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Molecular & Cellular Biomechanics 2024, 21(3), 510.
https://doi.org/10.62617/mcb510

Article

On account of "double carbon" targeted regional public buildings in Beijing—Research on carbon emission measurement

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CITATION

Zhang L, Lin M, Liu T, et al. On account of "double carbon" targeted regional public buildings in Beijing—Research on carbon emission measurement. Molecular & Cellular Biomechanics. 2024; 21(3): 510. https://doi.org/10.62617/mcb510

ARTICLE INFO

Received: 12 October 2024
Accepted: 1 November 2024
Available online: 25 November 2024

Abstract: Energy conservation and carbon reduction in the construction field is an important part of China's dual-carbon strategy. And construction operation Carbon emissions during the period. It is also the stage where carbon emissions account for the largest proportion of the whole life cycle of buildings, among which. The carbon emissions per unit area of public buildings are twice that of civil buildings. This study takes the sub-center of Beijing City as an example, focusing on "double carbon". Under the goal, the research on the measurement of carbon emissions of public buildings within a radius of about 812 square kilometers in the sub-center, from the perspective of urban construction development and the overall carbon emissions of regional-level buildings, on the basis of the research on the actual operation data of urban buildings, the bottom-up carbon emission measurement method of the sub-center has been established, combined with research data analysis, during the operation period, the carbon emissions per unit area of public buildings are twice that of civil buildings. This finding highlights the key role of public buildings in the stage with the largest carbon emissions in the entire life cycle of buildings. In addition, our study also puts forward the characteristics and suggestions of carbon emission reduction of public buildings in the sub-center area, which are instructive for formulating targeted work suggestions on the "dual carbon" goals of urban development. This study not only focuses on the carbon emission measurement of individual buildings, but also expands the perspective to urban construction development and regional levels, filling the gap in the overall research on regional building carbon emission measurement in existing research. It also combines the latest building energy-saving design standards and green building ratings to conduct detailed measurement and analysis of the carbon emission levels of buildings with different energy-saving design standards.

Keywords: double carbon target; regional level; carbon emission measurement

1. Introduction

"Carbon reaches the peak" Carbon neutrality (Hereinafter referred to as "double carbon" Goal) is an important strategic deployment put forward by the 20th National Congress of the Communist Party of China and an inherent requirement to promote China's high-quality development [1]. China's carbon emissions mainly come from the five major sectors of energy, industry, transportation, construction, agriculture and land use [2]. According to the 2022 China Construction Energy Consumption and Carbon Emissions Research Report, carbon emissions in the whole life cycle of buildings account for 50.9% of the national carbon emissions. Relevant studies show that in Production and construction of building materials. Build, Construction operation, building demolition Equal. In the life cycle of the building, the operation of the building. During this period, carbon emissions accounted for about the 60% of total emissions, the reduction of building carbon emissions in China. Reducing carbon emissions from buildings is crucial to achieve its “double carbon” goal for China [3].

Shang Chunjing, Zhang Zhihui and other scholars divided the carbon emissions in the construction sector into direct and indirect categories, and measured the impact of the construction industry on other industries’ carbon emissions by constructing relevant carbon emission coefficients [4]. Yuan Qingmin and others also used input-output tables to conduct an empirical study on the carbon emissions of 26 industries in Beijing, Tianjin and Hebei, and concluded that there is a carbon correlation between industries. Ji Junping (2007) used the input-output method (LCA) to study and compare the carbon emissions of different industries.

Carbon emission calculation is an important basis for “double carbon” work. An important foundation of work. At present, the calculation and statistical caliber and statistical methods of building carbon emissions are still not unified. Experts and scholars at home and abroad generally conduct quantitative analysis of the factors affecting carbon emissions from the micro (building structure) and macro levels (urbanization rate, energy consumption structure, economic development, population, etc.). Under the framework of the emission coefficient method, the carbon emission intensity of the construction area and the unit building area is used to calculate from the bottom up [5,6]. Carbon emissions in the field of urban construction. This kind of research focuses on building monomers and a variety of different energy types and building types. Whole life cycle or specific stage. Carbon dioxide emissions. Examine and calculate, lack of consideration for the development of urban construction and the overall study of building carbon emission measurement at the regional level, so as to put forward targeted urban development “double carbon” Target work suggestions.

