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Energy assessment of office buildings in China using LEED 2.2 and BEAM Plus 1.1

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ABSTRACT

LEED and BEAM Plus have been formally launched for more than 10 years. They are the two most recognized building environmental assessment schemes in China. Previous works have been done on benchmarking the energy assessment of the two schemes. However, benchmarking was either based on their earlier versions of which substantial changes have been made, or focused on their assessment issues and metrics without making reference to actual building characteristics. This paper compares the energy performance assessment results of three new office buildings in China (one in Beijing and two in Shanghai) using current versions of LEED and BEAM Plus. The three office buildings were chosen for their similarities in design. The study revealed that despite the variations in different aspects between LEED and BEAM Plus, assessment results of the three studied buildings were comparable. Amongst various building end uses, energy use for air-conditioning was found dominating the assessment results. Comparison results also show that although different tariff systems are adopted in Beijing and Shanghai, the difference will not affect the assessment results as long as same tariff system is used for predicting the energy cost of the baseline and design cases.

1. Introduction

China is the country with the largest population in the world. It has had double-digit rates of economic growth in the past two decades. This growth spurred rapid construction in the past 20 years. This rapid construction has tremendous impact on the energy consumption and environmental conditions in China; in particular the energy use intensity (consumption per square meter) for heating and air-conditioning for buildings. In 2005, China's building sector accounts for 27.8% of total energy use and probably accounts for 40–45% of total energy use from life-cycle prospective [1]. Although the building energy codes in China have been developed over two decades, there seems no major improvement to the energy efficiency of buildings in China. A survey of the energy performance of office buildings in China was conducted by the Ministry of Construction (MOC) in year 2000. The survey result showed that only 2.1% of the surveyed buildings satisfied the prescribed energy performance standard [2]. Decision therefore has been made by the government to reinforce the energy efficiency of buildings in China [3]. Mixes of regulatory and voluntary instruments have subsequently been introduced; which many believe is a more cost effective approach in dealing with environmental problems [4]. The "Design Standard for energy efficiency of public buildings GB50189-2005) [5]" and the "Standard for lighting design in buildings (GB50034-2004) [6]" are the two mandatory codes controlling energy use in office buildings. The codes set minimum performance criteria on building envelope components, and on the heating, air-conditioning and lighting systems. A more ambitious energy conservation target is specified in the recently issued voluntary building environmental assessment scheme "Evaluation standard for green building (GB/T 50378-2006)" [7]. The scheme (abbreviated as ESGB) is administered by China's Green Building Office (GBO) established in April 2008. Up to June 2009, 10 buildings have been successfully certified by ESGB [8], but details of the ten buildings are not available in public domain.

Although ESGB has been introduced in China, it has been observed that major building developers in China normally undergo additional assessment to demonstrate the improved environmental performance of their building assets in attracting international investors. Of the building environmental assessment schemes introduced in different regimes, the most-adopted scheme in China is undoubtedly Leadership in Energy and Environmental Design (LEED) scheme, which is developed by US Green Building Council (USGBC). The scheme has registered projects in progress in 24 different countries, and up to March 2012, there are altogether 172 certified projects in China [9].

Hong Kong is the wealthiest city in China, and has the world's largest number of skyscrapers. The Hong Kong Building

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Environmental Assessment Method (BEAM Plus) is a voluntary scheme first launched in December 1996 (formerly known as HK-BEAM). BEAM Plus, on a per capita basis, is the most widely used voluntary scheme of its kind in the world [10]. Over 200 top-class office buildings in Hong Kong are BEAM Plus certified. Since the Closer Economic Partnership Arrangement (CEPA) came into force in 2003, collaboration between Hong Kong and mainland China has been deepened in different aspects. Seeking BEAM Plus certification is increasingly being made a condition for building projects in China. It is therefore an advantage for the further development of both LEED and BEAM Plus if appropriate benchmarking of the assessment results between these two schemes can be established.

Previous works have been done on benchmarking the energy assessment of the two schemes. However, benchmarking was either based on their earlier versions (HK-BEAM 96 and LEED 2.0) [11] of which substantial changes had been made or focused on their assessment issues and metrics without making reference to actual building characteristics [12,13]. This paper compares the energy performance assessment results of three new office buildings in China (one in Beijing and two in Shanghai) using current versions of LEED and BEAM Plus. The simulation package HTB2 [14] and BECON [15] were employed to evaluate the energy use for air-conditioning, as well the whole building. The study included the determination of the benchmark of "equivalent" performance between the two schemes, and the sensitivity of various compliance criteria on the air-conditioning energy use. The results of this study will provide some insights to China and Hong Kong policy-makers for the further development as well as possibly future alignment of the two schemes.

2. Overview of LEED and BEAM Plus

LEED is developed by the US Green Building Council (USGBC) for the US Department of Energy [16–19] and so far is the most recognized building environment assessment scheme. The pilot version (LEED 1.0) [20] for New Construction was first launched at USGBC Membership Summit in August 1998. In March 2000, LEED Version 2.0 [18] 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 and constructions including LEED for New Construction: Offices, LEED for Schools, LEED for Core & Shell, LEED for Existing Buildings, LEED for Homes, LEED for Interior Construction and LEED for Neighborhood Development. The current LEED for New Construction was released in February 2010. Current versions for other building types were also released in 2010 [20].

In LEED for New Construction Version 2.2, several changes have been made in comparison to Version 2.1. Firstly, energy modeling is no longer a basic requirement. The fulfillment of the prescriptive requirements of relevant codes as defined by the US Department of Energy can be used as an alternative. Moreover, the energy performance assessment has been updated to require compliance with Appendix G of ANSI/ASHRAE/IESNA Standard 90.1-2007 and to include small power loads in the calculation as "process energy" loads. Furthermore, two other compliance paths that yield fewer points have been introduced, of which is easier and cheaper to achieve for small projects. There is also a new energy modeling protocol and more stringent performance criteria.

