosure policies currently under consideration. At the city level, Austin, Boston, Chicago, Minneapolis, New York, Philadelphia, San Francisco, Seattle, and Washington, D.C. all have mandated disclosure programs for commercial buildings, which require benchmarking. Other cities are currently considering similar programs; all existing programs use Portfolio Manager as the benchmarking tool.

As of 2013, Portfolio Manager includes data on the current and past performance of more than 300,000 buildings in the U.S., submitted by building owners or managers. It can provide a normalized, statistically significant score out of 100 for a large number of building types, it can help them qualify for ENERGY STAR and Leadership in Energy and Environmental Design (LEED) certification.

The Institute for Market Transformation (IMT) summarized the experiences of nine current U.S. programs (Burr, Keicher, and Leipziger, 2011). The main recommendation of the report is to follow EPA guidelines on the use of Portfolio Manager, allowing jurisdictions to avoid debates over building use and building type classifications and enabling easy integration of building data into the Portfolio Manager format. IMT also suggests that compliance should be established from existing tax records; data quality should be linked to a responsible party at the property via a signature; utilities should receive support for any new incurred costs of compliance, and the development of leases that include data access language should be encouraged.

Results from Implementing Governments[1]

While Europe has used mandated disclosure and benchmarking programs for many years, the U.S. is just beginning to implement these programs. Key program managers from each of the leading U.S. cities responded to questions during short telephone interviews. Even though individual contexts vary, several key findings emerged that could be informative for policymakers.

- All of the program managers believe a large information gap related to building energy consumption still exists in their jurisdictions, even after the benchmarking and mandated disclosure laws.
- Tenant authorization is required for building owners to access energy consumption data in many jurisdictions. Rules and support for utilities to facilitate easy access and release of aggregated building data are an important legal issue.
- Every program experienced delays in implementation, largely due to aggressive rollout schedules and budgeting issues related to the economic downturn in 2008.
- A commonly noted issue was the lack of a qualified workforce. A government program that certified contractors who could improve a building's energy performance was strongly desired.

Methodology

Our analysis of the potential of benchmarking in the commercial sector utilizes the Georgia Tech version (GT-NEMS) of the Energy Information Administration's (EIA) 2011 National Energy Modeling System (NEMS). GT-NEMS uses the same Fortran codes and input files as the EIA version of NEMS. However, because it is run on Georgia Tech's server, minor differences between the two versions occur. Like the EIA NEMS, GT-NEMS uses a combination of discount rates and U.S. government ten-year Treasury note rates to calculate consumer hurdle rates used in making equipment-purchasing decisions. Modifying the discount rates for these inputs is the primary means of estimating the impact of benchmarking policy.

The GT-NEMS inputs for discount rates are separated into seven population segments for each end-use (space heating, space cooling, ventilation, lighting, water heating, cooking, and refrigeration). Each population segment is capable of using a different discount rate for the end-use in question in each year. In the *Annual Energy Outlook 2011* (EIA, 2011a) Reference case, these discount rates are quite high; more than half of the consumer choices made surrounding lighting and space heating use discount rates greater than 100% (EIA, 2011b). While it is well known that consumers utilize high discount rates, such high discount rates are not substantiated by the bulk of existing research.

A literature review spanning four decades uncovered more than two-dozen studies estimating implicit discount rates for commercial consumers across the end-uses. The mean discount rates in this literature ranged from 17% (space heating and space cooling both) to 63% (refrigerators). The Simulation and Econometrics To Analyze Risk (SIMETAR) tool was used to develop continuous probability distribution functions for each end-use. GRKS distributions were used for space cooling, lighting, cooking, and water heating; space heating and refrigeration use

[1] Program managers from New York City, Seattle, Austin, Washington, D.C., and DOE's Building Technology Program were interviewed.

Weibull distributions as a better fit. Figure 1 illustrates the SIMETAR simulated discount distribution for six of the seven major commercial end-uses. Ventilation was the sole end-use to have no specific studies. Since ventilation functionally belongs to the greater HVAC (Heating Ventilation and Air-Conditioning) family, this study uses the space heating discount rate distribution to represent ventilation.

