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Center for Building Energy Research and Development (CBERD)

Building Energy Benchmarking in India: an Action Plan for Advancing the State-of-the-Art

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Table of contents

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1. Introduction

This document describes an action plan for advancing the state of the art of commercial building energy benchmarking in the Indian context. The document is primarily intended for two audiences: (a) Research and development (R&D) sponsors and researchers can use the action plan to frame, plan, prioritize and scope new energy benchmarking R&D in order to ensure that their research is market relevant; (b) Policy makers and program implementers engaged in the deployment of benchmarking and building efficiency rating programmes can use the action plan for policy formulation and enforcement.

This action plan was developed by the Centre for Building Energy Research and Development (CBERD), a joint effort between the Government of India Department of Science and Technology (DST) and the United States Department of Energy (DOE). Specifically, this action plan was developed under the Monitoring and Benchmarking (M&B) task in CBERD.

This action plan was developed based on input from three sources: benchmarking experts and industry feedback, literature review, and the expertise and experience of the M&B task team.

The scope of this action plan is limited to benchmarking R&D strategies and actions. The document also briefly describes deployment paths for each R&D strategy and action. However, it does not provide a detailed description of deployment strategies and actions and this document is not intended to comprehensively address deployment actions. While many of the R & D stratergies and actions will be executed by CBERD over the next few years, the action plan also includes recommendations that are beyond the intended scope of CBERD activities.

This document is organized as follows:

Section 2 describes a vision and high level goals for energy benchmarking in India.

Section 3 describes the current state of the art in India and compares it to global best practice.

Section 4 introduces three key strategies.

Sections 5-7 describe the three strategies and their related actions.

Section 8 describes the deployment channels.

The appendices include more details on the use cases and methodologies for benchmarking.

The reader does not have to read all sections in sequence. Those familiar with the benchmarking initiatives in India or interested in the actions alone may start directly with sections 4-7. Sections 3 & 8 may be read independently for those interested in more detail on those topics.

2. Vision and Goals

This Action Plan envisions the development of an integrated suite of methods, tools and practices for actionable energy information to spur energy efficient decisions in design and operation, rate energy efficiency, value energy efficiency in real estate transactions, create energy awareness and inform policy formulation and enforcement in commercial buildings. These methods, tools, and practices will be tested based on actual energy performance of buildings. Validation of these methods, tools, and practices using contextually appropriate data will lead to improved energy management analytics in commercial buildings.

This Action Plan also envisions that this integrated suite of methods, tools and practices are deeply embedded in market-facing deployment programs and policies. Toward that end, they should be:

- Contextually appropriate: considers technical features of buildings in India (e.g. design and operation, degree of space conditioning); business factors (e.g. Ownership, tenancy and operation practices); policy environment; geography (e.g. climate); and culture.

- Market relevant: considers interpretation and ease of use for end users (e.g. documentation, transparency, customizability); and commercial benefits (e.g. means to claim incentives, recognition and credibility). R&D results will be public domain and widely disseminared to stakeholders.

- Technically appropriate: the underlying approach should be technically defensible, accurate, and rigorous.

We propose the following R&D goals to measure progress towards this vision:

1. Develop peer-reviewed and validated whole building, asset, operational and system level benchmarking tools and techniques applicable to buildings which have a connected load of more than 50 kW.

2. Incorporate these tools and techniques in deployment programs and policies.

We anticipate a complementary set of goals for benchmarking deployment, which is beyond the scope of this document.

3. Current State of the Art in India

The performance rating of commercial buildings in India was started by Bureau of Energy Efficiency, Ministry of Power, Government of India in 2009 for offices and IT buildings.

The USAID funded ECO-III project expanded the building types to include hotels and hospitals. The project provided methodological improvements to the evaluation process along with a web-based tool in 2011. Thus far, the benchmarking and performance evaluation efforts in India have been limited to whole building level.

3.1. BEE Star Rating Program

The Bureau of Energy Efficiency (BEE) was established on 1st March 2002, under the provisions of Energy Conservation Act, 2001. It launched the Building Star Rating Program for office buildings in 2009. This program rates energy performance of commercial buildings on 1-5 star scale (Figure 1) with the 5 star label buildings being the most efficient**.** The program targets office and IT intensive buildings. To date, 108 day-use office buildings and 17 IT buildings have been awarded performance labels under this program.

The star labeling scheme was devised based on data from around 300 office buildings in three climatic zones namely warm & humid, composite and hot & dry. Energy Performance Index (EPI) in kWh / m^2 / year is used as the key performance indicator. The EPI calculations are based on site energy and include electricity purchased from the utility as well as that generated on site through diesel and gas based generators. A look-up table (Table 1) around the EPI is used for calculating the Star Rating for office buildings. Separate tables are available for different climatic zones and percent of conditioned area in the building. EPI is further normalized by the hours of operations (kWh/hr/ m^2) for IT buildings. More details about the program can be found at http://www.bee-india.nic.in

Air conditioned area > 50% built up		**Air conditioned area < 50% built up**	
Climate zone : Composite			
EPI (kWh/m^2/yr.)	**Star Label**	**EPI (kWh/m^2/yr.)**	**Star Label**
190 -165	1 Star	80 - 70	1 Star
165 – 140	2 Star	70 - 60	2 Star
140 – 115	3 Star	60 - 50	3 Star
115 – 90	4 Star	50 - 40	4 Star
Below 90	5 Star	Below 40	5 Star

Table 1: Example of a look up table - A building with an EPI of 125 kWh / m^2 / year in composite climate zone with air conditioned area of more than 50% of built up will qualify for a 3 Star label.

Figure 1: Typical energy performance label

3.2. Energy Conservation and Commercialization (ECO)–III efforts

The USAID funded ECO-III project started operations in October 2006 with an overall focus on improving energy efficiency in the building sector. It worked on advancing BEE's star labeling program to account for location, physical and operational characteristics of the building using a statistical approach in a transparent and rigorous way for offices, hotels and hospitals. The methodology provided a versatile and extensible system to rate a building.

The analysis [Sarraf et al, 2011a] was based on survey of around 900 offices, hotels and hospitals across the country. Regression analysis was used to establish the benchmarks and peer comparison was done through a distribution based comparison [Kumar et al, 2010]. A publically available web based tool was developed to calculate the EPI, energy consumption of the benchmarked building, a measure of building performance, and the final performance rating (Figure 2). The tool helps to establish a baseline for a building, track performance, and estimate savings potential among a portfolio of buildings. The analysis and methodology is documented at http://eco3.org/benchmarking

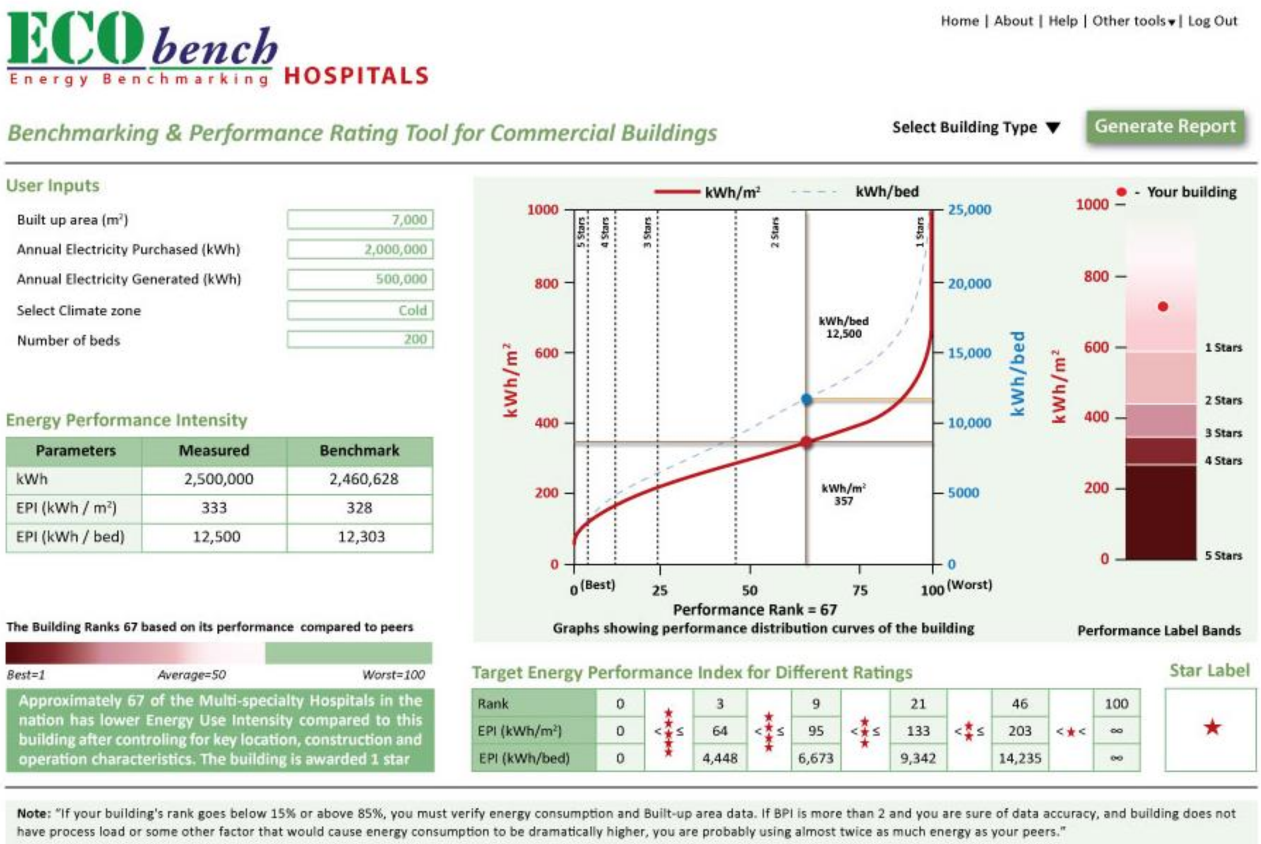


Figure 2: Screenshot of web-based tool to evaluate the performance of a building [Sarraf et al, 2011b].

