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HVAC System Energy-saving Design for One Super-high Office Building

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Abstract

This building is a first-class super-high office building. This article briefly introduces energy-saving technique and measures adopted in HVAC system, such as cooling and heat sources, water and air system etc.

Keywords: Energy storage, Large temperature difference, Variable flow rate, Heat recovery

1. Project Profile

The bird's eye view of Shanghai China Merchants Bank Headquarters project is shown in Fig. 1. This 208-meter-high architecture covers a floorage of 126,016 square meters. Its 9-floor north tower and 37-floor south tower are bridged by corridors. Ground floor of the north tower is designed as a conference hall and lobby, the 2nd floor serves as the Bank's business hall, and the 3rd and 4th floors are privileged areas for the Bank's VIPs. As to the south tower, the Ground floor functions as an entry lobby, the 5th, 20th, 36th floors as refuge and electromechanical rooms, the 6th for kitchen and dining hall, the 7th as conference hall, the 33rd to 35th floors as Banker's Club, and the others as office area. In addition, its underground spaces include 5 floors (note: 4 floors plus an entresol underground), which are basically garage, equipment rooms and etc., and are also equipped with appropriate number of service auxiliary rooms. The 4th floor underground is built with civil air defense, which is a Level 6 personnel shelter. The 2nd floor underground of the north tower is a dedicated bank coffer and safe box storehouse.

HVAC area in this project takes up 58,880 square meters, with the calculated cooling load reaching 8,056 kW in summer. Since 24-hour uninterrupted chilled water supply system is necessary for dedicated equipments inside the building, the load of this part is decided by the owner as 1,758 kW (500RT). As a result, the overall designed max cooling load in summer is 9,700 kW (2760RT). The winter HVAC thermal load for this project is 3,360 kW.

Four-pipe closed circulatory system is applied in the HVAC water pipelines in the project. Two-stage pump system is used for HVAC chilled water, with the temperature for supply water and return water ranging from 5 to 12. HVAC hot water adopts one-stage pump system, with the temperature for water supply and return water ranging from 52 to 39. The following energy-saving techniques and measures are mainly taken in the design of HVAC system.

2. Ice Storage

The cooling source in this project employs single-stage pump closed ice storage system, which is serial flow at the

Figure 1. Top view of China Merchants Bank Tower.

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upstream of the host, with the machine room located in the 4th underground floor in south tower. Cooling source system is set up with four 1,758 kW (500RT) Electricity-Driven Spiral Lobe Type chilled water units, 3 of which are of double operating modes, and the other of base load single operating mode. There is also one 703 kW (200RT) electric screw ground source heat pump unit. The total installed volume reaches up to 7,735 kW (2200RT). Cooling source is also set up with box-type incompletely frozen coiled ice storage unit, with a total ice storage volume of 26,897 kW•H (7650RTH).

The ice storage system can reduce the total installed volume for chilled water units, reducing the total volume of power distribution correspondingly, and make use of the trough electricity price in the night to cut down the overall operating cost.

3. Heat Storage

The project takes hot water storage system generated by normal pressure electric boiler as the heat source for the HVAC, and the machine room is located in the 1st floor underground. Heat source system is set up with two 1,800 kW normal pressure electric boilers in total, and two heat storage tanks with effective volume of 300 M^3. During 22:00 to 6:00 next day when valley electricity price prevails, the electric boiler processes to heat the water up to 90°C and store the heated water in tanks for use in the daytime next day. The design is characterized by total thermal storage which keeps the electric boiler off during heat supplying day as originally designed. Since the electric boiler works at night (similar to ice storage at night), it does not occupy the total power distribution itself.

Compared with the conventional gas-fired boiler, the electric boiler heat storage system works in normal pressure, thus anti-explosion, pressure relief, dedicated escape route are not required, nor are the chimney or chimney shaft. Although additionally equipped with water tanks, electric boiler heat storage system has a smaller overall footprint in the building than that of gas-fired boiler system. Meanwhile, it allows higher flexibility in installment since its deployment is independent from safety considerations.