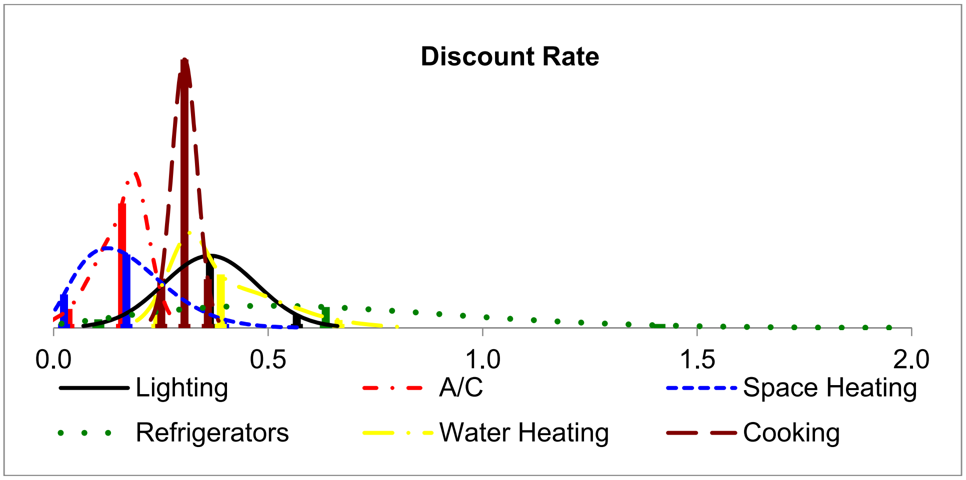


Figure 1. Probability Distribution Functions by End-use (Cox et.al., 2013).

The probability density functions were then divided into seven segments containing an equal area under the curve for each end-use. The median value of each of segments was used as an input into GT-NEMS in the Updated Discount Rates (UDR) scenario. To estimate the impact of benchmarking, the median discount rate would decline by five percentage points. The quotient of this "benchmarked" median discount rate and the updated median discount rate was calculated and used as an adjustment factor to the other six population segment medians to generate the "Benchmarking 5% Scenario". Given the uncertainty in the estimates of information-based discount rate modifications and the wide range of reported implicit discount rates (Azevedo et.al, 2013; Train, 1985), we also produce a Benchmarking 10% Scenario, which follows the same method but applies a 10% reduction to the median discount rate from the UDR scenario. GT-NEMS adds the rate of ten-year Treasury notes to these values, which vary by year according to macroeconomic conditions. The reference case Treasury note rates were subtracted from the updated discount rates so that the final hurdle rates calculated by GT-NEMS are consistent with the values suggested by the literature. All policy scenarios are implemented in 2015. In Table 1, space heating is used as an example to present the 2015 hurdle rates used in GT-NEMS across scenarios (these values represent the sum of the Treasury bill rates and the discount rates).

Table 1. Discount Rates across Scenarios for Space Heating in 2015

Percentage of Population			Discount Rate*			
Reference	UDR	Benchmarking 5% and 10%	Reference	UDR	Benchmarking5%	Benchmark-ing10%
27	14.2	14.2	1005.75	56.7	40.4	24.1
23	14.3	14.3	**105.75**	27.5	19.6	11.7
19	14.3	14.3	50.75	21.6	15.4	9.2
18.6	14.3	14.3	30.75	**17.4**	**12.4**	**7.4**
10.7	14.3	14.3	20.75	13.8	9.8	5.9
1.5	14.3	14.3	12.25	10.4	7.4	4.4
0.2	14.3	14.3	5.75	6.7	4.8	2.8

*Discount rates presented include the projected Treasury bill rate for 2015. **Bold** numbers represent the median estimate for the specific scenario.

Results

Sectoral Energy Consumption and Intensity

The energy consumption impacts of the two Benchmarking scenarios are similar. Compared to the Updated Discount Rate (UDR) Scenario, the Benchmarking 5% Scenario reduces the energy consumption of the seven major end-uses in the commercial sector in 2035 by 250 TBtus, a 2.3% reduction (Figure 2). The Benchmarking 10% Scenario would further reduce energy consumption by 20 TBtus. Although the energy savings may appear modest, they are the additional savings beyond the UDR Scenario, which itself represents primary energy savings of 2.8% in 2020 and 5.1% in 2035 relative to the EIA reference case.

