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What is the Green Performance of Civil Buildings? - An Empirical Study on China's Double-Certified Green Building Projects

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Abstract – *In the course of China's rapid economic development, huge amount of energy has been consumed. Therefore, the development of green buildings is of vital significance in reducing industrial energy consumption. This paper conducted an empirical study on the influencing factors of the green performance of civil buildings by adopting the generalized additive model. The results show that: (1) Government mandatory policies play a dominant role in green building development in China; (2) The role of local subsidies will be smaller and the best effect occurs when the subsidy is 2.2 USD/m^2 or higher than 5.9 USD/m^2; (3) Air quality in different regions has an impact on green building performance; (4) When the construction scale exceeds 20,000 m^2, the greater the construction scale, the lower the building green performance. Finally, this paper proposed countermeasures to further improve the green building performances in China.*

Keywords – China, double-certified projects, generalized additive models, green buildings.

1. INTRODUCTION

At present, as China develops its economy rapidly, it has consumed huge amount of natural resources. Direct energy consumption of buildings accounts for about one-third of the total energy consumption in the society. Large-scale development of green buildings in China will facilitate in realizing the overall goal of saving building energy up to 800 million tons of standard coal. More importantly, it will reduce industrial energy consumption through saving water and materials [1]. In the meantime, the development of green buildings is of great significance to the implementation of sustainable development strategy and building a conservation-oriented society [2].

In the construction field, engineering projects are always complied with mandatory norms and regulations. There is no experience in incentive measures for green buildings. Meanwhile, many participants are involved in the construction process. This paper tries to figure out whether the current incentive policies are highly efficient and whether environmental factors such as hazes accelerate the development of green buildings. This paper explores the factors influencing the green performances of green buildings and reveals the impact of these factors on the healthy development of green buildings in China.

Compared with the developed countries such as the United Kingdom and the United States, the development of green buildings in China started relatively late. China's green building evaluation standard (green standard, GBL) was introduced on June 1st, 2006, which was 16 years later than the United Kingdom, and 8 years later than the United States. However, China's construction output value and new construction areas rank the first in the world, which means China has a great potential for the development of green buildings. At the same time, with the increasingly prominent environmental problems and sustainable economic development, the Chinese government begins to take a positive and strong attitude towards green buildings.

In China, Green Label and Leadership in Energy and Environmental Design (LEED) certified buildings are the most popular form of green buildings in the green building market. According to the statistics of Green Building Map website[2], as of February 2016, the total number of green building projects in China (excluding Hong Kong, Macao and Taiwan, the same below) is 3,236, the total building area is nearly 330 million square meters. Among them, the total number of green labeling projects reached 2,225, and the number of LEED projects reached 893. The number of Green and LEED certified projects in the past decade is shown in Figure 1.

Figure 1 shows the changes of the total green building areas in China. According to the annual statistical data, the scale of China's green buildings entered an accelerated growing stage after 2012, newly added green building areas account for more than 80% of the current total during 2012-2015.

As of February 2016, there are 2,231 projects in China certified with green buildings design, of which there are 225 projects with green building operations certification, and 121 projects with both green building design label and green building operation. That is to say that 90% of the currently certified green label projects in China are with green building design certification.

If a building has two green qualifications, which has acquired two different types of green building certifications, it is known as a "Double Certifications Green Building". The mainstream of the double

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certification of green buildings in China is green label and LEED certification.

2 LITERATURE REVIEW

The theory of sustainable development is an indispensable concept to solve the environmental problem, which is the most challenging problem for the construction industry [3]. Many countries have developed corresponding specifications and requirements to popularize green building development. The Building Research Establishment Environmental Assessment Method (BREEAM) [4] was the earliest green building standard specification proposed in Britain in 1990. Afterwards, various countries introduced corresponding green building assessment systems. In 1998, the US proposed the green building assessment system LEED and relevant reference standards [5]. In 2006, the green building assessment standard (green standard, GBL) was introduced in China and proposed corresponding requirements for land saving, energy saving, water saving, material saving, indoor environmental quality and operation management. Many scholars further refined the assessment standards by adopting different methods to analyze factors restricting the extension of green buildings. He Xiaoyu *et al.* [6] applied Group AHP and an evidential reasoning approach to determine the index weights and measure the indicators in green buildings assessment according to the green buildings assessment standards, and established a set of scientific, typical and operable green building evaluation indicator system. Shad *et al.* [7] proposed a set of new integrated factors, defined 8 major and 61 minor stakeholders, developed the green building assessment tools in Iran by analytic hierarchy process (AHP), weighted harmonic mean method and entropy and evaluated five office buildings in Iran by adopting GIS and multi-standard decision-making methods. The results show that energy and water resources are the most important factors to protect the green office buildings of the important environmental factors. Li *et al.* [8] developed a multi-objective assessment model: objective, profession and time (OPT) from three dimensions, established OPT coordinate system based on China's green building logo (GBL) and Singapore green mark (GM) scoring center system by introducing the variable coefficient and inertia moment with a case study of a project in Chongqing that the compliance coefficient representing absolute equilibrium direction in OPT coordination system could prove compliance of actual projects in complying state with specific green building standards. The developed OPT model provides quantified and practical guidance for green building design and assessment. Banani *et al.* [9] proposed a framework for the development of sustainable non-residential building assessment standards in Saudi Arabia. To create this framework, they listed the main characteristics and categories by comparing five main building assessment methods (LEED, GBL and GM) and evaluated the survey data through analytic hierarchy process (AHP). A total of 9 standards and 36 sub-standards are defined in this research as the most suitable assessment standards for sustainable non-residential buildings in Saudi Arabia. Alshamrani [10] evaluated the school buildings and internal facilities in Canada through the measurement tools of life cycle assessment (LCA) and LEED. The results show that the concrete and masonry buildings have high energy consumption and global warming potential at life-cycle phases such as manufacturing, construction and demolition.