Beijing City Vice Center (Referred to as Deputy Center) located in the eastern part of Beijing, the regional area is about 812 square km. In recent years, the construction of the region has entered its peak, with an annual investment of hundreds of billions, many key projects and large energy consumption. In particular, a large number of public buildings represented by the three major cultural buildings have been put into use one after another. The construction scale of public buildings in the sub-center has shown a significant increase. Research shows that the carbon emissions per unit area of public buildings are twice that of civil buildings, in “double carbon”. In the context, Launch Deputy center Public Construct [7]. The research on carbon emission measurement is of great practical significance.

2. Establishment of building carbon emission measurement methods

2.1. Delineation of carbon emission calculation interface

General Specification for Energy Conservation and Renewable Energy Utilization in Buildings (GB5501)5-2021) It is required to calculate carbon emissions in newly built, expanded and renovated buildings, which plays a constraining role. Greenhouse Gas Emission Accounting Methods and Reporting Guidelines for Public Buildings Operating Enterprises (Trial Implementation) (Development and Reform Office Climate [2015] No. 1722) is the ecological environment system building carbon emission accounting system, which is biased towards guiding the use of buildings. It implements low-carbon operation and maintenance management for buildings, so it only involves the operation stage and only accounts for CO_2. At present, the carbon emission measurement method in the field of bottom-up construction is relatively mature, that is, it is calculated according to the construction area in the administrative area, the energy consumption intensity of buildings and the carbon emission factors of different types of energy. The boundary is the construction operation stage, and the calculated greenhouse gas is only carbon dioxide. The process is as shown in **Figure 1**.

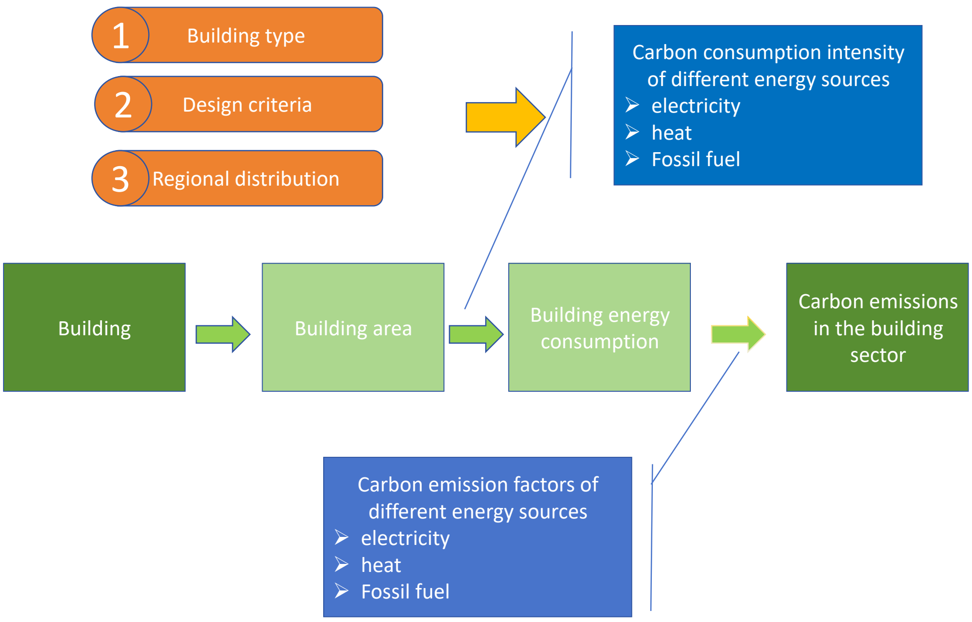

Figure 1. Bottom-up carbon emission measurement process in the construction field.

2.2. Measurement methods of carbon emissions

In the actual research, affected by factors such as building type, implemented energy-saving design standards and regional distribution, the energy consumption intensity of buildings varies greatly [8–12]. Therefore, in order to improve the accuracy of measurement results, part from the above three dimensions Deputy center. The building is further subdivided.