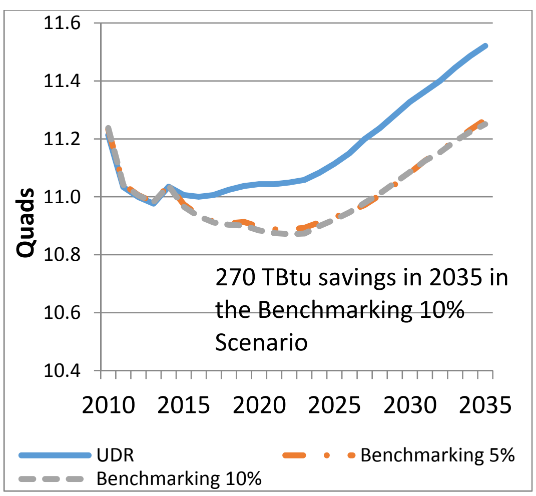


Figure 2. Energy Use in Major End-Uses.

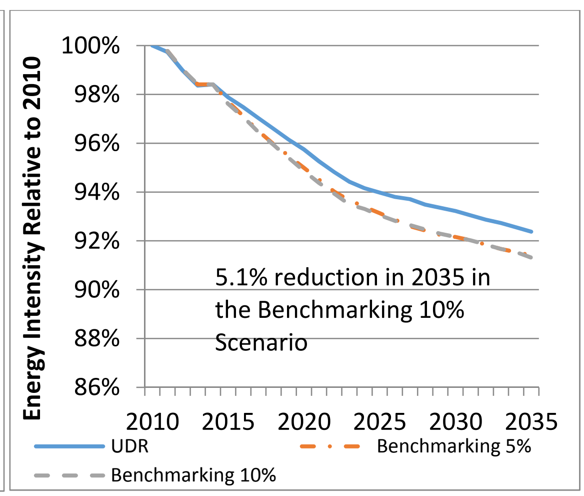


Figure 3. Change in Commercial Energy Intensity.

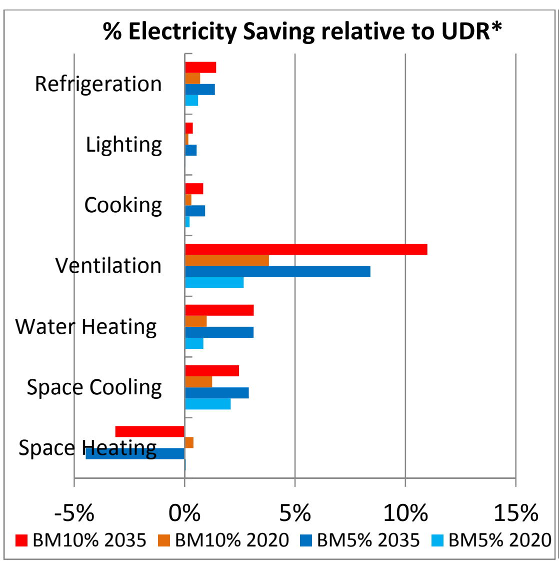
Model results suggest that as the policy reduces energy consumption, it does not affect the floor space area of the commercial sector. As a result, commercial energy intensity, measured in Btus per ft^2, would decline by more than 8.5% between 2010 and 2035 in both cases – an additional 1% decline from the UDR case. In other words, for each ft^2 of commercial floor space, the 2035 building stock would only require 91.5% of the energy consumed in 2010 to provide the same amount of energy service.

Energy Savings by Fuel Type and End-use

Figure 4 and 5 present the electricity and natural gas savings in both benchmarking scenarios, relative to the UDR scenario. Among the seven major commercial end-uses, electricity use in ventilation is the most sensitive to the benchmarking policy. Relying on electricity as the single energy source to meet service demand, ventilation would save 8.4% and 11.0% in 2035 in the Benchmarking 5% and 10% scenario, respectively. As the third largest commercial end-use, ventilation equipment consumes 460 TBtus of delivered electricity in 2035 in the UDR case; however, with benchmarking, consumers would be able to reduce their electricity use by 40-50 TBtus in 2035. The significant drop in electricity consumption is a result of a market shift from constant air volume ventilation equipment to variable air volume equipment.

