Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(6):2904-2913

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Modular construction and evaluation of green building technology system based on LEED

Wu Yun

Department of Architecture, School of Design, Jiangnan University, Wuxi, Jiangsu, China

---

ABSTRACT

The complexity of the goal and the diversity of factors determine that the green building is a complex system. However, previous studies were mainly aimed at single structure of a green building. Therefore, a systematic research on green buildings is necessary to carry out based on a whole green building system. In order to realize all benefit requirements of the green buildings, the theory of complexity science and system science analysis, and methods of various technical measures are adopted to study the mutual relations of project goals and the influencing factors. From the perspective of system research, this paper built a green building technology system model, decomposed and combined a series of theories and technology adopted in green buildings, which formed a green building design under the restriction of independent structures, different targets, and functional integration technology module systems.

Key words: Green building technology system, modular, LEED, green building rating

---

INTRODUCTION

Building and construction industry is vital to provide human development needs. This professional sector provides multiple products to enhance the quality of life. However, it is recognized that the construction practices are one of the major contributors of environmental problems. In 2012, U.S. Department of Energy estimated that buildings in the United States accounted for 73.6% of total electricity expenditures, and 40% of the total carbon emissions. In order to address the said environmental concerns, the concept of sustainability has been introduced to the building construction sector. The aim of green buildings is to develop environmentally friendly construction practices that contribute in energy savings, reductions of emissions, and reuse and recycle of materials. Research shows that green building practices can considerably reduce the building's environmental impact in terms of energy consumption. For example, a survey of 99 green buildings in the United States showed that an average of 30% less energy was used in green buildings compared to the conventional buildings.

The US Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) green building certification label has grown in popularity since it was first introduced in 2000. For many years it was commonly assumed that a LEED-certified building saved energy, though little performance data were available to confirm this assertion. Early studies of a selected LEED buildings yielded encouraging results. One such study by Rick Diamond looked mostly at Federal Buildings. Another study looked at a group of LEED buildings in the Pacific NW. In 2006 the USGBC commissioned the New Buildings Institute (NBI) to study energy use by commercial buildings certified under the LEED new construction (NC) version2 program. NBI completed their study in 2008 and concluded that LEED certification was, on average, yielding a 25-30% energy savings. That study immediately drew criticism for its methodology both in gathering and analyzing data. NBI made their data available to other researchers for independent analysis, this author being one of them.

The NYC Energy Benchmarking public dataset contains EUI data for 1044 large office buildings, comprising a total of 30.17 million m^2 (324,746,000 sf). Manual inspection revealed that some buildings appeared more than once in the database. If, in such cases, one record stood out as credible the credible record was retained and other records deleted. If a single credible record could not be identified then all records associated with the building were deleted. This process eliminated 42 records. 10 more building records were deleted because their site EUI were so high as to be unbelievable, ranging from 11,740 to 953,000 MJ/m^2 (1035-84,000 kBtu/sf).4 Finally, 39 additional records with site EUI<340 MJ/m^2 (30 kBtu/sf) were also eliminated because their EUI were judged to be unreasonably low. The remaining data set contains credible records for 953 office buildings, total area 28,571,000 m^2 (307,545,000 sf) and source EUI equal to 2890 MJ/m^2 (255 kBtu/sf), 3% lower than that of the 21 LEED buildings.

