A Survey of the Influence of Air Distribution on Indoor Environment and Building Energy Efficiency

Longkai Ma¹,*,† and Zhili Zeng²,†

1 School of mechanics and civil engineering, China university of mining and technology, Xuzhou, China;
2 College of Mechanical Engineering, ChongQing University, Chongqing, China
*Corresponding author’s e-mail: 26185966@cumt.edu.cn
†These authors contributed equally.

Abstract. With society paying more and more attention to energy conservation, building energy conservation has become a problem that must be considered in the design phase. In addition, modern life makes people spend more time indoors every day. Reasonable indoor air distribution positively impacts a comfortable indoor thermal environment and reduces building energy consumption. This paper discusses the influence of air distribution on indoor thermal comfort and building energy saving. Reasonable air distribution in the air-conditioned room will create a comfortable indoor thermal environment, which is helpful for the physical and mental health of personnel and efficient work. Meanwhile, it can also effectively reduce the equipment's initial investment and operating energy consumption and realize building energy savings. The design of indoor air distribution cannot be a single, isolated project. A comprehensive analysis based on each station's environmental thermal comfort requirements in the work area must be carried out to reduce air-conditioning operation energy consumption and achieve building energy-saving goals. For existing buildings and large space buildings, the corresponding air distribution design scheme should be designed reasonably. This paper also suggests future research directions on indoor air distribution.

1. Introduction

Building energy consumption accounts for a high proportion in the total social energy consumption. In China's total social energy consumption, building energy consumption accounts for about 20.7% [1]. Therefore, one of the most important tasks of energy conservation is to reduce building energy consumption. In the 2014 ranking of world building energy consumption, the energy consumption of American buildings accounted for 17% of the total building energy consumption worldwide, ranking first in the world. China accounts for 16.2%, ranking second globally [2]. Compared with other services, heating ventilation and air conditioning (HVAC) systems are the most energy-consuming services in large buildings, with the energy consumed by HVAC systems accounting for 30% to 50% of the total building energy consumption. Especially, in cold areas where heating is needed, energy consumption will be as high as 80%. The energy consumption of HVAC in large public buildings accounts for more than 60% of the total energy consumption of buildings [3,4]. With the increasingly serious energy crisis, energy saving will have an important impact on the design and operation of the HVAC system because of the huge energy consumption of the air conditioning system itself. Scholars have studied the airflow distribution of indoor air through computational fluid dynamics (CFD), experiments, and theoretical analysis. The research shows that the main factors affecting the air distribution in the air conditioning room are the air supply parameters, the form and position of the

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air supply outlet, the position of the return air vent, the position of the heat source, and the shape of the room. According to the different layout positions and forms of air supply outlet and return vent, different air distribution forms will form, mainly including up-supply and down-return, up-return down-supply, sidewall supply, and return, etc.

For the upper supply and lower return vent arrangement, according to the setting of the air supply distance, louver vent, nozzle or swirl vent can be selected. The advantage of this air supply and return mode is that it can reach a uniform temperature gradient for the action area, and it is easy to arrange the air inlet. The disadvantage is that the air volume to be processed is large, and the system's energy consumption is large. Moreover, with many upper duct, the installation is complex. In winter, the vertical temperature gradient is great, so the lower part is cold and the upper part is hot.

The air supply mode of up-return down-supply is mainly aimed at specific situations, such as the high humidity in the space and the autonomous heat source in the room. Down air supply can be achieved through seat vents, floor vents, etc., combined with some composite systems such as radiation cooling. In this air supply mode, the air exchange rate is faster. In addition, the temperature and humidity of the working area can be effectively controlled, and the energy-saving effect of the system is obvious. However, the air inlet is located at the bottom, the speed and temperature of the air supply need to be strictly controlled. Otherwise, it will blow up dust or cause human discomfort. In addition, due to special vents, the cost is high, and the maintenance is inconvenient.

The air supply mode of sidewall supply and return, the action area of the air conditioning, is set in the reflux range of jet. The advantages are that the range of the jet is far and the temperature field is easy to achieve stability. Moreover, the wind speed decays slowly. Therefore, the airflow and temperature in the action area are uniform and more energy-saving. However, in winter, because the buoyancy of hot air is large, it is difficult for heat to reach the action area, so the uniformity of temperature distribution is not as good as other ways [5,6].

This paper discusses the influence of air supply mode on the indoor environment and building energy efficiency. In detail, the influence of air distribution on indoor air conditioning is introduced firstly. Then influence of air distribution on building energy consumption is summarized. After that, the optimization design of indoor air distribution is presented. Finally, conclusions are drawn, and suggestions for future research are given.

