The synthetic evaluation and analysis on technology of energy saving reform for existing public buildings in Shanghai Area

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Abstract. Nowadays, a large proportion of old buildings in Shanghai area cannot satisfy the energy efficiency standards, thus the reform of existing buildings still plays an important role in the process of achieving energy saving target. However, the systematic study and evaluation of corresponding technology and those completed demonstration projects is lacked, which has affected the clear and reasonable understanding of government and related owners about the effectiveness of those reform projects as well as the investment payback. In view of this, a synthetic study was carried out to investigate the characteristic of energy consumption for public buildings in Shanghai firstly. Then a deep analysis was conducted on the energy-saving reform technologies involved in those projects, including usage frequency, energy-saving ratio and economic performance. The results show that the demonstration projects have good economic efficiency. The average static and dynamic payback period are 2.69 and 3.15 respectively. Among public buildings, hotel and shopping mall have a higher energy saving potential and better investment returns. Some involved technologies have good cost performance, such as LED light, pump frequency conversion, air source heat pump, glass filming and free cooling. This study could provide support for relevant owners and policy-making of governments.

1. Introduction
With the rapid development of China’s economy in the past decades, more and more energy is consumed [1]. Statistics suggest that the total construction area of existing buildings in China is more than 58 billion m², and it is still growing at a rate of 2 billion m² a year [2]. Building energy consumption has accounted for 28.5% of the total social terminal energy consumption [3], and the energy consumption per unit area for public building is more than twice as much as residential building [4]. Thus, public buildings account for a larger proportion of building energy consumption. Wan et al [5] investigated 16 public buildings in Wuhan and analyzed energy consumption characteristics based on energy consumption calculation. Li et al [6] set up an evaluation index of operating energy consumption of air conditioning system in public buildings based on measurement data. Ma et al [7] investigated 50 public buildings in Tianjin based on statistical data of energy consumption, and identifies the factors that have obvious effect on energy consumption.

Taking Shanghai as research object, there are about 0.2 billion square meters public buildings that were built before 2005, and 70% of them are office, hotel and shopping mall [8]. These buildings have worked more than 10 years, equipment aging and outdated design code make them consume more energy compared with newly built buildings. Hence it is necessary to reform these old buildings, and make them become more energy-efficient, which is also an important task for Shanghai government.
In order to promote the energy-saving reform of old public buildings, the government of Shanghai issued a series of policy about the demonstration of reform projects [10]. However, as more and more demonstration projects are built, there is no systematic evaluation and analysis on these completed projects, which has hindered the reasonable understanding of relevant owners and governments on the effectiveness of these reform technologies and the coming investment on energy-saving reform [11]. Therefore, this study investigates 100 demonstration projects (mainly focus on office, hotel and shopping mall) in Shanghai area, and make an analysis on the usage frequency, energy-saving ratio and economic performance of different types of reform technologies. It is expected that the results of this study could provide guidance on reform projects and reference for governments.

2. Characteristic of energy consumption for public buildings

The energy consumption for 100 demonstration projects in Shanghai area is investigated, and the characteristic of buildings and the frequency of retrofitted sections are presented as below.

2.1. Characteristic of energy consumption for hotel building

Compared with other public buildings, the energy consumption of hotel is more complicated, and the main characteristics are as follows. a) The requirement of indoor environment is stricter than other public buildings, and central air-conditioning system is adopted by most of hotels and runs all of the year. b) Hot water is provided all of the day to meet the needs of guest. c) Most hotels are multi-story building, and the elevators are used frequently. d) Most hotels have washhouse, so oil and gas are needed to produce steam. e) Dining room, swimming room and gymnasium have different energy consumption behavior. f) Different from other public buildings, hotel often runs under part-load condition because of the number fluctuation of guests. For hotel, energy consumption includes electricity, gas and oil. Electricity is used on air-conditioning, light, socket, elevator and washing, which is the main energy consumption and accounts for 70%. Gas and oil are used on heating, hot water and cooking etc., which account for about 30%. As is shown in figure 1, taking a typical hotel as an example, air conditioning, heating and hot water consume about 35.3% of energy, and lighting consumes about 24.7%. The other section of energy consumption comes from socket, laundry, cooking, fan etc. The energy saving retrofit for hotel mainly focuses on air conditioning, light and hot water system. Figure 2 gives the frequency statistics of retrofit for different energy consumption system for hotel, and it shows that air-conditioning, hot water and lighting system have higher frequency than other sections. The energy consumption per square before and after retrofit are shown in table 1, and the average energy saving ratio reaches up to 23.2%.

