BIPV Generation Efficiency Optimal Scheme—— Take Jiangning District of Nanjing City for Example

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Abstract. Building Integrated photovoltaic (BIPV) is more and more applied to the construction field with its advantages of being close to the load center, saving urban land and building materials. Especially under the current goal of 'carbon peak' and 'carbon neutrality', the integration of photovoltaic buildings is one of the important ways to achieve the effective application of renewable energy in buildings. But at present, the lack of relevant application cases of the technology, many owners interested in BIPV have remained on the sidelines. This paper mainly focuses on the economic and environmental benefit evaluation of the roof and curtain wall system of BIPV. By comparing the economic benefits and investment payback period, the owners provide the optimal investment plan, and analyzes the significance of 'two-carbon policy' by calculating the environmental benefits of BIPV. In this paper, Jiangning District of Nanjing city is taken as the pilot object to analyze the benefit of BIPV, and proposed the optimal design strategy of building photovoltaic integration suitable for this area through the benefit comparison of different schemes. In the roof and curtain wall benefit evaluation when we use the photovoltaic garden analysis site for solar radiation estimates, and then get the whole life cycle of photovoltaic system capacity, as the basis of economic benefit evaluation, then through the query related data to save the total coal as the basis of environmental benefit evaluation, combined with the project investment payback period, economic benefits and environmental benefits of comprehensive evaluation of the final plan. Through the above economic benefits and environmental benefits data comparison, photovoltaic roof has more investment value than photovoltaic curtain wall in both economic and environmental aspects. Taking Jiangning District of Nanjing city as an example, this paper illustrates the broad prospect of BIPV, and also provides a relatively clear data support and case reference for the promotion of BIPV nationwide in the future.

Keywords: BIPV; green building; carbon neutral.

1. Introduction

1.1. Macro background

During the 14th Five-Year Plan period, China's ecological civilization construction has entered a critical period of taking carbon reduction as the key strategic direction, promoting pollution reduction and synergistic reduction, promoting the comprehensive green transformation of economic and social development, and realizing the improvement of ecological environment quality from quantitative to qualitative change.

Under the carbon reduction target of tight time, coal and other fossil fuels as one of the main sources of carbon emissions in China, reducing China's carbon emissions should start with reducing the emissions of fossil fuels. By 2021, coal will account for 56% of China's total energy consumption, and the proportion of non-fossil energy consumption will increase to about 16.6% [1]. In 2021, global energy-related CARBON dioxide emissions reached 36.3 billion tons, of which China's carbon dioxide emissions exceeded 11.9 billion tons, accounting for 33% of the global total (see Figure 1) [2].

