Development of a Web-Based Building Energy Performance Benchmarking System

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ABSTRACT

The purpose of this paper is to introduce Energy Smart Tool, a new web-based building energy performance benchmarking system developed recently by Energy Sustainability Unit of National University of Singapore. It provides users with direct comparisons of their buildings' energy performance to other similar facilities, which helps to identify the position their facilities, and to set energy saving targets. A general discussion of the benchmarking procedure is given. It was learned during the development that benchmarking is firstly a continuous systematic process of evaluating one's own performance in relation to others. More importantly, it should be a process to identify best or poor practices, find reasons of successes or failures, and develop recommendations and implementations for improvement. Willingness of sharing information is the key for a successful benchmarking practice. The empirical findings of this study will contribute to the knowledge and understanding of using benchmarking for energy performance improvement of buildings.

KEYWORD

Energy efficiency, building energy performance assessment, online benchmarking, energy smart labelling

INTRODUCTION

Currently, the soaring oil price makes energy and environmental sustainability often the topics of discussions by media, governments and the public. Although there may be many reasons behind this, it keeps reminding people that energy is not that cheap any more. This starts to change the life styles of people and their attitudes toward energy use in work and daily life. In the long term, fossil fuel depletion is inevitable. However, to date there is no clear sign of finding alternative energy sources that can substitute for fossil fuels. The use of renewable energy (e.g. solar, wind, biomass and geo-thermal) and energy efficiency are believed to be the solutions for energy shortage and sustainable development. Among these two, the former has obvious constraints from the natural conditions, while the latter can be achieved more economically and effectively by using normal existing technologies. However, there are also difficulties for promoting and implementing energy efficiency. The difficulties are not from the natural conditions nor technologies but people, who lack responsibility, knowledge and motivation of energy saving.

Building sector is one of the major energy consumers, especially in a modern city like Singapore. Energy use in buildings made up 16% of Singapore's energy demand in

2004. Given Singapore's tropical climate, the need for air-conditioning forms a large part of the electrical demand, NEA (2006).

During the last 5 years, researchers from the Energy Sustainability Unit (ESU) of National University of Singapore (NUS) have been working hard in studying and promoting energy efficiency in buildings. Energy Smart Tool (EST), a web-based building energy performance benchmarking system, is the recent development based on their multi-year researches. The project is co-funded by three projects. They are EC-ASEAN Energy Facility (EAEF) project 68: Development of a Comprehensive Database for Building Energy Performance Benchmarking in the ASEAN Region, National Environment Agency of Singapore (NEA)'s Building Energy Smart Building Labelling Programme, and Jurong Town Corporation Singapore (JTC)'s project on Benchmarking Industrial Building Energy Performance.

The main objective of EST is to establish a knowledge-based building energy performance benchmarking system and an information sharing platform of promoting energy efficiency in buildings' designs, O&M practices and managements.

EST was developed based on a comprehensive database of building characteristics and energy consumption, which covers various building types (e.g. office building, hotel and industrial factory). It is useful for benchmarking, performance tracking, data retrieval, and classification, which pave the way for building energy labelling. Being a starting point in assessing building energy use and saving potential, currently the tool serves as pre-qualification process for energy smart buildings, the first building energy performance labelling programme in Singapore.

Since its launch in December 2005, EST has attracted over 70 users from various backgrounds, which include building owners, developers, energy services companies (ESCO), designer, government agencies and energy researchers.

CURRENT DEVELOPMENT OF EST

To ensure a comprehensive, independent and reliable benchmarking system of building energy performance, great attentions and efforts have been put carefully into each step of the development. These include data collection, verification, parameter analysis, indicator determination, and development of cumulative percentile curve and classification.

Data Collection

The current EST includes 3 building types, namely office building, hotel and industrial factory. For each building type, sample was carefully chosen to ensure that it is representative of the entire building stock and covers a wide spectrum of each building parameter. Data collections were mainly focused on overall building characteristics and energy consumptions, as well as energy efficiency measures.

