Technical and Economic Analysis on the Large-scale Application of Renewable Energy in Buildings

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Abstract: This paper mainly introduces the technical & economic analysis and evaluation on the monitoring data of two buildings in the Shandong Academy of Building Research by the application of data monitoring and evaluation system for renewable energy building application so as to provide a scientific and technical basis for further improving the efficiency of engineering application, and to maximize its benefits through effective management measures and technical means.

Key Words: technical & economic analysis and evaluation; renewable energy building application;

Ⅰ. Introduction

The application of renewable energy in buildings is a new technology, which can produce certain energy-saving, economic and environmental benefits. Though it has been promoted and applied for years, its technical benefits still lack some systematical analysis and researches. During the "12th Five-Year Plan" period, Shandong will popularize the application of ground-source heat pump system (GSHPS) in buildings, covering an area of 30 million square meters in total. The heat collection area of solar energy and building integration will exceed 60 million square meters. Besides, the application of solar photovoltaic technology in the building field is being continuously expanded. How to effectively assess the economic and energy-saving benefits of renewable energy building application engineering has become a research subject of relevant professional institutes.

This article mainly introduces the technical & economic analysis and evaluation on the monitoring data of two buildings in the Shandong Academy of Building Research by the utilization of data monitoring and evaluation system for renewable energy building application so as to provide a scientific and technical basis for further improving the utilization efficiency of engineering application, and to maximize its benefits through effective management measures and technical means. Through the application of a pilot project, a good technical-economic effect is obtained. The monitoring system researched and developed can provide effective monitoring and assessment services for the large-scale application of renewable energy in city buildings in the future. The technical and economic analysis on the pilot project is shown as follows.

Ⅱ. Pilot project profile

The three renewable energy building application systems, ground-coupled heat pump system, domestic solar water heating system and solar photovoltaic system of South Complex Building and Youth Apartment Building in the Shandong Academy of Building Research are chosen as the pilot project for monitoring. The basic information of the project is shown in Table 1.

Table 1 Pilot Project Profile

Building name	Building area	Basic information	Building function	Technology type
South Complex Building	3000m2	3 floors aboveground,1 floor underground in part	For testing or office work	GSHPS and solar photovoltaic system
Youth Apartment Building	1650m2	4 floors aboveground	For accommodation, catering or office work	GSHPS and solar domestic water heating system

Ⅲ. Construction cost of the monitoring system

In April 2012, in accordance with the *Technical Guideline for the Data Monitoring System of Renewable Energy Building Application Engineering (Trial Implementation)*, a data monitoring and evaluation system for renewable energy building application is installed on three renewable energy building application projects, achieving online monitoring, analysis and evaluation functions of three renewable energy building application systems. The construction cost mainly concerns monitoring software, data acquisition unit, monitoring equipment, piping material, construction and other expenses. The system construction equipment details are shown in Table 2.

Table 2 List of Monitoring System Construction Equipment for Renewable Energy Building application

SN	Equipment name	Specification	Qty	Unit
1	Server	IBM x3610	1	No.
2	Data acquisition unit	HT-CJ01	1	No.
3	Ultrasonic heat meter	DN50~700	2	Set
4	Solar irradiance meter	TBQ-2	1	No.
5	3-phase multi-function electronic watt-hour meter	DTSD1225 3X1.5(6)A	1	No.
6	3-phase electronic watt-hour meter	DTS73 3X1.5(6)A	2	No.
7	3-phase electronic watt-hour meter	DDS73 10(40)A	2	No.
8	Monitoring system software	Renewable energy data monitoring system software	1	Set
9	Wireless transmission module	SZ02-2K	9	No.
10	Outdoor temperature transducer	TM1302	1	No.
11	Water temperature sensor	TM1313	1	No.
12	Remote water meter	LXLY-15	2	No.
13	Shielded twisted pair cable	2*0.75	100	m
14	Power cord	φ2.5	3	Coil
15	Tubing	Slot, joint, wire, ply-yarn drill, etc.	1	Batch
Total		**90869**		

Through the data monitoring of ground-coupled heat pump, domestic solar water heating and solar photovoltaic systems in the pilot project, the monitoring indexes of the three systems are acquired and analyzed. The index content monitored is shown in Table 5

Table 3 Data Monitoring Content of Renewable Energy Building Application

System name	Monitoring content
Ground-coupled heat pump system	Outdoor temperature System power consumption Unit input power User-side inlet water temperature of the system User-side outlet water temperature of the system Heat source-side inlet water temperature of the system Heat source-side outlet water temperature of the system User-side flow of the system Heat source-side flow of the system User-side inlet water temperature of the unit User-side outlet water temperature of the unit Heat source-side inlet water temperature of the unit Heat source-side outlet water temperature of the unit User-side flow of the unit Heat source-side flow of the unit
Domestic solar water heating system	Outdoor temperature Feed water temperature Drainage temperature Feed water flow Drainage flow Power consumption of auxiliary heat source
Solar photovoltaic system	Outdoor temperature Solar irradiance Solar power generating capacity