In the circumstances that presently gas price being RMB 3.99/Nm^3 , its heat value 9.86 kW•H/Nm^3 (8500 kcal/Nm^3) and boiler efficiency hypothetically 0.9, a conventional gas-fired boiler spends 3.99/(8500/860×0.9)=RMB 0.449/(kW•H) for every unit of heat produced. While taking our eyes on electric boiler heat storage system, the efficiency can be almost deemed as 100%, system efficiency 0.95 (heat loss mainly caused by heat storage unit), the valley time electricity price in Shanghai (non summer, grade 35 kV) presently at RMB 0.327/kW•H. It is concluded that it takes 0.327/0.95=RMB 0.344/(kW•H) to produce every unit of heat. In the light of the analysis, electric boiler heat storage has considerable advantage over gas-fired boiler.

4. Ground Source Heat Pump

The cooling and heat source system in the project is set up with a ground source heat pump, which can make full use of renewable energy. This unit can connect in parallel with ice storage system in summer to supply cooling to the building, and to provide heat storage and supply heat in winter. When involved in heat storage operating mode, the supply and return water temperature of the unit falls in the range of 60~52°C, higher than the starting temperature for heat storage even after heat exchange with plate heat exchanger. It can run in series with electric boiler. The outlet water from the water tank is firstly warmed by plate heat exchanger and then heated by electric boiled to 90°C, which reduces the operating load of electric boiler, and thus cut down the whole power consumption for heat storage.

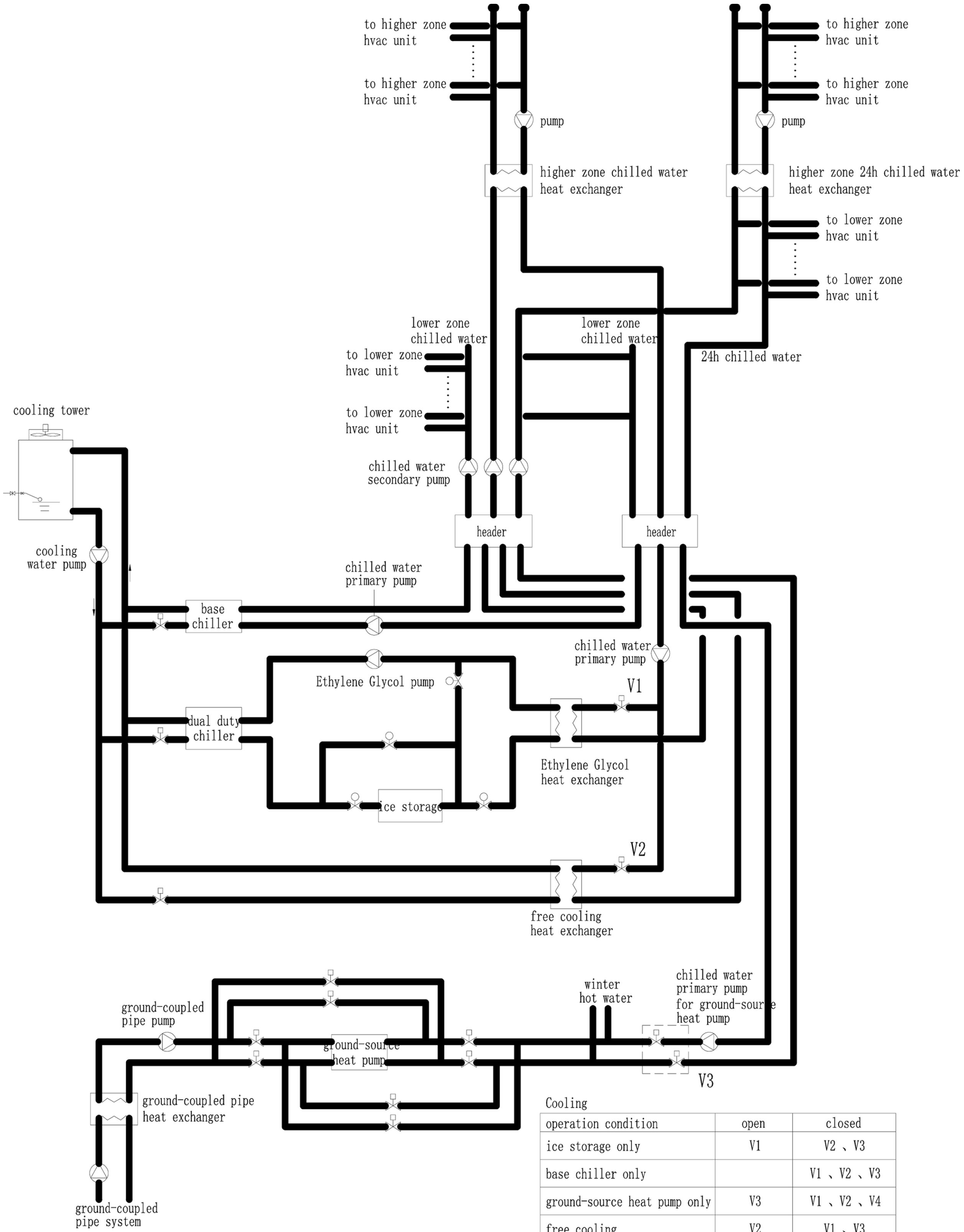
The diagram for cooling and heat source is detailed in Fig. 2.