All major end-uses except space heating show some amount of electricity savings. Space heating would see less electricity consumption in 2020; however, from the early 2020s, more electricity would be consumed by the end-use. This is the result of a technology shift from low-efficiency natural gas boilers, which have coefficient of performances (COPs) ranging between 0.78-0.80, to high-efficiency electric air source heat pumps (COP=3.3). This leads to more electricity consumption while it reduces the demand for natural gas (Figure 5). Air source heat pumps do not only displace natural gas boilers, they also reduce the market share of electric boilers (COP=0.94) and packaged space heaters (COP=0.93).

Although natural gas consumption for space cooling increases under the policy scenarios, this does not appear to have a significant impact on the overall energy consumption in the end-use because commercial buildings remain overwhelmingly depend on electric space cooling equipment. Water heating and cooking reduce their consumption of both natural gas and electricity.



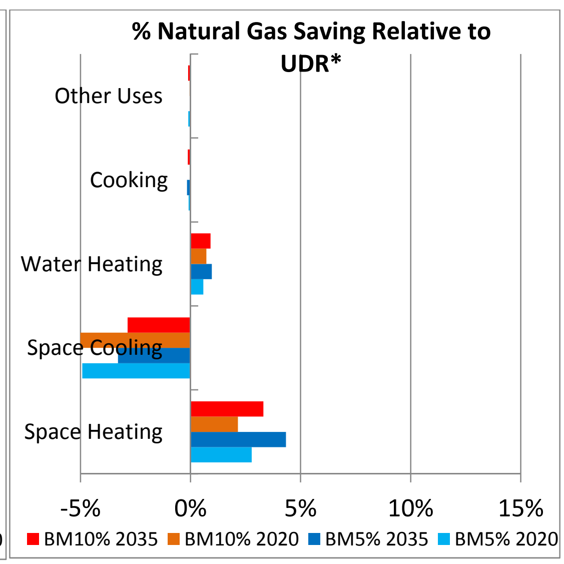


Figure 4. Electricity Savings by End-Use. Figure 5. Natural Gas Savings by End-Use.
* Positive numbers indicate energy savings. Negative numbers indicate more energy consumption

Energy Consumption by Building Type

GT- NEMS characterizes the U.S. commercial building stock using 11 building types (Figure 6). The savings for all building types grow bigger over time both in percentage terms and absolute energy terms with the exception of warehouses. Both Benchmarking 5% and 10% scenarios will, on average, save commercial buildings 1% of their total energy consumption in 2020, relative to the UDR case, or 2% for the seven major energy end-uses. The average impact grows to 1.5% in 2035. As the largest commercial building energy consumer, mercantile buildings would have the largest absolute primary energy savings in 2020 (16 TBtus in the Benchmarking 5% case and 15 TBtus in the Benchmarking 10% case), while assembly and education buildings would achieve the greatest relative savings (1.4% and 1.3% respectively). The savings may seem modest, but they are the additional savings beyond the UDR Scenario, which reduces energy consumption 3% by itself in 2020. Large and small office buildings and health care buildings all show consistently below-average energy savings. This is partly due to the significance of plug loads or electronic devices in these buildings' energy portfolio. Since this study only modified the discount rates used to purchase equipment in the seven major end-uses, the impact of the benchmarking policy on many electronic devices are not captured; therefore, the savings in these areas may be underestimated.

Different regions also show various energy saving potentials. Regions in colder climates, such as New England, Mid-Atlantic, North East Central, and the Mountain region all see greater energy savings with the policy (Figure 7). Natural gas is the predominant heating fuel in these regions. As discussed in Section 4.2, the benchmarking policy would shift the space heating end-use from relying on low-efficient natural gas equipment to using high-efficiency electric heat pumps, which would lead to significant energy savings. In fact, one common theme shared by these four regions is that space heating is their largest energy-saving source.