4. Key Strategies

Energy benchmarking has a wide range of applications. A comprehensive benchmarking R&D program requires coordinated and complementary responses to benchmarking needs across different use cases (See Appendix for a summary of use cases). The space of benchmarking in terms of the scale of operation (from portfolio of buildings to individual components like a ventilation fan) and the level of accuracy required at different levels is conceptually depicted in Figure 3 below.

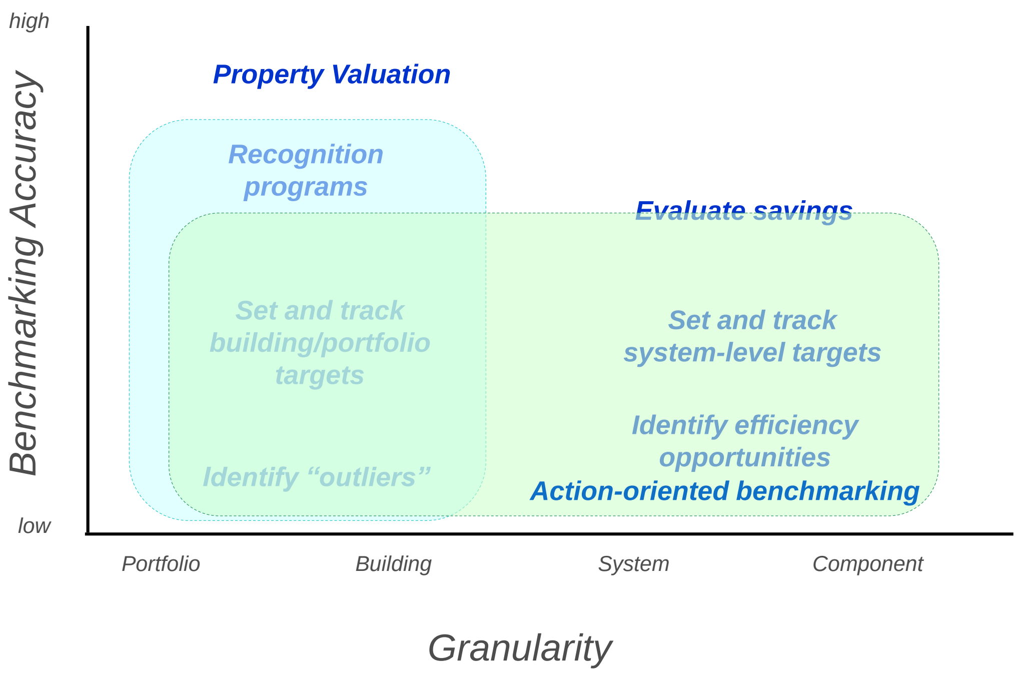


Figure 3: The space of benchmarking activities (Mathew 2009)

It is also important to recognize that energy benchmarking is not an end in itself and the level of effort for data collection, accuracy, analysis should be commensurate with the value of results for any given application i.e. to support energy-related decision-making. To be effective, benchmarking has to be integrated within a larger energy management system (EnMS) and process, which entails goal-setting, measurement, retrofits, and continuous improvement, such as the Plan-Do-Check-Act approach advocated by ISO 50001.

The specific implementation of the EnMS will vary based on organizational goals, building type and size, metering constraints, personnel skill and resources. To accommodate diverse application, we recommend using a Graduated Approach to benchmarking, as developed by the Usable Buildings Trust. This approach suggests that the benchmarking process should start off simple and build in complexity over time, in each level adding more detail, providing more information and superseding the level below. **For example, a three-**level approach might be structured as follows:

- Level 1: An easy entry level is proposed for the cases where detailed information is hard to get or may be less rewarding.
- Level 2: More detailed assessment is suggested where the need & scope for improvement is greater.

- Level 3: System level, more robust & intricate assessment is suggested where the detailed information is monitored and assessed.

The benefits of this approach are [Bosteels et al, 2010]:

- Graduated response makes assessment at different levels mutually consistent.
- Due to gradual increase in complexity, cases where the level of information is simple or not available are also applicable for benchmarking.
- All the cases where the need and scope for improvement is greater can be brought under the same framework.
- Graduated response allows any amendment to suit the knowledge available for each building sector.

The inherent flexibility within this approach guides users on where best to focus effective changes in behavior and performance of the building. It enables existing data and data collection mechanisms to be utilized in their initial format while improvements in the scope and quality of data can be done over time.

Three key strategies have been identified to respond to the diverse needs of benchmarking in the Indian context.

Strategy 1: Expand and improve whole building benchmarking

This strategy would provide benchmarks and evaluate energy performance at the whole building level. In addition to advancing the current work in this area in the Indian context, this strategy will focus on developing a graduated approach to benchmarking where users with varying needs and amount of information will be able to benchmark their buildings.

Strategy 2: Develop building asset & operational benchmarking

The asset and operation benchmarking approach decomposes the whole building performance information into its asset[1] and operational performance. Such decomposition helps to evaluate the building asset independent of how it is being operated and also ascertain how well the building is being operated given a particular asset quality. It allows evaluating, comparing, rating and incentivizing the building's assets and operations; identify retrofit and maintenance needs, perform asset management tasks, and assess demand response potential. In addition, it provides credible valuations for energy efficiency in real estate transactions and financing, leading to market transformation (ABEL, 2009). It can also help in becoming the basis for the implementation of ECBC and in supporting green building rating programs.

Strategy 3: Establish system level metrics & benchmarks

System level "Action-oriented" benchmarking extends generalized whole-building energy benchmarking to include analysis of system and component energy use metrics and features (physical and operational characteristics such as lamp type, cooling type). System level benchmark allows users to identify, screen and prioritize potential efficiency opportunities, which in turn can be

[1] Asset performance in this context refers to the energy efficiency characteristics of a building's physical assets, such as envelope, HVAC equipment, and lighting fixtures under standard operating conditions.

used to inform and optimize a full-scale audit or commissioning process (see figure 1) [Mathew et al. 2008].

These strategies are described in detail in sections 5, 6 and 7.

5. Strategy 1: Expand and Improve Whole Building Benchmarking

5.1. Overview & Purpose

Whole building benchmarking is fairly well established as a technique and method across the globe. In India, BEE provides performance labels using its own benchmarking program. As noted in the previous section, ECO-III was seminal in advancing the state of the art in India and several methodological improvements were suggested under the ECO-III project. The first of the three strategies is to build on the success of BEE and ECO-III, by expanding and improving the whole building benchmarking methodology. In this section, we present the known gaps and opportunities (Sarraf et al, 2011b) to further advance whole building benchmarking, and suggest key actions needed to address them.

5.2. Summary of R&D Opportunities

Methodology

- The benchmarks may be cognizant of more building and operation related parameters.
- The uncertainty around the benchmarked value may be quantified.
- Buildings with more detailed data may obtain more accurate benchmarks using the same methodology.
- The impact of correlated variables like area and use intensity maybe robustly estimated.
- The impact of climate is often not very significant and may be further explored.
- Current methodology is only sensitive to parameters with high variability like occupancy levels and schedules. The impact of 'level of service', indoor environment quality and available amenities on benchmarks may be explored
- The methodology may be extended to rate multi-use buildings.
- Instead of proposing only floor area for normalizing, there should be the option of choosing other normalizing parameters without any additional effort.

Building Data Collection.

- Data is available for only few building types namely offices, hotels and hospitals. Data collection can be expanded to other building types.
- Clearer definitions for key variables such as area and occupancy may be defined.
- Schedules and occupancy may be more comprehensively captured in data collection.
- Selection criteria for building types and subtypes used for model estimation and program implementation may be specified.
- Additional critical variables shall be such as data centers and heated swimming pools may be added in data collection forms.
- The data collection efforts should be representative of the building type or geographical coverage.
- There is a need to collect data and develop metrics that are more closely aligned with the core functions and productivity of an organization (e.g. meals in restaurants, guests in hotel, patients in hospitals etc.).