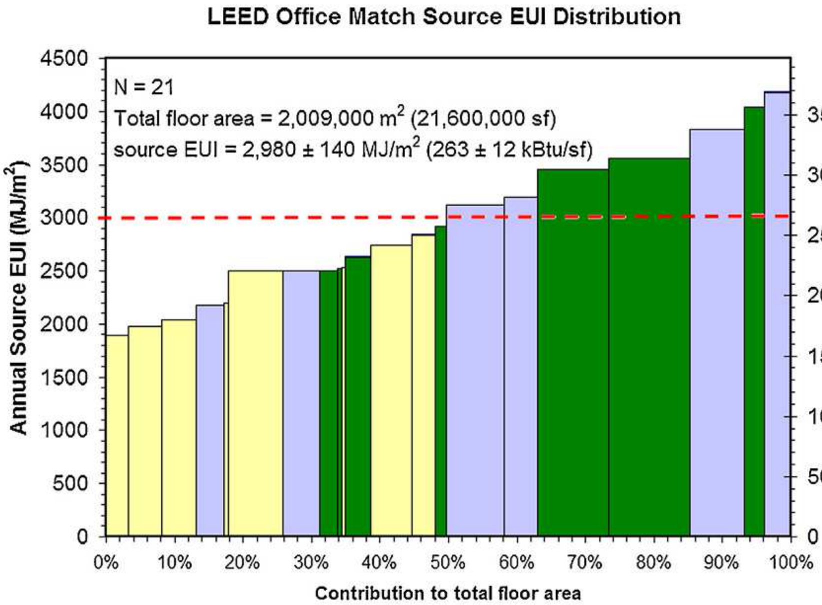

Figure 1. Each rectangle in this figure represents one of the LEED-21 office buildings. The height of the rectangle is the source EUI and the width represents the floor area of the building as a percentage of the 2.01 million m2 (21.6 million gsf) for the building set

Fig. 1 is a bar graph of the source EUI of these 21 LEED office buildings with bar width chosen to represent the floor area for each building as a percentage of the total area contained in the 21 buildings and color chosen to represent the level of LEED certification—Gold (yellow), Silver (gray), and Certified (green). The area of each rectangle represents the annual source energy (not intensity) associated with each building.

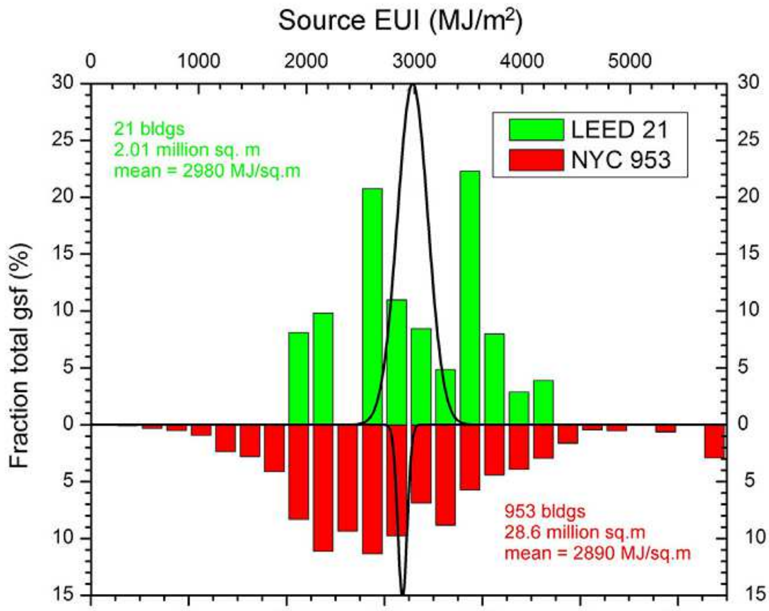

Figure 2. Source EUI histogram for LEED NYC office buildings (plotted up in green)and all NYC office buildings (plotted down in red)

Fig. 2 compares the area-weighted source EUI histogram for the LEED-21 office buildings (plotted up in green) with that for the 953 NYC office buildings (plotted down in red). The area-weighted means for the two histograms are represented by Gaussian curves with widths matching the standard deviations of these means (sdm). The graph confirms that the mean source EUI for the LEED-21 building set is, slightly higher than that for the 953 non-LEED NYC offices. The "overlapping" Gaussian curves indicate that this difference is not statistically significant – namely, the means of the two data sets are too close to resolve given their uncertain-ties (standard deviation of the mean).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].

OVERVIEW OF LEED AND BEAM PLUS

LEED is developed by the US Green Building Council (USGBC) for the US Department of Energy and so far is the most recognized building environment assessment scheme. The pilot version (LEED 1.0) for New Construction was first launched at 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 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. 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 equipment's and the installed lighting intensities. The standard requires the use of simulation programs that provide detailed hour-by-hour energy analysis of buildings.

Table1 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) and the other for existing office buildings (HK-BEAM 2/96). 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). 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.

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 2. Have the most significant impact on the overall rating , rating systems utilize.

