Lessons from the United States and China for Increasing Transparency and Harmonizing Measurement and Verification Practices in the Buildings Sector

Authors:

Carolyn Szum, Nan Zhou, Sara Lisauskas [1], Madeline Frieze[1], Xi Chen[2], Zhiming Pan[3]

[1]ICF International, [2] China Academy of Building Research, [3]Natural Resources Defense Council

Energy Analysis and Environmental Impacts Division
Lawrence Berkeley National Laboratory

China Energy Group

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Carolyn Szum and Nan Zhou
Lawrence Berkeley National Laboratory
One Cyclotron Road, MS90R2121
Berkeley, CA 94720
Email: ccszum@lbl.gov and nzhou@lbl.gov

Sara Lisauskas and Madeline Frieze
ICF International
9300 Lee Highway
Fairfax, VA 22031 USA
Sara.Lisauskas@icf.com and madeline.frieze@icfi.com

Xi Chen
China Academy of Building Research
#30 Beisanhuan East Road
Chaoyang District
Beijing, China 100013
chenxi@chinaibee.com

Zhiming Pan
Natural Resources Defense Council
Taikang Financial Tower 17th floor, Suite 1706
No. 38 Dong San Huan Bei Road
Chaoyang District
Beijing, China 100026
ZPan@nrdc-china.org

Abstract

In recent years, municipal governments globally have determined that building energy performance benchmarking and disclosure policies are effective in encouraging the development of a strong market for building energy efficiency (Dunsky et al. 2009). A comparison of global benchmarking and disclosure policies show a range of requirements, but most typically these include requirements to disclose annualized energy and usage data using standardized rating tools on a yearly basis or at the time of sale (BuildingRating 2010-2014). While valuable, disclosure data are only really effective if it inspires action (i.e., retrofits of underperforming buildings) and quantification of impact or "net savings" of policies (i.e., gross energy savings minus free ridership plus spillover plus market effects). Both of these objectives can be difficult to achieve from annualized, whole-building energy performance metrics alone. This paper will discuss results from a new initiative under the U.S.-China Clean Energy Research Center Building Energy Efficiency (CERC-BEE) program (an initiative to support top scientists, engineers, and policy analysts from the United States and China in collaborative research to accelerate the development and deployment of clean energy technologies in the buildings sector)[1] to jointly identify disclosure data points and develop automated building retrofit analytic tools for municipal benchmarking and disclosure programs that support better up-front assessment of retrofit opportunities; measurement and verification (M&V) of energy, cost and carbon dioxide (CO_2) reduction; and building energy policy evaluation, measurement, and verification (EM&V). The paper sheds light on how the

[1] The CERC-BEE is a ten-year initiative to support leading scientists from United States and China in collaborative research to accelerate the development and deployment of advanced building technologies in the buildings sector. Additional information can be found at https://cercbee.lbl.gov/ (CERC-BEE).

world's two largest economies and emitters of greenhouse gases (GHG) are increasing transparency and harmonizing M&V of building energy savings, providing lessons and opportunities for global scale-up.

Introduction

The Paris Agreement, which entered into force on October 5, 2016, aims to keep global surface temperature rise well below 2°Celsius (C) above pre-industrial levels by the end of the 21st Century (UNFCCC 2017). According to the International Energy Agency (IEA), achieving this target will require an estimated 77% reduction in total CO_2 emissions in buildings by 2050 compared to a baseline of 2012 (IEA 2013, 10). A significant portion of these reductions must occur in existing buildings. By 2050, 60% of the current building stock will still be in use in Europe and the United States (IEA 2013, 4-5), and in China, almost 3 billion square meters of building floor space will be more than 40 years old and require retrofit (Zhou et al. 2016, 4). Despite widespread consensus on the critical role existing building energy efficiency must play in mitigating climate change, current annual investment in building energy efficiency remains insufficient to meet these targets. Specifically, IEA estimates that annual energy efficiency investments must increase fourfold (to €488 billion) to achieve the energy efficiency targets pledged by countries in the Paris Agreement (IPEEC 2016, 38).

Among the most widely acknowledged barriers to building energy efficiency investment are lack of information and asymmetric information (Hsu 2013; IEA 2007). As markets require information to function well, lack of information on a building's energy usage prevents owners from investing in energy efficiency, as the costs and benefits cannot be calculated (Hsu 2013). Asymmetric information prevents prospective buyers, renters, and investors from incorporating the energy characteristics of a building into their purchase, leasing, and financing decisions, thus discouraging owners from investing in energy efficiency (as it is not a competitive differentiator and they cannot capitalize on their investment) (Palmer and Walls 2015; Hart 2015).

