Paper No 142: Energy Performance Benchmarking (EPB): A system to measure building energy efficiency

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Abstract

Benchmarking energy performance is an important step towards low energy buildings. Its most significant contribution is that it provides the building designer and energy management with a target for improvement. This paper discusses issues related to the development of a building energy benchmarking system for non-domestic buildings in Bahrain. The Energy Performance Benchmarking (EPB) system is a database and benchmarking software. Based on on-site surveys detailed audit information was obtained and incorporated into a system database. The database represents an archive for energy use in buildings and provides a comparative model. EPB software was developed in light of the differences and similarities between buildings. The operational variables considered in this software include climate, building type, floor area, occupancy and equipment. The software performs two functions: firstly, it assesses how efficiently buildings use energy, relative to similar buildings nationwide; secondly, the software sets a realistic and achievable energy target. This paper presents a study of a medium sized office building from Bahrain that was benchmarked using the EPB and compares the outcome with that from a recent benchmarking field study.

Keywords: energy performance, benchmarking system, office buildings, Bahrain

1. Introduction

Nations attempt to conserve energy, protect the environment and more recently prevent climate change. As buildings are one of the largest consumers of energy and a major contributor to the increase in the atmospheric CO_2 and hence climate change, a great deal of effort has been spent on establishing methods through which the energy efficiency of buildings can be improved. Benchmarking building performance is an example of such methods. It has been concern for many studies all over the world [1, 2, 3, 4, 5, 6, 7, 8, 9]. At a national level, the development of tools for benchmarking building performance has become a valid means of reducing the negative economic and environmental impacts of buildings. They help in assessing the performance of buildings along with providing criteria against which energy design and operation can be evaluated. Over the past few years many tools have emerged with different purposes. Some are enterprise tools provide a range of services. They have been developed to serve the clients of particular energy providers. Others are free on-line tools.

In general, the benchmarking tools can be categorised using different methods, including service, assessment criteria and the type of system, as illustrated in Table 1. Using the service method immediately shows four major categories including:

- Basic benchmarking: these are free tools serve the public
- Utility services: these are provided as a service to the utility customers
- Enterprise tools: these are commercial products serve large organisations
- Load libraries: these use data and models to develop load profiles in order to benchmark the whole-building load profiles.

When the assessment criteria method is used three categories can be found. The most popular criterion is the building performance index (EPI) in the form of energy utilisation index (EUI). Another criterion is the energy cost index (ECI). With the emphasis on the environmental sustainability the carbon emissions index (CEI) has become a very common criterion.

Table 1 Methods for categorising the benchmarking tools

Service	Assessment Criteria	System Type
Basic benchmarking	Energy utilization index (EUI)	Point-based
Utility services	Energy cost index (ECI)	Simulation model
Enterprise tools	Carbon emissions index (CEI)	End use index
Load libraries		Statistical model

