Energy-saving Design of Heating Ventilating Air Conditioning for Tall Space Structures

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Abstract. For Tall Space Structures, its Energy-saving design of Heating Ventilating Air Conditioning (HVAC) is very important. This paper discusses the importance of environmental adaptability and selection of cold and heat source in HVAC design. The paper first emphasizes the close relationship between energy efficient design and environmental adaptability, pointing out that HVAC solutions should be optimized according to the climatic conditions of a particular geographical location. By improving the environmental adaptability of the system, energy consumption can be reduced while meeting the needs of climate change and seasonal change. This paper also introduces the application of new heat source systems, such as air source heat pump and energy saving cold source system. In addition, this paper also discusses the application of clean energy and green materials in HVAC design of high-rise buildings. These integrated application approaches contribute to achieving sustainable development goals, reducing reliance on traditional energy sources and providing a more comfortable tall space environment.

Keywords: Tall space structures, Heating Ventilating Air Conditioning, cooling and heating source selection, energy saving and emission reduction.

1. Introduction

First, tall space building is a building with a large space and a certain height. It usually includes leisure and entertainment spaces such as theatres, gymnasiums, exhibition halls, shopping malls and so on. In addition, it also includes commercial spaces such as transport hubs, churches, and large complexes. Compared to conventional buildings, this type of building has a larger space and height. This results in a differential gradient in temperature and air circulation, which reduces the effectiveness of indoor air conditioning [1]. At the same time, taller spaces have more access routes to solve the problem of excessive personnel movement. This also concentrates on the operating load of the Heating Ventilating Air Conditioning (HVAC) system [2]. As a result, multi-functional zoning is also one of the characteristics of large space buildings. In summary, the characteristics of high and large space buildings have certain challenges for HVAC energy efficient design.

HVAC design is an indispensable part of tall space building engineering, which plays an important role in the comfort and energy saving of tall space buildings [3]. With the improvement of people's living standards, individuals have an increasing demand for tall space buildings. Therefore, the energy consumption of HVAC systems is also increasing, and the supply of fossil fuels is decreasing, which will lead to energy shortage [4]. Hence, energy saving and emission reduction is one of the main goals of HVAC energy-saving design at this stage, for example, using low-carbon design to reduce building carbon emissions, using green materials, reducing construction material waste, following the coordinated design concept. HVAC design which can save energy can not only reduce energy consumption and solve the problem of energy shortage but also improve the ecological environment and alleviate global warming.

In the actual design and construction of an HVAC system, it is inevitable to consume a certain amount of energy. If clean energy is used in the HVAC design of large space buildings, system design

optimization, and scientific construction, HVAC energy consumption can be reduced and the design level of large space buildings can be improved [5].

2. Environmental Adaptation and Selection of Cooling and Heating Sources

2.1. Climatic Conditions and Natural Ventilation

The energy-saving design of HVAC is inextricably linked to the design of environmental adaptability. Among other things, utilising the natural ventilation potential and analysing regional climatic characteristics are both important steps in energy-efficient design. The aim is to optimise the HVAC design according to the natural environment and climatic conditions of a specific geographical location. By enhancing the dynamic adaptability of the environment, the air conditioning system operates efficiently and can flexibly adjust the comfort level. In this way, it meets the needs of different climatic changes and seasonal alternations to reduce energy consumption and promote green development.

Local climatic conditions should be considered, and regional characteristics and seasonal changes can be understood by determining indoor and outdoor parameters [6]. By counting the indoor and outdoor parameters in the hot summer and warm winter regions of China, they are divided into cold, warm and mild zones [7]. For example, the library of Guangzhou Xinhua College, which is in the warm zone, adopts air-conditioning machinery to cool down in summer while the atrium space is closed in winter so that the air inside is warmed up by the influence of solar energy [8]. Thus, indoor comfort is improved without air-conditioning heating. Therefore, each project should first refer to the indoor and outdoor parameters of each area to design an energy-efficient HVAC system.

