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Application of energy saving technology in HVAC

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Abstract
HVAC systems are often used in commercial buildings and social public infrastructure. However, in recent years, with the improvement of material living standards year by year, people began to focus on comfortable living and living environment, which further widened the application scope of HVAC. However, the traditional HVAC technology only has the functions of heating, ventilation and air conditioning, and is weak in energy saving, consumption reduction, dust removal and environmental protection. In view of this situation, designers and technicians should constantly change their ideas, actively explore and innovate HVAC technology, and reduce the energy consumption of HVAC to the lowest point while meeting the normal life and work needs of users. This paper will introduce the researchers' exploration of new air-conditioning systems and the application of energy-saving optimization and environmental protection technologies.

Keywords: *HVAC; Energy consumption; environment protection*

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I. Technical principles of air conditioning systems

With the rapid development of China's economy, people's material living standards have significantly improved, and the requirements for indoor living environment comfort have also significantly increased. Therefore, improving indoor environmental comfort through HVAC is an indispensable part of today's building construction. However, the comfort it brings to people is obtained at the cost of high energy consumption. In today's society with energy shortages and environmental crises, people are increasingly aware of energy conservation and environmental protection. Therefore, if HVAC systems that consume high energy are not adopted.

Taking energy-saving technology measures will inevitably be eliminated. Therefore, researchers around the world have conducted large-scale research and analysis on HVAC systems in buildings, and discussed the main factors affecting the energy consumption of HVAC systems. The ultimate goal of these studies is to maximize the reduction of energy consumption in HVAC systems in buildings, so that HVAC systems can meet the requirements of promoting green buildings today.

The air conditioning system mainly consists of cold and heat sources, air handling equipment, air and hot water transmission and distribution systems, and indoor end devices. When summer arrives, refrigeration equipment can provide cold water or liquid refrigerant, and when winter arrives, boilers provide steam or hot water. The cold and hot water distribution system delivers cold and hot water to the air handling equipment, causing the air handling system to reach the point of air supply. Then, the treated cold and hot air enters the room, or the cold and hot water is delivered to the indoor air handling equipment, and the indoor temperature is maintained at a constant value through heat exchange.

II. Energy consumption analysis of air conditioning systems

With the development of the economy, people's living standards are gradually improving, and there is also a higher pursuit of building comfort. Warm winter and cool summer are the most basic requirements for building environments, especially in the context of global climate change, the importance of HVAC is self-evident. When people enjoy the comfort brought by HVAC, they should also see that behind comfort lies extremely high energy consumption and carbon emissions, which greatly damage the ecological environment and are inconsistent with environmental policies. Therefore, there is an urgent need for the emergence of green and energy-saving HVAC technology to contribute to the construction industry in building green buildings and strengthening China's ecological civilization construction.

Due to the rapid development of China's economy and the rapid increase in urbanization, the number of urban buildings is constantly expanding, and the proportion of energy consumption in buildings to the total energy consumption of society is also constantly increasing. Therefore, building energy conservation has become an important component of China's energy conservation work. Meanwhile, urban buildings are also one of the main causes of greenhouse gas emissions. In the IEA's energy efficiency report, residential natural gas consumption accounts for 30% of all industries, while electricity consumption accounts for 26%. The United Nations Environment Programme (UNEP) has revealed that building energy consumption accounts for 30% to 40% of total energy consumption, and by 2030, its greenhouse gas emissions will reach around 30%. Among them, the maximum energy consumption generated by heating and air conditioning systems accounts for 20% of the total energy consumption. In urban energy consumption, the carbon dioxide emissions generated by buildings account for more than 30% of the total emissions. At the same time, building energy accounts for 17.5% of global greenhouse gas emissions. As a developing country, China's energy consumption has been increasing year by year. In 2018, China's total energy consumption exceeded 3000Mtoe, making it the country with the highest total energy consumption in the world. Since entering the 21st century, the total energy consumption has increased by 196.7%. As the region with the largest heating usage, the northern region of China has gradually expanded its heating network in recent years with the progress of urbanization. Due to the expansion of the heating network, the energy consumption of centralized heating has begun to increase. From 2001 to 2019, the energy consumption of centralized heating increased by more than twice, from 4700 tons of standard coal to 1.34 million tons of standard coal. At the same time, residential heating consumption in cold northern regions accounted for more than 60% of total household consumption.