Firstly, a total number of 120 commercial office buildings were investigated in Singapore. After stringent statistical tests (i.e. data screening, verification, normality test, regression), 95 commercial office buildings were selected for the further database development. Case studies were then conducted in selected buildings to understand detailed building and system levels' energy performances, and identify good practices of energy efficient building design, operation and management. In the mean while, a national survey was conducted targeting 103 gazetted hotels, which include all the quality hotels in Singapore. Complete datasets were received from 29 of them (5 three star, 13 four star and 11 five star). This was used for the development of hotel energy performance benchmarking. The database of industrial factory is based on the landlord energy use for common area of 59 flatted factories in Singapore, which are naturally ventilated. The low spread of flatted factory design efficiency, and the large sample population indicate that the benchmarking data can provide a reliable profile of flatted factories' energy performance in Singapore. Table 1 shows a summary of key parameters in the databases of 3 building types.

TABLE 1: Summary of building characteristics

	N	Minimum	Maximum	Mean	Std. Deviation
Office	95				
Building age		1	22	11.82	6.055
Gross floor area (m^2)		2006	130000	34174.13	29484.582
Floor occupancy rate (%)		60	100	92.93	8.702
Operating hours (hrs/week)		44	74	56.33	6.764
Design efficiency (%)		28	100	74.26	15.487
People density (ppl/100 m^2)		1	10	3.74	1.885
Hotel	29				
Gross floor area (m^2)		1648	101998	33650	21207
Number of rooms		32	1200	464	208
Standard room area (m^2)[a]		24	41	30	5
Building age		1	75	20	14
Number of workers		12	600	203	147
Industrial factory	59				
Gross floor area (m^2)		14101	57292	23663	9223
Landlord common area (m^2)		2943	14579	6454	2098
Floor-to-floor height (m)		3.75	6.0	3.88	0.33
Occupancy rate of factory (%)		37	100	78.2	14.8
Operating hours of landlord common area ((hrs/week)		84	84	84	0

[a] Area of a standard double guest room

Energy Performance Indicators

Choosing proper and empirical performance indicator is crucial for the further development of benchmarking curve and classification system, but it is not an easy task. Normalization is often needed to remove the impacts of weather conditions, floor areas, building usage, operating hours, occupancy rate, special energy uses and other factors that bias the energy consumption of buildings but are out of the control of people, Sun (2006). The normalization strategy can be based on statistical parameter analysis, empirical experience, and models established in previous studies. Table 2 summarizes the indicators, energy usage intensity (EUI) adopted for the benchmarking of 3 building types.

Benchmarking Curve and Classification

Figure 1 shows the results of EUI cumulative percentile curve for each building type. The classification approach used currently is based on equal frequency rating (EFR) similar to that of US EPA's EnergyStar programme. For each building type, buildings are separated into 3 classes, of which the respective percentile rating is top 25%, 25% to 75% and 75% to 100%. A further discussion of alternative classification method is provided in the later part of this paper.

TABLE 2: Summary of energy performance indicators of office, hotel and industrial factory building

Office	
EUI = (TBEC - CPEC - DCEC)/ (GFA $_{\text{excluding car park}}$ - DCA - GLA*VCR)*(55/OH)	Eqn.1
where,	
TBEC: annual total building energy consumption (kWh/yr)	
CPEC: annual car park energy consumption estimated based on data of previous studies (kWh/yr), Yeo (2003)	
DCEC: annual data centre energy consumption estimated based on data of previous studies (kWh/yr), Sun (2004)	
GFA $_{\text{excluding car park}}$: Gross floor area exclusive of car park area (m^2), URA (2005]	
DCA: data centre area, which typically refers to the raised floor area (m^2)	
GLA: Gross lettable area, which is the sum of functional areas in building (m^2)	
VCR: Floor vacancy rate of gross lettable area (%)	
55: Typical weekly office building operating hours in Singapore	
OH: Weighted weekly building operating hours of gross lettable area excluding data centre area (hrs/week)	
Hotel	
$EUI_{norm} = EUI_0 - 51.567 \times \left(\frac{X_1 - 6.038}{2.215}\right) + 52.092 \times \left(\frac{X_2 - 0.172}{0.384}\right)$	Eqn.2
where,	
EUInorm: normalized EUI; EUI_0 : observed EUI, i.e. total building energy consumption per unit of gross floor area;X1: worker density, defined as number of workers on main shift per 1000 m^2 of GFA; and X2: dummy variable, which is 1 if the hotel is a three-star development and 0 if it is a higher class hotel (4 or 5-star).	
Industrial factory	
EUI = LDEC/ VLCA	Eqn.3
where,	
LDEC: landlord energy consumption (kWh/yr)	
VLCA: volume of landlord common area (m^3)	

