Session 2.12: Process of Urban Regeneration

Energy Benchmarking Tool for Low-Carbon Transformation in Hong Kong: A Scientific Approach and Its Practical Applications

Jason JZ YANG[a], Alvin TY LO[b], Karen HY CHEUNG[c], Cary WH CHAN[d], Benny KM CHOW[e], Paul SK SAT[f]

[a] *Arup, Hong Kong SAR, jason.yang@arup.com*
[b] *Arup, Hong Kong SAR, alvin.lo@arup.com*
[c] *Hong Kong Green Building Council Ltd., Hong Kong SAR, karen.cheung@hkgbc.org.hk*
[d] *Hong Kong Green Building Council Ltd., Hong Kong SAR, cary.chan@hkgbc.org.hk*
[e] *Hong Kong Green Building Council Ltd., Hong Kong SAR, benny.chow@hkgbc.org.hk*
[f] *Hong Kong Green Building Council Ltd., Hong Kong SAR, paul.sat@hkgbc.org.hk*

ABSTRACT

World energy consumption has increased rapidly in recent years and shows no indication of slowing. In Hong Kong, this situation is more critical due to its high demand in urban energy consumption and scarcity of natural resources within its jurisdiction. To push Hong Kong to the very forefront of the fight against climate change and form a low-carbon urban transformation, energy benchmarking is one of the most effective ways to set up industry's best practice and achieve sustainable development.

While there exist a few benchmarking programmes worldwide, such as ENERGY STAR Portfolio Manager in the US, NABERS in the Australia, they are limited to benchmarking the existing buildings without customised improvement advice to enhance energy efficiency. Hong Kong, with its extremely high-density urban form, starts to develop its own benchmarking tools in recent years for the unique built environment, some early attempts include HK BESTOO developed by Hong Kong Green Building Council (HKGBC) and Energy Utilisation Indexes and Benchmarks developed by Electrical and Mechanical Services Department (EMSD).

In order to accelerate the low-carbon urban transformation, a more comprehensive benchmarking system is needed to evaluate and improve the whole building energy performance. It will surpass the existing benchmarking programmes around the world by assessing the building to the system-level details and provide ratings based on different building system types. Additionally, the world's first "What-If" Function will provide the building owner with tailor-made suggestions to improve the building energy performance. This paper reviews the state-of-the-art methods in building energy benchmarking and proposes a new benchmarking system specifically catering to Hong Kong's unique built environment to promote the low-carbon urban transformation in Hong Kong. This project was initiated by the HKGBC with the aim to improve building energy performance in Hong Kong. Arup was appointed as the consultant to undertake studies.

Keywords: *low-carbon, urban transformation, energy benchmarking*

1. INTRODUCTION

In Hong Kong, buildings account for 60% of carbon emission and 90% of electricity use (HKPC, 2016). Focusing on making buildings more energy efficient with the initiative of the HKGBC is the key to grasping the opportunity of meeting Hong Kong's carbon reduction target without going into the current fuel mix debate. As shown in Figure 1, in order to fit in the roadmap of the overall carbon reduction target, 52% of the reduction in electricity in the building sector needs to be achieved by 2030, as compared to the level of 2005 (HKGBC, 2014). According to the Buildings Department, there are around 2,459 existing office/commercial buildings in Hong Kong. With proper strategies, retrofitting and optimising these existing buildings can bring large reduction to the entire building sector, almost half of the target. Along with Hong Kong's high-density building context, comes the large variation in building functions and base building provision. Simply comparing the Energy Utilisation Index (EUI) may miss the underlying factors and opportunities for improvement in energy efficiency. Among current available policies and strategies, benchmarking is likely the best tool to push the baseline of existing buildings and drive the market to meet this long-term target for Hong Kong. In the latest Energy Saving Plan from the Hong Kong Government also emphasises the importance of energy benchmarking as the first stage of the energy saving and green building transformation (Environment Bureau, 2015). This paper focuses on the benchmarking of Central Building Services Installation (CBSI) of Commercial Buildings (Office/ Retail) (HK BESTCOM).