In the building type Respect, refer to the building classification of Beijing's large-scale public building energy consumption management platform, in order to Deputy center Based on the building classification of the annual report of housing verification and statistics, Bring Deputy center public buildings. The building types required for carbon emission accounting of the public buildings of the sub-center are subdivided into office, commercial, education, culture, sports, medical and other types.

In terms of design standards, according to the country and Beijing. The development process of regional building energy-saving design standards subdivides public buildings into ten types of buildings, including non-energy-saving, 50% energy-saving, 65% energy-saving, 72% energy-saving, one-star green buildings, two-star green buildings, three-star green buildings, ultra-low energy-consuming buildings, near-zero energy-consuming buildings, and zero-carbon buildings.

By working with energy supply companies, we can obtain energy bills and consumption records of public buildings. These data usually include the amount of energy consumed and the time of consumption, and can provide accurate energy consumption values. Energy consumption data provided by property management companies, which may include consumption records of multiple energy sources such as water, electricity, and gas. Access the energy consumption management system of property management companies to collect energy consumption data of public buildings. These data may not be as comprehensive as the data of energy supply companies, but they can provide more extensive information on building energy consumption. Energy consumption data are directly extracted through the platform's database, and these data are usually standardized for easy comparison and analysis. For buildings where data cannot be obtained through the above channels, the research team conducts on-site surveys and measurements, including the use of energy consumption monitoring equipment to directly measure the energy consumption of buildings. The data obtained from different sources are integrated and cross-checked to ensure the consistency and accuracy of the data. In the case of missing or abnormal data, data interpolation is performed through statistical analysis methods.

In terms of regional distribution, it is different from residential buildings. The energy consumption of public buildings is greatly affected by the business type, and the business type of the building is closely related to the services it provides. Considering that the service volume of public buildings in areas with high population density is relatively large, the regional distribution of public buildings will have an impact on their energy consumption level. Therefore, when measuring carbon emissions in the field of sub-center buildings, it is also appropriate to classify the regional distribution of public buildings, that is, divide public buildings into core areas and expansion areas according to the controlled detailed planning of sub-centers.

According to the classification of the above building types, the bottom-up carbon emission measurement method in the sub-central building field is finally established. The calculation formula is shown in Equation (1):

$$C_{Architechtural\ field} = \sum_{h=1}^{n}\sum_{k=1}^{n}\sum_{j=1}^{n}\sum_{i=1}^{n}(A_{h,k,j} \times E_{h,k,j,i} \times EF_i) \qquad (1)$$

In the Equation:

$C_{Architectural\ field}$ is carbon emissions in the construction field, and the unit is tons of carbon dioxide ($t\ CO_2$);

H is the regional distribution of the building;

K is the energy-saving design standard implemented by the building;

J is the type of building;

$A_{h,k,j}$ is the construction area of the *j*-class building in the *h* area that implements the *k*-class building energy-saving design standard, and the unit is square meters (m^2);

I is the type of fossil fuel, including electricity, heat, natural gas and liquefied petroleum gas;

$E_{h,k,j,i}$ is the energy consumption of type *i* of type *j* buildings in the implementation of the *k*-class building energy-saving design standard in the *h* area;

EF_i is the activity factor of the first type of fossil fuels.

3. Research and analysis of the energy consumption intensity of public buildings

According to the current situation of energy management of the sub-center building, through three ways Public Conduct research on the energy consumption intensity of buildings. First, the energy supply company has accurate data. High degree, but Difficulty of obtaining Compare Big. The second is the property management company. Data acquisition is relatively easy, but the data is not very complete. The third is the energy consumption management platform of large-scale public buildings, which can obtain the electricity consumption data of large-scale public buildings.

3.1. Analysis of power consumption intensity

This survey Follow Deputy center Stop Incorporated into the energy consumption management platform of public buildings in Beijing. In the public building, remove the same owner and data abnormalities, and select a total of 202 sample data, among which the sample size of different types of buildings is shown in **Figure 2**.

