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Low Energy Certificate — an exploration on optimization and evaluation of energy-efficient building envelope

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Energy saving is the crucial task of green architecture, energy-saving design and evaluation should be interactive. Low Energy Certificate (LEC), an interactive computer program for energy efficiency and certification of building envelope, is briefly introduced in this paper in aspects of certification standards, procedure, methods etc. Through the evaluation report of Innovation-pavilion EXPA features and reference values of LEC are presented.

optimization and evaluation of energy efficiency, Low Energy Certificate (LEC), energy performance of building envelope, interactive

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1 Actual design and evaluation of energy-efficient buildings

What is green building? Until now, there is still no world-wide uniform definition to it and individual evaluation system for energy-efficient buildings has its own emphasis. In China's Evaluation Standard for Green Building (GB/T 50378), "Green building refers to the buildings that can maximally save resources (energy, land, water and material), protect the environment, reduce pollution, provide healthy, comfortable and efficient use space as well as be harmonious with the nature in the whole lifecycle." [1] The emphases are laid on resource-saving and environmental protection. For the moment, there are several internationally recognized green building evaluation or certification systems such as LEED (Leadership in Energy & Environmental Design, USA), BREEAM (Building Research Establishment Environmental Assessment Method, Britain), CASBEE (Comprehensive Assessment System for Building Environmental Efficiency, Japan), DGNB Certificate (Germany). Both China's Evaluation Standard for Green Building and US Green Building Council's LEED are comprehensive assessments which accentuate buildings' impact on the environment. [2]

In the current phase of green building development in China, the basic policy is to promote energy saving of buildings. [3]Aiming at green building, energy efficiency is the problem that should be solved at first. On this aspect, it is often required that design and evaluation could interact. To design energy-efficient buildings, the designers should be able to estimate/evaluate the building energy performance in the planning and scheme phase, so that to check the possibilities of energy saving according to the design scheme, to make appropriate adjustments betimes and to optimize the building energy performance.

For the present, most evaluation or certification systems for green building list the building energy performance as

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one item that can be presented neither directly nor thoroughly, and the interaction between design and evaluation is almost impossible. Furthermore, most green building evaluation systems cannot make necessary adjustments to reference data corresponding to different climate conditions when the evaluated building is sited in other regions, so these systems have less flexibility and less applicability.

Energy performance certificate for buildings (*Energieausweis*) issued by German Energy Agency (DENA) is for the moment the only one evaluation system especially aiming at buildings' energy requirements. *Energieausweis* showing general building data certifies the energy quality of the building and provides a clear summary of the analysis results. It presents energy efficiency with a color scale which shows at a glance how much energy the building requires compared to other buildings. In China, up to now, there are two projects awarded *Energieausweis*, i.e. Pujiang office building in Shanghai and Cheng Kai Yu Yuan residential buildings in Nanjing. The energy requirements rated by *Energieausweis* contain heating, hot water, lighting installation, ventilation and cooling. According to different energy carriers (such as gas, electricity, renewable resource etc.), the fore parts of energy supply chain including energy exploration, production, distribution and transition are measured with “preliminary energy consumption” so as to take resource preservation and environmental protection into consideration. Although *Energieausweis* presents the building energy quality comprehensively and directly, but as a European evaluation system, it cannot be directly adapted in China, since the regional climate conditions and political parameters are quite different. Furthermore, the calculation of *Energieausweis* is rather complicated and only the strictly trained, professional auditors with comprehensive building-physical and HVAC knowledge can make the calculation, which makes the interaction between design and evaluation more difficult.

In fact, it is desirable for building designers to be able to use basic data to find out the crucial positions for the improvement of building energy performance quickly and precisely. Logical, rational simplification of calculation and evaluation of building energy will help to realize the interaction between design and evaluation.

