Study on the design schemes of the air-conditioning system in a gymnasium

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Abstract-In view of designing the air conditioning project for a gymnasium successfully, the cooling and heating source schemes are fully studied by analyzing the surrounding environment and energy conditions of the project, as well as the analysis of the initial investment and operating costs, which indicates the air source heat pump air conditioning system is the best choice for the project. The indoor air conditioning schemes are also studied systematically and the optimization of air conditioning schemes is carried out in each area. The principle of operating conditions for the whole year is followed and the quality of indoor air and energy-saving are ensured by the optimized design schemes, which provide references for the air conditioning system design in the same kinds of building.

1. Introduction
The gymnasium is a large space building, having the characteristics of the higher height, wide span, large space, varied function, the use of the short-term, and so on. Huge power consumption would increase the running cost. Therefore, it is necessary to choose a practical and effective air conditioning design scheme for such a building [1]. The scheme is both technically feasible and economically rational. It is needed to achieve energy efficiency while ensuring good air quality and environmental comfort.

2. Project summary
The building area of this gym is 19820m2, and the building height is 29.2m. The gym is a three-floor frame with local underground, which consists of the center court, the audience area(pool area and seating area), the office and resting area, as well as the lobbies.

Figure 1. Effect drawing of the gymnasium
3. Study on the cooling and heating source schemes

3.1. The surrounding environment and energy conditions

The gymnasium is a cultural facility located in the city center, which is forbidden environmental pollution and flue gas emissions. There is no thermal net, thermal power plant, chemical plant and so on. The water, electricity and gas pipe network are complete. The peak electricity price is 1.42 yuan per kWh at 9:00-11:30 AM. The valley electric price is 0.55 yuan per kWh at 23:00-7:00. The normal electricity price is 0.88 yuan per kWh at other time. Relatively, the natural gas price is 3.8 yuan/m³.

3.2. Applicability analysis of cooling and heating source schemes

At present, there are several kinds of cooling and heating source solutions as follows:

The electric cold water chiller and the Municipal network for heating isn’t considered because of no municipal heat source in this project.

The electric cold water chiller and the gas boiler should be excluded. Because the boiler plant has exhaust emission which will pollute the environment and the chimney is not good appearance.

The gas absorption chiller also should be excluded, ditto.

The ground source heat pump is the mature technology, with good energy-saving and no environment pollution [2]. So it can be used as the cooling and heating source solution.

The water source heat pump technology is relatively mature and energy-saving, but it also leads to the water pollution and water loss [2]. So it is restricted by resource protection policies.

The air source heat pump is technically mature, environmental and energy-saving [3]. So it can be considered for cooling and heating.

In conclusion, the ground source and air source heat pump are analyzed economically as alternative choices.

3.3. Economic analysis

3.3.1. Load calculation. According to the load calculation, the maximum cooling load is 4093.76 kW and the heat load is 2310.44 kW. According to the survey, the maximum utilization rate is no more than 20%, and the maximum attendance rate is no more than 60%. Therefore, the operation rate of the system is 50%.

3.3.2. Economical comparison. The annual cost indicator method for the lifetime period:

\[ AF = B \left( \frac{i(i+1)}{2} \right)^{-1} + C \]

AF-the annual fee (ten thousand yuan); B-the initial investment (ten thousand yuan); C-annual operating cost (ten thousand yuan); n-service life (taking 20a); i-the recovery rate (taking 8%).

In addition to the aforementioned energy prices, the drilling cost of the underground pipe is 100 yuan/m and the cost of power capacity is 500 yuan/kW. The service life is calculated by 20 years. According to the research report, the frequency of air conditioning is 50%.

Table 1. The economic comparison of the two schemes

| Contents       | number | Each Content          | Ground pipe heat pump systems (unit: Ten thousand yuan) | Air source heat pump systems (unit: Ten thousand yuan) |
|----------------|--------|-----------------------|--------------------------------------------------------|--------------------------------------------------------|
| System Cost    | 1      | Cost of heat pump     | 225.2                                                  | 280.8                                                  |
|                | 2      | Cost of supporting units | 18.2                                               | 30.5                                                  |
|                | 3      | Cost of pipes of plant room | 5.0                                                  | 5.0                                                   |
|                | 4      | Cost of power capacity | 46.0                                                  | 70.2                                                  |
|                | 5      | Cost of ground pipes  | 1000.7                                                 | -                                                      |
|                | 6      | Cost of outdoor pipes | 40.8                                                   | 20.4                                                  |
Table 1 shows that the air source heat pump system is lower cost, energy saving and environmental protection between the schemes.