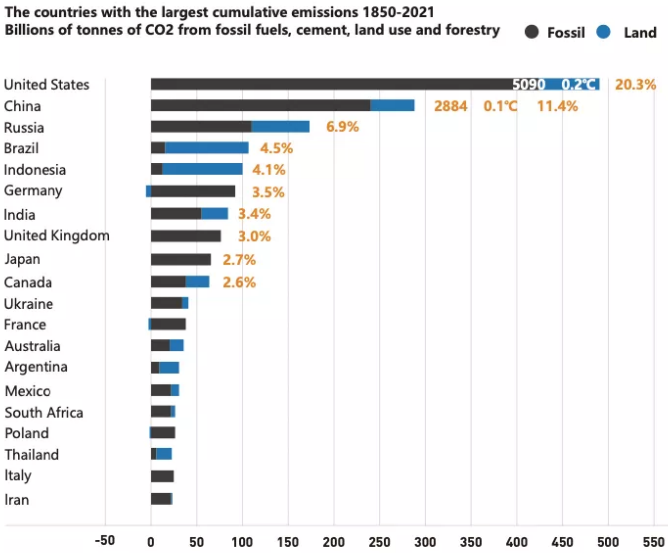


Figure 1 Countries with the largest global carbon emissions from 1850 to 2021

Construction is one of the three 'giants' of energy consumption in China. At present, China's construction area is about 67.1 billion square meters, with an annual growth rate of 2 billion square meters. The energy consumption of building operation accounts for about 22% of the total society's energy consumption. To achieve energy replacement in buildings, the promotion of zero-energy buildings is crucial to achieve the 'double-carbon' goal on schedule. At present, the application of new power generation building materials in buildings, making it itself into a 'power plant' to achieve 'zero energy consumption', reducing carbon emission is the direction of the development of the construction industry [3]. Photovoltaic building integration (BIPV, Building Integrated Photovoltaic) combines photovoltaic components and buildings, and makes full use of the surface space of buildings for power generation, which has great development prospects. The Notice on Reporting the Pilot Scheme of Distributed PHOTOVOLTAIC Development in the Whole County of [4] meets the standard of the Development of Housing and Urban-Rural Development jointly issued the Opinions on reducing the proportion of traditional fossil energy in terms of new factories and public buildings and implementing the integrated development of photovoltaic buildings. At present, Beijing, Tianjin, Shanghai, Chongqing, Inner Mongolia, Zhejiang and other places have issued the integration of photovoltaic buildings (BIPV) in the next 3 to 5 years,; on March 23,2021, Nanjing issued the notice of Nanjing Green Building Demonstration Projects, clarifying the guiding funds of green building demonstration projects for the city, so as to vigorously support the development of green building, and further research and develop BIPV technology and promote it.

From the national to the local, the integration of photovoltaic buildings is rising. With the encouragement of 'photovoltaic +' and other policies, the integration of photovoltaic buildings will usher in an era of vigorous development. BIPV was first proposed by the World Energy Organization in 1986[5][6]. Compared with BIPV technology applied in Europe and America,China started relatively later, but it has entered a period of rapid development with the support of relevant national policies.

2. Planning ideas

Before quantitative analysis, we proposed three schemes for photovoltaic module installation:

Plan 1: Give priority to putting the existing budget into photovoltaic roof projects (when the economic and environmental benefits of photovoltaic roof are better than those of photovoltaic curtain wall)

Plan 2: Give priority to putting the existing budget into photovoltaic curtain wall projects (when the economic and environmental benefits of photovoltaic curtain wall are better than those of photovoltaic roof)

Plan 3: The budget is divided into two parts:one part for building pv-roof, another part for building pv-curtain wall (divided into two situations: the economic benefit of the pv-roof is better than that of pv-curtain and environmental benefit is inferior to pv-curtain;pv-curtain's economic benefit is better than that of pv-roof and environmental benefit is inferior to the pv-roof.Combining both to achieve the highest economic and environmental comprehensive benefit.)

In the roof and curtain wall benefit evaluation,we use photovoltaic garden analysis site for solar radiation estimates, and then get the whole life cycle of photovoltaic system capacity as the basis of economic benefit evaluation, then through the query related data to save the total coal as the basis of environmental benefit evaluation, combined with the project investment payback period, economic benefits and environmental benefits of comprehensive evaluation of the final plan.

3. Advantages and requirements analysis of BIPV

3.1. Advantages of the BIPV

①Economic cost

During the '13th Five-Year' period, the cost of BIPV (materials and labor) decreased by 90%, and the cost is expected to reduce the cost of BIPV to 2.5 ￥/ W, with the economic conditions for comprehensive promotion. At the same time, in terms of the overall economic cost, the material cost of BIPV system is lower than BAPV. In terms of comprehensive cost, BIPV can save ￥164 per square meter. Compared with ordinary photovoltaic power station, it saves the cost of land, infrastructure and some building materials, and has high economy, see Table 1.