The underground heat exchanging buried pipes coming with ground source heat pump are laid as a pile foundation. Plate heat exchanger designed to isolate the pressure is placed between the underground buried pipes and the pipelines on the ground for higher safety.

Subject to the limit of water flow required when the ground source heat pump is running, the rated temperature of supply and return water for the unit's designed sizing while supplying heat ranges from 50 to 42°C, unable to run in parallel with the system's temperature range of 52~39°C, so that a bypass is connected in series at the main return pipe. In real operations, part of the water is withdrawn from the upstream of the main return pipe to support the unit running, mixed with the downstream of the main return pipe after being heated by the units, which will increase the overall temperature (theoretical value is about 42°C) of the return water, and then heated up to the temperature required by the system by plate heat exchanger in the heat storage tank. Since the ground source heat pump units accounts for little of the installed volume, incremental volume of the water temperature is unnecessary to be controlled when storing heat at night or supplying heat in the daytime, full-load running is enough.

5. Free Cooling Source from Cooling Tower

Cooling source machine room in this project is also set up with two plate heat exchangers, which are deployed between cooling water system and chilled water system. In winter when it is colder outside (involving conditions may be adjusted in real operations), chilled water units stop running, and the plate heat exchangers are put into operation, which make use of the cooling capacity of the cooling tower to produce chilled water with lower temperature to support the system running, and thus reduce energy consumption.