LEED adopts energy budget cost approach for evaluating the compliance of all proposed designs, which provides flexibilities in making trade-offs among the performances of different energy sources, envelope assemblies and service systems. A baseline building is assumed to calculate the energy cost budget for performance assessment, whereby the characteristics are specified accordance to ASHRAE 90.1-2007 standard. The achievement of higher energy performance levels of an assessed building is calculated based on annual energy consumption and cost using the Building Performance Rating Method in the ASHRAE Standard. The trade-offs are allowed within a certain design features including the envelope design, the energy performance of major equipments and the installed lighting intensities. The standard requires the use of simulation programs that provide detailed hour-by-hour energy analysis of buildings.

Table 1
Overview of LEED and BEAM Plus.

	LEED	BEAM Plus
History		
First Version	1998 (Version 1.0)	1996 (Versions 1/96)
Latest Version	2009 (Version 2.2)	2010 (Version 1.1)
Building types		
New construction	O	O
Interior construction	O	–
Core and shell	O	–
Neighbourhood development	O	–
Existing	O	O
Renovated	O	O
Mixed-use	O	O
Assessment method		
Certification	Hour-by-hour simulation	
Approach	Energy cost budget	Energy budget

BEAM Plus is a voluntary scheme first launched in December 1996. The original BEAM Plus scheme is named HK-BEAM which comprises two versions, one for new (HK-BEAM 1/96) [21] and the other for existing office buildings (HK-BEAM 2/96) [22]. It covered a wide range of issues related to the impacts of office buildings on the environment in the global, local and indoor scales. In 1999, additional versions for new residential buildings and hotel buildings were issued, together with updates of the new and existing office buildings versions.

Reviews of HK-BEAM 1/96 and 2/96 were done in 2003 and 2004 to address the implementation problems experienced and to expand the range of building types that the scheme could cover, leading to the introduction of new versions: one for new buildings (4/04) and the other for existing buildings (5/04) [23]. They were formally launched in 2005. Recently, associated with re-naming of HK-BEAM into BEAM Plus, Versions 1.1 for New Buildings and Existing Buildings were released in 2010 [24].

In HK-BEAM 4/04 and 5/04 versions, revisions have been made to expand the range of building developments that can be assessed; to include additional issues like building quality and sustainability; and to increase the weightings given to building energy efficiency. One of the major changes is the adoption of a new energy performance assessment framework that is based on the energy budget approach. The assessment is made by calculating the annual energy use for the assessed building and comparing it against the energy use of a commensurate baseline building, both of which are to be determined by computer simulation. The latest versions of BEAM Plus adopt the same approach in their energy performance assessment.

It can be seen in the above that several revisions have been made to LEED and BEAM Plus since they have been launched. To enable comparisons are conducted on the same basis, their latest version for new buildings are benchmarked. Accordingly, the evaluation is based on LEED for New Offices Construction 2009 and BEAM Plus for New Buildings 2010. Hereafter, they will be simply referred to as LEED and BEAM Plus. Major similarities and differences of the two schemes, as discussed above, are summarized in Table 1.

Table 2
The credit scale.

Credits	LEED Annual energy cost saving (ΔAEC_{COST}) (%)	BEAM Plus Annual energy use saving (ΔAEC_{ALL}) (%)
1	10.5	10
2	14	14
3	17.5	18
4	21	22
5	24.5	26
6	28	30
7	31.5	34
8	35	38
9	38.5	42
10	42	45

3. The credit scale

The two credit scales are compared in Table 2. It can be seen that LEED scale is based on the percentage reduction in annual energy cost (ΔAEC_{COST}) whilst BEAM Plus is based directly on the percentage reduction in annual building energy consumption (ΔAEC_{ALL}). The credit scale of BEAM Plus is slightly directed towards an incentive crediting approach such that proportionally more credits are awarded for higher level of energy consumption reduction. The maximum achievable number of credits[1] on annual energy consumption reduction is 10 both for LEED and BEAM Plus, which correspond to 9.3% and 7% of the total credits in each scheme (107 credits for LEED, and 143 credits for BEAM Plus). This indicates that they have given comparable weightings to energy-related issues.

In LEED, assessment is based on whole building energy use, which includes space heating, air-conditioning, lighting and other process energy consumptions. The minimum credit level is set at 10.5% reduction in annual energy cost. To be eligible for credit award, the process energy cost must exceed 25% of the total energy cost, or else, submissions must include documentation substantiating that the claimed process energy inputs are appropriate.

BEAM Plus assesses the annual energy consumption of the whole building. The minimum credit level is set at 10% reduction in annual energy use. The annual energy use accounts for the air-conditioning system, lighting and other process energy consumptions; but excluding the space heating. The lighting power and indoor equipment power densities are ascertained by site inspection.

4. The baseline criteria

The use of energy or energy cost budget approach for assessing a proposed building design provides flexibilities in making trade-offs among the performances of different envelope assemblies and service systems [25]. The energy budget is determined by incorporating a range of default characteristics for a baseline building to determine the energy budget for performance assessment. It is worth to note that whether or not a parameter is set as a default characteristic has a significant impact on the performance of an assessed building. Table 3 summarizes the baseline building characteristics of the two schemes, and the energy performance of three studied buildings (abbreviated as BJ1, SH1 and SH2) predicted by simulations. Details of the three studied buildings are given in Section 5.

[1] LEED awards points, while BEAM Plus awards credits. The term "credits" will be employed in this study for consistency.

4.1. Indoor design conditions

Indoor design conditions, including the space set-point temperature and relative humidity, ventilation rate, occupancy density, lighting power density, and small power intensity can influence substantially the air-conditioning energy use in a building [26].

LEED sets designer-specified values as default indoor design conditions for baseline buildings; with the exception of the baseline lighting power density. The baseline lighting energy consumption is determined based on the maximum permissible lighting power density by space type without occupancy control.