2. Influence of air distribution on indoor air conditioning

2.1. Influence of the air outlet layout on the indoor thermal environment

The research on indoor air distribution and indoor thermal comfort was carried out earliest in foreign countries. As early as 1945, the laboratory of the University of Kansas used measuring instruments to study the airflow organization of indoor hot air. This study was an advanced experimental research method of indoor airflow organization at that time. The experimental method concluded that for some buildings, the indoor comfort of the ventilation system with impinging jet was better than that of the displacement ventilation system. The ventilation system should be selected according to the construction conditions [7]. In 1974, P.V.Nielsen [8] from Denmark first used CFD method to simulate indoor airflow state. CFD has been introduced into the design business in Japan, Europe, and The United States, forming an efficient design system. Some famous projects, such as Fukuoka Stadium in Japan, Kansai Airport, Tokyo Metropolitan Stadium, New National Theater, Tokyo International Convention Center, various Winter Olympic Venues and Rose Park Stadium in the United States, have used CFD method to calculate and predict air distribution and temperature distribution to guide the optimization of engineering design [9].

CFD is also widely used in China to investigate indoor air distribution. Xu et al. [10] studied the airflow distribution and air quality in the room under the three modes of up-in and up-out, up-in and down-out, and displacement ventilation. The results showed that the room had good thermal comfort and good air quality with displacement ventilation. In 2015, Wu et al. [11] combined ventilation methods with indoor thermal comfort. With CFD method and zero-equation model to simulate three ventilation modes of up-supply up-return, up-return down-supply, up-supply and down-return in air-conditioning system, they compared the simulation results of temperature field, PMV, PPD and air age.
An [12] uses FLUENT as a platform to combine the custom function UDF. They use the RNG k-\varepsilon model combined with the wall function method and the Lagrangian method-based particle random trajectory model to establish the air-conditioned room's turbulence and particle model of the air-conditioned room. In the case of three types of air supply: up-inlet and down-outlet on the same side, up-inlet and down-outlet on the opposite side, bottom air supply and top return air, numerical simulations are performed on the airflow organization with air changes of 5 times/h and 10 times/h. The velocity field, temperature field, and air are obtained. The distribution rule of an age field and PMV-PPD thermal comfort index and the rule of the influence of different temperature and humidity combination conditions on the thermal comfort of personnel are demonstrated. The results show that the airflow organization of up-inlet and down-outlet on the same side is the best. Up-inlet and down-outlet on the opposite side will cause the airflow to not circulate. The temperature stratification of bottom air supply and top return air is obvious, with the highest energy utilization coefficient. The temperature has a great influence on human thermal comfort, while humidity has no obvious influence. Li [13] studied the indoor airflow organization of the nozzle side air supply and the new diffuser top air supply mode in summer. It was found that the temperature field and velocity field of the air conditioning room were greatly affected by the outlet wind speed of the supply air outlet under the condition of the nozzle side air supply. The lateral air distribution has a good mixing effect on the airflow in the room, forming a uniform temperature field and velocity field. The closing or opening of the light plate of the new type of top air distributor has little effect on the temperature. The top air supply attached to the ceiling and wall jet makes the room temperature and velocity distribution uniform. For ultra-low energy buildings that can provide a comfortable indoor environment and minimize energy consumption, Tian et al. [14] used ANSYS to analyze the different forms of fresh air outlets in the room and their position relationship. When the fresh air outlets are arranged near the air conditioning outlets, the form of louver fresh air outlets on the top side is better than that on the bottom diffuser. In addition, the spacing between the top side louver fresh air outlet and the air conditioning outlet should not be too large. If the distance is more than 400 mm, the cold air from the fresh air outlet cannot be heated by the hot air from the air conditioning outlet, making the working area near the fresh air outlet feel blowing.

2.2. Study on the influence of air supply angle on indoor comfort
In addition to the installation location of the air-conditioning air supply outlet, the air supply angle greatly influences indoor comfort [15]. If the angle is reasonable, it will effectively improve indoor comfort and reduce air conditioning energy consumption, which is conducive to building energy efficiency [10, 16]. In general, the air supply angle and the installation position of air-conditioning air supply outlet are important factors affecting indoor thermal comfort [17]. In 2014, Li [18] took the atrium of a hotel in Chongqing as the research object, simulating the air conditioning mode combining the nozzle side air supply and the floor air supply on both sides of the atrium through CFD. By analyzing the distribution of temperature, velocity, PMV and PPD, it was found that the optimal air supply angles in winter and summer were $+7^\circ$ and $-15^\circ$, respectively, verifying the effectiveness and reliability of CFD simulation of large-space air conditioning. The research results of Li [19] showed that the air supply angle of the swirl vent had a great influence on the airflow organization, human comfort and energy-saving effect in the multifunctional banquet hall. The results show that under the optimal working conditions of the multifunctional banquet hall, the air supply angle of the cyclone outlet is $45^\circ$ in summer and $60^\circ$ in winter. The comprehensive optimal parameters under the design conditions in summer were determined by orthogonal test analysis. Under winter conditions, the simulation results show that under the premise of ensuring fresh air supply, the combination of low-temperature radiant floor heating and convective heat dissipation coil heating has better comfort and lower energy consumption.

