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Benchmarking energy use assessment of HK-BEAM, BREEAM and LEED

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Abstract

The Hong Kong Building Environmental Assessment Method (HK-BEAM), Building Research Establishment Environmental Assessment Method (BREEAM) and LEED were formally launched in the 1990's. How well the certified and rated buildings compare with each other of an interest to building designers and policy makers. This paper describes how the baseline buildings, performance criteria and the credit scales of the three schemes compare with each other. By statistical analysis of the energy assessment results of 60 HK-BEAM certified buildings and the available data for BREEAM and LEED, it seeks to ascertained of buildings scoring excellent energy performance under different schemes belong to the top 5% in the market. Through this exercise, a systematic approach to benchmark the energy assessments across schemes has been established. With people nowadays paying greater attention to the environmental issues and the rapid development of the environmental schemes in various parts of the world, this study forms a good basis for future benchmarking of energy assessment schemes across nations.

Keywords: Benchmarking; HK-BEAM; BREEAM; LEED; Energy performance assessment

1. Introduction

The Hong Kong Building Environmental Assessment Method (HK-BEAM) is a voluntary scheme first launched in December 1996 [1,2]. The original HK-BEAM scheme comprised two versions, one for new (HK-BEAM 1/96) and the other for existing office buildings (HK-BEAM 2/96). It covered a wide range of issues related to the impacts of buildings on the environment in the global, local and indoor scales. In 1999, an additional version for new residential buildings was issued [3]. Under HK-BEAM 96, 52 commercial buildings have been successfully assessed.

Reviews of HK-BEAM 96 were done in 2003 and 2004 to address the implementation problems experienced and to expand the range of building types that the scheme can cover, leading to the publication of the latest versions for new buildings (4/04) and for existing buildings (5/04) [4], which were formally launched in 2005.

At the end of 2006, another eight commercial buildings/complexes were successfully assessed under HK-BEAM 04. On a per capita basis, HK-BEAM has assessed more buildings and more square meters of space than any other scheme in use worldwide. Building on this success, a question is raised as to whether buildings that have been rated and certified by HK-BEAM are equally good if assessed by the other schemes in developed countries like US, UK, Japan, other EU countries, PRC, etc. The need to benchmark HK-BEAM with other building environmental assessment schemes is recognized.

The first Building Research Establishment Environmental Assessment Method (BREEAM), launched and operated by the Building Research Establishment (BRE) in UK, came into prominence in 1990 [5,6]. Version 1 BREEAM for offices was first revised in 1993. The second revision was launched in September 1998. The current BREEAM version for non-domestic premises is BREEAM 2004 [7]. It covers a range of building types, including

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offices; industrial premises; retail outlets; schools, etc. It is the best-known scheme and has embraced 15–20% of the new office building market in the UK [8]. BREEAM has also been taken as a reference model when similar schemes were developed in Canada, New Zealand, Norway, Singapore and Hong Kong [9].

LEED was developed by the US Green Building Council (USGBC) for the US Department of Energy [10]. The pilot version (LEED 1.0) for new construction was first launched at the USGBC Membership Summit in August 1998. In March 2000, LEED Version 2.0 based on modifications made during the pilot period was released. Since then, LEED continues to evolve to respond to the needs of the market and to expand to cover other building types. The most current LEED for New Construction Version 2.2 was released in November 2005. Current versions for other building types, including schools, homes, etc. were either released in 2006 or scheduled to be released. So far LEED is the most recognized building environmental assessment scheme. The registered projects are in progress in 24 different countries, including Canada, Brazil, Mexico, India and China, and the World Green Building Council—an affiliation of seven national green building councils, including the US.

Surely BREEAM and LEED are the two most representative building environmental schemes. Considering the wide coverage of the environmental issues; the range of building types that are covered; and the significant difference in scope and assessment criteria between schemes, benchmarking the whole scheme will not come up with conclusive and indicative results. In this study, focus is given to benchmark the energy use assessment methods of new office buildings within HK-BEAM, BREEAM and LEED. This is on the basis that the first version of most schemes is on new office buildings, and energy use is the most tangible benefit to the building developers.

Given that most HK-BEAM certified buildings are assessed under HK-BEAM 96, the criteria and assessment method of HK-BEAM, BREEAM and LEED since then have been changed; earlier versions of BREEAM and LEED will be used for a fair comparison. Benchmarking will therefore be between HK-BEAM 96, BREEAM 98 and LEED 2.0. Hereafter they will simply be addressed as HK-BEAM, BREEAM and LEED.

In achieving the objectives, this study will be conducted as follows:

(i) review the energy assessment methods and criteria adopted;
(ii) benchmark the baseline building, the simulation tool used, and the performance criteria; and
(iii) identify the positioning of the certified buildings to benchmark the credit scales.