For categorising the benchmarking tools with respect to the system type four major systems can be observed, namely: points-based rating systems, simulation model system, end-use indices system and statistical model systems. BREEAM in the UK, LEED in the USA and HK-BEAM in Hong Kong are examples of the points-based rating systems [10]. These systems do not compare the building against each others, rather they provide criteria to assess how efficient and environmentally friendly a building is, and compare it to best-practice standards. Each of these systems has a scale made up of rang of credits to meet the requirements of different criteria about features and provisions that are intended to enhance energy performance. The BREEAM system uses actual consumption figures, while the calculation of benchmarks in the LEED and HK-BEAM systems are based on an idealised simulation model of building performance. This method reflects the simulation model rating system. Several advantages can be obtained when such a method is used: firstly, it takes into account a great number of variables that impact the energy consumption, secondly, it generates performance targets, and finally, it compares a wide rang of design alternatives. However, the result is based on simulation models which may not be well fitted with the real life and the actual buildings stock data.
The end-use and environmental indices system is another type of benchmarking system. It represents the way of obtaining benchmarks that reflect the relationship between the energy consumption and functional requirements. This way is efficient to carry out a performance benchmarking or an analysis to determine the relationship between energy use and the factors influencing this use. This type can be seen in some operational benchmarking systems such as the Display Energy Certificates (DECs) and EPLabel software in the UK and the Australian Buildings Greenhouses Rating (ABGR) system. For quantifying the energy efficiency of buildings in the UK the EPLabel software is used to produce a DEC based on either assumed or actual total amount of energy used by a building over a year. This amount is then compared with an established benchmark either in term of EUI or CEI. The advantage of this system is the ease of use, low cost and time saving [11]. The ABGR rates the performance of existing buildings using historical utility bills, while the new design is rated using the predicted CO_2 emissions. In the ABGR, only trained and accredited public building energy assessors can conduct the rating, which should be done in strict accordance with a detailed procedure for collecting and analysing the required data for the assessment [12].
The last system uses statistical and analytical techniques. In this type it is necessary to have a great amount of data for energy consumption and a high level of statistical significance to meet a good degree of accuracy. The use of statistical regression model-based benchmarking has been utilised by the Energy Star benchmarking system [13]. This system benchmarks the energy performance according to the actual energy consumption in the regional and national levels of the USA based on on-site surveys and a regression analysis.
The current study is an extension to a pervious paper presented in PLEA 2007 into benchmarking the energy performance of buildings in Bahrain. It uses the regression model-based benchmarking system and the methodology of the Energy Star to rate buildings. Different from that methodology, this system uses established benchmarks to determine the level of high and poor performing buildings and also to assess the efficiency of buildings in Bahrain. The benchmarking process in this study is based on actual regional data. Detailed audit information obtained from on on-site surveys of buildings in Bahrain was used as this represents the most practical and logical starting point.

2. System Philosophy

This paper presents an energy benchmarking system for office buildings. Benchmarking office buildings represents an important market due to the potential for improvement in offices comparing with that of domestic buildings, and with the current rapid economic and architectural boom in the Gulf States this sector is becoming of a great interest. Although this system was design to serve all the Gulf States, this study focuses on office buildings in Bahrain. It outlines the methodology used to develop the energy benchmarking system for this small country (700 km^2), starting from the first step of data collection and constructing the database to the rating of buildings and finding targets for their future performance. Fig. 1 illustrates the process of rating and targeting the energy performance of buildings by the EPB system.

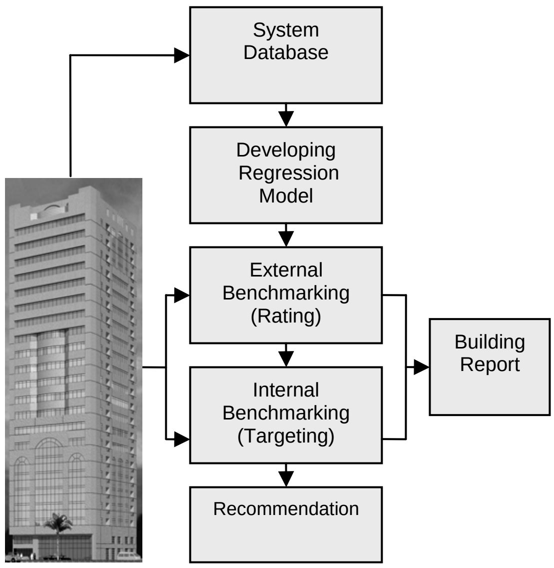


Figure 1 Process of rating and targeting the energy performance

The principal advantage of this system is that it rates the energy performance of building according to the actual and local energy consumption of buildings and not according to standards international baselines.