Table2 The credit scale

Credits	LEED Annual energy cost saving (AEC_{COST}) (%)	BEAM Plus Annual energy use saving (AEC_{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

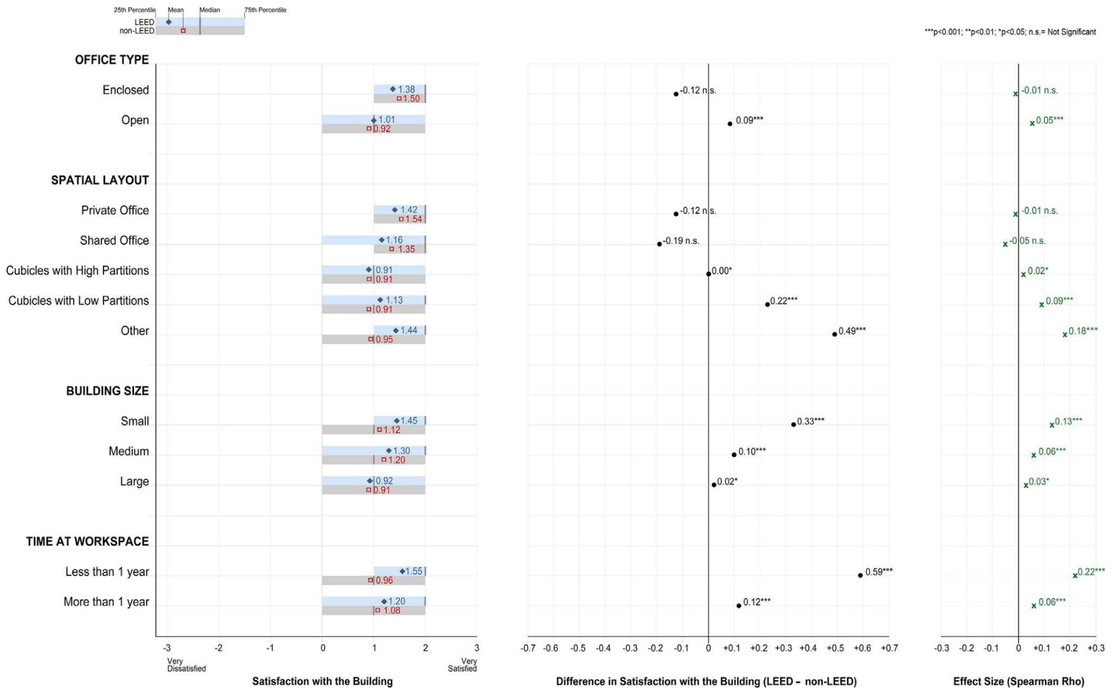

Figure 3. Mean, median, first and third quartile (left); Differences in mean values (LEED non-LEED) (center); Effect size (Spearman Rho) (right) of occupant satisfaction with the building for four non-environmental factors (office type, spatial layout, building size and time at workspace)