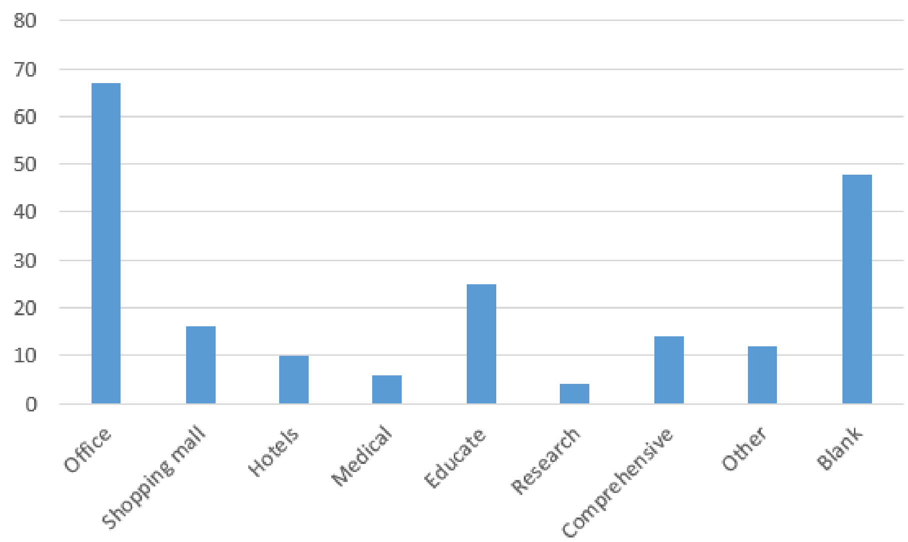

Figure 2. The number of samples of different types of public buildings.

Compare the research results with the electricity consumption data of public buildings released by the Beijing Energy Conservation and Environmental Protection Center, the Shanghai Municipal Housing and Construction Commission and the Beijing Large Public Building Energy Consumption Management Platform. The results are shown in **Figure 3**. It can be seen from the figure that although the power consumption intensity of different types of public buildings is different due to factors such as age and region, the order of power consumption intensity is basically the same from high to low, which is medical, shopping mall, office and education. The energy consumption management platform and research data of large-scale public buildings in Beijing show that the power consumption intensity of educational buildings is higher than that of office buildings. The main reason is that with the large-scale construction of sub-centers, although some large-scale public buildings are included in the management of the platform, the occupancy rate is not high because it has just been built, so the power consumption intensity is low.