Air supply angle is directly related to personnel comfort. With more office buildings using air conditioning for room cooling, due to the long-term direct blowing of air outlets in some stations, indoor personnel have a sense of blowing, overheating or super-cooling, leading to adverse reactions such as headache and dizziness [20]. In response to this phenomenon, Sun [21] simulated the air
supply angle of the air conditioning in the used office, and obtained a suitable air supply angle so that
most indoor personnel could meet the thermal comfort conditions such as indoor air temperature and
velocity. The angle-adjustable side air supply shutters are installed on the west side. In the middle
installed angle adjustable card four outlet fan coil. A diffuser with an angle of 45° is installed on the
east side. Sun simulated the situation of different air supply angles if each fan coil was opened alone.
The simulation results show that if the supply angle of the side supply fan coil is 0° or 30°, the supply
distance is far. In the working area with vertical height of 2 meters, the indoor temperature difference
and wind speed are small, so it is more comfortable. If the supply angle of the four-outlet fan coil is
45°, the indoor temperature distribution is relatively uniform. With a small wind speed, thermal
comfort is ideal. The simulation of three fan coils opening at the same time shows that the ideal
thermal comfort can be obtained. The measured results of the simultaneous opening of three fan coils
show that indoor the simulation results of indoor temperature are in good agreement with the
measured results.

2.3. The influence of air distribution in air-conditioning room on indoor thermal comfort
Unreasonable indoor air distribution of air conditioning will not only make the selection of air
conditioning equipment capacity too large, increasing the energy consumption, which is not conducitve to achieve building energy conservation, but also reduce the work efficiency of personnel, affecting the thermal comfort of the indoor environment [22].

The study of air distribution began in the 1920s. Human's poor comfort caused by cold air feeling
attracted the attention of researchers in the field of air conditioning [23]. Li [24] studied the air
distribution and thermal comfort in the office. He found that in the room with louver vent supplying
air at the top, people under the vent felt extremely uncomfortable. In the office with side air supply, the
area close to the vent had high wind speed and low temperature. In this case, the staff in this area
could not work normally. Li used the job satisfaction rate to evaluate the indoor thermal comfort of the
office building, analyzing the uncomfortable problems in the office more specifically and putting
forward optimization plans. For rooms where air distribution of air conditioning is easily changed,
measures such as adjusting air supply angle and additional flow diversion device can improve thermal
comfort. Aiming at the room where air distribution is not easy to change, the air distribution is
analyzed to adjust the station layout and improve the thermal comfort of the station. Therefore, to
improve the comfort of the workstation in the office, two ways can be adopted: improving the
distribution form of air distribution in the room and adjusting the layout of the workstation.

Meanwhile, in order to fully consider the requirements of occupants on different levels of thermal
comfort environment and air quality, Fanger [25] from Denmark proposed personalized ventilation,
which directly sent fresh air into the breathing area of indoor occupants according to their different
ventilation requirements resulting from their clothing and mental state. Zhao et al. [26] from Tsinghua
University compared the ventilation effects of four rooms by introducing a modified evaluation
parameter of air exchange efficiency. They found that different ventilation methods had various effects
on different personnel distribution in the room.

Reasonable air distribution can improve the comfort of indoor personnel and effectively discharge
indoor pollutants. Jiao et al. [27] from Hunan University conducted numerical simulation of indoor
temperature field, velocity field, pollutant concentration field and PMV-PPD distribution under mixed
ventilation and displacement ventilation. The results demonstrated that displacement ventilation had a
better effect on thermal comfort, while mixed ventilation better affected indoor pollutant removal
ability. In 2016, An [12] carried out a numerical simulation of the distribution of two kinds of particulate matter generated by indoor personnel activities under different air supply forms,
concluding that down-to-top delivery has better suppression and removal effect on particulate matter.

3. Influence of air distribution on building energy consumption
The form of air distribution is closely related to building energy consumption. Because some designers
do not pay enough attention to the indoor airflow organization, resulting in uneven indoor ambient
temperature, designers have to increase the capacity of the equipment. In addition, due to unreasonable
air flow organization, the operation time of air conditioning increases, so the operation energy
With the increasing attention to the energy-saving of air conditioning systems in large space buildings, Cheng et al. [29] carried out research on stratified air conditioning systems. The study found that the absolute energy-saving potential of the stratified air conditioning system is proportional to the discharge air temperature. Therefore, if the return air inlet and the discharge air outlet are arranged separately, increasing the discharge air temperature and improving the building energy-saving potential is beneficial. Under the test conditions, if the return air inlet and discharge air outlet are arranged separately, the energy-saving potential of stratified air conditioning is greatly improved with the decrease of return air inlet height. In 2017, Peng et al. [30] took Xinjiang International Convention and Exhibition Center as an example to theoretically analyze the composition of stratified air conditioning load and the calculation of airflow organization, and verified the theoretical design calculation through CFD simulation. It was found that stratified air conditioning had obvious advantages in energy saving in summer but no obvious advantages in winter.