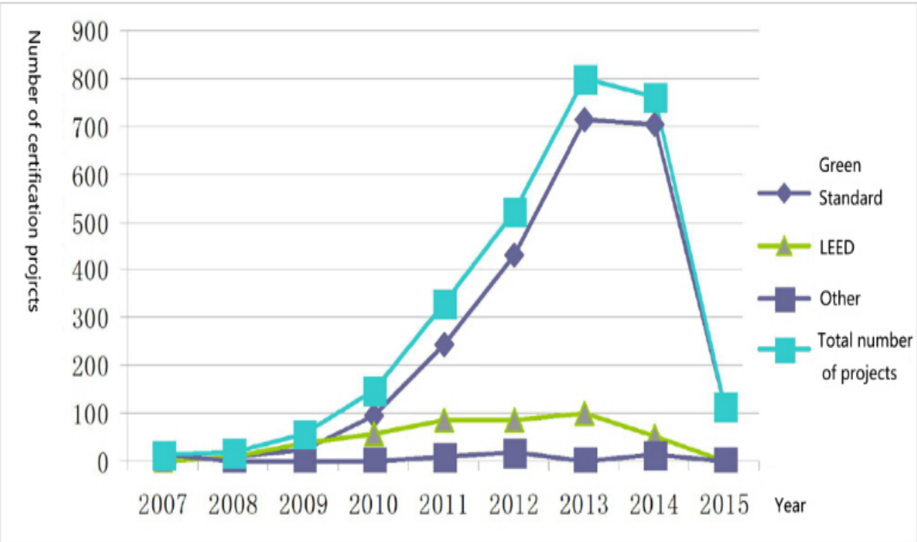

Fig. 1. Number of projects with green standard and LEED certification.

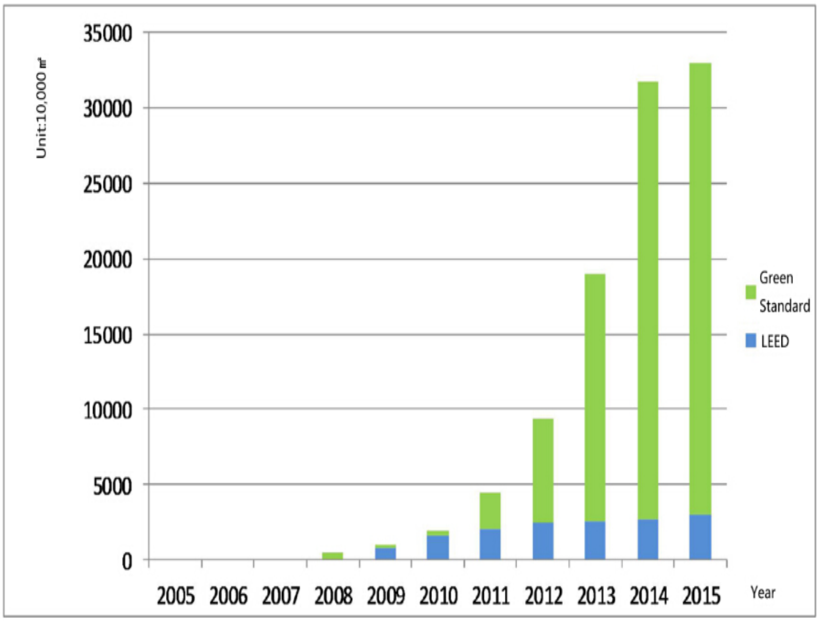

Fig. 2. Total area of China's green buildings (2005 – 2015).

Many scholars have also made empirical studies on the influencing factors of green building development. After comparing the legislation and practical experience between China, the US and the EU in terms of green buildings, Deng [11] proposed that China should take some measures to promote green building development, such as improving the awareness of green buildings and designing more diversified motivation tools. Xiaowen and Yisheng [12] constructed a structural equation model (SEM) of green housing marketing development from the perspective of green housing quality, supply side and demand side and obtained the key paths for the green housing marketing development through empirical analyses. The results show that mandatory policy of the government has the largest impact on housing quality, and government motivation has the largest impact on green housing supply. Xiaodong and Yongxiang [13] divided the green housing market into development decision-making, green housing demand and government action and made a dynamic analog simulation and prediction for the green housing market in Nanjing based on system dynamics. The results show that the green housing market, with a great potential for future development, will be gradually approved by the public and occupy a certain market share. The paper finally proposes countermeasures and suggestions for the development of the green housing market in China.

Government policy simulation is a factor to promote green building development. Aliagha [14] simulated green buildings in Malaysia through green taxation incentive policy. Wong *et al.* [15] believed that the primary factor affecting green buildings in Hong Kong was mandatory environmental regulations of the government by adopting questionnaire survey and key informant interview. Shazmin *et al.* [16] proposed that property tax assessment incentive measures could encourage green building development by property tax reduction, exemption and kickback. Chang *et al.* [17] argued that the government adopted subsidy policy, reward policy and economic innovation policy to promote green energy applications in building and infrastructure construction. Kuo *et al.* [18] explored the statistical data of the building industry from 1988 to 2014 and pointed out that green buildings success factors established clear specifications and standards for green building design and improvement and introduced mandatory or incentive policies according to local conditions.

Existing literature review shows that to date no scholars have ever analyzed the influencing factors of green buildings in terms of macroscopic economic factors, policy factors and specific factors of microscopic green building projects simultaneously. Therefore, this paper will make a quantitative analysis of the influencing factors of the green performance of China's green buildings by using the generalized additive model from the perspective of macroscopic economic factors, policy factors and specific factors of microscopic green building projects according to the objective project data on the basis of previous research findings, in an attempt to propose policy suggestions for the healthy development of green buildings in China.

