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Carbon Analysis of Star Green Buildings Different Climate Zones

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Abstract

Purpose: To study carbon emissions during operation and embodied emissions of green buildings in different regions and star grades. **Research methodology**: Explore the carbon emission benefits of different star green buildings through different sustainable carbon reduction strategies, and help promote the sustainable development of residential buildings. **Results:** The carbon emissions of star green buildings decrease from north to south. Northern residential buildings are most affected by renewable energy and envelop, while in southern regions, renewable energy and heating, ventilation, and air conditioning(HAVC) equipment performance improvement can be prioritized. The embodied emissions in the south are lower than that in the north, and the carbon reduction of recyclable materials can reach 22~48 $kgCO_2/m^2$. The total carbon emissions of the same star green buildings are gradually decreasing. Green buildings of high star grades and optimized building design can promote the comprehensive carbon reduction effect of buildings. **Conclusions:** The application of carbon reduction strategies that differentiate between operational carbon and implicit carbon under sustainable development has different carbon reduction characteristics. Based on the characteristics of different residential buildings, it is necessary to conduct in-depth analysis of carbon reduction features and formulate different sustainable development strategies to achieve maximum carbon reduction benefits.

Keywords: Grades; Star green buildings; Carbon emissions during operation; Embodied emissions

JEL Classification Code: Z0

1. Introduction

In China's total carbon emissions, the construction industry accounts for about 50% (Fan,2013). During the 13th Five-Year Plan period, although the growth rate of carbon emissions from the entire construction process in the country slowed down compared to the past, the average annual growth rate still reached 3.1% (China association of building energy efficiency, 2021). For building carbon emissions, indirect emissions are the main form, especially for new buildings. Improving building energy efficiency is one of the important measures to reduce indirect emissions. Applying new technologies, materials, and models to promote green buildings, reflecting environmental concepts such as energy conservation, land conservation, water conservation, and material conservation, has important practical significance for reducing resource consumption and environmental impact (Luo,2022).

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In recent years, China's green buildings have shown a large-scale and rapid development trend, achieving significant results in both quantity and coverage, with new green buildings accounting for over 90% (Liu,2022). Star green buildings shall be divided into three grades, namely one-star grade, two-star grade, and three-star grade. In addition to meeting the mandatory and rating requirements of assessment standards green building, strict adherence to technical requirements for envelop, sound insulation property, and air pollutants is also required. Among them, green buildings refer to the means of saving resources, protecting the environment, reducing pollution, fully utilizing renewable energy and green means based on Assessment Standard for Green Building, reducing building carbon emissions, and providing feasible and effective solutions for achieving China's carbon peak and carbon neutrality goals.

2. Data Processing Methods

Based on the General Code for Energy Efficiency and Renewable Energy Application in Buildings (hereinafter referred to as the "General Code"), this paper uses PKPM-CES carbon emissions software to study the operational carbon (heating, ventilation, and air conditioning(HAVC), lighting, hot water system, elevators, renewable energy and carbon sinks) and embodied emissions (building materials production, transportation, and construction) (Long, 2021) and explores the carbon emission benefits of green buildings of different star grades. Due to the fact that the carbon emissions during the demolition phase only account for 1%~4% (Liu,2024), the demolition phase is not considered in this study. The calculation for different regions shall be selected according to the General Code, including the thermal performance of the envelop, operating time of various systems, indoor temperature, personnel density, occupancy rate, and other information. This article discusses how optimizing the envelop, reducing artificial lighting, improving equipment performance, using renewable energy, and considering carbon sinks are the main strategies for sustainable development of residential buildings when operating carbon. Regarding the Embodied emissions in buildings, optimizing the envelop and using recyclable building materials are the main ways to reduce carbon emissions in residential buildings.