2. Review of assessment method

Table 1 compares HK-BEAM with BREEAM and LEED. It can be seen that the three schemes differ significantly in scope and assessment criteria. However, they generally include performance-based assessment, together with features and provisions that are intended to enhance energy performance (e.g. energy-efficient design, envelop performance, etc.). For new buildings, performance assessments are based on simulation/calculation. BREEAM assessed the ‘absolute’ performance to minimize the overall emission of CO_2, whereby HK-BEAM and LEED seek to determine the improvement in the design (as a percentage). The assessment compares the ‘assessed building’ with a ‘baseline’ building, assuming similar weather data, occupancy patterns, installed equipment, etc. There is no baseline case for BREEAM.

Table 1
General comparison

Item	HKBEAM	LEED	BREEAM
Assessment method	Mixture of performance-based and feature-specific criteria	Options of feature-specific criteria and energy cost budget method	Mixture of performance-based and feature-specific criteria
Simulation tool	HTB2 + BECON or approved equivalent	DOE-2 or BLAST or approved equivalent	No specific requirements. Actual consumption figures may be used where available
Scope of assessment	• Annual energy use • Maximum electricity demand • Energy efficient design • Envelope performance	• Energy-efficient design • Annual energy cost	• Annual CO_2 emissions • Energy-efficient design
Max. credit level performance based criteria	Reduction of 57% in annual energy use over the baseline case	Reduction of 60% in annual energy cost over the budget	Zero emissions
Min. credit level performance based criteria	120 $kWh/m^2/yr$	Reduction of 15% in annual energy cost over the budget	160 kg $CO_2/m^2/yr$
Baseline case/zero credit level	Compliance with the minimum requirements laid down by relevant laws or codes of practice	Compliance with ASHRAE/IESNA 90.1-1999 [38]	Compliance with DETR (1998) good practice guides
Energy-related credits/points (%)	23	25	20

3. Benchmarking the baseline building

The evaluation is between HK-BEAM and LEED. Between the schemes, the 'zero' credit level and the maximum credit level were determined according to the baseline case. To compare the energy performance criteria it is necessary to 'benchmark' the baseline buildings. Table 2 summarizes the values used in establishing the energy use criteria of the 'baseline case' and the 'assessed case.'

It is noted that the parameters used differ largely between the two schemes, in particular the default building, system operation schedules and the indoor design conditions.

4. Default schedules

The energy benefit of an energy-efficient measure may be dependent on the simultaneous building and system operation schedules. As energy use improvement is adopted to assess the enhanced energy performance of an energy-efficient measure, whether or not the energy benefit will be affected by the default schedules assumed is considered critical to benchmark the three schemes.

A parametric study has been performed to determine the sensitivity of annual energy use improvement to changes in default values. In the parametric study, a baseline building and an assessed building were established based on the characteristics of a hypothetical office building in Hong Kong [11]. The building characteristics and the system design values of the hypothetical office building were established by an extensive energy audit survey conducted previously [12]. The baseline building model is marginally in compliance with the relevant laws or codes of practice in Hong Kong, whilst the assessed building is the model used in establishing the upper benchmark of HK-BEAM.

The parametric study was performed by varying the schedules for the occupancy, the lighting system and the equipment. The variation was on the basis that only one set of schedule was changed for each simulation. The tools used for the prediction of energy use were the building heat transfer simulation program HTB2 [13] and the air-conditioning system simulation program BECON [14].

The results indicate that by the use of two different sets of operation schedules, the predicted reduction in energy use have a small difference of 0.74–1.43%. This shows that the predicted reduction in energy use is not sensitive to changes in building operation schedules. It can be concluded that if the same set of schedule, regardless of whether it is default or designer specified, is used to predict the annual energy use of both the baseline case and the assessed case, there is little influence on the relative enhanced energy performance; and in accordance, will not affect the assessment results of the two schemes.

5. Indoor design conditions

Indoor design conditions, including the dry bulb temperature set-point, the ventilation rate, the occupancy density, and the lighting and equipment power intensities can influence substantially the air-conditioning energy use in a building [15].

It is necessary to determine how the baseline energy use is affected if LEED's default indoor design conditions are used. The energy prediction model developed earlier to simplify HK-BEAM assessment [16] was used to determine the influence on the annual energy use of the baseline building in HK-BEAM. Table 3 summarizes the results. It is noted that the baseline energy use using LEED's default conditions leads to a reduction in baseline energy use by 38 kWh/m^2.

