

Innovative Energy Design for Energy Efficient Buildings - An Example from the Bullitt Center

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Abstract. In recent years, the extreme climate caused by global warming has brought serious consequences to the world. In order to alleviate the problem of global warming, many scholars have started to analyse energy-saving green buildings. Taking the Bullitt Center as an example, this paper illustrates the innovative applications of energy-efficient buildings in solar power generation, rainwater collection and utilization, toilet water conservation and resource utilization and room temperature regulation. It focuses on the differences in the use of solar power generation in winter and summer, the process of purification of rainwater into water, the comparison between composting toilets and vacuum toilets and the steps of regulating the room temperature by windows and ground-source heat pumps. This paper also talks about the limitations of these innovative applications. It could probably give reference to the subsequent construction of buildings, thus promoting energy saving and emission reduction in buildings and mitigating global warming.

Keywords: Energy efficiency, innovative design, architecture, Bullitt Center.

1. Introduction

With the impact of human activities on the ecological environment, a number of problems have emerged in recent years and human beings are gradually concerned about climate change and environmental protection. The Sixth Assessment Report of the IPCC reveals that the global average surface temperature for the last 10 years (2011-2020) is 1.09°C higher than that of 1850-1900 and 0.19°C warmer than that of 2003-2012. The last four consecutive decades have been the warmest decade since the 1850s. This shows that global temperatures are still on an upward trend and that global warming has not stalled [1]. Solving the climate problem is a matter of vital importance. On December 12, 2015, the Paris Agreement was adopted by 196 parties while on November 4, 2016, it entered into force. Its goal is to limit global temperature rise to less than 2°C above pre-industrial levels, preferably within 1.5°C [2]. Countries have demonstrated their determination to control the magnitude of climate change. The construction of a class of eco-friendly buildings to protect the ecological environment has become a hot research topic.

On the other hand, the global energy market is currently experiencing severe cyclical energy shortages, with below-average stocks of natural gas, oil and coal in major energy-consuming regions around the world and the sharply climbing prices of them. Electricity price in Europe has spiked dramatically due to the supply of natural gas and other energy sources. According to The Economist, wholesale electricity prices in Germany and France have risen by 36 percent and 48 percent respectively since the beginning of September 2021, currently hovering at a record high of around €160 per megawatt hour. In the UK, electricity prices, on the other hand, are as high as £385 per megawatt hour. In Asia, coal price has also gone up. In India, a major coal-producing country, coal reserves fell daily for three consecutive weeks, Bloomberg reported. Coal stocks at the country's power stations are 80 percent lower than they were in 2020, causing spot electricity prices to soar to their highest level in the past 12 years [3]. The continuous high price of traditional energy makes new energy products gradually become substitutes. With the continuous development of technology, solar power generation, rainwater recycling, geothermal energy use and other technologies can gradually optimize the energy structure of the building, thereby reducing energy consumption as well as environmental pollution, achieving the rational use of resources and recycling.

In such severe context, the Bullitt Center was founded in Seattle, Washington, USA on April 22, 2013. It is currently the most environmentally friendly commercial building in the world. In April of 2015, it was certified as 'Living Building' by the International Future Living Institute [4]. The Bullitt Center makes comprehensive use of many energy technologies to achieve net-zero water, net-zero energy and negative carbon emissions. The building is unique in its design of solar power generation, rainwater collection and utilization, water saving and utilization of toilets, and room temperature regulation system. It can be seen that energy efficient buildings have great potential in terms of eco-friendliness as well as energy saving. Therefore, this paper analyses the energy innovations of energy-efficient buildings, taking the Bullitt Center as an example, in the hope of contributing to future research on energy conservation in buildings.

2. Energy innovations

2.1. Solar power

The Bullitt Center has a powerful solar power system. The most central part of these solar panels is located on the roof of the Bullitt Center. There are 575 solar panels in total, covering 14,303 square feet [5]. This makes the Bullitt Center look like a square academic cap, which provides shade and increases the utilization of solar energy at the same time. In the first 10 years since its inception, the generation system of Bullitt Center generated 2,475,021 kWh of electricity, which is 551,481 kWh more than the demand, while the average annual electricity consumption of Seattle residents in one household is 13,375 kWh [6]. Therefore, in terms of total amount, the Bullitt Center is definitely self-sufficient in electrical energy. However, as the Bullitt Center is located in the northern hemisphere with latitude and longitude coordinates of about 47N and 122W, the difference in sunlight intensity between summer and winter results in seasonal fluctuations in the amount of electricity generated at the Bullitt Center. During the summer months, when light intensity is at its highest, the Bullitt Center generates much more electricity than it needs. The excess electricity goes into the local grid and is delivered to other places in need of electricity. During the winter months when light intensity is at its lowest, the Bullitt Center generates less electricity than it needs. The building requires electricity from the local grid [5]. In this way, the electricity transmission works in an annual cycle. To increase the sustainability, energy-efficient buildings need to maintain an overall balance of electricity generation and consumption.

