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Research on the Post Occupancy Evaluation of Green Public Building Environmental Performance combined with Carbon Emissions Accounting

Liang Yu[a], Zhenbo Sun[a], Ran Ding[a], Siwen Wang[a], Guohui Feng[a,*]

[a]*Shenyang Jianzhu University, Liaoning, 110168,China*

Abstract

The development of green building in China has reached a new stage, needs to turn to the total energy consumption control from the technology control[1]. We should avoid packing technologies in green building projects and regard achieving good environmental performance as the fundamental goal. In this paper, we use the method of post-occupancy evaluation and regard the building environmental performance as the core of the evaluation system, in order to reduce the influence on the accuracy of results from the measures evaluation. We establish the evaluation index system of green public building environmental performance in severe cold and cold regions, including the index of building life-cycle carbon emissions accounting. And we set up the application plan of index and the scoring method, then we put forward a kind of evaluation grade based on environmental performance level, finally proposed the POE System of Green Public Building Environmental Performance in Severe Cold and Cold Regions (POE-GPBEPC).

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Keywords: Green building; Post-occupancy evaluation; Environmental performance; Carbon emission;

1. Introduction

1.1. Analysis of energy condition and the energy saving potential in construction field

In 2013, Chinese total energy consumption was 37.5 tons of standard coal, a year-on-year growth of 3.7%. In energy efficiency, energy consumption of ten-thousand-yuan GDP is 0.73 tons of standard coal in 2013, decreased

* Corresponding author. Tel.: +86-158-4039-1122;.
E-mail address: sy_yuliang@163.com

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by 0.03 tons than 2012. The intensity of energy consumption has dropped by 9.9% in the first three years of 12th five-year plan, to complete the planning target of 61.5%[2]. At present, China's energy situation is grim, and there is a huge pressure on energy efficiency. With the rapid increase of the level of Urbanization, the field of architecture energy consumption has increased year by year with an enormous energy saving potential. From 2001 to 2011, public construction area increased by 0.8 times, the average energy consumption per unit area increased by 0.2 times, is the fastest growing classification of construction[3].

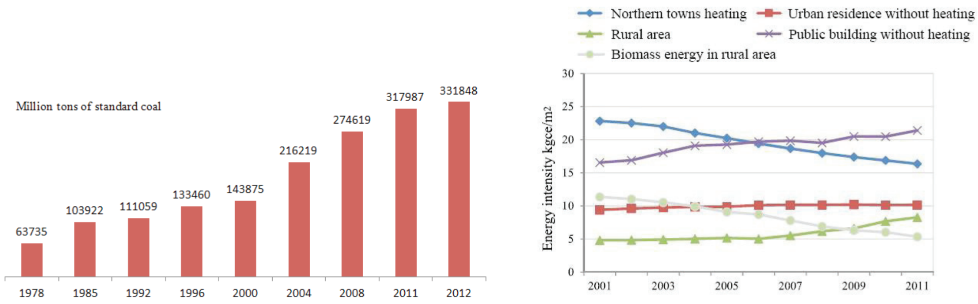

Fig. 1. (a) Energy condition; (b) Building classification energy intensity change

1.2. The development of green buildings in China has many problems

China's green building projects has increased year by year, but green building design label and operation label projects have developed unbalanced. Among them, green building in severe cold and cold regions and public building have an important position in the development of green building[4], Green building technology implementation and operation is poor; the actual operation performance is poor than designed, and there are many problems of energy consumption and Water consumption. Green building incremental investment is larger than the economic benefits[5]. What's more, study on green building post-occupancy evaluation lags behind in china, there is no relevant standards and building carbon emissions accounting is not involved. In summary, many contradictions constitute the motivation and basis for the POE evaluation of environmental performance to green public building in severe cold and cold regions.