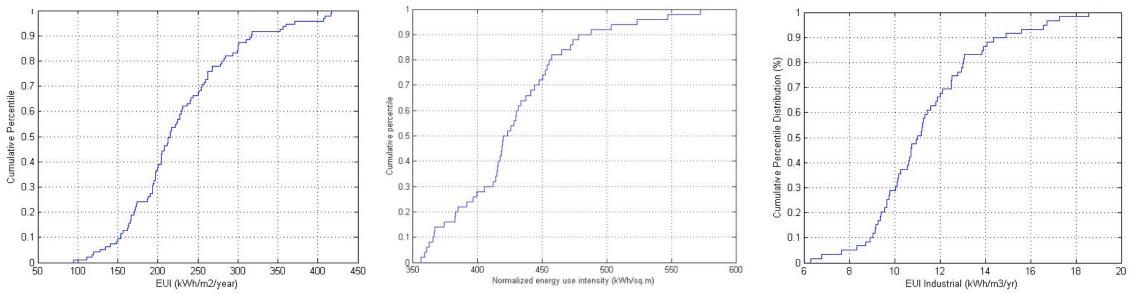

Figure 1: EUI cumulative percentile distributions of office, hotel & factory buildings

ON LINE BENCHMARKING PROCEDURES

Input Variables

The EST is designed to be a user friendly system. As a preliminary assessment process, it does not require data that are very hard to get, but only the key variables of building characteristics and energy consumption, which are essential for the primary data screening requirement and the calculation of energy performance indicators.

Output Results

Using office building benchmarking as example, the output results mainly include a benchmarking cumulative percentile curve with indication of the position of the current building under evaluation, comparison of EUI with industrial average and best practice, EUI classification details, summary of input data, and interpretations of benchmarking results and remarks of limitation.

Other Features

To facilitate users in data input and understanding results, the website also provides various help files. These include a general introduction of EST, guidance on how to use the tool, data screening criteria, detailed terminology, useful links to other referenced benchmarking tools, and an online survey to get feedbacks and comments from users. A printable report in PDF format is also downloadable from the website. In addition, News and Events introduces the latest development on EST and other progress of energy efficiency. Case Study shows the best practices of energy efficient buildings and gives recommendations to the others.

Limitations

The current version of EST however has its own limitations and it is highlighted to the users that the benchmarking is established based on the normalized overall building site energy consumption. Site energy is the actual building energy usage.

Each building is unique. It is very hard to normalize building energy consumptions by all the uncontrollable factors and make the benchmarking completely fair and accurate. In many cases, low energy consumptions do not necessarily mean buildings are efficient and high energy consumptions do not always mean that they are inefficient. Therefore, the outputs of EST should be used as a preliminary assessment of building energy performance rather than the final results. For further accurate investigation, it is recommended to engage accredited energy services company (ESCO), professional energy engineer or energy researcher to undertake a detailed energy audit.

LESSONS LEARNED

The development of Energy Smart Tool gave us a good opportunity to understand better the benchmarking technology in the application of building energy performance assessment practice. A general discussion of lessons learned is provided in this section. Recommendations are given.

First of all, it is important to know that benchmarking is a complex and systematic process. It does cost time and money. One of the main reasons why benchmarking studies sometimes fail is poor planning and the lack of a proper methodology. Benchmarking has been widely used in the fields of building energy performance assessment and labelling programmes. However, few of them can be learned and treated as template of comprehensive benchmarking, and their impacts on promoting building energy efficiency and energy saving are limited.

Therefore, before rushing into executing benchmarking, it is worth taking some time to learn the basics of benchmarking concept and its procedure. There are a number of books give general introduction and guidelines on benchmarking, for examples, Andersen (1996), Codling (1995), Carey (1995), Kirker (1995), Rolstadås (1995) and Wöber (2002).

Benchmarking- Definition and Concept

Benchmarking is a tool for improvement, achieved through continuous measuring and comparing against identified comparable best practices, studying reasons of their success, and obtaining information to develop recommendation and implementation.