2.2. Rainwater collection and utilization

The Bullitt Center has a unique and efficient rainwater collection and utilization system. Seattle is a region with abundant precipitation. Based on the expression "rainwater collection = monthly precipitation $\times$ area of water collection devices $\times$ transport efficiency", it can be calculated that the theoretical value of precipitation available to the Bullitt Center is approximately 300,000 gallons [7], which makes the use of precipitation as a source of water for the building entirely feasible. And in fact, precipitation is the only source of drinking water for the entire Bullitt Center. Some of the water is even recycled twice. The first stage of the entire rainwater harvesting system is the conversion of precipitation into clean water. Rainwater harvesting devices are installed on the roof of the Bullitt Center, whose outward extension design of the roof increases the efficiency of rainwater harvesting. The collected water is transported along pipes to a storage tank in the basement. This tank can hold 56,000 gallons of water [8]. The water is then purified by entering a water purification system. The first device is a vortex separator, which uses a certain pressure to inject the liquid containing particles and impurities from the rectangular inlet of the incoming fluid into the cone at high speed along the tangential direction. Then it makes the rainwater do spiral movement from top to bottom so that the liquid produces external vortex in the cone. In case of that, the solid particles in the liquid are thrown to the inner wall of the cone under the action of centrifugal force and are discharged along the inner wall from the bottom flow outlet under the force of gravity and the driving force of the liquid. The separated clean water reaches the bottom of the cone and then spirals up along the axis of the cone,

forming an internal vortex, which is discharged from the outlet of the vortex separator, thus achieving the separation of dirty water and clean water. This device can remove large particles from the water. The initially filtered water is then passed successively through two tanks with successively smaller sieve radii to filter out finer impurities. Thereafter, the fully filtered water is sterilized by ultraviolet light. The water is then ready for daily use, which implies the end of the first stage of the rainwater collection and utilization system.

The second stage of the rainwater collection and utilization system is the purification and reuse of gray water. Gray water is used water that comes from sinks, showers, laundry rooms, etc. and does not contain harsh chemicals. Gray water is the opposite of black water, which is used water that comes from toilets or contains harsh chemicals. Gray water is less pathogenic, requires less purification and is less harmful to humans when used twice. The gray water is collected via piping into a 550-gallon storage tank in the basement [8]. After purification, the gray water will first be used for toilet flushing in the toilets of the Bullitt Center. Excess gray water will be conveyed to the green wetland roof on the third floor of the Bullitt Center, which contains native plants, gravel and soil. This gray water follows a specific pipeline route watering the vegetation and is also purified by the vegetation and soil. The water will then flow down a biological channel made up of vegetation. It passes through 20 feet of gravel to reach the water table [8]. This biological pathway plays an important role in times of heavy rainfall. Excess rainwater is retained and absorbed by the layers of vegetation, greatly reducing the final flow into the ground, thus reducing urban surface runoff and flood flow around the site. The volume of precipitation that can be captured by the Bullitt Center's water conservation system was actually measured to be 128,800 gallons [7]. In terms of water use, the Bullitt Center is fitted with low-flow taps with vacuum toilet systems, which are designed to reduce water use while ensuring that they are able to perform their functions. Water utilization has been increased. With these water-saving designs and the tenants' awareness of water conservation, the Bullitt Center uses approximately 64,324 gallons of water per year [9], which is far less than the amount of water collected. The Bullitt Center can be self-sufficient in water resources. While the use of precipitation as a water source allows for a high degree of resource utilization, this sustainability is based on the premise that climatic precipitation is stable. Unusual changes in the weather can have a decisive impact on the water supply for the entire building. In addition, roofs may retain contaminants, water sources may harbour microorganisms, so water quality will deteriorate if water is stored in cisterns for more than five months [9]. Energy efficient buildings like the Bullitt Center need more diverse water supply options to cope with emergencies such as prolonged droughts and severe contamination of precipitation water quality.

2.3. Toilet water conservation and resource utilization

The Bullitt Center has an efficient toilet system. From 2013 to 2021, the toilets were on a composting system. This is an innovative type of toilet. It holds and biologically treats human excreta, which is broken down to form compost [10]. When the composting toilet at the Bullitt Center is used, the surrounding air will be drawn continuously into the toilet, making it less likely to produce odors. After use, the excreta will be piped into the composters in the basement. There are 240 composters and 24 composting rooms in the basement. Oxygen enters the composter through the toilet bowl and mixes with the excreta in the composter. The mixture will be heated to 165°C to kill potential pathogens and to control the humidity. Subsequent composting of the raw material will be fermented to form a product. The product can be used to fertilize vegetation in the Bullitt Center and beyond. The advantages of this approach are highlighted by the facts that the composting toilet saves 96 percent of water throughout the process compared to a standard flush toilet [8], the fan extraction and foam flushing could probably maintain the cleanliness of the toilet and the faeces is converted to fertilizer more quickly. However, this type of processing has many disadvantages. The large size of the composting machines and the close arrangement of the composters in the composting room make it difficult to carry out maintenance on these composters. As the correspondence between the toilet and the composting machine is fixed, the amount of compost in different composting machines is

different, the composting cycle is not synchronized and the management work is more cumbersome. Foam water flushing of the toilet is not effective and toilet paper residue is sometimes found on the inner wall of the toilet. When there is a power failure, the extractor fan does not work, which means the toilet cannot effectively remove odors [11]. To address these issues, the toilet system underwent a major overhaul in 2021, replacing the composting toilets in the toilets with vacuum toilets. Vacuum toilets make greater use of air pressure differentials instead of water pressure differentials to remove faeces. Without the need for large amounts of water flushing, they save about 70% of water compared to standard flush toilets [8]. It can be seen that the design of toilets can greatly affect the amount of water used and the efficiency of resource utilization, which is an important part of increasing energy efficiency in buildings.