Ⅳ. Benefit analysis of the pilot project

According to the monitoring indexes acquired by the data monitoring system of renewable energy building application, an analysis and assessment is conducted on the utilization benefits of such renewable energy sources as conventional energy substitution amount, carbon dioxide emission reduction, sulfur dioxide emission reduction, dust emission reduction and cost saving of three renewable energy systems respectively.

A.Calculation method for conventional energy substitution amount of GSHPS

When calculating GSHPS conventional energy substitution amount, themonitoring system of the pilot project selects a coal-fired boiler as the comparison object of GSHPS in winter, with the boiler efficiency of 65%; and selects a conventional air conditioning system as the comparison object in summer. For the refrigeration coefficient of the water chilling unit, it adopts the minimum standard value 4.1 as prescribed in 5.4.5 of *Design Standard for Energy Efficiency of Public Buildings*. The calculation formula is shown as follows:

1) Calculation of coal saving amount of GSHPS in winter

$$Q_{\mathrm{gl,bm}} = \frac{Q_{\mathrm{c,s}}}{c_1 q_{\mathrm{m}}} \times c_2 + W_{\mathrm{s,t}} \times 0.3 \times c_3$$

$$Q_{\mathrm{dy,bm}} = W_{\mathrm{s,t}} \times c_3$$

$$Q_{\mathrm{bm,heating}} = Q_{\mathrm{gl,bm}} - Q_{\mathrm{dy,bm}}$$

Where,

$Q_{\mathrm{gl,bm}}$——Accumulative amount of standard coal consumption of the boiler, t_{bm};

$Q_{c,s}$—— Accumulative heat exchange amount for the condenser side of the system in winter, kWh;

$W_{s,t}$——Accumulative power consumption of the system in winter, kWh;

$Q_{dy,bm}$—— Accumulative amount of standard coal consumption of the heat pump unit, kWh;

$Q_{bm,heating}$—— Amount of standard coal saving in winter, t_{bm};

c_1 —— Boiler thermal efficiency, 65%;

q_m——Calorific value of coal, 5.815 kWh/kg;

c_2—— Conversion coefficient between coal and standard coal, 0.7143;

c_3——Conversion coefficient between electricity and standard coal, 0.3619.

2) Coal saving amount of GSHPS in summer

$$Q_{ls,bm} = \left(\frac{Q_{e,s}}{c_4} + W_{s,t} \times 0.3 \right) \times c_3$$

$$Q_{dy,bm} = W_{s,t} \times c_3$$

$$Q_{bm,cooling} = Q_{ls,bm} - Q_{dy,bm}$$

Where,

$Q_{ls,bm}$——Accumulative amount of standard coal consumption of the water chilling unit, t_{bm};

$Q_{e,s}$——Accumulative heat exchange amount for the evaporator side of GSHPS in summer, kWh;

$Q_{dy,bm}$——Accumulative amount of standard coal consumption of the heat pump system, t_{bm};

$W_{s,t}$——Accumulative power consumption of GSHPS, kWh;

$Q_{bm,heating}$——Amount of standard coal saving in summer, t_{bm};

c_3——Conversion coefficient between electricity and standard coal, 0.3619;

c_4– Refrigeration coefficient of the water chilling unit,4.1.

3) Calculation of annual coal saving amount of GSHPS

$$Q_{bm} = Q_{bm,heating} + Q_{bm,cooling}$$

Where,

Q_{bm}—— Accumulative amount of standard coal saving, t_{bm};

$Q_{bm,heating}$——Accumulative amount of standard coal saving in winter, t_{bm};

$Q_{bm,cooling}$—— Accumulative amount of standard coal saving in summer, t_{bm}.

B.Calculation method for conventional energy substitution amount of the solar water heating system

The conventional energy substitution amount of the solar water heating system is calculated according to the operating efficiency of the heat gain and supplementary heat source of the solar water heating system. The formula is shown as follows:

$$Q_{bm} = \frac{Q_{s,y}}{c_8 q_m}$$

Where,

Q_{bm}——Conventional energy substitution amount of the solar water heating system, t_{bm};

$Q_{s,y}$——Heat gain of the solar water heating system, kWh;

q_m——Calorific value of coal, 8.14kWh/kg;

c_8——Operating efficiency of supplementary heat source, with electric auxiliary heating of 0.31,and natural gas auxiliary heating of 0.84.