The purpose of a benchmarking study is not only a comparing evaluation but learning for achieving improvement. In addition to performance benchmarking of key figures (e.g. total building energy consumption), process benchmarking of system, building design, operating and maintenance practice, management should be the central elements in the evaluation and compassion. Too much focus on performance benchmarking gives little information about how to improve or close the gap of competitors.

Case studies where things have gone wrong or not as smoothly as in the norm can actually be a good source for learning. If learning from successful cases is a form of benchmarking, learning from less successful ones can be thought of as benchmarking avoidances.

The great success of benchmarking is related to its inherent characteristics of being a knowledge-sharing and motivational process. Therefore, the primary attitude about benchmarking is "sharing". It is the willingness of benchmarking partners to share between competitors. This makes benchmarking not only a great opportunity, but also, a great challenge. Equally, the government and research institute need to share their information and data, and interact with public and building sector practitioners to motivate practicing in energy efficiency and share ideas of how to improve.

Benchmarking Process

A building energy performance benchmarking should include the following steps: plan, search of benchmarking partners, investigation and data collection, data analysis, database and classification, identification of best practices, reasons of success (case study), recommendation and implementation of improvement, and recycle.

Highlights of planning

1. Determine benchmarking objectives and targeted benchmarking partners
2. Select process of benchmarking, including timelines, tasks and subtasks.
3. Design methodology, including sampling, standardization of data collection form and terminology, finding key performance indicators, etc.

Highlights of search of benchmarking partners

1. Set criteria of targeted comparable benchmarking partners

2. Establish mutual-trust benchmarking partnership with participants, which will contribute to a continuous and reliable benchmarking.

Highlights of investigation and data collection

1. Control the quality of data collection. Benchmarking is a rubbish in and rubbish out system. Inaccurate or biased data may totally distort the truth and destroy the reliability and reputation of the benchmarking.
2. Obtain information of both building performance level and process level, which can not only tell how well it performs but also explain how and why.
3. Always double check the data and information obtained. Conduct personal meeting, interview, site visit and walk-through observation for data verification.

Highlights of data analysis

1. Perform rigors statistical tests to ascertain data validity, normality, integrity, and remove extremes and outliers from further analysis.
2. Develop normalization strategy based on the results of parameter analysis, engineering experiences and literature review of relevant studies.
3. Determine normalized performance indicators (e.g. EUI)

Highlights of establishing database and classification

1. Build up benchmarking cumulative percentile distribution curve and lookup table of adopted performance indicators.
2. Classify buildings into various classes based on their relative positions to others in the database. Two classification methods are recommended, including equal frequency rating mentioned before and fuzzy clustering classification, Santamouris (2006). The former is currently the most commonly used method and the latter is a new method recent developed, which is used to identify natural groupings of objects and classify them according to existing similarities. It is believed to be a better solution than the equal frequency rating method which defines energy classes based on the frequency distribution of buildings and by considering an equal number of buildings for each class, especially when the performance indicators are not normally distributed.

Highlights of identification of best practices, reasons of success, recommendation and implementation of improvement

1. Detailed case studies are most useful to identify best practices and obtain information that will help improve energy performance of other benchmarking partners.
2. It starts with identifying typical buildings of each energy class discussed before. A method of find typical building using principle component analysis (PCA) is explored by Lehmann (2006). However, this is beyond scope of this paper.
3. Close each case study with an evaluation report, which showcase the whole benchmarking process and the lessons learned toward good energy performance and energy saving in building.
4. General report of recommendation and implementation of improvement.

Highlights of recycle

Benchmarking should not be a one-time event but a continuous process for improving performance. This includes the following activities:

1. Recalibrate the benchmarks, i.e. update and expand database, tract performance of existing partners, evaluate new best practices and improvements.
2. Recycle the benchmarking process, i.e. adjust objective/partners of benchmarking, change benchmarking areas.
3. Re-examine the benchmarking method and process based on experiences and lessons learned in practices, and new method and technology available.

CONCLUSIONS

Benchmarking is a powerful tool for improvement. In the field of building energy performance benchmarking, there are a lot more to be learned and to be done. Currently, there is growing number of initiative working on online systems in order to support the benchmarking process. The energy smart tool is a pilot practice for on line building energy benchmarking, and has shown positive impacts on promoting energy efficiency and energy saving. Further efforts will be focused on building system and process benchmarking, case studies of best practices, intelligent classification technology, database update and expansion, and last but not least information sharing and education.

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