2.1 Building the Database

The most important part of the effort of developing the EPB system is building the database. Based on on-site surveys carried out by the Electricity and Water Conservation Directorate of Bahrain, detailed audit materials were obtained. With especial consideration to building type, floor area and operation parameters, a statistical analysis of these materials helped in constructing the system database. As electricity is the only form of energy used for powering buildings in Bahrain (700 km^2), the source of energy and climate impact were given less consideration. However, the system takes into account the source energy and cooling and heating degree-days when big countries in the Gulf States such as Saudi Arabia and Oman are concerned. The purpose of the database is to act as an archive for building data coupled with providing a regression model for the benchmarking software. This model is automatically updated when any new building is added by an authorised operator. Four performance parameters were identified as key variables that can be used to estimate the energy consumption of office buildings, including area, office equipment, operation schedule and occupancy. The efficiency technologies under the control of the energy management and those with unusual or highly variable were excluded.

2.2 Developing the Software

The software performs two benchmarking functions: firstly, rating current building performance, secondly, sets a target for future performance. Rating building is a form of external benchmarking that allows the energy managers to measure the level of performance in their buildings comparing to buildings with same physical and operational characteristics. Setting a target is a form of internal benchmarking that help to determine a goal for future performance. The purpose of first function is to compare the performance of similar buildings based on actual operating data. So it first predicts how the performance of a building should be with respect to a chosen group of buildings from the database or to the mainstream buildings in Bahrain. This is done using the following liner regression equation.

$$EPI=C_0+C_1*Area+C_2*Equip+C_3*Oper+C_4*Occup$$

Statistically, this equation is used to know the relationship between several independent or predictor variables and a dependent or criterion variable. In the current case, the NPI is the dependent and variables in the right side of the equation are the independents where C_1, C_2, C_3 and C_n represent the equation coefficients and C_0 is a constant. The software uses the result of dividing the actual EPI on the estimated EPI as the ratio of the building efficiency. The software then rates the buildings on a scale of 1-100 by converting the efficiency ratio to a performance percent. The smallest the ratio the highest the percent and the more efficient the building is. Fig. 2 illustrates the cumulative distribution of energy performance for the buildings in the database. The marked point represents the ratio in the efficiency distribution and the percent in the rating distribution.

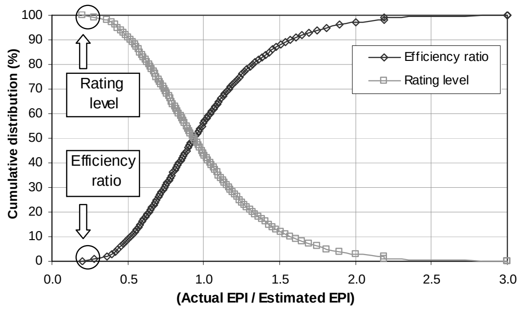


Figure 2 Rating the energy performance of buildings

To assess the efficiency level of buildings the benchmarking process ranks them based on their actual energy performance. As illustrated in Fig. 3, four ranks are available: high performers (often above 80), standard performers (50-80), poor performers (20-50) and extremely poor performers (under 20). It is important to note that the limits of each rank are determined with the consideration of the best and worst energy performers in the database. The rate and actual EUI and CEI of buildings can be used for producing a building performance report or certificate.

Buildings ranked below 80 or high performers often have sizable to dramatic energy consumption potential. These buildings can be subject to performance targeting process. The target is established based on the actual consumption data of the best performing buildings (rank 80) in the database and the consumption of the building subjected to the targeting process. In order to set a realistic and achievable target for the future performance, the reduction in the energy consumption is calculated as the difference between the energy consumption of the high performer of the same type and size and the actual energy consumption of the building in question.

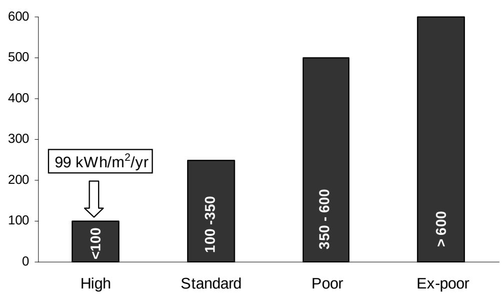


Figure 3 Ranks of energy performance

3. Implementation

3.1 Building Characteristics Considered in this Implementation

For the purpose of this implementation an existing office building from Bahrain was used. The Arab Financial Services (AFS) building is a medium size office building and was subject to a recent field benchmarking process. It has a ground floor and 8 more storeys as shown in Fig. 4. The gross floor area is 4572 m^2 of approximately 508 m^2 for each floor. Details of the building's physical and operational characteristics are illustrated in Table 2.

