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STUDY ON ENERGY SAVING RETROFITTING STRATEGIES FOR EXISTING PUBLIC BUILDINGS IN SHANGHAI

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ABSTRACT

Public buildings include office building, schools, hotels, hospitals, retails and others. This paper selects two types of existing public buildings – office and hotel to conduct research. It firstly introduces and analyzes the feasible energy saving retrofitting strategies and technologies for existing public buildings in Shanghai, mainly about building envelope, HVAC system and lighting system. Then it builds up prototypical models, with whole building energy analysis software—EnergyPlus, for office and hotel respectively to simulate and calculate the annual energy saving and payback period of the various strategies. Therefore the different features of the two types of buildings and the energy saving effects of various strategies used on them are studied.

The results show that the energy saved by each one strategy may be different for different types of existing buildings. For office buildings, such ECMs (energy conservation measures) as external shading, energy efficient lighting system, daylighting in perimeter area and variable pumps have short payback period. While for hotels, external shading, variable pumps and temperature reset have short payback period.

1. INTRODUCTION

With the economic development of China, energy consumption quickly increases. Shanghai, the largest economic center of China, is a short-of-energy city and the pressure of energy conservation is big. Therefore, energy saving for existing buildings is of practical significance to Shanghai.

At present, researches on the energy saving retrofit for existing buildings include policy analysis, appropriate technologies, operation and management (O&M) and so on. Xu[1] emphasized that, in China, the energy saving retrofit for existing buildings should establish different retrofit technologies and standards for different areas according to their own facts. Zhou[2] analyzed basic technical requirements of the energy saving retrofit for existing residential buildings in northern areas in China. H. Tommerup and S. Svendsen[3] gave a short account of the technical energy-saving possibilities that are present in existing dwellings and performed detailed calculations in a case with two typical buildings to estimate the total savings potential. Anne Grete Hestnes and Niels Ulrik Kofoed[4] examined different low energy retrofitting measures in terms of energy, indoor environment and economy to evaluate a set of retrofitting strategies designed for ten existing office buildings. M.Santamouris et al.[5] analyzed energy consumption data from 158 Hellenic hotels and estimated energy savings that resulted from the use of practical retrofitting techniques, materials and new energy efficient systems. G. Verbeeck and H. Hens [6] discussed economically feasible ways and means including envelope insulation measures, better glazing and renewable energy system and finally found out a logical hierarchy of energy-saving measures. Caglar Selcuk Canbay et al. [7] developed new HVAC control strategies and tuned control loops in a shopping center to reduce energy consumption. Agis M. Papadopoulos et al. [8] evaluated the feasibility of energy saving renovation measures in a representative sample of buildings under realistic conditions. Stig-Inge Gustafsson[9] dealt with how to optimize retrofit measures, such as insulation measures and changing the heating system. The result showed that the heating system had a vital influence on the optimal amount of extra insulation which was to be applied. M. Santamouris and E. Dascalaki[10] gave an analytical description of the activities carried out within the frame of the project that aimed to develop global retrofitting strategies, tools and design guidelines in order to promote successful and cost-effective implementation of passive solar and energy efficient retrofitting measures to office buildings. Chen[11] summarized low-cost energy-saving operation management measures for commercial buildings in Shanghai, such as auto-controlling lighting system, dynamic adjusting the operation of HVAC system and so on. Wu[12] used DOE-2 to simulate and analysis the influence of building envelope, under different air-conditioning operation modes, on annual cooling and heating consumptions of public buildings in

Shanghai. In this paper, two types of existing public buildings ——office and hotel are selected to conduct relative research, prototypical models for office and hotel are respectively built up to simulate and calculate the annual energy saving and payback period of the various energy saving strategies.

2. Feasible energy saving retrofitting technologies

For public buildings (especially office buildings and hotels), about 50%～60% of the total energy consumption is used for space cooling and heating, while 20%～30% is used for lighting[13]. In hot summer and cold winter regions in China, building envelope consumes 35% of the energy consumption on cooling and heating. Therefore, building envelope, HVAC system and lighting system have great potential of energy saving.

2.1 Building Envelope

External walls and roof are the main components of building envelopes; their insulation performance directly influences the energy consumption of buildings. Improving thermal insulation of external walls and roof is one of energy saving retrofitting measures.

Window is the weakest component of building envelope for insulation performance. The area of external windows should be as small as possible, after ensuring the sunshine, lighting, ventilation. And the insulation performance of external windows should be good enough to reduce heat loss. The ECMs for external windows include enhancing glazing performance and adding external sunshade, etc.