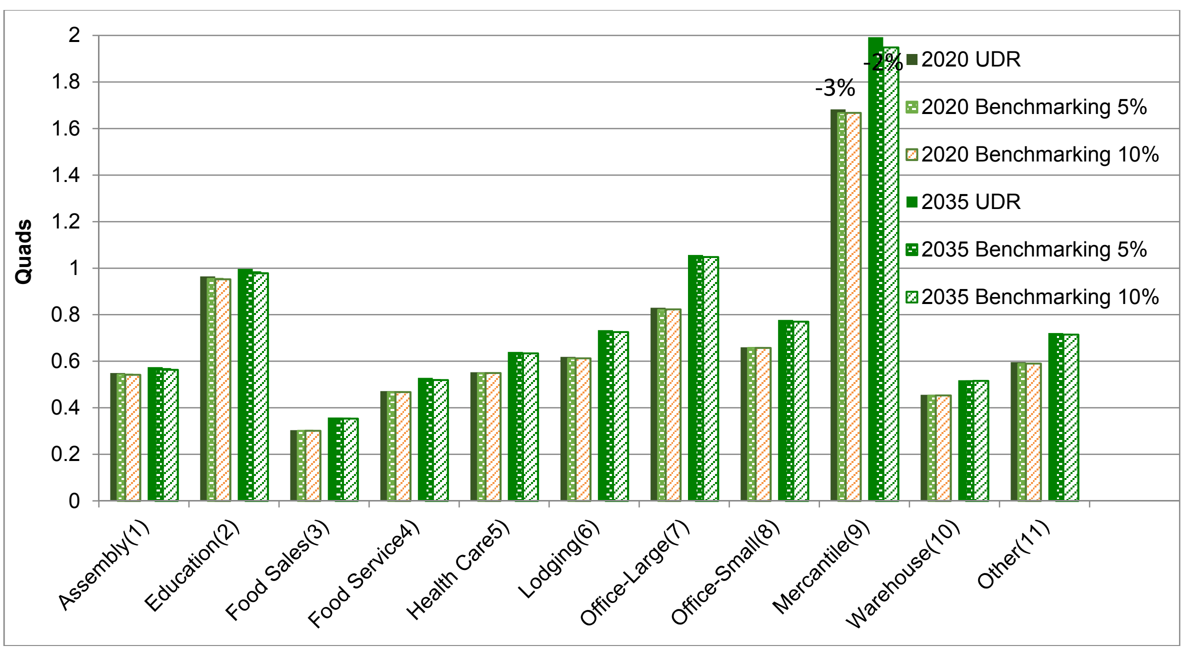


Figure 6. Energy Consumption by Building Type

The South Atlantic, East South Central, and West South Central divisions are more likely to lag in achieving energy savings across many building types partly because space heating accounts for a smaller part of their total energy budgets. In addition, a larger portion of the space heating demand is already met by electric heat pumps in these southern regions and therefore, the room for improvement is not as large as it is in the Northern and the Mountain regions.

