Methods to Reduce Building Energy Consumption

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Abstract. With the development of science and technology, the density of modern buildings in urban areas has increased to a large extent, giving rise to a sharp increase in building energy consumption. Therefore, it’s of great significance to reduce the energy consumption in buildings. The paper discussed the factors of energy consumption in industrial, residential, and commercial buildings, which can be divided into space heating, cooling, water heating, and lighting. There are also several methods of cutting down on wasted energy in buildings in this paper, including the heat pump system, the green roof, and the use of the pyroelectric effect. The heat pump system is an equipment which can transfer heat from a cooler space to a warmer space. It transfers heat instead of generating it to save energy costs in an evaporation and condensation cycle. The cool roof is designed to reflect and absorb heat from the sun. As the roof temperature decreases, the urban heat island (UHI) is mitigated and it’s relatively easier to cool the inner temperature. The green roof, roof with vegetation, soil, and drainage layers, works similarly but it also produces fresh fruits. In addition, the thermoelectric effect can convert heat into electricity to produce energy based on the temperature difference. It can take advantage of electricity to create temperature differences as well. The essay introduced several methods to reduce building energy consumption, which can be useful in developing countries such as China to solve the problem caused by industrialization and mitigate carbon emissions.

Keywords: Building energy consumption, heat pump, cool roof, green roof, pyroelectric effect.

1. Introduction

Nowadays, the energy consumption of buildings rises in a sharp trend and has become a great part of the whole energy consumption. It’s estimated that in the European Union, the energy consumed in buildings made up 37% of the whole energy in 2004. The figure is similar in Britain. Given the fact that industry and transport energy only accounts for 28% and 32%, the proportion of buildings is relatively highly important [1]. So, it's clear that the building is inextricably interwoven with energy.

The world witnessed a consistent upward trajectory in global total energy consumption and the emissions of carbon dioxide in the past four decades. In China, as coal is still used widely, the emissions of carbon dioxide are extremely great, raising people’s concern about the environment. (Fig. 1) [2]. As a result, it’s of great importance to cut down on the overall consumption of energy, especially in China. So, the energy consumption in buildings should be taken into consideration. As coal, oil, and natural gas, known as fossil fuels, contribute to about one-third of China’s total energy consumption in buildings, replacing them with renewable resources should also be put into schedule.

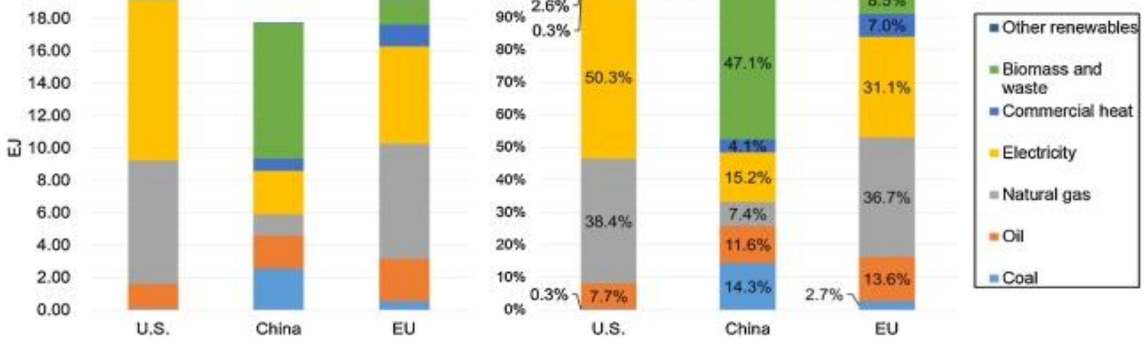

Figure 1. Building final energy consumption by fuel types in the U.S., China and the E.U., 2010. https://www.sciencedirect.com/science/article/pii/S0378778816305783

There are several factors contributing to the great drain on energy. First, after the Second World War, the global environment became peaceful and stable, which led to a consistent increase in the density of the population. Many residential and industrial buildings sprang up in return. What's more, in modern times, there is greater demand for living conditions, such as shower equipment with warm water, lighting systems, and various electrical appliances. In industrial buildings, more hi-tech facilities are shown with advanced science and an urgent need for more production, leading to the utilization of large amounts of energy. Additionally, compared with the medieval or Renaissance, people currently spend much more time sitting in buildings instead of wandering on the streets. The extra time in summer or winter will increase the working hours of cooling or heating facilities [1]. Therefore, it's no wonder that the energy consumption is so high.