Waiting station is also a common large space building. The waiting hall on the ground floor of Xiongan Station is a typical tall space. The design adopts a decentralized air supply unit system and air supply with attached jet combined with the end of side nozzle. By means of computer simulation, Li et al. [31] compared the air distribution in the personnel activity area of the waiting hall under three working conditions in summer (attached air supply, nozzle side air supply, attached air supply combined with nozzle side air supply). They obtained the better air supply mode, checking the design working conditions in winter. The results show that compared with the centralized all-air system, the energy consumption of the distributed system is reduced by about 30% in summer, and the air supply mode with attached jet combined with nozzle is reduced by 15% in summer compared with the traditional nozzle side supply mode.

In view of the "chimney effect" in large stadiums and the uneven temperature distribution in the front and rear seating areas, Hua [32] found that compared with the up-send down-return air distribution form for large stadiums, down-send up-return form was more energy saving. If the occupancy rate is greater than 70%, the lower air supply and radiant cooling plate are used to eliminate the space cooling load. If the occupancy rate is below 70%, down-send up-return form can be directly used to eliminate the cooling load. Gao [33] from South China University of Technology took a university gymnasium in Guangzhou as an example to optimize the original air distribution. He optimized the unreasonable distribution of velocity field and temperature field in the gymnasium. On the basis of satisfying PMV-PPD, the optimized air conditioning system saved 16.9% in average during the whole year, achieving good economic effect. Lai [34] first modified the solution of the inner surface temperature of the building envelope in the stratified air conditioning load calculation, proposing a solution model to correct the simplified calculation results. The theoretical calculation was used to analyze the whole room air conditioning load with upper supply and lower return and the stratified air conditioning with side supply and lower return under various working conditions. The air conditioning load of the two methods and the theoretical load energy saving rate of the stratified air conditioning were obtained. To verify the distribution of temperature and air speed fields during actual operation and find out the optimal air distribution design scheme, Lai used FLUNT to simulate the working conditions of typical rooms in summer and winter, obtaining the applicability of full-room and stratified air conditioning. The energy-saving effect of stratified air conditioning is significant in summer, but the energy-saving rate in winter is lower than that in summer. Due to cold air infiltration and unreasonable design in Chongqing, the heat capacity is much higher than the calculated heat load. This will result the heating effect of air conditioning is insufficient in winter. To verify the accuracy of theoretical calculation, Lai analyzed working conditions in summer and winter for three large space buildings in Chongqing: the hall of inpatient building, the hall of outpatient building and the hall of office building. For a large space building, comprehensively considering its refrigeration energy consumption and air cabinet transportation energy consumption, the energy consumption of the air conditioning system when the design requirements are met is obtained.
4. Optimization design of indoor air distribution

4.1. Optimization of air distribution in indoor thermal environment of existing buildings

Reasonable air distribution form not only can guide people to carry out the air conditioning design of new houses reasonably, but also plays an important role in guiding people to effectively improve the air distribution of existing buildings. In 2016, the urban public building area in China reached 11.7 billion m². As the indoor environment design standards and specifications of some existing public buildings were not yet perfect when they were built, the existing indoor environment was more prone to problems, so it has been attracting people's attention [35]. In 2013, Awbi [36] obtained the average indoor PPD and PMV values through experiments. The results showed that the comfort of some buildings using displacement ventilation system was not as good as that using impinging jet ventilation system. In 2014, Di and Wang [37] studied the low-frequency sinusoidal air supply for different air distribution models in a dynamic environment. They concluded that if air supply and return vents are located on both sides of the room, air flow fluctuations have a positive impact on human thermal comfort. Zheng et al. [38] carried out CFD simulation on floor air supply and side air supply in a typical office room. They found that the average temperature of the side air supply's working area and non-working area was lower than that of floor air supply, and the air mixing degree was higher than that of floor air supply. At 21°C, floor air supply creates better indoor thermal comfort, but side air supply has a higher energy utilization factor because of higher air mixing and heat exchange. Zhou et al. [39] carried out numerical simulation of different air supply modes on temperature field, pollutant concentration field and velocity field in conference room was analyzed and compared. It was found that the indoor temperature, air speed and pollutant concentration were more uniform under the top air supply mode. It is concluded that the top air supply is more suitable for the conference room.

4.2. Optimization design of air distribution of air conditioning system in large space buildings

Since the 1980s, the scale of large-space architecture has become huge because of the progress of architectural technology and the gradual growth of people's demand for cultural life [40, 41]. Different from traditional small and medium-sized buildings, large space buildings are characterized by large space height, large proportion of the outer wall, small proportion of the use area in the whole space, etc. Reasonable air flow organization design is particularly important for its air conditioning design [42].