To address information gaps and asymmetries, municipal, regional, and national governments globally are experimenting with building energy performance benchmarking and disclosure policies, and in some cases, benchmarking, disclosure, and auditing policies. Today, more than 30 countries around the world have in place some type of mandatory building energy rating policy (Buss, Majersik, Zigelbaum 2013). In general, they have found that these policies are effective in encouraging the development of a strong market for building energy efficiency, by allowing the market to properly account for and value energy efficiency (Dunsky et al. 2009). For instance, among the first cities in the United States to adopt benchmarking and disclosure laws was New York City as part of its Greener, Greater Buildings Plan (GGBP).[2] New York City comprises approximately 50% of all buildings participating in benchmarking and disclosure programs in the United States and has had compliance rates of 75% for its policies (Hsu 2013, 266). The GGBP targets 22,000 buildings accounting for 45% of the city's energy consumption. It consists of four regulations, including requirements for annual energy and water benchmarking (Local Law 84) and requirements for energy use audits and retro-commissioning every ten years (Local Law 87) (Dickinson and Tenorio 2011, 11; Wang and Zhang 2012). As a result of these regulations, from 2010 to 2013, New York City reduced gross energy use by 5.7%, GHG emissions by 9.9%, energy costs by €250 million, and created 3,132 jobs (Seiden et al. 2015, i-ii). Energy service companies in New York City also reported a 30% increase in business in response to requirements for annual energy and water benchmarking under Local Law 84 (Hurley and Burr 2011, 1). More qualitatively, disclosure requirements have led to a better understanding of tracking energy usage and the various metrics involved in normalizing data to allow for comparisons and benchmarking in New York City. Additionally, tenants and investors have grown in awareness and attention to energy use (Seiden et al. 2015).

Despite the merit of these policies, several shortcomings have been identified. These include: (1) the need for additional analysis of results, such as energy efficiency improvement recommendations and financial analyses (Dunsky et al. 2009; Palmer and Walls 2015; Pan et al. 2016).; (2) the need for additional data to conduct quality evaluation, measurement, and verification (EM&V) of benchmarking and disclosure policies (Todd et al. 2012; Palmer and Walls 2015); (3) more efficient and cost-effective auditing of buildings for retrofit opportunities (Hsu 2013, 266); and (4) greater standardization and automation of the benchmarking and disclosure process (Kontokosta 2013; Pan et al. 2014).

To help address these shortcomings, a team of researchers from Lawrence Berkeley National Laboratory, China Academy of Building Research (CABR), ICF International (ICF), and Natural Resources Defence Council (NRDC), under the U.S.-China CERC-BEE consortium, is carrying out research to identify the minimum set of

[2] The GGBP targets 22,000 buildings (commercial, industrial, institutional, multifamily, and mixed use) accounting for 45% of the city's energy consumption (Dickinson and Tenorio 2011, 11). The policy consists of four regulatory pieces, including requirements for annual energy and water benchmarking (Local Law 84) and requirements for energy use audits and retro-commissioning every ten years (Local Law 87) (Wang and Zhang 2012).

data disclosure points that could be required as part of U.S. and Chinese benchmarking and disclosure policies to: (1) increase efficient, cost-effective identification of building energy saving opportunities through application of web-based, automated retrofit analytical tools; and (2) improve the EM&V of benchmarking and disclosure policies. Further, where no public or private web-based, building retrofit analytical tools exist, to develop new tools that can easily be utilized with existing disclosure data to increase investment in building energy efficiency.

The paper presents their research and findings and is organized as follows. Part I provides an introduction to the topic and a justification for the research. Part II defines key terms and presents the research methodology. Part III presents a general overview of municipal benchmarking and disclosure policies in the United States and China, including the data points collected and disclosed; the audit policies and tools implemented; and the potential limitations of these benchmarking and disclosure policies. Part IV discusses what additional data could be made public, and/or new tools developed, to support more efficient, cost-effective identification of retrofit opportunities, building M&V, and policy EM&V. Part V draws conclusions.

