CARBON EMISSION-BASED MEASUREMENT OF FLOOR AREA RATIO BONUS FOR RESIDENTIAL GREEN BUILDINGS IN CHINA

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ABSTRACT

Green building development in China relies mainly on compulsory measures that lack incentive policies to motivate the enthusiasm of real estate developers. A floor area ratio bonus is encouraged by the Chinese State Council. In order to ensure the feasibility of a reward quota, residential buildings that met the requirement for energy efficiency during the official assessment in Ningbo in 2014 were selected as research objects. The amount of energy and water savings in terms of the Assessment Standard for Green Building is converted into carbon emissions. Carbon emissions of different star-rated green buildings are then measured in accordance with the actual water and power consumption of residential dwellings in 2014. A regression equation is set up concerning the floor area ratio and index for residential land per capita. A carbon emission-based method is proposed for measuring the reward quota associated with floor area ratio and recommendations are given for development using green building.

KEYWORDS

green building, carbon emission, index for residential land per capita, floor area ratio.

1. INTRODUCTION

In order to reduce energy consumption by the construction industry, the Chinese government has encouraged developers to adopt green building. There is a strict evaluation system for green building called Assessment Standard for Green Building (ASGB), which includes land saving, energy saving, water saving, materials saving, and environmental protection. According to the amount of resource savings, green buildings are divided into three star-levels. The more resources saved, the higher the number of stars is. However, this green building policy is not mandatory, which led to slow development of green building before 2014. Green building has increased rapidly since green building became compulsory for certain types of buildings in provincial capitals and country planning cities in 2014, according to the Action Plan of Green Buildings. The total number and area of green buildings certified in 2014 increased by 43%

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and 45%, above those certified in past years [1]. This indicates that macro-level policy issued by the government plays an important role in the development of building energy efficiency. This phenomenon explains why real estate developers lack enthusiasm in building green buildings under the optional policy. Generally, green buildings cost more. In order to motivate the enthusiasm of enterprises, the Action Plan of Green Buildings includes encouragement by local governments to promote some incentive policies like rewards for a higher floor area ratio (FAR). Provinces and cities such as Fujian, Hubei, and Changsha have specified a 0.5–6% reward value for FAR; however, getting these data mainly depends on expert experience.

2. LITERATURE REVIEW

FAR awards to green building has been implemented in many countries. For example, the Singapore government grants developers who achieved the highest Green Mark Platinum or Green Mark Gold Plus Award an additional floor area up to 2% of the total gross floor area of the project [2]. Hong Kong has implemented a similar gross floor area concession since 2011 [3]. With the rapid development of the total number of green building in these cities, green buildings have become a popular market practice [3]. However critics believe that the reward for increased FAR goes against the livability objective of green buildings. Rewards for increased FAR will put significant pressure on the surrounding facilities and environment. For example, unreasonable reward of higher floor area ratios will lead to a direct increase in the community population, which will aggravate the shortage of educational resources [4] and add to traffic congestion [5,6]. This will also decrease the solar irradiation received on the building facade and roof [7]. Schwieterman [8] pointed out that the bottom of the buildings that obtained FAR rewards lacked enough sunlight. The change of FAR also involves huge commercial interests, because land resources are so scarce in China. For these reasons, it is imperative to assess the reward quota reasonably.

Because floor area concessions influence many aspects of green buildings, such as the reputation of developers, the speed of housing sales, and availability of job opportunities [3], it is difficult to quantify these factors. However, building energy consumption can be quantified because the pressure placed on public facilities and the natural environment by increasing FAR is produced by human activities [5,6], which will increase energy consumption. Finally, the influence of the FAR reward could be converted into carbon emissions. Because the purpose for developing green buildings was to decrease energy consumption and carbon emission [9,10]; in this paper, we analyzed the reward quota of FAR from the perspective of carbon emission.