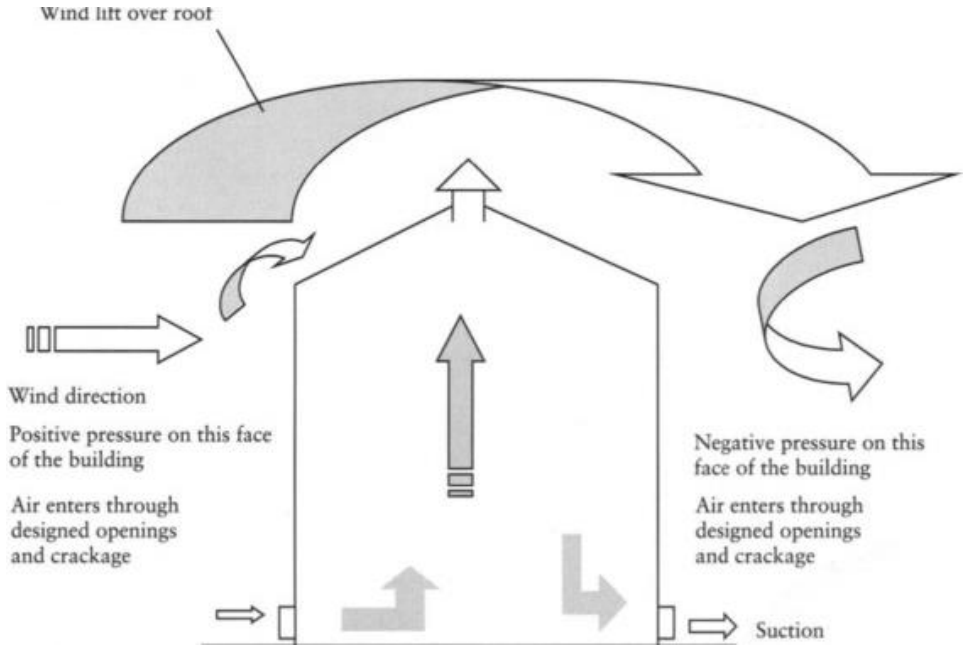

Fig. 1 Principle of natural ventilation [9]

Natural ventilation is a passive cooling technique, as shown in Fig. 1, which utilises the difference in wind force and thermal buoyancy to promote airflow to reduce energy consumption and improve indoor air quality [6,10]. At the same time, the orientation and layout of the building also affect the effect of natural ventilation all the time. For example, a north-south orientation is most favourable for buildings. This reduces the heat gain from solar radiation, and solar energy can be used to reduce energy consumption for both cooling and heating [11]. Energy consumption can be reduced and design strategies optimised by prioritising north-south orientations as described above, or by using staggered layouts and other efficient natural ventilation strategies [11]. For large commercial buildings, good indoor air quality can be achieved through reasonable natural ventilation design, thus reducing the reliance on traditional air-conditioning systems and achieving energy savings [12].

2.2. The Option of Cold Source and Heat Source

The option of cold and heat sources has a significant impact on the energy saving of HVAC systems [13]. At present, many construction projects are based on electricity, which causes a large energy consumption, so how to choose cold and heat sources is a major goal to optimize the energy saving and emission reduction of HVAC systems. When designing tall space buildings, first, it is necessary to correctly select the cold and heat source, and the installation must be based on the space structure to ensure that the HVAC effect is effectively played. It should also be combined with local resources and indoor and outdoor environment changes, from the aspects of the economy, safety, energy saving, and other comprehensive considerations [2].

With the rapid development of the social economy, some large venues in first-tier cities have adopted many energy-saving and environmentally friendly new equipment and technology, which not only improves the energy loss of HVAC systems but also improves the comfort of tall buildings. The air source heat pump system is a new heat source system, which mainly uses high energy to flow heat from low heat sources (water, soil, and air heat) to high heat sources (coal, oil and gas, and electric energy). The air source heat pump system can convert low heat energy into high heat energy because low heat energy cannot be directly utilized, to achieve the goal of saving high heat energy [2]. Ice storage cold source system is an energy-saving cold source system, which uses the low power of the power grid at night to cool and store in the form of ice. Then, the ice is melted to provide cooling capacity for the air conditioner during the daytime peak electricity consumption, thus achieving the role of transferring peak power load and improving the primary energy utilization efficiency of the power plant [14]. The schematic diagram of the ice storage system is shown in Fig. 2.