6. Benchmarking the simulation tool

It can be seen in Table 1 that HK-BEAM recognizes HTB2 + BECON whilst LEED recognizes DOE2 or

Table 2
Indoor design conditions

Parameter	HKBEAM		LEED	
	Baseline case	Assessed case	Energy cost budget	Assessed case
Occupancy schedule	Default, but different schedules are used			
Occupancy density (m^2/person)	9	As designed	25	
Indoor design conditions	25.5 °C/54% (maximum)	As designed	23.9 °C	
Lighting schedule	Default, but different schedules are used			
Lighting power density (W/m^2)	25	As designed	14	As designed
Equipment schedule	Default, but different schedules are used			
Equipment power density (W/m^2)	25	As designed	8	
Air-conditioning schedule	Default, but different schedules are used			
Min. ventilation rate (L/s/person)	10	As designed	10	
Building envelope	OTTV = 30 W/m^2 [32]	As designed	Compliance with base envelop requirements	As designed
Infiltration ($L/s/m^2$)	A/C on—0.09, A/C off—0.45		A/C on—nil, A/C off—0.2	

Table 3
Baseline energy use

Indoor design condition	HKBEAM	LEED	Difference
Ventilation rate ($L/s/m^2$)	1.1	0.4	+0.7
Indoor set-point temperature (°C)	25.5	23.9	+1.6
Lighting power density (W/m^2)	25	14	+11
Equipment power density (W/m^2)	25	8	+17
Infiltration rate ($L/s/m^2$)	0.09	0	+0.09
Assumed COP	2.7	2.7	0
Overall baseline energy use increase	+38 kWh/m^2		

BLAST. There is no specific requirement on the simulation tool for BREEAM, despite the fact that BRE, the operator of BREEAM, has considerable experience in modeling and simulating energy use in buildings using their tools such as the Simplified Building Energy Model (SBEM) [17]. It is acknowledged that there must be predictive differences between simulation softwares caused by algorithmic differences, modeling limitations, input differences, etc. Given that assessments are based on design, which depends on the software simulation accuracy, there is a need to conduct systematic benchmarking of the simulation softwares. However, SBEM is relatively new, and only came into widespread use in 2006 following revisions to Part L Building Regulations in England and Wales. Its intended use is as a carbon dioxide emissions compliance tool. There is very little SBEM data available in the public domain [18]. Benchmarking therefore focuses on HTB2 + BECON and DOE2.

ASHRAE Standard 140 Standard Method of Test (SMOT) [19] specifies test procedures for evaluating the technical capabilities and ranges of applicability of computer programs that calculate the thermal performance of buildings and their HVAC systems. Standard thermal performance and mechanical test procedures have been applied in validating HTB2 + BECON and DOE 2.1E. There are 40 carefully described test case building plans and equipment specifications—the basic cases; the in-depth cases and the HVAC equipment cases. The basic cases test the ability of the programs to model combined effects such as thermal mass, direct solar gain windows, window shading devices, etc., whilst the in-depth cases evaluate the specific heat gain mechanisms. The HVAC equipment cases test the ability of programs to model the performance of space cooling equipment using manufacturer design data. The outputs from the thermal performance tests were used for the mechanical tests.

In the study, the system and building characteristics of a typical commercial building in Hong Kong (Building X) were used to form the skeleton of the tests. Building X was selected because a complete set of building, system and equipment details is available. The result of the study indicated that HTB2 overpredicted the solar heat gain when window overhang type shading devices were used. DOE2.1E was found to have overpredicted the heating and cooling loads. However, the overall predictions are within the acceptable range of the SMOT tests. Detailed results are reported in a separate study [20].

The evaluation confirms that the two simulation tools are in compliance with ASHRAE Standard 140 and can be considered acceptable to each other.

7. Benchmarking the performance criteria

The performance criteria are to enable the determination of different levels of energy performance and credit values. The maximum credit level of HK-BEAM is 57% improvement over the baseline case, whilst that of LEED is 60%. BREEAM sets a target to acquire zero carbon emissions. Minimum credit level has been given by the schemes. For the baseline case, no specific values have been given, but the schemes have specified the conformance to the relevant regulatory requirements or the basic design requirements.

The information given in the documents is not sufficient to reveal the performance criteria of BREEAM and LEED, whereby the criteria for HK-BEAM are known to the authors as well as in public literature [11]. Reference is therefore made to the performance criteria of HK-BEAM in an attempt to derive the criteria for the other two schemes.

It is noted that the baseline level (AEU_b); the minimum credit level (AEU_m) and the best achievable level (AEU_a) of HK-BEAM for air-conditioning of the baseline building are 138; 120 and 59 kWh/m^2, respectively. The corresponding maximum reduction in energy use is 79 kWh/m^2 and the percentage of energy reduction ($\Delta AEU = 57\%$) given in Table 1 is determined as

$$\Delta AEU = \frac{AEU_b - AEU_a}{AEU_b} \times 100\%. \quad (1)$$

If the default schedules and indoor design conditions of LEED are used, according to the previous section, the baseline level will be revised to 100 (i.e. = 138–38 kWh/m^2) and hence the minimum credit level and the best achievable level in energy use are 85 and 40 kWh/m^2, respectively. The corresponding maximum reduction in energy use is 60 kWh/m^2.