5.3. Actions

5.3.1. Add more building types

The benchmarking and performance labeling methodology is specific to building use types and sub-types (Table 2). It is important to establish categories in order to enable comparison between buildings with similar characteristics. There is a need to expand the current building types to include more diverse uses and have specific information about sub-types within each of these types.

		Office	Hospital	Hotels	Retail
Included sub-types	**Use**	Administrative/professional office	One Specialty	Resort / Heritage	Single store
		Bank/other financial	Multi specialty	Business	Mall
		Government office			
		Other office			
		Software Development			
		Assorted/Multi-tenant			
	Users	single organization			
		multi organization			
	Level of service	Class A	NABH accreditation	5 star	
		Class B		4 star	
		Class C		3 star	
				1 and 2 star	
	Ownership	Owned	Government	Owned	Owned
		Leased	Private	Leased	Leased
	Operator	Single	Single		Single
		Multiple	Multiple		Multiple
Inclusion criteria			In patient		
Excluded sub-types			Clinics		Strip Malls
Special use		Data centers / MSC	Cafeteria	In house laundry	Refrigeration
			In house laundry	Restaurant	Electronics
				Heated swimming pool	Multiplex
				Conference facility	Restaurants

Table 2

Table 2: Matrix of Building Types and Subtypes

5.3.2. Collect more data

The validity of data collection process directly impacts the integrity and usefulness of the benchmarking system's results [ASTM E2797, 2011]. Hence, it is important that data collection process should be well documented, accurate and reliable. Actions are needed to ensure availability of representative data set with reasonable accuracy based on a graduated approach. At the same time, it may be useful to create large composite datasets using information from multiple like utilities, municipal corporations and other local bodies, business associations, to create a comprehensive understanding of the building sector.

5.3.3. Improve Methodology

The existing method compares the whole building energy consumption of the building under consideration with a benchmark building of similar characteristics. There is a need to improve the existing methodology to accommodate the new requirements in the Whole building benchmarking program as listed below:

- **Augmenting the statistical labels with a technical scale.**
  A statistical rating scale rates a building in comparison to its peers, whereas a technical rating scale compares a building's energy performance to technical potential reference points, such as net zero energy performance. [DOER, 2010] This provides ways to identify areas of potential intervention and thus increase the relevance of rating.

- **Integration with other tools, codes, rating schemes (ECBC, LEED, GRIHA)**
  What one does with the benchmarks is equally important as the benchmarking and labeling process itself. One of the key ends of this process is the integration of benchmarks and labels with building codes, other intent-based rating tools, and simulation-based tools. Benchmarking methodology should be developed in a manner that allows for better integration with codes and intent-based rating systems. Integration with other tools helps to reduce the credibility gap between design intent and the actual performance.

- **Exploring alternate approaches**
  Alternate benchmarking approaches should be explored like point based rating, raw data visualization method (EPI), Regression & Distribution based statistical method, simulation & model based approaches, Hierarchical end use metrics, and nested regression models..

- **Subtypes treatment and Special use adjustment**
  A methodology should identify a way to deal with the special uses in the various building types. Issues pertaining to building subtypes and the level of services are the other two concerns which should be significantly resolved.

- **Quantifying and expressing uncertainty in benchmarks**
  Benchmarks have different levels of accuracy and it is important to understand the confidence bands around these values. The methodology should allow estimation of benchmarks using limited or detailed information about the facility together with associated uncertainty. Typically, a building with more information about its physical and operational characteristics will have more accurate benchmarks compared to another building with less information. This quantification of uncertainly may not be very useful for policy implementation, but may have significant meaning if subsequent actions are being planned based on the benchmark values.

- **Data quality & Missing data**
  Develop protocols to ensure that data is consistent, accurate, replicable, verifiable and comparable, and gathered over a sufficient period of time.

6. Strategy 2: Develop Building Asset and Operational Benchmarking

6.1. Overview and Purpose

A building's energy performance depends on how the building is designed and constructed (asset characteristics), and the way it is operated (operational characteristics). Assets determine how good are the building's design, materials, construction, equipment, and systems in terms of their potential to save energy. Operations determine how well the building is being used, operated and maintained.

The asset and operation benchmarking approach decomposes the whole building performance information into its asset and operational performance. Such decomposition helps to evaluate the building asset independent of how it is being operated and ascertain how well the building is being operated, given a particular asset quality.

The asset benchmark evaluates the potential performance of building's installed components that remain constant or are unaltered over a longer period. These components include Envelope (roof, wall, openings, shading), artificial lighting system, heating, cooling and air distribution systems, and service hot water. The operations component deals with factors that govern how the building is being used and operated. These factors include operation schedules, maintenance policies, occupants' behavior, and plug loads.

Benefits

The asset and operation benchmarks may help to: [ABEL, 2009]

- Evaluate, compare, rate and incentivize the building's assets and operations.
- Track the asset and operation performance of buildings and portfolios over time to monitor performance, identify retrofit and maintenance needs, perform asset management tasks, and assess demand response potential.
- Provide credible valuations for energy efficiency in real estate transactions, financing, leading to market transformation.
- Create national standards for asset and operations benchmarks that can become basis for implementation of ECBC, green building rating programs and support performance based contracts.
- Create foundation for energy disclosure regulations.

The asset and operations benchmarks are useful to designers, owners, operators, facility managers, investors and financial agencies, and occupants. They are also useful to utilities and government agencies at different levels in policy formulation and enforcement.

6.2. Examples of Asset and Operation benchmarks

Asset and Operations benchmarks have been in use in the US (Figure 4), Europe, China, and Australia. The European Union's asset rating tool is implemented across several member countries [BPIE 2010] to support the Energy Performance Building Directive (2002). Table 3 [Leipziger, 2013] lists some of the asset and operation rating benchmarks worldwide.

Australia	Canada	China	E.U	U.S
NABERS Nat HERS ACT hers	CRESNET E-Scale	MOHURD	Germany : Energieausweis France : DPE (Diagnostic de performance énergetique) UK : EPC (Energy Performance Certificate)	HERS Massachusetts BEAL : Building Energy Asset Labeling, DOE Commercial Building Energy Rating Tool California Commercial Building Energy Asset Rating System BEARS

Table 3: Examples of Asset and Operational Rating across the world (Leipziger, 2013)

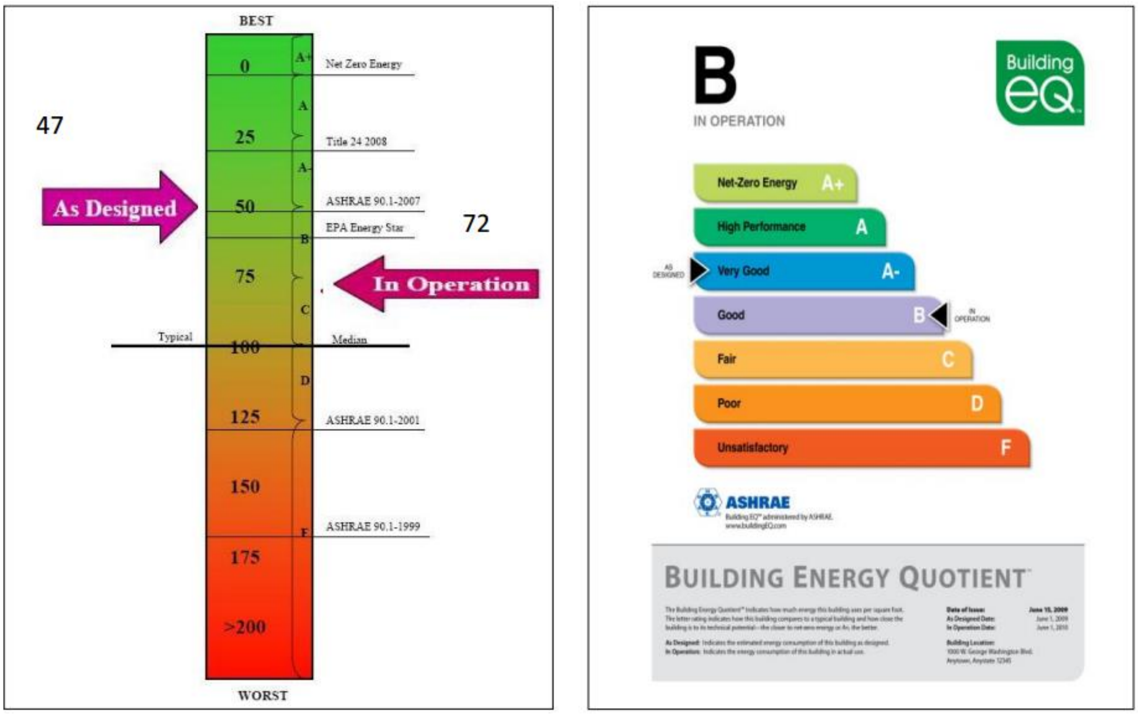


Figure 4: Example of Asset Rating by ASHRAE: Building Energy Quotient

6.3. Summary of R&D Gaps

There exist several gaps in current state of asset and operation benchmarking globally:

1. **The concept of operations benchmark**: The implementations in Europe, the USA and elsewhere have used the word 'operational benchmarking' synonymously with 'whole building benchmarking'. This Action Plan proposes to use 'operations benchmarking' along with 'asset benchmarking ' as the two components of the whole building benchmarking. The operation benchmarking will solely look at the issues of the way the building is being operated, given a fixed asset quality. This will be useful to help monitor the operational performance once the asset has been established as is the case with most buildings in use.