Conversely, BEAM Plus sets default indoor design conditions for baseline buildings different to designer-specified values. The default space set-point temperature and relative humidity were set to correspond to the threshold conditions stipulated in the Code of Practice for Energy Efficiency of Air Conditioning installations [27]; while that of the lighting power intensity was referenced to values in the Code of Practice for Energy Efficiency of Lighting Installations [28]. Occupancy density and equipment power intensity are not governed by any codes in Hong Kong, and thus the default values were set by reference to previous surveys results [29]. The default ventilation rate was determined by reference to recommendations given in ASHRAE [30] and CIBSE Standards [31].

It is noted from the above that indoor design conditions can be used as trade-off items in BEAM Plus assessment, but not in LEED.

4.2. Building envelope

In defining the envelope characteristics of the baseline building, LEED adopts a performance rating method to specify the type of assemblies provided, shading coefficient for fenestrations, and *U*-values for building components including walls, roof, fenestrations and floor. It has also been specified that the total fenestration area is limited to 40% of the gross wall area or the actual fenestration area percentage, whichever is smaller, and is to be assumed uniformly distributed across four distinct building orientations. In respect of building orientation, the baseline building performance under four orientations including its actual orientation and three other orientations by rotating the entire building by 90°, 180°, and 270° will be equally considered.

For BEAM Plus, although compliance criteria for the building envelope are not explicitly given, the regulatory control over the overall thermal transfer value (OTTV) is taken as the envelope design for baseline buildings. Calculation of OTTV follows the method and data given in the OTTV Code [32]. The modification of the envelope design of the assessed building into that of the baseline building model is recommended to be made through adjusting the window-to-wall area ratio (WWR). The WWR will be adjusted based on its actual orientation such that the OTTV of the envelope of the baseline building model will just meet the code requirement, which restricts the OTTV as 30 W/m^2 for a building tower and 70 W/m^2 for a podium.

4.3. Air-conditioning system

LEED specifies the methods to determine the air-conditioning system parameters using the performance rating method. The baseline building system selection is determined based on the building type, building area, number of floors and the heating fuel source for the air-conditioning system. Electric chillers will be assumed for the baseline building regardless of the cooling energy source. Chillers' coefficient of performance (COP) is defined based on cooling capacity ranges. Total fan power is set based on the total supply air volume and system classification as constant air volume (CAV) or variable air volume (VAV). Pump power is set based on

Table 3
Design and baseline characteristics and energy performance of three studied buildings by LEED and BEAM Plus.

Building	BJ1			SH1			SH2		
Parameters	Design	Baseline		Design	Baseline		Design	Baseline	
		LEED	BEAM Plus		LEED	BEAM Plus		LEED	BEAM Plus
Indoor design conditions									
Temperature (°C)									
Office	24	24	23	25.5	25.5	23	24	24	23
Retail	24	24	22	26	26	22	24	24	22
Relative humidity (%)	55–65	55–65	50	55–65	55–65	50	50–60	50–60	50
Occupancy density (m^2/person)									
Office	10	10	9	12.5	12.5	9	12.5	12.5	9
Retail	3	3	4.5	25	25	4.5	12.5	12.5	4.5
Ventilation rate (l/s/person)									
Office	5.5	5.5	10	10	10	10	11	11	10
Retail	5.5	5.5	7	7	7	7	11	11	7
Lighting power density (W/m^2)									
Office	10	10	15	10	10	15	10	10	15
Retail	15	15	18	15	15	18	15	15	18
Equipment power density (W/m^2)									
Office	20	20	10	20	20	10	20	20	10
Retail	20	20	20	20	20	20	20	20	20
Envelop features									
Wall heat transfer coefficient (W/m^2 K)	1.4	0.86	OTTV = 30 W/m^2 and 70 W/m^2	0.51	0.86	OTTV = 30 W/m^2 and 70 W/m^2	0.34	0.86	OTTV = 30 W/m^2 and 70 W/m^2
Roof heat transfer coefficient (W/m^2 K)	0.31	0.37		0.51	0.37		0.43	0.37	
Window heat transfer coefficient (W/m^2 K)	3.3	3.2		3.3	3.2		1.9	3.2	
Shading coefficient									
Office	0.3	0.3; 0.5(N)	0.3	0.3	0.3; 0.5(N)	0.36	0.4	0.3; 0.5(N)	0.34
Retail	0.78	0.3; 0.5(N)	0.3	0.78	0.3; 0.5(N)	0.66	0.4	0.3; 0.5(N)	0.44
Window-to-wall ratio									
Office	0.65	0.4	0.75	0.5	0.4	0.5	0.6	0.4	0.6
Retail	0.8	0.4	0.75	0.3	0.4	0.3	0.88	0.4	0.4
Air-conditioning system performance									
Type of air-side system	VAV and Fan coil unit	VAV and CAV	VAV and CAV	Fan coil unit	CAV	CAV	VAV and Fan coil unit	VAV and CAV	VAV and CAV
No. of chiller	8	8	8	5	5	5	5	5	5
Type of heat rejection system	Water cooled	Water cooled	Water cooled	Air cooled	Air cooled	Air cooled	Water cooled	Water cooled	Water cooled
Chillers' COP	5.6	6.1	5.7	3.2	2.8	2.9	6.1 and 6.7	6.1	5.5 and 5.7
Fan power (W/L/s)	0.8	1.7 (CAV) 1.9 (VAV)	1.6 (CAV) 2.1 (VAV)	0.43	1.7	1.6	1.2	1.7 (CAV) 1.9 (VAV)	1.6 (CAV) 2.1 (VAV)
Chilled water pump power (W/L/s)	0.54	0.35	0.61	0.47	0.35	0.43	0.3	0.35	0.26
Condenser water pump power (W/L/s)	0.37	0.3	0.4	NA	NA	NA	0.49	0.3	0.4
Energy efficient features									
Lighting control	Include	Nil	Nil	Include	Nil	Nil	Include	Nil	Nil
Heat recovery	Include	Nil	Nil	Include	Nil	Nil	Include	Nil	Nil
Fresh air demand control	Include	Nil	Nil	Include	Nil	Nil	Include	Nil	Nil

BJ1 is a case study building in Beijing; and SH1 & SH2 are case study buildings in Shanghai.

the circulating medium as chilled water or condenser water. LEED also specifies the system sizing method for baseline buildings.