In determining the same for BREEAM, whereby the minimum credit level is specified as 160 kg $CO_2/m^2/yr$ (all end-uses), it is required to convert the CO_2 emissions to the equivalent electricity consumed for air-conditioning (including heating). According to the national statistics [21] and the publicized data [22] in the UK, air-conditioning and heating contribute to 55% of the energy use amongst all end-uses and the conversion factor for CO_2 emission is 0.43 kg CO_2 per kWh electricity consumed. Based on these figures, it can be estimated that the equivalent electricity consumed at the minimum credit level is 205 kWh/m^2.

Given that the schemes are based on different climatic conditions, whereby the energy use levels may differ largely from each other, and adding that BREEAM may base on actual consumption figures, whilst the other two rely on simulation results, we cannot comment at this point on which scheme sets higher or lower performance criteria. Reference is made to the annual energy use characteristics for air-conditioning in the UK. According to the figures provided in CIBSE guide F [23], the average energy use for air-conditioning of typical offices is 434 kWh/m^2. This is reduced to 237 kWh/m^2 for offices in compliance with good practice requirements, which is also interpreted as the baseline energy use.

The performance criteria of the three schemes determined in the above are compared in Fig. 1. It can be seen that the performance criteria, expressed in percentage reduction in energy use relative to the baseline case of the schemes, compared well with each other, except that BREEAM sets a more aggressive reduction target to require zero carbon emission.

8. Benchmarking the credit scales

The credit scales of the three schemes are summarized in Fig. 2. It can be seen that HK-BEAM and LEED adopt a linear scale, whilst BREEAM adopts an incentive crediting scheme, i.e. proportionally higher number of credits is awarded for an increase in performance level. Given that the credit scales of the three schemes differ amongst each other, the credit level awarded by individual scheme cannot simply reflect the actual performance of the certified building. To benchmark the credit scale of the three schemes, there is a need to identify the distribution of the office buildings for different credit levels.

LEED certified buildings (certified, silver, gold and platinum) are claimed to be better than code requirements and are in the top 25% of the market standard [24]. The figures of 17 certified buildings indicate that the mean energy savings is 27% [25]. Similar to LEED, the zero-credit level (baseline) of HK-BEAM and BREEAM were determined based on compliance with the code and

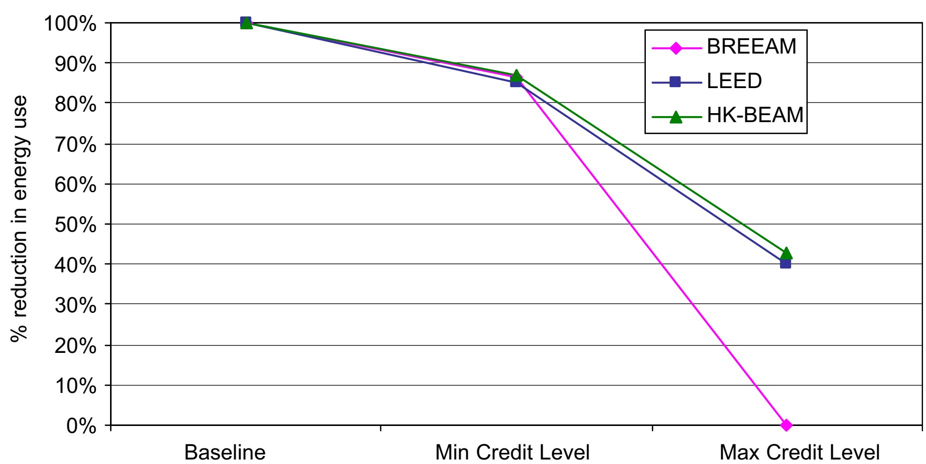

Fig. 1. Performance criteria of the schemes.