Key Terms and Research Methodology

Building Benchmarking and Disclosure

Building energy performance benchmarking and disclosure policies, which began to emerge in the late 1990s, fit into the broad category of policies known as information laws, regulatory disclosure, or transparency laws. These policies require “the mandatory disclosure of information by private or public institutions with a regulatory intent” and have been applied previously in financial markets, health care, nutrition, etc. (Hsu 2013, 264). In the context of building energy efficiency, benchmarking and disclosure policies require building owners to evaluate a building’s energy performance using standardized rating tools (either *operational rating tools*, which evaluate a building’s actual operating energy performance, or *calculated rating tools*, which calculate the energy performance of a building’s physical characteristics and equipment) and to disclose these results to buyers, renters, financiers, or to the general public at either the time of sale or lease (*triggered disclosure*), or at annual intervals (*scheduled disclosure*) (Dunsky and Hill 2013). The rationale for these policies is that publicizing building energy performance provides valuable information to renters, buyers, and financiers, allowing them to incorporate the cost of building operation when making purchase, lease, and financing decisions (Palmer and Walls 2015). This incentivizes building owners to improve the energy performance of their buildings, as energy performance becomes a differentiator when competing for buyers and renters, thereby mitigating split incentives (Hart 2015). Furthermore, scheduled disclosure policies help to stimulate a market for building energy efficiency more broadly by supporting government and utilities in targeting energy efficiency programs and energy service providers in identifying potential customers (Dunsky and Hill 2013).

Audit Policies and Tools

Audit policies often accompany benchmarking and disclosure policies. While benchmarking and disclosure provides information on a building’s energy performance relative to peers, audit policies provide useful information about equipment, systems, occupancy, and space uses, which can help explain building energy use variations (Hsu 2013). Typically, audits are conducted in-person by certified professionals and include an assessment of the energy savings potential for a building and recommended energy conservation measures (ECM). However, web-based, retrofit analytical tools have begun to emerge to complement in-person audits. These tools do not necessarily replace in-person audits, but they can accelerate the adoption of ECMs by cost-effectively pre-screening buildings for energy savings opportunities before expensive audits are undertaken. Typical capabilities of retrofit analytical tools include estimating energy and cost savings potential and identifying ECMs for a building. The most common retrofit analytical tools utilize (1) empirical data driven methods, (2) normative methods or (3) physics-based energy modelling (Lee, Hong, and Piette 2015).

Research Methodology

The methodology applied to carry out this research included the following steps. First, the teams conducted desk research to assess the data currently collected and made public as part of U.S and Chinese benchmarking and disclosure programs. European programs were also assessed briefly to determine policy trends globally. Second, the team identified the retrofit analytical tools available in the U.S. and Chinese markets today and assessed the data input requirements and output information of these tools. Third, the team cross-mapped the data disclosure requirements with the data inputs and outputs for the retrofit analytical tools and determined the minimum set of data points that could be utilized with these tools. Fourth, the team identified current policy shortcomings. Fifth, the team determined what additional data, if any, could be collected and/or made public to overcome policy shortcomings. The team also built on precursor work to identify new retrofit analytical tools for development that would be more aligned with current publicly-available data from benchmarking and disclosure programs.

Research Findings and Discussion

Benchmarking, Disclosure, and Audit Requirements in the United States

U.S. states and municipalities began adopting benchmarking and disclosure policies beginning in 2007, with the state of California passing Assembly Bill 1103, requiring commercial rating and disclosure at the time of building sale, lease, or financing. In 2008, Washington, D.C enacted the first municipal policy with annual benchmarking and public disclosure, followed shortly by Austin, Texas and then New York City a year later (Burr, Majersik, and Zigelbaum 2013). Currently, there are 26 city, state, and county commercial benchmarking policies in the United States (BuildingRating 2016b). The following sections describe the data collection, disclosure, and audit requirement associated with 14 of these policies. The 14 policies selected for more detailed review were chosen because they provided readily accessible publicly available information on their benchmarking and disclosure policies.

Table 1. Typical Data Disclosure Requirements for U.S. Cities

	Building Type			Recipient of Disclosure		Time of Disclosure	
U.S. Jurisdiction	**Municipal**	**Commercial**	**Multifamily Residential**	**Local Government**	**Public Website**	**Annual**	**Point of Transaction**
Austin	X	X	X	X		X	Buyers
Atlanta	X	X	X	X		X	
Berkley	X	X	X	X	2018	X	Buyers, Lessees
Boston	X	X	X	X	X	X	
Cambridge	X	X	X	X	X	X	
Chicago	X	X	X	X	X	X	
Kansas City	X	X	X	X		X	
Minneapolis	X	X		X	X	X	
New York	X	X	X	X	X	X	
Philadelphia	X	X	X	X	X	X	Buyers, Lessees
Portland, OR	X	X		X	2017	X	
San Francisco	X	X		X	X	X	Buyers, Lessees, Lenders
Seattle	X	X	X	X		X	Buyers, Lessees, Lenders
Washington, D.C.	X	X	X	X	X	X	Buyers
# of Cities	14	14	11	14	8	14	5
% of Cities [a]	100%	100%	79%	100%	57%	100%	36%

[a] Percentage is out of a total 14 cities that disclose data publicly (on websites) in the United States.
(BuildingRating 2016b; IMT 2015; DC.gov)

U.S Data Collection Requirements

All of the 14 policies that were assessed require disclosure to the government on an annual basis. Benchmarking data are reported for all of these cities through the ENERGY STAR Portfolio Manager® tool, a free, online tool of the U.S. Environmental Protection Agency (EPA) that tracks energy and water consumption, and GHG emissions for U.S. buildings.[3] The following are the data points required to generate a benchmark score for all property types in the United States. Eight of these jurisdictions (57%) currently disclose their building energy performance data publicly. Six (36%) of the jurisdictions also disclose data at the point of transaction for buyers or renters (Table 2).