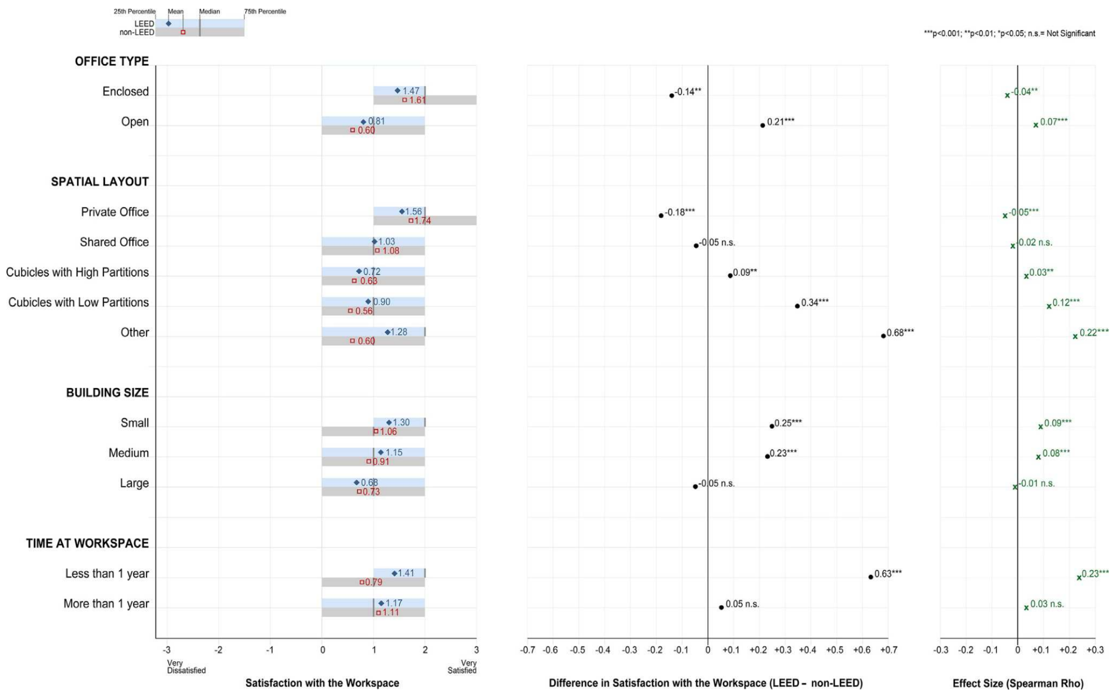

Figure 4. Mean, median, first and third quartile (left); Differences in mean values (LEED non-LEED) (center); Effect size (Spearman Rho) (right) of occupant satisfaction with the workspace for four non-environmental factors (office type, spatial layout, building size and time at workspace)

However, it must be noted that the mean votes of occupant satisfaction with the building (Fig. 3) and with the work space (Fig. 4) as well as with the other 15 IEQ parameters featured in the CBE survey database are always higher in enclosed offices than in open spaces for both LEED and non-LEED certified buildings. These results are in line with the conclusions of that detected in private offices a significantly higher satisfaction with the amount of space e which was found to be the most predictive factor of satisfaction with the workspace. Satisfaction with most other IEQ parameters was also significantly higher in private and shared offices than in cubicles with high, low, or no partitions.

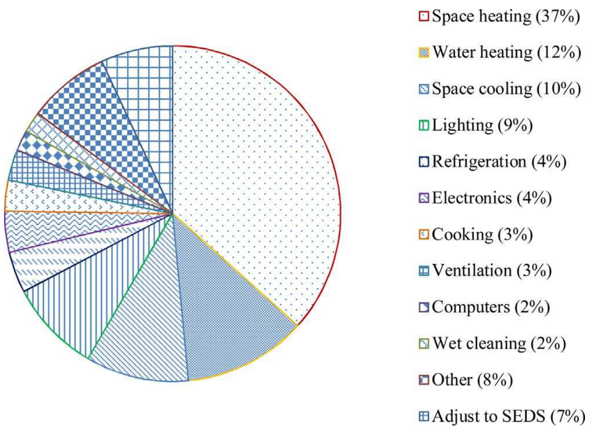

Figure 5. Building site energy consumption by end use in 2010

Figure 6. DesignBuilder model of the studied building

Figs. 6 show an actual photograph and the DesignBuilder model of the studied green building respectively.

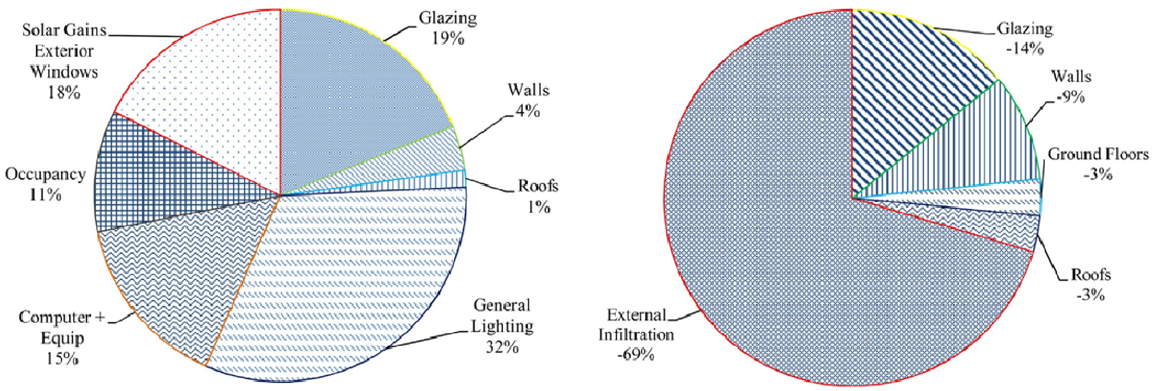

Figure 7. Displays the heat transfer of the studied green building through the walls and roof in the winter typical week