For the air distribution design of large space air conditioning system, the main methods for predicting indoor air distribution include jet formula, simulation experiment, regional model and CFD. Zhao et al. [43] showed that jet formula had a small scope of application, short prediction period and poor reliability of results. The regional model is difficult to be applied to mechanically ventilated rooms. The simulation experiment is the most reliable, but the prediction cycle is long and it is not convenient to use. CFD can consider all kinds of possible indoor disturbances, boundary conditions, and initial conditions to comprehensively reflect the indoor air distribution and find the optimal air distribution scheme. Therefore, CFD method is widely used in air distribution design of large space air conditioning system [42].

The function of large space building is diverse, so there are different air vents in the same space. Since the 1970s, many scholars have proposed different vent models to simplify vent inlet boundary conditions. Vent models can be classified into the direct description and indirect description according to different description processes. The direct description class includes the basic model and momentum model [44–45], which is not limited by whether the supply air jet is isothermal or restricted. Therefore, in large-space simulation, this description of vent model has been widely used [46–47]. However, to obtain the vent air supply parameters, more grids are needed. Therefore, Zhao Bin proposed the momentum model of n-point vent on the basis of momentum model. The study showed that this model could obtain satisfactory results to simulate the common inlet boundary conditions of the air conditioning vent [48–49]. However, although the indirect description of vent model simplifies the problem, it has certain limitations and is not commonly used in large space simulation [50].
Generally, for theater, multi-purpose hall and other crowded occasions, if only the flow field and temperature field of the whole space is studied, the heat dissipation of lamps and equipment can be directly dispersed to the plane, without a specific geometric shape to express. However, when the thermal comfort around the human body is concerned, it is necessary to simplify the personnel, lamps and equipment into the appropriate shape for studying. Meanwhile, the accurate setting of convection and radiation heating rate of heat source has an important influence on the prediction of large space airflow and energy consumption evaluation. According to the different environment of the large space and the difference in the vertical temperature distribution of the wall surface, the boundary conditions of the wall surface are set. Special attention should be paid to the treatment of boundary conditions of glass curtain walls [42, 50].

Through numerical simulation, Yu [5] obtained that the vertical temperature gradient in the whole area of large space stratified air conditioning is obvious, especially in the upper part, where the hot air moves upward obviously and the temperature near the roof is high. The jet flow at the stratification only bears the load below the stratification. Fan coils need to be set separately to ensure the local temperature of the upper layer. Meanwhile, the top discharge mode needs to be set. Heat is brought out through air flow, thereby reducing the heat transfer from the top heat storage to the lower part, and reducing the convective heat transfer in summer. But too much discharge can also have adverse effects. In practical engineering, there are many kinds of air distribution schemes for ventilation and air conditioning of large space buildings. Among them, the more widely used forms are the whole room air conditioning scheme with upper supply and lower return and the stratified air conditioning scheme with central side air supply. Aiming at the air flow organization engineering calculation of full-chamber air conditioner and stratified air conditioner, Wang [51] simplified the calculation formula by dimensionless processing of parameters. The calculation charts of air flow organization of two air conditioners in winter and summer are drawn. Moreover, it is found that the energy saving rate is 12.6-18.9% when the relative stratification height is less than 0.5. Therefore, in the design of stratified air conditioning, the relative stratified height should be controlled below 0.5. Through the analysis of three kinds of large space buildings with typical "physical characteristics of load", it is found that the buildings with "physical characteristics of load" as the block heat source (such as machinery factory) should choose the stratified air conditioning mode of medium air supply first. The "physical characteristics of load" is the horizontal heat source of buildings (such as the lecture hall) suitable for up- supply and down- return room air conditioning; "Physical characteristics of load" for the vertical surface heat source of buildings (such as the atrium) could choose the middle to lower stratified air conditioning for comfort and energy saving. The change of the number of air inlets in the whole room air conditioning mode has little effect on the average temperature of the working area. However, the change of the average velocity in the working area will decrease significantly with the increase of the number of air outlets, and the increase of the number of air outlets will greatly improve the uniformity of the temperature field and velocity field in the working area. Therefore, under the premise that the air supply speed meets the conditions, a certain number of air outlets should be ensured. When the air supply outlets on both sides of the stratified air conditioning are staggered, the collision strength between the air supply jets can be effectively reduced, so as to reduce the disturbance of the air supply jet to the gas in the non-air-conditioning area and reduce the waste of air supply cooling.