This essay will discuss some methods to reduce energy consumption in buildings. Firstly, there are two methods to reduce the energy spent on maintaining the temperature difference between the inner and outer sides of the buildings, namely the heat pump and the thermoelectric technologies. Secondly, though the great number of buildings in downtown areas occupy a large area, the roofs of them are not utilized thoroughly. The cool and green roof are created to take advantage of the wide area of the roof, cool the temperature, and mitigate the UHI. All these methods help produce or utilize renewable energy so that carbon emissions and environmental pollution will be mitigated.

2. Composition of Energy Consumption in Buildings

In another published study, the author discussed how energy was used in residential buildings in four countries in 2003. Space conditioning consumed more energy than the other two factors among the four countries and domestic hot water ranked second in the UE, USA, and UK. In Spain, the energy consumption of lighting and appliances represents a slightly higher proportion of 32% than the one of domestic hot water accounting for 26%, which is probably because of the weather and yearly average temperature. In office buildings, the heating ventilation air conditioning (HVAC) utilize almost half of the total energy, namely 48% in the US and 55% in the UK [1].

From the statistics, it is clear that space conditioning should be put due priority in reducing energy consumption. One of the reasons is that the energy used in lighting and boiling water is likely to remain unchanged shortly. Another reason is that considering that there are many more developing countries than developed countries like the US and UK globally, the sum and height of office buildings will follow a growing trend, and the energy consumption in space heating, cooling, and ventilation will rise sharply. As the global temperature rises due to the greenhouse effect, the percentage of space conditioning will continue to surge. Maintaining the temperature difference requires a large sum of energy, and even more if leaking windows or unsealed doors exist in buildings. That's partly the reason why this essay focuses on taking advantage of the temperature difference between indoor and outdoor spaces.

3. Application of Heat Pump

The thermal efficiency of a heat pump is valued by the coefficient of performance (COP), which is the ratio between the useful thermal energy and the drive energy. The size of COP is limited by the temperature of the hot and cold places according to the second law of thermodynamics. There are also several factors in the efficiency of a heat pump: the electricity generation, the type of refrigerant, the size, and the thermostat controls [3].

The heat pumps can be classified into air-source and geothermal heat pumps. The air-source pump is applied widely. With the two coils set indoors and outdoors, the air-source heat pump can absorb the heat in the room and release it outside in summer or do the reverse process in winter. Different from the air-resource heat pump, the ground source heat pump has one coil buried underground to release or absorb heat. The ground source heat pump system is relatively better than the air-resource heat pump with eco-friendly and efficient advantages. Compared with traditional heating or cooling systems, heat pumps emit less greenhouse gases and use less energy [4]. Fig. 2 is the Basic Vapor Compression Cycle.

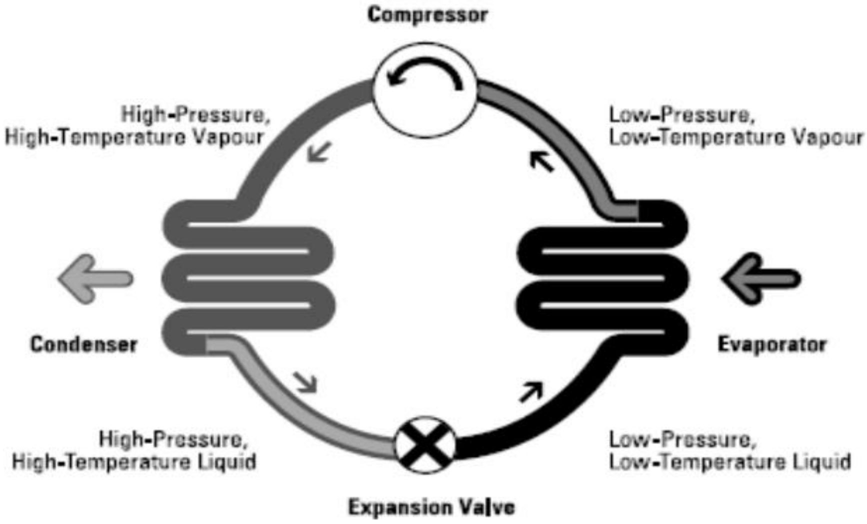

Figure 2. Basic Vapor Compression Cycle.
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As the need to mitigate the greenhouse effect and carbon emission is urgent currently, it's important to apply the heat pump globally to save energy and do less damage to the environment. Compared with the coal boiler, gas-oil boiler, and other facilities using fossil fuel for warming or cooling, the ground-to-water heat pump and air-to-air heat pump have low carbon dioxide emissions when producing the same amount of heat [3].