Based on the information in Fig. 7, general lighting is the highest indoor heat emitting source in the summer typical week, which is followed by the glazing and exterior windows. These 3 factors produce 70% of the heat gains in the studied green building. In order to improve the energy performance of the studied building, an energy efficient lighting design should be considered. It will not only reduce the cooling energy requirement but also the power use for artificial lighting. To mitigate the heat gain through the glazing and windows, shading devices and the double-skin fac¸ ade could be utilized. Gratia and De Herde stated that the solar protection devices, such as blinds, could substantially reduce the solar energy gains through the glazing and windows, and Chan et al. In the winter, the building’s energy loss distribution is different from the energy gains in summer. 26% of the energy was lost through the building facades (glazing, walls, and roof), 3% through the ground floor, and a major part (69%) through the external infiltration.

EVALUATION OF GREEN BUILDING

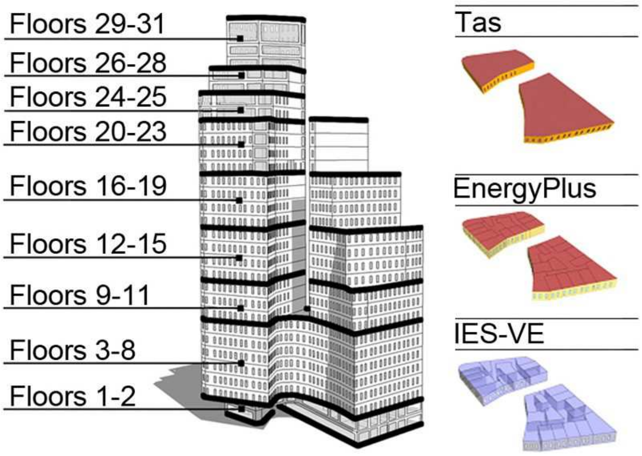

Figure 8. 'Average floors' model (left) and a typical 'Average floor' in the three tools (right)

Shown in fig.8 and fig.9, the case-study building selected for the study is a 14,000 sqm, 32 story student residential hall, located in London, UK. The building is comprised of 470 studios and several common areas. Its bottom floors as well the south – west fac¸ ades of its top stories (24th to 32nd floors) are fully glazed. The east fac¸ ade of the building has 10% glazing, and the other facades – between 16 and 20%. Due to the complexity of the case-study the model was simplified through the use of one 'average floor' for every 2–5 adjacent

Table 3 A comparison of the modeled 'Designed', 'Notional' and 'Baseline' building properties

Category	Designed building	Notional building (BREEAM)	Baseline building (LEED)
Simulations' orientation	As designed	As designed	4 simulation in a 90◦ rotation interval
Model geometry	As designed	As designed	As designed
Thermal zones	Each room is a thermal zone	As designed building	As designed building
Fenestration	As designed	1.5 m × full fac¸ ade width, or 40% of wall area, whichever smaller Sill height – 1.1 m	Same as designed building, or 40% of wall area, whichever smaller
Glass–frame ratio	10% of window area	10% of window area	Not mentioned in ASHRAE 90.1-2007. Modeled as 10% of window's area
Domestic hot water Energy source	As designed: gas boiler	As designed	ASHRAE 90.1-2007 sec 7.4.1: Electricity
Efficiency	SCoP: 90%	Minimum SCoP: 83.6%	Minimum SCoP: 93%
Ventilation rate	2 ACH at occupancy times[a]	According to NCM's database[b]	As designed
Infiltration[c]	5 m^3/h per m^2 envelope at 50 Pa.0.35 ach	5m^3/h per m^2 envelope at 50 Pa. 0.35 ach	Same as designed building
Internal gains	Hourly data by SPPARC	As designed	As designed
Thermostat[d]	20–25 ◦C	As designed	As designed
U-Value (W/m^2 C) Source	As designed	NCM 2010	ASHRAE 90.1.2007
External wall	0.24	0.26	0.365
Internal wall	1.8	1.8	0.365
Fenestration[e]	1.65	1.8	2.56
Ground floor	0.2	0.22	0.2
Upper floor/ceiling	0.19	1	0.214
Periphery[f]	0.005	0.005	0.005