It can be seen that if the operation of HVAC systems cannot avoid the consumption of non renewable and traditional energy, it will have a significant impact on the long-term healthy development of the construction industry. The energy consumption problem in various countries around the world has become apparent, with building energy consumption becoming more prominent. In China, people have gradually realized the issue of building energy consumption. However, the energy consumption of HVAC has reached half or even more of the overall energy consumption of buildings, which is very detrimental to the long-term development of the construction industry and also does not comply with sustainable development strategies.

III. Energy saving technology for air conditioning systems

In the process of carrying out energy-saving design of HVAC systems, the first thing to adhere to is the principle of comfort. The main function of HVAC systems is to regulate and control indoor temperature, and comfort is one of the most basic conditions to meet people's requirements for building comfort. When adjusting and controlling temperature, it is necessary to fully utilize the role of different links of the HVAC system, fully consider factors such as wind speed and humidity, reasonably complete the setting of the HVAC system, and optimize its energy-saving effect.

3.1 Alternative technologies for cold and heat sources

In the 20th century, the extensive use of fluorocarbons caused damage and pollution to the environment. Scientists have continuously studied and discovered the enormous destructive and polluting effects of fluorocarbons. Nowadays, fluorocarbons are rarely used in electrical appliances. After years of continuous research by scientists, refrigerant technology has been improved. During this period, various new refrigerants such as R134a, DP-1, and Fluid-H have also been successively rejected. However, after years of unremitting efforts, foreign scientists have invented a new type of automotive air conditioning refrigerant HFO-1234yf, which is not only environmentally friendly and low toxic, but also has better stability and compatibility. At the same time, Chinese scientists have also developed various items that can replace refrigerants, such as refrigerant R32/125/161, which can be used as a substitute for R22 refrigerant. Although the refrigeration effect of R32 refrigerant is not as good as that of R22, R32 has more advantages in environmental protection. Nowadays, many manufacturers in the market are promoting R410A as a substitute for R22, with lower costs. However, R410A's environmental damage is on par with R22, which is why harmful refrigerants can be replaced. Replacing with a new type of refrigerant can also better achieve energy conservation and environmental protection [7].

Therefore, researchers have also conducted research on other types of refrigerants. A mixture of HFO (hydrofluorocarbons) and HFC (hydrofluorocarbons) is considered a possible compromise solution to replace widely distributed HFC (such as R134a, R404A, or R410A). This is to reduce greenhouse gas emissions from refrigeration and air conditioning systems [8]. Alireza Zendehboudi et al. investigated the operation of R450A as a refrigerant in refrigeration systems [9], as R450A has a relatively low GWP (Global Warming Potential) of 547 and is a hydrofluorocarbon compound. Due to its comparability in thermodynamic properties, safety classification, operating pressure and material, as well as lubricant compatibility, it is a non flammable and low toxicity substitute compared to R134a. Although its refrigeration capacity slightly decreases, its energy performance is comparable. Research has shown that compared to R134a, the average compressor power consumption of R450A is reduced by 7.9%, and the COP (energy efficiency ratio) is reduced by 2.9% [10]. In addition, the ODP (ozone depletion capacity) of R290 is 0, GWP is 20, and the implementation of the Kigali Amendment has further accelerated the reduction of hydrofluorocarbons. Therefore, R290 has received increasing attention due to its excellent environmental protection and thermal properties [11]. However, due to the flammability of R290, countries have been continuously exploring its large-scale market-oriented use. With the continuous upgrading and improvement of safety measures for the R290 system, on May 9, 2019, IEC announced the official approval of increasing the A3 refrigerant filling limit for self-contained commercial refrigeration display cabinets under standard IEC 60335-2-89 from 150 g to 500 g [12]. This indicates that IEC's understanding of combustible refrigerants is gradually improving from technical measures to safety.