3. METHODOLOGY AND DATA

3.1 Generalized Additive Model Building

As a non-parametric expansion of the generalized linear model (GLM), the generalized additive model is characterized by direct processing and response to the non-linear relationship between the dependent variable and a number of independent (explanatory) variables. It can fit the model through data law, with the following general expression:

$$G(\mu) = \sum_{i=1}^{k} F_i(x_i) + \varepsilon \quad (\mu = E[Y/X]) \tag{1}$$

Where, $F_i(x_i)$ is a non-parametric function describing the relationship between $G(\mu)$ and i-th explanatory variable and can be obtained through spline smoothing method. ε is the random error term.

Economic development and government policies have exerted effects on the development of green buildings in China. In the areas with more powerful economic strengths, the green technology is more mature, and the developers' financing is easier, resulting in a better development of green buildings. Meanwhile, the government policies also play a role in promoting the development of green buildings in China. The policies include mandatory policies and incentive policies. The mandatory policies refer to the policies restricting enterprises' behavior through administrative penalty and restrictions and indirectly act on the decision-making of enterprises for green development, so as to affect the performances and overall development of green buildings. The incentive policies refer to the policies implementing regulations and controls through interest rates, prices, revenues, credits, tax rates, exchange rates, plot ratios and other means of reward.

The generalized additive model is established according to the impact of economy and policies on green building development:

$$\text{Score}=f(\text{JJFZ})+f(\text{ZXLD})+f(\text{JLLD})+\varepsilon \quad (2)$$

Where, JJFZ represents economic development, taking the per capita GDP (USD) in the region; ZXLD represents execution strength, taking the green building area (10,000m^2) reaching the standard in policies of various provinces; JLLD represents the strength of subsidy, taking the ratio of the total policy subsidies (USD/m^2) at each level of two-star buildings in various provinces to the incremental cost (USD/m^2) of two-star buildings.

3.2. Semi-Parametric Additive Model Building

The expression of the semi-parametric additive model is:

$$f(\mu) = X_{\mathrm{i}}^T \beta + \sum_{i=1}^{k} g_i(x_i) + \theta \quad (\mu=E[\mathrm{Y/X}]) \quad (3)$$

Where, $i \geq 1$. $X_{\mathrm{i}}^T \beta$ on the right of the formula is linear part and generally the main part of the whole model and can explain the general trend of the dependent variable; $\sum_{i=1}^{k} g_i(x_i)$, as the non-parametric part, can make a fine readjustment to the model to better fit the sample data. θ is the random error term.

The influencing factors of the green building development include project input, project planning and green design. Project input refers to investment of manpower, material and financial resources. The selection and investment of manpower and material resources are different in each project, but they can be measured by investment of financial resources. It is commonly known that the more the project input, the more significant the project effect. Generally speaking, the greater the project scale, the larger the building area, the more complex and the poorer controllability of the project, the greater the risks for the project to reach a high-level green performance. For project site selection, the meteorological factor is the primary factor [19]. The air quality is the concentrated expression [20] of unfavorable meteorological factor, so the air quality in 2013 is used. The project was completed before 2013, so the impact of the air quality is not considered, so as to better reflect the impact of different building sites on the green building performances. The project green design in this paper is measured by the number of stars of the green mark.

According to the above description, the semi-parametric additive model is established as follows:

$$\text{LEED score} = \beta_1\text{Inv} + g(\text{AQI}) + \beta_2\text{RGFA} + \beta_3\text{GBL} + \beta_4\text{Bonus} + \theta \quad (4)$$

Where, Inv represents the project investment. Considering the time value, all project investments are converted to the present value in 2007 and the interest rate is 3% (mean value considering the deposit interest rate changes in 2007-2015). AQI represents the project site selection difference, i.e. air quality status, which it is expressed by air pollution index. The generalized additive model is an effective tool to analyze the impact of the climatic factors because its smoothing function is sufficient to express the possible complex non-linear trend when the function form is not clear. RGFA is the reciprocal of the building area; GBL is the project green design and is measured by design mark (number of stars) and valued as “1, 2, 3”. Bonus represents the project awards and is a dummy variable valued “0, 1”.

3.3 Data Sources

China's top 20 provinces of national green building development are selected in this paper for research due to large differences in the provincial economic policies. The provincial green building development is measured by comprehensive score of provincial green building development and the data came from green building map network (www.gbmap.com).

The variable value and data sources are shown in Table 1. The data of economics and policies of China's top 20 provinces of green building development are collected and shown in Table 2.

According to above analysis, the specific parameter factors mainly considered for green buildings include project investment, government subsidies, project construction scale, construction project site selection (considering local air quality status) and green design factors. The variable value and data sources are shown in Table 3.

The Table 3 shows that the variables are set by means of double-certified project characteristics. The green building assessment standard (green standard, GBL) is divided into design identity and operation identity. More than 90% green building projects in China are subject to design identity certification, so it is advisable to measure the project green design factors through green building assessment identity levels (No.

of stars). Compared with the green standard design identity, the LEED assessment system, containing design and construction parameters, is a comprehensive assessment system, and it reflects the green performances of green buildings. In terms of indicator selection, LEED score ratio rather than LEED score is used this paper because four versions of LEED assessment system have been issued so far and the total assessment score of each version is different. Therefore, it is more rigorous and accurate to select the score ratio.

Table 1. List of measurement indicators and data sources.

Variables	Measurement indicators	Data sources
Economic development	Per capita regional gross domestic product	Yearbook
Execution strength	Green building area reaching the standard of the policy requirements	Annual new commencement area in policy document and yearbook
Subsidy strength	Ratio of policy subsidy limit (including public subsidy and local government subsidy) per square meter of two-star buildings in each province to the incremental cost per square meter of two-star buildings	Subsidy per square meter: policy documents Incremental cost: green building statistical reports
Green building development	Comprehensive score of provincial green building development	Green building map network

Data source: from related literature collected by the authors.