C. Calculation method for the conventional energy substitution amount ofthe solar photovoltaic system

The conventional energy substitution amount of the solar photovoltaic system is calculated according to generating capacity. The formula is shown as follows:

$$Q_{bm} = \frac{W \times c_3}{1000}$$

Where,

Q_{bm}——Conventional energy substitution amount of the solar photovoltaic system, t_{bm};

W——Generating capacity of the system, kWh;

c_3——Conversion coefficient between electricity and standard coal,0.3619.

D.Carbon dioxide emission reduction

The carbon dioxide emission reduction is calculated according to the conventional energy substitution amount of each system. The formula is shown as follows:

$$Q_{CO_2} = c_5 \times Q_{bm}$$

Where,

Q_{CO_2} ——Carbon dioxide emission reduction, t_{bm};

c_5 —— Carbon dioxide emission factor of standard coal, 2.47;

Q_{bm}—— Conventional energy substitution amount of the system, t_{bm}.

E. Sulfur dioxide emission reduction

The sulfur dioxide emission reduction is calculated according to the conventional energy substitution amount of each system. The formula is shown as follows:

$$Q_{SO_2} = c_6 \times Q_{bm}$$

Where,

Q_{SO_2} ——Sulfur dioxide emission reduction, t_{bm};

c_6 ——Sulfur dioxide emission factor of standard coal,0.02.

Q_{bm}——Conventional energy substitution amount of the system, t_{bm}.

F. Dust emission reduction

The dust emission reduction is calculated according to the conventional energy substitution amount of each system. The formula is shown as follows:

$$Q_{FC} = c_7 \times Q_{bm}$$

Where,

Q_{FC} ——Dust emission reduction, t_{bm};

c_7——Dust emission factor of standard coal, 0.01;

Q_{bm}——Conventional energy substitution amount of the system, t_{bm}.

G. Cost saving

The accumulative cost saving of GSHPS, the domestic solar water heating system and the solar photovoltaic system of the pilot project is calculated based on the conventional energy substitution amount of each system and in accordance with the standard coal price via domestic conversion of 1,000 yuan/t_{bm}. The formula is shown as follows:

$$M = 1000 \times Q_{bm}$$

Where,

M ——Accumulative operating cost saving, yuan;

Q_{bm}——Conventional energy substitution amount of the system, t_{bm}.

According to the above calculation formulas, the monitoring system obtains the conventional energy substitution amount,carbon dioxide emission reduction, sulfur dioxide emission reduction, dust emission reduction, cost saving, etc. of the three systems in the pilot project from Jun. 2012 to Sep. 2015. The monitoring results of economic and environmental benefits are shown in Table 6

Table 4 Summarization of Monitoring Data Regarding Economic and Environmental Benefits of the Pilot Project

Name	Time	Cost saving (yuan)	Conventional energy substitution amount (ton)	Carbon dioxide emission reduction (ton)	Sulfur dioxide emission reduction (ton)	Dust emission reduction (ton)
Ground-coupled heat pump system	2012	31427.60	31.4276	77.6262	0.6286	0.3143
	2013	29985.60	29.9856	74.0644	0.5997	0.2999
	2014	25468.30	25.4683	62.9067	0.5094	0.2547
	2015	12785.40	12.7854	31.5799	0.2557	0.1279
Domestic solar water heating system	2012	2103.40	2.1034	5.1954	0.0421	0.0210
	2013	2910.70	2.9107	7.1894	0.0582	0.0291
	2014	2240.80	2.2408	5.5348	0.0448	0.0224
	2015	1245.20	1.2452	3.0756	0.0249	0.0125

Name	Time	Cost saving (yuan)	Conventional energy substitution amount (ton)	Carbon dioxide emission reduction (ton)	Sulfur dioxide emission reduction (ton)	Dust emission reduction (ton)
Solar photovoltaic power generating system	2012	111.80	0.1118	0.2761	0.0022	0.0011
	2013	372.00	0.372	0.9188	0.0074	0.0037
	2014	184.20	0.1842	0.4550	0.0037	0.0018
	2015	65.30	0.0653	0.1613	0.0013	0.0007
	Total	**108900.30**	**108.9003**	**268.9837**	**2.1780**	**1.0890**

The table above shows that during the operating period from Jun. 2012 to Sep. 2015, the three systems in the pilot project realized total cost saving of relatively conventional energy of 108,900 yuan, standard coal saving amount of 108.9003t, carbon dioxide emission reduction of 268.9837t, sulfur dioxide emission reduction of 2.178t, and dust emission reduction of 1.089t.

