ENERGY AUDIT AND CONSERVATION POTENTIAL ANALYSIS OF A LARGE COMPREHENSIVE COMMERCIAL BUILDING

by

Chunzhi ZHANG, Nianxia YUAN, and Qianjun MAO *

School of Urban Construction, Wuhan University of Science and Technology, Wuhan, China

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With the rapid development of large-scale public buildings, energy consumption has increased, of which the energy consumption of comprehensive commercial buildings can reach 10~20 times the common building energy consumption, and has great energy saving potential. In this paper, a large comprehensive commercial building in Chengdu is taken as an example to analyze the energy consumption through the actual energy consumption data, viewed from the energy-saving and emission-reduction and static investment payback period point. The results show that the energy saving rate of the building can be achieved by 32.64%, the emission reduction is 6196.52 t CO_2 *per year, and the investment recovery period is only about 0.90 years, which provides a reference for similar buildings.*

Key words: *comprehensive commercial building, energy audit, energy saving measures, energy saving potential*

Introduction

The rapid growth of economic activities in China has led to increasing energy consumption in public buildings. According to the investigation of Building Energy Conservation Center of Tsinghua University, China, the energy consumption of public buildings in China accounts for 27.9% [1, 2], and the proportion of commercial building continues to show an upward trend. In this situation, the potential returns on energy-saving measurements are enormous. As a result, it is of great significance to improve the energy management and energy-saving reconstruction of the large-scale commercial buildings. Not only it can promote the utilization of new energy, such as solar energy and cold-water storage, but also promote this study of new energy sources [3-6].

Researches concerning the energy consumption characteristics, the energy saving measures and the energy saving rate of commercial buildings are very topical and rapidly developing. Compared with other public buildings, the energy system of commercial building is more complicated [7]. It mainly includes power distribution system, HVAC, lighting, building elevator, water supply and drainage, office and some other energy equipment. As for energy-saving measures, it mainly involves three aspects: construction, technology and management. Common energy-saving measures more refer to the last two, such as lighting modification, HVAC system transformation, renewable energy utilization, behavioral energy saving, and optimization of management systems [8, 9].

*Corresponding author, e-mail: maoqianjun@163.com

Energy conservation technology using in commercial buildings has attracted extensive attention. This paper is about one commercial building energy audit in Chengdu, China which was built in 2006, and energy-saving potential analysis based on the energy consumption data from 2012 to 2015. We hope to use the detailed calculation of energy consumption, payback period (PBP) and emission reduction, and the above energy-saving measures applied to the actual project, analyze its energy-saving potential.

Energy audit of the building

Survey on the building energy systems

The commercial building is located in Chengdu and used in 2006. Building area is 170000 square meters, and a total of five floors (including underground), it is symmetrical layout. The underground is a big supermarket, the first floor to the third floor is the department store, and the fourth floor is for the catering and entertainment. Building envelope structure based opaque glass curtain wall, doors and windows are toughened glass. On the fourth floor, the roof of the atrium is glass, with a radiation proof sunshade film and the waterproof and heat insulation measures of the opaque roof.

The air-conditioning system of this building is a centralized cold and heat source station, with two direct-fired lithium bromide absorption chillers and two centrifugal chillers. The coefficient of performance of the direct-fired lithium bromide absorption chillers is 1.19, and the coefficient of performance of centrifugal chillers is 5.81. The cooling capacity of equipment is enough, so the centrifugal chiller basically does not run. The air-conditioning terminal units of the shopping mall are packaged air conditioners, and some of the main stores are equipped with fan coins and fresh air units. Heating operation is generally done during December, January, and February and cooling operation is generally done during the end of April to early November. The property management department estimates the operation cost of direct-fired lithium bromide absorption chiller is 4 RMB*/m^2, and the centrifugal chiller energy cost is 5 RMB/m^2, in addition, the cooling capacity of direct-fired lithium bromide absorption chiller is a greater priority operation.

The ventilation system of the underground rooms are equipped with some ventilation fans, the garages are on both sides of the building, which has a total of 6 floors (including mezzanine), the garage takes a non-closed envelope, so as to ensure air quality and save the ventilation and lighting energy consumption.