2. **Definition of asset and operation components**: The asset and operation components may vary from case to case especially during a real estate transaction. The assets may be seen as what will be retained after the new owner occupies a facility and may vary from case to case. Thus the definition of assets and operation components may be kept flexible enough to work with a 'kit of components' approach.
3. **Reconciling gaps between asset, operation and whole building benchmarks**: The difference of benchmarks between asset and operation are often difficult to explain and are found to be confusing to users [ABEL, 2009]. These differences could be attributed to one of the many factors (related to the building or an artifact of assumption, model, etc.). Though we use the term 'operation benchmarking' differently from the current practice, we will still have to reconcile the asset and operation benchmarks to the whole building benchmark.
4. **Need of appropriate modeling framework**: A robust modeling framework needs to be developed cognizant of the Indian building industry practices and data availability. Grounds for making tradeoffs among accuracy, scalability and resources required for arriving at meaningful benchmarks in the Indian context needs to be developed.
5. **Knowledge about the key factors:** key factors affecting the asset and operation benchmarks in the Indian context should be determined. Cost-effective and innovative methods of data collection for these factors shall be developed.
6. **Lack of a standardized national level framework for data collection and modeling for policy implementation**: there are no national level framework for evaluating asset and operation performance of buildings with standard definitions of asset and operation components, choice of rating scale, methodology, and data collection template. This information is important from a policy implementation perspective, especially for implementation of design based codes, to determine trade-offs between rigor and ease of adoption. The R&D gap lies in generating knowledge to make these tradeoffs transparently and efficiently. .

6.4. Actions

6.4.1. Design framework for asset and operation benchmarks

Formulate the technical design of asset and operation benchmarking to address the R&D gaps

- Provide clear definitions of the asset and operation components of the building that affect energy consumption. The modeling framework should provide enhanced feature to define assets and operations as a flexible basket of components depending on the user's need.
- Build on the international experience along with the needs of various stakeholders (including industry, government, and rating agencies) in the Indian context.
- Create a robust, intuitive, credible and scalable framework for applicability across building types.
- Develop a cost effective framework with agreeable tradeoffs between cost of benchmarking and accuracy.
- Formulate output tailored to use cases.
- Create standardized framework for implementation of national level policies such as ECBC and inform initiatives such as LEED-India and GRIHA through asset and operation benchmarking.

6.4.2. Explore and develop appropriate methodology

Develop a methodology to create asset and operations benchmark models to

- Address the issues of technical design involving the definitions of asset and operation components, reconciling the gaps between asset, operation and whole building benchmarking, and the understanding of key parameters from technical, market and policy perspectives.
- Create model structure that can be calibrated using detailed data from varied sources (survey, sub-metered, parametric-synthetic, and simulated) but is implemented using readily available data (data collected by walk-in audits or EIS, if installed) and has low cost of benchmarking and verification.
- Provide intuitive interpretation of the asset and operation for ease of implementation and linkages to the whole building benchmarking.
- Choose methodology after comparative analysis of applicable methods - Statistical, Simulation model based, Hybrid, based on data needs, simplicity of application and understanding, and industry adoption. Developing benchmarking methods based on statistical methods works best if the system level data is available (which is rarely the case). However, it is one of the simplest and the most cost effective implementation methodologies. Simulation based method provides a more granular understanding of the performance of various asset and operation components but which are difficult to calibrate to actual conditions and need a higher skill set to implement. A third alternative is a hybrid approach of using statistical and simulation based strategies in combination with technical or expert opinion in consideration with data availability, available skill set and ease of implementation.

6.4.3. Create data collection template and protocols

Create standardized data collection templates to support model calibration and end-user benchmarking activities. This will involve

- Identifying key parameters that affect asset and operation benchmarks.
- Creating standardized data collection template for different asset and operation components
- Using graduated approach for data collection with mandatory and 'good to have' parameters based on sensitivity analysis.
- Developing ways to collect data which has high impact on benchmark results but are difficult to collect.
- Developing innovative ways to collect data on parameters which are important but difficult or expensive to collect [Crowe et al, 2012].
- Finally, develop a data collection template based on the tradeoffs between data availability, cost and impact on benchmarking.

7. Strategy 3: Establish System Level Metrics and Benchmarks

7.1. Overview and purpose of system level benchmarking

System level "Action-oriented" benchmarking extends generalized whole-building energy benchmarking to include analysis of system and component energy use metrics and features (physical and operational characteristics such lamp type, and cooling type). Such benchmarking allows users to identify, screen and prioritize potential efficiency opportunities, which in turn can be used to inform and optimize a full-scale audit or commissioning process (see Figure 5) [Mathew et al. 2008].

Action-oriented benchmarking extends traditional whole-building benchmarking in the following ways:

- End use benchmarking: shows the energy intensities and savings opportunities within each end use (e.g. annual lighting energy use in kWh/m^2/yr, ventilation airflow efficiency W/litres/sec) and its priority relative to other end uses.
- Features benchmarking: identifies the efficiency characteristics of specific systems (e.g. cooling type), components (e.g. pump type), and operational conditions (e.g. chilled water temperature reset).
- Correlating features with end-use energy intensities, which can help assess the approximate savings potential from specific actions.

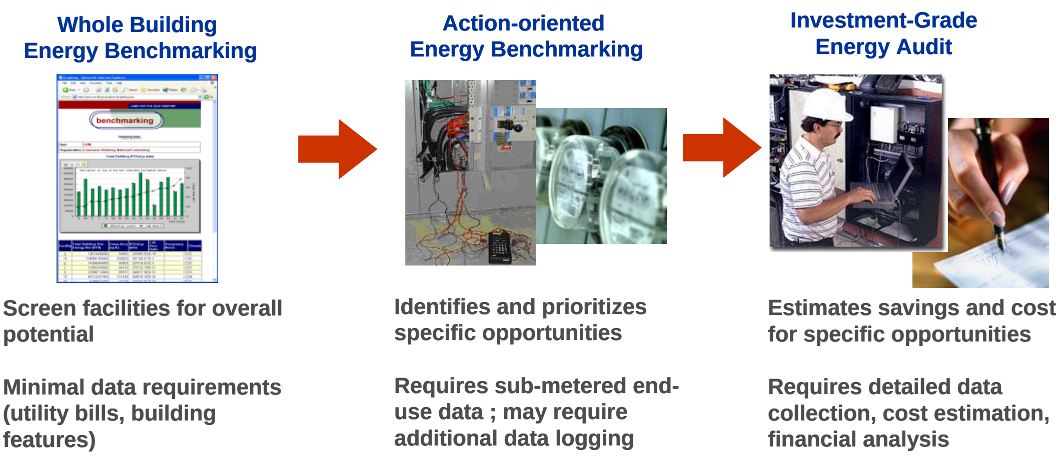


Figure 5 Action oriented benchmarking [Mills et al.2008]

The choice of metric itself often dictates the actions identified and thus care should be taken to use appropriate metrics. User-defined filters such as location or building type can make the results more actionable and context-relevant. It should be noted that action-oriented benchmarking is not an "audit in a box" and is not intended to provide the same degree of accuracy afforded by an energy audit. However, selected system level metrics can be used to focus and prioritize audit and upgrade activity and track performance at the system level. They may also be used in new construction to track efficiency over the course of the design-build-commission process.

7.2. Examples of system level benchmarking

End-use energy benchmarking shows the overall potential for reductions in energy intensity within each end use and its priority relative to other end uses. The Carbon Trust in the UK [Action Energy 2003] has demonstrated the application of end-use benchmarking to identify efficiency opportunities in office buildings in the United Kingdom. Figure 6 shows the range of energy intensities for various end-uses in large office buildings in the California Commercial End Use Survey (CEUS) data set. All end-uses show a wide range. Lighting has the highest median value, followed by cooling, office equipment, and ventilation. Users can plot their building's end use to identify and prioritize which end uses offer the greatest opportunity for savings.