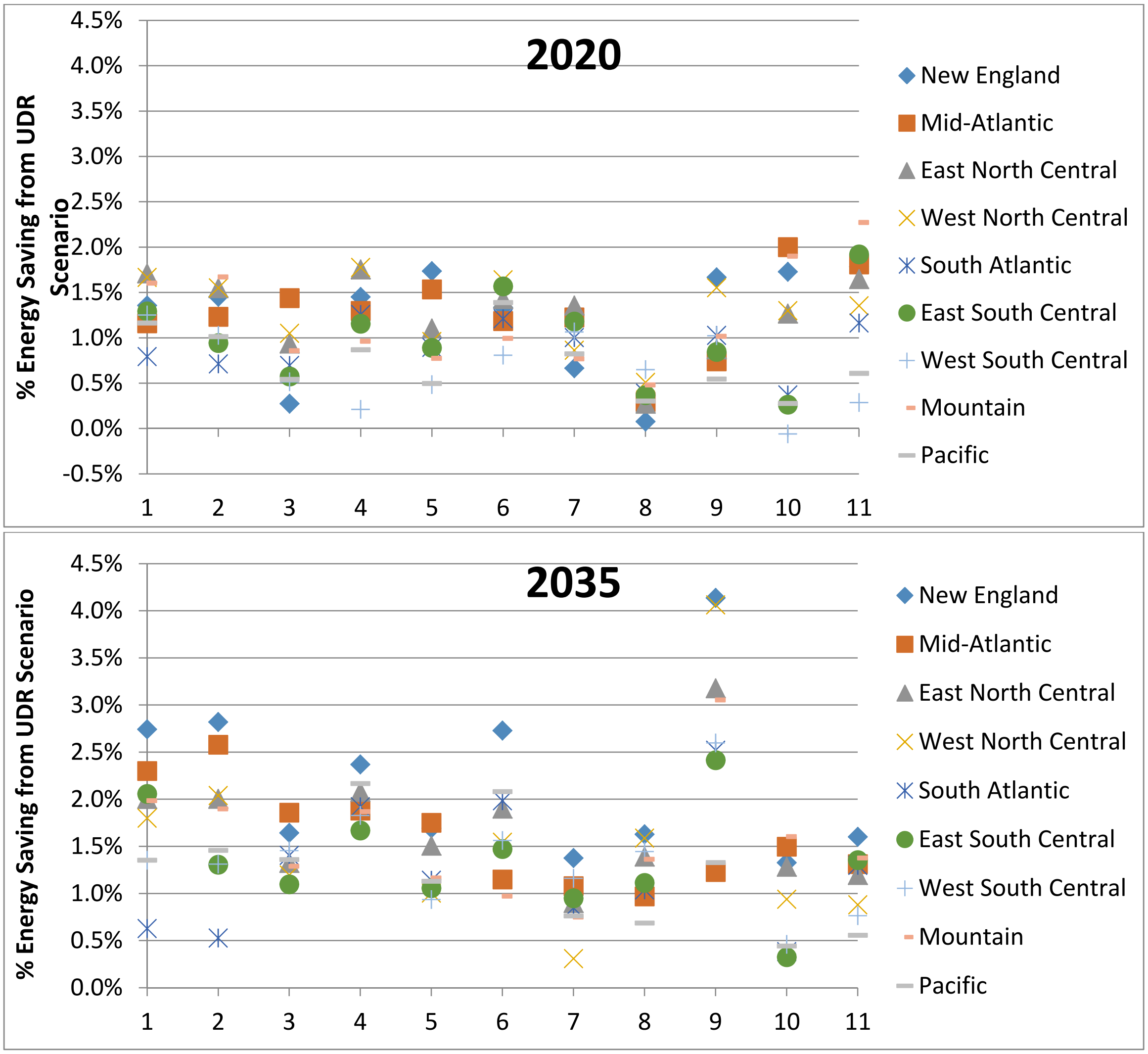


Figure 7. Regional Energy Saving Potentials by Building Type in 2020 and 2035.

Figure 7 demonstrates the percentage energy savings by region and by building type under the Benchmarking 5% scenario, which could inform state and local policymakers on where to focus their energy-efficiency efforts. The numbers on the x-axis represent the 11 building types, corresponding to the numbers in the parentheses on the x-axis of Figure 6. New England stands out by almost doubling its energy savings between 2020 and 2035. The analysis shows that New England would transform itself from being the region with the lowest percentage energy savings in buildings such as food sales and large and small office buildings (#3, 7 and 8) in 2020 to the leader of energy savings in most building types in 2035.

Energy Price Impact by Region

The two benchmarking scenarios would likely have uneven regional impacts. New England sees the deepest reduction in electricity rates and a paired t-test shows that the reduction is statistically significant (Table 2). In 2020, the electricity rate in the Benchmarking 5% scenario is 2.5% lower than the UDR scenario and doubles by 2035. The significant drop in the electricity rate and inelastic natural gas prices are partly responsible for the technology shift in the space heating end-use from natural gas equipment to electric equipment.

Except for New England, all other regions would achieve modest reductions in their electricity rates, ranging from a minimal change in East South Central in 2020 under the Benchmarking 5% Scenario to a 1.1% reduction in the Mid-Atlantic and West South Central regions in 2035 under the same scenario. All census divisions see statistically significant price reduction in at least one policy scenario; four of them experience significantly lower prices in both scenarios. Although the nation would experience a lower electricity rate in 2020 and 2035, the differences are not statistically significant.