Table 2. Data of economics and policies of top 20 provinces in China.

No.	District	Economic development (USD)	Execution strength (10,000 m^2)	Subsidy strength	Comprehensive score of provincial green building development
1	Jiangsu	12040	10000	0.8	864.25
2	Shanghai	14319	1391.01	1.2	514.25
3	Guangdong	9334	4000	0.7	450.5
4	Beijing	14705	3500	0.77	370.75
5	Shandong	8953	5000	0.54	345.25
6	Tianjin	15475	563.054	0.51	289.25
7	Zhejiang	10736	0	0.51	198
8	Hubei	6933	3165.08	0.51	189
9	Hebei	5880	3792.92	0.51	187.25
10	Shaanxi	6901	1685.3	0.68	149.25
11	Henan	5452	4000	0.51	106
12	Fujian	9334	2789.41	0.51	99
13	Sichuan	5166	4298.32	0.51	80.75
14	Hunan	5922	3387.24	0.51	72.75
15	Liaoning	9588	0	0.51	72.25
16	Shanxi	5157	1512.17	0.51	68
17	Anhui	5063	3762.9	0.51	65.75
18	Chongqing	7037	1500	0.97	61.5
19	Jiangxi	5099	1497.47	0.51	57.25
20	Guizhou	3888	2048.94	0.51	32

Data source: from relevant websites collected by the authors.

Table 3. List of measurement indicators and data sources of specific parameter factors.

Variables			Measurement indexes	Data sources
Specific parameter factors for green building project	Project investment	Project investment	Total cost of the project	China Engineering Network
		Project awards	The national award policy was introduced in 2012. For the project completed before 2012, the government award is not granted and the score is "0"; for the project completed after 2012, the government award is granted and the score is "1"	Green building map website (www.gbmap.com)
	Development planning	Project construction scale	Project building area	Green building map website (www.gbmap.com)
		Construction project site selection	Mean value of air quality index (AQI) in 2013	(www.tianqihoubao.com)
	Project green design		Green building assessment logo (GBL) design start level (level 1, 2 or 3)	Green building map website (www.gbmap.com)
Project green performance			LEED score ratio	GBIG website

Data source: from relevant websites collected by the authors.

Table 4. Statistical analysis of project data.

Index	Category	Frequency number	Frequency
Region	Coastal provinces	16	64%
	Inland provinces	9	36%
Area	≥20,000m^2	19	76%
	< 20,000m^2	6	24%
Building type	New buildings	25	100%
	Existing buildings	0	0
Whether to enjoy government subsidy	Yes	14	56%
	No	11	44%
Green logo star level	Two-star	11	44%
	Three-star	14	56%
LEED level	Platinum	5	20%
	Gold	17	68%
	Silver	1	4%
	Certified	2	8%

Data source: Data summary sheet of dual authentication green building projects in China (Appendix 1).

This paper selects 25 projects as the research objects and the data are shown in Appendix 1.

Through statistical analysis of the data collected, the results are shown in Table 4. The sample characteristics are basically consistent with the overall situation of green buildings in China. In the coastal provinces, the green buildings develop fast and the ratio of the buildings obtaining LEED gold certification is the highest (68%), which is close to the national average (60%). And nearly 80% of all certified projects have building areas of more than 20,000 m^2 and all of 25 buildings are new buildings, eliminating the impact of different building types on our estimation results.

4. EMPIRICAL RESULTS AND ANALYSIS

4.1 Generalized Additive Model Approach

The generalized additive model can be implemented by the mgcv (Mixed GAM Computation Vehicle) package in the default package of the R software. The GAM function in the mgcv package is used to perform the basic fit of the model.

The author's used R 3.2.3 software GAM package for programming, entered model 2 and then standardized the original data.

After the impact factors are gradually increased in model 2, AIC value is decreased from 241.1544 to 235.92, indicating that the fitting degree of the model is gradually increased with the explanatory variable. The AIC (Akaike Information Criterion) information criterion is used to test the fitting degree of the model after the gradual addition of the factors, the smaller the value is, the better the fitting effect of the model [21]. F test was used to evaluate the significance of each factor. The final fitting results are shown in Table 5.

It is thus seen that the economic development, execution strength and subsidy strength have passed 5% significance test. From the partial residual fitting chart as shown in Figure 3, the economic development and execution strength have positive impacts on the green building development. The subsidy strength has a partial positive correlation with the green building development. When the subsidy strength is below a specific value or above a specific value, the green buildings in these regions develop well with the increase in the subsidy strength.

The data of the horizontal axis in the fitting chart of execution strength partial residual is reduced to the original data, as shown in Figure 4. When the green building area reaching the government standard is below 30 million m^2, the tangential slope of the curve shall be smaller than that of the curve when the building area is above 30 million m^2. That is, when the green building area reaching the government standard is above 30 million m^2, the increase in unit area reaching the standard has stronger positive impact on the green building development in that region.

Table 5. GAM model assessment results.

	Sum Sq Sum of squares Sum Sq	Mean Sq Mean square error Mean Sq	F value	Pr(>F) F test Pr(>F)	
s(JJFZ)	5.6152	5.6152	44.7534	0.0002801	***
s(ZXLD)	7.4617	7.4617	59.4699	0.0001151	***
s(JLLD)	0.7340	0.7340	5.8498	0.0461858	*
AIC 235.92					
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

Data source: simulation results through R3.2.3 software based on the data in Table 3.5.