Gibbs [11] used questionnaire information in a statistical analysis of policies for developing green buildings in the UK (including design, construction, building materials, etc.), and found that the effects of green buildings on reducing carbon emissions had been widely recognized by society. Computation rules and factors influencing building carbon emissions are interesting subjects that attract the attention of researchers on building energy-efficiency. In these studies, a building life cycle is divided into different stages [12,13,14]. The carbon emission of different stages has been widely researched, such as for construction and demolition, and carbon emission is calculated using energy conversion based on engineering bills of quantities [15,16]. In the stages of operation and maintenance, carbon emission measurement is usually calculated through the method of energy consumption statistics [17,18]. The factors influencing carbon emission, such as the building's physical properties [19,20], climatic conditions [21], stimulating factors from policy [22], lease terms of homeowners [23], and so on, were

also studied. Countries around the world have made standards to unify the carbon emission rules for buildings.

The Green Building Council of Australia (GBCA) [24] proposed a method for calculating carbon emissions of public buildings in accordance with the characteristics of energy consumption of the country's public buildings. The British Building Research Establishment (BBRE) [25] conducted a comprehensive analysis of carbon emission generated from energy consumption by buildings and carbon emission reduced using renewable energy and clean energy systems and developed a simplified model of building energy consumption. The German Sustainable Building Council (GSBC) [26], based on annual carbon emission per unit floor area, established a database of carbon emissions generated during production, application, and even demolition of building materials. The Japan Sustainable Building Consortium (JSBC) [27] collected energy consumption data of a reference building and set up a model of carbon emission throughout the building life cycle. The Ministry of Housing and Urban-Rural Development of China released an industrial standard, namely the Standard for Sustainability Assessment of Building Project (JGJ/T222), in which energy consumption at different stages of the life cycle was determined in accordance with a bill of quantities, construction scheme, specifications of construction equipment, design parameters from drawings; and then incorporated data on the water, electricity, gas, and heat used in daily operation.

Building carbon-emission could be used in an assessment method to analyze building energy consumption and to guide urban construction planning. Firth [28] compared the carbon emission reduction of buildings based on the Code for Sustainable Homes (2008) (CSH) to the dwellings already constructed in the city of Leicester, UK. The result showed that carbon emission reduction produced by heating energy is about 35%, and carbon emission reduction produced by appliance energy is about 6%. Mediha [29] assumed that the O_2 produced by green areas equals the CO_2 emissions produced by domestic use in residential areas. This method was used for maintaining the carbon-oxygen balance in land use planning. Yin [30] combined land use and land cover empirical coefficients with statistical methods and evaluated the urban carbon and oxygen balance in Beijing. The results indicated that the ecosystem services in Beijing were not adequate to offset the urban carbon emissions and oxygen consumption. These studies revealed that carbon emission-based measurement is effective as a guide to the planning of urban construction.

As discussed in the literature review, some research has been conducted on the green building floor area awards, but these studies have focused on the factors contributing to the area concession, and lack a quantitative evaluation of the amount of concession awarded. Furthermore, a great deal of work has been done to measure the carbon emission of buildings, but little work has been focused on researching the reward for improved floor area ratios, based on building carbon emission, especially considering the difference in carbon emission between green and traditional buildings. In addition, existing methods regarding carbon emission do not associate carbon emission with FAR. Reasonable FAR could provide a system for achieving ecological balance in cities, and a scientifically valid FAR reward quota would be beneficial for stimulating the development of green building.

In order to do this, first, we selected all the residential buildings of Ningbo that were newly built in 2014 as samples, and collected the regulatory control index of every project. Second, we analyzed the resource saving provisions in the ASGB, and calculated the proportion of these residential buildings that met the provisions required by the ASGB. Then the theoretical resource savings in the ASGB were combined with the actual resource consumption to measure

the carbon emission of star-rated green buildings and non-green buildings. Finally, we fit and analyzed the correlation of the equation between FAR and IRLC, and made a carbon-emission equation relative to FAR to determine the reward quota.

3. METHODOLOGY

3.1 Data source

All the data used in this study were collected from architectural drawings and the energy efficiency evaluation report, provided by the Ningbo Housing and Urban Rural Development Committee. A total of 249 projects that met the requirements for energy efficiency of civil buildings during the official assessment of Ningbo in 2014 were selected as the research objects. Only the data for residential buildings were analyzed, because the building specification-and-control indexes contained the index for residential land per capita (IRLC). The IRLC can help establish the correspondence between consumption of water, electricity, and gas per capita, and carbon emission. The IRLC is the reciprocal value of residential density, and it equals the land area (not building area) of a residential project divided by the resident population. There was data for 108 residential buildings, and 31 of them met the standards for green buildings. Specifically, 22 were one-star buildings, six were two-star buildings, and three were three-star buildings. By referring to evaluation reports on green buildings in various projects, specific provisions regarding the standards for green buildings, along with parameters such as IRLC and FAR, were obtained.