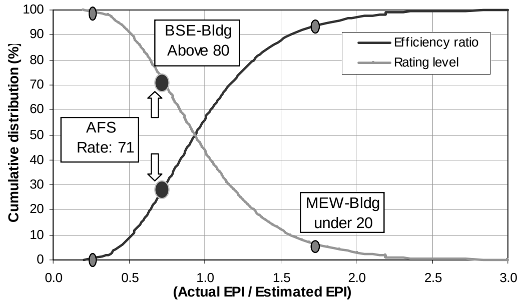
Figure 4 Front View of the Arab Financial Services (AFS) building

Table 2 Details of the building's physical and operational characteristics

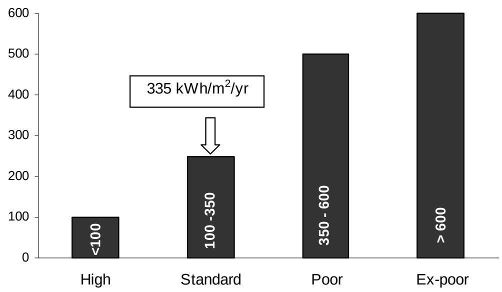
Building Parameters	
Type	Office building
No. of floors	9 floors
Floor area	4572 m^2 – 508 m^2 each
Floor height	2.3 m
Building system	
Computers	2.9 per 100 m^2
Lighting	Florescent / spot light 18.5 W/m^2
HVAC system	Central
Set point temperature	Winter 22°C
	Summer 24°C
Building operation	
Schedules	60 hours/week
Occupancy	3 per 100 m^2
Annual electricity Consumption	1535220 kWh
EUI	302 kWh/m^2/yr
CEI	211 kgCO_2/m^2/yr

3.2 External Benchmarking: Rating Buildings

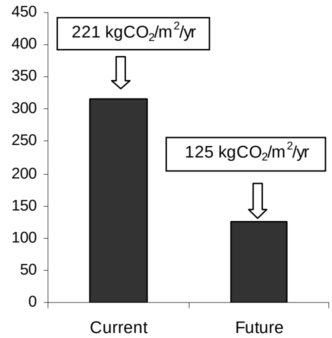
Fig. 5 illustrates the building report which contains building statistics, a rating scale, a rank indicator and a future target. The building statistics show that the efficiency ratio of the AFS building is 0.731. This ratio is positioned at the level of 29 on the rating scale. According to this scale, the studied building can be rated at 71 with respect to the buildings in Bahrain. The rank indicator shows that this building falls in the category of standard energy performer.



Rating Scale



Rank Indicator



Future Target

Figure 5 Building Report

For validation this outcome was compared with that from a recent benchmarking field study in reference [14]. In that study a group of office buildings was benchmarked including the case building. The same group of buildings was chosen from the database. Back to the building report, the bold point in the rating scale indicates the rate of AFS building relative to the chosen group, while the arrow in the rank indicator refers to the building as a standard energy performer. This building was benchmarked by the previous study as a poor energy performance, as shown in

Fig. 6. The poor, in the previous study and standard, in the EPB system, performers are simply because the previous study ranked building into only three categories (best, poor and worst). Therefore, it is clear that the system outcome shows almost the same results of the previous benchmarking study where BSE-Bldg is the best energy performer and the MEW-Bldg is the worst performer while the AFS building is a poor energy performer between them. Nevertheless, in the field study, there is no indication of the rate of each building relative to others. Clearly, the presented system not only provides almost the same result in terms of the status of building energy efficiency but also rates the building among each others more precisely.