Table 1 Comparison of BAPV and BIPV

Contrast item	BAPV system	BIPV system
Aluminum magnesium manganese house panel	Includes vertical locking edge aluminum magnesium manganese roof panel and aluminum alloy T-shaped support,around ￥200/m^2	/
System bracket accessories	Including fixtures, guide rails, fixings, etc., about ￥0.3/W×120W/m^2=￥36	Including supporting light steel purlin, aluminum alloy pressing strip, rubber sealing strip, fixings, etc., about￥0.6/W×120W/m^2= ￥72
Photovoltaic power generation module unit panel	Includes photovoltaic panels and aluminum alloy frames: 120W/m^2×￥2.8/W=￥336	Includes photovoltaic panels and aluminum alloy frames, around 120W/m^2×￥2.8/W=￥336
Comprehensive cost (material price)	Aluminum magnesium manganese house panel, system bracket accessories, photovoltaic power generation module unit panel in total: ￥572/m^2	System bracket accessories, photovoltaic power generation module unit board in total: ￥408/m^2
conclusion	The integrated roof system can save materials ￥164/m^2	

②Life cycle

Traditional photovoltaic power generation modules are in the open environment, the life is generally no more than 25 years. BIPV photovoltaic power generation module only expose the roof and have a good sealing environment; use PVB as module packaging adhesive, with good heat

resistance, cold resistance and humidity resistance; select photovoltaic special wire (double cross-layer polyethylene tin-soaked copper wire), large wire diameter, and excellent connector and other equipment, so as to extend the life, can reach 50 years and above [7].

③ Architectural appearance

It installs photovoltaic modules simultaneously in the building to ensuring the hidden design of junction box and cable; unit panels and maintenance walkways of photovoltaic modules are directly used as roof panels, using aesthetic knowledge[8] to integrate architecture and aesthetics.

④Roof force

BAPV photovoltaic power generation roof pressing metal plate and photovoltaic panels have a more complex force situation, the wind load force will make it produce fatigue effect,which will affect the safety,while BIPV is convenient, high safety, using double-sided tempered glass with suitable thickness to ensure safety.

⑤Waterproof performance

After the BAPV roof is installed, the pressed metal plate roof will be installed. There are hidden dangers of water leakage caused by the lifting, trampling or aluminum magnesium manganese plate settlement deformation, load, overload, etc., and it is difficult to repair, easy aging and other problems,while the roof system of BIPV adopts the hydrophobic glass panel, main sink, waterproof sealing and drainage system. The components are fixed and sealed with each other, the butt welding water coating edge, with anti-vibration system —— no perforated connection[9], reduce the hidden danger of water leakage.

⑥Construction difficulty

BAPV construction is divided into two phases, the cycle is long, and the construction of vertical lock edge aluminum magnesium manganese house panel is difficult,while BIPV is easier and faster.

⑦Roof operation

BIPV roof design installation modular module for single battery components, single disassembly and repair, easy maintenance; the roof is equipped with overhaul aisle pedal, not damaging the roof and component[10] during maintenance.

3.2. Demand analysis

According to the official energy data released by the National Bureau of Statistics, clean energy accounted for 25.5 percent of the total energy consumption in 2021, increasing 1.2 percent compared with last year. It can be seen that the whole country is promoting the popularization and further development and utilization of clean energy. As an important part of the development of clean energy, the photovoltaic industry has also been vigorously developed and supported.

Since the '13th Five-Year Plan', the rapid development of the photovoltaic industry and the reduction of the cost of the photovoltaic system have provided a huge endogenous power for the implementation of the building photovoltaic integration project. Under the premise of the same service life, although BIPV has large investment in the initial stage, in the later stage, the direct economic benefits mainly come from the cost saved by light energy generation instead of traditional energy consumption, the surplus power grid sales income and the government subsidy policy; the indirect economic benefits come from environmental protection and social economy.

Nowadays, the public life has been inseparable from electricity. Electricity is the basic energy for economic development, providing energy supply and power support for the development of various industries of the national economy. Electricity consumption is an important indicator for the country and the public to determine the level of regional economic growth, and is known as the 'thermometer' of national economic development. In the comparison of electricity consumption in the first half of 2022, the electricity consumption in Nanjing was 25.724 billion KWH, ranking the third and the fifth, and the industrial electricity consumption was 14.706 billion KWH, ranking the eighth in the province.