3.2 Analysis of provisions of carbon emission reduction contained in the ASGB

Based on the ASGB, the items related to carbon emission were classified by land saving, energy saving, water saving, materials saving, indoor environmental quality, and operations management. Among the land saving items, parameters like IRLC are related to carbon emission caused by power usage of families; among energy saving items, the energy consumption level of air conditioners is related to carbon emission; among water saving items, power is consumed during transportation and purification of water, so the water-saving rate is related to carbon emission. Given the maximum energy consumption at the operation stage of buildings (accounting for 75–85% of total energy consumption [31,32,33]), the work reported in this paper was focused on the energy consumption of buildings during operation, while neglecting items regarding materials saving, indoor environmental quality, and operations management. The carbon emission-related provisions for evaluating green buildings are summarized in Table 1.

To compare quantitatively the conditions of power saving and water saving between green buildings and those failing to meet the standards of green buildings (buildings that fail to meet the standards of green buildings are traditional energy saving buildings, herein referred to as non-green buildings), λ was defined as the rate of power and water saved. Specifically, it refers to the rate of the limit of power and water saved by green buildings, compared with that of non-green buildings, as shown in Equation (1):

$$\lambda = \varepsilon \cdot \left(\phi_{gb} - \phi_{ngb} \right) \tag{1}$$

Where λ is the rate of power/water saved by green buildings, ε is the rate of power/water saved in the provisions of the ASGB, ϕ_{gb} is the proportion of green buildings that meet provisions, and ϕ_{ngb} is the proportion of non-green buildings that meet provisions.

TABLE 1. Carbon emission-related indexes for evaluating green buildings.

No.	Provisions	Proportion of star-rated green buildings that meet provisions			Proportion of non-green buildings that meet provisions
		1-star	2-star	3-star	
4.1.6	The ratio of green space should not be less than 30%	22/22	6/6	3/3	77/77
4.1.12	Average heat island intensity outdoors should not be higher than 1.5°C	22/22	6/6	3/3	77/77
4.1.14	Every 100 m^2 greenbelt should have 3 trees (arbor) at least	22/22	6/6	3/3	77/77
4.2.2	The performance coefficient and energy efficiency ratio of water chilling (air conditioning) units of the central air-conditioning system should comply with the specifications in GB50189	0/22	0/6	0/3	0/77
4.2.5	The power consumption per unit air volume of the fan and energy efficiency of transporting hot/cold water of central air-conditioning system should comply with the specifications in GB50189	0/22	0/6	0/3	0/77
4.2.6	The performance coefficient and energy efficiency ratio of the water chilling (air-conditioning) unit of the central air-conditioning system should be one level higher than those specified in GB50189	0/22	0/6	0/3	0/77
4.2.8	Energy recovery system should be in the residence with the central air-conditioning system	0/22	0/6	0/3	0/77
4.2.9	The renewable energy used should account for 5% or more of the total energy consumption of buildings	8/22	6/6	3/3	25/77
4.2.10	The energy consumption of the air conditioner should not be higher than 80% of the value specified by existing national standards	0/22	2/6	1/3	0/77
4.2.11	The renewable energy used should account for 10% or above of the total energy consumption of buildings	0/22	4/6	3/3	0/77
4.3.3	Water-saving appliances are applied, and the water-saving rate should not be lower than 8%	22/22	6/6	3/3	77/77

TABLE 1. Carbon emission-related indexes for evaluating green buildings. *(Cont.)*

No.	Provisions	Proportion of star-rated green buildings that meet provisions			Proportion of non-green buildings that meet provisions
		1-star	2-star	3-star	
4.3.7	Non-conventional water sources such as reclaimed water and rainwater should be used for greening and vehicle cleaning	6/22	6/6	3/3	0/77
4.3.4	Municipal water supply and underground water should not be used for landscaping	22/22	6/6	3/3	77/77
4.3.11	The utilization rate of non-conventional water sources should be higher than 10%	6/22	6/6	3/3	0/77
4.3.12	The utilization rate of non-conventional water sources should be higher than 30%	0/22	0/6	0/3	0/77