![Figure 1. Energy consumption of different energy system for hotel building.](image1)

![Figure 2. Energy saving retrofit frequency of different energy system for hotel building.](image2)
Table 1. Energy consumption per square before and after retrofit for hotel building.

| Energy consumption Per unit area | Maximum Value (W/m²) | Minimum Value (W/m²) | Average value (W/m²) |
|----------------------------------|----------------------|----------------------|----------------------|
| Before retrofit                  | 354.3                | 137.0                | 230.6                |
| After retrofit                   | 278.9                | 104.2                | 173.7                |

2.2. Characteristic of energy consumption for office building

The energy consumption of office building has the following characteristics: a) Thermal performance of envelope has a large impact on energy consumption. The U value of building envelope is about 2.0 W/(m²K) before 2005, while it turns to be 1.0 W/(m²K) after 2005 when new energy saving rule was implemented. b) The energy consumption of air conditioning, light and other facilities for office building are regular and stable, and the intensity of energy consumption depends greatly on office area per capita, working time etc. Reducing the energy consumption of office appliances during non-working hours or replace them with high-efficiency ones plays an important role in retrofit projects. c) For the service equipment, such as elevator, water heater and water pump, they often start-stop frequently, and their load change randomly. The energy consumption of them accounts for 5%~10%. d) Special equipment, such as telecom room, consumes a large proportion of energy, which accounts for about 30~40% for office building. e) Many office buildings have a long history, and are confronted with equipment aging and rising users, which also pushes up the intensity of energy consumption.

For office building, electricity is mainly used for air-conditioning, light, socket, fan and pump etc., while oil and gas are often used for space heating. Taking a business office as an example, it is presented in figure 3. Air conditioning consumes the largest proportion of energy and accounts for 37%. And the other large parts are lighting system and indoor facilities which account for 30% and 24% respectively. The energy-saving retrofit of office building mainly focuses on air-conditioning and lighting system, and the control system also has a relatively high frequency, as is shown in figure 4. According to the energy consumption data before and after retrofit in table 2, the average energy saving ratio is up to 23.3%.

Figure 3. Energy consumption of different energy system for office building.

Figure 4. Energy saving retrofit frequency of different energy system for office building.

Table 2. Energy consumption per square before and after retrofit for office building.

| Energy consumption Per unit area | Maximum Value (W/m²) | Minimum Value (W/m²) | Average value (W/m²) |
|----------------------------------|----------------------|----------------------|----------------------|
| Before retrofit                  | 184.4                | 49.8                 | 119.1                |
| After retrofit                   | 134.3                | 39.4                 | 91.4                 |
2.3. **Characteristic of energy consumption for shopping mall**

Compared with hotel and office building, shopping mall has the following characteristics: a) Shopping mall is often very large, and has high people flow density and indoor heat gain. The impact of thermal performance of envelope on energy consumption for shopping mall is small. b) The early built shopping mall often adopts constant-air-volume air conditioner and fixed-frequency fan and pump, which leads to high energy consumption for the part of transmission and distribution system. c) Shopping mall often opens more than 12 hours both on weekdays and weekends. d) Some shopping malls also have refrigerating equipment with high energy consumption, which needs specific technology to save energy.

For shopping mall, electricity is the main type of energy consumption. In addition to the air-conditioner, socket, light, electricity also supports the refrigeration system. And gas is mainly used for heating, hot water or cooking. Taking a shopping mall as an example, as shown in figure 5. Air-conditioning and heating system account for the largest proportion (totally 57.4%), followed by light, indoor facilities and service system. The energy retrofit for shopping mall focuses on air-conditioning, lighting system and other sections, just as shown in figure 6. The other sections include adding human induction device on escalator, adding lid on freezer, adding energy control system and so on. The average energy saving ratio for shopping mall is about 26.2% based on the energy consumption data before and after retrofit presented in table 3.

![Figure 5. Energy consumption of different energy system for shopping mall.](image)

![Figure 6. Energy saving retrofit frequency of different energy system for shopping mall.](image)

| Energy consumption Per unit area | Maximum Value (W/m²) | Minimum Value (W/m²) | Average value (W/m²) |
|---------------------------------|----------------------|----------------------|---------------------|
| Before retrofit                 | 362.1                | 112.9                | 255.1               |
| After retrofit                  | 279.6                | 88.9                 | 188.3               |

3. **Usage frequency of reform technologies for public buildings**

The energy saving retrofit of public buildings is subjected to many factors, such as building property, characteristic of energy consumption, complexity of energy system, energy saving potential and payback period. In practice, the energy saving technology that is easy to implement, and has good effect and quick market repay is adopted usually. Figure 7 gives the top 10 technologies for hotel, office and shopping mall respectively, and these technologies have a relatively high usage frequency. It can be seen that, for hotel, LED light is the most popular technology. In addition, replacing the oil burning boiler and gas burning boiler with air-source heat pump or water heater is also widely used. For office building, LED light, variable-frequency pump, air-source heat pump and group control of refrigeration plant room have a high frequency. And replacing the single-glass window with double-glass window is also popular in the retrofit of office. As to shopping mall, besides LED light, adding lid on freezer is an easy and cheap way to reduce the energy consumption, which is frequently used. And variable-frequency fan, condensation heat recovery, free-cooling are also popular technologies.
Figure 7. Energy-saving technology based on frequency: a) Hotel building; b) Office building; c) Shopping mall.