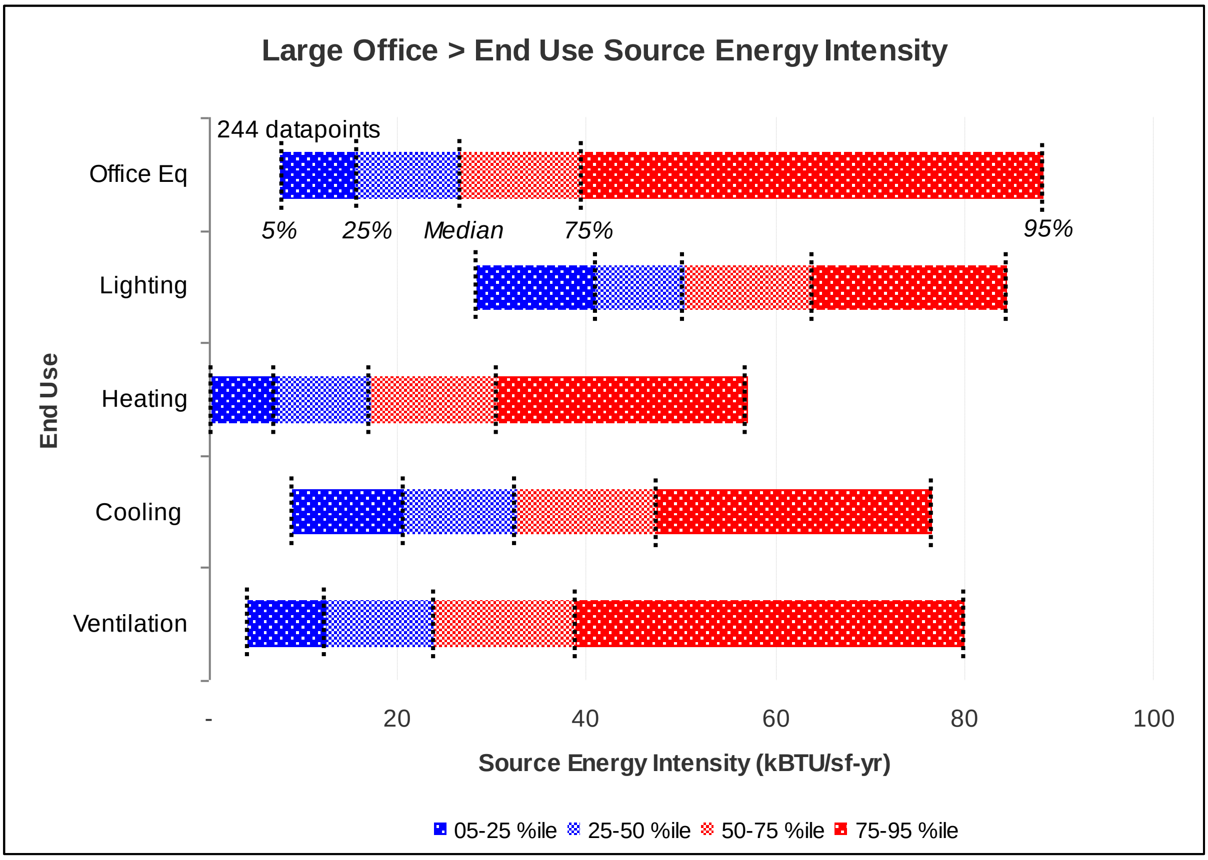


Figure 6. End use energy intensity for large office buildings in California. Source energy for electricity counted at 10.28 kBtu/kWh

Statistical distributions of these features allow users to "benchmark" the presence or absence of energy efficiency features in their building, relative to the prevalence of these features in the peer dataset. For example, Figure 7 shows the prevalence of different types of temperature controls for schools and large office buildings. While energy management systems (EMS) are very dominant in large office buildings, there is a wider range of system types in schools, with only about 24% having EMS.

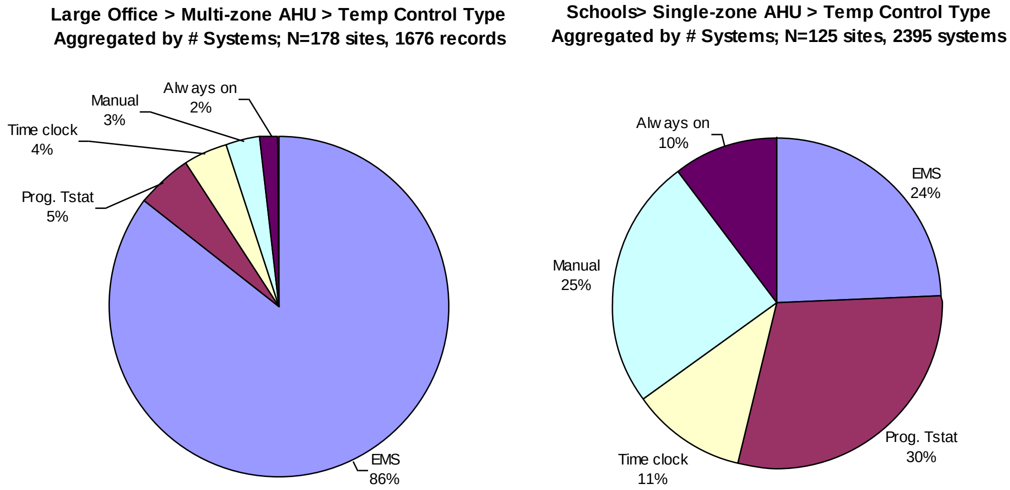


Figure 7 Prevalence of different types of temperature controls for schools and large office buildings

Component and system efficiencies such as HVAC power density [Kavanaugh et al. 2006] are another form of features-based benchmarking. LBNL has developed action-oriented benchmarking guidelines for laboratories, cleanrooms and data centers [LBNL 2009]. For each of these metrics, the guideline defines performance benchmarks and efficiency actions that can be inferred from them. The guidelines for laboratories include 27 system-level metrics. For example, Ventilation system W/cfm is defined as the total power of supply and exhaust fans divided by the total flow of the supply and exhaust fans in cfm. It provides an overall measure of how efficiently air is moved through the laboratory, from inlet to exhaust, and takes into account low pressure drop design as well as fan system efficiency (motors, belts, drives). Figure 8 shows the range of ventilation system efficiency at peak loads for various laboratories in the Labs21 benchmarking database, along with benchmark values for different levels of efficiency. There is a wide range of efficiencies, from 0.3 W/cfm to 1.9 W/cfm [Mathew et al. 2010].

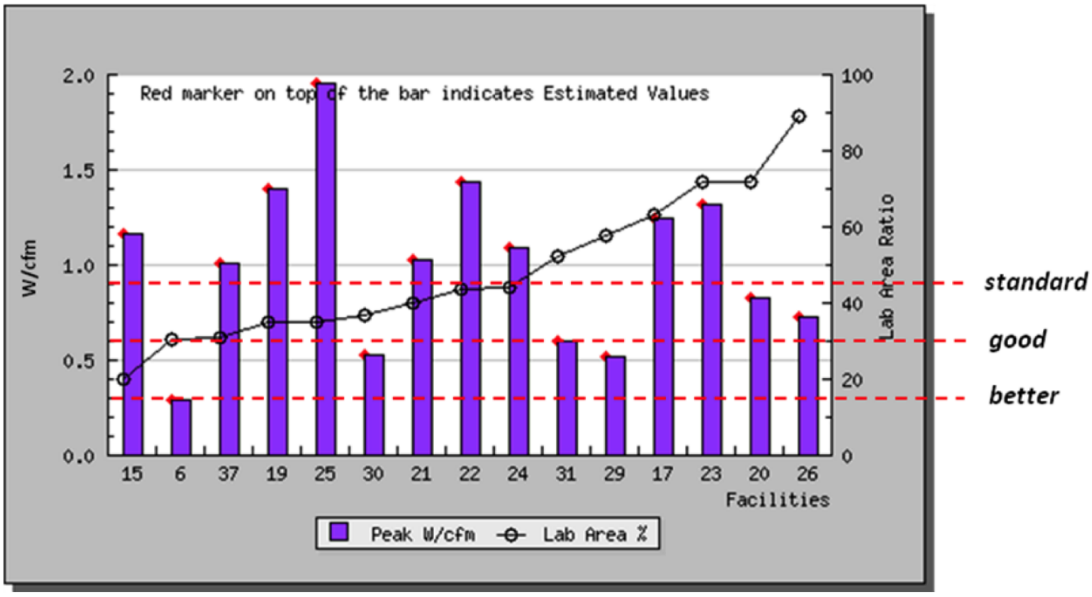


Figure 8 Ventilation W/cfm data from the Labs21 benchmarking database. Benchmarks for standard, good and better practice are based on Labs21 [2007]

7.3. Summary of R&D gaps

1. Lack of standard lists of benchmarking metrics. While there have been several efforts to define key metrics for efficiency for specific projects, there do not yet exist standard "go-to" lists of system benchmarking metrics for different building types and contexts across the commercial sector. Similar to what LBNL developed for labs, cleanrooms and data centers, we need to develop a standard set of metrics for other segments, especially for small office buildings, quick service restaurants, large retail. Furthermore, we need to develop standard definitions for each metric, and how to interpret those definitions for different system configurations and metering options e.g. ventilation system efficiency for distributed packaged units vs. central air handlers.

2. Lack of normative benchmarks. In addition to the metrics themselves, we also need to define normative benchmarks for each of these metrics in order to evaluate and interpret the level of efficiency. For example, standard, good, and better practice benchmarks for ventilation W/cfm. Normative benchmarks may need to be adjusted based on key drivers such as climate, building type, hours of operation, etc.