In this sense, Low Energy Certificate (LEC) made an instructive exploration. LEC as a planning and controlling implement including a certification system is a simple, easy-to-use evaluation system with veracity and validity. Both architects and the approving authority with average knowledge could use LEC with an economically acceptable expenditure to understand and evaluate the energetic reactions of buildings. Excluding influences of equipments, energy types and politics, and meanwhile taking the differences of climate conditions into full consideration, LEC program can analyze the energy performance of the building envelope in virtue of basic building physical data, evaluate it and offer optimization suggestions.

2 LEC — an evaluation and optimization program for energy efficiency of the building envelope

LEC is an interactive evaluation/optimization program for the building envelope. It can evaluate the energy efficiency of building envelope and building elements separately for the periods of heating, cooling and the whole year. The evaluation results are marked with a simplified star system, and more stars mean the higher energy efficiency of the building envelope. In order to adapt to China, LEC program is integrated with the Chinese compulsory norm — Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005). More Informations see http://www.lowenergycertificate.com/

2.1 Basis and processes of the LEC-evaluation

The calculations to evaluate the energetic quality of the building envelope are based on the results of physical balance equation. According to Chinese compulsory norm--Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005), German norm DIN 4108-2, DIN 4108-6, and DIN V18599-2: 2007-02, LEC makes calculation under the consideration of the geometry, envelope construction, orientation, materials, building utilization, climate conditions etc. but excluding influences of HVAC equipments and user behaviors.

2.1.1 Evaluation standard for the heating periods

For the heating periods, a reference building is defined considering the geometry, the climatic region, orientation of azimuth and surface normal as well as the use that correspond to the evaluated building. As far as the building construction and elements are concerned, it complies with the Chinese Construction Standard of the 1980s, i.e. the standard used before Building Energy Conservation Ordinance was issued.

For the evaluation of heating, the end results of the heat losses (including loss of heat transmittance through the building envelope and ventilation heat losses) and the thermal heat gains for the heat period (including solar gain of heat and internal gain of heat) are summed up. The difference between the annual thermal heating need of the examined building and that of the reference building is the estimated amount of energy saving used for evaluation (see Table 1).

2.1.2 Evaluation standard for the cooling periods

The heat protection in summer is supposed to achieve the comfort interior temperature without air-conditioning or the cooling energy need of usage-depending air-conditioned rooms is as low as possible. For non air-conditioned rooms, it should be guaranteed that the limiting value for the physiological beneficial internal temperature is not exceeded. The

Table 1 LEC-standard for winter and summer periods

Standard for winter periods	Referring to the reference building
1 ☆ Chinese building standard of the 1980s	annual heating energy demand ≥71%
2 ☆☆	annual heating energy demand 70%–51%
3 ☆☆☆	annual heating energy demand 50%–31%
4 ☆☆☆☆ 2007 European standard	annual heating energy demand 30%–21%
5 ☆☆☆☆☆ 2009 European building standard for low energy consumption	annual heating energy demand ≤ 20%

comfort level for the summer periods according to the German requirement of DIN 4108-2 is proved to be a practical base reflecting very well the scope of the climate that is just tolerable in the summer periods.

The evaluation of the energetic reactions of buildings in summer is based on a process resulting from the requirements of the German norm DIN 4208-2 which were especially adjusted to the climatic region of the world. The criterion “cooling energy neutral” defined for facades is described by interplay of the size of the window, the characteristics of the glazing as well as the sun protection, sunblind and shading devices etc., which limits an exceeding of certain maximum temperatures to a few hours per year. Simply, a cooling-energy-neutral facade can make the room with no usage keep acceptable temperatures without cooling. Increased internal loads or the possibility of an increased ventilation to lower the room air temperature are not considered, since such dynamic heat exchanges have nothing to do with the energy quality of the building envelope.

The hours of the internal temperature exceeding the limiting value and each climatic region with regard to each cooling period are used as criteria. With the help of a dynamic thermal and energetic building simulation done by TRNSYS -- a calculation program developed by the Solar Energy Laboratory of the University of Wisconsin-Madison, solar input values (see Table 2) are calculated as characteristic values of individual cooling-energy-neutral façades with different orientations in different climate regions and the results are taken as the basis of LEC-evaluation.