In Table 1, the analysis of carbon emission terms in the ASGB is mainly about index items such as ground vegetation, wind and heat environment, renewable energy, rainwater utilization, etc. It should be noted that air conditioning energy efficiency indicators in the ASGB are stricter than those in the traditional energy-saving building standard. These evaluation provisions are beneficial for reducing carbon emission produced by power consumption but are only suitable for use in dwellings with central air conditioning of which there were none in 2014 in Ningbo. Some assessment terms about lighting and ventilation in the ASGB that are beneficial for saving energy are also present in the traditional energy saving building standard, so these terms are not listed in Table 1.

The rate of power/water saving of star-rated green buildings compared with non-green buildings is shown in Table 2. With respect to the two provisions, in which the utilization rate of renewable energy is specified as 5% and 10%, respectively, the one that saves more energy shall prevail during calculation. For example, between the provisions 4.2.9 and 4.2.11, 10% should be used to calculate the energy saved by using renewable energy in two-star green buildings (i.e., $\lambda = 10\% \times (4/6 - 0) \approx 6.6\%$.

TABLE 2. Rate of power/water saving of star-rated green buildings.

Indexes	1-star	2-star	3-star
Water saving	2.7%	10%	10%
Power saving by air conditioner	—	6.6%	6.6%
Power saving by renewable energy	0.96%	6.6%	10%
Gas saving	—	—	—

3.3 Model of carbon emission

The main factors that generate carbon emission during the operation stage of buildings include water, electricity, and gas. Items related to power consumption such as air conditioners, lighting, elevators, domestic hot water, and auxiliary equipment for renewable energy are incorporated into electric energy. Carbon emission from purification and transportation of tap water, as well as that produced during exploitation, transmission, distribution, and combustion of natural gas are also taken into account. More details about the basis for calculating carbon emission generated by comprehensive energy consumption of water, electricity, and gas, are shown in Table 3.

The data on natural gas consumption is based on the Subject Plan of Gas for Urban Areas in Ningbo 2001–2020. By means of interpolation, the heat consumption quota of gas per capita for urban residents in 2014 was calculated and was equal to 2804.62 MJ. Given the low heat value of 38.01 MJ/m^3 in the Chunxiao Oil and Gas Field, the natural gas consumed per capita was 73.79 m^3/a. In accordance with the Code for Planning and Design on Urban Residential Areas (GB50180) (2002), and supposing each household has 3.2 persons, the carbon emission of each household was 772 kg/a.

The data on electric energy consumption is based on the statistics of electricity used by residents in Ningbo in 2014 and was provided by the Ningbo Electricity Authority [34]. An ordinary family consumes about 2700 kWh every year, so the carbon emission generated during electricity utilization by each household in Ningbo was 2133 kg/a.

The data on water consumption is based on the Water Resources Bulletin of Ningbo in 2014 [35]. The volume of domestic water used by urban residents was 232 L/person/day (i.e., 270.9 t/a per household), which is equivalent to 56.9 kg/a carbon emissions.

The sum of carbon emission generated by water, electricity, and gas use in residential buildings in Ningbo in 2014 can be written as Equation (2):

$$C_{emi} = C_{emi,w} + C_{emi,e} + C_{emi,g} \tag{2}$$

Where C_{emi} is the total carbon emission in residential areas, and $C_{emi,w}$, $C_{emi,e}$, $C_{emi,g}$ is the carbon emission related to water, electricity, and gas, respectively.

Then, the actual consumption data is put into Equation (2), and the result is shown in Equation (3):

$$C_{emi} = C_{emi,w} + C_{emi,e} + C_{emi,g} = (772 + 2133 + 56.9) \cdot n = 2961.9 \cdot n \tag{3}$$

Where n is the number of households. The number of households n can be represented by the ratio of land area (A_L) used in a project to IRLC (I_{RLC}). According to the City Residential Area

TABLE 3. Conversion coefficient of standard coal for consumption of water, electricity, and gas.