BEAM Plus is similar to LEED that stipulates a range of the minimum permissible performance for different air-conditioning systems and equipments. The requirements include the chillers' COP, the installed fan power per unit flow rate, the allowable of pressure drop in water piping system, the minimum motor efficiency, etc. However, unlike LEED, BEAM Plus assumes same system type and capacity for the baseline and design cases, and system sizing method is not specified.

4.4. Building operation schedule

The energy benefit of an energy efficient measure is dependent on the simultaneous building and system operation schedules. In LEED and BEAM Plus, the baseline building occupancy, lighting, equipment and other operation schedules must be the same for the baseline and design cases. For modeling non-standard efficiency measures such as lighting controls, natural ventilation, demand control ventilation, etc., LEED allows the use of designer-specified schedules but prior approval on the revised schedules have been obtained from the rating authority.

5. The case study buildings

Three office buildings, one locates in Beijing (BJ1), and the other two in Shanghai (SH1 and SH2) were selected as case study buildings for benchmarking energy use assessment of BEAM Plus and LEED. The considerations for selection were: (i) the three buildings are comparable in building characteristics; and (ii) they are the first group of prime office buildings in China designed and constructed to qualify for LEED and BEAM Plus certifications. The sample size seems to be small but considering the limited availability of prime office buildings in Beijing (858,543 m^2) [33] and Shanghai (964,037 m^2) [34], the three studied buildings are already representing characteristics of 20% building stocks of this type. Building and system characteristics, as well as default and design parameters of the three studied buildings are discussed and compared below.

5.1. Building and system characteristics

BJ1 is a two-tower building with 22 storeys aboveground and 2 storeys underground. The total height is 108 m above the ground, and the total floor area is 168,000 m^2. 3/F to 22/F are for office use; and other floors are for retail purpose. The central chilled water system comprises eight numbers of water-cooled centrifugal chillers (each 3500 kW), together with the same numbers of cooling towers and condenser water pumps (plus one standby) for heat rejection of chillers. Chilled water is distributed through a primary/secondary piping network to variable air volume (VAV) air handling units (AHU) for offices and fan coil units (FCUs) for retails. BJ1 is also provided with occupancy control for lighting system, heat pipe for exhaust air heat recovery and demand control for fresh air supply.

SH1 is 25 storeys aboveground and 3 storeys underground. The total height is 101.4 m above the ground. 4/F to 25/F are for office use; 1/F to 3/F are for retail use and other floors are carpark space. The total floor area of the building is 38,000 m^2. The building adopted five numbers of air-cooled screw chillers (each 1258 kW). Chilled water is distributed through a single-loop pumping system to FCUs of the whole building. SH1 is also provided with occupancy control for lighting system, heat pipe for exhaust air heat recovery and demand control for fresh air supply.

SH2 has the same number of aboveground and underground floors as SH1. The total height is 104.8 m above the ground. 3/F to 25/F are for office use; 1/F and 2/F are for retail use and other floors are carpark space. The total floor area of the building is 54,400 m^2. The central chilled water system comprises five numbers of water-cooled chillers, together with the same numbers of cooling towers and condenser water pumps (plus one standby) for heat rejection of chillers. Three of the chillers adopt centrifugal compressor (each 2990 kW) and the other two adopt screw compressor (each 1406 kW). Chilled water is distributed through a primary/secondary piping network to VAV AHUs for offices and FCUs for retails. Similar to BJ1 and SH1, the building is provided with occupancy control for lighting system, heat pipe for exhaust air heat recovery and demand control for fresh air supply.

Table 4
Design and baseline OTTV (W/m^2) by LEED and BEAM Plus.

Building		BJ1		SH1		SH2	
Premises		Office	Retail	Office	Retail	Office	Retail
Design		27.7	75.3	24.6	34.7	35.0	58.1
Baseline	LEED	16.6	23.3	21.1	11.8	21.2	22.4
	BEAM Plus	30	70	30	70	30	70

5.2. Default and design parameters

There are differences between LEED and BEAM Plus in terms of units used for quantification of building envelope characteristics and pump power. In order to provide a common basis for comparison, these two performance metrics need to be converted into equivalent parameters.

Given OTTV is widely used in a considerable number of regimes [35], and detailed requirements for walls, roof, fenestrations and floor are specified by LEED to enable the calculation of OTTV, it is chosen as the common parameter for comparison of building envelope characteristics. Calculation of LEED's default OTTV follows the method and data given in the OTTV Code [32].

In LEED, default pump power is assumed based on pump operating against a fixed pressure, and a range of minimum combined impeller and motor efficiency for pumps of different purposes, while that in BEAM Plus is simply based on a minimum pump efficiency of 60%.

Upon conversion, default and design characteristics of the three studied buildings for compliance with LEED and BEAM Plus are presented and compared in Table 3. Table 3 summarizes the performance parameters for indoor design conditions, building envelope features, air-conditioning system performance, and energy efficient features. It can be seen that BEAM Plus sets a relatively lower default requirements than LEED in indoor design conditions, including the cooling temperature and humidity set-points, ventilation rate, occupancy density, lighting power density and gains from the equipment. Given indoor design conditions can be used as trade-off parameters for BEAM Plus but not LEED, gaining of credits in BEAM Plus can be achieved through the use of more stringent indoor design conditions, while LEED can only rely on the improvement in envelope performance, adoption of energy efficient features, use of more energy efficient air-conditioning system and equipment, and provision of occupancy control for lighting system.

The default OTTV of LEED is slightly lower in comparison to BEAM Plus (16.6–23.3 W/m^2 vs 30 W/m^2 and 70 W/m^2, Table 4). The result indicates that the envelope characteristics specified in LEED are not biased to cold climate conditions. Given United States covers a vast geographical area, and the temperature difference from the south to north is very large, the default values may have taken into account optimizing the energy consumed for summer cooling and winter heating. It can also be been seen that amongst the three studied buildings, SH2 has the highest OTTV value and deviates most from the baseline requirement.