For the evaluation of cooling periods, LEC compares the solar input value of the estimated building with that of the cooling-energy-neutral façades. LEC calculates cooling energy demand and cooling load per unit area, and then gives corresponding evaluation of the building envelope for cooling periods (see Table 3).

2.1.3 Evaluation standard for the whole year

After that the energy demand is calculated and estimated separately for the heating and cooling periods of each climatic region, the energy demands for both heating and cooling will be summarized and identified within the

Table 2 Solar input value

S Solar input value	$= A_G \times g \times F_C$
	A_G , glass proportion of facade
	g , energy transfer coefficient of glass
	F_C , shading coefficient

framework of an overall estimation for the building (see Table 4). For this, both regional climate conditions and the duration of the heating or cooling period are considered.

2.2 LEC evaluation procedure

Following the menu, the users can input corresponding information and data including basic project information, reference climate, orientation, zoning, utilization, construction type, thermal transmittance etc. LEC calculates energy demand per unit area for the heating and cooling periods, and generates individual reports for building areas, building elements and windows as well as reports on energy performance rating.

Reference climates: The maps of the countries are divided into color-marked areas. The different colored overlaps represent the climate regions. Characteristics and divisions of the climate regions in China are based on the Chinese Norm GB 50189-2005. Climate zones -- Hong Kong, Macao and Taiwan were added as individual climate zones. Once the reference climate is chosen, corresponding climate factors including the duration of heating or cooling periods will be given with diagrams and charts.

Zoning: The more detailed the input of the zoning of the building, the more accurate the following energetic evaluation.

Table 4 LEC evaluation system by awarding stars

LEC-standard	Explanation
1 ☆★★★★	The building does not correlate with any permit standard.
2 ☆☆★★★	It corresponds to the minimum requirements according to GB 50189
3 ☆☆☆★★	It corresponds to the increased requirements according to GB/T 50378
4 ☆☆☆☆★	It is comparable to the European building standard
5 ☆☆☆☆☆	It is comparable to an increased European building standard

Utilization: according to the usage, there are three building types, i.e. residential building area, office and /or business building area and others. For different utilization, different boundary conditions will be chosen correspondingly during evaluation. For example, according to the standards, the limiting value of the interior temperature can be exceeded temporarily, but not longer than 10% of the whole staying time. The staying time will be counted as 24 h per day in living rooms but only as 10 h per day in office rooms. In addition, there is a difference between the ventilation behaviors in these two different areas. Office buildings are ventilated more than houses but the ventilation intervals in houses are longer than in offices. Another reason to make a difference is because of the dissimilar internal thermal loads caused by technical devices and people, since the internal load referring to a short period in office building is much higher than that in houses.

Construction type: lightweight construction and heavy construction. Lightweight construction refers to the buildings with suspended ceiling, light partition walls, and cavities under the roof. This includes rooms in which at least 4 out of 6 surfaces of the internal wall (walls/ceiling/floors) are separated from the solid building parts by siding. Heavy construction refers to the buildings with solid concrete ceilings, solid partition walls and floor-boarding without sidings. This includes rooms that are mainly built without the siding of the heavy internal building element. The constructive designed building parts, e.g. solid concrete ceilings, heavy partition walls and floor-boarding must have contact areas with the air of the room. The difference between the two given construction types regarding the evaluation is that a heavier construction has a higher heat storage capacity than a lighter building type. The heat storage capacity is another characteristic crucial to the energetic evaluation.

The volume and area of building zones will be calculated automatically. U-value of building elements can be either input directly or calculated with the input of materials and thickness.

2.3 Example of LEC-evaluation — pavilion of innovation EXPA

The Pavilion of Innovations (PoI) was constructed under the support of Lower Saxony State of Germany (Niedersachsen) and Anhui Province of China on the occasion of the EXPO 2010 in Shanghai, the objective is to present the possibilities of energy efficiency, innovative construction methods and construction techniques. The pavilion itself is a pilot project with low energy consumption. After the EXPO 2010, PoI is intended to be put into research use for more than three years.