### 4. Study on the indoor air conditioning system schemes

#### 4.1. Key points of air conditioning zoning and system division

4.1.1. *The inner and outer division of air conditioning systems.* Because of the large depth, the load characteristics of the inner region and outer area differ. The load of the outer area is influenced by the climate, but the load of the inner area is nearly steady. So different air conditioning systems are needed to apply in the inner and outer area \[^4\].

4.1.2. *The principle of division of air conditioning system.* Several air conditioning systems are divided according to different functions and different running time \[^4\]. A separate system will be adopted in areas where the functionality is likely to change, such as the audience area of the stalls. When hosting large sporting events, the audience area may be turned into the venue. The air-conditioning system should be able to switch.

#### 4.2. The design concept of the air conditioning system

The gym is characterized by its neat, empty and high. Therefore, it is suitable for the use of the stratified air conditioning, so as to avoid the heat of the upper part and reduce the effective cooling load \[^5\]. According to the analysis of the load, the pavilion adopts a layered air conditioner, which is estimated to be 31.5% energy saving compared with total air conditioning. Audience area seats adopt the way to send wind from below, return wind from above, which is a good way to realize the stratified air conditioning. And it can improve the supply air temperature difference in summer and increase the energy efficiency ratio of refrigeration system. It also can reduce the supply air temperature in winter.

#### 4.3. The study on the air conditioning plan of the gym

4.3.1. *Air conditioning scheme of center court.* The space height of the center court is 7.5 meters, which is a large space. Therefore, it should consider to use a layered air conditioner, which makes the heat from the top expelled outside through the exhaust system and achieve the energy-saving goal. It is best to use the top facilities for natural ventilation. When playing the small ball games, the wind speed is no more than 0.2 m/s and the noise is below 50dB. Based on the above reasons, the optional schemes include two forms: all air constant air volume system, top nozzle air supply and jet side air supply. The comparison is as follows.

| Operation cost | 7 | 1424.9 | 8 | 406.9 |
|----------------|---|--------|---|-------|
| operation cost | 8 | Cost of summer electricity | 44.78 | 64.23 |
| 9 | Cost of winter electricity | 18.56 | 20.41 |
| Annual cost | totals (7)+20+ totals (10) | 134.59 | 104.99 |
Table 2. Analysis of the air conditioning schemes of the center court

| AC Design plan                  | Air distribution               | Space description | AC Effect | Appearance | Initial cost | Energy Consumption | Operating cost |
|--------------------------------|--------------------------------|--------------------|-----------|------------|--------------|--------------------|-----------------|
| CAV all air conditioning       | The upper supply and bottom return | Top manifold       | better    | bad        | high         | high               | high            |
| CAV stratified air conditioning| the side supply and bottom return | No pipe at the top | good      | good       | low          | low                | low             |

By comparison, the best solution is side air supply and lower return wind. The return air inlet is located in the entrance.

4.3.2. Air conditioning scheme of the audience area in the stall area. The seating area of the pool is located in the stadium, which is temporary and transferable. When holding a special competition, the area is the audience area. Considering the requirement of energy saving, it tries to adopt the way of under-seat supply. When holding a big games, the area is converted into the venue. It is converted to the side air supply and lower return wind. Within 3 meters above the ground, the wind speed is no more than 0.3 m/s. Likewise, noise controls below 50dB. Based on the above reasons, there are three forms of available options as follows.

Table 3. Analysis of the air conditioning schemes of the stall area

| AC Design plan                  | Air distribution               | Space description | AC Effect | Appearance | Initial cost | Energy cost | Operation cost |
|--------------------------------|--------------------------------|--------------------|-----------|------------|--------------|-------------|---------------|
| CAV all air conditioning       | upper supply, bottom return    | Top manifold       | better    | bad        | high         | high        | high          |
| CAV stratified air conditioning| side supply, bottom return     | No pipe at the top | cold draft| good       | low          | low         | low           |
|                                | under-seat or side supply      | No pipe at the top | good      | good       | low          | lower       | low           |

By comparison, it is the optimal plan of air supply under the seat which can be converted to side air supply and lower return wind.