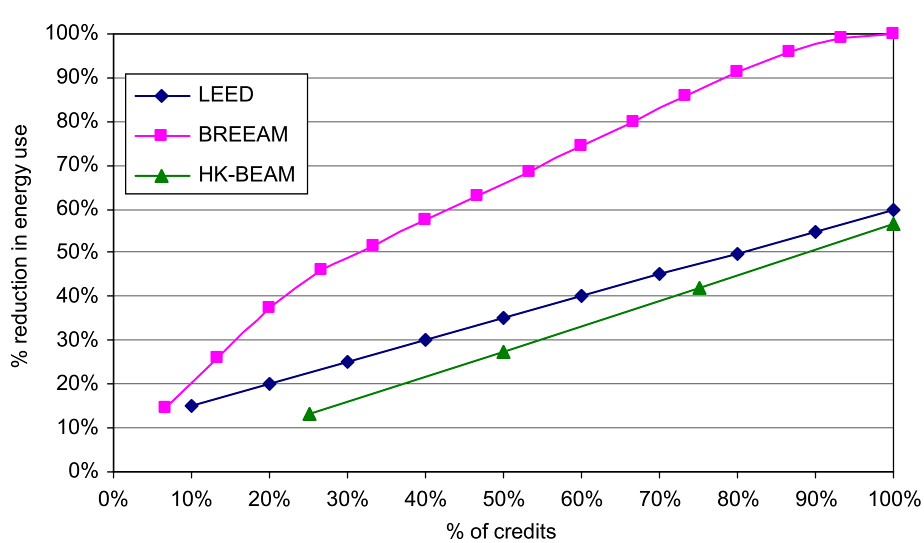

Fig. 2. Credit scale of the three schemes.

Table 4
The annual energy use and design data of 60 office buildings in Hong Kong

Bldg. no.	A/C area (m^2)	Q_{LGT} (W/m^2)	VR (L/s/person)	OCC (m^2/person)	HR system	AEC ($kWh/m^2/yr$)
1	23,526	20.0	7.0	9.0	WC	83.4
2	1905	25.0	7.0	9.0	AC	120.0
3	50,000	27.0	7.0	9.0	AC	128.0
4	21,000	20.5	9.0	9.5	AC	134.7
5	32,165	20.0	7.0	9.0	WC	116.8
6	51,907	17.2	7.0	8.0	WC	76.5
7	44,066	20.0	11.3	10.0	AC	149.4
8	10,917	25.0	10.0	9.0	AC	129.4
9	37,227	25.0	10.0	9.0	AC	75.3
10	37,227	25.0	9.5	9.0	AC	101.9
11	29,477	15.0	10.0	9.0	WC	71.0
12	17,756	15.0	10.0	9.0	WC	91.0
13	4449	15.0	10.0	9.0	WC	77.0
14	13,978	15.0	10.0	9.0	WC	98.0
15	21,444	15.0	10.0	9.0	WC	91.9
16	18,387	25.0	10.0	9.0	WC	83.0
17	44,440	20.0	10.0	9.0	AC	119.1
18	43,230	17.8	7.5	7.5	WC	106.3
19	5672	13.8	10.0	12.0	AC	90.0
20	29,698	14.6	10.0	11.3	AC	82.5
21	14,105	20.0	10.0	15.0	WC	78.5
22	10,916	14.0	10.0	9.0	WC	85.1
23	9590	14.0	10.0	9.0	WC	101.7
24	16,327	14.0	10.0	15.0	WC	80.2
25	11,873	13.2	10.0	9.0	WC	56.2
26	8674	13.3	10.0	9.0	WC	105.9
27	10,000	14.0	10.0	9.0	WC	62.1
28	62,938	25.0	10.0	8.0	WC	85.5
29	6938	15.0	10.0	10.0	AC	108.4
30	6877	25.0	10.0	10.0	AC	93.9
31	5170	15.0	10.0	9.0	WC	64.8
32	34,300	25.0	13.4	9.0	WC	148.0
33	36,872	18.0	5.1	9.0	AC	103.6
34	36,872	15.0	10.0	9.0	AC	120.0
35	55,476	27.0	6.3	5.9	WC	141.1
36	61,438	25.0	8.0	6.5	WC	132.0
37	16,302	17.7	10.0	14.0	AC	94.8
38	4248	15.6	8.0	10.0	AC	104.3
39	1459	22.8	8.0	7.0	AC	97.3
40	4465	24.8	8.7	10.0	AC	99.5
41	15,838	37.0	5.2	7.0	AC	104.0
42	60,275	18.4	7.0	7.0	WC	85.8
43	56,515	21.7	8.0	9.0	WC	70.2
44	136,178	14.2	4.7	9.0	AC	147.3
45	53,835	10.6	7.0	7.0	WC	78.0
46	22,603	19.2	7.5	7.0	AC	99.1
47	53,000	12.8	8.0	6.0	WC	89.7
48	63,839	25.0	7.0	7.0	AC	123.0
49	33,010	16.2	7.5	9.0	WC	128.1
50	39,461	17.3	7.5	9.0	WC	115.8
51	29,698	14.6	16.8	11.0	AC	72.1
52	50,000	27.0	7.4	9.0	WC	107.5
53	57,425	10.5	10.0	7.0	WC	114.3
54	56,219	10.5	10.0	7.0	WC	106.4
55	37,460	10.5	10.0	7.0	WC	1116.0
56	33,672	13.0	9.3	9.3	WC	138.0
57	64,476	30.0	7.5	7.0	WC	79.6
58	61,570	22.3	7.5	7.0	WC	83.8
59	12,576	12.6	8.3	9.3	AC	113.9
60	72,888	14.0	8.0	9.2	AC	83.8