The lightings of the public territory and garage are energy-saving lamps and these lamps will be replaced as LED lamps, and the lightings of the shops are installed by the renters. Control mode is manual control, and emergency lamp for inductive control. According to tests, the average lighting power density (LPD) is 15.67 W/m^2 of the shops and the LPD of the garage is 1 W/m^2.

This building has 44 elevators for different purposes, including 34 escalators and all the constant frequency operation. The water pumps and a fire-fighting pool (800 m^3) are all located in the underground floor. Sewage directly discharged to the municipal pipe network.

The situation of the building energy consumption

Total energy consumption

The big supermarket on the underground is managed by a renter, which the energy consumption data of it is not counted. Therefore, this paper focuses on the analysis of energy

*6.2 RMB = 1$US

consumption of the above ground part of the building with construction area of 149665.39 m^2. The property management department made monthly statistics on electricity consumption, water consumption and gas consumption from 2012 to 2015. Natural gas is mainly used for air-conditioning and heating, and cater gas meter by the renters to apply for installation and self-payment, so this part of the cater gas consumption can not be measured in the total energy consumption in the building.

Monthly electricity consumption from 2012 to 2015 is shown in fig. 1, the figure shows that the annual electricity consumption with a weak upward trend, and the electricity consumption in December and August increased significantly. Monthly consumption of gas trends are basically the same as the electricity consumption. The electricity, gas, and water consumption data are converted into standard coal according to the local conversion coefficient, the energy consumption of the mall can be drawn, as shown in fig. 2. From this figure we can see that electricity accounted for 85.19%, the focus of the energy-saving work of the mall is to save electricity.

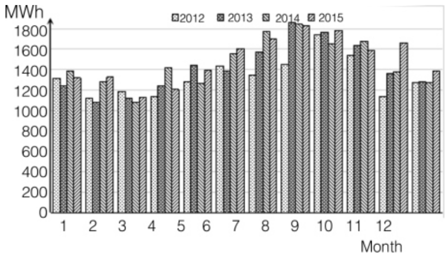

Figure 1. Monthly electricity consumption from 2012 to 2015

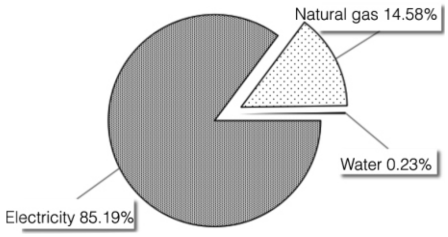

Figure 2. Average energy consumption composition from 2012 to 2015

Sub-energy consumption

The commercial building has a total meter, in addition, according to the household who has installed the meter, and equipped with some sub-metering devices. The consumption of each energy system can be calculated according to the building's total meter and sub-metering devices.

It can be concluded that the average energy consumption of each energy system from 2012 to 2015 is shown in tab. 1. It indicates from the table that the energy consumption of air-conditioning system is the biggest, and the energy consumption of ventilation system is the lowest. Figure 3 shows the average energy consumption ratio of each energy system from 2012 to 2015. As can be seen from fig. 3, the energy consumption of heating and air-conditioning sys-

Table 1. Average energy consumption of each energy systems from 2012 to 2015

Project name	Electricity (MWh)	Natural gas [m³]	Total equal value (tce)
Refrigeration system	7038.57	561126	3003.94
Heating system	1867.79	235233	901.94
Elevator system	925.28	0	305.34
Ventilation system	323.31	0	106.69
Living water pump	120.45	0	39.75
Lighting and catering	6839.45	0	2257.02
Building	17114.84	796359	6614.68

Comment: 1 kWh electricity = 0.33 kgce, 1 m³ natural gas = 1.2143 kgce, the same below.