In addition to hydrofluorocarbons, Jian Sun et al. applied CO2 as a refrigerant in the refrigeration system of supermarket warehouses [13]. Supermarkets are the most energy intensive commercial buildings, and for a typical supermarket, their annual electricity consumption exceeds 2 million kilowatt hours, with refrigeration systems accounting for 40-60% of the total electricity consumption in the supermarket. In addition, supermarket refrigeration systems are one of the largest refrigerant consumers. The current supermarket refrigeration system relies on high GWP hydrofluorocarbon refrigerants. They found that under mild climate conditions with higher annual and daily average temperatures, CO2 transcritical systems with heat recovery are an effective solution. Research has shown that due to the higher COP of CO2 compressors, better prospects for TEWI (Total Equivalent Warming Effects), and smaller economic losses caused by refrigerant leakage, CO2 compressors can become a suitable alternative to HFC compressors in the future.

3.2 Ground source heat pump technology

The shallow soil, water, and other substances on the surface can absorb and store solar energy, and the temporarily stored energy can be converted again using ground source heat pump technology to achieve the purpose of regenerating and utilizing shallow surface energy. Ground source heat pump technology has obvious advantages in specific applications, as it can effectively replace the heat dissipation function in traditional refrigeration systems, thereby reducing electricity consumption in HVAC applications and achieving cost savings. In addition, ground source heat pump technology can efficiently utilize and convert energy, reduce the combustion process, and achieve the effect of pollutant emission control, which can better protect the environment. Fully utilizing ground source heat pump technology during the heat dissipation process can greatly save energy. Currently, many electrical appliances use water resources for heat dissipation, and utilizing soil heat dissipation can greatly reduce the consumption of water resources. It is precisely with many advantages that ground source heat pump technology is widely used in HVAC systems, playing a significant role in cost savings, system energy conservation, and many other aspects.

The domestic ground source heat pump started relatively late and has started industrialization in recent years, and is in a high-speed development stage. From 1980 to 1998, the main focus was on conducting ground heat pump simulation experiments at Tianjin University and Tianjin Business School. From 1998 to 2004, Chongqing Jianzhu University, Hunan University, Tianjin University, Shandong University of Architecture and Technology, Tsinghua University and other institutions achieved certain results in theoretical and experimental research. The initial ground source heat pump project was mainly carried out by domestic engineering companies acting as agents for foreign products. In recent years, there have been many equipment manufacturers and an increasing number of engineering companies in China. For example, Beijing Daxing International Airport adopts a ground source heat pump system. This project focuses on the research of a centralized buried pipe ground source heat pump system in the flood storage and detention area of the airport. It fully utilizes shallow geothermal energy, couples natural gas, electricity and other conventional energy sources, and combines multiple energy-saving technologies such as flue gas waste heat recovery, ice storage, and large temperature difference to centrally solve the cooling and heating needs of nearly 2.57 million square meters of public buildings in the airport supporting area. The successful implementation of this project provides design and engineering experience for the technical promotion of large-scale centralized shallow ground source heat pump systems, and also provides technological support for the country to achieve the goals of carbon peak by 2030 and carbon neutrality by 2060.

However, for buried pipe systems, due to the small thermal conductivity of the underground rock and soil layer, the heat capacity is extremely high, and the heat diffusion ability is extremely poor. Therefore, extracting heat from underground requires a large amount of buried pipes, with a relatively large initial investment and a large area of land required; At the same time, due to the large area of our country's population and significant climate differences in different regions, ground source heat pumps are mainly used for cooling in the south and for heating in the north, resulting in excessive consumption of underground heat in the north, excessive injection of heat into the underground in the south, and an imbalance of heat. Year-round imbalances in soil temperature can occur, and the heat transfer performance of soil heat exchangers is greatly affected by the thermal properties of the soil, so auxiliary heat sources are usually needed.