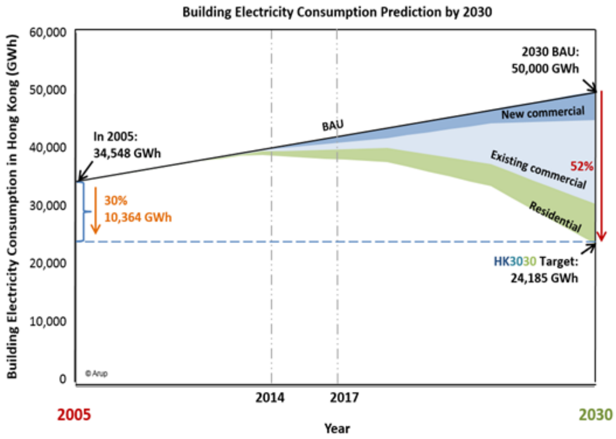

Figure 1: Impact of carbon reduction in Hong Kong's building sector

1.1 State-of-the-art methods and existing rating programmes worldwide

Originally, the word "benchmark" was used exclusively in topography to precisely define a reference point in terrain or geological analysis. When the term was first used in building industry, it referred to energy benchmarking, specifically assessing the energy performance of buildings of similar type. Many research projects have been conducted since the emergence of energy benchmarking in building industry. Broadly, the existing energy benchmarking methods can be put into four categories (Sartor et al., 2000):

Points-based Rating System: A system provides standards and guidelines to measure how efficient and environmentally friendly a facility is. A good example is the USGBC's Leadership in Energy and Environmental Design (LEED) rating system. However, the scoring system for building energy efficiency can be misleading, which requires a careful review of the points-based rating mechanism (Turner and Frankel, 2008).

Hierarchal and End-use Metrics: It is a process of categorising the whole building level energy use and gradually looks into the underlying systems and components level to capture the performance data. This approach requires segmented data that are usually not readily available, which requires the sub-metering of the system and component loads, following the hierarchical process (Sartor et al., 2000).

Statistical Approach (Regression): Statistics for a population of similar buildings are used to generate a benchmark against which the building Energy Utilisation Index (EUI) is compared. This data-driven methods provide an efficient method to compare building energy performance (Chung, 2011) (Hong et al., 2015). This method can effectively normalise the EUIs by removing the effect of building characteristics (Chung, et al., 2006). US Environmental Protection Agency's ENERGY STAR Portfolio Manager Programme, for example, accounts for the differences between buildings through the use of regression models and normalisation methods that are used to generate a ranking score based on energy efficiency ratios (ENERGY STAR, 2011).

Simulation Model-based Approach: It calculates energy benchmarks based on an idealised model of building performance. Modelling approach in benchmarking has the advantage of flexibility, able to be tweaked to account for a wide range of factors that contribute to variation in energy use. A disadvantage is the gap between the calibration of simulation modelling and actual building operation (Sartor et al., 2000).

Globally, several building benchmarking programmes have been developed based on some the above methods. The US EPA's ENERGY STAR Portfolio Manager Programme and National Australian Built Environment Rating System (NABERS) are based on historical energy consumption data and adopts statistical approach (Hicks and Neida, 2000) (Hicks and Clough. 1998). ASHRAE's Building Energy Quotient (bEQ) rating system adopted the simulation model-based approach for its "As Designed" evaluation method. For Singapore, the benchmarking reporting is conducted annually. However, there is some preliminary analysis and normalisation for chiller ages, data centre area, etc. (BCA, 2016).

1.2 Challenges in benchmarking programmes in Hong Kong

Though many building benchmarking programmes are available, they may hold certain limitations in the case of the benchmarking programme in Hong Kong. Existing programmes such as ENERGY STAR Portfolio Manager Programme and NABERS are based on local building context and are not globally compatible, especially in Hong Kong, where buildings are unique in their complex mixed-use nature. More studies were conducted identifying other energy performance factors beyond the current limitation of existing benchmarking programmes (Olofsson et al., 2004) (Signor et al., 2001).

Based on the literature review, it can be concluded that the statistical approach is adopted by a majority of the benchmarking programmes. However, a tailor-made methodology for building energy benchmarking in Hong Kong should be developed based on Hong Kong's building context and associated factors. On top of that, more innovative functions shall be created to accelerate the retrofit of existing buildings and drive the low-carbon transformation in Hong Kong.

2. METHODOLOGY

2.1 General considerations

In order to develop a new benchmarking programme for Hong Kong based on the statistical approach, it is essential to understand the benchmarking process. Through extensive research on various studies to conduct building benchmarking (Matson and Piette, 2005) (Pérez-Lombard et al., 2009), it can be concluded that a qualifying building energy benchmarking process should contain at least four steps illustrated in Figure 2. This process should not be treated as a purely statistical process, but rather an integrated process supported by both solid engineering reasoning and statistical analysis.