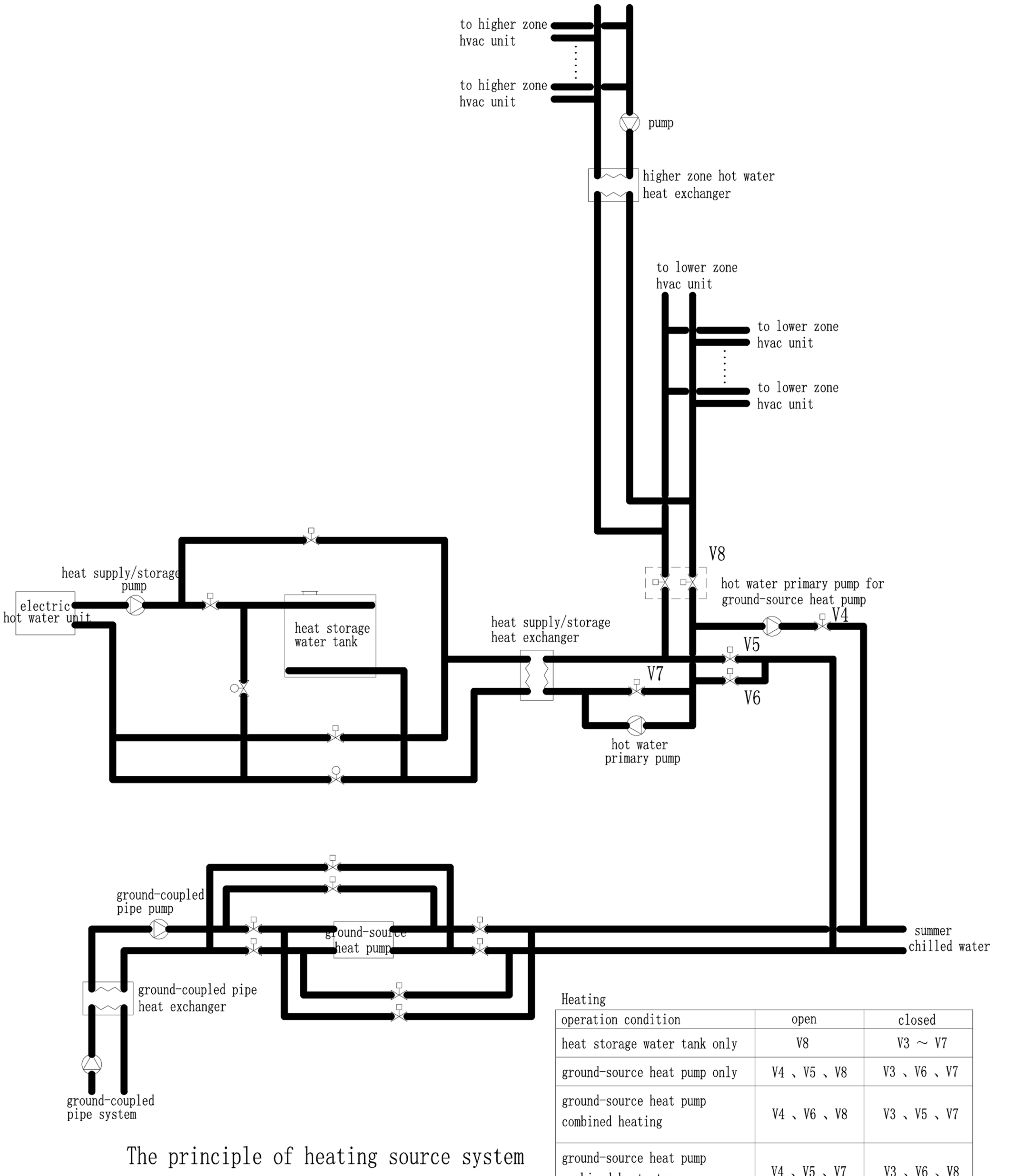


The principle of cooling source system

Cooling

operation condition	open	closed
ice storage only	V1	V2 、V3
base chiller only		V1 、V2 、V3
ground-source heat pump only	V3	V1 、V2 、V4
free cooling	V2	V1 、V3
combined cooling (free cooling not involved)	V1 、V3	V2 、V4

The inner valves of ice-storage、electric heat storage、ground-source heat pump、cooling tower are set normally , not mentioned here repeatedly。



operation condition	open	closed
heat storage water tank only	V8	V3 ～ V7
ground-source heat pump only	V4 、V5 、V8	V3 、V6 、V7
ground-source heat pump combined heating	V4 、V6 、V8	V3 、V5 、V7
ground-source heat pump combined heat storage	V4 、V5 、V7	V3 、V6 、V8

The inner valves of ice-storage、electric heat storage、ground-source heat pump、cooling tower are set normally ,not mentioned here repeatedly。

Figure 2. The diagram for the principle of cooling and heat source system.

6. Adjustable Fans at the Cooling Tower

The control of cooling tower in the project is rather in the way of total volume control than one-to-one operation, i.e., all of the cooling towers start running when part of the chilled water units are initiated. At the moment, since part of the water flows through all of the cooling towers, its actual heat exchanging effect is better than the rated operating mode, which makes it possible to meet the temperature of the outlet water from the tower while lowering the fan speed and reducing forced ventilation, and thus energy consumption of the fan is cut down. With small load, if all the fans in the cooling towers stop running and the outlet water temperature from the tower is still too low, some of the water channels in the cooling towers will be closed. Since there are four cooling towers in this project, differential control can be finely achieved when using double speed fans, avoiding the high cost factors when using frequency inverting control.