Working medium	Coefficient of standard coal	CO_2 converted by standard coal	Carbon emission
New water	0.0857 kgce/t [a]	2.4567 t/tce	0.21 kg/t
Electricity	0.32 kgce/kwh [a]	2.4567 t/tce	0.79 kg/kwh
Oil field gas	1.33 kgce/m^3 [a]	2.4567 t/tce	3.27 kg/m^3

[a] General principle for calculation of total production energy consumption, GB/T2589-2008

Planning and Design Standard (GB50180), the average household has about 3.2 people; so the I_{RLC} could be expressed in Equation (4):

$$I_{\mathrm{RLC}} = \frac{A_{\mathrm{L}}}{3.2n} \tag{4}$$

Thus, Equation (2) can be written as Equation (5), which represents the carbon emission of non-green buildings. This is the carbon emission equation based on statistics for the consumption of building electricity, water, and gas in 2014.

$$C_{emi} = 2961.9 \cdot \frac{A_{\mathrm{L}}}{3.2 I_{\mathrm{RLC}}} = \frac{A_{\mathrm{L}}}{I_{\mathrm{RLC}}} \cdot 925.6 \tag{5}$$

Where the units of A_L and I_{RLC} are m^2.

Based on the statistics of Table 2, a one-star green building can save water (2.7%) and electricity (0.96%) when renewable energy is used. Thus, the formula for calculating carbon emission of one-star green buildings (indicated by subscript "1") is as follows:

$$C_{emi,1} = n \cdot 2939.86 = \frac{A_{\mathrm{L}}}{I_{\mathrm{RLC}}} \cdot 918.7 \tag{6}$$

Similarly, the formula for calculating the carbon emission of a two-star green building (indicated by subscript "2") is as follows:

$$C_{emi,2} = n \cdot 2674.6 = \frac{A_{\mathrm{L}}}{I_{\mathrm{RLC}}} \cdot 835.8 \tag{7}$$

The formula for calculating the carbon emission of a three-star green building (indicated by subscript "3") is as follows:

$$C_{emi,3} = n \cdot 2602.11 = \frac{A_{\mathrm{L}}}{I_{\mathrm{RLC}}} \cdot 813.2 \tag{8}$$

4. RESULTS AND DISCUSSION

4.1 Relationship between carbon emission and FAR

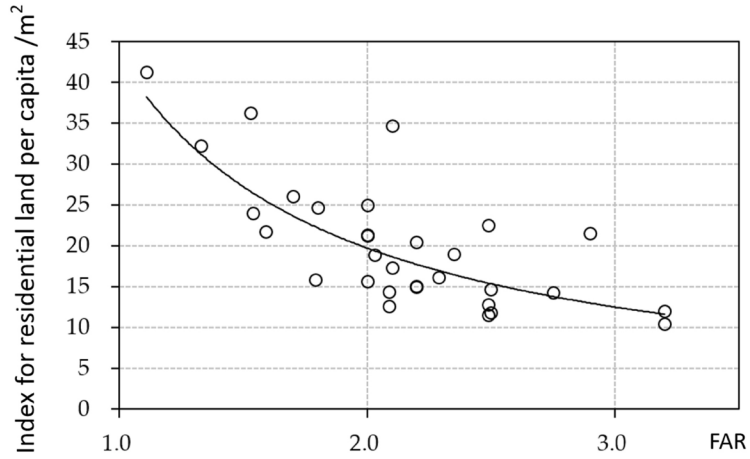
FAR is closely related to the economic benefit of a real estate project and to the benefit of the eco-environment in residential areas. Although evaluation indexes are not set for residential buildings in accordance with FAR in the ASGB, the FAR has been linked to the IRLC in research [36]. To investigate the correspondence between FAR and IRLC in Ningbo, regression analysis was performed. The results show that the FAR of green buildings and non-green buildings are both significantly correlated (at 0.01 level) with the IRLC, representing a high degree of confidence. Specifically, the correlation between the FAR of green buildings and the IRLC was 0.669, as shown in Figure 1(a), whereas the correlation between the FAR of non-green buildings and IRLC was 0.576, indicating they are moderately (i.e., not strongly) correlated.