Natural gas prices are less responsive to the benchmarking policy, and the variations are smaller across regions. All regions see a modest (less than 1%) reduction in natural gas prices except New England, where natural gas could become slightly more expensive for New England due to the shift in heating fuels. The nation as a whole would see significantly lower natural gas prices in 2020 and 2035.

Table 2. Impacts on Electricity and Natural Gas Prices in the Commercial Sector^

Electricity			Natural Gas		
Census Division	2020	2035	Census Division	2020	2035
New England*,*	-2.5% (-2.7)	-5.0% (-4.4%)	New England*,--	0.1% (0.5%)	0.0% (-0.2%)
Mid-Atlantic*,*	-0.0% (-0.3%)	-1.1% (-0.8%)	Mid-Atlantic *,*	-0.2% (-0.3%)	-0.6% (-0.7%)
East North Central*,*	-0.9% (0.7%)	-0.9% (0.6%)	East North Central *,*	-0.7% (-0.2%)	-0.2% (0.1%)
West North Central*,*	0.1% (0.4%)	-0.8% (-0.1%)	West North Central*,--	-0.8% (-0.4%)	-0.4% (-0.1%)
South Atlantic*	-0.5% (0.1%)	-0.2% (0.0%)	South Atlantic*,*	-0.5% (0.0%)	-0.3% (-0.2%)
East South Central --,*	0.0% (0.1%)	-0.9% (0.0%)	East South Central --,*	-0.5% (-0.1%)	-0.3% (0.0%)
West South Central*, --	-0.4% (0.0%)	-1.1% (0.0%)	West South Central*,*	-0.8% (-0.2%)	-0.5% (-0.1%)
Mountain*,--	-0.5% (-0.3%)	-0.6% (-0.4%)	Mountain*,*	-0.7% (-0.3%)	0.1% (-0.1%)
Pacific*,--	-0.2% (-0.1%)	-0.5% (0.0%)	Pacific*,*	-0.6% (-0.3%)	-0.5% (-0.3%)
U.S. Average --,--	-0.5% (-0.3%)	-1.1% (-0.9)	U.S. Average*,*	-0.5% (-0.1)	-0.3% (-0.1%)

Notes: 1. ^ Numbers in the first row represent energy price changes under the Benchmarking 5% Scenario. Numbers in the parentheses represent energy price changes under the Benchmarking 10% Scenario.
2. Symbols following the census division names indicate the significance level of Benchmarking 5% and 10% scenario, respectively. * indicates the price difference between the policy and reference scenarios is statistically significant at a 5% level. --means that the difference is not statistically significant at a 5% level.

On average, the commercial sector as a whole would experience half a percent drop in both electricity and natural gas prices in 2020 under the Benchmarking 5% Scenario. The electricity rate reduction would grow deeper over time, reaching 1.1% in 2035. The downward pressure on electricity and natural gas rates would produce economy-wide benefits to consumers as utility bills decrease and they have more discretionary income.

Cost Effectiveness

The benchmarking policy creates downward pressure on both the amount of energy consumed in the commercial building sector and the prices of the two major fuels. As a result, commercial energy consumers would see sizable savings on their energy bill. It is estimated that by 2020, the energy expenditure savings would total \$6.3 billion under the Benchmarking 5% scenario. The savings would grow bigger over time to reach \$28.3 billion in 2035 and \$39.7 billion by the time the impact of the policy ends (Table 3).

In addition to saving energy, pollutant emissions would also fall. The commercial sector CO_2 emissions would drop by 8 million metric tons (MMT) in 2020 and 10 MMT in 2035. Using the social cost of carbon estimated by the U.S. Environmental Protection Agency (EPA, 2013), the cumulative societal benefit from avoided CO_2 emissions is \$2.2 billion by 2035 and \$7.3 billion by the time the impact of the policy ends. The benefit to the society grows to \$3.1 billion in 2035 after accounting for some of the criteria pollutants (SO_2, NO_x, $PM_{2.5}$, PM_{10}).

Last but not least, the benchmarking policy would allow commercial consumers to spend less on buying new equipment. This is due to the shift from inefficient to high-efficiency equipment, which may cost consumers a little more in the short run, but reduces the long-run turnover. As a result, the sector would spend a cumulative \$18 billion less on equipment purchases in 2035. The benefits add up to \$56.7 billion in 2035, and by the time the impacts of the program stop, society would be \$69 billion better off.