With regards to the air-conditioning system performance, LEED sets a higher requirement on chiller coefficient of performance (COP), exemplary for centrifugal water-cooled chillers, which is 6.1 versus 5.7 of that of BEAM plus. LEED also sets a higher requirement on condenser pump power per unit water flow rate (0.3 versus 0.4 W per L/s). The difference is small for the default fan power per unit air flow rate (W per L/s). They both give separate default fan power for variable air volume (VAV) and constant air volume system (CAV) to allow the different characteristics of the two types of systems to be taken into account. While for energy efficient features, they are excluded in the baseline case of LEED and BEAM Plus and therefore can be used as trade-off features.

Comparison has not been made on building and system operations schedules. This is because previous study results have made it clear that if the same set of schedules, regardless if default or designer-specified schedule is used to predict annual energy use of the baseline and design buildings; there is little influence on the relative enhanced energy performance of a design option [25].

Climatic data is same for the baseline and design cases. Typical weather year data of Beijing and Shanghai identified by the National Meteorological Center of China are used for energy simulations [36].

6. Energy assessment results

6.1. Air-conditioning and whole building energy use

For benchmarking the energy assessment of LEED and BEAM Plus, the default and design values were assumed for the three studied buildings for energy simulations. HTB2 [14] and BECON [15] (HTB2 + BECON) is two linked-programs. They were employed for prediction of annual energy consumption for air-conditioning the baseline and design cases. They were chosen because HTB2 + BECON have come into widespread use in Hong Kong since the introduction of mandatory codes and voluntary schemes in 1996. They were also used for establishing the baseline case in the earlier versions of BEAM Plus [29]. Previous evaluations indicate that HTB2 + BECON and DOE-2 are in compliance with ASHRAE Standard 140 and can be considered acceptable to each other [13]. Their predictions for an existing building in Hong Kong have been also compared favorably with measured energy data [37]. The simulated results were used for the calculation of the percentage reduction in annual energy consumption for air-conditioning (ΔAEC_{AC}) as shown in Eq. (1):

$$\Delta AEC_{AC} = \frac{AEC_{AC,b} - AEC_{AC,d}}{AEC_{AC,b}} \times 100\% \quad (1)$$

Where subscripts b and d represent the baseline and design values. Results are summarized in Table 5.

Based on the predicted ΔAEC_{AC}, and annual lighting (ΔAEC_{LGT}) and small power (ΔAEC_{SPW}) consumptions, ΔAEC_{ALL} of LEED and BEAM Plus for the three studied buildings were calculated. Results are also summarized in Table 5. The simulated consumptions are considered reasonable as judged from the design building energy end-use splits (Fig. 2) of which is comparable to results reported in other studies [38,39]. By relating ΔAEC_{AC} and ΔAEC_{ALL} of the three studied buildings assessed by LEED and BEAM Plus as shown in Fig. 1, it can be seen that they are strongly correlated ($r^2 = 0.92$) to reveal that the level of savings achieved by the air-conditioning system is the most dominant.

6.2. Influence of default parameters

As can be seen in Table 5, ΔAEC_{AC} and ΔAEC_{ALL} assessed by LEED is substantially smaller than that of BEAM Plus. One reason is due to the relatively higher default requirement set by LEED on lighting power density (LPD) as can be seen in Table 3. The higher default requirement set by LEED on air-conditioning system is another reason.

In identifying the default air-conditioning system parameter that differs most between LEED and BEAM Plus, a ratio ($R_{AC(X)}$) relating the relative annual electricity consumption saving ($\Delta AEC_{AC(X)}$) achieved by equipment X assessed by the two schemes is adopted for the analysis. The ratio will give an indication of the influence of various default parameters on the baseline consumptions of LEED and BEAM Plus. Too large or too small the ratio indicates there is major difference in default requirements.

Table 5
Summary of AEC and ΔAEC for various end uses.

Building	End uses	AEC (kWh)			ΔAEC (%)	
		LEED	BEAM Plus	Design	LEED	BEAM Plus
BJ1	AC	1.08E7	1.39E7	6.05E6	44	56
	LGT	1.06E7	1.43E7	7.80E6	27	46
	SPW	9.77E6	5.42E6	9.77E6	0	−80
	ALL	3.12E7	3.36E7	2.36E7	24	30
SH1	AC	4.10E6	5.72E6	2.46E6	40	57
	LGT	2.33E6	3.42E6	2.13E6	9	38
	SPW	1.98E6	1.13E6	1.98E6	0	−76
	ALL	8.41E6	1.03E7	6.57E6	22	36
SH2	AC	4.43E6	5.62E6	4.18E6	6	26
	LGT	2.99E6	4.38E6	2.04E6	32	53
	SPW	3.49E6	1.93E6	3.49E6	0	−81
	ALL	1.09E7	1.19E7	9.71E6	11	19

AC, air-conditioning; LGT, lighting; SPW, small power; ALL, all end-uses.

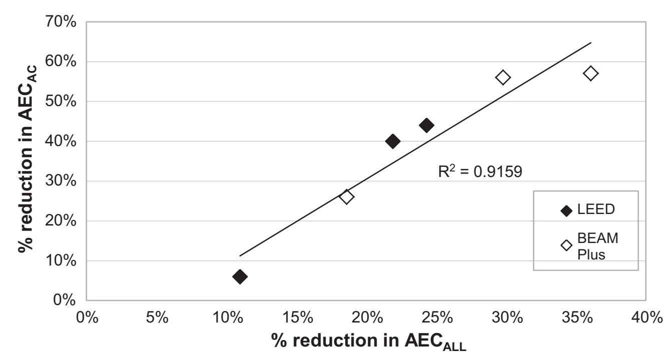

Fig. 1. Relating % reduction in AEC for A/C (ΔAEC_{AC}) and whole building (ΔAEC_{ALL}).