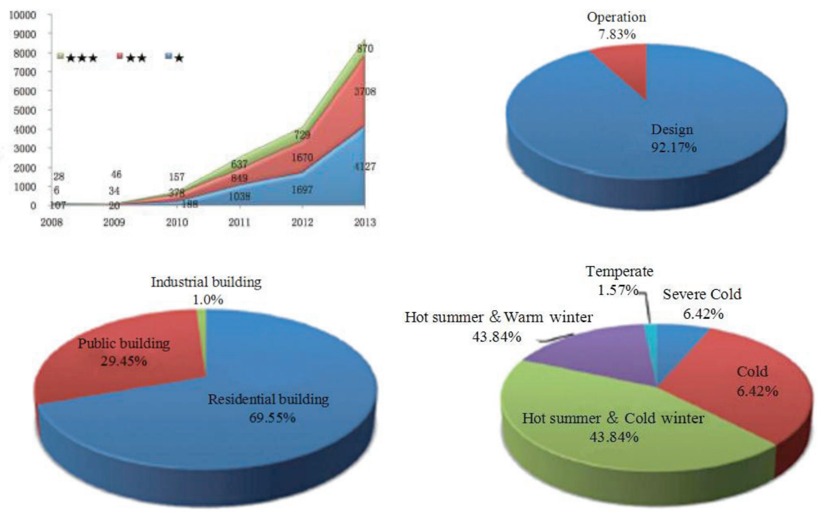

Fig. 2. (a) Development of green building projects year by year; (b) The proportion of green building design and operation label projects; (c) Different type of green building; (d) Green building label in different climate

2. Methods

2.1. The establishment of evaluation index system

We divide the target item of the POE index of environmental performance to green public building in severe cold and cold regions into seven indexes on class one, including indoor environmental quality, quality of service, outdoor environmental quality, energy consumption, resource consumption, outdoor environmental load, building life-cycle carbon emissions. The span of evaluation grade distribution is four with a total of sixty-nine performance Indexes. Among the part of the quality of service, there are multiple views evaluation indexes of using property to public building, which reflects the characteristics and superiority of the post-occupancy evaluation. Giving expression to the building functionality and user's intuitive feeling through these indexes can truly reflect the comprehensive environmental performance and operation effect, feedback the design and provide improvement basis for developers.

Building life-cycle carbon emissions accounting is comprehensive, scientific and accurate, it can reflect effect of energy saving and emission reduction comprehensively by energy saving technology, the application of renewable energy and clean energy, building envelope performance and equipment efficiency improvement[6]. There is no in the related standards of china. Building carbon emissions accounting and evaluation needs a standardized database and the determined reference architecture. As a comprehensive evaluation index, it has interference with other factors. It is difficult to directly participate in the score. Therefore, in this study, building carbon emissions is independent, not a score index, measure and analysis the building carbon emissions and compare with the similar construction, as a basic technical support for the improvement of the assessment system of green building in china.

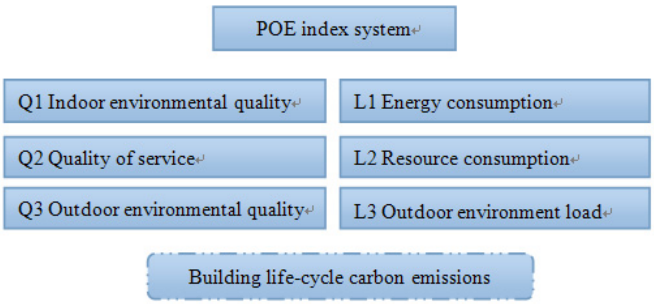

Fig. 3. POE index system of environmental performance to green public building in severe cold and cold regions

2.2. Application of indexes

First of all, In view of the special feature of the building life-cycle carbon emissions, we divided the POE index system into two parts: formal indexes and carbon emissions index.

On the one hand, we obtain the basic evaluation index information of participating project through the application of the formal indexes (not include Building life-cycle carbon emissions). We establish a set of application plan matching index system to collect the data of these formal indexes, including the check list of environmental load, indoor environmental quality measurement, quality of service and satisfaction survey.