4.3.3. Air conditioning plan of the seating area of the building. The load of the seating area is very high, so it is suitable for all-air system. It tries to use air supply under the seat. The air flow is strictly separated from the competition area, so as to prevent turbulence from entering the audience area. Noise controls below 50dB. There are three forms of the proposed solution: top jet air, nozzle air supply side and air supply under the seat and upper return air. The comparison is as follows.

Table 4. Analysis of the air conditioning schemes of the seating area

| AC Design plan                  | Air distribution               | Space description | AC Effect | Appearance | Initial cost | Energy cost | Operation cost |
|--------------------------------|--------------------------------|--------------------|-----------|------------|--------------|-------------|---------------|
| CAV all air conditioning       | upper supply and bottom return | Top manifold       | better    | bad        | high         | high        | high          |
| CAV stratified air conditioning| side supply and bottom return | No pipe at the top | cold draft| good       | low          | low         | low           |
|                                | under-seat supply and upper return | No pipe at the top | good      | good       | low          | lower       | low           |

By comparison, under-seat air supply is adopted as the optimal scheme.
4.3.4. **Air conditioning scheme of other areas.** The north and south halls on the floor 2 are used for resting and waiting, having the characteristics of short-term use and 6 meters height. So they are suitable for all-air stratified air conditioning systems. Due to the deep depth, the systems should be divided into the outer area and the inner area systems. The Office and resting Areas on the floor 1, and the hallways on the floor 1-3 are needed to control at any time and are the lower heights. So they are suitable for primary air fan-coil systems.

4.3.5. **Summary of the air-conditioning schemes.** In conclusion, there are 22 air conditioning zones and 28 air-conditioning systems. The summary is shown in table 5.

| Position          | nature         | Partition number | AC system                  | System number | Air distribution     | outlet                |
|-------------------|----------------|------------------|----------------------------|---------------|----------------------|----------------------|
| Center Court      | Inner area     | 1                | CAV stratified air conditioning | 2             | Side supply side return | Spherical nozzle |
| Stall Area        | Inner area     | 4                | CAV stratified air conditioning | 6             | Bottom supply upper return | Seat nozzle          |
| Floor1-Seat Area  | Inner area     | 4                | CAV stratified air conditioning | 6             | bottom supply upper return | Seat nozzle          |
| Floor2-Seat Area  | Outer area     | 1                | CAV stratified air conditioning | 2             | bottom supply upper return | Seat nozzle          |
| Floor2-lobbies    | Outer area     | 2                | CAV stratified air conditioning | 2             | side supply bottom return | Double louvers      |
| Floor1-Offices and halls | Inner area | 2            | F.C.U+FA                      | 2             | upper supply upper return | Double louvers |
|                    | Outer area     | 2                | F.C.U+FA                      | 1             | upper supply upper return | Double louvers |
| Floor1-3 hallways | Outer area     | 6                | F.C.U                         | 6             | upper supply upper return | Double louvers |

4.4. **A composite figure of the air conditioning systems**

In order to show the total of 28 air conditioning systems in the 22 air conditioning zonings, the combination of the air conditioning scheme is as follows

**Figure 2** Schemes of the air conditioning on the first floor

**Figure 3** Schemes of the air conditioning on the second floor

5. **Conclusion**

According to the survey, the use frequency of the air-conditioning is only 20% on average in the gym. The investment recovery period is so long that the ground source heat pump should not be used in the
gym. Comparatively, the investment recovery period of air source heat pump is short and the annual operating cost is low. Besides, the gym is in hot summer and cold winter zone. So the air source heat pump is applicable to the project.

The air-conditioning project in the gym consists of 22 air-conditioned zonings and 28 air conditioning systems. It is flexible and convenient for operation partition. The stratified air conditioning reduce the cold load on the top of the large space. The under-seat air supply in the audience area raises the supply air temperature and lowers the enthalpy of the air. The air conditioning scheme has achieved the purpose of technical feasibility and economic efficiency.

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