2.2 HVAC System

The energy consumption of HVAC system mainly consists of two parts: the energy consumed by cooling and heating sources that supply chilled water and hot water to air handling units and terminals, the energy consumed by fans and pumps for air and water distribution. The ECMs of HVAC system include resetting supply temperature of chilled water and hot water according to outdoor air temperature, using VAV (variable air volume) system instead of CAV (constant air volume) system, using VFD pumps in chilled water and hot water loop, air-side economizer, water-side economizer (free cooling by cooling tower), improving equipment efficiencies, air-side free cooling and so on.

2.2 Lighting System

Energy consumption of lighting system takes a large amount of total building energy consumption and thus it has great energy-saving potential. The ECMs for lighting system include replacing normal lights with high efficiency lights, installing daylighting switching/dimming systems in perimeter zones, strengthening maintenance of lighting system, etc.

Among all the ECMs described in above paper, some are suitable to be used in Shanghai but some are not very suitable. In summary, ECMs appropriate for existing public buildings in Shanghai include improving thermal insulation of exterior walls (U-factor), enhancing glazing performance of exterior windows, temperature reset in mild seasons, VAV system, VFD pumps, air-side free cooling, high-efficiency lights, daylighting.

3. Model development

3.1 Baseline models for existing office and hotel buildings in Shanghai

Joe Huang[14] researched on existing commercial and residential buildings around the U.S. based on the building descriptions and energy consumptions of over 4000 commercial buildings collected by CBECS (Commercial Building Energy Consumption Survey), and then used DOE-2 to develop and model nearly 500 prototypical buildings by building type, vintage, and city, defining their internal conditions and operating schedules, HVAC systems, and then simulate their hourly energy profiles. These models can be used to analysis the energy saving potential of many ECMs. In this paper, the prototypical models of existing office and hotel buildings are developed based on the information from Shanghai Commercial Building Information Database[16] and EnergyPlus[15] is selected as the program to simulated the models.

The office building model has 25 stories above grade with floor-to-floor height from 2nd floor 25th floor of 4.2m and that of 1st floor of 6m. The total building height is 106.8m. The total floor area of the building is 43,750 m^2, among which, 2500 m^2 is unconditioned. The window-to-wall ratio is 70%. The core of the building contains lifts, elevators, stairs, toilet and mechanical rooms, and so on. The main function of the building is office, but there are entrance hall, banks and retail shops on the first floor. According to the height and usage of the office building, the power of the elevators is estimated as 320kW; the operating schedule of the elevators is specified referring to User Manual of ASHRAE 90.1[17]. The yearly electricity cost of elevators in the office building is estimated about 431,492RMB.

The hotel building has 12 stories above grade with floor-to-floor height from 2nd floor 12th floor of 3.5m and that of 1st floor of 5m. The total building height is 43.5m. The total floor area of the office building is 23,400m^2, among which, 1500 m^2 is unconditioned. The window-to-wall ratio is 40%. The main function of the building is hotel, while there are main hall, café shops, retail shops and washhouses on the first floor and kitchens, dining-rooms on the second floor. Diesel boilers only produce hot water for space heating and gas water heaters produce domestic hot water. According to the height and usage of the hotel building, the power of the elevators is estimated as 160kW; the operating schedule of the elevators is specified referring to User Manual of ASHRAE 90.1[17]. The yearly electricity cost of elevators in the hotel building is estimated about 507,672RMB.

Tables 1 and 2 list the input data of weather data, envelope, internal loads, set points, operating schedules and HVAC system of the office and hotel models. The envelope and HVAC system of the office and hotel models are obtained from the survey results of 32 buildings. The internal loads (occupancy, lighting and plug), operating schedules and set points are set according to China Standard----GB 50189-2005[13].

The rates of electricity and gas for commercial buildings in Shanghai are listed in Table 3 and are input to the models to calculate the energy cost.

