

Review and prospect of stratified air conditioning technology of large space buildings

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Abstract: This paper analyses the energy saving property of stratified air conditioning and it shows that the technology applies to the large space buildings, and its effect on energy saving is apparent. Its cooling load and air distribution have their characters. Its calculation of air distribution mainly adopts two methods: one is model experiment; the other is mathematical model predicting. However, each of them has advantages and disadvantages, so they need to be improved. This paper describes development of stratified air conditioning technology in foreign countries, mainly in Japan and America. It also reviews that technology in China and predicts its good prospect in the future.

Keywords: large space buildings; stratified air conditioning; technology of energy saving

1. Introduction

As an important technological mode of building environmental control, air conditioning becomes more and more popular. The advancement of air-conditioning technology improves human lives and working conditions, yet in the other hand it has given rise to a series of problems, such as big energy consumption, and breaking atmosphere zone layer, indoors air quality etc. With the appearance of "energy crisis" in the 1970s, people came to realize the importance of energy saving. And nowadays, 20-30% of energy is used to air-conditioning system, thus energy saving is being paid more attention in some nations, especially in developed ones. So energy saving of building, especially air-conditioning energy saving of building has drawn the attention of the whole humankind, which needs more study and analysis.

With the fast development of our economy, application of the technology becomes gradually extensive, which leads to the energy's increasing quickly, so air-conditioning energy saving is becoming more and more important. As to those high and big workshops with air conditioning, the area amounts to several thousand square meters and the height ten meters or even more, thus the energy of the air-conditioning is very considerable. The space which provides for workers' activities, depositing and establishing machinery is known as the work area, it is usually underlying space from floor to several meters above the ground; the rest upper space is built for building construction or installing cane. In this kind of workshops, the space

under work zone should establish air-conditioning, therefore rational air distribution can only be that air-condition is installed in the underlying zone, and it only adopts simple ventilation and heat transfer but not air-conditioning. This kind of air conditioning the method was called the "stratified air conditioning". In the high and big air-conditioned factory premises, it is not proper to adopt the technology unless when the height $H \geq 10$ ms, factory premises capacity $V > 10000$ m³s, the height of air-conditioning area divided by the height of factory premises $h_1/H \leq 1/2$ [1].

It proves that adopting stratified air conditioning can save the cooling load, initial investment and operation cost, as compared with the whole-room-air-condition. According to abroad reviews, the cooling load can induce 14% and under very conditions even 50% of energy. But we should notice that air-conditioning operates in the winter does not necessarily save energy unless the proper technology is realized in the design.

2. The character of load of stratified air conditioning

The computation of load of stratified air conditioning primarily refers to computation of cooling load in the summer. As to winter, it must be based on the heat-supply of the whole-room-air conditioning[2].

According to the analysis of the load of stratified air conditioning, two parts constitute the load of air-conditioning zone. The first is provided by itself and second from other space. But its cooling load should be made up of that coming from the air-conditioning zone and fresh air.

The load formed by itself includes cooling load by envelop such as walls, windows etc and inner heating such as equipment, lighting and so on. While what transferred from non-air-conditioned zone is constituted as heat removal by convention and radiant heat. The amount transferred is decided by the heat exchange by ceilings, walls, windows and the heat body to the floor of non-air-conditioned zone and the heat transfer of non-air-conditioning zone to the air-conditioning zone. As to the quantitative analysis, a few practical methods have been brought forward by many domestic and abroad scholars.

In summer, the temperature under the ceiling is always the highest while lowest in the floor. Through positive analyses, it can be concluded that the floor of the air-conditioned zone receives the most of radiant heat. For the heat storage and transfer of floor, only a small part of its radiant heat is actually sent to indoor air, and then becomes cooling load of conditioned zone[3].

3. Air distribution of stratified air conditioning

The air distribution of stratified air conditioning is very important for it is relevant directly to the effect of air conditioning. If air distribution in conditioned zone works and air sent to the room can serve well, the height of stratified air conditioning can be reduced as soon as possible, load can be diminished and the volume of air-conditioned equipment decreased and the cost of operation, thus, saved. But the design of the stratified air conditioning must accomplish nice stratification which can be separated as conditioned zone and non-conditioned one. Therefore it can satisfy the air conditioning parameter and contribute to energy saving[4].