PoI consists of two reinforced concrete cubes, a glass corridor and a membrane canopy (see Figure 1). [4] The one-story high block is a showroom for techniques while the two-story high cube is used as information/consulting area. Two cubes are connected by a glass corridor. The falcate

Figure 1 EXPA rendering and first floor plan.

membrane canopy over the one-story showroom, the glass corridor and some open space can act as a sunshade and collect rain water either for the sanitary use or to be purified for other reuse.

According to the LEC-evaluation for PoI, the energy performance of the pavilion achieved the 4-stars standard. Furthermore, LEC made the separate evaluations on information/consulting area, technique showroom and the glass corridor for heating periods, cooling periods as well as annual periods, which present the energy performance of each part for each period of time clearly (see Table 5).

The LEC-evaluation program can also evaluate divided areas and individual building elements, and calculate the technical characteristic values of windows. Take the two-storyed information/consulting area as an example. This building part with a trapezoid-shaped plan and 7.5m height was built with prefabricated walls and semi-prefabricated or cast-in-place reinforced concrete floors. Two of the external walls tilt outwards on the top with 10°. LEC reports on energy efficiency of information/consulting area and individual building elements, material performance, technical characteristic values of windows are made as Tables 6–8. [4]

2.4 Interaction between design and evaluation

The function of analysis provided by LEC can help the designers to find the weak position of the building envelope concerning building energy efficiency and make the relevant adjustment for optimization. To do that, the aimed standard so as related, required information and data can be input at first. After calculation, LEC can offer suggestions on building elements from aspects of zoning, glazing, construction, area etc. With LEC, the comparison of different energy-concerned schemes can also be made easily as long as factors including glazing area, window types, sunshade form, material, construction are changed correspondingly.

Even if the aimed standard of the comprehensive energy efficiency of the building envelope is achieved, LEC can help to make optimization related to details. For example, LEC found out that the south external wall of a building envelope with LEC 4-stern-standard has no ideal energetic performance in the cooling periods and made suggestions such as using widows with better insulation, taking sun-protection measures or reducing the glazing area (see Figure 2) [4]

3 Exploration on optimization and evaluation of energy efficiency for building envelope

Besides the energy performance of the building envelope, the actual building energy efficiency is also influenced by equipments and their efficiency, energy sorts and efficiency, building quality, users' behaviors and other factors. The excellent thermal isolation of the building envelope is the base to achieve optimization of building energy consumption and energy-saving. Evaluation aimed at the energy efficiency of the building envelope can objectively present the

Table 5 LEC evaluation report on EXPA

Building evaluation				☆☆☆☆★
Building area	Utilization	Construction type	Volume (m^3)	Effective area (m^2)
Information consulting area	office/business	lightweight construction	355.10	142.04
Glass corridor	office/business	lightweight construction	52.27	20.91
Showroom	office/business	lightweight construction	176.90	70.76
Building area	Heating period	Cooling period	Annual balance	
Information consulting area	☆☆☆☆★	☆☆☆☆★	☆☆☆☆★	
Glass corridor	☆☆☆★★	☆★★★★	☆☆★★★	
Showroom	☆☆☆☆★	☆☆☆★★	☆☆☆★★	

Table 6 LEC evaluation report on EXPA information & consulting area

Building area	Information/consulting area				☆☆☆☆★
Building elements	Orientation	Inclination	Area (m^2)	*K*	LEC standard
External wall 1	north	60°<α<90°	40.79	0.33	☆☆☆☆★
External wall 2	west	60°<α<90°	72.80	0.27	☆☆☆☆☆
External wall 3	north	60°<α<90°	25.66	0.27	☆☆☆★★
External wall 4	east	60°<α<90°	38.69	0.27	☆☆☆☆★
Ceiling 1	horizontal	0°<α<30°	69.13	0.18	☆☆☆☆☆
Raised ground floor	horizontal	0°<α<30°	51.65	0.36	☆☆☆☆☆