Table 1
The input data of the office model

Items	Office Model	Items	Office Model
Weather Data	IWEC of Shanghai	Fresh air	
Envelope		Main hall	2.7L/s/person
External wall	U=1.60W/m^2.K	Bank	5.5L/s/person
Roof	U=0.75W/m^2.K	Retail	5.5L/s/person
Window	U=3.02W/m^2.K	Office	8.3L/s/person
	SHGC=0.54,SC=0.63	Set points	24°C for cooling and 20°C for heating with dead band
Shading	Interior shades only in summer		
Infiltration	0.2ACH in perimeter area, 0ACH in internal area	Operating schedules	
		Main hall	7:30~18:30
Internal loads		Bank	8:30~16:30
Lighting		Retail	9:00~18:00
Main hall	11W/m^2	Office	8:00~17:30
Bank	15W/m^2	Unconditioned	7:30~18:30
Retail	15W/m^2	HVAC system	
Office	15W/m^2	Air distribution system	4-pipe fan coil + fresh air
Unconditioned	11W/m^2	Water system	Three centrifugal chillers (COP=5.5), one gas boiler (η=80%), single-speed open cooling tower, constant speed primary/secondary chilled water pump, constant speed hot water pump
Equipment			
Main hall	5W/m^2		
Bank	20W/m^2		
Retail	13W/m^2		
Office	18W/m^2		
Unconditioned	5W/m^2		
People			
Main hall	20m^2/person		
Bank	6m^2/person		
Retail	10m^2/person		
Office	4m^2/person		
Unconditioned	20m^2/person		

Table 2
The input data of the hotel model

Items	Hotel Model	Items	Hotel Model
Weather Data	IWEC of Shanghai	Fresh air	
Envelope		Main hall	2.7L/s/person
External wall	U=1.60W/m^2.K	Café	2.7L/s/person
Roof	U=0.75W/m^2.K	Retail	5.5L/s/person
Window	U=3.02W/m^2.K	Washhouse	2.7L/s/person
	SHGC=0.54,SC=0.63	Dining-room	5.5L/s/person

Shading	Interior shades only in summer
Infiltration	0.2ACH in perimeter area, 0ACH in internal area
Internal loads	
Lighting	
Main hall	10W/m^2
Café	20W/m^2
Retail	12W/m^2
Washhouse	13W/m^2
Dining-room	13W/m^2
Room	15W/m^2
Corridor	5W/m^2
Unconditioned	5W/m^2
Equipment	
Main hall	2W/m^2
Café	20W/m^2
Retail	13W/m^2
Washhouse	20W/m^2
Dining-room	5W/m^2
Room	20W/m^2
Corridor	0W/m^2
Unconditioned	0W/m^2
People	
Main hall	20m^2/person
Café	15m^2/person
Retail	6m^2/person
Washhouse	20m^2/person
Dining-room	10m^2/person
Room	15m^2/person
Corridor	20m^2/person
Unconditioned	20m^2/person
Room	11L/s/person
Corridor	2.7L/s/person
Set points	24°C for cooling and 20°C for heating with dead band
Operating schedules	
Main hall	01:00~24:00
Café	01:00~24:00
Retail	01:00~24:00
Washhouse	8:00~17:00
Dining-room	7:00~20:00
Room	01:00~24:00
Corridor	01:00~24:00
Unconditioned	01:00~24:00
HVAC system	
Air distribution system	4-pipe fan coil + fresh air
Water system	Two centrifugal chillers (COP=5.5), one oil boiler (η=70%), single-speed open cooling tower, constant speed primary/secondary chilled water pump, constant speed hot water pump

Table 3
Energy rates for commercial buildings in Shanghai

Spring, Autumn, Winter	Peak time	08:00~11:00,18:00~21:00	0.973 RMB/kWh
	Normal time	06:00~08:00,11:00~18:00,21:00~22:00	0.591 RMB/kWh
	Valley time	22:00~06:00	0.296 RMB/kWh
Summer(July, August, September)	Peak time	08:00~11:00,18:00~21:00	1.003
	Normal time	06:00~08:00,11:00~18:00,21:00~22:00	0.621
	Valley time	22:00~06:00	0.229
Demand charge	30RMB/kW*month(according to the maximal demand)		
Gas rate	2.3RMB/Nm^3		
Oil rate	6200RMB/ton		

3.2 ECM options based on baseline office and hotel models

In order to compare the energy saving effects, several ECMs (Energy Conservation Measures) are simulated based on baseline office and hotel models. Table 4 and 5 list ECMs for office and hotel models, respectively.