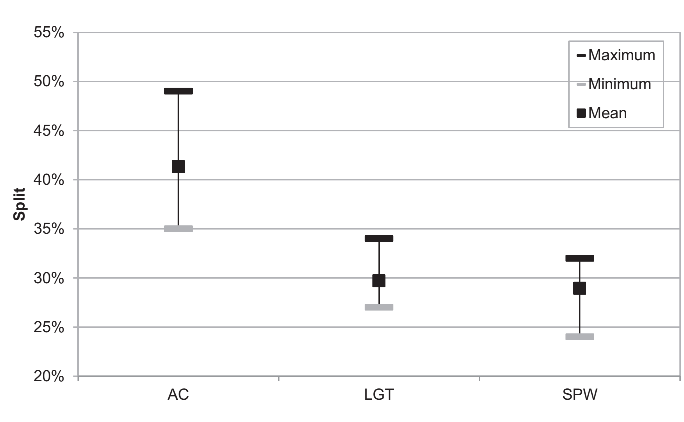

Fig. 2. Building energy end-use splits.

Table 6
Relative annual electricity consumption saving ($\Delta AEC_{AC(X)}$) achieved by various equipments.

Equipment (X)	BJ1			SH1			SH2		
	ΔAECAC(X)		RAC(X)	ΔAECAC(X)		RAC(X)	ΔAECAC (X)		$R_{AC(X)}$
	LEED	BEAM		LEED	BEAM		LEED	BEAM	
AHU and FAU fans	61%	65%	0.95	7%	70%	0.10	18%	27%	0.67
Chillers	26%	47%	0.54	55%	46%	1.20	17%	44%	0.38
P.L. chilled water pumps	44%	58%	0.76	3%	6%	0.46	0%	−24%	−0.01
S.L. chilled water pumps	29%	60%	0.49	–	–	–	21%	11%	1.91
Condenser water pumps	−15%	53%	***−0.29***	–	–	–	−62%	−1%	***52.12***
Cooling towers	2%	9%	0.23	–	–	–	1%	7%	0.10
Lower inner fence	–	–	−0.27	–	–	−0.31	–	–	−1.53
Lower outer fence	–	–	1.40	–	–	1.50	–	–	2.98

AHU, air handling unit; FAU, fresh air handling unit; P.L., primary loop; S.L., secondary loop.

Table 7
Building energy use and energy cost by LEED and BEAM Plus.

Building	Annual energy consumption (AEC_{ALL}), kWh			Annual energy cost (AEC_{COST}), RMB	
	Design	Baseline		Design	LEED baseline
		LEED	BEAM Plus		
BJ1	2.36E7	3.12E7	3.36E7	2.18E7	2.88E7
SH1	6.57E6	8.41E6	1.03E7	5.16E6	6.76E6
SH2	9.71E6	1.09E7	1.19E7	8.85E6	1.04E7

The ratio is mathematically shown in Eq. (2), and results are summarized in Table 6.

$$R_{AC(X)} = \frac{\Delta AEC_{AC(X),LEED}}{\Delta AEC_{AC(X),BEAM}} \quad (2)$$

where $\Delta AEC_{AC(X),LEED}$ and $\Delta AEC_{AC(X),BEAM}$ are the percentage reduction in annual energy consumption of air-conditioning equipment X assessed by LEED and BEAM Plus respectively.

It can be seen in Table 6 that $R_{AC(X)}$ ranged between −0.29 and 52.11. For a range of values, too large or too small values are often defined as outliners. Outliner is often an observation in a data set which lies outside the inner fence of the lower and upper quartiles. Accordingly, the outliners for the range of $R_{AC(X)}$ of each case study building are highlighted (in italic) in Table 6. It can be seen that the outliners belong to condenser pump consumption both for Buildings BJ1 and SH2 to indicate that LEED sets a much higher requirement than BEAM Plus in this aspect.

6.3. *Energy cost saving*

Based on the predicted ΔAEC_{ALL} and year round energy consumption profiles, the energy cost savings (ΔAEC_{Cost}) were computed based on tariffs of Beijing [40] and Shanghai [41] (Fig. 3). Note that the tariffs are not a fixed value within a day and thus hour-by-hour calculation of savings is needed. Results of the three studied buildings are shown in Table 7. It can be seen that despite the difference in tariff between Beijing and Shanghai, ΔAEC_{ALL} correlates well with ΔAEC_{Cost} to conclude the tariff will not introduce much influence on the ΔAEC_{Cost} and assessment results as long as same tariff system is used for calculating the energy budget of the baseline and design cases.

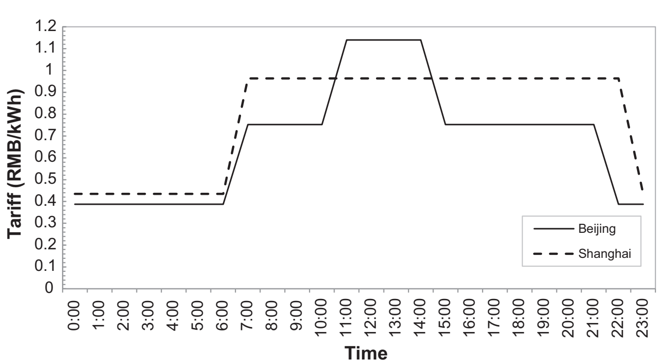

Fig. 3. Tariffs of Beijing and Shanghai.

6.4. *Credits scored*

The number of energy credits scored by the three studied buildings based upon the credit scale of LEED and BEAM Plus are summarized in Table 8. It can be seen that the total number of energy credits scored under BEAM Plus scheme are constantly higher than that of LEED scheme. However, when the credits scored were weight-adjusted according to the percentage contribution of the energy credits (Section 3); the resultant numbers of credits scored under the two schemes became similar. The results indicate that despite the more stringent baseline requirements set by LEED, the performance requirements of the two schemes are comparable. This is consistent with survey results indicating that the actual energy use of LEED certified and BEAM Plus buildings are on average 28% and 32% more efficient than average performance of other building stocks [42,43].