For real estate businesses, in order to maximize benefits, FAR is usually set high in real estate project planning. Consequently, the gross area and number of residents in a community

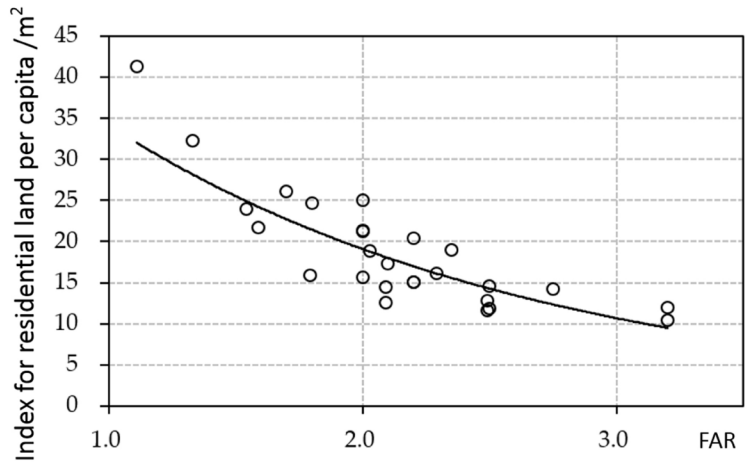
also increase. Given the fixed land area of projects, the IRLC is small. Thus, the t-test was used to remove some abnormal data [37]. Therefore, projects with much higher FAR and IRLC were excluded; specifically, the number of qualified green buildings was reduced to 27 (four projects removed), and the number of qualified non-green buildings was reduced to 62 (15 projects removed). The correlation analysis was performed again to test the data after removal. The correlation between FAR of green buildings and IRLC reached 0.815, indicating that they were highly correlated, as shown in Figure 1(b). The corresponding fitting equation is Equation (9). The correlation between FAR of non-green buildings and IRLC reached 0.59, indicating they were still moderately correlated. See Table 4 for specific data used in the correlation analysis. The statistical analysis also indicates that the indexes for regulatory planning of green buildings have significant interrelation compared with non-green buildings, and that the popularization of green building also helps planning departments to manage the ecological balance in urban areas.

$$I_{\mathrm{RLC}} = 43.294R^{-1.226} \tag{9}$$

FIGURE 1. Fitting curve between FAR and IRLC of green buildings, (a) Raw data (Pearson's r = 0.669), (b) After removal of abnormal data (Pearson's r = 0.815).



(a)



(b)

Where R is the floor area ratio (FAR).

By substituting the fitting Equation (9) of IRLC and FAR into Equations (6), (7), and (8); we obtain the carbon emission equations of 1-star, 2-star, and 3-star (indicated by subscript "1," "2," "3") green buildings, as shown in Equations (10), (11), and (12).

$$C_{emi,1} = 21.2 A_{\mathrm{L}} \cdot R_1^{1.226} \tag{10}$$

$$C_{emi,2} = 19.3 A_{\mathrm{L}} \cdot R_2^{1.226} \tag{11}$$

$$C_{emi,3} = 18.8 A_{\mathrm{L}} \cdot R_3^{1.226} \tag{12}$$

4.2 Relationship between green building and carbon emission reduction target

According to the carbon emissions equations (5), (6), and (7), we know that carbon emission of one-star green buildings is less than traditional energy saving buildings by 0.75%, and carbon emission of two-star green buildings is less than traditional energy saving buildings by 9.7%, taking two-star green buildings as an example, the calculation formula is shown in equation (13).

$$\frac{\left(\frac{A_{\mathrm{L}}}{I_{\mathrm{RLC}}} \cdot 925.6 - \frac{A_{\mathrm{L}}}{I_{\mathrm{RLC}}} \cdot 835.8\right)}{\frac{A_{\mathrm{L}}}{I_{\mathrm{RLC}}} \cdot 925.6} = 9.7\% \tag{13}$$

In China the promotion of green building is increasing. According to *Zhejiang Green Building Regulations*, Zhejiang province was going to enforce the one-star green building standard in all new buildings from 1 May 2016. However, one-star green buildings have a weak effect on reduction of carbon emission. In 2009, the Chinese government promised to reduce carbon emission per unit of GDP by 40% to 50% in 2020 compared with 2005 levels (see the Copenhagen Accord). Considering the growing per capita GDP of China, the energy consumption for transportation, industry, and building each accounted for one third. Modest energy conservation in buildings would contribute little to achieve the carbon emission reduction target for 2020; consequently, meeting the carbon emission reduction target of China in 2020 calls for a policy of at least a compulsory two-star green building standard for all new buildings.