3. Lack of robust and replicable logic models for inferring efficiency actions from system level benchmarks. The core purpose of system level benchmarking is to identify potential efficiency opportunities. To date, this has mostly been done implicitly or with expert input. To scale the use of action-oriented benchmarking, it is necessary to develop logic models that can "interpret" the benchmarks and identify potential efficiency actions.

4. Lack of empirical data. There is a significant paucity of system level measured data for setting normative benchmarks. While many large and medium size buildings now have energy management and control systems (EMCS), there are still many challenges to using EMCS data for computing system level benchmarking metrics. Sometimes EMCS are not even be configured to store data. In other cases, they may be missing certain key data needed for calculating metrics. Even when data are available, it takes a significant and concerted effort to collect, cleanse and compile these data into a dataset that is broadly usable for benchmarking. Data collection should also consider the use of proxy metrics when primary metrics are cost-prohibitive. A related gap is the lack of standard specifications for Energy Information Systems (EIS). Standard EIS specifications can help expand the data collection across many buildings in a consistent manner.

7.4. Actions

7.4.1. Identify and prioritize system level metrics

The applicability and priority of benchmarking metrics will vary by building type, size, and other factors. Accordingly, prioritized lists of metrics should be developed for each market segment.

- We recommend initial segmentation based on type and size, although additional segmentation may be required in some cases (e.g. based on ownership and tenancy).

- For each market segment, determine the major end uses based on empirical data, expert opinion, or simulation analysis. A segmented approach allows for incremental build-up of a suite of metrics.

- Determine and prioritize metrics for each end use based on relevance for identifying actions and ease of measurement. It is important to develop a graduated list that allows for different levels of analysis. E.g. “top 3” metrics, 5-10 metrics, and up to 20 metrics. The key here is to strike a balance between level of effort and value of decision-grade information. (See appendix for a draft list of technical metrics.)

7.4.2. Explore, develop appropriate methodology & model to benchmark & infer actions

There are various approaches to benchmarking. But generally, the normative benchmarks will be set in one or more of the following ways:

- *Simple statistical distributions.* For certain metrics, a simple statistical comparison to other buildings can provide a basis for benchmarking. For example, Figure 9 shows the range of plug loads measured in various laboratories on a university campus.
- *Regression models.* In this approach, a multiple regression on a database yields an equation that relates relevant building characteristics to the metric of interest. This approach is used in EnergyStar™, and works well provided there is a large enough representative dataset to run a regression.
- *Simulation-based models.* In this approach, a simulation model is used to calculate a benchmark (typically representing an “ideal” case) against which the actual energy use can be compared. The model accounts for the relevant building characteristics. For example, Labs21 has developed a simulation-based approach to assess the overall efficiency potential for a laboratory building using energy effectiveness ratio (EER). EER essentially compares facility energy use to an “ideal” efficient energy use derived from a simulation model.
- *Engineering standards and practices.* For many system and component level metrics, benchmarks can be set based on engineering standards and best practices. For example, Labs21 developed a set of benchmarks for low-pressure drop design in laboratory HVAC systems (Table 4) [Labs21 2007].

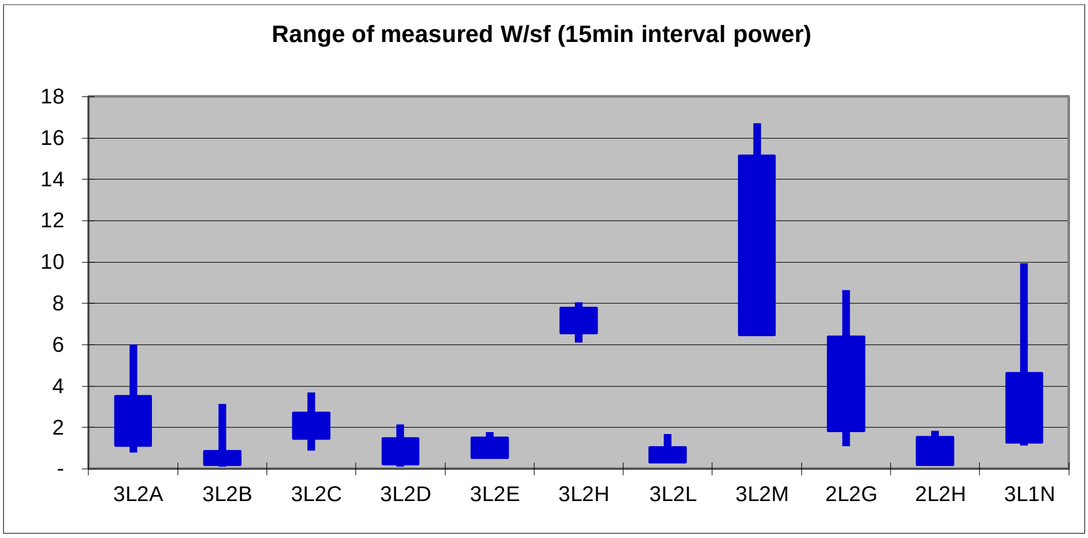


Figure 9 Range of measured 15-min interval power for various laboratory spaces in a building at UC Davis. The upper and lower ends of the lines represent maximum and minimum respectively. The upper and lower ends of the boxes represent 99th and 1st percentiles of the measurements respectively.

Component	Standard	Good	Better
Air Handler face velocity	500	400	300
Air handler pressure drop	2.7 in w.g	1.7 in w.g.	1.00 in w.g
Energy Recovery device pressure drop	1.00 in w.g	0.60 in w.g	0.35 in w.g
VAV control devices pressure drop	Constant Volume, N/A	0.60 – 0.30 in w.g	0.10 in w.g
Zone temperature control coils pressure drop	0.42 in w.g	0.20 in w.g	0.00 in w.g
Total supply and exhaust ductwork pressure drop	4.5 in w.g	2.25 in w.g	1.1 in w.g
Exhaust stack pressure drop	0.7 in w.g full design flow through entire exhaust system, CV	0.7 IN w.g full design flow through fan and stack only, VAV system with bypass	0.75 in w.g averaging half the design flow, VAV system with multiple stacks
Noise control (silencers)[1]	1.0 in w.g	0.25 in w.g	0.0 in w.g
Total	10.32 in w.g	6.15 in w.g	3.3 in w.g
Approximate fan power requirement (W/cfm)[2]	2.0	1.2	0.6

1 Good Practice corresponds to the use of low –pressure drop sound attenuators. Better practice corresponds to eliminating the need for sound attenuators by appropriate duct design and layout.

2 To convert pressure drop values into the commonly used metric of W/cfm, these assumptions were used in the fan power equation: 0.62 fan system efficiency (70% efficient fan, 90% efficient motor, 98% efficient drive)

Table 4 Benchmarks for component pressure drops in laboratories, based on engineering standards & practices.[Labs21 2007]

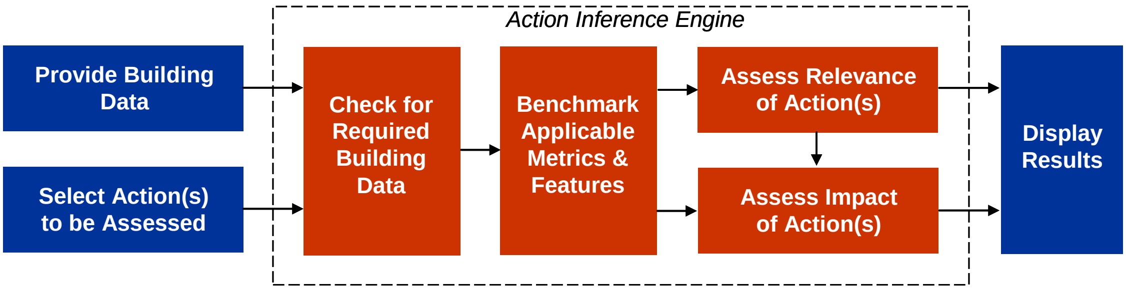
The approach used will be different for each benchmarking metric, based on factors such as data availability and methodological appropriateness. It is anticipated that most of the system and component level metrics will initially be based on a combination of engineering standards and practices, as well as simple statistical distributions where data is available. But there should be an on-going effort to collect measured data so that we can develop robust empirically-based benchmarks. Each of the above approaches has strengths and limitations, and hybrid approaches that combine these may also be a viable option. For example, simulation-based data may be used to "fill-in" data gaps in statistical distributions derived from empirical data.

7.4.3. Inferring actions from benchmark data

The core value of system level benchmarking is that it can be used to provide guidance on energy efficiency actions. Of course, such guidance cannot be specific enough to substitute for a full energy audit. Rather, the approach is to work from a predefined list of actions, and then assess the relevance and impact of each of these actions for the given building using benchmarking-level data:

- "Relevance" in this context simply indicates how likely the action is to be applicable to the building being benchmarked. It is largely determined by the presence or absence of a relevant features. For example, the relevance of the action "Install EMS lighting controls" would be relevant if the building currently has only manual controls.
- "Impact" indicates the effect of this action in reducing overall energy use. Note that an action with high relevance may not necessarily have high impact. For example, in a laboratory building with standard fluorescent lamps, switching to energy efficient lamps may have a high relevance, but a low impact because lighting is a small percentage of total energy use.