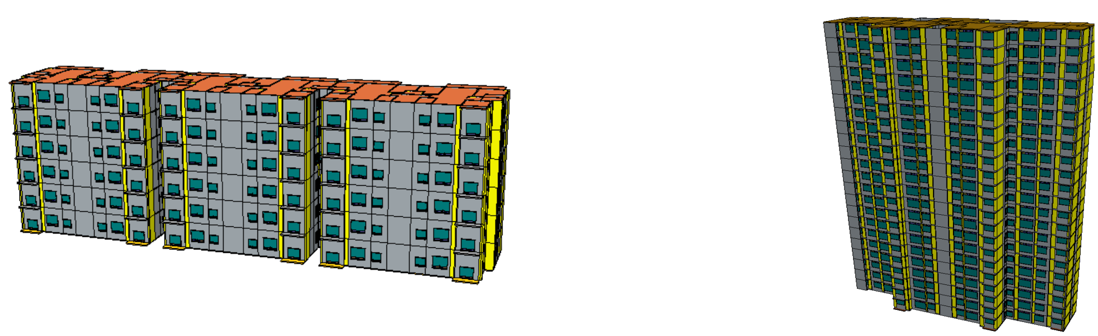
3. Calculation Parameters

3.1. Basic Building Information

Two typical residential buildings are selected in this project as research objects, and the building information is shown in Table 1. Establish a BIM model based on the PKPM software platform (see Figure 1), analyze building energy consumption and carbon emissions, and study the changing trends of operational carbon emissions and embodied emissions under sustainable development strategies of green buildings with different regions and star grades.

Table 1: Building Foundation Information

Project	Height (m)	Number of layers	Ground floor area (m^2)	Building area (m^2)
Multi-story residential building	18.0	6	4062.97	677.16
High-rise residential building	70.4	22	677.16	423.19



(a) Multi-story residential building (b) High-rise residential building

Figure 1. Typical Residential Model

3.2. Calculation Parameters

Using buildings that meet the requirements of the General Code as conventional buildings, focusing on envelope, HVAC, lighting, hot water, elevators, renewable energy, green space ratio, etc., different proportions are increased compared to conventional buildings (as shown in Table 2), exploring the carbon reduction level and proportion of green buildings of one-star, two-star, and three-star grade, and exploring the impact of operational carbon emissions. Room air conditioners are used for cooling in cold and severe cold regions (northern regions), municipal heating system is used for heating, and room air conditioners are used for cooling and heating in other regions (southern regions).

Table 2: Setting of Operational Carbon Strategy under Sustainable Development Strategy

Climate Zoning	Star Grade	Thermal Performance of Envelop	Performance coefficient of HVAC equipment		Lighting Power Density (W/m2)	Elevator Energy-saving Level	Application of Renewable Energy	Greening Rate (%)
			Heat Source	Cold Source				
Cold and Severe Cold Regions	One-star	Increase by 5%	Municipal Heating System	5	6	Conventional Elevator System	No	35
	Two-star	Increase by 10%	Municipal Heating System	5.4	5	VVVF	30% Rooftop Photovoltaic Power Generation	40
	Three-star	Increase by 20%	Municipal Heating System	5.8	5	VVVF with Energy Feedback	50% Rooftop Photovoltaic Power Generation	45
Other regions	One-star	Increase by 5%	4	4	6	Conventional Elevator System	No	35
	Two-star	Increase by 10%	4.5	4.5	5	VVVF	30% Rooftop Photovoltaic Power Generation	40
	Three-star	Increase by 20%	5	5	5	VVVF with Energy Feedback	50% Rooftop Photovoltaic Power Generation	45

4. Result analysis and discussion

4.1. Energy consumption indicators for building operation in different regions

For conventional buildings, the difference in carbon emissions between buildings in different regions mainly comes from the carbon emissions generated by HAVC. The operating carbon emissions of buildings in different regions follow the pattern: severe cold regions(SC)>cold regions(C)>hot summer and warm winter regions(HW)>hot summer and cold winter regions(HC)>warm regions(W) (as shown in Table 3). The operating carbon emissions of every region are lower than the national average of 29.02 kg $CO_2/(m^2 \cdot a)$ for residential buildings (China association of building energy efficiency, 2021).

Table 3: Operating Carbon Emissions in Different regions

Project	Climate Zoning	Total Carbon Emissions (kg CO2/(m2·a))	Project	Climate Zoning	Total Carbon Emissions (kg CO2/(m2·a))
Multi-story Residential Buildings	Severe Cold Region(SC)	27.02	High-rise Residential Buildings	Severe Cold Region(SC)	18.76
	Cold Region(C)	20.54		Cold Region(C)	15.99
	Hot Summer and Cold Winter(HC)	14.12		Hot Summer and Cold Winter(HC)	11.48
	Hot Summer and Warm Winter(HW)	15.96		Hot Summer and Warm Winter(HW)	14.62
	Warm Region(W)	7.88		Warm Region(W)	5.73

According to Standard for Energy Consumption of Building, the energy consumption of residential buildings in SC and C is divided into non-heating energy consumption and building heating energy consumption, which are respectively represented by the annual energy consumption per household and the annual coal consumption per square meter; The energy consumption of buildings in other regions is only managed based on non-heating energy consumption indicators, which include winter heating energy consumption. The energy consumption indicators during building operation after considering photovoltaic power generation are shown in Figures 2 and 3.