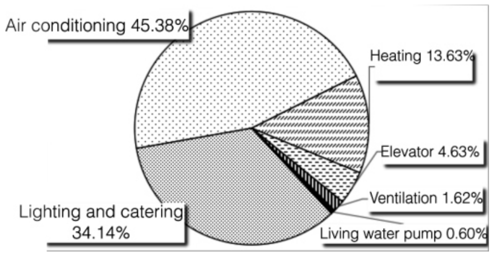

Figure 3. Average energy consumption ratio of each energy systems from 2012 to 2015

tem has accounted for more than half of the total energy consumption of the building, and air-conditioning energy consumption is far greater than the heating energy consumption.

Energy consumption index

According to the building's total energy consumption, sub-energy consumption and construction area, we can calculate the average energy consumption index and cost index. Table 2 is the average energy consumption index of each energy system in the period from 2012 to 2015. Table 3 is the energy cost index of each energy system from 2012 to 2015. From this table we can conclude:

– From 2012 to 2015, the average integrated electricity consumption (non-water) of the mall was 133.93 kWh/(m^{2}a). The constraint value and guidance value of the non-heating energy consumption index of the B class large shopping building in the hot summer and cold winter area are 260 kWh/(m^{2}a) and 210 kWh/(m^{2}a), respectively, in the energy consumption standards for civil buildings in China. Due to incomplete statistics of energy consumption, the average integrated electricity consumption is small, which can meet the requirements of energy consumption standards for civil buildings.

Table 2. Average energy consumption index of each energy system from 2012 to 2015

Project name	Standard coal [kgcem^{2}a^{-1}]	Integrated lectricity [kWhm^{2}a^{-1}]	Standard ceoal [kgceh^{-1}]	Integrated electricity [kWhh^{-1}]
Refrigeration system	20.07	60.82	685.83	2078.27
Heating system	6.03	18.26	205.92	624.01
Elevator system	2.04	6.18	69.71	211.25
Ventilation system	0.71	2.16	24.36	73.82
Living water pump	0.27	0.80	9.08	27.50
Lighting and catering	15.08	45.70	515.30	1561.52
Building	44.20	133.93	1510.20	4576.36

Table 3. Energy cost index of each energy system from 2012 to 2015 [RMBm^{2}a^{-1}]

Project name	2012	2013	2014	2015	Average
Refrigeration system	48.76	59.93	61.63	63.14	58.37
Heating system	16.15	14.54	18.48	20.24	17.35
Elevator system	6.08	6.08	6.03	6.13	6.08
Ventilation system	2.12	2.12	2.11	2.14	2.12
Living water pump	0.79	0.79	0.78	0.80	0.79
Lighting and catering	44.28	43.35	42.48	49.74	44.96
Building	118.19	126.81	131.51	142.20	129.68

- From 2012 to 2015, the average energy consumption per unit of construction area of the mall was 44.20 kgce/(m^2a), higher than the public buildings' (schools, office buildings, shopping malls, hotels, information centers, *etc*.) energy consumption which is 37.48 kgce/(m^2a) in Chengdu, China. It has a certain energy-saving space.
- From 2012 to 2015, the average air-conditioning heating energy consumption of the mall was 26.10 kgce/(m^2a), which accounted for 59.01%, much higher than the large public building air-conditioning heating energy consumption ratio (28%) in Chengdu, China. It has great energy-saving space.
- From 2012 to 2015, the average energy cost unit of construction area is 129.68 RMB/(m^2a), and the trend is increasing year by year. Operating costs can also be reduced by adopting energy saving measures.

Indoor air quality

The outdoor environment temperature in Chengdu was 19-25 and rainy on October 20, 2016. Air-conditioning system was not running when tested outdoor and indoor thermal environment and indoor air quality. The measurement results are shown in tab. 4, and the test time is 10:00-11:00, October 20th, 2016. The measuring range and accuracy of the measuring instruments are shown in tab. 5. From this table we can see that in the absence of air-conditioning system's operation, the temperature and relative humidity of the area meet the requirements of the thermal environment in China. The CO_2 concentration in the air-conditioning area is lower than the limit value (1000 ppm), which meets the requirements of indoor air quality.