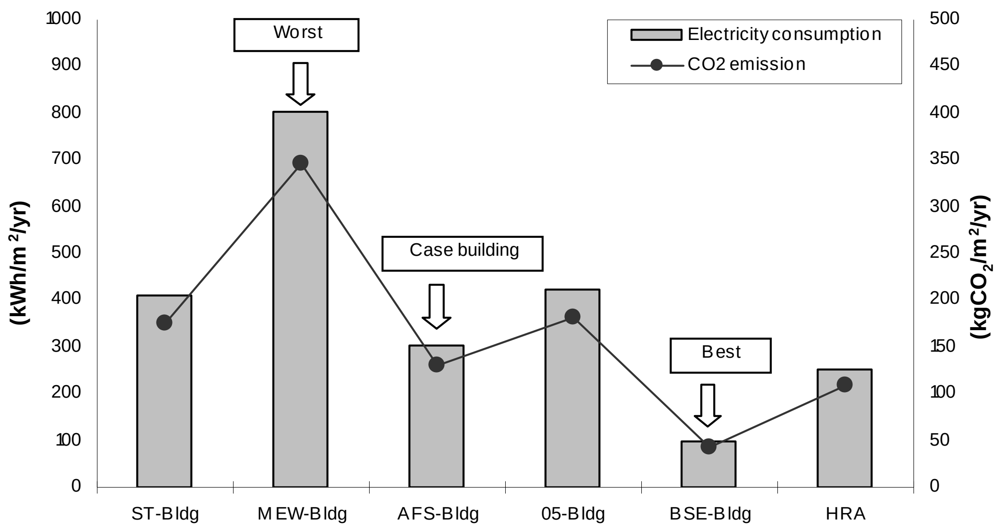


Figure 6 Benchmarking result from field study

3.3 Internal Benchmarking: Targeting Future Performance

As the studied building is below 80 or a high energy performer, it is assumed that there is a potential for energy savings. In order to set a realistic and achievable target for the future performance the improvement in the EPI is estimated with the consideration of the rank 80 or the high performer level of similar buildings and the actual EPI of the studied building. To reach the rate 80 for the building under study the difference between the high performance level and the actual level was first calculated. The difference is calculated as a percentage and then converted to kWh/m^2/yr and kgCO_2/m^2/yr. The obtained value indicates the required reduction in the energy consumption and CO_2 emissions to achieve rate 80 or the high performer rank. The output of the software shows the required reduction to achieve the high performer rank. As illustrated in the building report the building which has 335 kWh/m^2/yr or 221 kgCO_2/m^2/yr needs to reduce 235 kWh/m^2/yr or 96 kgCO_2/m^2/yr to be ranked as a high energy performer or to reach the level of 80. The reporting of the most cost effective saving measures to achieve the high energy performance rank is subject for future development.

4. Conclusion

A new system for benchmarking the energy performance of buildings in Bahrain was developed. It works as a comprehensive archive for building data in Bahrain and as benchmarking software. The benchmarking process in this system is based on a regression analysis of actual local building data. The tested case building demonstrated the effectiveness of the presented system in benchmarking the energy performance of buildings. The outcome of the software not only shows almost the same result of a recent field study but also rates the building among each others more precisely.

Although some systems, such as LEED, are partly used in Bahrain, most these systems are based on simulation models and international benchmarks which may not be well fitted with the actual buildings stock data in Bahrain. Furthermore, these systems need a certain level of experience in building engineering which probably makes it impossible for architects and building owners to perform such benchmarking. The principal advantage of the presented system is that it benchmarks the energy performance of buildings according to the actual local energy consumption and not according to building simulation or standards international baselines. It also requires a minimum knowledge of building engineering.

It is expected that the building industry in Bahrain will likely benefit from the introduction of such a system, and the most benefits can be obtained when this system is incorporated into the official web site of the Electricity and Water Conservation Directorate. It can provide design teams, building managements and owners with the means to check the energy efficiency of buildings and rating their performance relative to the building stock. This is useful in energy design and compliance with building regulations.

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