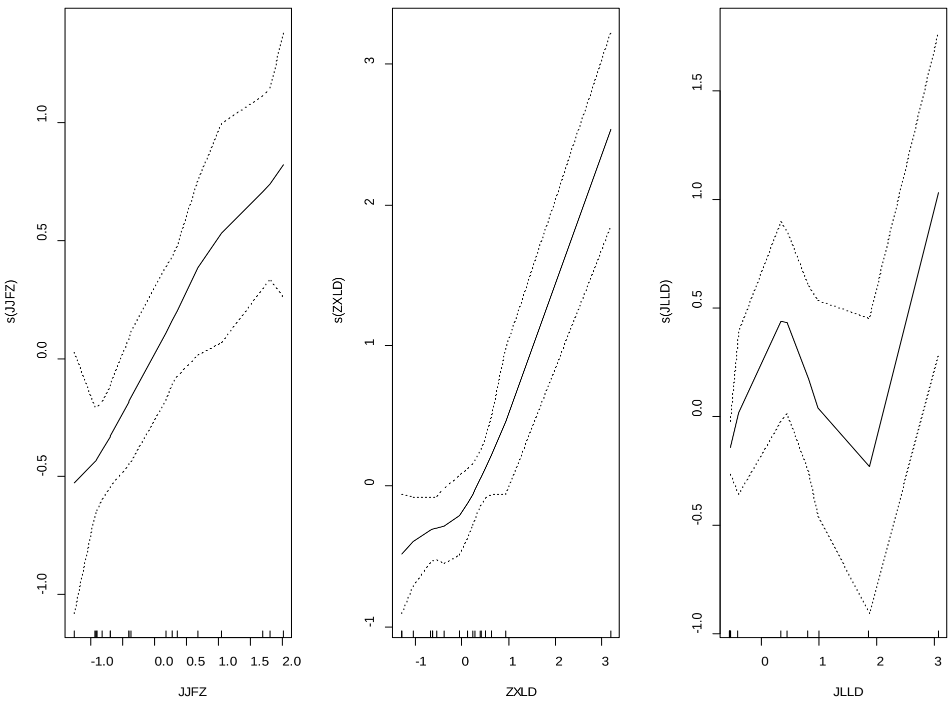

Fig. 3. Fitting chart of the partial residual.

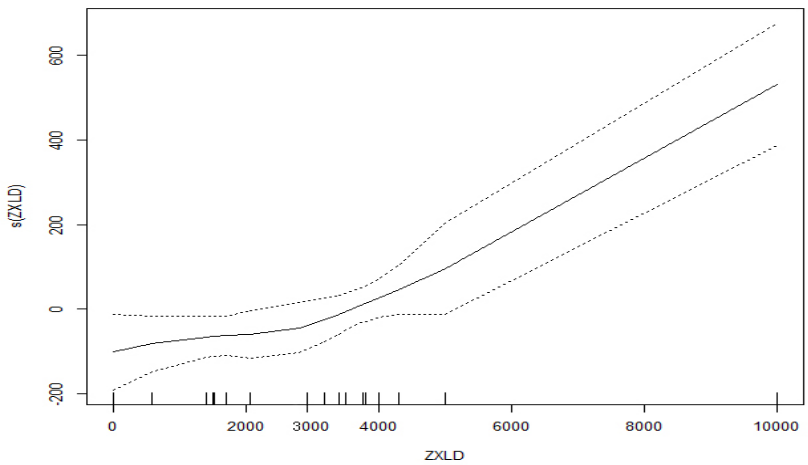

Fig. 4. Fitting chart of partial residual of the execution strength.

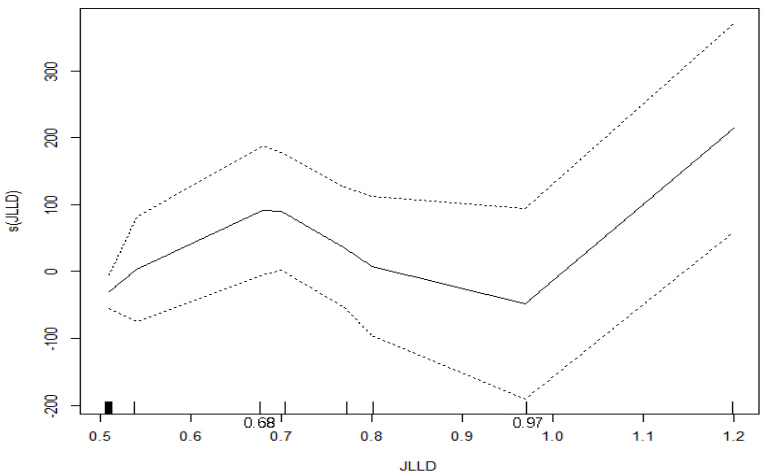

Fig. 5. Fitting chart of partial residual of the subsidy strength.

The fitting chart as shown in Figure 5 of partial residual of subsidy strength reduced to the original data shows that the regional green buildings develop better with the increase in the coverage ratio when the subsidy strength is below 0.68 or above 0.97, *i.e.* when the government subsidy limit can cover the incremental cost below 68% or above 97%. When the subsidy strength is between 0.68 and 0.97, the increase in subsidy strength did not promote green building development.

A lot of mandatory policies and incentive policies on green buildings were introduced in China between 2012 and 2013. Then, the green building areas have increased rapidly throughout the country. To compare the effectiveness of the execution strength and subsidy strength, the model weight Akaika weight (w_i) is used to calculate the relative variable importance (RVI). The greater the model weight, the more probability for a true model. The formula of w_i is as follows:

$$w_i = \frac{\exp(-0.5(AIC_i - AIC_{\min}))}{\sum_{i=1}^{n}\exp(-0.5(AIC_i - AIC_{\min}))} \qquad (5)$$

Where, w_i is AIC weight of i-th model, AIC_i is AIC value of i-th model and $AIC_{\min}$ is the minimum AIC of all n alternative models.

The weights of all models containing a variable are summed to obtain the weight of the variable. The greater the weight, the more important the variable. The importance of each variable is shown in Table 6.

The execution strength is compared with the subsidy strength. The importance of the former to the green building development is greater than that of the latter, indicating that the government mandatory policies rather than incentive policies play the major role in the promotion process of green buildings.