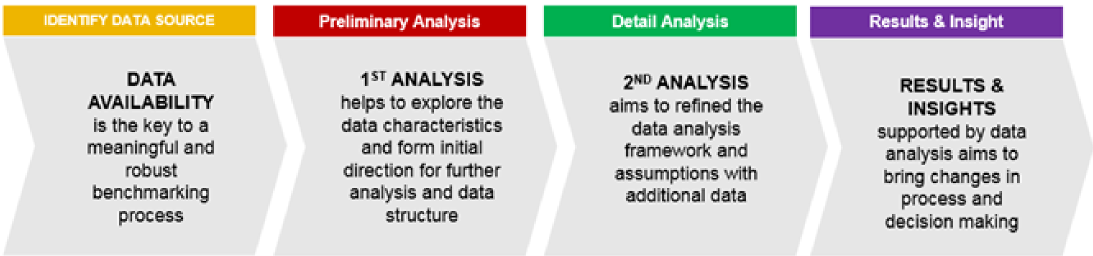

Figure 2: Basic steps of building energy benchmarking process

The process of benchmarking is to normalise, or in other words, to eliminate variation in buildings' inherent characteristics before evaluating their energy use. There are some fundamental rules that should be clarified before this method could be applied to the real database. The building energy consumption depends on many parameters. These parameters include physical constraints (system type, area, operation pattern, etc.) and performance factors (lighting power density, system efficiency, etc.). These physical constraints explain the basic characteristics of a building, while the performance factors are performance related, which describe how efficiently a building performs given its physical constraints. Though the performance factors are directly related to the energy consumption, they are not parameters that explain buildings' physical variations and therefore should not be used for normalisation. Instead, the performance factors could be used for energy use prediction and optimisation.

Before going into the details of methodology, it is necessary to visualise the process of the benchmarking tool from the users' (building owners and management company) perspective in order to optimise its attributes. Based on the characteristics of the two types of parameters, a new benchmarking tool can be developed containing two major functions: i) A Basic Tool for building normalisation supported by statistical analysis; ii) An Advanced Tool based on performance factors with "What-If" Function, which serves the purpose of the retrofit optimisation process. Two functions can be integrated as shown in Figure 3 to form a feedback system and help make decisions for energy efficient retrofitting.

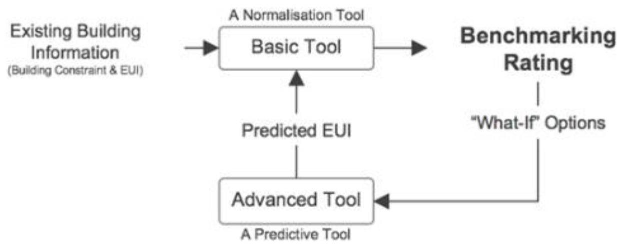

Figure 3: The integrated benchmarking system

2.2 Data processing

Data Collection and Filters

The database for the energy benchmarking was established with the support from Electrical and Mechanical Services Department (EMSD). Data sets were initially collected and analysed for the purpose of the development. Due to the variation of data quality, a filtering process was designed to remove outliers inappropriate for the benchmarking tool. Certain data sets were filtered out to ensure that the remaining can represent the energy use pattern of typical buildings in Hong Kong.

Categorisation

Through the preliminary analysis, the distinctive difference in EUI is found for buildings with centralised system of air handling unit (AHU) or fan coil unit (FCU) and decentralised systems (Figure 4). This is mainly due to the difference in energy use by air-side systems. For AHU and FCU system, the fan energy for distributing the conditioned air is on account of the building owner and tenant respectively. For the decentralised system, all the energy associated with air-conditioning is consumed by the tenant. So it is necessary to divide the buildings into three categories based on these system types.

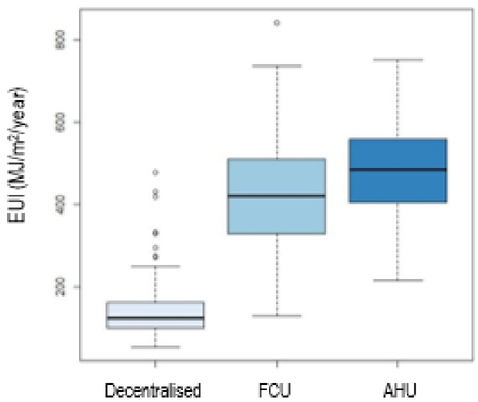

Figure 4: EUI for commercial buildings with different air-conditioning systems

2.3 Basic tool development

Regression Analysis

For the Basic Tool, the main focus was to develop a multivariate regression model for each of the category, namely FCU, AHU and Decentralised buildings. In order to make sure the regression equations represent the effect of the most significant features affecting the building energy performance, the development process includes: i) Reviewing available variables as building constraints; ii) Perform regression iterations by including different variables and transformations; iii) Review statistical indicators and determine the best regression model.