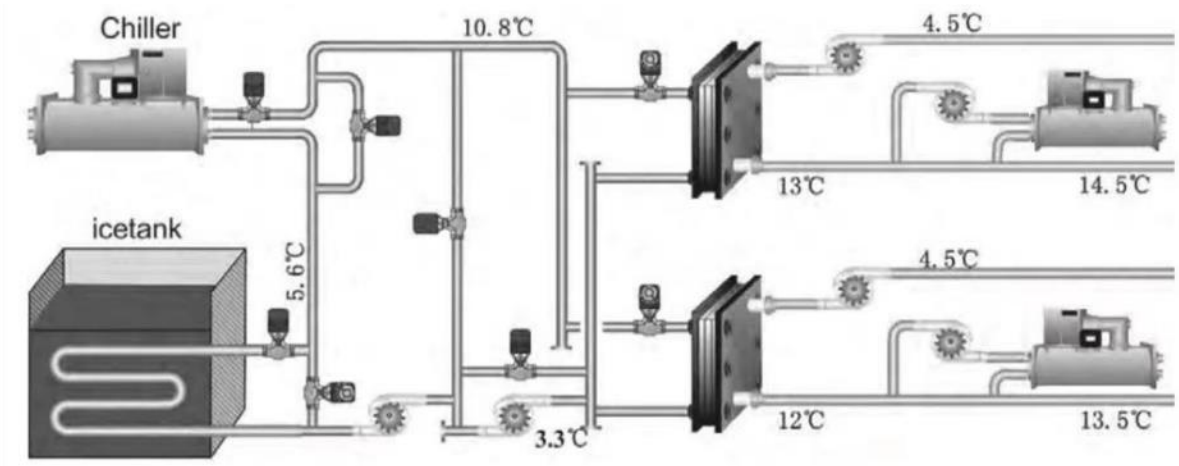

Fig 2. The schematic diagram of the ice storage system [14]

In the choice of heating and cooling sources, the principle of adapting to local conditions should be followed. The selection of appropriate modern technology can not only ensure the operation of the entire HVAC system is more stable and reliable, but also ensure the normal operation of HVAC equipment, and provide people with a more comfortable high-space environment [2].

3. Energy-saving Design of HVAC Systems for Tall Space Buildings

3.1. Clean Energy Application & Green Materials

In the HVAC design of tall space buildings, the application of clean energy and green materials are complementary to their relationship. On the one hand, energy-saving design reduces energy demand; on the other hand, clean energy and green materials meet energy demand. Therefore, the combination of the three can reduce the dependence on traditional energy sources. At the same time, it also achieves the goal of sustainable development by promoting each other and jointly maximising the comprehensive benefits.

As shown in Fig. 3, solar heat pump technology, which is a clean energy source, has a large impact on its air conditioning system. This technology is used for air conditioning cooling and air heating through the conversion of solar energy into electrical or thermal energy [10]. In addition, wind energy is also converted into mechanical or electrical energy through wind and water power, which can be used to drive fans in air conditioning systems [10]. Meanwhile, ground source heat pumps utilise the stable temperature of the ground for cooling and heating, which further improves energy efficiency [10]. In large space buildings, solar energy as its important clean energy source is classified into active and passive applications [5]. Among them, the active application is to use solar energy to drive the system for heating and cooling [5]. This means that the system needs to actively collect and convert solar energy to meet the HVAC needs of large spaces. Passive applications, on the other hand, utilise solar heat for absorption cooling [5].

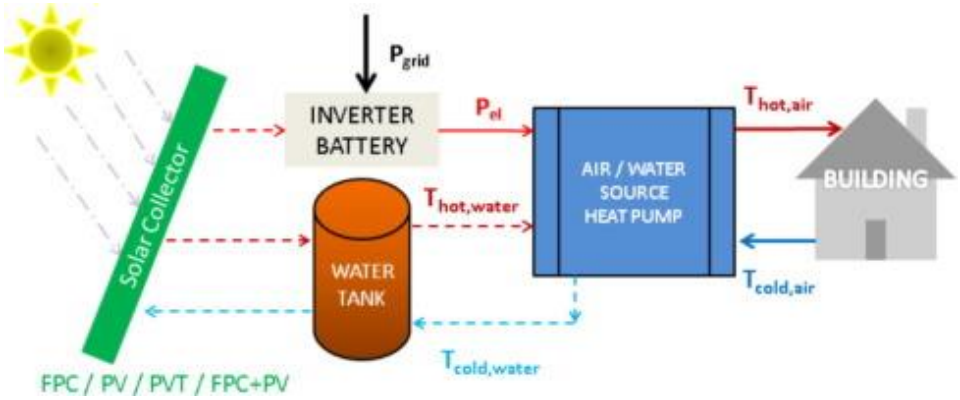

Fig. 3 Solar heat pump technology [15]

Under modern science and technology, green materials are not only regarded as green and environmentally friendly materials but also have good performance and high safety [10]. This is conducive to the promotion of eco-friendly development. They include recycled materials, energy-saving materials, low-volatile VOC materials, biodegradable materials and water-based coatings [5]. In the HVAC system of public buildings, the selection of appropriate green materials according to specific needs and scenarios has an important impact on sustainability. For example, nano-insulating coatings with good thermal insulation properties can reduce the energy consumption of air-conditioning systems by lowering the surface temperature of buildings and reducing heat and cold transfer [16].