Through experiments and numerical simulation, Yu [5] found that stratified air conditioning can effectively reduce the overall air conditioning load of atrium buildings. Air supply speed is an important factor in the formation of the air flow partition surface of the stratified air conditioning. If air speed is too high, the air flow of the jet collide and interferes with each other. With overall air flow disorganized, the air flow partition surface cannot be formed, which strengthens the convection between the air-conditioned area and the non-air-conditioned area. When the air supply speed is too low, the air flow partition surface cannot be formed. With same total air supply volume, increasing the number of vent can reduce the air supply speed. So stratification effect and the comfort level of people in the action area are better. Cheng et al. [52] simultaneously simulated the influence of vent arrangement on the energy saving potential and environmental thermal comfort of the stratified air-conditioning system applied to different buildings. The results show that the uniformity of indoor air distribution can be improved by adding reasonable air supply for large buildings. Thermal comfort
problems such as excessive temperature difference between head and foot can be avoided. For small and medium-sized building space, if the height of the return air inlet drops, the return air flow induces the cold air of the supply air, and cooling capacity at the height of the human head is insufficient. In 2016, Wang [53] took a atrium in Shenzhen as an example to adjust and improve thermal comfort by changing quantity of air supply in the middle of each floor of the atrium. After simulation analysis, if quantity of air supply in the first and top floors is 1.1 times and 2.31 times of the standard floor, respectively, the discomfort caused by the chimney effect in summer can be eliminated. Based on simulation calculation, Huang [54] concluded that the recommended range of air supply speed of stratified air conditioners in the atrium of shopping malls in the Pearl River Delta in summer is 4-6m/s. If the temperature difference of air supply is 8 ℃, the thermal comfort of human is the best. The recommended range of air supply height is 4.6-6m and discharge ratio at the top of the shopping mall atrium is 5%-15%. Multi-factor orthogonal experiment was used to optimize the thermal comfort under different air supply conditions. The optimal thermal comfort was obtained if the air supply temperature difference was 8 ℃, with the air supply speed of 5.2m/s, the air supply height of 4.8m, and the air discharge ratio of 12%. Huang described the pearl river delta region shopping mall atrium’ thermal comfort evaluation parameters in summer, which showed the evaluation reference in summer. Meanwhile, by changing the air supply temperature, air supply speed, air supply height and air exhaust ratio at the top of the mall, the scheme of optimizing the thermal comfort of the atrium was given, which provided a reference for the design of the atrium air conditioning engineering in the mall. Guo et al. [55] established a three-dimensional model of an underground supermarket in Chongqing to study its indoor airflow organization. This supermarket adopts the air supply on the diffuser and air return from the side of the louver vent. The on-site measurement method and CFD numerical simulation were used to obtain the temperature field and velocity field distribution in the supermarket. The numerical results are in good agreement with the actual measurement results.

5. Conclusion and outlook
This paper discusses the importance of air conditioning air distribution, air distribution on indoor thermal comfort, and building energy saving. The following conclusions can be drawn:
(1) The installation position of the air outlet of the air conditioner and the angle of the air supply are important factors affecting indoor thermal comfort. If its design is reasonable, it will effectively improve the indoor comfort and the work efficiency of worker, and affect the indoor thermal environment.
(2) The form of air distribution is closely related to the energy consumption of the building. Because some designers did not pay enough attention to indoor air distribution, resulting in uneven indoor ambient temperature, designers had to increase equipment capacity. In addition, due to the unreasonable airflow organization, the air conditioner's operating time and long-term operation with large air volume have been increased, and the air conditioner's energy consumption has increased. It is not conducive to building energy saving.
(3) A reasonable form of airflow organization can guide people to carry out the air conditioning design of new houses rationally and play an important role in guiding people to effectively improve the airflow organization of existing buildings. Moreover, in view of the large space height, the large proportion of the outer wall of the large space, and the small proportion of the use area in the entire space, the appropriate airflow organization form is designed.
In terms of the future research direction, the following avenues of improvement can be followed:
1) For large space buildings such as airport waiting rooms and atrium, glass curtain walls are often used. The solar radiation through the large glass curtain walls has a significant impact on the thermal comfort of the human body and greatly impacts the temperature field and flow field of the large space. Therefore, further research is needed to select a suitable radiation model to describe this physical process.
2) During the raging period of the new crown pneumonia virus, for special places such as pharmaceutical factories and hospital wards, in addition to ensuring a good indoor thermal
environment and achieving energy-saving operation, it is also necessary to strictly control the distribution of airflow to ensure the cleanliness of the indoor environment.

Reference

[1] Zhao Donglai, Hu Chunyu, Bai Desheng, etc. Current status and development trend of China's building energy efficiency technology[J]. Building Energy Efficiency, 2015(3): 116-121. (in Chinese)

[2] China Building Energy Conservation Association. China Building Energy Consumption Research Report (2016) [R]. China Building Energy Conservation Association Energy Consumption Statistics Professional Committee. 2016. (in Chinese)

[3] Zhuo Mingsheng, Liang Rongguang, Xu Shisong. Discussion on energy saving of central air-conditioning system in modern building [J]. Refrigeration, 2004(03): 78-81. (in Chinese)

[4] Jeniček V, Krepl V. Energy, environment and sustainable development [J]. Areal Research & Development, 2014, 41(3): 427-440.