It is also noted that four to five credits are scored by Buildings BJ1 and SH1, whilst SH2 scored only 2 credits. Given ΔAEC_{AC} correlates well with ΔAEC_{ALL}, focus is given to evaluate reasons for the difference in ΔAEC_{AC} amongst the three studied buildings. It is well accepted that the difference in ΔAEC_{AC} can be explained by the interactive effect of different factors which include their variations in building, system and equipment characteristics. The resultant effect of different factors can be reflected by the average system performance, COP_{AVE} and ΔCOP_{AVE} as shown in Eqs. (3) and (4):

$$COP_{AVE} = \frac{PCL}{MED} \quad (3)$$

$$\Delta COP_{AVE} = \frac{COP_{AVE,d} - COP_{AVE,b}}{COP_{AVE,b}} \times 100\% \quad (4)$$

Table 8
Savings and credits scored by LEED and BEAM Plus.

Building	Annual energy consumption savings (ΔAEC_{ALL}), %		Annual energy cost savings (ΔAEC_{COST}), %		Credits scored	
	LEED	BEAM Plus	LEED	LEED	BEAM Plus	
					Actual	Weight-adjusted
BJ1	24	30	24	4	6	5
SH1	22	36	24	4	5	4
SH2	11	19	15	2	3	2

Table 9
Average Air-conditioning (AC) system performance and savings.

Building	Average AC system performance			ΔCOP_{AVE} (%)		ΔAEC_{AC} (%)	
	LEED	BEAM Plus	Design	LEED	BEAM Plus	LEED	BEAM Plus
BJ1							
PCL	26,200	30,700	23,800				
MED	7.76E3	9.80E3	5.48E3	29	39	44	56
COP_{AVE}	3.4	3.1	4.3				
SH1							
PCL	4832	6796	4221				
MED	2.13E3	3.28E3	1.62E3	14	26	40	57
COP_{AVE}	2.3	2.1	2.6				
SH2							
PCL	9044	11,103	8151				
MED	2.67E3	3.51E3	2.45E3	−2	5	6	26
COP_{AVE}	3.4	3.2	3.3				

Units for PCL and MED are kW.

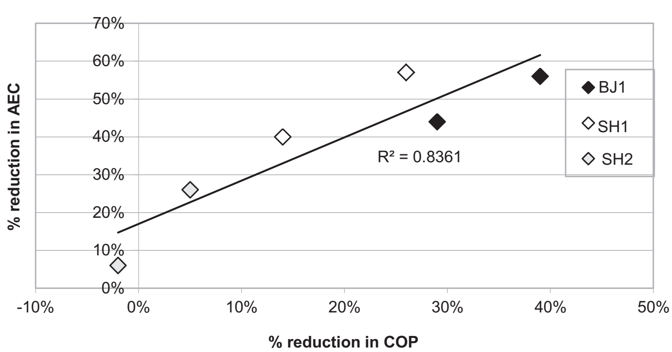

Fig. 4. Relating % reduction in COP (ΔCOP_{AVE}) and AEC (ΔAEC_{AC}).

where PCL is the peak cooling load (kW), MED is the maximum electricity demand for air-conditioning (kW), and subscripts b and d represent the baseline and design values.

Results of the three studied buildings are summarized in Table 9. Regression analysis indicates that ΔCOP_{AVE} exhibits strong correlation with ΔAEC_{AC} (Fig. 4, $r^2 = 0.84$) to explain that the low score of Building SH2 is due to the relatively lower average COP of the air-conditioning system. This is consistent with the previous observations that energy assessment result is dominated by the energy use for air-conditioning.

7. Conclusion

A side-by-side comparison on the default parameters, trade-offs allowed and credit scales of the energy assessment of LEED and BEAM plus was conducted based on building and system characteristics of three case study buildings. Energy assessment results and statistical analysis indicated that LEED was more stringent than BEAM Plus in the default indoor design conditions and condenser pump power, and in the trade-off allowed. While other default requirements for establishing the baseline building were found similar. However, despite the variations between the two schemes in different aspects, the assessment results of the three studied buildings in terms of credit scored in the two schemes were comparable, which were two to five credits out of a maximum of 10 credits. Amongst various building end uses, energy use for air-conditioning was found dominating the assessment results. The assessment results also revealed that although different tariff systems were adopted in Beijing and Shanghai, the difference would not affect the assessment results as long as same tariff system was used for predicting the energy cost of the baseline and design cases.

Due to limited availability of good quality office buildings in China, schemes benchmarking in this study were done based on three case study building with similar design. Further benchmarking work is recommended to be done for buildings with diverse design characteristics to verify the conclusion drawn in this study.

References

[1] K. Tanaka, C. Ge, M. Suga, S. Matsuoka, The role of environmental management capacity on energy efficiency: evidence from China's electricity industry Word Bank energy project in China: influence on environment protection, in: International Association for Energy Economics, North America Conference, Denver, CO, USA, September 18–21, 2005.
[2] R. Yao, B.Z. Li, K. Steemers, Energy policy and standards for built environment in China, Renewable Energy 30 (2005) 1973–1988.
[3] J. Liang, R.M. Yao, B.Z. Li, Y. Wu, An investigation of the existing situation and trends in building energy efficiency management in China, Energy and Buildings 30 (10) (2007) 1098–1106.
[4] W.L. Lee, F.W.H. Yik, Regulatory and voluntary approaches for enhancing building energy efficiency, Progress in Energy and Combustion Science 30 (2004) 477–499.
[5] China Ministry of Construction, National Standard of the People's Republic of China (GB50189-2005). Design Standard for Energy Efficiency of Public Buildings, Ministry of Construction of the People's Republic of China Enforcement, 2005, April 4.
[6] China Ministry of Construction, National Standard of the People's Republic of China (GB50034-2004). Standard for Architecture Lighting Design, Ministry of Construction of the People's Republic of China Enforcement, 2005, December 1, 2004.
[7] ESGB, Evaluation Standard for Green Building (GB/T 50378-2006), Ministry of Construction of the People's Republic of China, 2006, March 7.
[8] Xin Hua News, China, June 24, 2009, see: http://www.news.cn/