Table 4
ECMs for the office baseline model

Options and cases (combined options)	Descriptions
Option 1	Improving the insulation of external walls, reducing U-factor to 0.96W/m^2·K
Option 2	Enhancing glazing performance of exterior window to U=2.14W/m^2·K/SHGC=0.45
Option 3	Using external shading devices instead of interior window shading
Case 1	Option 1+ Option 2+ Option 3
Option 4	Using high-efficiency lighting luminaries to reduce the LPD of office areas to 12 W/m^2
Option 5	Option 4+daylighting dimming in perimeter area
Option 6	VFD secondary chilled water pump and VFD hot water pump
Option 7	Resetting chilled water and hot water supply temperature according to outside air temperature
Case 2	Option 6+ Option 7
Case 3	Option 1+ Option 2+ Option 3 +Option 4+ Option 5+ Option 6+ Option 7

Table 5
ECMs for the hotel baseline model

Options and cases (combined options)	Descriptions
Option 1	Improving the insulation of external walls, reducing the U-factor to 0.96W/m^2·K
Option 2	Enhancing glazing performance of exterior window to U=2.14W/m^2·K/SHGC=0.45
Option 3	Using external shading devices instead of interior window shading
Case 1	Option 1+ Option 2+ Option 3
Option 4	VFD secondary chilled water pump and VFD hot water pump
Option 5	Resetting chilled water and hot water supply temperature according to outside air temperature
Case 2	Option 6+ Option 7
Case 3	Option 1+ Option 2+ Option 3+ Option 4+ Option 5

4. Simulation Results

4.1 Simulation results of office baseline model and ECM options

Fig.1 illustrates the breakdown of yearly electricity consumption of office baseline model. HVAC system (including chiller, cooling tower, pump and fan) is the biggest electric consumer in the model, which accounts for 47% of total electricity consumption, while lighting and equipment account for 26% and 27% of the total electricity consumption, respectively. Since four-pipe fan coil system is used in the baseline model, pumps transport chilled water and hot water to coils in rooms while fans mainly supply fresh air, the electricity consumption of pumps accounts for 14% of total electricity consumption, but the electricity consumption of fans accounts for only 4% of total electricity consumption.

Table 6 shows the simulated results of yearly energy consumption and costs of office models. It also lists the static payback period of each ECM of the office building. Among the single ECM options, external shading, high-efficiency lights, daylighting and VFD pumps have big energy saving effect and short payback periods, while high performance envelope does not have obvious energy saving effect and the payback period is pretty long.

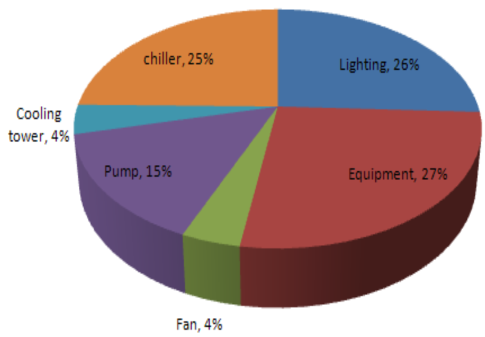

Fig.1. Electrical consumption breakdown of office baseline model.

Since office buildings are normally with big internal loads and their HVAC systems operate intermittently, e.g., from 7:00 am to 6:00 pm in weekdays, in summer high performance envelope with better insulation will prevent heat loss to outdoor during non-operating period, which may cause extra warming-up cooling loads. For office buildings located in the city like Shanghai with hot summer and cold winter, high performance envelope might not be a good ECM. External shading can reduce cooling load by decreasing the solar radiant heat gain. High-efficiency lights and daylighting dimming can reduce the internal cooling load due to lighting, which have big energy saving effects. VFD pumps can reduce not only the energy consumption of pumps, but also that chillers and cooling towers.

If all the ECMs are applied to the office building, it will be much better than the baseline model, with approximately 21% yearly cost saving and only 5.25 year payback period.

Table 6 Energy consumption and payback period summaries of office baseline model and ECM options

	Energy consumption(GJ)	Total cost (×10^4 RMB)	Cost saving(×10^4 RMB /y)	Investment(×10^4 RMB)	Static payback period(y)
Baseline model	56769	493			
Option 1	56700	493	0	46	—
Option 2	55929	485	8	457	57.2
Option 3	56093	486	7	3	0.44
Case 1	55225	478	15	507	33.8
Option 4	54397	471	22	24	1.1
Option 5	50992	438	55	30	0.54
Option 6	54110	470	23	9	0.41
Option 7	56727	493	0	0	—
Case 2	54101	471	22	9	0.43
Case 3	45667	389	546	546	5.25

Table 7 Energy consumption and payback period summaries of hotel baseline model and ECM options