2.4. Room temperature adjustment

The Bullitt Center has a unique room temperature control system. Room temperature regulation is carried out in two main ways: one is the regulation of indoor and outdoor heat transfer and the other is the regulation of above-ground and below-ground heat transfer. The first approach focuses on the design of the windows. Some windows of the Bullitt Center are triple glazed, which effectively reduces the exchange of heat between indoor air and outdoor air. Unlike the pan windows or pivot windows of everyday life, the windows at the Bullitt Center can be pushed straight outwards flat, with air rushing in around the panes. This design not only allows for breathability, but can also let warm air in and cold air out during the winter months. The outside of the windows are also designed with blinds. It is possible to control the intensity of the sunlight coming into the room by changing the shape of the blinds, which not only changes the brightness of the room, but also regulates the solar heat radiation absorbed in the room, thus regulating the temperature. This unique blind design shows different functions in different seasons. In summer, it diffuses direct light and reduces heat radiation. In winter, it maximizes the use of natural light while preventing glare in the work area. In addition, the opening and closing of the windows and the state of the blinds can be automated by the system based on the temperature and light intensity [12].

The second approach is centered on heat pump's heat transfer. Pipes are buried under the floor of each floor and in the soil at a depth of 400 ft below ground while 26 geothermal wells are located underground as well [8]. The entire system uses the aqueous glycol solution as the heat transfer medium, connecting the underground heat source to the interior. The large specific heat capacity of water enables the solution to draw a lot of heat while the glycol lowers the freezing point. When the content of ethylene glycol is 60 percent, the freezing point of the solution can reach -48.3°C . Therefore, the use of an appropriate proportion of glycol-water mixture can prevent the heat pump from malfunctioning due to the freezing of the heat transfer medium in cold winter. In addition, glycol-water solution is relatively safe, non-corrosive and has little wear and tear on the equipment, so glycol-water solution is a good choice of heat exchange medium in ground source heat pump system. Additionally, since the temperature at 400 feet below the Bullitt Center is maintained at 53 degrees Fahrenheit, this depth is also the site of the heat pump's heat transfer. In the winter, the heat from the ground is transferred to the heat transfer medium. It in turn transfers the heat to the interior of the house, which is enough to heat water from 35 degrees Fahrenheit to 90 degrees Fahrenheit, making the interior of the house warmer than the outside. The compressor in the ground source heat pump system pushes the heat exchange medium to continuously circulate, allowing the room to receive heat continuously. In summer, the indoor heat can also be transferred to the ground through the heat transfer medium in the heat pump. By switching the direction of operation of the compressor, the indoor temperature can be maintained lower than the outdoor temperature [8]. This approach saves electricity compared to air conditioning and reduces greenhouse gas emissions such as carbon dioxide compared to the use of fireplaces. Therefore, it is greener and more energy efficient. In addition, the Bullitt Center also employs a high-efficiency fresh air heat recovery system (80% total heat recovery efficiency), radiant cooling ends, workplace air conditioning air supply and 11 other

active energy system optimization techniques to further reduce the total building energy consumption by 14% [13].

3. Summary

In the context of global warming and to make buildings more ecologically sustainable, this paper takes the Bullitt Center as an example and explores the possibilities for buildings to be designed to be low carbon and energy efficient. In terms of environmental adaptation, the Bullitt Center makes full use of solar power generation through rooftop solar panels; the Bullitt Center collects and treats rainwater for water supply through pipelines and rainwater collection and utilization systems; the Bullitt Center makes full use of resources through the composting toilets and saves water through the vacuum toilets; and the Bullitt Center regulates room temperature through window designs that make use of moving air and solar heat and ground source heat pumps that make use of geothermal heat. From a technological point of view, artificial intelligence and other advanced technologies are also used in the Bullitt Center, making the relevant regulation more timely and convenient. At the same time, tenants also follow the principle of energy saving in the building. In a combination of environmental features, technology and people's awareness of conservation, the Bullitt Center has achieved a breakthrough in net-zero water, net-zero energy and negative carbon emissions. What's more, its life expectancy is up to 250 years, making it a truly sustainable and energy-efficient building. By taking into account and utilizing the characteristics of local natural resources in building design, incorporating appropriate scientific and technological products and promoting low-carbon and energy-saving to the population, ecologically sustainable, energy-efficient buildings will become more and more popular and efficient. The rise of such buildings can make a significant contribution to the mitigation of global warming.

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