

# Energy-Saving retrofitting strategies in historical buildings

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## Abstract

Building efficiency has become an important part of energy-saving policies in the world. However, ecological energy-saving research on historical buildings (HB) is still relatively new. In this paper, principles of HB retrofitting project are briefly described and the strategies for energy-saving in HB used before are summarized. An example of a HB at University of Shanghai for Science and Technology (USST) is analyzed for strategies in preservation of historical and natural value, energy efficiency, and sustainable development. Based on this precedent at USST, this paper offers three suitable eco-energy saving strategies, including air-conditioning efficiency, renewable energy utilization and natural ventilation.

*Keywords: Historical building, energy-saving strategies, building retrofitting, natural ventilation*

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## 1. Introduction

Since the United Nations Climate Conference was convened in Copenhagen, Denmark, environmental problems have attracted much public attention. Facing the energy crisis, environmental devastation and greenhouse gas effects, the need for energy alternatives and emissions reduction is growing fast [1]. Developments of sustainable design have become an urgent task in the world. Building energy consumption accounts for nearly 30% of total energy consumed, therefore better efficiency plays a very important role in protecting the environment and saving energy [2]. In this paper, we investigate a renovated historical building's energy saving strategies by the research of a site on the USST campus.

Regarded as a sign and symbol of a city, historical buildings represent a unique style and have well-defined cultural features. "Flowers and trees are growing around the bay of the Pu Jiang River, three or five red buildings stand by the river, and Hujiang University is here". This is a description of the USST campus 70 years ago, used to be Hujiang University at that time, located in the west bank of Huangpu River in northeast Shanghai. Since 1906, over 40 years ago, more than 50 Gothic Style buildings were built to form the university's beautiful campus. More than 30 of the historical buildings on the USST's campus were included in a published list of excellent buildings in Shanghai. These buildings preserve the historical form of the campus from the Hujiang University period. Therefore, they represent a rare and precious cultural heritage for Shanghai and China.

The traditional American, three-sectioned, college layout and architectural styles were adopted by Hujiang University. It was designed by the American architect Henry Murphy in the MUPPHY&DANA Planning Office in 1919 and was Murphy's second project in China. Compared with the typical cold gray gothic-style campus, the Hujiang campus was lively and its appearance showed the trend of convergence. This style is considered as a simplified Gothic Revival style. Among the HB's in the original Hujiang campus, many features of the gothic style can be found, such as steep roof, vertical lines, elaborate window ornamentation, external buttresses, decorative minaret, castle entrance, connected towers and wall relief.

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## 2. Ecological Energy-Saving Strategies

According to current specifications and codes for conservation and renovation of historical buildings and cultural heritages, the strategies for protecting the outstanding HB require keeping the original state of the building. The repairing must be consistent with the original characteristics, including the materials and textures used to be as similar as possible. While protecting the architectural heritages, the building efficiency can be improved to maintain low energy consumption [3]. For the reconstruction of historical buildings, the architectural and history style cannot be changed or altered, and a balance between energy efficiency and architectural heritages should be achieved.

Outstanding historical architectural style and internal structure of buildings cannot be changed during repairing. This results in some disadvantages in energy-saving implementation during the renovation. Walls of all the HBs are made of red brick, and roof is composed of tile, well, linoleum, roof plate then purlin layers without insulation. According to the design standard for energy efficiency of public buildings, energy saving measures for outside retaining structures is needed. However, this may cause destroying of the original façade of the exterior insulation system and changing the original structure of external wall insulation system, therefore these options cannot be adopted [4]. Although external wall insulation systems can avoid the impact on original façade and structural system, it will still affect the building's interior. Furthermore, the general strategies that change the building's structure, including building shading system, wind porch and wall insulation, are not suitable for renovating historical buildings as well. Using a precedent study of HB at USST, this paper provides three strategies for energy saving reconstruction; improving air-conditioning efficiency [5], renewable energy utilization and natural ventilation [6].

## 3. Improving Air-Conditioning Efficiency

Shanghai is located in a hot summer and cold winter climate zone. Under extreme weather conditions, air-conditioning systems are heavily used to regulate indoor thermal comfort. However, this method is plagued by high energy consumption, which results in harmful emissions and the destruction of the ozone layer [7]. Currently, the historical buildings at USST are equipped with the traditional split wall air conditioners that are damaging to the architectural image of these old buildings. As shown in Fig. 1, the air-conditioning units being used are bad for the environment because they have low operation efficiency, high energy consumption and are loud. Based on studies of the Environment and Architectural Academy at USST, the researchers recommend replacing the current air conditioning with a new centralized air conditioning system to achieve energy savings during the reconstruction [8].



Fig. 1. Air-conditionings units making great damages to HB facades.