For LEED EA credit-1, the performance improvement was calculated (evaluated by energy expense) for both the 'Designed' and 'Baseline' buildings by each BPS tool. Fig. shows that despite the differences in the overall predicted energy demand generated by the various BPS tools, the performance improvement between the 'Designed' and 'Baseline' building was similar in all three tools (around 3%). Though transforming the 'energy demand' into 'total energy expenses' increased the performance improvement from 3% to 8%, neither of the BPS tools showed an improvement of more than 10% (a minimum value required by LEED). Therefore, neither of the simulations was able to achieve any LEED EA credit-1 points.

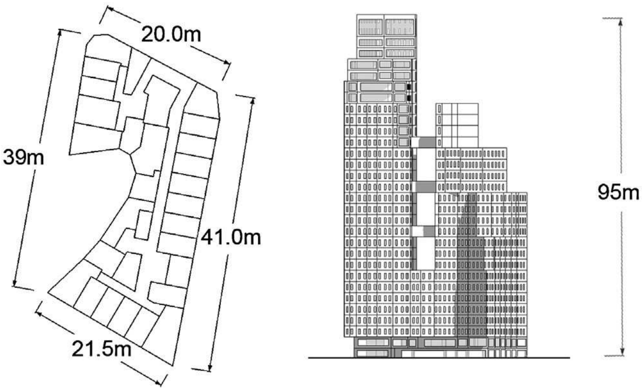

Figure 9. A typical 3–8 'Average floor' floor plan (left) and west elevation of the building (right)

Table sums up the score of the energy sections out of the overall scores of BREEAM and LEED, as it was calculated by each BPS tool.

A comparison between NCM 2010 and ASHRAE 90.1-2007 shows that although NCM and ASHRAE 'Designed building' energy demand were practically identical in each BPS tool (Fig. 8a), the differences between the 'Designed building' system properties in each standard (HVAC and domestic hot water systems,

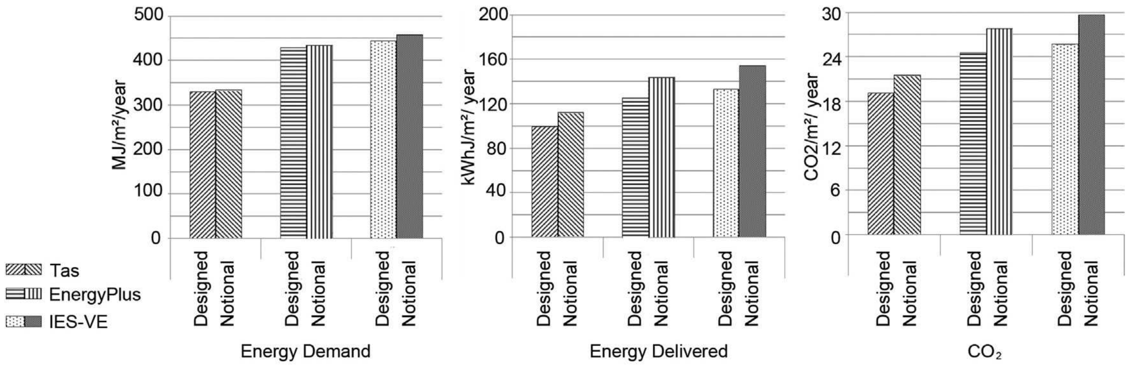

Figure 10. EPR-NC components in the 'Designed' and 'Notional' buildings

The results illustrated in Fig. 10 and Table 4 show that despite the variation in total energy consumption between the BPS tools, the calculated performance improvement of the 'Designed building' compared with the 'Notional building' for each consumption parameter (demand/delivered/CO2 emissions) were similar in all three BPS tools (approximately 2% improvement). As a consequence, the Ene-01 score in all three tools was within the same range (6–7 Ene-01 credits). The difference between the overall BREEAM score for each tool was under 1%. Fig. 6 also illustrates the impact of the transition from the original BPS tools outputs – 'energy demand' – into 'Energy delivered' and 'CO2 emissions' values. In all BPS tools this change increased the calculated performance difference between the 'Designed' and 'Notional' buildings from 2% to approximately 10%.