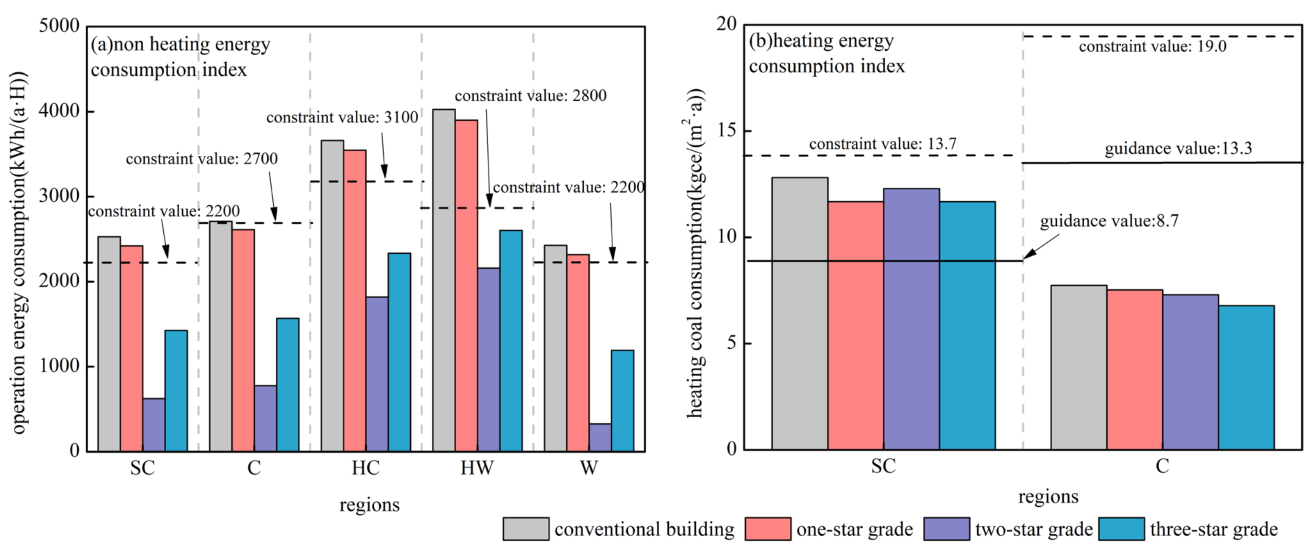


Figure 2. Energy Consumption Indicators for The Operation of Multi-story Residential Buildings

For multi-story residential buildings in non-severe cold regions with the same star grade, the non-heating energy consumption index is highest in HW, with an overall index of 2600~4030 kWh/(a·H), followed by HC, which are about 250~400 kWh/(a·H) lower than the index in HW. The non-heating energy consumption index is lowest in W, where the energy consumption trends of HAVC in HW >HC > W. The non-heating energy consumption indicators of two-star and three-star green buildings are both lower than the constraint value in Standard for Energy Consumption of Building, indicating that the envelop, equipment performance, and renewable energy have a significant carbon reduction effect on residential buildings. For the heating energy consumption index of multi-story residential buildings in SC, all-star grades green buildings in SC have reached the guidance value of 13.7 kgce/(m^2·a), while the index in C is even lower, reaching the guidance value of 8.7 kgce/(m^2·a).