Nanjing is located in the middle and lower reaches of the Yangtze River. Ground span east longitude 116°18 'to 121°57', north latitude 30°45 'to 35°20', solar altitude Angle 34.53, annual average solar radiation is 4860 Mj / m (data from Su J28-2013); annual sunshine hours (absolute

sunshine) is 2000-2600h, sunshine percentage is 48-59%; annual total solar astronomical light emission 4600-5440 MJ / m, annual radiation energy per square meter is equal to 170 tons of standard coal. With the powerful conditions for the use of solar power generation and the implementation of photovoltaic power generation project[11].

At the end of 2021, the total installed photovoltaic capacity of Nanjing was 710,000 kW, accounting for 3.7% of the provincial photovoltaic capacity; although the annual photovoltaic power generation increased by 28.8% year on year, it only accounted for 3.1% of the province. Although Nanjing city has favorable conditions for the implementation of photovoltaic power generation, the total amount of photovoltaic power generation is low. This plan will take Jiangning District of Nanjing city as a pilot, and apply related cases in the construction area to compare the economic and environmental benefits, so as to put forward targeted planning plans.

4. Case introduction

The proposed building in this scheme is located in Jiangning District, Nanjing City, Jiangsu Province, with latitude and longitude conditions east longitude 118.83 and 31.95, and the total horizontal radiation of the location is 1300.2KWH/㎡. The building has 18 floors, with a total construction area of 737 ㎡ and a height of 57.8m. There is no other shelter near the building, and the sunshine condition is good. See Figure Figure 2 for specific details.

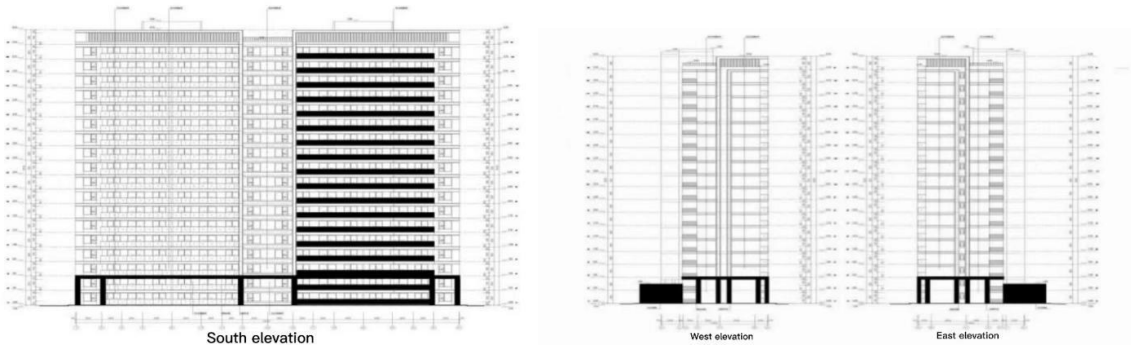


Figure 2 High-rise building model

By inquiring the relevant information of various types of performance photovoltaic modules, this design selects the monocrystalline silicon photovoltaic modules with YL450D-40d with the highest technical maturity, the most sufficient market conditions and high cost performance. Component data are shown in Table 2.

For the photovoltaic installation of the roof part, this scheme selects the optimal irradiation Angle of the project site to lay the roof plane, and a total of 85 modules were installed. For the photovoltaic installation of the curtain wall[12][13], the plan is to install the photovoltaic curtain wall on the south and east and west facades of the building. The inclination of photovoltaic curtain wall is 90. The specific design is as follows: the curtain wall of the south facade is 52.94m, 52.35m in width, 80cm away from the ground, and 1275 components; the east and west facades are 46.71m and 10.94m wide, and the two facades have 450 components.

Table 2 Parameters of photovoltaic modules

Basic parameter	peak power	450W
	Power tolerance	0/+5
	component efficiency	20.70%
	Maximum system voltage	1000VDC/1500VDC
	Maximum fuse rating	20A
	working temperature	40℃~85℃
	Size (length, width, height)	2094MM/1038MM/35MM
	weight; scale; heft; avoirdupois; ponderance	20.35Kg

5. Evaluation of the economic and environmental benefit

5.1. Power generation calculation of the roof and curtain wall

Now, the research and application of BIPV photovoltaic roof are relatively mature.The following economic and environmental benefit analysis based on roof is used to the photovoltaic park revenue analysis website.Input the corresponding parameters in accordance with the requirements,the photovoltaic system cost in accordance with the international energy network/photovoltaic headlines (PV-2005) in May (may for photovoltaic clinch a deal intensive month) large EPC price(4￥/ w) data, do not consider the operational cost,export the project configuration table (see table 3),select different kinds of photovoltaic module configuration scheme.