Table 3. Cost Benefit Analysis of Benchmarking Policy[a]

	Cumulative Social Benefits (Billion 2009-\$)					Cumulative Social Costs (Billion 2009-\$)		Benefit/Cost Analysis
Year	Energy Expenditure Savings	Value of Avoided CO_2	Value of Avoided Criteria Pollutants	Equipment Outlays	Total Benefits	Compliance Costs	Total Costs	Net Social Benefits
2020	6.3 (2.8)	4.6 (6.1)	1.4 (3.4)	6.4 (5.4)	18.7 (17.7)	0.1	0.1	
2035	28.3 (22)	7.3 (9.3)	3.1 (7.3)	18.0 (21.7)	56.7 (60.9)	0.1	0.1	
Total Impact[b]	39.7 (31.7)	8.6 (11.0)	3.0 (8.2)	18.0 (21.7)	69.0 (72.6)	0.1	0.1	68.9 (72.5)

[a]Present value of costs and benefits were analyzed using a 3% discount rate. Values reported in table 3 are the Benchmarking 5% value followed by the Benchmarking 10% value in parentheses. [b]The total impact accounts for the energy savings and its related benefits occurring throughout the lifetime of the commercial equipment, assuming an average lifetime of 20 years.

Buildings with multiple tenants will require aggregation services in order to determine the energy footprint of an entire building. The additional cost incurred by this service we call the compliance costs. These costs were determined using the 2003 Commercial Building Energy Consumption Survey data (EIA, 2007), which provides the number of multi-tenant buildings with electric and natural gas service. It is assumed that the cost of compliance will be the same for each building, following the ConEdison model in New York City, and is set at $102.50 (2011-$) for electricity and natural gas, such that a building needing aggregation for both fuels would incur costs of $205. The cumulative compliance costs aggregate to $0.1 billion, which is two orders of magnitude smaller than the total benefits. As shown in Table 3, at the end the program, the total net societal benefit would reach $68.9 billion in the Benchmarking 5% scenario and $72.5 billion in the Benchmarking 10% scenario.

Connecting National Results to City Efforts

EPA reviews of Portfolio Manager participants show savings greater than our modeling suggests, as highlighted earlier, reducing energy consumption by 7% after three years of Portfolio Manager use. While this is impressive, it is also a self-selected group, so the real benefit of benchmarking for all buildings is probably somewhere between these two points. Comparing city experiences is also difficult, since individual contexts and laws vary greatly. While all of them include mandated disclosure, the means of disclosure varies; while New York City and San Francisco have widely-available public databases on energy consumption, Seattle only reveals such information at point of sale.

All of the cities that have adopted a benchmarking law are signatories to the Mayor's Climate Protection Agreement and have sustainability or climate action plans that explicitly target energy consumption as a driver of CO_2 emissions. The legal authority associated with the plans and the enforcement authority of the agencies tasked with implementation is important and varies across cities. New York City is the leader in producing publicly available data regarding their benchmarking and mandated disclosure law, and they show a 3% improvement in the median energy use intensity of office buildings over the course of the last two years (PlaNYC, 2013). It is not known if improvements like this are occurring in the other jurisdictions with these laws.

Conclusion

Benchmarking policies that require utilities to submit building energy data to a uniform database accessible to building owners and tenants would improve energy efficiency in U.S. commercial buildings. In 2035, 250 TBtus of primary energy consumption could be avoided by the benchmarking policy, a 5.1% reduction relative to the UDR case. The impact of the policy is unevenly distributed across end-uses, building types and regions. Ventilation possesses the greatest energy saving potential, followed by space heating, which sees a shift from using natural gas as its predominant fuel to more electricity usage. Mercantile buildings would benefit the most due to the policy, followed by education and assembly. In terms of regional impact, New England stands out as a clear winner while the southern regions generally lag behind. Besides the clear energy benefits, the modeling results indicate that the cumulative social benefits would reach $69-$72 billion in 2035, significantly outweighing the cumulative social costs.

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