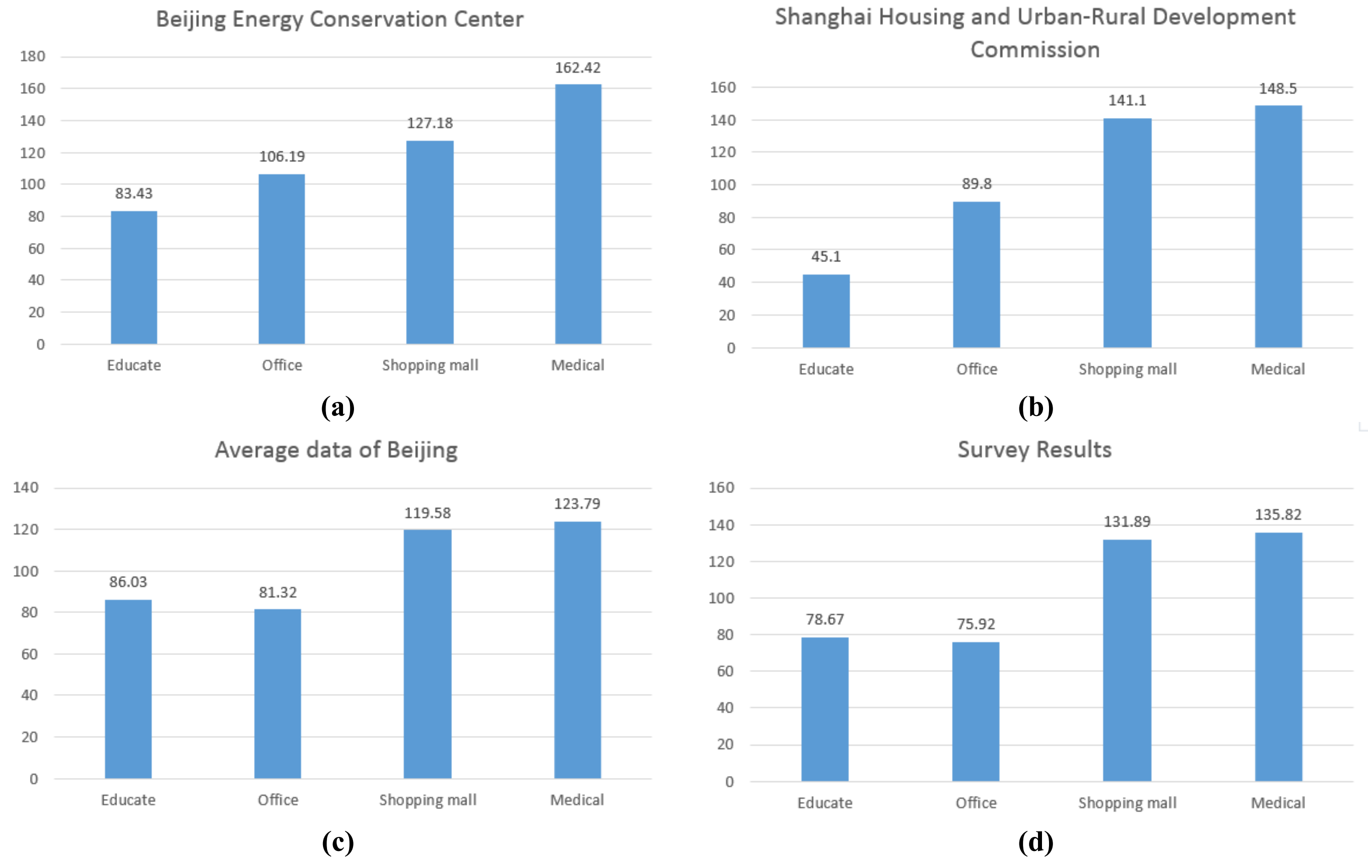

Figure 3. Comparison of power consumption intensity: **(a)** Beijing Energy Conservation Center; **(b)** Shanghai Housing and Urban-Rural Development Commission; **(c)** average data of Beijing; **(d)** survey results.

The data on electricity consumption of public buildings in Shanghai are relatively consistent, but there are slight differences. Data from the Shanghai Municipal Housing and Construction Commission show that the electricity intensity of educational buildings is slightly lower than that of office buildings, which may be related to the more advanced energy-saving measures of educational buildings in Shanghai. In addition, compared with Guangzhou, the electricity intensity of commercial buildings in Beijing's sub-city center is lower, which may be related to the more intensive commercial activities in Guangzhou and the higher frequency of air conditioning use caused by climatic conditions.

The electricity consumption characteristics and functional requirements of different types of public buildings lead to differences in energy consumption intensity. For example, medical buildings have the highest electricity consumption intensity due to their 24-hour operation characteristics and high demand for medical equipment, life support systems, and continuous lighting. In contrast, office buildings have lower energy consumption during non-working hours, but their energy consumption intensity is higher during peak hours on weekdays. Shopping malls also show high electricity consumption intensity due to long business hours and high-load operation of lighting and air-conditioning systems. The electricity consumption intensity of educational buildings is affected by specific functional areas such as teaching activities, laboratory equipment use, and libraries. Through the analysis of data from the Beijing Public Building Energy Consumption Management Platform, we found that although the occupancy rate of new buildings is not high, their design and construction standards tend to be more energy-efficient, which may reduce the overall electricity consumption intensity in the future.

3.2. Analysis of heat consumption intensity

This survey involves obtaining thermal data of five types of buildings from the heat supply company. For Deputy center public buildings, although the information of the age of its construction has been further collected after the research, due to its Whether. The energy-saving transformation has been completed. The information is incomplete. Therefore, it was not analyzed by age, only its average heat consumption intensity was calculated, as shown in **Table 1**.

Table 1. Heat consumption intensity of public buildings.