Table 4. Test results of indoor air quality

Area	CO_2 concentration [ppm]	Temperature [°C]	Relative humidity [%RH]	Wind velocity [ms^{-1}]	Illumination (Lux)
Fourth-floor atrium	642	25.8	60.8	0.11	232
Third-floor atrium	632	26.4	57.9	0.17	264
Second-floor atrium	631	25.8	60.3	0.05	79.8
Second-floor aisle	792	25.7	60.8	0.08	354
Store	699	25.8	72.1	0.12	1139
Office	859	23.4	69.5	0.05	114.8
Garage	568	22.5	71	0.1	17.17
Outdoor	531	22.4	70.3	0.11	6909

Analysis of energy-saving potential

Energy saving renovation of existing buildings, as a social and economic activity, takes into account the effect of renovation, and it also needs to consider its investment cost and PBP. Usually we calculate the static investment PBP and the carbon emission [10].

Evaluation indexes of energy saving

Economic evaluation

The static PBP analysis method ignores the operation cost and the time value of money, which is widely used in the economic analysis of building energy saving measures. In this paper, we only need to consider the financial recovery ability of the project, and the economic analysis is carried out by this method. The equation for PBP is:

Table 5. Instruments of test

Name	Probe	Function	Range	Accuracy
Thermal comfort tester	A1091	Illumination	0.01 Lux to 19.99 Lux	(0.02 Lux + 8% of r.)
			20.0 Lux to 199.9 Lux	± (0.1 Lux + 8% of r.)
			200 Lux to 1999 Lux	(1 Lux + 8% of r.)
			2000 Lux to 20000 Lux	(10 Lux + 8% of r.)
	Thermocouple	Temperature	–200 to +1400	(1.0 °C +8% of r.)
	A1144	Temperature	–40 to +60	0.1
		Relative humidity	0% RH to 100% RH	0.1% RH
CO_2 tester	Testo 535	CO_2 concentration	0 to + 5000 ppm CO_2	(50 ppm CO_2 2% measured value)
			+5001 to + 9999 ppm CO_2	(100 ppm CO_2 3% measured value)

$$PBP \quad \frac{\Delta IC}{\Delta OC} \tag{1}$$

where ΔIC is the total cost increase after the energy-saving reconstruction, RMB and ΔOC – the difference in annual operating expenses, RMB per year. The PBP are expressed in years [11,12].

Carbon emission calculation

Carbon emissions include direct energy emissions and indirect energy emissions, industrial production process emissions and recycling, the equation for carbon emission is:

$$E_{CO_2} \quad E_D \quad E_{ID} \quad E_{IP} \quad E_R \tag{2}$$

where E_{CO_2} is the total CO_2 emissions of the project, t CO_2 (ton of CO_2, the same below), E_D – the direct emissions of energy, that is the carbon emissions generated by fossil fuel combustion, t CO_2, E_{ID} – the indirect emissions of energy, that is the carbon emissions generated by net purchase of electricity and heat, t CO_2, E_{IP} – the emission of industrial production process, that is the carbon emissions generated by other chemical reactions or physical processes in the process of industrial production, t CO_2, and E_R – the amount of carbon which can be recycled in the process of industrial production, which is produced by the project, but has been recycled as raw material or solidified in the export product, thereby reducing the amount of carbon emissions, t CO_2.

The energy consumption of large commercial buildings is dominated by electricity, so in this paper, we only consider the indirect emission of energy when we calculate of carbon emission, the equation is:

$$E_{ID} \quad AD_e EF_e \quad AD_h EF_h \tag{3}$$

where AD_e is the net purchase of electricity, 104 kWh, EF_e – the average annual emission factors of power supply, 9.779 t $CO_2/10^4$ kWh, AD_h [GJ] – the net purchase of electricity heat, and EF_h – the thermal emission factors, 0.11 t CO_2/GJ.

Different system's energy-saving potential

The lighting system

If the energy saving lamps and fluorescent lamps are replaced with LED lamps, then the public area can be set with light induction device or timing operation to reduce lighting energy consumption. However, the building needs more 121200 RMB to the lighting renovation, and it can save operating costs 269400 RMB per year, PBP are 0.45 years, and emission reductions is 265.57 *t* CO_2 per year. The energy-saving benefit of it is shown in tab. 6.