In order to avoid the impact of local soil environment on ground source heat pumps, Xueyou Zhang et al. studied the operational performance of a solar ground source heat pump hybrid system constructed by Hebei University of Technology, consisting of a ground source heat pump system and a solar assisted ground source heat pump system. They used a system with two heat pump units. A BHE (in well heat exchanger) and BTES (in well heat storage) were designed for these two heat pump units. The first heat pump unit is used for a pure ground source heat pump system to meet the cooling load requirements of the entire building in summer and partial heating load requirements in winter. The second heat pump unit is coupled with the solar seasonal heat storage system in the SAGSHP system to meet the remaining heat load demand of the building. Meanwhile, solar seasonal heat storage systems store solar energy in BTES during non heating seasons to balance soil temperature [15]. For solar ground source heat pump hybrid systems, increasing the heating ratio of solar assisted ground source heat pump systems within a certain range can effectively improve the COP of the hybrid system during the heating season. The results show that solar space heating can improve the performance of high-temperature ground source heat pump systems by nearly 25.8%. Linhua Zhang et al. designed a composite system of ground source heat pump and floor radiation air conditioning [16], which can be used in winter and summer, saving room space. This system can also reduce the initial investment rate and operating costs of the air conditioning system, especially in summer. Due to the performance of underground soil temperature, as long as the heat and energy in winter and summer are sufficient, floor radiation heating has no effect on the properties of the soil at the same time. It can also improve the performance of heat pump units and affect the coefficient. The advantages of ground source heat pumps far outweigh their disadvantages, and what researchers need to do is to avoid these disadvantages as much as possible or find ways to solve them. Ground source heat pump is a very environmentally friendly way of energy use, which uses the solar radiation energy borne by water resources and does not cause environmental pollution. It is now widely used in the air conditioning and water heater industries.

3.3 Independent temperature and humidity control system

The independent temperature and humidity control system is a system that adjusts indoor temperature and humidity through different control systems. Compared with traditional air conditioning systems, the main difference between this system and traditional air conditioning systems is that it has two independent systems that handle the sensible heat load and latent heat load of indoor temperature and humidity, respectively. At present, the sensible heat load is mostly treated with high-temperature chilled water, and the end equipment mainly uses dry fan coils, radiation plates, etc. The latent heat load is relatively high, and solution dehumidification and rotary dehumidification are used to prevent the surface of the fan from getting damp, pipes or walls, and improve indoor air quality. With the support of the National Eleventh Five Year Plan for Science and Technology Support (2006-2010), design institutes, research and development institutions, equipment manufacturers, and other institutions participated in the collaborative research and development of the system. In recent years, the department has continuously promoted newly developed processing equipment and practical applications. In the early stages, the system consisted of commonly used devices in traditional systems. At present, equipment components specifically designed for the company have been produced, including high-temperature chillers, dry fan coils, liquid dehumidifiers, outdoor air dehumidifiers, etc. Since 2006, approximately 4 million square meters of non residential buildings have adopted this system. With the rapid development of its unique equipment and applications, the system has been widely applied [17]. Due to the independent temperature and humidity control system, traditional air conditioning systems avoid the need for reheating to reach the appropriate temperature when the humidity meets the requirements and the temperature is low after air treatment. On the basis of unified treatment of chilled water, it also increases energy waste [18]. Therefore, this system better meets the requirements of indoor temperature and humidity than traditional systems, and has huge energy-saving potential.

In terms of system design, researchers have designed different temperature and humidity independent control systems for different occasions. Ding Weixiang et al. designed a THIC system for swimming pools [19]. For indoor heat load, high-temperature chillers are used to prepare chilled water in summer, and in winter, valves can be switched to connect the pipeline to the boiler and heat exchanger to prepare hot water; For indoor humidity load, a heat pump solution fresh air unit is used. The treated fresh air can not only regulate the indoor humidity environment but also maintain hygiene requirements [20]. In Guiyang, Zhang Hangming and others studied a combination system of a solution humidification fresh air unit and a capillary radiation plate. The heat pump type solution humidification fresh air unit utilizes the moisture absorption characteristics of salt solution to centrally treat outdoor fresh air, reducing its moisture content and relative humidity. The fresh air processing unit bears all the fresh air loads, indoor humidity loads, and some sensible heat loads, ensuring that the temperature and humidity of the fresh air mixed with the indoor hot and humid air are within the design range, while meeting the requirements of personnel's fresh air volume and hygiene. Capillary radiation plates are used at the indoor end, and the high-temperature chilled water generated by the high-temperature chiller is sent into the capillary through the transmission and distribution system to bear the remaining sensible heat load indoors, reduce the temperature of indoor surfaces and air, and meet the needs of indoor personnel. In addition to civil buildings, THIC systems can also be applied to hospital operating rooms with high cleanliness requirements.