It should be stressed here that the incentive policies have exerted an impact on green building development. However, the incentive policies in China include two levels: the overall policies introduced by the state (national level) and the supplementary policies issued locally (provincial level). The national policies are the same throughout the country, so the essence of above problem is that the differences in local subsidies exert a significant impact on China's green building development. Nevertheless, such impact is not simply positive or negative correlations. In view of the measurement indexes given in Table 1:

$$\text{Subsidy strength} = \frac{\text{national subsidy for two star buildings} + \text{local subsidy}}{\text{incremental cost of two star buildings}} \qquad (6)$$

If the national subsidy policy is unchanged (subsidy 6.6 USD per m^2 for two-star buildings), the local green buildings develop better with the increase in the subsidy limit when the local subsidy limit for twp-start buildings is 0~2.2 USD per m^2 or more than 5.9 USD per m^2, *i.e.* when the subsidy strength value is below 0.68 or above 0.97. If the incremental cost of green buildings is gradually reduced, it is proper that the range of the incremental costs covered by local subsidies should be around 0~17% or above 46%.

4.2 Semiparametric Additive Model Approach

The authors used R 3.2.3 software GAM package for programming, entered model 3, removed the abnormal value in the original data for standardization, and conducted parameter estimation and statistical test. The results are shown in Table 7.

Table 6. Variable importance.

	JJFZ	ZXLD	JLLD
RVI	0.975	0.999	0.934

Data source: calculated by the author according to Equation 6.

Table 7. Simulation results.

Parameters	Sum Sq Sum of squares Sum Sq	Mean Sq Mean square error Mean Sq	F value	Pr(>F) F test Pr(>F)	
Inv	0.012579	0.012579	2.5919	0.1357087	
RGFA	0.107904	0.107904	22.2329	0.0006344	***
GBL	0.038671	0.038671	7.9679	0.0165860	*
Bonus	0.022384	0.022384	4.6121	0.0548781	.
Non-parameters			F value	Pr(>F) F test Pr(>F)	
S (AQI)			5.0981	0.0452588	*
AIC:-41.761					
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

Data source: simulation results through R 3.2.3 software based on the data in Appendix 1.

It is evident that the construction project site selection, project construction scale and green design factors have passed 5% significance test. Bonus project awards have passed 10% significance test. The project investment Inv and Bonus project awards do not have significant correlations with green building performance. After adding two variables, however, AIC reduces from -39.4081 to -41.761, indicating that the fitting degree of simulation has been improved. Therefore, the two factors finally remain in the model.

The importance of the variables with significance by the incremental ΔAIC before and after the variable is added was evaluated. The greater the ΔAIC, the more important of that variable (see Table 8). The greater the ΔAIC value of the project green design indicates the greater impact on the green building performance, followed by project construction area and the construction project site selection.

The fitting chart 6 of the partial residual shows that the green design factors have positive impacts on green building performance. The project construction area in the model is reciprocal, so the project construction scale has a negative correlation with green building performance. From the point of view of local government policies, there are certain requirements for public buildings with the construction area of over 20,000 m^2 in many provinces and cities. In the 25 projects selected for this study, the construction scale of nearly 80% projects is above 20,000 m^2. Therefore, we can further conclude that the smaller the construction scale, the higher the building green performance when the construction scale exceeds 20,000 m^2, because the large-scale public buildings are difficult to reach relevant standards in terms of greening rate, permeable area, roof greening utilization, large-area glass curtain wall, renewable energy resource utilization, basement lighting and reclaimed water reuse, so as to affect the final water saving and energy saving performances of the building.

Table 8. Model ΔAIC analysis.

	AQI	RGFA	GBL
ΔAIC	1.4637	3.8957	6.2228

Data source: Simulation results of R 3.2.3 software based on the data in Appendix 1.

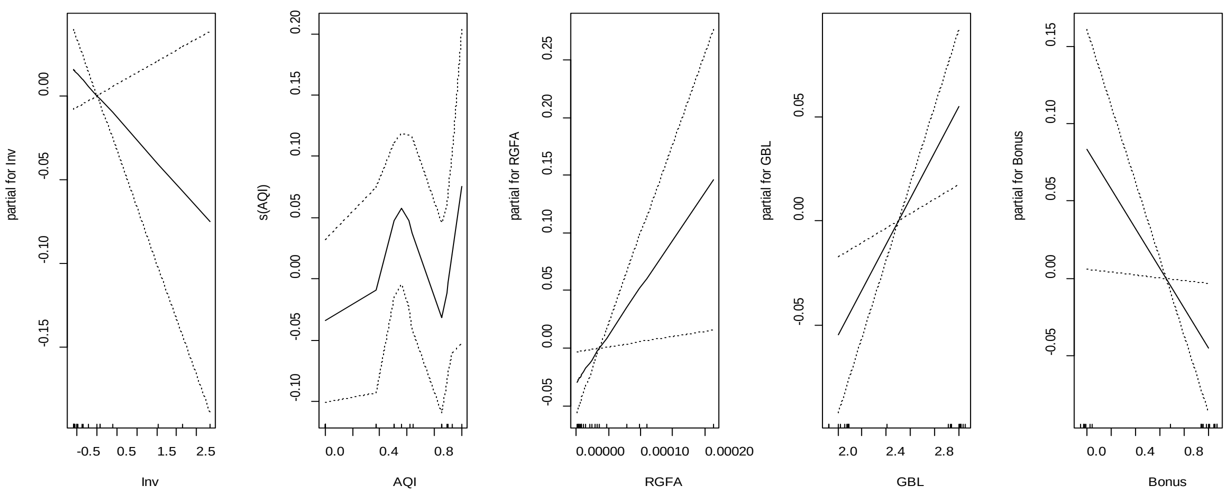

Fig. 6. Fitting chart of the partial residential.