Table 2. Data Input Requirements for U.S. ENERGY STAR Portfolio Manager Benchmarking Tool

Data Input Requirements for all Property Types
Property Name
Property Address

[3] The ENERGY STAR Portfolio Manager is an online tool created by the U.S. Environmental Protection Agency to evaluate the energy efficiency of U.S. buildings against the national stock. It can be accessed at https://portfoliomanager.energystar.gov/pm/login.html.

Property Type
Year Built
Gross Floor Area
Number of Buildings
12 consecutive months of energy data for all fuels
Additional Data Input Requirements for Select Property Types [a]
Office: Number of workers, number of computers, weekly operating hours, percent heated, percent cooled
Hotel: Number of rooms, number of workers, presence of cooking, number of commercial refrigeration/freezer units, percent heated, percent cooled

[a] Additional data points are required for each property type in order to normalize for the statistically significant drivers of energy usage for that property type. These data points vary by type. Samples are included in the table. (ENERGY STAR Portfolio Manager)

U.S. Public Disclosure Requirements

The eight cities that publicly disclose data have been further reviewed to identify the data fields that are published. The building level information for all cities includes property name and address, gross floor area, ENERGY STAR score, annual total GHG emissions, property type, and annual site energy use intensity (EUI). Seven of the eight cities (88%) include annual source EUI, and six (75%) include year built and annual weather normalized site and source EUI. Annual energy use by type (electricity, natural gas, etc.) is reported by four cities (50%) (Washington, D.C, Cambridge Chicago, and Philadelphia). A full list of data fields disclosed by city can be found in Table 3 below.

Table 3. Data Points Typically Disclosed on Websites in U.S. Benchmarking and Disclosure Programs

Data Points Typically Disclosed on Websites in U.S. Benchmarking and Disclosure Programs	Number of U.S. Cities	Percent of U.S. Cities[a]
Property Name	8	100%
Address and Other Identifying Fields (Record Number, Property ID, etc.)	8	100%
Gross Floor Area	8	100%
ENERGY STAR Score	8	100%
Annual Total Greenhouse Gas Emission	8	100%
Property Type	8	100%
Annual Site EUI	8	100%
Annual Source EUI	7	88%
Annual Weather Normalized Site EUI	6	75%
Annual Weather Normalized Source EUI	6	75%
Year Built	6	75%
Annual Greenhouse Gas Emission Intensity	5	63%
Annual Water Use	4	50%
Annual Electric/Gas/Fuel Oil/District Steam Use	4	50%
Number of Buildings on the Property	4	50%
Annual Water Use Intensity	3	38%

[a] Percent is out of a total eight cities that disclose commercial data publicly (on website) in the United States.
(BuildingRating 2016a; NYC; City of Cambridge; City of Boston.gov 2014; DC.gov; SF Environment; City of Chicago; City of Philadelphia; Minneapolismn.gov 2016)

U.S. Audit Policies

Of the 14 evaluated cities, only six (42%) require post-benchmark audits, of which all (100%) involve in-person audits as opposed to automated screening tools (IMT 2015; BuildingRating 2016b; Austin Energy 2017; Atlanta Building Energy Efficiency; City of Boston.gov; NYC; SF Environment; Seattle.gov). Further, of these cities, only two (33%), New York and Seattle, require post-audit action. In New York, buildings larger than 50,000 square-feet are required to conduct retro-commissioning of base building systems every 10 years according to Local Law 87 (Wang and Zhang 2012). Similarly, in Seattle, buildings 50,000 square-feet and more are required to tune-up their building energy and water systems every five years (IMT 2015). In Boston, buildings need to complete an energy assessment or energy action every five years; however, the details of compliance are still under development (City of Boston.gov 2014).