7. Large Temperature Difference between Supply and Return Water

HVAC chilled water system uses large temperature difference (7ºC) between supply and return water, whose designed temperature is 5~12ºC. Compared with ordinary 5ºC temperature difference, the system has reduced water flow, in theory the energy consumption for water flow transportation along the pipelines is reduced by (1/5-1/7) / (1/5) = 28.57%. The cooling water system supporting chilled water units also employs 7ºC large temperature difference supply and return water with designed temperature of 32~39ºC.

HVAC hot water system utilizes 13ºC large temperature difference to supply and return water with designed temperature of 52~39ºC. Compared with ordinary 10ºC temperature difference, the system has reduced water flow too. In order to further lower down the pipeline flow rate and reduce the friction, the pipe diameter is increased in an appropriate manner when designing the pipelines (piping as per the flow at 10ºC for specific calculation). So in theory the energy consumption for water flow transportation along the pipelines is reduced by $[1/10-1/13\times(10/13)^2)]/(1/10)=54.48\%$.

Although the water system is huge and complicated, the defined requirement for transportation energy efficiency ratio in the energy saving specifications can be met after the above-mentioned measures are taken.

8. Partition of the Water System

The nominal height for the 4 floors underground is -18.75 meters, and 182.50 meters for the 37 floors on the ground, HVAC water system covers from the base of the 4th floor underground to the ceiling of the 36th floor. The 5th, 20th and 36th floors are for refugee and equipment rooms, whose nominal height are 19.50 meters, 96.30 meters, 179.20 meters respectively.

The total height difference for the HVAC water system reaches up to about 200 meters. If the method of "one pump for all" is used, the bearing pressure for the equipment and pipelines shall reach 2.5 MPa, which surely will cause safety and reliability issues to the pipelines and the connection thereof, increase the cost for units, pumps, plate exchangers and the pipeline accessories as well. As per the actual situations of this building, the HVAC system is divided into high and low partitions, with the heat exchanging devices located at the 20th floor, the clear height for low partition system is 124.1 meters, whose designed fixed point pressure is 1.4 MPa; and the clear height for high partition reaches 86.2 meters with fixed point pressure of 1.1 MPa.

The low partition uses cooling and heat source system to supply water, and supply and return water temperature of its chilled and hot water is 5~12ºC and 52~39ºC respectively. Considering the actual running status of the plate heat exchangers, the design adopts heat exchanging temperature difference of 1.5ºC for chilled water and 2ºC for hot water, so the supply and return water temperature in the high partition is 6.5~13.5ºC and 50~37ºC respectively.

9. Adjustment of the Variable Flow of the Water System

HVAC chilled water uses two-stage water supply system, meanwhile a secondary pump is placed after the heat exchange in high partition. Where the primary pump in low partition corresponds to chilled water units and ice storage plate heat exchanger. In order to ensure the stable operation of chilled water units, the pumps are running in constant flow, only the number of pumps is under start/end control. In accordance with the high/low partition system of ordinary HVAC and 24 hour dedicated cooling supply system, 3 sets of two-stage pumps are installed in total, where the two sets for ordinary HVAC are equipped with 3 pumps for each (2 in use and 1 standby), and the other one set for 24 hour dedicated cooling supply is installed with 2 pumps (1 in use and 1 standby). Heat exchange in high partition for ordinary HVAC employs 2 plate heat exchangers, and installs 3 two-stage pumps in high partition, with 2 in use and 1 standby. 24 hour dedicated cooling supply uses 1 set of supply and return water pipeline, which supplies heat exchange for high partition system when used by low partition users, heat exchange in high partition uses 2 plate heat exchangers (1 in use and 1 standby), and installs 2 high partition two-stage pumps, 1 in use and 1 standby. For two-stage pumps both in low partition and high partition, differential pressure transducers are placed at the least favorable ends of the system respectively, to keep the available pressure difference at the least favorable ends constant via adjusting the pumps by frequency inversion when change in load alters the demand of flow, thus obtaining energy saving effect.

Since HVAC heat source is obtained via plate heat exchangers from the heat storage tanks, hot water uses one-stage pump variable flow system, in the mean time a secondary pump is installed after heat exchange in high partition, whose frequency inversion control is the same as that of low partition two-stage pumps and the high partition secondary pump for chilled water.