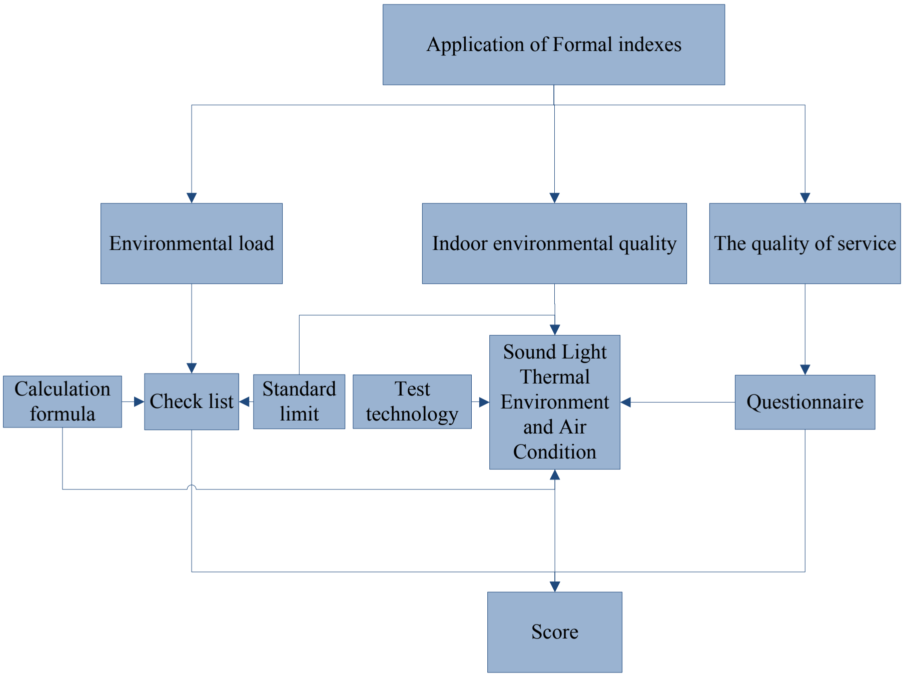

Fig. 4. Application of formal indexes

On the other hand, we established the life-cycle carbon emissions accounting model to applicate the index of building life-cycle carbon emissions to evaluate the level of building carbon emissions. According to the system boundary of building life-cycle carbon emissions, considering the factors influencing the carbon emissions among each process, finally raise the building life cycle carbon emissions calculation formula:

$$LCCO_2 = C_{p,co_2} + C_{t,co_2} + C_{c,co_2} + C_{o,co_2} + C_{m,co_2} + C_{d,co_2} + C_{w,co_2} \quad (1)$$

Construction phase: carbon emissions of material production process (p), carbon emissions of material transport process (t), carbon emissions of building construction process (c); Operation and maintenance phase: carbon emissions of operation process (o), carbon emissions of maintenance process(m); Demolition and disposal phase: carbon emissions of demolition process (d), carbon emissions of waste disposal process (w).

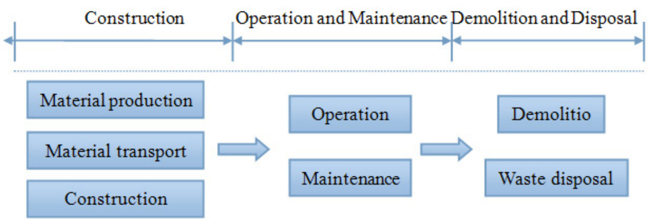

Fig. 5. The system boundary of building life-cycle carbon emission

(1)Material production process

Building materials have their own life cycle, including production of building materials and recycling. In this paper, in this process, only calculate the material production, do not consider recycling. Building carbon emissions of demolition and disposal process of building materials will be involved in the demolition and disposal phase. The calculation formula is as follows:

$$C_{p,CO_2} = \sum_{i=1}^{n} C_{p,i} X_{p,i} \tag{2}$$

i: types of building materials; Cp,i: carbon emissions factor of building materials i; Xp,i: total consumption of material i during construction.