The statistical indicators adjusted R-Squared and t-scores are both investigated during the process. Since the regression model is not a prediction tool, adjusted R-Squared alone can be misleading because it is affected by the characteristics of the database and chosen variables. So the t-scores were also investigated to make sure the level of uncertainty associated with regression parameter estimates are minimised for the statistical analysis.

Rating System

After the regression model is developed, a rating scale for the building energy performance can be established based on the Energy Efficiency Ratio (EER):

$$EER = \frac{EUI_{measured}}{EUI_{normalised}}$$

Equation 1

With the above ratio, a building can find out its relative performance against other buildings from the percentile ranking shown in Figure 5. If a building's $EUI_{measured}$ is lower than $EUI_{normalised}$, the EER value and percentile value will be lower, indicating the building is more energy efficient when compared to the market norm. For example, if the corresponding percentile is 20th, its energy performance is better than 80% of the similar buildings.

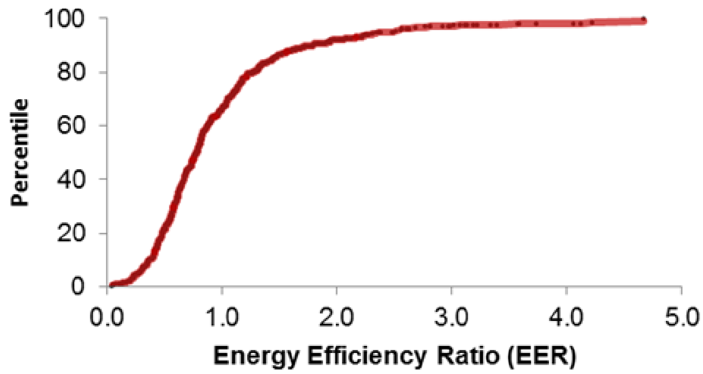

Figure 5: Distribution density and cumulative distribution function for the rating system

2.4 Advanced tool development

The Advanced Tool provides opportunities for strategic planning and future improvement before actual implementation, which overcomes the limitation that the existing benchmarking tools only provide the rating based on the normalised building EUI. The "What-If" Function focuses on three major systems: air-conditioning, lighting and lifts. To achieve that, the correlation between the change of performance factors and the relative energy saving for that particular system should be understood, and then the energy saving for the whole building can be predicted. Among the three systems, the air-conditioning system is the most sophisticated with many possible configurations. Series of energy models were simulated to allow user to choose from as many as 12 systems with different heat rejection types, chiller types (constant speed vs variable speed), chilled water supply loops and oil-free chillers. For each case, a range of average rated coefficient of performance (COP) values was simulated. All the simulation results form a large matrix of energy consumption for a typical building. Once the "What-If" Function knows which case the existing system belongs to, the relatively more efficient systems will show up in the "What-If" Function as improvement options. The "What-If" Function for lighting is based on the calculation of the change in lighting power density, operation hours and occupancy sensors. For lifts, the "What-If" Function focuses on lift system type with different efficiencies.

3. DEVELOPMENT OF THE ONLINE PLATFORM

The outcome of the study is a comprehensive online platform for commercial buildings (office/ retails) in Hong Kong (http://hkbest.hkgbc.org.hk) as part of HKGBC Benchmarking and Energy Saving Tool Series to target the key energy consuming sectors. The Free Benchmarking Tool gives a general rating for the user and the Recognition Scheme is a paid service that offers detailed rating output and Advanced Tool with "What-If" Function. It is also a certified rating process with the engagement of an authorised assessor to provide professional advice.

4. CONCLUSION

Traditionally, a one-dimensional index was used to describe energy efficiency, comparing a building's energy use over time against itself. This provides little insight into improvement actions for individual buildings. In response, this paper introduced a new approach to transform Hong Kong into a low-carbon urban development. The outcome of the study is an integrated benchmarking system developed for Hong Kong's unique building context to evaluate the building energy performance and provide optimal retrofit measures with a "What-If" Function. This benchmarking programme has been developed to support decision making by revealing high-level information such as each building's market position in terms of energy use, energy-saving potential for the key energy consuming building sectors and the local market's performance compared to the rest of the world. This allows building owners to understand the real energy performance against similar buildings through a verified assessment process. The successful launch of the tool is a milestone for Hong Kong to achieve its long-term energy-saving target.

ACKNOWLEDGEMENT

This is a consultancy study commissioned by the HKGBC and the project with funding support by the Construction Industry Council. The project team is indebted to the Construction Industry Council, the HKGBC, EMSD and other organisations that have contributed to the collection of building data together with excellent advice and insights in the process of the development.

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