Central air conditioning systems consist of five parts; cold and heat sources, air treatment equipment, wind systems, water systems and air automatic control and regulation devices. In the summer, air conditioning units will cool down the refrigerant water and then pump it to the treatment equipment for heat exchange with the air, as shown in Fig. 2(a). The formative cold air will be transported to the inside room, and a small part of the indoor endothermic cool air is drained outside. In winter, the water will be heated by the air-conditioning heat pump units, then pumped to the air treatment equipment for heat

exchange, and pumped back to the room after becoming hot air, as shown in Fig. 2(b). A small part of the hot air will be drained outdoor by the air conditioning duct systems.

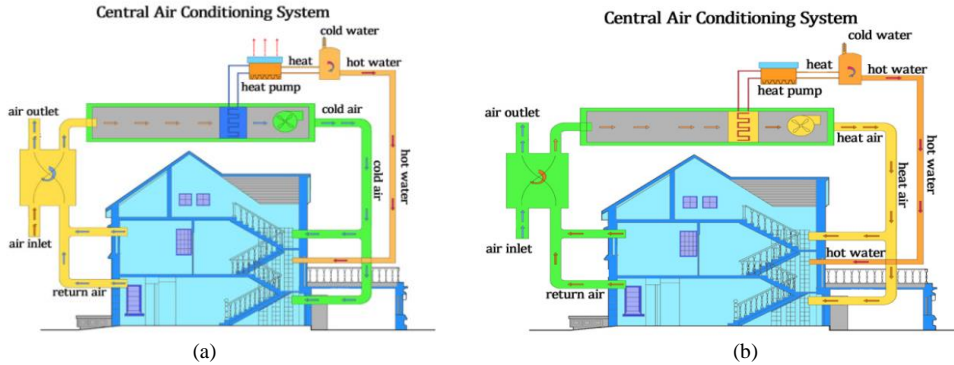


Fig. 2. Schematic diagram of central air conditioning (a) in summer and (b) in winter.

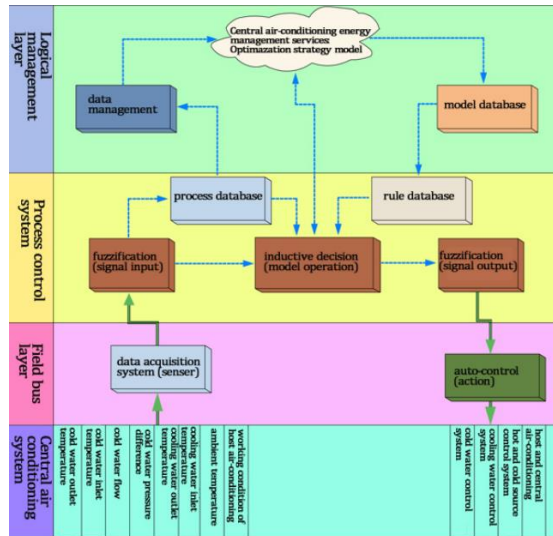


Fig. 3. Logic structure diagram of new central air-conditioning control system.

Fig. 3 shows the differences of working principle between the general central air conditioning and new central air conditioning system, which manifested into mainly four points; automatic control and regulation equipment, ventilation system, cold and heat sources re-use, and air-supplying system.

### 3.1. Automatic control and regulation equipment

Traditional central air-conditioning and equipment regulations are controlled by quantitative water, and temperature or constant air volume. In operation, it is laborious for the staff to adjust water quantity, water temperature or air quantity according to the temperature outside. However, the new central air conditioning system is an intelligent system that can automatically adjust water quantity, water temperature or air quantity according to the large buildings load and outdoor temperature. Combined with the adaptive PID precise control algorithm, fuzzy control theory, collecting operating and meteorological parameters of this intelligent system could control chillers, by chilling water pumps, cooling pumps and cooling tower fan in a centralized way [9]. This system not only automatically adjusts outputs of all devices according to load, but also automatically adjusts the chilled water outlet temperature, which greatly improves the efficiency and solves the difficult coordination problem of central air conditioning. This allows the central air conditioning to work in the most energy-saving way and good air quality of

indoors is achieved. The new central air-conditioning system is a practical and reliable automatic control system, which meets the requirements of comfort, energy saving and manageability. In addition, system transportation strategy and process optimization algorithm are adopted in the system, which can reduce 30% of air conditioning energy consumption. The endmost fan coil uses brushless DC technology that not only makes little noise but also achieves high efficiency; an average of 40% consumption saved over the traditional AC fan coil section.