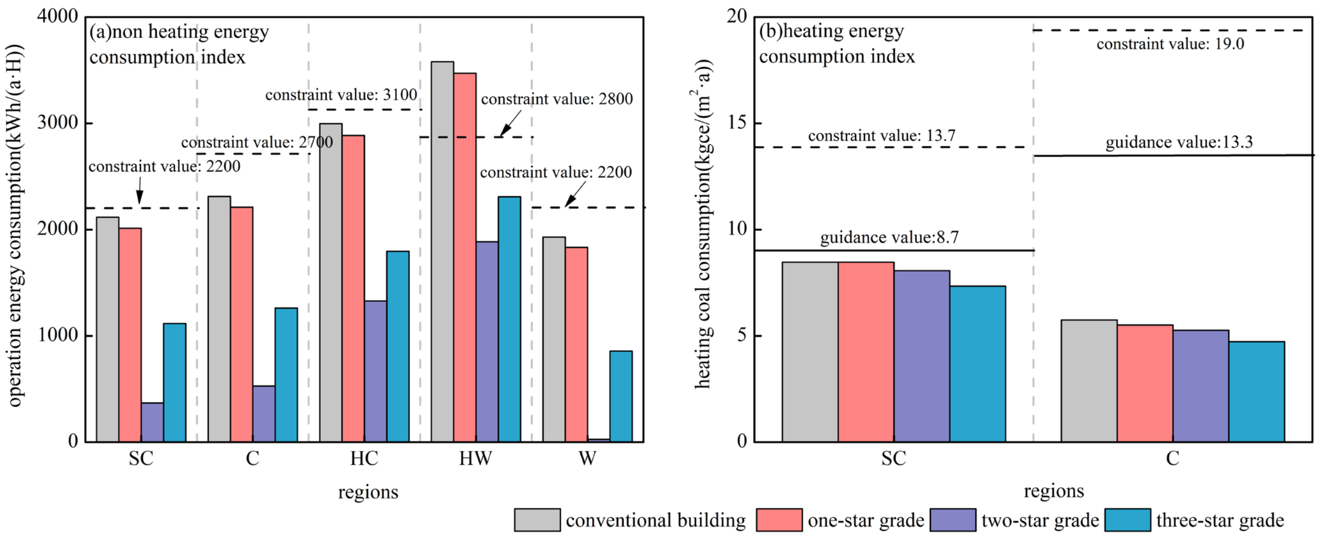


Figure 3. Energy Consumption Indicators for The Operation of High-rise Residential Buildings

For high-rise residential buildings, except for conventional buildings and one-star high-rise residential buildings in HW, the non-heating energy consumption indicators of high-rise residential buildings in other scenarios are lower than the constraint value, and the heating energy consumption indicators in SC and C are lower than the guidance value. The trend of non-heating energy consumption indicators in high-rise residential buildings is similar to that of multi-story residential buildings, but the overall energy efficiency of the buildings is better than that of high-rise residential buildings.

Taking C with HC as examples of three-star residential buildings in the north and south, this study explores the carbon reduction benefits of various sustainable development strategies on operational carbon (see Table 4). Considering all strategies, the carbon emissions of residential buildings in the north and south have the greatest impact, with a maximum carbon reduction rate of around 40%. For residential buildings in the north, the impact of renewable energy and the improvement of envelop performance can be given priority consideration. For residential buildings in the south, renewable energy and the improvement of HVAC equipment performance can be given priority consideration. Different sustainable development strategies should be considered for different regions to achieve maximum carbon reduction benefits.

Table 4: The impact of different sustainable development strategies on carbon reduction during operation

Serial Number	Strategy	Carbon Reduction Rate(North)(%)		Carbon Reduction Rate(South)(%)	
		Multi-story Residential Buildings	High-rise Residential Buildings	Multi-story Residential Buildings	High-rise Residential Buildings
Strategy1	Improvement of envelop performance	6.13	8.15	2.83	4.30
Strategy2	Performance improvement of HVAC	0.85	1.22	7.26	7.74
Strategy3	Reducing lighting power density	3.05	2.66	4.47	3.69
Strategy4	energy-saving measures for elevators	2.16	2.54	3.15	3.52
Strategy5	renewable energy sources	13.40	16.20	16.40	18.78
Strategy6	Comprehensive strategy (strategies 1~5)	27.40	33.07	36.25	40.06

4.2. Embodied emissions in different regions

In the calculation of carbon emissions, embodied emissions mainly includes the carbon emissions generated during the production and transportation of building materials used in buildings, as well as during the construction and demolition of buildings. Due to the small proportion of carbon emissions during the demolition phase in the total life cycle of buildings, this study does not consider the demolition phase. In different regions, the trend of the deviation ratio between embodied emissions and measured values is as follows: HW > W > HC > C > SC (as shown in Figure 4). The actual measured value of embodied emissions is selected from the value of 11.78 kg CO_2/m^2 in China Building Energy Consumption Annual Report 2020 (China association of building energy efficiency, 2021).