The chillers

If we can use the cold-water storage technology to save the operation cost by using the policy of peak and valley time-of-use electricity price in Chengdu, and the chiller is idle at the peak of electricity. According to the operation from May to September 2016, the running time curve of each chiller is shown in fig. 4. We can see that it is feasible to use a centrifugal chiller as a chilled water storage chiller. The temperature range of the cold water is 5-13, the cooling time of the centrifugal chiller is 23:00-7:00, and the transformation benefit is shown in tab. 7.

Table 6. Benefits of lighting reform

Name	Power [kW]	Quantity	Lighting time [h]	Simultaneous coefficient [%]	Consume power [kWh]
Energy saving lamp	0.018	3443	4380	75	203.58
T5	0.028	4015	4380	75	369.30
T5	0.024	480	4380	75	37.84
T8	0.018	222	4380	75	13.13
T8	0.036	1166	4380	75	137.89
LED lamp	0.016	9326	4380	75	490.17
Power saving		271.57 MWh			
Emission reduction		265.57 t CO_2			
Reduce cost		269400 Yuan*			
Investment		121200 Yuan			
PBP		0.45 year			

*6.27 Yuan = 1 $
Comment: the average price of electricity is 0.99 RMB/kWh, the same below

The packaged air conditioner

The energy consumption of air-conditioning terminal system of the building accounted for about 55% of the total, and the packaged air-conditioners were constant frequency operation. If the packaged air-conditioner can be added with the frequency conversion device, the energy consumption of the air-conditioning system can be saved. It is proved that this measure has a remarkable effect of saving electricity and the electricity saving rate is up to 44% [13]. After adding the frequency conversion device, the energy saving benefits is shown in tab. 8. From the table, the frequency conversion of packaged air-conditioner need to be more invested 1 million RMB, the PBP are 0.83 years, the reduction is 991.03 *t* CO_2 per year.

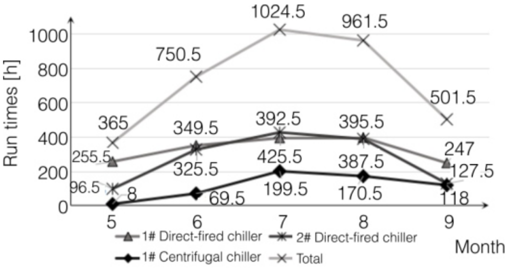

Figure 4. Running time curve of each chiller

Besides, the packaged air-conditioner can take heat recovery technology to recover the exhaust air of the cold or heat, pre-cooling or

Table 7. Benefit of chilled water storage

Refrigerating capacity [kW]	Power [kW]	Cool-storage capacity [kWh]	Electricity consumption [kWh]	Electricity price difference [RMB/kWh]	Reduce cost (10^4 RMB)	Volume [m^3]	Investment (10^4 RMB)	PBP [Year]
3164.4	544.8	25315.2	4358.4	0.78	81.97	1925	250	3.05

Table 8. The benefits of frequency conversion renovation of packaged air conditioner

Equipment power [kW]	Quantity	Running time [h]	Power saving rate [%]	Power saving [MWH]
30	4	2520	44	133.06
22	2	2520	44	48.79
15	34	2520	44	565.49
11	24	2520	44	292.72
5.5	12	2520	44	73.18
18.5	3	2520	44	61.54
4	10	2520	44	44.35
Total power saving			1219.13 MWh	
Reduce cost			1.21 million RMB	
Emission reduction			991.03 *t* CO_2	
Investment			1 million RMB	
PBP			0.83 years	

preheating fresh air to achieve energy saving. The energy saving rate of heat recovery device is about 6.5% [14], the benefits of packaged air-conditioner after exhaust air heat recovery is shown in tab. 9. As we can see from the table, the exhaust air heat recovery device need to be invested 2 million RMB, the PBP are 2.63 years, the reduction is 752.34 *t* CO_2 per year.