The degree of specificity in assessing relevance and impact for each action is a function of the depth and detail of the database and availability of data for the individual building being benchmarked. For example, in the *EnergyIQ* tool, both relevance and impact are rated in qualitative terms (e.g. high, medium, low). Figure 10 provides illustrative examples of the criteria for determining the relevance and impact of selected actions in *EnergyIQ,* using applicable metrics and features. Additionally, the tool will indicate the typical cost-effectiveness of each action i.e. based on current practice, but not specifically for the given building [Mathew et al. 2008].



	Assessment Criteria	
Actions	**Relevance of Action**	**Impact of Action**
Install efficient lamps	Benchmark *Installed W/sf* and calc percentile; If > 50% : High If < 50%, > 25% : Medium If < 25%, > 5% : Low If < 5% : N/A	Calc ratio of *Lighting Source EI* to *Total Source EI* If >= 0.3 : Same as Relevance If < 0.3, >= 0.1 : One level lower than Relevance If < 0.1 : Low
Install efficient ballasts	Benchmark *Ballast Type* : If 'Magnetic' : High If Std electronic, high eff magnetic : Medium If Adv electronic : Low	Calc ratio of *Lighting Source EI* to *Total Source EI* If >= 0.5 : Same as Relevance If < 0.5, >= 0.3 : One level lower than Relevance If < 0.3 : Low
Improve fan efficiency	Benchmark *Installed hp/cfm* and calc percentile; If > 50% : High If < 50%, > 25% : Medium If < 25%, > 5% : Low If < 5% : N/A	Calc ratio of *Vent Source EI* to *Total Source EI* If >= 0.3 : Same as Relevance If < 0.3, >= 0.1 : One level lower than Relevance If < 0.1 : Low

Figure 10 Conceptual illustration of action inference mechanism (top), with illustrative examples of how benchmarking metrics and features are used to qualitatively rate ("high-medium-low") the relevance and impact of energy efficiency actions in Energy IQ

7.4.4. Collect, compile and publish empirical system level energy performance data

As noted in the section on gaps, the lack of measured data is key barrier to effective system level benchmarking. While simulation- and expert-opinion-based approaches may be a short term alternative, they are not a substitute for outcome based approaches using empirical data. The major components for this effort are to:

- Develop a standard list of data collection requirements for system level benchmarking, tailored and prioritized as needed for different market segments. This list should be *derived and driven by the metrics and use cases* for benchmarking (see section 2.1.1).
- Conduct a broad effort to collect *existing* data where available. This will involve outreach to a broad set of building owners and service providers that are likely to have the data and willing to share it. It may be helpful to have standard templates for any legal agreements to address data confidentiality. Also, it may be helpful to coordinate and combine the benchmarking data collection with other data collection requirements so that are not overwhelmed with multiple data requests.
- Conduct targeted effort to collect *new* data to address gaps in existing data. New data collection is generally more intensive per building and therefore should be carefully targeted based on the use cases and prioritization.
- Map and cleanse collected data into a common data format to enable analysis. For example, LBNL is developing the Building Energy Data Exchange Specification (BEDES) as a common data specification for empirical energy analysis, with input from a broad set of stakeholder in the US [DOE 2013]. The common data format should have clear definitions of each data field. The cleansing rules should include data type checks, out-of-range checks and in-range checks. Experience with the DOE Buildings Performance Database (BPD) indicates that data mapping and cleansing is a significant effort and should not be underestimated.
- Publish the data, anonymizing it as needed to address any data confidentiality considerations. The data may be published just as a raw dataset (e.g. in a manner similar to the way the US Energy information administration publishes the CBECS data) or it may be made available through a tool.

While the above data collection efforts will address the short term needs, they do not address the need for on-going empirical data collection. In the medium- and longer-term, we need a constant "feed" of empirical data from permanently installed Energy Information Systems (EIS). The CBERD project will begin to address this through its effort to develop packaged scalable EIS for broad deployment.

8. Deployment Channels

There are four primary deployment channels for benchmarking. Below we briefly describe each of these, how we plan to engage them, and some specific considerations for each of the four strategies.

8.1. Public Sector Deployment Programs

Public sector programs are generally the predominant means for deploying benchmarking tools. In India, the BEE has been at the forefront of deploying benchmarking tools and is therefore a primary stakeholder and 'customer' for R&D results. Accordingly, we strongly recommend that BEE should be routinely briefed and engaged to ensure that the R&D activities and outputs are directly relevant and responsive to the BEE programs. Additionally, the phasing and prioritization of R&D efforts should be informed by BEE's benchmarking program development schedule. We recommend quarterly or semi-annual stakeholder meetings with BEE.

Figure 11 shows the recommended approach to integrate CBERD and BEE's activities. CBERD will provide technical leadership for benchmarking R&D, including the design of building and system level data collection templates, possibly development of specifications for benchmarking and building labeling tools. BEE's work is currently supplemented by three organizations: US agency for International Development (USAID), the Shakti foundation, and the United Nations Development Project – Global Environment Fund (UNDP-GEF). These organizations are working with BEE on the execution and implementation of different elements of Commercial Building Benchmarking and Labeling program including data gathering on a periodic basis, tools development, and other technical activities. Utilities, industry and academic institutions can play an advisory role. Utilities in particular can advise and help with data collection.

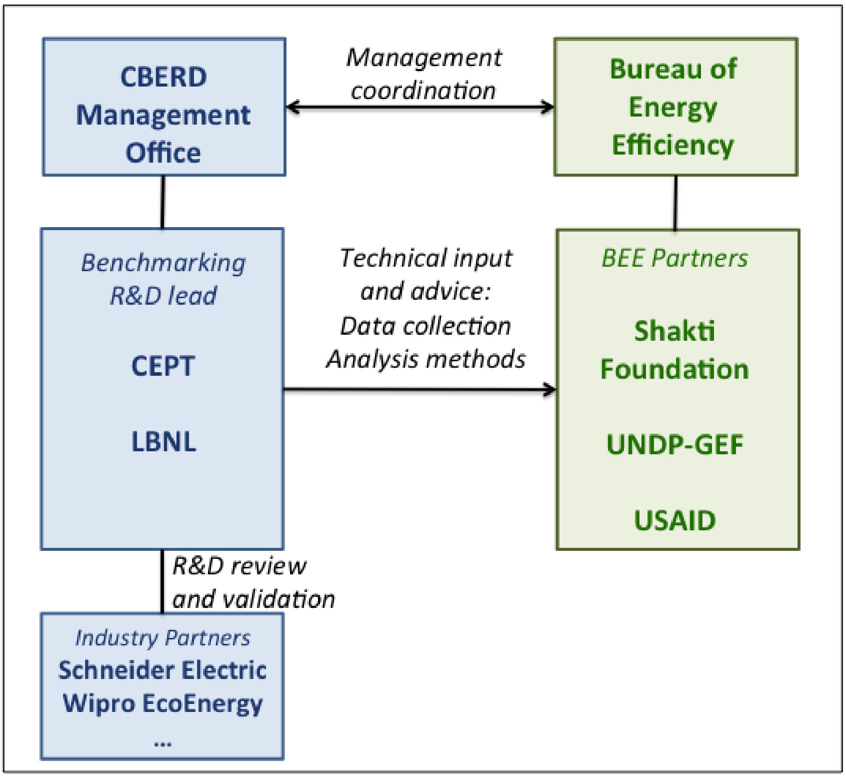


Figure 11. Recommended approach to integrate CBERD and BEE benchmarking activities.

Advances in whole building benchmarking is the most pertinent for the near term, as there are already benchmarking tools in place and it is important to ensure that R&D results are incorporated into these tools as they are being updated. Currently, BEE does not have asset rating programs and system level benchmarking in its portfolio. However, these may be a natural extension of its whole building benchmarking tools and programs, and may even help enhance the motivation for using benchmarking as system level benchmarking provides more actionable output. The system level applications can be selectively rolled out by segment.

8.2. Industry Organizations

Benchmarking R&D outputs may also be promoted by various industry organizations whose mission is aligned with benchmarking goals and objectives. Key organizations include the Indian Green Building Council (IGBC) and the Indian Society for Heating, Refrigerating and Air conditioning (ISHRAE), GRIHA and Confederation of Real Estate Developers' Associations of India. IGBC may be interested in incorporating whole building and asset rating tools in its rating systems. ISHRAE could disseminate and promote the use of HVAC system-level benchmarks among HVAC engineers. Sector specific organizations (e.g. hotels, hospital accreditation boards) may be interested in selected tools that are of particular interest to their members.

We propose the following approach to engage each industry organization:

- Identify specific ways in which each of the three benchmarking strategies described above can support their organizational goals.
- Identify specific features or other modifications needed to meet their organizational needs.
- Commit to a development and deployment plan. This should include commitments from the organizations to deploy benchmarking tools and from researchers to incorporate features that respond to the organization's needs.
- Conduct quarterly or semi-annual meetings to track progress, obtain market feedback and discuss new R&D results.