4. Energy-saving ratio of reform technologies for public buildings

Figure 8 presents the top 10 technologies for three types of public buildings from the viewpoint of energy-saving. For hotel building, heating and hot water consume a large proportion of energy, and changing the oil or gas burning boiler with heat-source tower heat pump or air-source heat pump and hot-water heater has a good energy-saving effect. Besides, centrifugal chiller also has a good performance. For office building, replacing the oil-burning boiler and LiBr absorption chiller with
VRF air-conditioning unit saves the most energy (16.5%). And air-source heat pump, LED light and centrifugal chiller also reduce considerable energy consumption. For shopping mall, the energy systems often work under part-load, and screw chiller has the highest energy saving ratio (19.2%). And LED light, variable-frequency centrifugal chiller and air-source heat pump also save more than 9% of energy consumption.

5. Economic performance of reform technologies for public buildings

The retrofit cost per unit area for the three types of buildings is presented in table 4. And it shows that the rank of average retrofit cost is: Office> Hotel> Shopping mall. The average static and dynamic payback period are used for the economic performance evaluation of retrofit projects, and the results are shown in figure 9. It can be seen that shopping mall has the lowest static and dynamic payback period (2.12 and 2.6 years respectively), while the payback period of office building is the largest (5.13 and 5.6 years respectively), which means that the economic performance of shopping mall retrofit is the best. As to the economic performance of different technologies, the amount of investment for the technology that could save 10 thousand kWh is used. Figure 10 gives the top ten technology ranking for the three public buildings. For hotel, condensation heat recovery is the most economic efficient technology whose cost is only 9000 yuan per 10^4 kWh. And LED light, group controlling of refrigeration room also have a good economic performance. The high cost for screw chiller makes it less economic efficient. For office building, the average cost of technology is greater than that of hotel. LED light and energy-controlling system are the best cost-efficient technology, and saving one kWh only costs 2 yuan. Similar to screw chiller, centrifugal chiller also costs a lot, which make it less cost efficient. It is worth noting that variable-frequency fan does not have a good economic performance. For shopping mall, compared with the other two public buildings, the average cost that could save the same energy is the lowest. For example, the variable-frequency for centrifugal chiller, variable-frequency pump, solar power system, adding lid on freezer only need less than 1 yuan per kWh, which have good economic performance.

| Type          | Maximum value (¥/m²) | Minimum value (¥/m²) | Average value (¥/m²) |
|---------------|----------------------|----------------------|----------------------|
| Office        | 593                  | 47                   | 149                  |
| Hotel         | 233                  | 108                  | 112                  |
| Shopping mall | 179                  | 68                   | 105                  |

Figure 9. Static and dynamic payback period for three types of public buildings: a) Static payback period; b) Dynamic payback period.
6. Conclusions
Generally, the demonstration projects have good economic efficiency, the average static and dynamic payback period are 2.69 and 3.15 years respectively. Among the public buildings, shopping mall and hotel have better economic performance and investment return, which is also proved by the market selection. The average investments per unit area are 112 and 105 yuan, and the static payback period are 2.5 and 2.0 years respectively. The intensity of energy consumption for the two public buildings are large, and the energy-saving potential is great. Thus, the focus of energy saving retrofit for public buildings should be placed on hotel and shopping mall. The static payback period of office buildings reaches up to 5.5 years, and some case is more than 6 years. Thus, it should enhance investigation and explore better retrofit plan. Most office adopt rental mode, and the renter pays the lighting fee, which makes the investigator difficult to get profits of lighting retrofit. The average retrofit cost per unit area of demonstration projects is about 107 yuan, and the government subsidy accounts for 25% of total cost. It’s expected that the subsidy could promote the energy-saving retrofit of public buildings in Shanghai. The energy saving and economic performance of technology vary for different types of building. For hotel, LED light, air-source heat pump and condensation heat recovery are the most efficient technology. As to office building, LED light, variable-frequency pump and group controlling of refrigeration equipment have better performance. And for shopping mall, LED light, adding lid on freezer, variable-frequency fan and free cooling are efficient technologies.

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