Table 4. Audit Policies for U.S. Benchmarking and Disclosure Programs

City Names	Retrofit Analytical Tools Applied?	Audits In-Person?	Action Required?	Description of Audit Policy
Austin	No	Yes	Yes	Audits required for multifamily every 10 years and

				upgrades required for high energy use buildings
Atlanta	No	Yes	No	ASHRAE level II audits every 10 years
Boston	TBD	TBD	Yes	Policy in development, audits or actions every 5 years anticipated
New York	No	Yes	Yes	ASHRAE level II audits, retro commissioning (RCx) for buildings 5,000 square meters or more every 10 years
San Francisco	No	Yes	No	ASHRAE level I or II audits or RCx every 5 years
Seattle	No	Yes	Yes	Building systems tune-up required for nonresidential buildings over 5,000 square meters every 5 years
# of Cities	0	4	4	
% of Cities [a]	0%	28%	28%	

[a] Percentage is out of a total 14 jurisdictions assessed in the United States.
(IMT 2015; BuildingRating 2016b; Austin Energy 2017; Atlanta Building Energy Efficiency; City of Boston.gov; NYC; SF Environment; Seattle.gov).

Quantified Impact of Benchmarking and Disclosure Policies in the United States

As discussed in the introduction, analysis shows that benchmarking and disclosure policies have generated results. In addition to New York City, several other U.S. cities have shown energy use intensity reductions as a result of benchmarking and disclosure policies. For instance, the evaluation results in Washington D.C. and San Francisco showed that the energy use intensity decreased by 6% from 2010 to 2012 and 7.9% from 2010 to 2014, respectively (Pan et al. 2016, 10). In another study, Austin, New York, San Francisco, and Seattle energy expenditure per unit of floor area declined 3% after the first reporting deadline in the city's policy (Palmer and Walls 2015, 19; Pan et al. 2016, 10).

Benchmarking, Disclosure, and Audit Requirements in China

Building energy performance disclosure policies emerged beginning in 2007 in China, around the same time that these policies emerged in the United States. In 2008, the Ministry of Housing and Urban-Rural Development (MOHURD) issued the *Civil Building Energy Efficiency Regulation* formally requiring government office buildings and large-scale public building owners to conduct building energy efficiency evaluation and labeling, and publicize, announce, or disclose the evaluation results in accordance with the national relevant provisions (Civil Building Energy Efficiency Regulation 2008).[4] Further, to complement this policy, the central government promulgated policies to establish platforms to monitor the dynamic energy consumption of buildings on a real-time basis in Beijing, Shenzhen, and Tianjin. At present the national government maintains a national on-line, real-time, building energy monitoring platform that conducts hourly, daily, weekly, monthly, and annual monitoring of building energy performance metrics, including whole-building, system, and equipment energy usage (by fuel type) (Xia 2014). Given these policy actions, 8,432 buildings have disclosed energy usage information to the central government and 2,680 buildings' energy usage is monitored in real time by MOHURD (Pan et al. 2014, 9).

Despite this progress, considering that large-scale public buildings account for 5.3 billion square meters and 36% of China's total construction area, the policy uptake has been slow relative to the magnitude of the problem (Yu 2010, 11). According Pan et al., this has had to do with lack of detailed implementation guidelines and a unified standard for building energy data collection and disclosure, making compliance and enforcement problematic. Further, the data reported to the central government is not synthesized, processed, or shared in a timely manner, meaning the market transformation benefits of the policy aren't fully being realized (Pan et al. 2014).

To address these shortcomings, in 2014, with funding from The World Bank and the Global Environment Facility (GEF), China's Ministry of Housing and Urban-Rural Development (MOHURD) initiated an Energy Performance Benchmarking and Disclosure Program (EPB&PD) modeled after the benchmarking and disclosure policies and programs in the United States. The policy is currently being piloted in the cities of Beijing and Ningbo, China for government and commercial office buildings, hotels, and hospitals. Underpinning the pilot program in Beijing is a municipal building energy performance benchmarking tool modeled after the U.S. EPA ENERGY STAR Portfolio Manager tool, allowing building owners to evaluate whole-building operational energy performance relative to peers in the market. Similar to ENERGY STAR, the Beijing Building Energy Consumption Benchmarking Tool provides a 1 to 100 score, where 50 is average and 75 indicates performance better than 75% of the market. It normalizes for factors such as climate, weather, size, and occupancy, and converts site to source energy for a more equitable comparison of performance. Based on the results of the pilot programs in Beijing and Ningbo, MOHURD will establish a national building energy performance

[4] A large-scale public building is non-housing civil building larger than 20,000 square meters.

benchmarking tool and platform (modeled after ENERGY STAR and the Portfolio Manager tool) and a voluntary building energy performance data disclosure policy to overcome informational barriers to building energy efficiency in China. The World Bank/GEF pilot programs in Beijing and Ningbo will conclude in late 2017 and a phased roll-out of the national policy is anticipated to begin in 2018 or thereafter (CABR 2014). Already, in anticipation of national roll-out, some municipal districts are beginning to experiment with their own benchmarking and disclosure policies. Among these is Changning District, Shanghai, a district receiving funding from the International Bank for Reconstruction and Development (IBRD) and GEF to pilot low-carbon city policies (The World Bank 2017). The following sections describe the data collection and disclosure requirements included in the pilot programs in Beijing and Ningbo and most likely to be incorporated into a national benchmarking and disclosure policy for China.