In large buildings, for attaining the above request, it is usually adopted as shooting to send breeze. Specifically, there are many ways of stratified air conditioning distribution. Generally, it is proper to adopt middle horizontal jet air supply, underlying air return at the same side and rowing air at the upper space. As to the space of large span, it is reasonable to adopt bilateral air supply and bilateral underlying air return. When the air conditioning system provides cold flow, processed air is sent to relative stationary space at a speed, thus it can form jet which goes to the range we ask for, its temperature and speed is being reduced sufficiently; air flow deviates obviously. When the jet

comes to static pressure or part of them to wall impediment, the big part of air current which is sent to the room can be ejected from air, returning from pipe and other poles and slots. Thus under the control of jet air supply, conditioned zone forms a big cycle, making underlying work zone in return zone and the balanced field of temperature and speed comes into. But rather than the air-conditioned area (namely big space of upper part), non-conditioned air zone has no requirements of parameters, where it is permissible of existing bigger perpendicular temperature difference. As to remaining heat that comes together in the upper part can be excluded through appropriate path[5].

4. Situation of researching in stratified air conditioning technology at abroad

It has been forty years since the stratified air conditioning technology emerged at abroad. In the early 1960s, it is already applied in a foundry factory, Philadelphia of USA. Afterwards, in 1964 it is exhibited in the Museum of General Electric Corporation of New York, and in 1968 it is successively applied in the Grillage factory and Willmilton nuclear processing plant and Shelifborton distributing station. The United States also lead off study of stratified air conditioning. Moreover, its cooling load computing method was studied in the 1970s, for instance, L • Gorton and D • Ball etc in Kansas State University in the United States both studied cooling load of stratified air conditioning and air distribution by simple mathematic models.

Stratified air conditioning was applied in Japan in the 1970s and air distribution of tall buildings was also studied by experiments. In 1974, Limlinman et al. made model experiments and contrast of stratified air conditioning on the spot of the large precise mechanics factory in Kobe, cooling load being able to save 38% of energy. Gongchuanbaozhi et al. got computing theory of cooling load of stratified air conditioning and made model to proceed with experimental research and contrast present work since 1974 to 1980 with more than ten dissertations published. He pointed out the phenomenon of convection heat removal in the place of stratified air conditioning and computed it. He also studied computed method of cooling load of stratified air conditioning in theory[6]. Since 1980s, it has been widely used in tall civil buildings in Japan, such as unlocked atrium of Bingsong hotel completed in 1982,

Zhanghuanghou hotel in 1988, closed atrium of Dongji hotel in Tokyo in 1990 and Muzhang international exhibiting station of Japan meeting center in 1989[7][8].

5. Domestic situation of the research on stratified air conditioning technology

Since 1970s, there are many technologists studying stratified air conditioning technology and contributing to many documents and figures. In 1976, its design was first adopted in the second workshop of Nanjing turbulent hydraulic factory by the second design institute of the first mechanics department (air conditioning area is 15330m²; three spans are 30m, 27m and 21m; last quarter height marks are 22m, 15.3m and 15.3m; height mark of place of stratification is 6.3m) which was completed in 1980 and reached to the criteria in 1981 after proper practice. In 1977, the stratified air conditioning in Tianjin first lathe factory and Xi'an transformer factory was designed by the 6th and 7th design institutes. In 1978, it was also designed in GezhouBa hydraulic power plant. And what is important is that they got good effect.

In 1979, stratified air conditioning technology research of tall building was designed by the second, 6th and 7th design sections of mechanical industry department, which was charged by the Air Condition department of the Chinese Science Institute, and they drew several conclusions such as "multiple jet air conditioning distribution computation", "cooling load computation of stratified air conditioning" and "systematic choice of stratified air conditioning" in 1981. In order to synthesize all the domestic outcomes, 《practical manual of air conditioning design》 published in 1993 introduced the scope of application of stratified air conditioning, the method of air conditioning, computation of cooling load, air current distribution and system form in detail. What's more, the book provided a few formulas.