Type of building		Heat consumption intensity (GJ/m^2)	Thermal consumption intensity (kgce/m^2)
Office building	Office-1	0.24	8.05
	Office-2	0.15	5.27
	Office-3	0.08	2.57
	Office-4	0.34	11.44
	Office-5	0.20	6.86
	Office-6	0.40	13.66
	Mean value	0.24	8.25
Commercial buildings	Business-1	0.18	6.17
	Business-2	0.29	9.99
	Business-3	0.23	7.97
	Business-4	0.09	3.11
	Mean value	0.16	5.47
Educational buildings	Education-1	0.17	5.87
	Education-2	0.23	8.00
	Education-3	0.20	6.68
	Education-4	0.26	8.73
	Mean value	0.20	6.71

Compared with other northern cities such as Tianjin, the heat consumption intensity of public buildings is lower, which may be related to the energy-saving measures taken in Beijing and the good insulation performance of buildings. Compared with southern cities such as Shenzhen, Beijing's heat consumption intensity is higher, which is mainly due to the fact that northern cities need more heating energy in winter.

Newer buildings may have more advanced insulation and energy-efficient windows, which reduces heat loss, while older buildings may not have undergone energy-saving retrofits, resulting in higher heat loss.

3.3. Analysis of gas consumption intensity

The study obtained gas data from gas supply companies from four types of public building construction. The gas data of building types, namely office, commercial, medical and educational buildings, are all used for cooking. The average gas consumption intensity is shown in **Table 2**.

Table 2. The average gas consumption intensity of different types of buildings.

Serial number	Type of building	Gas consumption intensity (m^3/m^2)
1	Office building	0.71
2	Commercial buildings	4.98
3	Educational buildings	1.76
4	Medical building	1.76

Differences in natural gas consumption intensity are primarily related to building use and cooking needs. Commercial buildings, especially those containing food services, have significantly higher natural gas consumption intensity than other types of public buildings. Natural gas consumption in educational and medical buildings is mainly used for heating and hot water supply, while natural gas consumption in office buildings is relatively low. Data from the Beijing Urban Sub-center show that commercial buildings have the highest natural gas consumption intensity, which is related to their high proportion of catering service functions. The relatively high intensity of natural gas consumption in educational and medical buildings may be related to their ongoing need for hot water and heating.

4. Analysis of the carbon emission level of public buildings in the sub-center

Based on the research and analysis of energy consumption, this study establishes the energy consumption intensity of buildings with different building types, different regional distributions, and different energy-saving design standards in the sub-center, among which some Principle Explain As follows:

(1) The power consumption of non-energy-saving buildings in public buildings is 20% higher than that of buildings that implement the 50% energy-saving design standard, mainly based on the Interim Measures for the Management of Electricity Consumption Limits for Public Buildings in Beijing (Beijing Construction Law [2020] No. 5), which stipulates that buildings with electricity consumption exceeding the limit of 20% are buildings that are not qualified for assessment.

(2) Considering the change of the vacancy rate of office buildings with the population of the sub-center, the intensity of electricity consumption after 2024 will be increased to the average of 81.32 kWh/m^2 in Beijing. 2024 is chosen because the second batch of public institutions can be relocated to the sub-center at the end of 2023, and the inter-time population size basically reaches to the peak.

(3) Cooking is rarely involved in cultural and sports architecture, and the gas heating part is included in the statistics of thermal consumption, so its gas consumption is zero.

According to the existing building carbon emission measurement method of the sub-center built, the benchmark values of different types of building carbon emissions have been measured. After that, based on the carbon emission level of buildings with the highest energy-saving standard, combined with the carbon reduction benefits of green buildings, ultra-low energy consumption buildings and near-zero energy consumption buildings (**Table 3**), calculated different types of sub-centers Public. The carbon emission level of buildings, as shown in **Tables 4–7**. The carbon emission factors of electricity, heat and gas are 0.604 t CO_2/MWh, 0.11 *t* CO_2/GJ, 55.54 *t* CO_2/TJ, the low heat of gas is 389.31 GJ/10000 Nm^3.

Table 3. Summary table of carbon reduction benefits.