8.3. EIS Vendors

Over the last few years, there has been a significant increase in the number of commercially available EIS products. These products have a range of capabilities and features. At one end of the spectrum are products that offer basic tracking of energy use and cost. At the other end, there are products that offer advanced analytics and visualization. While a few offer benchmarking, it is mostly limited to simple whole building benchmarking. EIS products can be an effective channel for deploying new benchmarking R&D because it enhances their value proposition while also increasing the awareness and use of benchmarking as a part of energy management. Furthermore, users do not need to learn a new tool to do benchmarking.

We intend to work directly with the CBERD industry partners to incorporate benchmarking R&D results into their products. Beyond that, we recommend direct outreach to the broader EIS vendor community to publicize R&D results and facilitate deployment within their products.

8.4. Academic and Vocational Training Institutions

In order to fully realize benchmarking as standard practice, it is critical incorporate it into the curricula in professional degree courses as well as vocational training programs. Initial targets should include architectural and building-related engineering degree programs, as well as building operator training programs. The CBERD project already has several academic institutions as partners who can pilot R&D results in their curricula. Following that, standard training modules can be developed for wider deployment in other institutions.

9. Concluding remarks

The benchmarking strategies mentioned in this document are conceived to be technically rigorous and stand the scrutiny of the scientific community. At the same time, they should be simple and intuitive for the end users who are the final consumers of this research. Further, the models should use readily or easily obtainable data for estimating benchmarks or evaluating performance.

We prescribe the notion of graduated approach within each of the three strategies. At the whole building level, the users should be able to work with very basic information about their building and obtain useful benchmarks. Those with more data can still use the method and tool to obtain relevant information with a higher degree of accuracy. In asset and operation benchmarking, the proposed methodology will use standard definition of assets and operations, but should also be extensible to allow more flexible definitions of assets depending on what part of the building changes hands in a real estate transaction. Similarly, in system level benchmarking, users can benchmark key systems performances at the minimum and go up to the component level, given they have enough information about the same. It should be noted that here we are proposing an attribute of the methodology that should allow us to work at different scales and degree of available information rather than requiring different models for each of them.

We also propose that the models used in the three strategies should be compatible and nested so as to arrive at consistent and synchronized benchmarking estimates at all the three levels - whole building, asset and operations, and system and component level.

Some other key points to consider during evolution of methodology are listed below (Sarraf et al, 2011b). We are not proposing any definite answers or making value judgment but merely highlighting the issues that need to be addressed while working on these strategies.

Extensibility: The methodology should be generic and easily extended to more building types

Scale: Various options exists for choosing the appropriate scale for performance evaluation e.g . 0-100 percentile scores where zero represents the best performing building and 100 represents the worst building in the stock; [-inf to + inf], where zero represents a net zero energy building and 100 represents the stock median or a code compliant building; A-H grades and so on. Further, it needs to be ascertained whether the scores lie on a linear, logarithmic or a geometric scale. Factors such as intuitive appeal, supporting policy goal, need for peer review, etc. would affect the choice of scale.

Primary energy metric: The primary energy metric for evaluating performance should be simple and intuitive at the user level, possibly invariant to the market related issues of electricity supply and reliability. Ideally, the benchmarks should be estimated using both site and source energy.

Benchmarking methodological options: Each strategy should be based on the best-suited methodology to address its specific goals but they should possibly be able to integrate under a larger common framework. The broad methodological options include Statistical, Simulation, and Technical or expert based option. Given the complexity of the task, hybrid methods comprising of one or more of these may be required.

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11. Appendix

11.1. Benchmarking Use Cases for the Indian Context

No.	Use Cases	Granularity	Key Performance Indicators	Methodology options/ considerations	Current State of Art	New developments needed
1.	Screen buildings based on overall EE	Building	- total site/source EUI	A: Peer comparison using simple filtering of dataset B: Peer comparison using multi-variate regression model *(optional)*	A: Well established. Tool available for a few building types. B: Basic methodology is well established.	A: Collect new data and cover more Building types. B: Identifying significant variables and developing more robust models. May require additional parameters and more buildings.
2.	Rate/label overall building EE	Building	- overall score - total site/source EUI	B: Peer comparison using multi-variate regression model C: Comparison to model-based technical benchmarks	B: See #1. C: Limited use for benchmarking (e.g. UK), but modeling is well established.	B: see #1 C: Will need detailed data on a few buildings to calibrate the scale. Normalization could be via simulation model or pre-calculated factors.
3.	Evaluate building asset EE	Building	- asset score - total EUI w/ normalized ops	C: Comparison to model-based technical benchmarks F: Features-based benchmarking *(optional)*	C: Prototype tool developed in US (DOE asset score). Some EU benchmarks have developed method? F: Not developed for benchmarking	C: Define asset and operational variables; Assess methodology used in US and adaptation or further development needed for India. F: First need to explore feasibility of this approach.
4.	Evaluate building operations EE	Building	- operations score	X: TBD	Not developed	Explore methods
5.	Set and track overall building EE targets	Building	- total site/source EUI	B: Peer comparison using multi-variate regression model C: Comparison to model-based technical benchmarks	C: Generally not done using benchmarking. F: Implicitly covered in some audit tools.	C: Develop model-based approach for system level benchmarks; Need to collect limited measured audit-type data to calibrate models. F: Adapt existing audit tools methods.

6.	Evaluate demand response potential	Building	- annual Peak W/ m^2 - seasonal Peak W/ m^2	A: Peer comparison using simple filtering of dataset	C: Generally not done using benchmarking	C: See #5; Need to assess robustness of benchmark based savings calculations to conventional parametric simulation.
7.	Set and track system level EE targets	System	- system EUI (e.g. kWh/ m^2) - system efficiency (e.g. kW/ton)	C: Comparison to model-based technical benchmarks D: Comparison to expert-based technical benchmarks E: Nested regression models	B: See #2 C: See #2	B: see #2 C: see #2
8.	Identify potential EE measures	System	N/A	C: Comparison to model-based technical benchmarks F: Features-based benchmarking	C: See #5 D: Generally not done using benchmarking E: Not developed	C: See #5 D: Need to adapt expert system methods and list of experts. E: Need to develop methods
9.	Assess potential savings from EE measures	System	- savings % - savings EUI	C: Comparison to model-based technical benchmarks	See #7	See #7
10.	Cross-check results from engineering models	Building System	- total site/source EUI - system EUI (e.g. kWh/ m^2) - system efficiency (e.g. kW/ton)	A: Peer comparison using simple filtering of dataset B: Peer comparison using multi-variate regression model E: Nested regression models	A: See Energy IQ and high tech benchmarks B, E: See #8	A: Need to expand system metrics and building types B,E: See #8
11.	Track EE trends in building stock. Influence perfor mance-based codes	Portfolio	- stock site/source EUI	A: Peer comparison using simple filtering of dataset B: Peer comparison using multi-variate regression model	A: Unclear if benchmarking has been used	A: need to collect demand data; need definitions for seasonal peaks
12.	Set and track portfolio EE targets	Portfolio	- portfolio site/source EUI	B: Peer comparison using multi-variate regression model C: Comparison to model-based technical benchmarks	A, B: Several tools using CBECS, RECS, etc.	A, B: See #1

11.2. Draft Technical Metrics

A	Whole Building metrics	Units
1	Annual Energy Consumption, EPI	KWh / m^2.a
2	Peak Load (operational)	W / m^2
3	Annual Energy Consumption, Source	mJ / m^2.a
4	Annual Energy Consumption / FTE (beds, rooms, occupant)	kWh/a/person
5	Annual Energy Cost Intensity	INR / m^2
B	**HVAC Metrics**	
1	HVAC Annual Energy Consumption	kWh / m^2.a
2	HVAC Peak** (Rated, at Peak cooling load, Average)	W / m^2
3	Cooling System Efficiency** (Aim: Chiller operation efficiency, control sequencing)	kW / TR
4	Building Cooling Load (rated, peak)	m^2 / TR
5	Air Distribution System Efficiency (Rated)	W / cfm
C	**Internal Lighting Metrics**	
1	Lighting Annual Energy Consumption	kWh / m^2.a
2	Lighting Peak Load (Installed, Operational)	W / m^2
D	**Plug and Process Metrics (includes UPS and Raw Power)**	
1	Plug Annual Energy Consumption	KWh / m^2.a
2	Plug Peak Load (Operational)	W / m^2
E	**Building Type Specific Metrics**	
a	**Hotels**	
1	Annual energy use intensity	kWh / room or room nights
2	Hot water energy use intensity	kWh/..
3	Space heating	kWh / m^2 a
b	**Hospitals**	
1	Annual energy use intensity	kWh / bed
2	Hot water / Steam energy use intensity	kWh / ..
3	Space heating	kWh / m^2 a
c	**Office**	
1	Annual energy use intensity	kWh / FTE - hr, kWh / m^2 – hr
2	UPS system efficiency (at full charge)	%
d	**Retail**	
1	Annual energy use intensity	kWh / m^2-hr