[5] Yu Xin. Numerical simulation study on air conditioning of large atrium space in large office buildings using CFD[D]. Beijing University of Architecture and Architecture, 2017. (in Chinese)

[6] Zhu Qiqi. Simulation experiment research on indoor airflow organization and particle distribution under different air supply modes [D]. Shandong Jianzhu University, 2019. (in Chinese)

[7] Agha-Hossein M M, El-Jouzi S, Elmualim A A, et al. Post-occupancy studies of an office environment: Energy performance and occupants’ satisfaction [J]. Building and Environment, 2013, 69: 121-130

[8] P.V.Nielsen. Flow in air conditioned rooms (English translation): [Ph D Thesis]. Copenhagen: Technical University of Denmark, 1976

[9] Zhang Jingqing. Research on the boundary conditions of the numerical simulation of large space air conditioning[D]. Chengdu: Southwest Jiaotong University, 2006. (in Chinese)

[10] Xu Li, Weng Peifen, Sun Weimin. Numerical analysis of indoor airflow organization and indoor air quality under three ventilation modes [J]. Acta Aerodynamics, 2003, 21(03): 311-319. (in Chinese)

[11] Wu Xianqing, pay equal. Numerical simulation of the influence of ventilation methods on indoor thermal comfort [J]. Refrigeration and Air Conditioning, 2015, 29(1): 16-21. (in Chinese)

[12] An Puyan. Numerical simulation study of indoor air distribution and particle distribution[D]. Hunan University, 2016. (in Chinese)

[13] Li Hongmei. Experimental and simulation study of indoor air distribution with side air supply from nozzles and new diffuser top air supply[D]. Chang'an University, 2017. (in Chinese)

[14] Tian Jing, Liu Shaoliang, Mao Hongzhi, Zhao Yanyan. Simulation study on bedroom interior environment of ultra-low energy consumption residential buildings [J]. Building Technology, 2021, 52(04): 425-428. (in Chinese)

[15] Wang Fujun. Computational Fluid Dynamics Analysis: Principle and Application of CFD Software. [M]. Tsinghua University Press, 2004. (in Chinese)

[16] Shang Shaowen, Xu Ying, Bo Shiqiang, Li Longxin, Bi Xue. Simulation and analysis of the effect of different ventilation methods in the office [J]. Journal of Shenyang Jianzhu University (Natural Science Edition), 2017, 33(01): 143-151. (in Chinese)

[17] European Standard, EN 15251, Indoor Environmental Input Parameters For Design and Assessment of Energy Performance of Buildings-Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics, 2007

[18] Li Chao. Computational research and optimization method of air distribution in hotel atrium air conditioning[D]. Southwest University, 2014. (in Chinese)

[19] Li Jiarong. Calculation analysis and optimization research on airflow organization of air conditioning in multifunctional banquet hall [D]. Southwest University, 2016. (in Chinese)

[20] Zhang Junfu. Indoor air quality testing and air distribution analysis of office buildings [D]. Xi’an University of Architecture and Technology, 2012. (in Chinese)
[21] Sun Yongli. Research on the influence of air-conditioning air supply angle on indoor comfort[D]. Shandong Jianzhu University, 2019.(in Chinese)

[22] Yu Wenhong, Li Yang, Gao Yan. Air-conditioning indoor air distribution and building energy efficiency[J]. Building Energy Efficiency, 2017, 45(05):7-9+16.(in Chinese)

[23] Huang Feng, Qin Xionghong, Qu Yunxia, et al. The influence of different air supply methods on thermal comfort[J]. Energy Conservation, 2009, (1): 46-49.(in Chinese)

[24] Li Yang. Research on indoor air distribution and thermal comfort of air conditioning systems in office buildings[D]. North China University of Technology, 2017.(in Chinese)

[25] Fanger P O. Human requirement in future air-conditioned environments: a reasearch for excellence[C]. Proceeding of HVAC 99, 1999:86-92.(in Chinese)

[26] Zhao B, Wu J, Li X, et al. Evaluating the Ventilation Effect of Different Ventilation Types by Occupant Air Exchange Efficiency[J]. ASHRAE transactions, 2005, 111(2).

[27] Jiao Junjun, Gong Guangcai, Shao Chunsheng. Numerical simulation of the influence of airflow organization on indoor air quality[C]. Proceedings of the 2008 Annual Conference on HVAC and Refrigeration. 2008:284. (in Chinese)

[28] Liu Fei. The influence of building thermal environment on human thermal comfort and building energy consumption[J]. Popular Science and Technology, 2010,(9):58-59.(in Chinese)

[29] Cheng Yuanda, Zhang Xinghui, Jing Shenglan, Du Zhenyu. The effect of vent layout on energy saving potential and head-to-foot temperature difference of stratified air conditioning system[J]. Heating Ventilation and Air Conditioning, 2016, 46(06): 116-121+127.(in Chinese)

[30] Peng Jianbin, Zhang Congli, Wang Jiang. Design and simulation of layered air conditioning for Xinjiang International Convention and Exhibition Center [J]. HVAC, 2017, 47(4): 73-77.(in Chinese)

[31] Li Guiping, Wang Tiancheng, Sun Zhaojun, et al. Airflow organization optimization design of the air conditioning system in the first-floor waiting hall of Xiong'an Station [J]. Heating Ventilation and Air Conditioning, 2021, 51(9): 2430.(in Chinese)