Remarks:
A/C area: total conditioned area; Q_{LGT}: lighting load intensity; VR: ventilation rate; OCC: occupancy; HR system: type of heat rejection system, AC = air cooled; WC = water cooled; AEC: annual energy consumption.

regulation requirements. However, there is no information to indicate how well the HK-BEAM and BREEAM certified buildings compare with typical practice in the market.

Reference is made to the simulated energy performance of the 60 HK-BEAM certified office buildings. The annual energy use data are summarized in Table 4. The energy use distribution of the certified buildings and the standard normal curve determined by Eq. (2) based on the population mean and standard deviation are compared in Fig. 3. It is noted that the distribution of energy use of the HK-BEAM certified buildings resembles the standard normal curve and thus exhibits a normal distribution:

$$Z_i = \frac{x_i - \mu_i}{\sigma}, \tag{2}$$

where x_i is the ith energy use level, from 50 to 160 kWh/m^2 in an incremental level of 10 kWh/m^2, μ the population mean, 100.7 kWh/m^2, σ the standard deviation of the population, 22.8 kWh/m^2 and Z_i the standard normal variable to calculate probability associated with the ith energy use level.

Assuming that the energy use of the office buildings in Hong Kong also exhibits a normal distribution, and the HK-BEAM certified buildings belong to the top 25%, the energy performance distribution of the commercial buildings in Hong Kong as a whole can be determined by a statistical method [26]. The process starts by scaling down the standard normal variable Z_i of the 60 assessed buildings to the range of 0.675 ($Z_i = 0.7501$) to 3.0 ($Z_i = 0.9990$), to represent the top 25% area under the normal curve. The Z_i values can then be regressed to

$$Z_i = 0.0238x_i - 3.8464. \tag{3}$$

Hence, σ and μ can be postulated as 42 and 162 kWh/m^2, respectively. Based on σ and μ, the energy performance distribution of the office buildings in Hong Kong can be constructed, as shown in Fig. 4.

The results confirm that HK-BEAM certified buildings are also in the top 25% in energy performance on the following basis:

- It is noted that the energy use at the top 25% is 139 kWh/m^2, which matches well with the baseline case used in establishing the performance criteria of HK-BEAM.
- It is noted from surveys that the annual energy consumption of central air-conditioning systems in commercial buildings in Hong Kong (paid for by the landlord) may range from 150 to 400 kWh/m^2. This depends on the mix of types of premises (e.g. offices, retail shops, restaurants, etc.) in the building, and other factors, such as medium for air-conditioning heat rejection, plant performance, hours of operation, etc. The whole building consumption, including tenants' consumption, may range from 150 to 450 kWh/m^2 [27–29]. The predicted maximum consumption level (325 kWh/m^2) matched well with the actual energy use obtained from surveys. This is determined by scaling up the predicted energy use by a factor of 50% to get the actual energy use (i.e. $325 \times 1.5 = 488$ kWh/m^2). The 50% margin was determined based on a previous detailed study [30–32], which closely examined how the predicted energy use of 26 existing buildings is affected by some inevitable factors, for instance: overtime air-conditioning provisions; reduced coefficient of performance of chillers due to aging and oversized plant.

On the assumption that the energy performance of the office buildings in the UK and US also exhibit a normal distribution, the x-axis in Fig. 4 can be scaled up, according to each of their performance criterion, to get performance distribution curves for the UK and US. The results are shown in Fig. 5. Note that the UK figures, based on actual consumption figures, appear to be much higher than the US figures determined by simulations.