10. VAV Full-air HVAC

Variable air volume (VAV) full-air HVAC system is applied to all of the corridors, Banker's Club, and standard office floors, all of the VAV BOX are in the form of zero-fan and single duct and under the mode of variable static pressure control.

A Shared VAV system is used for corridor and Banker's Club which do not separate inner partition and outer partition and supply cooling in summer and heat in winter. For the standard office floors, it is divided into inner partition and outer partition with a VAV system for each, where the inner partition supply cooling throughout the year and the outer partition supplies cooling in summer and heat in winter, and thus the comfort is further improved.

The floor plan for HVAC in standard floors is detailed in Fig. 3.

Due to the narrow machine room in standard floors, the two systems are combined into one HVAC unit during design. The HVAC unit uses no-volute fan, places them in the front of HVAC unit, then installs two treatment tunnels respectively, between which cold and hot coils and humidifier are placed, and thus such a machine can be used for two purposes. It eliminates the conventional method that a VAV BOX is reheat in outer partition while HVAC unit process goes into inner partition status, thus avoiding the cold-hot offset during reheating in outer partition, and obtaining energy saving effect.

Structural map for HVAC unit is detailed in Fig. 4.

11. Heat Recovery from Air Exhaust

For standard office floors, 2 fresh air and air exhaust HVAC units for centralized treatment are placed in the machine room on the 20th floor, corresponding to the upper and lower sections. Actually, the HVAC unit is the combination of fresh air HVAC unit and air exhaust HVAC unit, inside of which is installed with full-heat recovery runner in addition to fresh air pre-heating coils, through the runner part of the energy from air exhaust is recovered, thus HVAC load is reduced and energy consumption is cut down. An air valve is installed along the runner side respectively by fresh air and air exhaust tunnels. Usually all of the valves are closed during HVAC seasonal operations to ensure the heat recovery function of the runner; and they are started in transitional seasons to reduce the flow resistance of the runner and cut down the energy consumption of the fan.

12. Variable Fresh Air Volume

For fresh air and air exhaust system in standard floors, CAV electric control valve is installed on each floor, meanwhile the fans in the centralized fresh air and air exhaust