Building category	Technical system	Carbon reduction benefits
Residential buildings	One-star green building	The whole life cycle of buildings can reach about 10%–12%.
	Green building two-star	The full life cycle of buildings can reach about 18%–26%.
	Green building three-star	The full life cycle of buildings can reach about 26%–37%.
	Ultra-low energy consumption buildings	The full life cycle of buildings can reach more than 35%.
	Buildings with near-zero energy consumption	The full life cycle of buildings can reach more than 40%.
Public buildings	One-star green building	The whole life cycle of buildings can reach about 9%–14%.
	Green building two-star	The full life cycle of buildings can reach about 24%–27%
	Green building three-star	The whole life cycle of buildings can reach about 36%–45%.
	Ultra-low energy consumption buildings	The whole life cycle of buildings can reach more than 30%.
	Buildings with near-zero energy consumption	The full life cycle of buildings can reach more than 35%.

Table 4. Carbon emission intensity of sub-central office buildings.

Regional distribution	Energy-saving standards	Carbon emission intensity (kgCO_2/M^2)	
		Before 2024	After 2024
Core area	Not energy-saving	137.1900	141.1058
	50 percent	87.7042	90.9673
	65 percent	75.6097	78.8728
	72 percent	69.9656	70.8098
	One-star green building	63.8086	64.5785
	Two-star green building	57.6516	58.3473
	Three-star green building	52.3342	52.9657
	Ultra-low energy consumption buildings	50.3752	50.9831
	Buildings with near-zero energy consumption	47.5766	48.1507
	Zero-carbon construction	0.0000	0.0000
Expansion area	Not energy-saving	134.4387	138.1587
	50 percent	85.4115	88.5114
	65 percent	73.3170	76.4169
	72 percent	67.6729	68.3539
	One-star green building	61.7176	62.3388
	Two-star green building	55.7624	56.3236
	Three-star green building	50.6193	51.1287
	Ultra-low energy consumption buildings	48.7245	49.2148
	Buildings with near-zero energy consumption	46.0175	46.4807
	Zero-carbon construction	0.0000	0.0000

Table 5. Carbon emission intensity of sub-center commercial buildings.

Regional distribution	**Energy-saving standards**	**Carbon emission intensity (kgCO_2/M^2)**
Core area	Not energy-saving	186.9906
	50 percent	130.7433
	65 percent	118.6488
	72 percent	113.0047
	One-star green building	103.0603
	Two-star green building	93.1159
	Three-star green building	84.5275
	Ultra-low energy consumption buildings	81.3634
	Buildings with near-zero energy consumption	76.8432
	Zero-carbon construction	0.0000
Expansion area	Not energy-saving	139.1937
	50 percent	90.9125
	65 percent	78.8180
	72 percent	73.1739
	One-star green building	66.7346
	Two-star green building	60.2953
	Three-star green building	54.7341
	Ultra-low energy consumption buildings	52.6852
	Buildings with near-zero energy consumption	49.7583
	Zero-carbon construction	0.0000

Table 6. Carbon emission intensity of sub-center education buildings.

Regional distribution	**Energy-saving standards**	**Carbon emission intensity (kgCO_2/M^2)**
Core area	Not energy-saving	141.4580
	50 percent	91.6392
	65 percent	79.5447
	72 percent	73.9006
	One-star green building	67.3973
	Two-star green building	60.8941
	Three-star green building	55.2776
	Ultra-low energy consumption buildings	53.2084
	Buildings with near-zero energy consumption	50.2524
	Zero-carbon construction	0.0000
Expansion area	Not energy-saving	138.6069
	50 percent	89.2632
	65 percent	77.1687
	72 percent	71.5246
	One-star green building	65.2305
	Two-star green building	58.9363
	Three-star green building	53.5004
	Ultra-low energy consumption buildings	51.4977
	Buildings with near-zero energy consumption	48.6368
	Zero-carbon construction	0.0000

Table 7. Carbon emission intensity of sub-center medical buildings.