Chinese Data Collection Requirements

Given that emerging Chinese benchmarking and disclosure policies are modeled on U.S. programs and tools, the data Chinese buildings must collect in order to participate in municipal benchmarking and disclosure programs are similar to those in the United States. Table 5 indicates data requirements for the Chinese building energy performance benchmarking tools.

Table 5. Data Input Requirements for Beijing Building Energy Consumption Benchmarking Tool

Office	Building area; area of office/restaurant/shopping/underground garage/data center; operating hours; number of computers; number of staff; rental rate; monthly energy consumption (all fuels) (total energy consumption required and consumption by fuel type desirable)
Hotel	Building area; number of rooms; number of staff; occupancy rate; number of cold storage rooms; area of retailors/kitchen/laundry/fitness room; monthly energy consumption (all fuels): monthly energy consumption (all fuels) (total energy consumption required and consumption by fuel type desirable)
Hospital	Building area; number of staff; operating hours; average number of days in hospital bed per month; average number of hospital beds in use per month; outpatient visits and emergency treatment visits per month; monthly energy consumption (all fuels): monthly energy consumption (all fuels) (total energy consumption required and consumption by fuel type desirable)

Chinese Public Disclosure Requirements

The data publicly disclosed in China's municipal benchmarking and disclosure programs are more simplistic than the fields commonly disclosed in U.S. cities and limited to just seven data points as outlined in Table 6. In the Beijing and Ningbo pilot programs, disclosure of the following data points is mandatory for government buildings and voluntary for privately owned buildings. Data are disclosed on an annual basis and posted to a website for limited users to analyse. It is likely that any forthcoming national policy will follow suit.

Table 6. Chinese Municipal Benchmarking and Disclosure Data Points

Year Built	Gross Floor Area
Property Name	Benchmark Score (1 to 100)
Property Address	Annual weather normalized source energy use intensity
Property Type	

Chinese Audit Policies and Tools

According to CABR, there are no audit requirements associated with the energy performance benchmarking and disclosure pilot programs in Beijing and Ningbo, and it is unlikely that the national policy will require this. Further, according to CABR, there are no public or private retrofit analytic tools that use either empirical data or normative methods to drive retrofits.

Cross-Mapping of Benchmarking and Disclosure Policies with Retrofit Tools

The table below includes retrofit analytical tools that are commonly used in the United States to identify energy savings opportunities in commercial buildings. Tools that were selected for review include: (1) those that are empirical, data driven tools that rely on real measured data for benchmarking, and (2) those that are normative, using reduced order models with simple input and output data (Lee, Hong, Piette 2015). These types of tools are most appropriate for generating a quick evaluation of energy performance, as compared with more detailed physics-based modeling tools. Tools that were selected for review utilize actual utility data to evaluate energy efficiency opportunities, since the goal of this research is to identify how utility data from benchmarking and disclosure policies can be used for retrofit identification and M&V. Most tools below are web-based tools, but some are stand-alone or private software tools. Table 7 includes a summary of inputs and outputs for the various tools. The minimum data points needed to generate energy savings recommendations are monthly utility data, simple building characteristics (e.g., gross floor area, building type), and weather data. Simple building characteristics are generally available from benchmarking and disclosure public datasets, and weather data can easily be obtained. Monthly data are not usually published. Many of the retrofit analytical tools that were reviewed require interval data as an input, instead of monthly utility data. Interval data are not usually collected in benchmarking and disclosure policies.