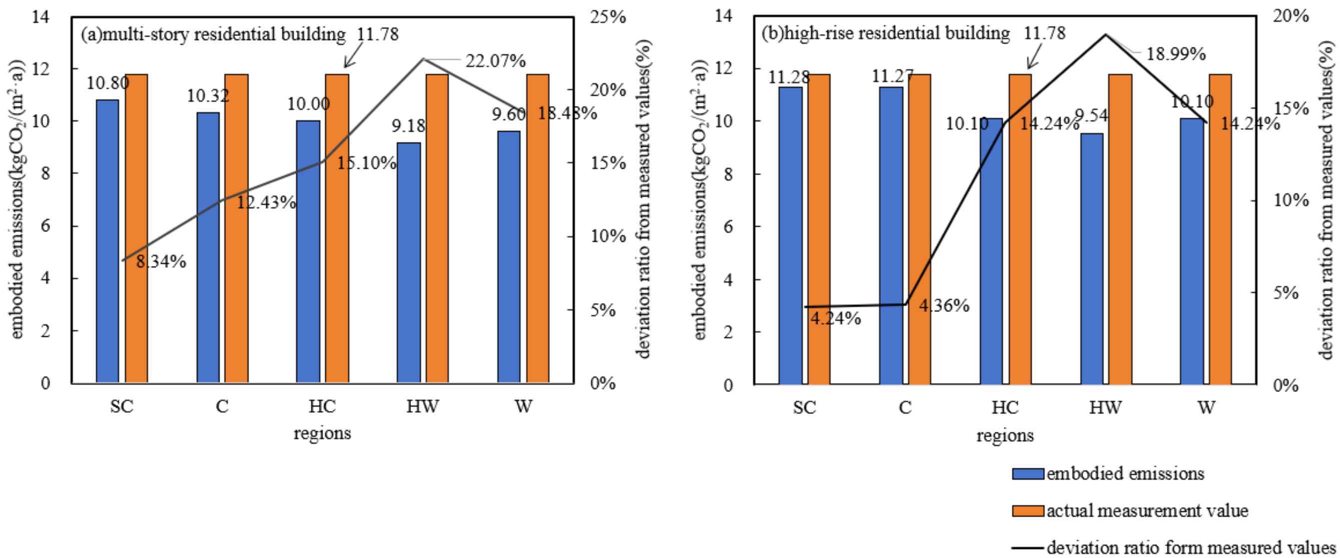


Figure 4. Embodied Emissions in Different Regions

Li (2006) studied the impact of material regeneration rate on the energy consumption of renewable materials, while Ren (2014) studied the impact of recyclable materials on the carbon emission factors of building materials. Recyclable materials, such as steel bars, concrete, doors and windows, hollow bricks, etc., can be processed into new materials or reused as raw materials, which can reduce carbon emissions from upstream material production in building materials. In this project, some materials are considered to be recyclable for carbon reduction, and the transportation carbon emissions generated during the transportation of these materials to the treatment site after building demolition can reach a carbon reduction of 22~48 $kgCO_2/m^2$, with an increasing trend from the north to the south.

4.3. Carbon reduction rate of green buildings of different star grades

As the green building star grade increases, the embodied emissions slightly increases, the operating carbon gradually decreases, and the total carbon emissions decrease, reflecting the comprehensive emission reduction effect of high star green buildings. Compared with conventional buildings, the carbon reduction ratio of one-star green buildings reaches 7.8%~12.0%, the carbon reduction ratio of two-star green buildings reaches 9.6%~19.5%, and the carbon reduction ratio of three-star green buildings reaches 12.4%~23.0%. The overall carbon emission reduction ratio is slightly higher in the south than in the north. The highest carbon reduction ratio for three-star green buildings in the south can exceed 20%, while the highest carbon reduction ratio for three-star green buildings in the north can reach 16.54%. For high-rise residential buildings, the trend of carbon reduction benefits is similar to that of multi-story buildings. Compared with conventional buildings, the carbon reduction ratio of one-star green buildings is between 7.2% and 12.6%, the carbon reduction ratio of two-star green buildings is between 12.6% and 18.5%, and the carbon reduction ratio of three-star green buildings is between 17.4% and 22.0%.