Table 3 Project Configuration Table

INV（kw）	Number of INV（stand）	Supporting components（w）	Total power（w）	Number of pv modules	Specific configuration
30	9	380	324900	855	Single inverter configuration: inverter power 30 kW, component model 380W, 5 access roads, each with 19 components, 95 components in total;the total capacity is 36100W and PV/inverter ratio is 1.20
30	9	420	340200	810	Single inverter configuration: inverter power 30 kW, component model 420W, 5 access roads, each with 18 components, 90 components in total;the total capacity is 37800W and PV/inverter ratio is 1.26
30	9	450	344250	765	Single inverter configuration: inverter power 30 kW, component model 450W, 5 access roads,

					each with 17 components, 85 components in total;the total capacity is 38250W and PV/inverter ratio is 1.27
30	9	460	331200	720	Single inverter configuration: inverter power 30 kW, component model 460W, 5 access roads, each with 16 components, 80 components in total;the total capacity is 36800W and PV/inverter ratio is 1.23
30	9	490	330750	675	Single inverter configuration: inverter power 30 kW, component model 490W, 5 access roads, each with 15 components, 75 components in total;the total capacity is 36750W and PV/inverter ratio is 1.23
30	9	500	337500	675	Single inverter configuration: inverter power 30 kW, component model 500W, 5 access roads, each with 15 components, 75 components in total;the total capacity is 37500W and

					PV/inverter ratio is 1.25
30	9	510	344250	675	Single inverter configuration: inverter power 30 kW, component model 510W, 5 access roads, each with 15 components, 75 components in total;the total capacity is 38250W and PV/inverter ratio is 1.27
30	9	530	324360	612	Single inverter configuration: inverter power 30 kW, component model 530W, 4 access roads, each with 17 components, 68 components in total;the total capacity is 36040W and PV/inverter ratio is 1.20
30	9	540	330480	612	Single inverter configuration: inverter power 30 kW, component model 540W, 4 access roads, each with 17 components, 68 components in total;the total capacity is 36720W and PV/inverter ratio is 1.22
30	9	550	336600	612	Single inverter configuration: inverter power 30 kW, component model 550W,

					4 access roads, each with 17 components, 68 components in total;the total capacity is 37400W and PV/inverter ratio is 1.25
17	1	380	20520	54	Single inverter configuration: inverter power 17 kW, component model 380W, 3 access roads, each with 18 components, 54 components in total;the total capacity is 20520W and PV/inverter ratio is 1.21
17	1	420	21420	51	Single inverter configuration: inverter power 17 kW, component model 420W, 3 access roads, each with 17 components, 51 components in total;the total capacity is 21420W and PV/inverter ratio is 1.26
17	1	450	21600	48	Single inverter configuration: inverter power 17 kW, component model 450W, 3 access roads, each with 16 components, 48 components in total;the total capacity is 21600W and

					PV/inverter ratio is 1.27
17	1	460	20700	45	Single inverter configuration: inverter power 17 kW, component model 460W, 3 access roads, each with 15 components, 45 components in total;the total capacity is 20700W and PV/inverter ratio is 1.22
17	1	490	20580	42	Single inverter configuration: inverter power 17 kW, component model 490W, 3 access roads, each with 14 components, 42 components in total;the total capacity is 20580W and PV/inverter ratio is 1.21

Roof selection of a single inverter configuration: inverter power of 30kW, Component Model # 450W, 5 roads, 17 pieces per circuit component, 85 components, The total capacity of 38250W, Capacity ratio is 1.27, After selecting all types of single inverter configurations for comparison, This configuration is the highest total generation of all scenarios, The solutions that benefit the most, The total installed capacity is 76,500 w; The curtain wall uses the website of the photovoltaic park to calculate the power generation of the photovoltaic curtain wall[14].Select single inverter configuration (selection process is the same as roof): inverter power 30kW, Component Model # 450W, 5 roads, 17 pieces per circuit component, 85 components, The total capacity of 38250W, Capacity ratio is 1.27, After selecting all types of single inverter configurations for comparison, This configuration is the highest total generation of all scenarios, The solutions that benefit the most, The total installed capacity of the south facade is 382,500 w, The total installed capacity of both the east and west facades is 38,250 w.