[9] USGBC. US Green Building Council, 2012, see http://www.usgbc.org/LEED/Project/CertifiedProjectList.aspx
[10] P. Chan, HK-BEAM Society reception to celebrate the one hundredth green building in Hong Kong. Press Release, May 24, 2005.
[11] W.L. Lee, J. Burnett, Benchmarking energy use assessment of HK-BEAM, BREEAM and LEED, Building and Environment 43 (11) (2008) 1882–1891.
[12] W.L. Lee, Benchmarking energy use of building environmental assessment schemes, Energy and Building 45 (2012) 326–334.
[13] W.L. Lee, F.W.H. Yik, J. Burnett, Assessing energy performance in the latest versions of Hong Kong Building Environmental Assessment Method (HK-BEAM), Energy and Buildings 39 (3) (2007) 343–354.
[14] D.K. Alexander, HTB2—A model for the thermal environment of buildings in operation (Release 2.01), User Manual. Welsh School of Architecture R&D, UWCC, Cardiff, UK; 1997.
[15] F.W.H. Yik, BECON–A Building Energy Consumption Estimation Program, User Manual, Department of Building Services Engineering, The Hong Kong Polytechnic University, HK, 1998.
[16] USGBC. US Green Building Council, 2007, see http://www.usgbc.org/DisplayPage.aspx?CMSPageID=220
[17] LEED. Green Building Rating System. Version 1.0. US Green Building Council, August 1998.
[18] LEED–Reference Package. Version 2.0. US Green Building Council, June 2001.
[19] LEED–Reference Package. Version 2.2. US Green Building Council, June 2005.
[20] USGBC, US Green Building Council, 2012, see http://www.usgbc.org/Store/PublicationsList_New.aspx?CMSPageID=1518
[21] HK-BEAM, An Environment Assessment for Air Conditioned Office Premises, Version 1: New Offices, Business Environment Council, Hong Kong, 1996.
[22] HK-BEAM, An Environment Assessment for Air Conditioned Office Premises. Version 2: Existing Offices, Business Environment Council, Hong Kong, 1996.
[23] HK-BEAM Society HK-BEAM, An Environment Assessment for Air Conditioned Office Premises. Version 4/04: New Buildings and Version 5/04: Existing Buildings, Building Environment Council, Hong Kong, 2004, see http://www.bse.polyu.edu.hk/Research_Centre/BEp/hkbeam/HK-BEAMWEB/HK-BEAM-2004.htm
[24] BEAM Plus BEAM Plus NB Version 1.1 and EB Version 1.1, Building Environmental Assessment Method. HKGBC and BEAM Society, Hong Kong.
[25] W.L. Lee, H. Chen, Benchmarking Hong Kong and China energy codes for residential buildings, Energy and Building 40 (9) (2008) 1628–1636.
[26] W.L. Lee, F.W.H. Yik, J. Burnett, Simplifying energy performance assessment method in the Hong Kong building environmental method, Building Services Engineering Research and Technology 22 (2) (2001) 113–132.
[27] Electrical and Mechanical Services Department, Code of Practice for Energy Efficiency of Air-conditioning Installations, The Hong Kong SAR Government, 2007.
[28] Electrical and Mechanical Services Department, Code of Practice for Energy Efficiency of Lighting Installations, The Hong Kong SAR Government, 2007.
[29] F.W.H. Yik, J. Burnett, P. Jones, W.L. Lee, Energy performance criteria in the Hong Kong Building Environmental Assessment Method, Energy and Buildings 27 (1998) 207–219.
[30] ASHRAE, Ventilation for Acceptable Indoor Air Quality. ASHRAE Standard 62. 1-2007, American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc, Atlanta, 2010.
[31] CIBSE Guide F: Energy Efficiency in Buildings, Chartered Institution of Building Services Engineers, UK, 2004.
[32] Buildings Department Code of Practice for Overall Thermal Transfer Values in Buildings, Hong Kong SAR Government, 1995.
[33] Cushman & Wakefield Office Snapshot Marketbeat—Beijing, China, A Cushman & Wakefield Research Publication, 2012.
[34] Cushman & Wakefield Office Snapshot Marketbeat—Shanghai, China, A Cushman & Wakefield Research Publication; 2012.
[35] F.W.H. Yik, K.S.Y. Wan, An evaluation of the appropriateness of using overall thermal transfer value (OTTV) to regulate envelope energy performance of air-conditioned buildings, Energy 30 (1) (2005) 41–71.
[36] Meteorological Database National Meteorological Center China Meteorological Administration and Department of Building Science Tsinghua University, China Climatic Data for Building Thermal Environmental Analysis, China Architecture and Building Press, 2005.
[37] KW Kwok, Development of Building Energy Simulation Program Assessment Scheme. MEng Dissertation. Department of Building Services Engineering, the Hong Kong Polytechnic University, HK, 2002/03.
[38] J. Eom, P. Kyle, L.E. Clark, P.L. Patel, S.H. Kim, China's Building Energy Use: A Long-term Perspective based on a Detailed Assessment, U.S. Department of Energy, Pacific Northwest National Laboratory Richland, Washington, USA, 2012 January.
[39] N. Zhou, M.A. McNeil, D. Fridley, J. Lin, L. Price, S. Rue du Can, J. Sathaye, M. Levine, Energy Use in China: Sectoral Trends and Future Outlook, Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, USA, 2007 January.
[40] Life in Beijing Series, Beijing International, 2012, see: http://www.ebeijing.gov.cn/feature_2/GuideToHeatingElectricityWaterAndGas/PriceGuide/t1107813.htm.
[41] Shanghai Electricity Tariff Shanghai Municipal Committee, Shanghai, China, 2009 (Chinese), See: http://www.shec.gov.cn
[42] C. Turner, Energy Performance of LEED for New Construction Buildings, Final Report U.S. Green Building Council, March 4, 2008.
[43] W.L. Lee, F.W.H. Yik, Regulatory and voluntary approaches for enhancing energy efficiency of buildings in Hong Kong, Applied Energy 71 (2002) 251–274.