(2) Material transport process

Carbon emission of material transport process is also a great proportion. Carbon emission of material transport process is related to the mode of transport, transport distance and other factors, has its own characteristics, so we calculate it separately. Carbon emission of material transport process refers to carbon emissions of the process to transport building materials from the manufacturer to the construction site. Carbon emissions of this process mainly come from the energy consumption of traffic means. Input parameters of the model: The amount of the building materials, transport distance, carbon emission factor of the mean of transport.

$$C_{t,CO_2} = \sum_{i=1}^{n} C_t X_{t,i} D_i \tag{3}$$

Di: the average distance transportation to the site of building materials i; Xt,i: the amount of building materials i; Ct: carbon emission factor of the traffic mean (CO_2 emissions of the traffic mean per unit building material in unit distance).

(3) Construction process

After the building materials are transported to the construction site, they start building and constructing in the field of the construction site. Carbon emissions of this process mainly come from all sorts of construction equipment with electricity or fuel consumption. Collect specific electricity and fuel consumption data for these varieties of construction equipment, calculated carbon emissions as follows:

$$C_{c,CO_2} = \sum_{i=1}^{n} C_i E_{c,i} \tag{4}$$

Ci: CO_2 emissions of unit energy i; Ec,i: the amount of energy i.

(4) Operation process

Carbon emissions of building operation process mainly come from the HVAC, electrical lighting, domestic hot water and other energy and resource consumption.

$$C_{o,CO_2} = \sum_{i=1}^{n} C_i E_{o,i} Y \tag{5}$$

Ci: carbon emission factor of energy or resources I; Eo,i: the amount of energy or resources i; Y: the useful life of the building.

(5) Maintenance process

Carbon emissions of building maintenance process is very complex, mainly consider maintenance and updates of building materials and equipment. Firstly Estimate the number of building updates and maintenance times by calculating the ratio of the life of the building and the life of each building materials. Then calculate the carbon emissions generated by materials updates[7]. Carbon emissions of maintenance and updates calculate empathy.

$$C_{m,CO_2} = \sum_{i=1}^{n} C_{p,i} X_{m,i} \left(\frac{Y}{Y_{m,i}} - 1\right) + \sum_{i=1}^{n} C_{e,i} X_{e,i} \left(\frac{Y}{Y_{e,i}} - 1\right) \tag{6}$$

Cp,i: carbon emissions factor of building materials i production; Ce,i: carbon emissions factor of equipment i production; Xm,i: the amount of building materials I; Xe,i: the number of equipment I; Y: design life of the building; Ym,i: the service life of materials I; Ye,i: the service life of equipment i.

(6) Demolition process

Building demolition process refers to the removal of abandoned construction and site preparation etc. The carbon emission of demolition process mainly comes from the power consumption of construction machinery and equipment and other fuel consumption. Calculate the CO_2 emissions of the dismantling stage according to the following equation.

$$C_{d,CO_2} = \sum_{i=1}^{n} C_i E_{d,i} \tag{7}$$

Ci: CO_2 emissions of unit energy I; Ed,i: the amount of energy i.