[32] Hua Yawei. Airpak-based airflow organization energy-saving design and energy-saving operation research of large-scale stadiums and gymnasiums [D]. Jilin Jianzhu University, 2016.(in Chinese)

[33] Gao Zhiming. Research on Numerical Simulation and Energy-saving Optimization of Air-Conditioning Air Distribution in Gymnasium[D]. South China University of Technology Master's thesis, 2012: 5-39.(in Chinese)

[34] Lai Hejing. Energy consumption analysis of different airflow organization forms of air conditioning systems in tall and large spaces [D]. Chongqing University, 2011.(in Chinese)

[35] Research Center for Building Energy Efficiency, Tsinghua University. Annual Development Research Report on Building Energy Efficiency in China [M]. Beijing: China Building Industry Press, 2018.(in Chinese)

[36] Awbi H.B.. Ventilation of Buildings [R]. New York: Spon Press, 2013.(in Chinese)

[37] Di Yuhui, Wang Shancong. Effects of different airflow organization forms on human thermal comfort under dynamic conditions[J]. HVAC, 2014, (08): 106-109+105.(in Chinese)

[38] Chenxiao Zheng,Shijun You,Huan Zhang,Wandong Zheng,Xuejing Zheng,Tianzheng Ye,Zeqin Liu. Comparison of air-conditioning systems with bottom-supply and side-supply modes in a typical office room[J]. Applied Energy,2018,227:

[39] Zhou Bo, Song Shengbo, Dong Liguo. Numerical simulation of the environment in a public office building [J]. Journal of Shenyang University of Industry and Technology, 2018(02):213-218.(in Chinese)

[40] Huang Chen, Li Meiling. Research on indoor vertical temperature distribution in large space buildings[J]. HVAC, 1999(05): 28-33.(in Chinese)

[41] Fan Cunyang. Air-conditioning design of large space buildings abroad[J]. HVAC, 1996(04): 39-49.(in Chinese)

[42] Pan Dongmei, Xu Xiangguo, Wang Yilin, Wang Limin, Shao Junqiang. Simulation of airflow organization in tall spaces-literature review[J]. HVAC, 2018, 48(01): 131-138. (in Chinese)
[43] Zhao Bin, Lin Borong, Li Xianting, et al. Prediction methods and comparison of indoor air distribution [J]. HVAC, 2001, 31(4): 82-86. (in Chinese)

[44] Shafqat Hussain, Patrick H. Oosthuizen. Numerical investigations of buoyancy-driven natural ventilation in a simple atrium building and its effect on the thermal comfort conditions [J]. Applied Thermal Engineering, 2012, 40(7): 358-372

[45] Nielsen P V. Description of supply openings in numerical models for room air distributions [G]. ASHARE Trans., 1992, 98(1): 963-971

[46] Chen Q Y, Moser A. Simulation of a multiple-nozzle diffuser [C]. Proceedings of the 12th AIVC Conference on Air Movement and Ventilation Control within Buildings. Ottawa, 1991: 1-13

[47] Zhang Dongjie, Jin Yuanguo. Numerical simulation of large space air conditioning system [J]. Refrigeration and Air Conditioning, 2009, 23(6): 118-122. (in Chinese)

[48] Jiang Haibin. CFD numerical simulation and thermal comfort of airflow organization in large space stratified air-conditioning system Analysis and Research [D]. Zhenjiang: Jiangsu University, 2008: 34-35. (in Chinese)

[49] Zhao Bin. N-point vent momentum model for numerical simulation of indoor air flow [J]. Chinese Journal of Computational Mechanics, 2003, 20(1): 64-69. (in Chinese)

[50] Zhao Bin, Li Xianting, Yan Qisen. Numerical simulation of air supply range of orifice air-conditioning air outlet [J]. Mechanics and Practice, 2002, 24(1): 18-21. (in Chinese)

[51] Wang Long Pavilion. Research on the optimization of air distribution design in different tall and large space buildings [D]. Chongqing University, 2015. (in Chinese)

[52] Cheng Yuanda, Yang Jinming, Zhang Xinghui, Du Zhenyu. The layout of the air outlets of the layered air conditioning system in different buildings, Optimization Research [J]. HVAC, 2018, 48(04): 100-107. (in Chinese)

[53] Wang Shuo. Application of CFD technology in thermal environment design of tall atrium [J]. Building thermal ventilation and air conditioning, 2016, 35(6): 77-78. (in Chinese)

[54] Huang Huaming. Research on optimization of summer thermal comfort in the atrium of the Pearl River Delta shopping mall [D]. Guangzhou University, 2018. (in Chinese)

[55] Guo Yujie, Yao Liping, Zhang Yongdong, Lai Hejing, Wang Mengning. Research on measurement and numerical simulation of indoor air distribution in underground supermarkets [J]. Fluid Machinery, 2019, 47(12): 62-66. (in Chinese)