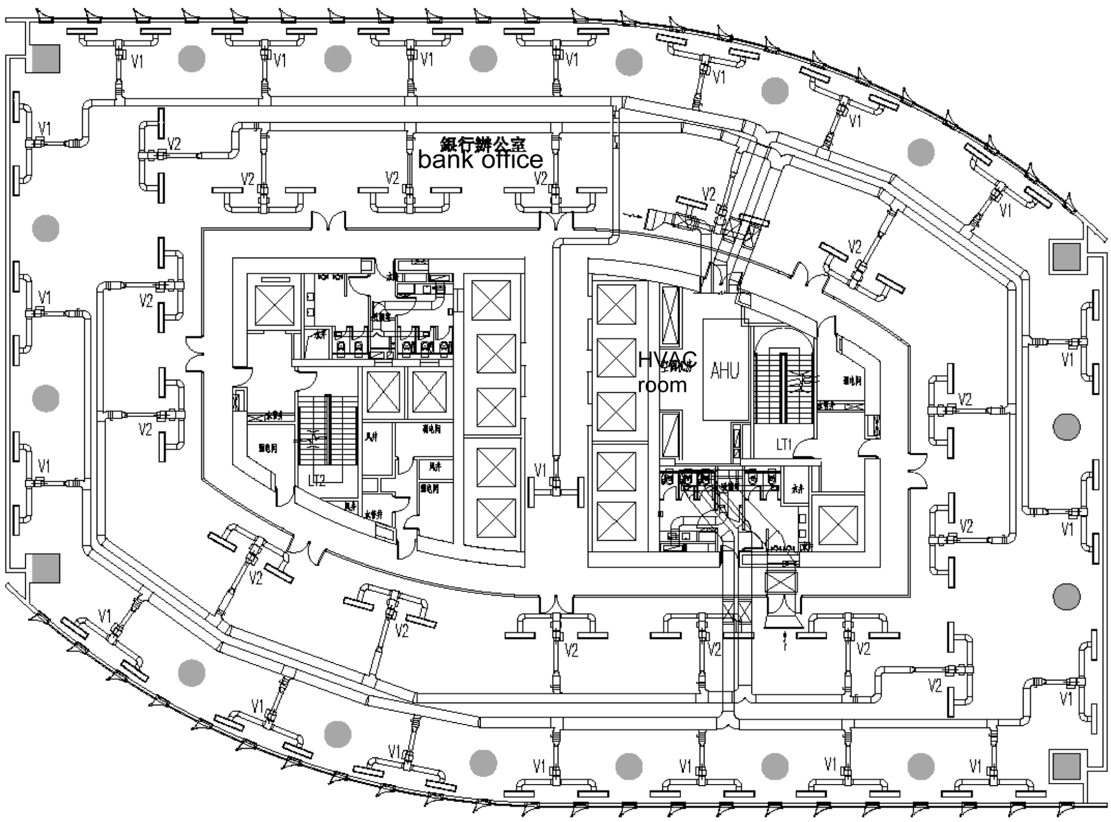


Figure 3. Floor Plan for HVAC System in Standard Floors.

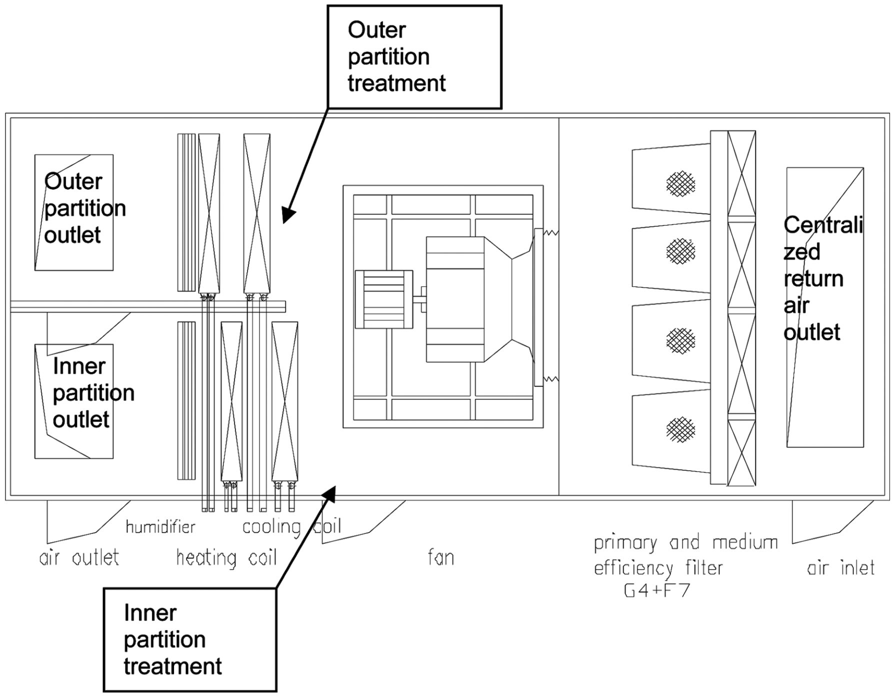


Figure 4. A Structural Map for HVAC Unit in Standard Floors.

HVAC unit use constant and static pressure control of frequency inversion and speed to reduce energy consumption.

The design also employs the measure of variable fresh air volume, avoiding unnecessary HVAC loading, and saving energy consumption. Considering loss of control due to system shock and difficulty in balancing the fresh air and air exhaust during system control, the control method of two shifts of CAV high and low is applied in the design, whose value can be predefined according to the difference between fresh air and air exhaust volumes. Indoor CO_2 detection is also set up with upper and lower limits, CAV high shift is initiated when it reaches the upper limit and stays for a certain period of time; and CAV low shift is enabled when it reaches the lower limit and stays for a certain period.

13. Conclusion

In the design of HVAC system, there are various energy-saving techniques and measures, which shall be selected as per the features of each project, unchecked accumulation shall be prohibited. The project targets for LEED silver prize, completes feasibility and economic analysis and comparison in advance, fully negotiates with owners and relevant consulting companies ahead of specific implementation, and finally decides the above-mentioned energy-saving measures as per the actual situations.

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