	Energy consumption(GJ)	Total cost (×10^4 RMB)	Cost saving(×10^4 RMB /y)	Investment(×10^{4}RMB)	Static payback period(y)
Baseline model	66451	434.8			
Option 1	66332	433.6	1.2	52	43.4
Option 2	66102	431.3	3.5	147	42.1
Option 3	66210	432.9	1.9	1	0.52
Case 1	65820	428.8	6	200	33.4
Option 4	65309	427.4	7.4	2.3	0.31
Option 5	66203	433.5	1.3	0	0
Case 2	65115	426.5	8.3	2.3	0.28
Case 3	64388	420.0	14.8	202	13.7
Case 3	45667	389	546	546	5.25

4.2 Simulation results of hotel baseline model and ECM options

Fig.2 illustrates the breakdown of yearly electricity consumption of hotel baseline model. Different from the office baseline model, in the yearly electricity consumption of hotel baseline model, HVAC system (including chiller, cooling tower, pump and fan) only accounts for 27% of total electricity consumption, while lighting and equipment account for 37% and 36% of the total electricity consumption, respectively.

Table 7 presents the simulated results of yearly energy consumption and costs of hotel models. It also lists the static payback period of each ECM of the hotel building. Among the single ECM options, external shading and VFD pumps have big energy saving effect and short payback periods, while high performance envelope does not have obvious energy saving effect and the payback period is long. External shading decreases the solar radiant heat gain to reduce cooling and its payback period is also short. VFD pumps reduce not only the energy consumption of pumps, but also that of chillers and cooling towers. Temperature reset strategies almost does not need any cost, but it has not bad cost saving effect.

If all the ECMs are applied to the hotel building model, the energy saving effect not big either, with only 3.3% yearly energy consumption saving and long payback period.

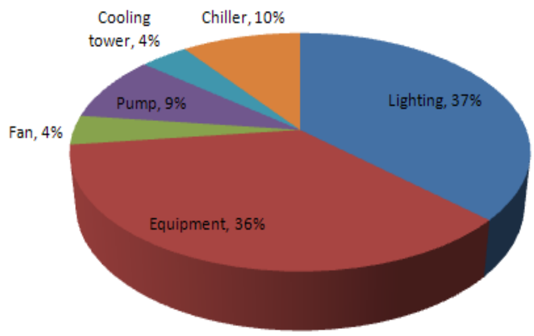

Fig.2. Electrical consumption breakdown of hotel baseline model

5. Conclusions

Baseline models for existing office and hotel buildings are built based on surveying data with whole building energy analysis software—EnergyPlus. Energy conservation measures are applied to baseline office and hotel models, respectively, to simulate and calculate the annual energy saving and payback period of the various strategies. Therefore the different features of the two type buildings are studied and energy saving retrofitting strategies appropriating for existing public buildings in Shanghai are found out. Conclusions can be drawn as followed:

(1) As the different usage of office and hotel buildings, lighting and equipment run only on duty time in office buildings, while in hotel buildings, lighting and equipment run throughout the entire day. Therefore the sum of the energy consumption of lighting and equipment in hotel buildings is much greater than in office buildings.

(2) One specific ECM has good energy saving effect on one type of building, but it may be not appropriate for the other type of building. For example, high-efficiency lights and daylighting dimming in perimeter area have great energy saving effect on office buildings, but they are not appropriate for hotel buildings retrofitting, because hotel buildings have higher standard requirement of visual comfort, which limits the application of high-efficiency lighting systems.

(3) One specific ECM might have different degree of energy saving effect on different types of buildings. For example, the effect of better insulation external wall on hotel buildings is better than on office buildings. In Summary, for office buildings, high performance window glass, external

shading, energy saving lights, daylighting dimming in perimeter area, variable pumps are effective ECMs; while for hotel buildings, high performance external wall and window glass, VFD pumps are effective ECMs.

(4) For existing office buildings, external shading, high efficiency lights, daylighting dimming in perimeter area and VFD pumps have short payback period. High performance external wall and window glass, temperature reset do not have obvious energy saving effect.

(5) For existing hotel buildings, external shading, variable pumps and temperature reset have short payback period. High performance external wall and glass have long payback period due to the high cost. Solar hot water system can be employed to reduce the energy consumption for domestic hot water, which might be analyzed in later research.

(6) The accuracy of simulating and analyzing energy saving effects of ECMs with prototypical models greatly depends on the rationality and representation of prototypical models. Building prototypical models are based on the surveying data from Shanghai Commercial Building Information Database. If the database can be enlarged by more building data, it will be more helpful to build more typical prototypical models and then achieve more persuasive study results.

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