The different locations of building projects affect the green performances of the buildings, that is, the air quality on green performance has a partial positive correlation. When the air quality is good and pollution index is low, or when the air quality is deteriorated and air pollution index is high, the rise of air pollution index will promote the improvement of green building performance. That means when the building is located in the city with good air quality or in a city with bad air quality, the people are sensitive to the changes of air quality with the pressure of public opinions. In other words, the greater social responsibilities the enterprises bear the higher green performance of the buildings they constructed.

The air quality status is reset to the original data, as shown in Figure 7.

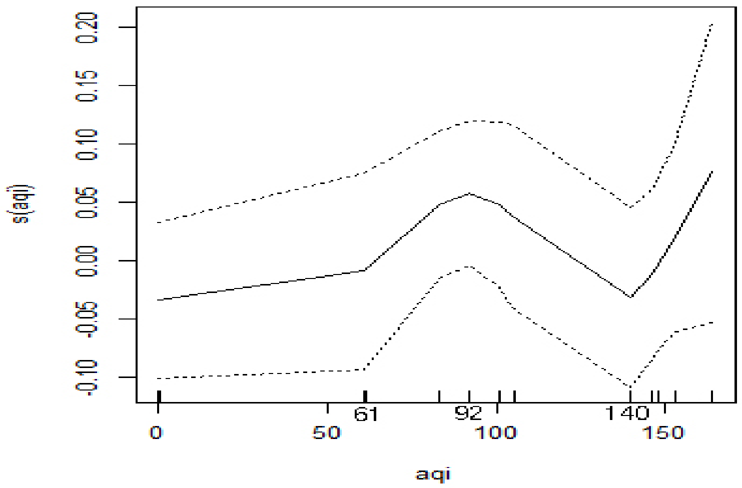

Fig. 7. Fitting chart of partial residential of air quality status.

Table 9. City categorization.

Category	Air pollution index	City
Category I	0~61	Guangzhou
Category II	61~92	Shenzhen
Category III	93~139	Guiyang, Chongqing, Shanghai and Beijing
Category IV	140+	Xi'an, Tianjin, Changsha and Suzhou

Data source: Appendix 1 and Figure 7.

According to the turning points in Figure 7, the ten cities involved in the double-certified green buildings are classified into four categories, as shown in Table 9. Considering the practical circumstances in China, the air quality in the China's South-East coastal areas such as Guangzhou and Shenzhen is better than that in the inland regions. When the air pollution index rises in this region, people's expectations for the green building performance will rise, expressing in the improvement of green building performance. Similarly, in the northwest districts with poor air quality throughout the year, such as Xi'an, people's expectations for green building performance will also rise when the air pollution index gets higher.

Since category I, II and IV cities are sensitive to air quality, the government may consider strengthening publicity for indoor air quality policies of the buildings in these cities, so as to further promote the green building development.

The negative role of project investment in green building performance is not significant, and that of the green subsidies in green building performance is not significant either.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

5.1 Conclusions

(1) Government mandatory policies play a dominant role in green building development in China. From the partial residual fitting chart as shown in Figure 3, the policy execution strength has a positive impact on the green building development; the subsidy strength is only partially positively correlated to the green building development. In 2013, the Chinese central government issued mandatory policies and subsidy policies for green building simultaneously, and China's green building development has entered a rising stage ever since. The analysis of the macro data shows that the two policies have exerted significant impacts on green building development. Through comparison of the importance of the policy execution strength and subsidy strengthen to the green building development, the weight of the policy execution strength is 0.999 and of the subsidy strength is 0.934. The importance score of the former is higher. It indicates that it is the government mandatory policies that have mainly promoted China's green building development since 2013; and the green building

develops faster as the policy execution strength increases.

(2) The role of local subsidies will be smaller and the best effect occurs when the subsidy strength is 2.2 USD/m^2 or higher than 5.9 USD/m^2. The empirical analysis in this paper shows that the role of the local differential subsidies will be getting smaller when the green building market is gradually improved. The subsidy strength is the ratio of the sum of the public subsidies and local subsidies to the incremental cost of buildings. From the fitting chart of partial residual of the execution strength as shown in Figure 4, the local green building is better developed with the increase in the coverage rate when the subsidy strength is below 0.68 or above 0.97, i.e. when the government subsidy limit can cover less than 68% or more than 97% incremental costs. When the subsidy strength is between 0.68 and 0.97, the increase in the subsidy strength cannot promote green building development. The subsidy policies introduced currently are classified into two levels: the national level and the local level. Taking a two-star building for example, if the national subsidy strengthen is maintained at 6.6 USD/m^2, the local supplementary subsidy strength is 0~2.2 USD/m^2 or above 5.9 USD/m^2; and the regional green buildings develop better with the increase of the subsidy limit. If the incremental cost of the green buildings is gradually reduced, it is suitable that the incremental cost range covered by local subsidies is 0~17% or above 46%.

(3) Air quality in different regions has some impact on green building performance. From the fitting chart of partial residual of air quality status in Figure 7, there is a partial positive correlation. That is, when the air quality index is between 0 and 92, the air quality is positively correlated to the green building performance. According to the city division of the air quality index, Guangzhou and Shenzhen are between 0 and 92; when the air quality index is higher than 140, the air quality is positively correlated to the green building performance. According to the city division of the air quality index, Xi'an, Changsha and Suzhou are higher than 140. The analysis of the micro data of green building projects shows that the green building performance will be different in different cities affected by air quality, people in the cities with good air quality such as Guangzhou and Shenzhen and the cities with poor air quality such as Xi'an, Tianjin, Changsha and Suzhou are sensitive to air quality and green buildings located in such regions may reach higher performance since the developers are forced to bear large social responsibilities due to the great pressure from public opinions.