Table 4 Calculation of the average annual power generation of photovoltaic roof and curtain wall

Electricity generation calculation table		
age	Annual generating capacity of roof （10 thousand KWh）	Annual generating capacity of curtain wall （10thousand KWh）
1	8.777	21.0816
2	8.729	20.9656
3	8.680	20.8488
4	8.632	20.732
5	8.583	20.6156
6	8.535	20.4996
7	8.486	20.3968
8	8.438	20.266
9	8.389	20.1496
10	8.341	20.0328
11	8.292	19.9164
12	8.244	19.8
13	8.195	19.6836
14	8.147	19.5668
15	8.098	19.4504
16	8.049	19.334
17	8.001	19.2176
18	7.952	19.1008
19	7.904	18.9844
20	7.855	18.868
21	7.807	18.7508
22	7.758	18.6348
23	7.710	18.5184
24	7.661	18.402
25	7.613	18.2848
total	204.876	492.1012
Annual average of 25 years	8.195	19.684048

5.2. Economic benefit evaluation of roof and curtain wall

25 years of daily maintenance expenses= installed gross capacity ×Daily maintenance costs×25

The total installed capacity of the roof is 76.5kwp, the total installed capacity of the curtain wall is 459 kwp, and the daily maintenance cost is 8￥/ KW. After calculation, the daily maintenance cost of the roof for 25 years is ￥15300(combined in the net cash flow statement), and the daily maintenance cost of the 25 years of the curtain wall is ￥36720(combined in the net cash flow statement).

Total power generation benefit＝annual energy output ×（0.391＋0.1）×3＋annual energy output ×0.391×22

According to the relevant subsidy policy, the subsidy amount for the first three years is RMB 0.1 ￥/ kwh; the total power generation benefit of photovoltaic roof system is 825,646.25RMB. The analysis of the income of the system is to reduce the income of the system from the total daily

maintenance cost of the system and the total daily maintenance cost of the system. Compared with the installed capacity, the income of the economic benefits of the system can be obtained per watt. The revenue generated by photovoltaic roof system is about 10.6￥/WP; the total power generation benefit of photovoltaic curtain wall system is ￥1983168. From the revenue analysis of the system, the revenue generated by photovoltaic curtain wall system is about 4.12 ￥/ WP.

Table 5 Total net cash flow statement of rooftop BIPV investment

Age	Electricity sales revenue （￥10 thousand）	Cld （￥10 thousand）	Net cash flow（￥10 thousand）	Accumulative total of net cash flow （￥10 thousand）
1	4.309507	30.6	-26.290493	-26.290493
2	4.285939	0	4.285939	-22.004554
3	4.26188	0	4.26188	-17.742674
4	3.375112	0	3.375112	-14.367562
5	3.355953	0	3.355953	-11.011609
6	3.337185	0	3.337185	-7.674424
7	3.318026	0	3.318026	-4.356398
8	3.299258	0	3.299258	-1.05714
9	3.280099	0	3.280099	2.222959
10	3.261331	0	3.261331	5.48429
11	3.242172	0	3.242172	8.726462
12	3.223404	0	3.223404	11.949866
13	3.204245	0	3.204245	15.154111
14	3.185477	0	3.185477	18.339588
15	3.166318	0	3.166318	21.505906
16	3.147159	0	3.147159	24.653065
17	3.128391	0	3.128391	27.781456
18	3.109232	0	3.109232	30.890688
19	3.090464	0	3.090464	33.981152
20	3.071305	0	3.071305	37.052457
21	3.052537	0	3.052537	40.104994
22	3.033378	0	3.033378	43.138372
23	3.01461	0	3.01461	46.152982
24	2.995451	0	2.995451	49.148433
25	2.976683	0	2.976683	52.125116