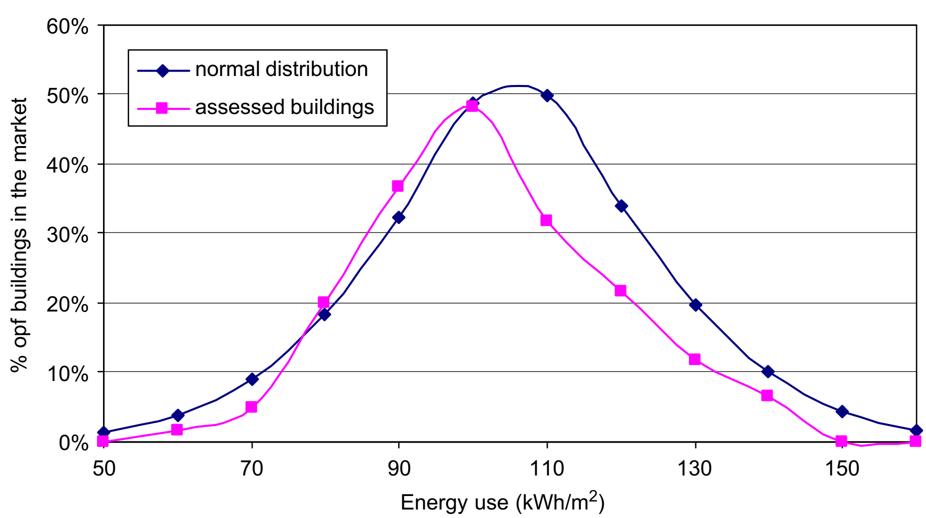

Fig. 3. Distribution of a standard normal curve and the assessed buildings.

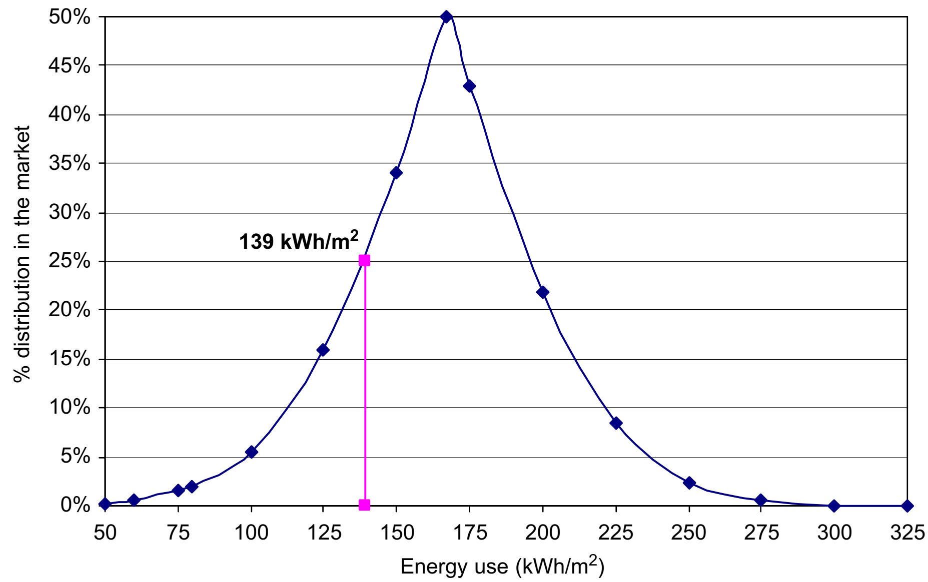

Fig. 4. Distribution of energy performance of office buildings in Hong Kong.

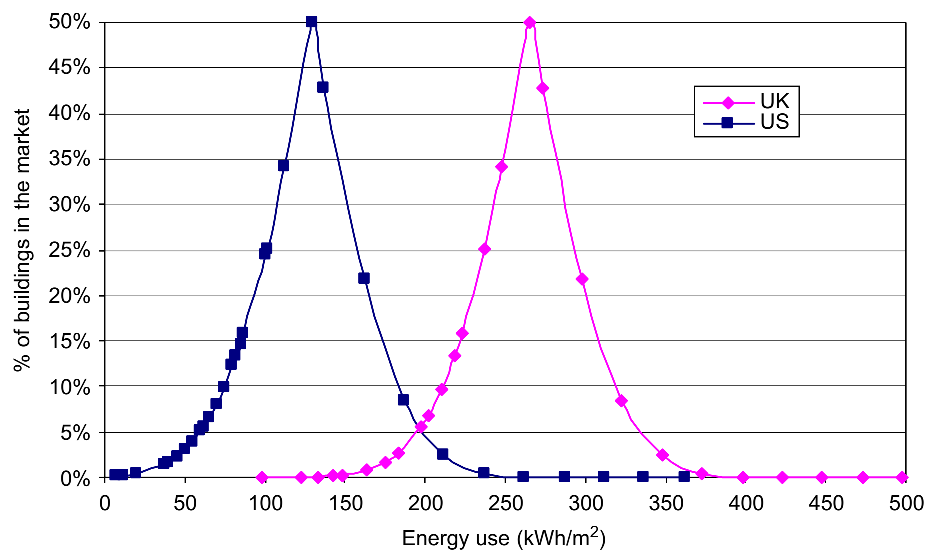

Fig. 5. Distribution of energy performance of office buildings in the UK and US.