Table 7. U.S. Retrofit Analytical Tool Attributes

	Building Performance Database (BPD)	C3 Commercial	Agilis Energy	FirstFuel	Chicago Loop Energy Retrofit Tool (Chicago area only)	HELiOS	Retroficiency/Ecova	Consortium for Building Energy innovation (CBEI)	Commercial Building Energy Saver (CBES)	Customized Calculation Tool (CCT)	Johnson Controls Inc. (JCI) LEAN Energy Analysis
Tool Inputs											
Accessibility for the public (Yes/No)	Yes	No	No	No	No	No	No	[a]	Yes	Yes	No
Utility Bills	X [b]	X	X	X	X	X	X	X	X	X	X
Time Series Interval Energy Data		X	X	X		[a]	X		X		
Climate/Weather Data [c]	X	X	X	X	X	X	X	X	X	[a]	X
Simple Building Characteristics [d]	X	X	X	X	X	X	X	X	X	X	X
Detailed Building Characteristics [e]					X	X	X	X	X	X	
Tool Outputs											
Energy and Cost Savings Estimates	X	X	X	X	X	X	X	X	X	X	X
Recommended ECMs	X	X	X	X	X	X	X	X	X	X	X
Benchmark Again Peers	X	X	[a]	X					X		X

Lee, Hong, and Piette 2015

[a] Unknown; [b] Yearly source and site EUI; [c] A range of factors, including but not limited to, indication of climate zone, daily outdoor temperature, daily wet bulb temperature, heating degree day (HDD), cooling degree day (CDD); [d] Includes building type, vintage, floor area, occupancy density; [e] Goes beyond that listed in the simple category

Current Limitations of Policies in the United States and China

In general, while benchmarking and disclosure policies have obvious merit in overcoming informational barriers, policy analysts have identified a number of shortcomings of these policies.

Need for Additional Analysis of Results

There is widespread agreement that benchmarking and disclosure policies are only a means to an end, and results need to be coupled with energy efficiency improvement recommendations, financial analyses, references to government or utility incentives, financing programs, and options for more detailed building analysis in order to drive energy efficiency investments (Dunsky et al. 2009; Palmer and Walls 2015; Pan et al. 2016).

Need for Additional Data to Conduct Effective EM&V for Benchmarking and Disclosure Programs

EM&V refers to activities determining the effects of a building energy efficiency policy or program. This often includes quantifying the "net savings" of building energy benchmarking and disclosure policies. Net savings equal gross savings minus free ridership plus spillover plus market effects, where free ridership is the program savings attributable to program participants who would have implemented a building energy efficiency practice in the absence of the program; spillover refers to additional reductions in energy consumption that are due to the program influences beyond those directly associated with program participation; and market effects refers to a change in the structure of the market or the behaviour participants which affect consumption patterns (beyond policy impact) (Violette and Rathbun 2014). According to numerous policy analysts, the data that are currently disclosed as part of benchmarking and disclosure programs are not sufficient to quantify the impact or net savings of building energy efficiency policies and additional information on buildings is required (Todd et al. 2012; Palmer and Walls 2015).[1]

Single Building Audits Can be Time-consuming and Costly

According to statistics from the California Energy Commission (CEC) and U.S. Department of Energy (DOE), cost differs significantly between benchmarking and disclosure programs that require audits and those that do not, as consultants can charge ten times more for more complex and detailed data analysis and modelling as part of audits. For example, the benchmarking and disclosure component of New York City's GGBP is estimated to cost €450-€1,400 per building. Auditing adds an additional €1.41 per square meter. Assuming a typical New York City building is 20,000 square meters, the difference between benchmarking and disclosure and auditing amounts to almost €29,000 (Hsu 2013, 266).

Need for Greater Standardization and Automation
While China has made some progress on establishment of real-time building energy usage monitoring platforms, both countries still rely on manual data collection and input of energy data into databases and on-line benchmarking tools to a great extent. This is a time-consuming process and leads to numerous human errors, which increases costs to both program administrators and building owners that must validate the data (Kontokosta 2013, 41). Thus, in both countries there is a need for greater automation and standardization of the benchmarking and disclosure process to increase cost-effectiveness (Kontokosta 2013; Pan et al. 2014).

Policy Recommendations

Taking into account the status of benchmarking and disclosure and audit policies in the United States and China today, as well as the noted shortcomings of these policies, the following are recommendations for additional data points that should be collected and/or made public as part of municipal benchmarking and disclosure programs to support more efficient and cost-effective assessment of retrofit opportunities, M&V, and policy EM&V. Where no public or private retrofit analytical tools exist, recommendations are made for new tools that could utilize existing benchmarking and disclosure data to increase energy efficiency investment in buildings.