Table 6 Total net cash flow statement of curtain wall BIPV investment

Age	Electricity sales revenue （￥10 thousand）	Cld （￥10 thousand）	Net cash flow（￥10 thousand）	accumulative total of net cash flow （￥10 thousand）
1	10.3510656	98.33508	-87.9840144	-87.9840144
2	10.2941096	0	10.2941096	-77.6899048
3	10.2367608	0	10.2367608	-67.453144
4	8.106212	0	8.106212	-59.346932
5	8.0606996	0	8.0606996	-51.2862324
6	8.0153436	0	8.0153436	-43.2708888
7	7.9751488	0	7.9751488	-35.29574
8	7.924006	0	7.924006	-27.371734
9	7.8784936	0	7.8784936	-19.4932404
10	7.8328248	0	7.8328248	-11.6604156
11	7.7873124	0	7.7873124	-3.8731032
12	7.7418	0	7.7418	3.8686968
13	7.6962876	0	7.6962876	11.5649844
14	7.6506188	0	7.6506188	19.2156032
15	7.6051064	0	7.6051064	26.8207096
16	7.559594	0	7.559594	34.3803036
17	7.5140816	0	7.5140816	41.8943852
18	7.4684128	0	7.4684128	49.362798
19	7.4229004	0	7.4229004	56.7856984
20	7.377388	0	7.377388	64.1630864
21	7.3315628	0	7.3315628	71.4946492
22	7.2862068	0	7.2862068	78.780856
23	7.2406944	0	7.2406944	86.0215504
24	7.195182	0	7.195182	93.2167324
25	7.1493568	0	7.1493568	100.3660892

The payback period of rooftop BIPV is the ninth year, and the payback period of curtain wall BIPV is the 12th year.

5.3. Evaluation of the environmental benefit of the roof and the curtain wall

According to the average coal consumption of thermal power supply in China is 325 grams of standard coal / kWh, about 665.847 tons of standard coal can be saved in the 25-year life cycle of photovoltaic roof, and about 1599.33 tons of standard coal can be saved in the 25-year life cycle of photovoltaic curtain wall.

Table 7 Calculation value of environmental benefits of photovoltaic system

	CO_2	SO_2	NO_2	Dust
Photovoltaic roof emission reduction/t	1152.58	14.65	6.66	11.32
Photovoltaic roof environmental benefits/t	26509.34	87900	53280	24904
Photovoltaic curtain wall emission reduction/t	2768.44	35.19	15.99	27.19
Photovoltaic curtain wall by environmental benefits/t	63674	211140	127920	59818

Taking the reference discount coefficient is 0.7143, the tons of raw coal saved in the life cycle of the photovoltaic system can be calculated. The price of raw coal takes the average price of raw coal of 4000 cards in China in August 2022 is 750 ￥/ ton, then:

Total environmental benefits of the system=Total emission reduction benefits+The value of saving resources

From the formula, the total environmental benefit that can be obtained from the photovoltaic roof system is 891,718.7RMB, and the environmental benefit generated by the photovoltaic roof system is about ￥11.66/Wp. The total environmental benefit of the photovoltaic curtain wall system is ￥1662,050, and the environmental benefit generated by the photovoltaic curtain wall system is about 3.62 ￥/ Wp.

Table 8 Comprehensive Comparison of the economic and environmental benefits

	Economic benefits （￥/wp）	Environmental benefit （￥/wp）	The total amount of raw coal saved（t）
Photovoltaic roof	10.6	11.66	665.847
Photovoltaic curtain wall	4.12	3.62	1599.33

6. Prospects

Table 9 Total solar radiation amount and average annual peak sunshine time in different regions [15]