3.2. Common Techniques for HVAC Energy-saving Optimization

At present, in the design of HVAC systems in large spaces, frequency conversion speed regulation technology is the main technology. Through the efficient operation of the frequency conversion system, the application problems of the HVAC system are dealt with from an all-round and multi-angle, and the diversified use needs of large space buildings are met, to reduce the operating cost of the HVAC system and avoid energy consumption [10]. The application of frequency conversion energy-saving technology can save about 30% of energy consumption [17]. The traditional air conditioning system uses a fixed frequency operation mode, which always maintains the same power output as long as it runs, which leads to energy waste [18]. The variable frequency energy-saving technology does not need to design variable frequency speed regulating motors with fixed operating loads but only needs to adjust the cold water, water pump units, and wind units according to the actual situation of the system and user needs, to reduce the operating load and achieve the purpose of energy saving [10]. By combining external changes, the power of the HVAC system can be effectively adjusted to ensure the match with the environment and low energy consumption to ensure the efficient operation of the system under the optimal power [18]. After the use of variable frequency technology, the variable frequency energy-saving system and variable wind facilities that constitute HVAC will form a variable air volume system, which can not only improve indoor comfort but also reduce the energy consumption level of HVAC [19].

3.2.1 Application of low-temperature air supply technology

Traditional air conditioning systems usually regulate indoor temperature by circulating coolant to and from indoor and outdoor evaporators and condensers, but this method has an impact on the environment and increases energy consumption [20]. Low-temperature air supply has a remarkable energy-saving effect. As the air volume of the low-temperature air supply air conditioning system is reduced, the system conveying equipment is reduced, and the energy consumption of the conveying equipment is also reduced. Although the COP value of the refrigerator in the ice storage system is reduced, the economy of the air conditioning system is improved as a whole [20]. The principle of low-temperature air supply technology is to reduce the indoor temperature by using cooler air, which can be achieved by installing condensers and fans in the room [18]. Low-temperature air supply system generally adopts an all-air system and variable air volume terminal device to control different areas respectively, while improving the overall performance and advantages of the system and reducing energy consumption [10]. Low-temperature air supply technology also reduces the initial investment of equipment and saves management costs, as shown in Table 1. Low-temperature air supply system can also be combined with an ice storage system, the ice storage system can easily obtain low-temperature chilled water, and the use of a low-temperature air supply system can reduce the energy consumption of the fan, to achieve the effect of energy saving.

Table 1. Air conditioning system initial investment comparison [21]

Air conditioning system	Relative investment coefficient
Non-storage conventional air conditioning system	1.0
Partial cold storage and conventional air supply system	1.18 ~ 1.26
Partial ice storage and low temperature air supply system	0.86 ~ 0.73

3.2.2 Waste heat cycle technology

In traditional HVAC systems, the exhaust gas is discharged directly to the outside without treatment, and the exhaust heat is not properly utilized, which will lead to energy loss and thermal pollution. If this heat can be heated in fresh air, then under the same internal load, the fan load will be reduced and the indoor air quality will be improved [22]. The application of waste heat cycle technology in energy-saving design of building HVAC systems is more common, which cannot only save energy but also reduce energy consumption and reduce environmental pollution. The application principle of this technology is that in cooperation with the circulation system, the heat is effectively transferred and the waste heat is reasonably distributed. During the thermal cycle, if the power and heat transmission systems are not in the same loop, the radiation of the liquid during the heat transfer can be avoided and the pollution can be effectively reduced. As for the waste heat of the circulation loop, the reuse can effectively save thermal energy resources, thus improving the operating level of the heating system [17].

4. Conclusion

This paper studies the energy-saving design of HVAC in tall space structures, and draws the following conclusions:

(1) The use of natural ventilation potential, according to the natural environment and climate conditions in a specific geographical location, can optimize the energy-saving design of HVAC, so that it can reduce energy consumption and promote green development.

(2) HVAC energy-saving design of tall space structure requires the correct selection of cold and heat sources, so energy-saving and environmentally friendly new equipment and new technology can be used, such as ice storage system, air source heat pump system. They not only increase the energy consumption of HVAC systems, but also provide people with a more comfortable high-rise space environment.

(3) The use of renewable energy such as solar energy, wind energy, geothermal energy, combined with green materials can effectively reduce energy waste and promote the development of HVAC system design in the green direction.

(4) The energy consumption of HVAC system needs to be reduced. The application of frequency conversion energy-saving technology, low-temperature air supply technology and waste heat cycle technology not only ensures the use of tall space buildings, but also achieves the purpose of energy conservation and emission reduction.

In short, the energy-saving design of high-rise buildings in the HVAC design stage cannot only ensure the use of large space buildings, but also meet the relevant requirements of energy conservation and environmental protection. In order to achieve sustainable development, it is necessary to further explore the methods and technologies to solve these problems while promoting these technologies to ensure their feasibility and practicability. Only in this way, HVAC energy-saving technology can be more widely used in construction projects and make greater contributions to the future construction of mankind.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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