4.3 Reward quota for preferred FAR in green building

Based on Equations (10), (11), and (12), the carbon emission of different star-rated green buildings and carbon emission in the case of different reward quotas of FAR can be calculated.

TABLE 4. Analysis of correlation between FAR and IRLC.

Building	Significance level	Pearson correlation	
		Raw data	After removal of abnormal data
Green building	0.01	0.669	0.815
Non-green building	0.01	0.576	0.59

In Figure 2, supposing the land area (A_L) equals 10,000 m^2, the carbon emission of different star-rated green buildings were calculated based upon a FAR reward quota of 2% (two-star green buildings) and FAR reward quota of 3% (three-star green buildings). It can be seen that the carbon emission in the case of 3% FAR reward quota of three-star green buildings (GB) is higher than that of two-star green buildings (GB). In addition, the FAR reward quota for different star-level green buildings when carbon emission values are equal can also be calculated by letting Equation (11) equal Equation (12). The result is as follows:

$$R_2 \approx 1.02 R_3 \tag{14}$$

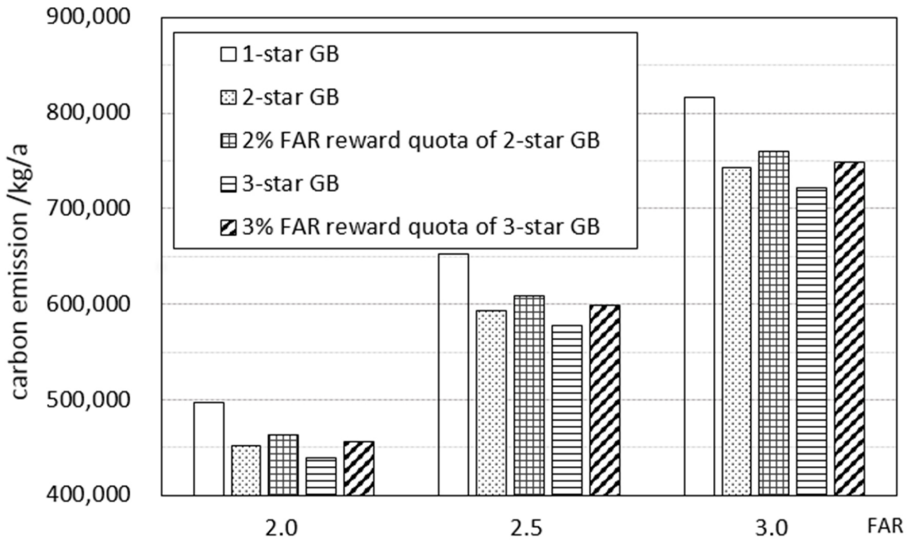
This indicates that when the FAR reward quota of three-star green buildings is 2%, their carbon emission is equal to that of two-star green buildings. From the perspective of carbon emission, when the reward quota of FAR or the above ground floor area exceeds 2%, the carbon emission of three-star green buildings is lowered by one star; this weakens the significance of carbon reduction in green buildings by saving energy.

4.4 Applicability and reasonability discussion of the FAR bonus

The quota of FAR bonus in this paper is not suitable for every city in China. China has a vast territory, and the climate varies greatly from region to region; therefore, the planning and building standard varies correspondingly. According to City Residential Area Planning and Design Standard (GB50180), China is divided into seven building-climate regions, and buildings in the same climate zone are subject to the same building standard. The design parameters of the buildings considered in this paper contain all the residential buildings in Ningbo that were new in 2014. Ningbo is located in an area with hot summers and cold winters, so the results for buildings in Ningbo could represent other cities in areas with similar climate (hot summer and cold winter).