Zhang Haibo analyzed the application of temperature and humidity independent control systems in clean operating rooms, including systems that handle sensible heat, such as high-temperature cold sources, waste heat elimination end devices (using refrigeration pumps), cooling pumps, cooling towers, etc; The wet load is borne by the system that processes latent heat, which consists of a fresh air treatment unit and an air supply terminal device [21]. The results show that this system can save 88.9% of electricity compared to conventional air conditioning systems. Bowen Guan et al. studied an industrial environment temperature and humidity independent control air conditioning system based on liquid desiccants. In this system, a liquid dehumidifier is used to handle the humidity load. Compared with traditional systems, it reduces the requirement for cold source level and avoids reheating [22]. During the cooling season, the THIC system helps factories save 23.3% of energy compared to traditional systems.

The independent temperature and humidity control system is a relatively new technology, which has a very obvious energy-saving effect, but the cost is relatively high. Not only in comfort air conditioning, but also in clean engineering. With the increasing demand for operating costs in society, there will be more and more such projects. In the use of temperature and humidity independent control systems, there is also great room for development in solution dehumidification [23]. Choosing a suitable regeneration solution and the heat source of the regeneration solution have a significant impact on the efficiency of the dehumidification system. It is hoped that there will be a breakthrough in solution dehumidification, so that temperature and humidity independent control systems can be widely used.

3.4 Other energy-saving technologies

Wind energy is the kinetic energy generated by the flow of air, and is a form of solar energy conversion. Through wind turbines, wind energy can be converted into mechanical energy, electrical energy, thermal energy, etc. Converting wind energy into kinetic energy can be combined with cogeneration technology, achieving the supply of electricity on one hand; On the other hand, it realizes the cooling and heating of HVAC systems. In HVAC systems, natural ventilation and mechanical ventilation are generally used to accelerate indoor heat dissipation by injecting fresh air into the building, in order to achieve the purpose of cooling. But the disadvantage of this technology is its instability, which requires certain conditions such as wind around the building [24]. Sui Qiuyu and others designed an air refrigeration cycle system with natural cooling, which consists of a closed cycle composed of components such as a compressor, blower, expander, cooler, and regulating valve [25]. When the outdoor temperature conditions are suitable, the compressor and expander stop working, and the circulation changes to natural cooling circulation. The return air in the machine room only needs the blower to provide circulating power, and it exchanges heat with low-temperature outdoor air in the cooler. After reaching the air supply conditions, it is sent back to the machine room. Taking measures to increase flow paths and valves to enable the air cooling system to have natural cooling function, facilitating the year-round compound operation of air cooling and wind side natural cooling, and reducing initial equipment investment.

Solar energy is an important component of renewable energy and is widely used in industrial production. Solar energy technology, as one of the highly respected new energy technologies in recent years, can effectively reduce energy consumption through its application in HVAC systems. Civil buildings can install solar energy collection facilities on the rooftops or other locations with sufficient lighting, and convert the collected solar energy into electrical energy through these solar collectors. Combined with cold, heat, and power triple technology, civil buildings can be provided with electricity, heating, cooling, or directly converted into thermal energy for heating. Among them, solar assisted air source heat pump systems are widely used domestically and internationally due to their universal applicability [26]. By using two different forms of heat sources to compensate for the shortcomings of single heating, multi energy collaborative planning and design [27] are carried out, thereby achieving maximum energy-saving space and economic benefits of the system [28]. Khoa Xuan le et al. used TRNSYS to study the performance of an air source heat pump heat storage combined system under high temperature conditions. The results showed that direct coupling had better heating performance than continuous coupling [29]. Sun Wei et al. [30] tested a solar and air source heat pump timed hot water supply system in a dormitory on site. After optimizing the system through hourly temperature comparison control schemes, the total energy consumption of the system was reduced by 12.2%.

IV. Conclusions

With the continuous development of the economy and the continuous development of buildings, the use of HVAC is becoming more and more common. As the core part of its refrigeration system, its quality and function also need to be double guaranteed. Applying energy-saving and environmental protection technologies to HVAC systems can not only reduce non renewable energy consumption, lower economic costs, and achieve higher economic benefits, but also meet the path of sustainable development in China and better protect the environment.

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