Additional Data That Should Be Made Public

Data that Should be Made Public for Better Retrofit Identification and M&V in the United States
At a minimum, simple building characteristics (building size, location, and building type), weather data, and monthly energy use (broken down by fuel type) are necessary to support retrofit identification in the United States. Simple building characteristics are generally available from U.S. benchmarking and disclosure public datasets, and weather data can be easily obtained. Monthly data are not usually published. However, monthly data are usually collected and used to comply with benchmarking requirements. For example, in the United States, monthly data are entered into the ENERGY STAR Portfolio Manager tool to generate annual EUI values. If this information was required to be disclosed, it would be available for easy identification of retrofit opportunities, and for use for M&V. Alternatively, if functionality could be added to tools like the ENERGY STAR Portfolio Manager to allow retrofit opportunities to be identified using these data, the retrofit opportunities could be disclosed. Many of the U.S. retrofit analytical tools that were reviewed require interval data for electricity as an input, instead of monthly utility data. The additional granularity of interval data provides more insight for identifying energy efficiency measures and estimating electricity savings. One policy option to consider is whether interval data should be disclosed, in some form, to obtain better data to target energy efficiency opportunities. This is a more complex undertaking, since interval data are not currently necessary to comply with current benchmarking and disclosure requirements.

Data that Should be Made Public for Better Retrofit Identification and M&V in China
In China, as discussed earlier, there are no public-access, web-based, retrofit analytical tools that can utilize data driven or normative approaches to quantify energy and cost savings potential for a building and specify ECMs. Given this, China could address the shortcomings of benchmarking and disclosure programs from two angles, and leapfrog the United States. First, it could develop new, web-based retrofit analytical tools to screen for energy and cost savings opportunities and identify ECMs. Ideally, the retrofit tool would use the fewest data points necessary to quantify and identify energy saving opportunities, which currently consist of monthly utility data, simple building characteristics (gross floor area, location, and building type), and weather data. One option that the U.S.-China CERC-BEE team is exploring is development of an open-source, online, public-access version of JCI's LEAN Energy Analytic Tool. LEAN draws on the ASHRAE Inverse Modeling Toolkit (Kissock, Haberl, and Claridge 2003). The tool regresses monthly energy usage versus ambient temperature; compares model coefficients to similar buildings to identify energy and cost-savings opportunities; and manipulates model coefficients to quantify energy and cost-saving potential (JCI 2016). In a study completed last year for U.S. DOE, LEAN provided Chinese building operators with the highest value, in terms of actionable information relative to the amount of input data required (Szum, Lisauskas, and Zhao 2016). Development of an open-source version of LEAN would mean the source code for the tool was published and available for modification and enhancements. Opportunities to apply the tool in the United States could also be evaluated. Linking to, or integrating, with ENERGY STAR Portfolio Manager would provide the simplest approach for building operators that are already utilizing the tool for benchmarking and disclosure requirements.

Data that Should be Collected and Made Public for Policy EM&V in the United States and China

The randomized control trial (RCT) is generally seen as the most accurate method of EM&V for a behaviour-based energy efficiency program. The RCT controls for free riders, and near-term participant spillover. Because market effects are essentially longer term spillover effects, they can be controlled in an RCT that spans more than a few years. In an RCT, a study population is defined first, then customers are randomly assigned to either a treatment group (participants in the benchmarking and disclosure program) or to a control group (nonparticipants). By randomly assigning individuals to either the treatment or control group, the influence of observable differences (building location, age, etc.) and unobservable differences (attitudes toward energy use, etc.) are eliminated. In an RCT, there are three methods for calculating net savings: (1) post-period comparison, which determines the differences in energy use between the control and treatment groups after participation in the program; (2) difference-in-differences (DiD) approach, which compares the change in energy use for the two groups between the pre- and post-participation periods; (3) linear fixed effects regression (LFER), where a regression model identifies the effects of the program by comparing pre-and post-program utility data for the treatment group to the utility data for the control group (Todd et al. 2012). At a minimum, all three methods require building size and monthly energy usage pre- and post-policy. The third method also requires number of occupants and thermostat settings. This suggests the potential for increasing the data made public to at least monthly energy usage (which is not made public now in U.S. and Chinese disclosure policies).

Conclusions

In recent years, municipal governments around the world have found that building energy performance benchmarking and disclosure policies can effectively overcome information gaps and asymmetries. Available data for select cities in the United States shows that energy savings per unit of floor space for these programs range between 6% and 8% over a two-year period (Pan et al. 2016, 10). However, policy shortcomings exist, and simple modifications could result in more comprehensive analysis of results, more cost-effective methods to identify and quantify energy savings opportunities and conduct EM&V, and greater standardization and automation. At a minimum, making monthly energy consumption data public, pre-and post-policy, (which is collected to utilize U.S. and Chinese benchmarking tools) would advance toward the above-mentioned objectives. Interval data should also be explored, although this is a more complex undertaking, since interval data are not necessary to comply with current benchmarking and disclosure requirements in the United States or China. Finally, to address the policy shortcomings from another direction, new retrofit and M&V tools should be developed to make better use of existing public data from benchmarking and disclosure programs.

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