### 3.2. Ventilation system

In summer, a lot of heat is emitted outside by air ventilation systems, which can cause urban heat island effect [10]. If the heat can be recycled, it would not only contribute to the environmental initiatives, but also improve energy efficiency. The new central air conditioning ventilation system conducts a pre-heat-exchange with outdoor fresh air. This exchange happens when the cold air discharged in the summer can conduct an early exchange to the hot air outdoors and when the hot air is discharged in winter, and it can also conduct an early exchange to the cold air outdoors. Cooling and heating energy consumption can be greatly reduced for the air conditioning.

### 3.3. Cold and heat sources re-use

In winter, air conditioning heat pump units provide heat for the room as well as hot water. The air conditioning heat pump units recycle the discharged heat to provide free hot water for the house. This can greatly improve the energy efficiency of the air conditioning system. It is estimated that 25% of energy can be saved by new central air conditioning using the heat recovery system.

### 3.4. Air supply system

The new central air conditioning system uses an independent fresh air system and floor variable air volume system that takes activity in the indoor space into consideration. The fresh air provided by the underground ventilation system comes from bottom to top, so the fresh air zone forms near the ground to achieve good air quality around the users. The traditional air conditioning is the top-down mode, so fresh air easily mixes with indoor air, which will reduce the indoor air quality and temperature of the indoor activity layer [11]. In order to reach the appropriate indoor quality, air conditioning energy consumption will be increased. The underground ventilation system will guarantee high-quality fresh air to the indoor users, and the fresh air content is 30% higher than the traditional air conditioning system.

The fresh air provided by the underground ventilation system circulates from bottom to top, which is conducive to a comfortable temperature environment for the human body. To achieve the same effect for surface temperature, the temperature supplied by the traditional air conditioning needs to be maintained from 17 to 20°C, but the temperature supplied by the underground air conditioning only needs to be maintained from 21 to 24°C [12]. Compared to the traditional system, this will save 20% energy, and dramatically reduce the energy consumption. In addition, the power, data, communications and other cable or equipment can be located under the raised floors, to greatly increase the flexibility of office space. The office staff can also adjust the heat environment around the office to a comfortable level. Air conditioner circulating pump can get maximum transport efficiency ratio  $ER = 0.0228 < 0.0241$  (in summer) by the listed several energy-saving mode above. This is consistent with national standard "Public Building Energy Efficiency Design Standards" (GB50189-2005).

## 4. Full Utilization of Renewable Energy

With constant challenges of energy supply, raising costs of fossil fuels and the tremendous impact of greenhouse gases on the global climate, it is an important part of the sustainable development to seek renewable energy to replace fossil fuels in the future. Solar energy, geothermal energy and other renewable energy utilization are the optimal energy sources for future buildings. Renewable energy is also valuable in the reconstruction of historical buildings [13].

To protect HB architectural style, installment any additional auxiliary facilities on the building's façade or top are not allowed. However, some different strategies can be adopted without changing exterior appearance, such as putting solar collector panels on building roof to achieve the integration and function. The historical building at USST has a slope roof, where the solar collectors can be installed to the South to absorb maximum solar radiation [14]. The installation forms can be aerial, affixed roof or embedded installation. In this case, to avoid damages to the HB's roof, affixed roof installation is selected. Solar collector panels not only effectively collect the solar energy, but also act as the roof tiles. The panels can keep the house warm in winter and also keep cool air insulated in summer, which can greatly reduce the energy consumption of air conditioning, as shown in Fig. 4.

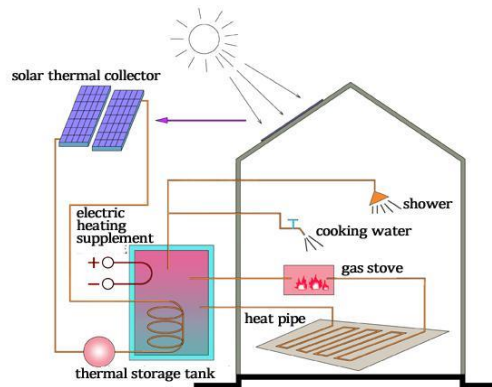


Fig. 4. Schematic diagram of building integrated solar energy.

Solar energy is clean, safe, and accessible without mining and transportation costs and effects. However, it can be discontinuous and unstable. Generally speaking, most solar water heaters have to use auxiliary heating power, which can cause pressure on the public power system during peak usage time. For ecological efficiency improvements, solar energy heat pump technology can be used to accumulate the heat during the off-peak periods [15]. By using a multi-function tank heat accumulator, the solar will be used to collect the heat in the daytime and then gather the heat through off-peak electricity during nighttime. These methods will reduce the load of the public power system and save energy costs. According to the sunshine in this region, the actual rate of solar energy can be ensured up to 52%, and the central grid electricity can make up for the insufficiencies. Thus using solar power greatly reduces the use of unsustainable energy, which means a lot to China's energy saving initiative.