At present, China is now taking steps to adopt the technology. The Shanghai Tower is an example of a heat pump application with 12 chillers, a geothermal heat pump, a building management system, and a central performance management system.

4. Application of Cool Roof

The cool roof and green roof are both designed to produce or save energy based on the large areas of roofs downtown. With the incorporation of solar energy technologies into the design, construction, and operation of buildings, the cool roof and green roof are cost-effective and can maximize the area available in the building.

The cool roof is an idea that applies cool materials to the roof to cut down on the energy needed to maintain the low indoor temperature, especially in summer. The cool materials reflect the radiation from the sun to absorb less solar heat. The efficiency of the cool roof is dependent on the figure of the solar radiation, the temperature difference between the roof surface and the air, and the material of the roof [5]. As the area of the roof is increasing due to the city development, the application of a cool roof will relieve the cooling load of urban areas and ease the UHI. A study that focused on the case in London pointed out that the cool roof in an office building could reduce the surface temperature as well as the air temperature by 2-3 Celsius. As a result, there are fewer hours with the temperature over 25 Celsius in the building [5]. It is important to improve the temperature comfort in office buildings to boost the working efficiency of the office workers.

However, the cool roof also rejects the solar heat in winter, indicating that more energy will be used for heating the building. So, applying a cool roof should be based on accurate calculations to minimize the total energy. In tropical regions with high solar radiation such as India or Singapore, the efficiency of cool roofs will increase and the disadvantage in winter will be neglected while in those countries with high latitudes, the cool roof is not welcomed. The technology of a cool roof can also be integrated with solar panels to make full use of solar radiation and minimize the heat absorbed by the surface of the roof.

5. Application of Green Roof

The green roof is another strategy to reduce the energy spent maintaining the inner temperature. There are various types of vegetation planted on the growth medium, below which are many types of layers (Fig. 3) [6]. What's more, the benches for people to rest and the drainage system are usually added to manage the rainfall and relieve the mood of the office workers [6].

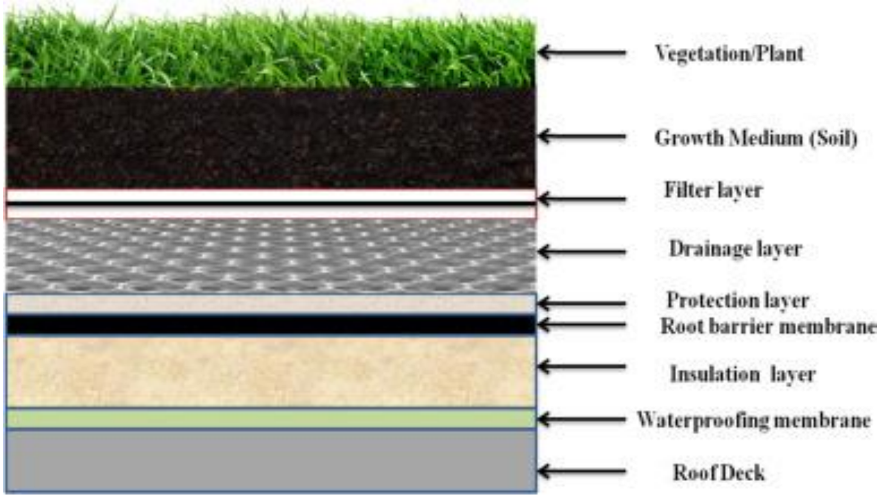

Figure 3. Typical components of a green roof.
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Social, economic, and environmental benefits exist in the technology, enabling it to be adopted around the globe. First and foremost, the green roof can mitigate the UHI like the cool roof as well as improve thermal comfort. The green roof can absorb more solar radiation than the cool roof, ending up with more energy saved in cooling the building. The cooling effect is also found to be greater in summer and smaller in winter [6]. Additionally, green roofs can clean the dirty air in urban areas, providing people with an environment free of air dust particles and pollutants. It can also improve the quality of water similar to the way it cleans the air and manages to reduce the flow when there is a storm.