Table 4 Sub-index weights heavy green building

		Section with the outdoor environment w1	Energy conservation and energy use w2	Water conservation and water use w3	And materials and material resource use w4	Indoor Environmental Quality w5	Construction Management w6	Operation and Management w7
Design Evaluation	Residential building	0.20	0.30	0.20	0.15	0.15	0	0
	Public Buildings	0.15	0.35	0.10	0.20	0.20	0	0
Run Evaluation	Residential building	0.15	0.20	0.20	0.10	0.15	0.10	0.10
	Public Buildings	0.10	0.25	0.15	0.15	0.15	0.10	0.10

$\Sigma Q = w_1 Q_1 + w_2 Q_2 + w_3 Q_3 + w_4 Q_4 + w_5 Q_5 + w_6 Q_6 + w_7 Q_7$

Modular contains two main processes: the decomposition module and module integration. Modular decomposition refers to a complex system behavior according to certain rules of contact (interface standard) can be decomposed into semi- independent design self-discipline subsystems (modules) have a certain function of ; module integration is in accordance with the rules established contact (interface Standard) sub-modules will be decomposed integrate constitutes a more complex system or process. The modular design is based on the modular decomposition, in accordance with established rules of contact modules having a different function is formed to integrate the integrated system to meet different functional requirements (product). Ulrich believes that when the product design flexibility and rapid innovation has become a major factor, modular design is particularly important. Proper implementation of modular, it can accelerate product innovation through autonomy (within the module) and modularity (mix and match between the modules). When the system reaches a certain scale independence, modules significantly between the elements, modular design with respect to the integration of design more environmentally strain, modularity is an effective way to manage complexity. Modular design (or form a modular structure) is divided into three stages: (1) design rule stage , to determine the modular decomposition rules ; (2) independent parallel action stage design for each module individually designed ; (3) system integration and testing phase, the module is integrated to form a system to meet the functional requirements .

CONCLUSION

With the continuous promotion of the concept of sustainable development in the social, economic development, construction of sustainable development has become the focus of world attention. Green building in order to achieve " people - Architecture - Nature" harmony among the three , and sustainable development as the goal, in the whole life cycle of the building to maximize the conservation of resources (energy, land , water, materials) , protect the environment and reduce pollution as a means to achieve sustainable development. Green building has become an inevitable trend in building research and development. Countries in the world combined with national conditions, from sustainable development, the harmonious coexistence of man and nature studies on the angle of green building technologies, policies, regulations and standards. Our researchers learn from other countries on the basis of advanced research , combined with China 's national conditions for green building content, technology , regulations, standards , etc. were studied green building system has begun to take shape . Based on past studies of unilateral green buildings, from the perspective of system theory of green building design goals, influencing factors, such as green building technology with a systematic study, and based on the theory and design of a modular approach to green building technology systems and design methods of research and application. This paper studies the following conclusions : (1) From the perspective of green building systems starting to study the relationship and mutual influence between the target system for green building , green technology, construction and other intrinsic construct a model of green building technology system . (2) The use of a modular theory, combined with the characteristics of green building technology systems, green building technology system for discrete representation of the theory and methods proposed green building techniques to build a modular system. Namely the use of AHP, efficiency score was constructed a modular system of green building technologies and green building programs cast blocks. According to the theory and methods of green building techniques to build a modular system, combined with the region’s climatic conditions and resources to build a green building technology modular system. (3) is proposed based on the modular integration of green building design methods and design process , and green building program evaluation studies , including research evaluation index system , evaluation methods. Evaluation method proposed "green building evaluation technical details” green building technologies and design solutions based modules.

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*, **2005**, 18–21.

[2] R. Yao, B.Z. Li, K. Steemers, Energy policy and standards for built environment in China, *Renewable Energy*, **2005**, 30, 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*, **2007**, 30 (10), 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*, 2004, **30**, 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**.

[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**.
[7] ESGB, Evaluation Standard for Green Building (GB/T 50378-2006), Ministry of Construction of the People's Republic of China, **2006**.
[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