Table 7 LEC0020evaluation report on certain building element

Building element	External wall 1		☆☆☆☆★
Orientation	north	standard for winter period	☆☆☆★★
Inclination	60°<α<90°	standard for summer period	☆☆☆☆★
Total area	48.10 m^2		
Net area	40.79 m^2		
Material	Density (g/cm^3)	*K* (W/mK)	Thickness(m)
Nanoporputz	1.8	0.700	0.002
Lightweight concrete	1000	0.490	0.250
Timber fiber isolation	110–450	0.035	0.080
Plasterboard	800	0.250	0.010

Table 8 LEC evaluation report on glazing

Building area	Information/consulting area			☆☆☆☆★
Elements	Glazing	Area (m^2)	*U*-value (W/m^2K)	*g*-value
External wall 1	window 1	7.31	1.60	0.59
External wall 2	window 2	0.75	1.60	0.60

External wall 2	window 3	0.75	1.60	0.60
External wall 3	window 4	5.74	1.60	0.75
External wall 3	window 5	8.61	1.60	0.75
External wall 3	window 6	5.74	1.60	0.33
External wall 4	window 7	3.13	1.60	0.59
External wall 4	window 8	4.19	1.60	0.01

energetic reaction of the building itself so as to help designers choose the rational scheme for the building envelope in the early planning phase and build a favorable base for optimization of building energy performance.

LEC is an exploration on the energetic evaluation regarding building envelope. Excluding the influences of equipments and energy sorts, LEC makes the full consideration of climate conditions, and the rationally, measurably simplified calculation of building energy demands makes LEC more applicable. Since the basic data of climate regions of China according to Chinese national norms are integrated into the program database, LEC can be used as a valuable reference and in practice of the evaluation of energy efficiency in China.

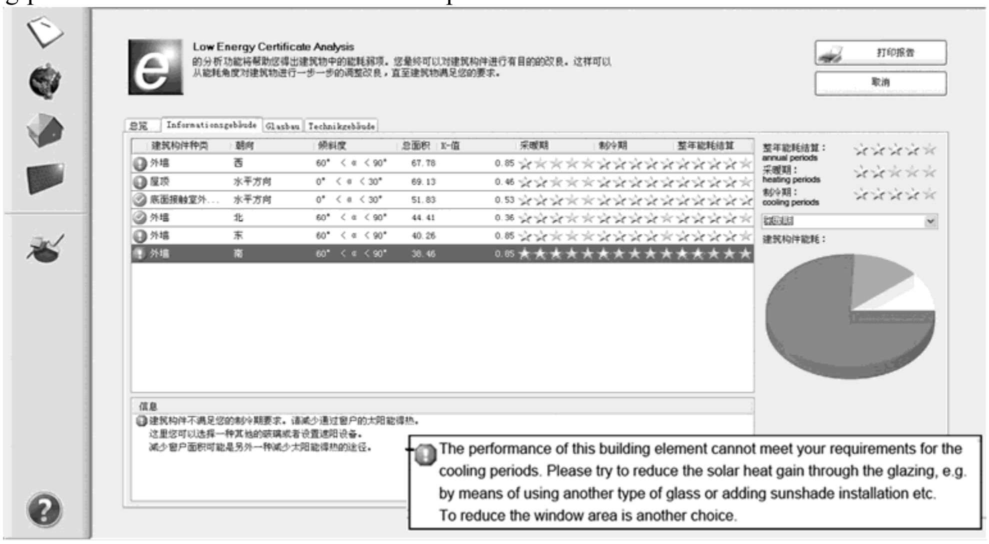

Figure 2 LEC-analyses pointed out the weak position of the building envelope concerning energy performance for the cooling period.

At the same time, LEC can be also used as a program to optimize the design concerning energy performance of the building envelope. The function of analyses can help to make inspection and adjustments, and realize the interaction between design and evaluation to a certain extent, and help people to make full considerations of energy saving in the early design phase.

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