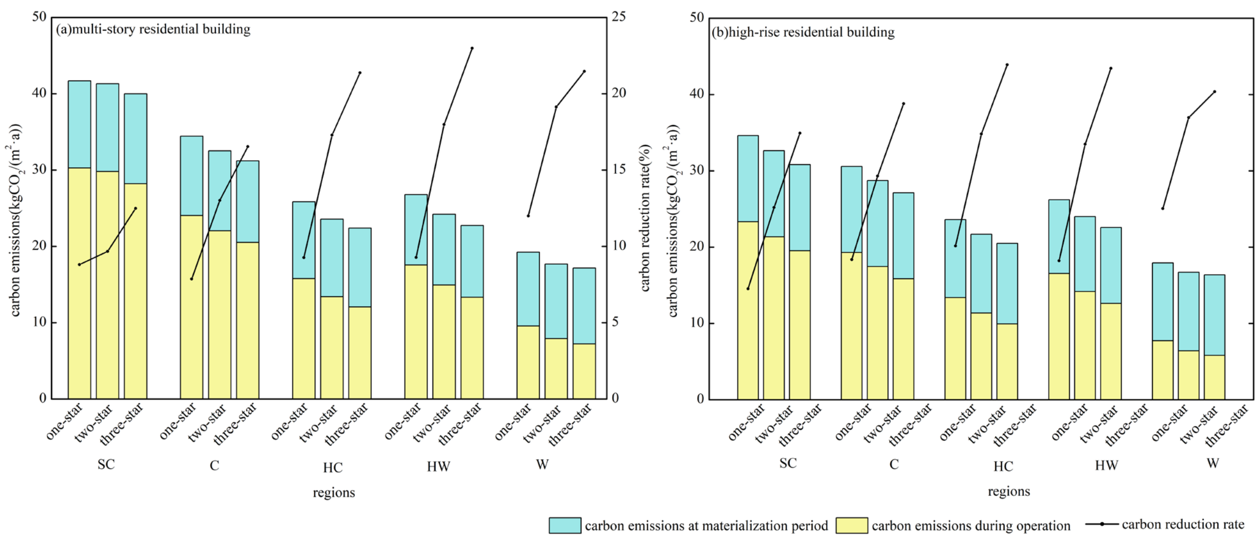


Figure 5. Carbon Emissions and Reduction Rates in Different Regions

Compared with multi-story residential buildings, the overall carbon emissions level of high-rise residential buildings is lower than that of multi-story buildings. Optimizing building design can to some extent optimize and control carbon emissions levels; In addition, the operating carbon per unit area of high-rise residential buildings is slightly lower, and the embodied emissions per unit area has increased. In the southern region, the embodied emissions basically exceeds the operating carbon. Overall, from north to south, there is a significant reduction in carbon emissions during operation, which is related to the climate conditions in various regions. The demand for HAVC is gradually decreasing, and the contribution to overall carbon emissions is gradually increasing.

5. Conclusions

This article uses PKPM-CES carbon emission calculation software to focus on studying the carbon emissions of buildings in different regions and star grades, investigating operational carbon and embodied emissions. In the study, by studying the application of operational carbon and embodied emissions under sustainable development, it was found that improving the performance of envelop, optimizing HVAC systems, lighting systems, elevator systems, fully utilizing renewable energy, using recyclable building materials, considering green carbon sinks, have different carbon reduction benefits.

The carbon emissions of green buildings of various star grades show a decreasing trend from north to south; the non - heating energy consumption indicators of the vast majority of star green buildings meet the national standard limit requirements; Increasing renewable energy has a significant carbon reduction effect on the operational stages of various regions.

For the northern regions, increasing renewable energy and improving the performance of envelop have the best carbon reduction effect on residential building operations, and the potential for sustainable development is more prominent; For residential buildings in the south, priority can be given to improving the performance of renewable energy and HVAC equipment. Different sustainable development strategies can be considered for different regions to achieve maximum carbon reduction benefits.

(2) The embodied emissions in the southern region are lower than those in the northern region, and the embodied emissions in every region are lower than the national average. The carbon reduction of recyclable materials can reach 22~48 kgCO2/m2, and shows an increasing trend from north to south.

(3) For different regions, the trend of total carbon emissions from green buildings of the same star grade is SC > C > HC > HW > W. The total amount gradually decreases, and the carbon reduction ratio shows SC < C < HC < HW < W. The trend of emission reduction rate increases, indicating that the higher the star grade of green buildings, the greater the impact of the

comprehensive carbon reduction effect; At the same time, the overall carbon emissions level of high-rise residential buildings is lower than that of multi-story buildings, and optimizing building design can to some extent optimize and affect carbon emissions levels, promoting sustainable development of residential buildings.

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