Regional distribution	**Energy-saving standards**	**Carbon emission intensity (kgCO$_2$/M^2)**
Core area	Not energy-saving	182.8769
	50 percent	126.1549
	65 percent	114.0604
	72 percent	108.4163
	One-star green building	98.8757
	Two-star green building	89.3351
	Three-star green building	81.0954
	Ultra-low energy consumption buildings	78.0598
	Buildings with near-zero energy consumption	73.7231
	Zero-carbon construction	0.0000
Expansion area	Not energy-saving	133.6560
	50 percent	85.1375
	65 percent	73.0430
	72 percent	67.3989
	One-star green building	61.4678
	Two-star green building	55.5367
	Three-star green building	50.4144
	Ultra-low energy consumption buildings	48.5272
	Buildings with near-zero energy consumption	45.8313
	Zero-carbon construction	0.0000

This study measures and analyzes the carbon emissions of public buildings in Beijing's sub-city center, which may not fully represent the carbon emissions of public buildings in other cities or regions, limiting the general applicability of the research results. In particular, it is difficult to obtain data on building energy-saving renovation and operation, which may affect the accuracy of carbon emission calculations. In addition, some data may not fully reflect the latest building operations.

In the future, it is necessary to strengthen cooperation with government departments, energy supply companies, and property management companies to obtain more comprehensive and updated building energy consumption data to improve the accuracy and timeliness of the research. Optimize the existing carbon emission calculation model and verify it in other regions to improve the applicability of the model. Compare and analyze the carbon emissions of public buildings in different cities or regions to enhance the representativeness and universality of the research results.

5. Conclusion

(1) The research results show that, for commercial buildings, the power consumption intensity in 2017 was 101.05 kWh/(m^{2}a) is lower than 140.98 kWh/(m^{2}a) in 2007, while the opposite is true for office buildings. Its power consumption intensity of 82.59 kWh/(m^{2}a) in 2017 is higher than 74 in 2007. 82 kWh/(m^{2}a). Based on this, it can be determined that the "Energy-saving Design Standards for Public Buildings"

(GB 50189-2015) has little impact on the power consumption intensity of public buildings. The main reason is that public buildings have certain economic capacity, and they often carry out energy-saving transformations according to their own energy consumption, such as replacing lighting and empty Adjusting equipment, etc. In addition, the management policy of public energy consumption buildings implemented by Beijing is also one of the reasons for promoting the continuous transformation, repair and upgrading of public buildings.

(2) From the perspective of regional distribution, the core area and the expansion area Overall construction scale. The difference is not big, but the carbon emissions in the expansion area Obvious Higher than the core area, which is mainly caused by the high carbon emission intensity of buildings. Although the core area has a large population density, more high-rise buildings, and the public buildings provide a large amount of services, the high green and low-carbon level of buildings in the core area leads to the peripherals of the same construction volume Expansion area High carbon emissions.

(3) From the perspective of the green low-carbon level of buildings, the green low-carbon level of public buildings is relatively high, with the proportion of green buildings reaching 27.77%. The total carbon emissions of non-energy-saving buildings are only 105,700 tons, accounting for 7.56% of the total carbon emissions of public buildings. Considering the current implementation of 50% energy-saving design standards. The volume of public buildings is large, so it is appropriate to promote the transformation and upgrading of this kind of buildings with reference to green buildings in the future.

(4) Energy conservation and carbon reduction in the construction operation stage is the focus of implementing the dual-carbon strategic goal in the construction field. Follow Public Looking at the field of construction carbon emissions. Mainly focus on lighting, terminal electricity, Heating and cooling Aspects, Electricity and heat are the two aspects that cause the largest carbon emissions, and relevant carbon reduction technologies also need to be focused on.

(5) Operation of public buildings Stage, Strengthen the measurement, detection and intelligent management of building carbon emissions, encourage government-invested buildings to give priority to green property management, reduce operating energy consumption through scientific management, and maximize resource conservation and environmental protection. Projects of government-invested public buildings with a scale of more than 3000 square meters need to be included in the basic information verification and energy consumption information platform of Beijing public buildings for management.

Author contributions: Conceptualization, LZ; methodology, LZ and TL; validation, LZ, FZ and HL; investigation, ML; resources, LZ; data curation, LZ; writing—original draft preparation, LZ; writing—review and editing, LZ; funding acquisition, LZ. All authors have read and agreed to the published version of the manuscript.

Funding: 1) Research on the Reconstruction of Modular Course System Based on BIM Certification Level Standards in Higher Vocational Colleges (Project No.: 2020Z183-SXZ); 2) Research on energy saving system of air flow organization optimization in 3D visualization data center based on CFD (Project No.: 2023X007-KXZ).

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

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