District category	Annual radiation (Mj/miY)	Annual radiation (kWh/my)	Annual sunshine time (h/Y)	Average annual peak sunshine time(h)	Average daily peak sunshine time(h)
First class area	6680~8400	1855~2333	3200~3300	1854~2300	5.08~6.3
Second class area	5852~6680	1625~1855	3000~3200	1624~1854	4.45~5.08
Third class area	5016~5852	1393~1625	2200~3000	1387~1624	3.8~4.45
Forth class area	4190~5016	1163~1393	1400~2200	1132~1387	3.1~3.8
Fifth class area	3344~4190	928~1163	1000~1400	913~1132	2.5~3.1

As can be seen from the data in Table 7-1, the four regions of the pilot areas are in a relatively weak position compared with the total solar radiation and the average annual peak sunshine time in most regions of China. However, even if the pilot area is not very dominant in solar energy in the country, it can still create such considerable economic and environmental benefits, which further demonstrates the value and significance of promoting BIPV in sufficient sunshine areas and even the whole country. If the example of this study is extended to other regions, the following points:

Pay attention to the longitude and latitude of the area, the amount of light in different latitude, the roof optimal tilt Angle is different;

The installation of BIPV photovoltaic equipment on the facade of the best tilt Angle of the photovoltaic curtain wall and the ground needs to be considered by the benefits of sunshine and footprint, and at the same time, the occupation of land resources and the benefits brought by photovoltaic power generation;

Due to the limitations of this study,some of the data use empirical data, so a large number of experiments should be introduced for data refinement correction in the subsequent national promotion process, and decisions should be made after comprehensively considering the construction costs, land resources and power generation benefits. If the experimental conditions are missing, we can use the pvsyst software for light simulation, and simulate the average annual sunshine amount by adjusting the curtain wall Angle and the geographical location parameters, which is also the direction of our subsequent research.

7. Conclusion

Through the above study and analysis, the following conclusions can be obtained:

①The economic benefit generated by photovoltaic roof is greater than the economic benefit generated by photovoltaic facade. According to the case data, the economic benefit generated in the 25-year life cycle of photovoltaic roof system is 10.6/WP, and the economic benefit generated in the 25-year life cycle of photovoltaic facade system is 4.10 / WP. It can be seen that the photovoltaic roof system based on the perspective of economic analysis is more value creation ability than the photovoltaic facade system. However, from the perspective of resource utilization, although the efficiency of photovoltaic facade system per unit WP is less than half of that of the roof, given the considerable usable area of the building facade, especially in the background of the current shortage of land resources, the development potential of photovoltaic facade is immeasurable.

②The environmental benefits generated by photovoltaic roof are greater than those generated by photovoltaic facade. According to the case data, the environmental benefit generated in the 25 year life cycle of photovoltaic roof system is about 11.66/WP; and the 25 year life cycle of photovoltaic curtain wall system is about 3.62 / WP. Especially in the context of today's energy crisis and ecological destruction, the photovoltaic power generation system is of long-term significance to promoting building energy conservation and ecological protection. At the same time, if economic benefit and environmental benefit form opposite relationship, sacrifice economic benefit and ensure environmental benefit is also forward-looking and worth advocating vigorously.

③After the above quantitative analysis of the data study, the final scheme 3 is selected as the optimal benefit scheme. By comparing the data of economic benefits and environmental benefits, suggestions can be given for the owners who plan to install the photovoltaic power generation system in Jiangning District, Nanjing city, Jiangsu Province.That is, the rooftop photovoltaic power generation system with high power generation efficiency should be preferentially selected under the premise of a certain budget. If there is still some surplus budget after the construction of the rooftop photovoltaic system, it can be considered from the perspective of reasonable use of the facade to build the photovoltaic curtain wall system.

Photovoltaic building integrated system is an important trend in the development of photovoltaic power generation system. Nowadays, with the continuous development of modern science and technology, energy crisis and ecological deterioration have become a topic of wide concern in the world. As a renewable resource, if solar energy can maximize the efficient utilization, it has important strategic significance for the national energy supply and energy security. As an important form of photovoltaic power generation, photovoltaic building integration can save the transmission cost without occupying additional land resources, and increase the aesthetic performance for the building to form the urban wind standard. To sum up, the photovoltaic building integration will certainly have a broad market in the future building field.

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