(4) When the construction scale exceeds 20,000 m^2, the greater the construction scale, the lower the building green performance. It can be seen from the partial residual fitting chart 6 that the reciprocal of the project building area is positively correlated to the green performance of the green building, indicating that the project construction scale is negatively correlated to the green building performance.

There are certain green requirements for public buildings with the building area more than 20,000 m^2 in some provinces and cities. However, with the increase of the construction scale, the building green performance is gradually reduced. On the one hand, the greater the construction area, the more complex the process, the poorer the controllability and the greater the risk; on the other hand, for large buildings, the green building assessment standards may be imperfect.

5.2 Policy recommendations

The following recommendations are proposed based on the above conclusions:

(1) Continue to vigorously promote government mandatory policies. It is advisable to vigorously promote the government mandatory policies under current circumstances of imperfect green building market. On the one hand, vigorous implementation of mandatory policies indicates sufficient green building supplies, which will strengthen the existing market competition and force developers to take more energy-saving and environmental-friendly green technology, so as to reduce long-term operation and maintenance costs and destruction to the environment and improve the market competitiveness and eventually achieve standardization of the green building market. On the other hand, sufficient green building supplies can promote standardized development of green buildings, so as to reduce the marginal development costs and risks of green buildings and further attract more developers to enter the green building market.

(2) With the improvement of the green building market, the local subsidies are gradually reduced and even cancelled. When the green building market is gradually improved, the role of the local differential subsidies will become smaller. Taking two-star buildings for example, the local governments may gradually readjust the existing subsidy limit to the range of 0~2.2 USD/m^2. That is, the local subsidy higher than 2.2 USD/m^2 may be reduced to 2.2 USD/m^2 and the existing subsidy below 2.2 USD/m^2 can be properly increased. With gradual reduction in the incremental cost of green buildings, it is suitable that the incremental cost range covered by local subsidies is 0~17%. When the green building market trends becomes stable, the subsidy policies should be cancelled.

(3) Strengthen green building publicity in Guangzhou, Shenzhen, Xi'an, Tianjin, Changsha, Suzhou and other cities. The above cities are sensitive to air quality changes, so vigorous promotion of green buildings that are closely related to human health or introduction to indoor air quality related building standards in these cities will be easier to arouse attention to the environmental health issues, and great pressure from public opinions will force the developers to bear greater social responsibilities, so as to greatly promote improvement of local green building performance.

(4) Increase the input in green technology for large public buildings and improve relevant green standards. The public buildings greater than 20,000 m^2 are difficult to reach relevant standards in terms of greening rate, permeable area, roof greening utilization, large-area glass curtain wall, renewable energy resource utilization, basement lighting and reclaimed water reuse, so as to

affect the final water saving and energy saving performance of the buildings. The government should strengthen research input in this aspect, find out reasonable solutions and may improve green standards based on practical circumstances.

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APPENDIX

Appendix 1: Data Summary Sheet of Double-certified Green Building Projects in China.

Project No.	Project name	Project location	Development time	Development investment (10,000 USD)	Project awards	Building area (m^2)	Construction project site selection AQI	Project green design	LEED score
1	Glodon Headquarters	Beijing	2011-2015	176	1	30111	0	3	0.64
2	Beijing NO2 Experimental Primary School	Beijing	2011-2014	324	1	10080	105	3	0.75
3	Greenland Group Headquarters	Shanghai	2010-2011	102941	0	41900	0	3	0.64
4	Hongqiao Vantone Center	Shanghai	2012-2014	1369	1	84748	140	2	0.42
5	Shanghai Shanghai Pu Yi Building	Shanghai	2013-2015	1029	1	6884．16	140	2	0.73
6	Eastern Harbor International Building	Shanghai	2008-2010	3235	0	39800	0	3	0.61
7	Expo 2010 Shanghai China Expo Center	Shanghai	2008-2010	16176	0	142000	0	3	0.57
8	CNOOC Bulding	Shanghai	2012-2014	26471	1	127439	140	2	0.42
9	Suzhou Positec China Headquarter	Jiangsu	2014-2015	199	1	12629	153	3	0.78
10	Wuhan Center	Hubei	2010-2012	14706	0	321417	0	3	0.65
11	Wuhan GangGu New World Center	Hubei	2011-2012	132352	0	345900	0	2	0.55
12	Mastersite Acura Guangzhou Zhujiang New Town Branch	Guangdong	2010-2015	3676	1	184527	61	3	0.57
13	Kingkey 100 Tower	Guangdong	2007-2011	73529	0	234000	61	2	0.60
14	Baoan Center Library	Guangdong	2010-2015	9051	1	48000	83	2	0.57
15	Baoan Centre Youth and Children Palace	Guangdong	2010-2015	3221	1	34000	83	2	0.58
16	Shenzhen Vanke Headquarte	Guangdong	2007-2010	1836	0	1213019	0	3	0.83
17	Shenzhen Institute of Building Sciences office	Guangdong	2007-2009	1138	0	18200	0	3	0.61
18	The Green Building Museum of Hangzhou	Zhejiang	2009-2010	882	0	4679	0	3	0.88

19	Changsha Northstar Delta A1 Office Tower	Hunan	2011-2014	4412	1	65961	146	2	0.60
20	Tianjin TEDA H2 Building	Tianjin	2010-2014	25588	1	21306	148	3	0.57
21	PV Module Fab AUO Energy (Tianjin) Corp	Tianjin	2010-2011	2059	0	45100	0	3	0.63
22	Getrag Office Building	Jiangxi	2009-2011	691	0	113500	0	2	0.55
23	ChinaWest Technology Park	Guizhou	2012-2015	8824	1	130763	92	2	0.62
24	LFC,LIFAN CENTER	Chongqing	2010-2015	36765	1	168880	101	2	0.55
25	BlueScope Xian Main Office	Xi'an	2012-2014	1471	1	9129	164	3	0.79

Data source: relevant network data and literature.