Ⅴ. Analysis on indirect economic benefit of the monitoring system

In the pilot project, through the analysis and evaluation on such GSHPS indexes as power consumption, unit input power, flow, temperature difference, cooling (heat) capacity, COP and EER by the monitoring system, it is found that there are some unreasonable problems in the operating process of the heat pump unit. Such problems are mainly reflected in the following aspects:

(1) The heat pump unit frequently starts and stops. Seen from the instantaneous monitoring data uploaded once every 5 minutes, the heat pump unit may stop for 5 minutes every 15~20 minutes. Through analysis, the reason is that the end users of the system –Youth Apartment Building and South Complex Building have inconsistent using periods. The employees of Youth Apartment basically do not use air conditioning or heating in day time, while the employees of South Complex Building do not use air conditioning or heating in night time. The heat pump unit is arranged according to the total area of the two buildings, thus, there is a problem of “big horse pulling a small carriage”. And the frequent starting and stopping of the heat pump unit may cause the increase in electricity consumption and failure rate of the unit.

(2) The user-side water pump and the heat source-side water pump are not equipped with a supporting frequency converter, thereby, operating with motor in constant frequency all day.

For the two problems, the energy saving control method combining frequency conversion and linkage technology is adopted to conduct frequency conversion control over the user-side water pump so as to match its operating conditions with the load change of the end, and to conduct linkage control over the ground source-side water pump so as to synchronize it with the unloading or halt mode of the unit. Through technical rectification, the power consumption of GSHPS is obviously lowered, with saving efficiency up to 34%. Every year, the operating cost about 30,000 yuan can be saved, with an obvious energy-saving effect.

The comparison of power consumption before and after rectification is shown in Fig. 1.

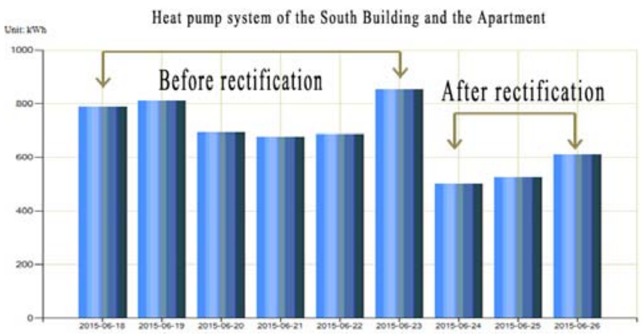

Fig. 1 Power Consumption Comparison of GSHPS before and after Rectification

Ⅵ. Investment payoff period of the monitoring system

Seen from the analysis above, the three renewable energy building application systems of the pilot project are energy-saving technologies, which have produced large economic and environmental benefits. In addition, through the construction of the monitoring system, certain economic benefits can still be obtained based on the system operation optimized by the monitoring data. The investment payoff period of the monitoring system is obtained through the sum of equipment, construction and material costs divided by the saved operating cost of the monitoring system. The calculation formula is shown as follows:

$$\text{Expected investment payoff} = \frac{\text{Monitoring system equipment cost} + \text{Construction and materials cost}}{\text{Saved operating cost}}$$

$$= \frac{90869}{30000} = 3.03\text{years}$$

Ⅶ. Social and economic benefit analysis

The research results and the pilot project show that relevant government authorities may utilize the renewable energy monitoring system to master the conventional energy substitution amount, carbon dioxide emission reduction, sulfur dioxide emission reduction, dust emission reduction and saved costs of all renewable energy building application projects within the administrative region in an hourly and all-around way. Through these technical data related to energy saving and environments, overall application level of renewable energy in the building field can be known in time, and strong data support can be provided for the decision-making of the government. Moreover, these technical data can also help relevant government authorities to develop feasible implementation schemes and relevant incentive policies, playing a positive role in the extensive promotion of renewable energy building application.

By utilizing this data monitoring system, the administrative department may also analyze and evaluate the performance indexes and evaluation indexes of all projects monitored within jurisdiction, estimate the application effect of projects, spur the Owner to adopt a more rational management method or advanced technical rectification scheme, and further improve the operating efficiency and economic benefits of renewable energy building application engineering.

Ⅷ. Conclusion

According to the analysis on the monitored data of the three application projects of renewable energy in buildings in Shandong Academy of Building Research, the application effect of renewable energy in the building field is good. Besides, through the installation of the data monitoring system of renewable energy building application, the operation effect of the renewable energy system can be further enhanced to produce energy-saving benefits. In accordance with this mode, if widespread implementation of the monitoring on renewable energy building application projects can be carried out, and the monitoring system can be utilized to conduct a comprehensive supervision on the renewable energy projects of various city buildings, the economic and environmental benefits generated will be more obvious.

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