## 5. Natural Ventilation

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Natural ventilation, the original means of regulating indoor environment, is a mode with great potential. It has several advantages such as energy saving, improving indoor thermal comfort and air quality. Air conditioning technology was quickly implemented to office, commercial and residential developments,

but this mechanical ventilation is still widely used today. Now, due to mass pressure on the large use of electricity and requirements to improving indoor air quality, scientists have begun to research and understand the overlooked importance of natural ventilation [17].

The process of natural circulation includes various methods of ventilation, such as, wind pressure, heat pressure and mechanical auxiliary [18]. Modern natural ventilation is a comprehensive utilization of indoor and outdoor conditions, which differs from the past method of simply opening windows and doors. For example, we organize the natural ventilation according to the architectural environment and layout, building structure, solar radiation, climate, and indoor heat source, among others. In buildings' construction, we achieve good natural ventilation effects by means of optimal design of atriums, double walls, wind towers, doors, windows and roofs. The main modes of natural ventilation commonly used in buildings are as follows:

- Wind pressure

The basic driving force of natural ventilation is wind and heat pressure. Wind pressure can be regarded as the main way of natural ventilation in a favorable external environment.

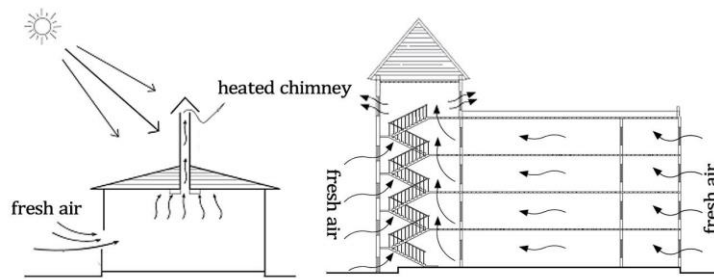


Fig. 5. Principle of solar chimney and heat pressure ventilation.

- Heat pressure

Another driving force of passive ventilation is temperature, specifically heat pressure ventilation. It adopts the internal and external air pressure between buildings, called the “chimney effect” to achieve the goal of natural ventilation. By using the theory of hot air rising, air vents are set at the top of the building to release the dirty, hot air to the outside, allowing the cold fresh air to be sucked from the bottom of the building. Heat pressure effect is related to the height difference between the air inlet and outlet, and it is also related to the temperature difference between the inside and outside. The greater the height or temperature the difference is, the more obvious the heat pressure effect. In architectural design, we can use a vertical cavity that is through the layers of the building inside, such as staircases, courtyard and pulling air shaft, to meet the requirements of the ratio between air intake and outlet. Finally, hot air in the building could be removed by an easily controlled outlet on the top to achieve the purpose of natural ventilation, as shown in Fig. 5. Compared with wind pressure ventilation, heat pressure ventilation can be more easily adapted to variable wind environment giving it a broader applicability [19].

- Wind pressure and heat pressure

- Mechanical auxiliary

In some large buildings, the ventilation path is long and the flow resistance is large, therefore relying on the natural wind pressure and heat pressure is often insufficient to achieve effective natural ventilation. For cities with serious air and noise pollution, natural ventilation will directly bring dirty air and noise into buildings, which is harmful to the user's health. In this case, the mechanical auxiliary ventilation system is necessary. This system has a comprehensive air circulation channel, supplemented with air-handling that has a more sustainable process, using soil pre-cooling, warm, and deep well heat transfer, and speeds up the indoor ventilation with various machine-assisted ways. For some buildings with a number of rooms and complex forms, CFD provides an optimal way to design energy savings in buildings [21]. This paper selects Fluent Air-pak as a research tool to study airflow field at USST [22]. Air-pak can accurately simulate the air quality, heat, pollution and comfort of the airflow ventilation

systems, and reduce design risk and cost. The theory and governing equations are provided by Tom, Blocken and Carmeliet.

## 6. Conclusions

"Energy savings" has become a basic state policy of China, and is going to be the key focus of many professions. However, HB energy saving reconstruction is still a new topic in China, and there are many aspects to explore and practice to improve efficiency.

In this paper, a historical building at USST was studied and three feasible eco-energy saving strategies were proposed. According to the analysis of natural ventilation, using new central air-conditioning and renewable energy technology, up to 30% total annual energy consumption can be reduced. In addition, we can use professional equipment simulation and analysis to optimize the design to achieve the desired effect. In the energy saving renovations for HB, the building needs to be regarded as a living organism, to allow the improvements to achieve a harmony with the nature. As the green building concept is becoming more deeply rooted in the social agenda and the importance of implementing energy conservation and emissions reduction is growing, HB's have potential to be redevelop as a natural ecosystem that makes use of natural ventilation and other green design methods.

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