On the basis of Figs. 4 and 5, the frequency of occurrence of office buildings in the three countries/cities for different credit levels can be determined. The results are summarized in Fig. 6. The credit levels are represented by the fraction of maximum credits for ease of comparison. It can be seen that to score energy credits under BREEAM is the most difficult; both for high and low credit levels. However, it is the easiest to score 40% credits under HK-BEAM, but becomes difficult for higher credit level, and is vice versa for LEED.

9. Scheme development

As knowledge, experience and available data have increased, it has resulted in changes to the performance criteria, the credit scales and the baseline building requirements in HK-BEAM, BRREEAM and LEED.

The latest version of HK-BEAM (04) is based on the energy budget approach. The credit scale has been revised to adopt an incentive-crediting scheme [33]. The performance criteria have been relaxed to require 10% and 45% reduction in energy use for minimum and maximum credit levels [4], respectively, but the baseline building requirements have been raised to require full compliance with building energy codes issued by the HKSAR Government [34–38].

The energy assessment in BREEAM 2004 for new offices has been extended to assess the building envelope performance. The corresponding credit value allocated for CO_2 emissions has thus been reduced. The credit scale has been relaxed to award more credits for the same CO_2

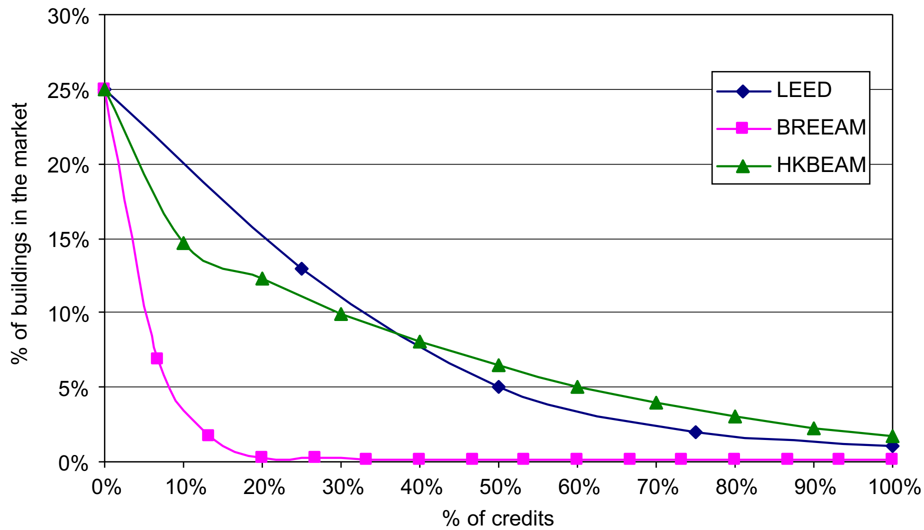

Fig. 6. Frequency of occurrence for different credit levels.

emission level. The baseline building and the performance criteria remain unchanged [39]. The baseline building defined in LEED Version 2.1 is ASHRAE 90.1 (1999) [40] compliant, whilst LEED Version 2.2 uses ASHRAE 90.1 (2004) [41]. The credit scale remains linear in nature. The requirements of the baseline building have been raised, but the performance criteria have been lowered. It has been changed to require 10.5% and 42% reductions in energy use for minimum and maximum credit levels [42], respectively.

It is noted that among the three scheme developments, BREEAM 2004 is the one that has relaxed the performance requirement. This is reasonable because to score credits under BRREEAM 98 has been identified the most difficult. LEED and HK-BEAM, on one hand relax the performance criteria, but raise the baseline building requirements on the other. Such changes, according to the initial implementation results of HK-BEAM 04, reward the high-performance buildings and penalize marginal buildings. This is consistent with the objectives of the schemes' development in encouraging early certified buildings to achieve a higher performance level.

10. Conclusion

A methodology to benchmark the energy assessment of three representative building environmental assessment schemes has been established. Based on the available data, the benchmarking study has concluded that amongst the earliest versions of HK-BEAM, BREEAM and LEED:

- The performance levels of the baseline buildings are comparable.
- The simulation tools are both in compliance with ASHRAE Standard 140.
- The market positions of the certified buildings are in the top 25%.
- The difference in energy use assessment methods, baseline buildings, simulation tools and performance criteria do not affect the assessment results.
- It is most difficult to score credits under BREEAM.
- Buildings that scored excellent energy performance under HK-BEAM, BREEAM and LEED belong to the top 5% in the market.

Given that international efforts are focusing on developing a generic assessment framework to facilitate international comparison [43,44], the benchmarking results above provide useful information for future development of the three schemes in moving toward these objectives.

It is also noted that the level of performance needed to achieve certifications of the latest versions of the three schemes, namely: HK-BEAM 04, BREEAM 2004 and LEED 2.2, have been changed, and new schemes may evolve over time; the benchmarking protocol established in this study can be used to help continuous evaluation of the schemes should assessment results become available.

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