(7) Waste disposal process

We classified the construction waste according to the use value, divided into three categories: materials which can be directly used, renewable or recyclable materials and waste materials without use value. For example, among abandoned building materials, the materials can be directly used are windows, beams, larger size timber, renewable materials mainly refers to the mineral materials, metals, and their shape and function will be different with original materials after regeneration. Carbon emissions of this process mainly include two parts: Materials recycling and transport consumption. Materials recycle contains three main parts: For materials which can be directly reused, reduce energy and resources consumption of raw materials; For the renewable materials, reduce energy and resources consumption, but increase energy and resource consumption of renew processing; The process for landfill waste materials without use value has a slight impact on carbon emissions, so we do not consider it in count. The carbon emissions of materials transport can be calculated as follows:

$$C_{w,CO_2} = \sum_{i=1}^{n} \beta C_{r,i} X_{w,i} - \sum_{i=1}^{n} (\alpha + \beta) C_i X_{w,i} + C_{t,CO_2} \tag{8}$$

α: the rate of materials i which can be directly used after demolition; β: the rate of renewable or recyclable materials i after demolition; Cr,i: carbon emissions factor of the renew processing to renewable or recyclable materials; Xw,i: the total amount of waste materials.

2.3. Scoring method of indexes

We use 5 points scoring method for each index distinguishes quality of environmental performance. Then we set the score method differently between qualitative and quantitative index:

(1)1 point for minimum standard, 5 point for the highest standard. The indexes such as user satisfaction are difficult to divide into 5 level, can be divided into 3 levels (1, 3, 5); if the evaluation result do not even meet the 1 point score standard, the index score will be 0;

(2)Qualitative and a part of quantitative indexes can be evaluated by qualified or (unqualified), qualified is recorded as 5 point, unqualified is recorded as 0.

Table 1. The level of performance and score

Score	Performance level
1	Just meet the performance level of the basic building code, user satisfaction is low
2	Meet the general performance level of public buildings
3	Reach green building performance requirements, users expressed general satisfaction
4	Building performance has improved than the general green
5	Reach high standards of green building performance levels, users are very satisfied

After each single index was 5 points scored, we use the weighted mathematical model to calculate all qualitative and quantitative index score, and accumulate to the respective upper stage according to four index span. Then we get the final evaluation result of POE-GPBEPC value. The POE-GPBEPC value represents the level of environmental performance of the participating building, as the measure of the finally environmental performance evaluation results. Mathematical models are as follows (with one class index as an example, two, three and four class indexes of class two, three and four will be similarly calculated):

$$\text{POE-GPBEPC} = \sum_{i=1}^{n} \omega_i Q_i \tag{9}$$

In the formula: ωi----The weight of site and traffic, energy consumption, resource consumption, indoor environmental quality, service quality; Qi----The score of site and traffic, energy consumption, resource consumption, indoor environmental quality, service quality.

2.4. Evaluation result and grade

According to the POE-GPBEPC evaluation model, the score should be between 1~ 5. Then we converting score for the hundred mark system, full marks are 100 points. If all of environmental performances meet the level of basic public building code, the score will be 20, if all of environmental performances reach the level of green building performance requirements, the score will be 60. Analysis shows that most of buildings' performance level can achieve the qualified line 1 points above based on going through document review, but they generally can't meet green building level requirements 3 points totally; When the projects meet the general building performance level and some performance indexes reach the requirements of green building, we can judge such building get into green building. Therefore, we set the evaluation grade based on the benchmark of 40 points. There are three levels of the evaluation grade, in order to guide the green public building towards a better level. Because the score will be increased more and more difficult with the improvement of performance, we set the POE-GPBEPC grade is as follows: one-star: 40 to 60, two-star: 60 to 75, three-star: above 75 to 100.

3. Conclusions

This research established the POE index system of environmental performance to green public building in severe cold and cold regions, combined with the index of the building life-cycle carbon emissions accounting. Then we set the way for index scoring on a scale of five and a centesimal system for rank division. Finally we put forward POE-GPBEPC (The POE System of Green Public Building Environmental Performance in Severe Cold and Cold Regions). The results of this paper provide a basic theoretical support and evaluation method to verify and evaluate the environmental performance and the operation effect of green public building in the severe cold and cold regions. It has a reference value to post-occupancy evaluation of green buildings in china. In addition, we add carbon emissions accounting into the index system, which is also an exploration of the new generation of evaluation standard for green building in china.

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