Despite its advantages, the green roof has a higher cost of installation and maintenance than the cool roof. Its impact is also limited in cold weather. Considering the long-term cost savings, a green roof is a good option while a cool roof is relatively more affordable to small companies.

6. Application of Thermoelectric Technologies

Thermoelectric technology is based on the Peltier effect. As the direct current is passed through different types of semiconductors, the heat is absorbed on one side and is released on another side. In buildings, the heat is transferred from the indoor environment to the outdoor environment. It utilizes electricity to cool or heat the inner side of the building. It can be applied to buildings combined with solar panels, in which the light is converted into electricity according to the photovoltaic effect. The solar thermoelectric system can greatly reduce the cost of energy as it uses far less electricity than conventional cooling systems [7].

In the past, the main way for buildings to mitigate the loss of energy in maintaining inner temperature is to apply materials with high insulation to the building envelopes. Compared with the current thermoelectric system, the insulation is passive and will also hurt heat emissions in summer [7]. In summer, the radiation from the sunlight will reach a peak, thus the efficiency of the solar panels will increase to fulfill the demand to cool the indoor environment.

There's also a method to reduce energy consumption among thermoelectric technologies, which is the thermoelectric generation technology. This technology is based on the Seebeck effect rather than the Peltier effect. If there is a temperature difference on two sides of a loop, the current will be created. With the theory, the temperature difference can be utilized to produce electricity. As the electricity can be generated, the energy consumption can be compensated.

The thermoelectric generation technology has not been widely applied in the building now. It's partly because the temperature difference between the inner and outer sides of the building is not enough to generate a large quantity of electricity. What's more, the thermoelectric system has a low energy conversion efficiency. However, the technology can be used in solar panels. As the solar radiation creates extra heat in the panels, the working efficiency will be affected. The thermoelectric system can take advantage of the temperature difference between the surface of the panel and the heat sink. Therefore, the thermoelectric system can generate electricity as well as improve the efficiency of the solar panel [8].

Thermoelectric systems can also be combined with other technologies such as radiative sky cooling, which can cool the building by emitting thermal infrared radiation into space. In the traditional radiative sky cooling system, a cold storage tank is equipped to store the cooling energy. By installing the thermoelectric cooling system, the efficiency will increase. Radiative sky cooling can help cool the hot side of the thermoelectric cooling system to improve the emission of heat. The combined system makes up for the shortcomings of the thermoelectric system, namely the low energy conversion efficiency [9].

Currently, the methods to improve the efficiency of the thermoelectric system focus on increasing the COP. One method is to use suitable materials, which should have high conductivity of heat and electricity. As is known to all, metal materials usually have high electricity conductivity but low heat conductivity. Therefore, the semiconductors surpass conventional metal conductors in this field.

Additionally, the alternating current can replace the direct current in the thermoelectric system. Compared with the direct current, the alternating current provides the system with a lower temperature on the cold side to enhance efficiency and working hours [10].

7. Conclusion

The essay has discussed several ways of reducing energy consumption in buildings. A heat pump is considered as the practical solution because it costs low and transfers, instead of generating, heat through operation, which could efficiently accomplish the goal of enhancing energy utilization efficiency. It is a relatively mature solution compared with the other two methods. As the heat pump doesn't emit pollutants and greenhouse gases, it caters to the global need for environmental protection. The cool roof has the benefit of low cost. This allows it to be widely applied in large areas. However, its efficiency is limited by the weather, radiation, and many other factors, and aggravates the energy load in winter. Integration of solar energy and cool roofs are considered alternatives to enhance solar energy utilization in buildings. The green roof has a relatively higher cost of installation and maintenance than the cool roof. However, it can have a significant effect in decreasing urban temperature to cut down on energy consumption as well as beautify the environment to improve the working efficiency of office workers. The thermoelectric technologies mostly have low COP, which is disadvantageous in reducing energy consumption. Fortunately, when combined with other technologies such as radiative sky cooling and solar panels, the thermoelectric system can increase its efficiency as well as improve the performance of the other system.

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