Energy saving potential in management

Energy saving of behavior should focus on the lighting system and air-conditioning system management. The research shows that through the establishment of behavioral energy saving management system, lighting energy consumption can be reduced by 22%, air-conditioning energy consumption can be reduced by 15%. The energy saving benefits of behavior management is shown in tab. 10, the table shows that energy saving behavior can save electricity 3279.99 MWh, save costs 3.28 million RMB, and reduce emission 3207.51 t CO_2 per year.

Table 9. Benefits of exhaust air heat recovery

Air-conditioning consumption [MWH]	Power saving rate [%]	Power saving [MWh]	Reduce cost [10^4 RMB]	Emission reduction [t CO_2]	Investment [10^4 RMB]	PBP [year]
11835.98	6.5	769.34	76.16	752.34	200	2.63

The building can install smart electricity meters, and then add some intelligent gas meters, intelligent water meters and a monitoring system, it can also build a public building energy regulatory platform to achieve a comprehensive real-time monitoring of water, electricity and gas. According to the U. S. Department of energy statistics, the efficient energy management system can help the building reduce 5% to 25% of energy and the energy-saving calculation by 5%. As energy saving and investment of the energy management system shown in tab. 11, the energy regulatory platform need to invest 1 million RMB, the PBP are 1.01 years, the reduction is 980.07 *t* CO_2 per year.

Table 10. Benefits of behavior management

Name	Consumption	Energy saving rate [%]	Saving	Reduce cost [10^4 RMB]	Power saving [MWh]
Lighting power consumption [MWh]	6839.45	22	1504.68	149.26	1504.68
Air-conditioning gas consumption [m^3]	796359	15	119453.85	46.35	439.36
Air-conditioning power consumption [MWh]	8906.36	15	1335.95	132.53	1335.95
Total power saving			3279.99 MWh		
Total reduce cost			3.28 million RMB		
Emission reduction			3207.51 *t* CO_2		

Table 11. Benefits of energy management system

Total electricity consumption [MWH]	Power saving rate [%]	Power saving [MWh]	Reduce cost [10^4 RMB]	Emission reduction [t CO_2]	Investment [10^4 RMB]	PBP [year]
20044.47	5.00%	1002.2	99.22	980.07	100	1.01

Summary of energy-saving reconstruction benefits

Through these energy-saving measures, we can effectively solve the fourth floor's comfort problems in summer by optimizing energy-using equipment and operational strategies, recycling waste heat and maximizing energy savings in premise with meeting the comfort requirements. At the same time, we should make full use of low power load at night to save operating costs.

After the implementation of the previous transformation program, the benefits of energy saving transformation are summarized in tab. 12. The whole project needs to be invested 6.62 million RMB, saving operating costs 7.33 million RMB per year, saving standard coal costs 2158.94 t per year, the PBP are 0.90 years, emission reductions is 6196.52 t CO_2 per year.

Table 12. Summary of energy-saving reconstruction benefits

Project	Power saving [MWh]	Coal saving [tce]	Emission reduction [t CO_2]	Reduce cost [10^4 RMB]	Investment [10^4 RMB]	PBP [year]
Behavior management	3279.99	1082.40	3207.51	328.14	–	–
Energy management	1002.22	330.73	980.07	99.22	100	1.01
Lighting reform	271.57	89.62	265.57	26.94	12.12	0.45
Chilled water storage	–	–	–	81.97	250	3.05
Frequency conversion reform	1219.13	402.31	991.03	120.69	100	0.83
Heat recovery	769.34	253.88	752.34	76.16	200	2.63
Total	6542.25	2158.94	6196.52	733.12	662.12	0.90

Conclusion

The energy-saving reconstruction of the mall can save standard coal 2158.94 t per year, the overall energy saving rate reached 32.64%, emission reductions are 6196.52 t CO_2 per year, while the comprehensive investment recovery period are only 0.90 years, energy-saving and emission-reduction effect are remarkable.

The large-scale of commercial buildings have great energy-saving potential. The improvement schemes provided in this paper are feasible solutions and have reference value for similar buildings. But at the same time, we should not blindly pursue new technologies and new programs during energy-saving reconstruction. We should combined with the characteristics of the building itself based on the actual energy consumption, choose the appropriate transformation program after energy consumption audit, otherwise, it may backfire.

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