From then on, stratified air conditioning in large buildings was widely used in our country such as the workshop of nuclear reactor plant, premises of large hydraulic power plant, premises of heavy precise machinery, the assemble workshop of diesel engine and so on. Air distribution is adopted through middle side air supply and underlying air return, which can save energy by 15%-40%. The Sanxia electricity plant is worldwide for the technology in the most part, and thus

obtaining good result[9]. Since 1990s, the technology was used in tall civil buildings, such as Zhuhai airport's waiting hall completed in 1995, waiting hall of Shenzhen international airport in 1998, the waiting hall of the Capital counterpart in 1999.

6. Situation and prospect of stratified air conditioning technology

In the past decades, stratified air conditioning technology has been improved substantially at home and abroad not only in engineering technology progress but in practical basic research. Certainly, these results are only primary. There is much work to perfect it, for instance, indoors heat radiation and removal cannot be calculated accurately; a few computing methods are not precise and the applying scope is very limited.

Since now, there are two means to study the very technology. The first one is model experimenting according to like theories, which can test the requirement of design and meanwhile direct modes by doing experiments of observing air current. The second one is to adopt mathematical and physical model to estimate. Because of big volume and ultra speed of computer and development of computed hydromechanics, we can make three dimensional turbulent numerical analysis by turbulent model of $K-\varepsilon$ equation and conjecture method to proceeds with three-dimension number and obtain the distribution of velocity and speed of air current of complex big space. In addition, imitation to the temperature of big space can be attained through synthetic analysis of indoors air and heat flow.

Both of the means have been increasingly used and developed in different degrees in the past years. The former has been always the more available method since now, but it always takes much time and investment, which exist great difficulties in applications. However some abroad experts think it is still the main mean to study the air flow, but it may not be correspondent to the prototype by diminishing proportion, so we should make 1:1 entitative experiment as soon as possible, although it is difficult to do. As to the latter, the key point lies in the mathematic model's constructing, bounded conditions and the development of computer. But it is effective when the shape is simple, the flow space is complete and the bounded condition is easy. But there is still a bit of model did not come to success, with the causes

being the bounded conditions' complexity which amounted to the solvent and execution's not working[10].

With the emergence of 21st century, the whole world increasingly focuses on the energy saving, especially on the air conditioning energy saving, therefore the stratified air conditioning technology attains gradually wide use. Accompanying with the fast development of technology of airflow's surveying and new instruments' emergence, the model experiment method will match with the prototype more exactly. Mathematic and physic model estimating method also got great development under the computer's support, which thus becomes increasingly complete. With the society's advancement, continuous development of science and technology, the stratified air conditioning technology of large space buildings will be sure to be perfect.

References

- 1 Zhao Yi et al. Design of stratified air conditioning in large premises. Heating Ventilating and Air Conditioning. 2002, No.2(in Chinese).
- 2 Lu Yaoqing. Practical air-conditioning design manual of providing heat. Chinese construction industry press, 1993(in Chinese).
- 3 Zou Yueqin et al. "Study on the methods of heat transformation load's computing of stratified air conditioning". Heating Ventilating and Air Conditioning. 1983, No.3(in Chinese).
- 4 Zou Yueqin et al. "Study on the methods of air conditioning's air flow distribution". Heating Ventilating and Air Conditioning. 1983, No.2(in Chinese).
- 5 Lu Yaoqing. "Design manual of providing heat and ventilation". Chinese construction industry press.1987(in Chinese).
- 6 Chen Bing. "Status situation of large space air conditioning's study in Japan". Heating Ventilating and Air Conditioning.1994, No.3(in Chinese).
- 7 Fan Cunyang "Air conditioning design and record of project of large space buildings". 2000(in Chinese).
- 8 Fan Cunyang. "Design of abroad large space buildings air conditioning". Heating Ventilating and Air Conditioning .1996, No. 4(in Chinese).
- 9 He Tianqi et al. Summer stratified air conditioning distribution and analysis in electrical department of SanXia electrical factory. Journal of Chongqing Jianzhu University, 2000, No. 1(in Chinese).
- 10 Ma Renmin. Abroad status situation of airflow study. Heating Ventilating and Air Conditioning, 1989, No. 1(in Chinese).