According to the calculations in this paper, the reward quota for three-star green buildings should be less than 2% of FAR, which creates a trade-off between development of green buildings

FIGURE 2. Carbon emission in the case of different reward quotas of FAR.



and progress toward a low-carbon community. In contrast, in New York about 100,000 m^2 of open space was created in the 1970s using reward quota policy [38], which indicates the efficiency of Macro-economic policy. Current reward quotas of 0.5–6% of FAR have been applied in several provinces and cities in China. Some measures, like financial incentives, are also used in the cities of Beijing and Tsingtao. According to the incentive program, a three-star residential green building could obtain at most CNY 1.5 million. In fact, CNY 1.5 million is not enough to attract a developer's interest compared with the real estate investment. Take a residential zone as an example. If the total building area were 200,000 m^2, when the FAR bonus was 2%, the reward area obtained would be 4000 m^2. Considering that the price of housing is more than 10,000 Yuan/m^2 in most capital cities, the real estate developer could earn more than CNY 40 million. Therefore, the FAR bonus is more attractive to developers than the financial incentive. Meanwhile, when the FAR is 3, according to formula (15), this 3-star green building residential zone could reduce carbon emission 184 t/a more than a 1-star level building.

$$C_{emi,1} - C_{emi,3} = (21.2 - 18.8) A_{\mathrm{L}} \cdot R_3^{1.226} = 184583 \text{ kg/a} \tag{15}$$

5. LIMITATIONS AND APPLICABILITY RECOMMENDATIONS

This FAR bonus study is based on the evaluation index of ASGB, building design parameters, and building energy consumption data in Ningbo, China. Because the ASGB is a Chinese national standard, the indicators of resource conservation are suitable for most large-medium cities in China. The building design parameters such as FAR, and building density have been defined at the land transfer stage. These parameters are similar in economically developed cities. Because Ningbo is a sub-provincial city, its building energy consumption can serve as a reference for other Chinese cities. Therefore, the findings of this study could be used for most large-medium cities in China.

For foreign cities, there are some differences among the three indexes of assessment standard, building design parameters and building consumption data. These are as follows: I) the energy saving line and water saving line in green building assessment standards are different, such as the ASGB, LEED, and CSH [39]. Although they follow similar principles, a small difference would change the result of the FAR reward quota. II) There is a significant difference in building design parameters among different countries. Control plan indexes such as FAR and building density are defined by the conditions in a country. For example, City Residential Area Planning and Design Standard (GB50180) states that the average household has about 3.2 people in China, which also affects the results of IRLC. III) Building energy and water consumption are decided by the resource status and economic level in different countries. Thus, the quantitative conclusions of this study are suitable for most Chinese cities, but the carbon emission computational model for FAR bonus is suitable for all cities worldwide.

6. CONCLUSIONS

The carbon emission-related provisions in the ASGB were summarized and analyzed. By this measure, and compared with non-green buildings, 1-star, 2-star, and 3-star green buildings save energy (0.96%, 13.2%, and 16.6%, respectively) and save water (2.7%, 10%, and 10%, respectively). Carbon emission reduction of 1-star and 2-star green buildings was found to be 0.75% and 9.7%, respectively, when compared with reductions by traditional energy saving buildings. In order to realize the goal of carbon emission reduction by 2020, instead of the

current policy, all new buildings should comply with at least the two-star green building standard. To achieve rapid development of green buildings, there is a need for guidance by incentive policies. However, only 3-star green buildings can receive a quota of FAR reward less than 2%. Otherwise, their effect on reducing carbon emission will be the same as that of 2-star green buildings.

According to this paper's research, the conclusion can be drawn that there is a strong correlation between FAR and IRLC for green buildings, and a moderate correlation for non-green buildings. A carbon emission equation based on FAR was created for star-rated green buildings. This empirical model can be extended to other cities worldwide. The method used is as follows: I) Identify resource indicators such as energy and water savings based on the green building assessment standard. II) Analyze architectural design drawings, and obtain the ratio of buildings that achieved the star-related green building standards for these resource indicators. III) Establish a fitted relationship between FAR and IRLC. IV) Convert the resource consumption data into carbon emissions, and construct the carbon emission equation with FAR and A_{LX}.

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AUTHOR CONTRIBUTIONS

All authors contributed extensively to the work presented in this article. Yanhui Mao analyzed the data and wrote the paper; Xuemei Gong examined this article and provided some significant advice; Yun Ye collected the data and provided some significant advice.

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