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ABSTRACT

The ice storage air conditioner is one of the main measures to move the electricity from the peak to the valley. But ice storage system is not spreaded widely in industry in China because of the big space demand and difficult construction, so developing of ice thermal storage system in commercial buildings and home will be a new field which is worth research and development. So a digital multiple variable refrigerant volume air conditioning system with sub-cooled ice storage system has been designed and researched in this paper. The system fundamentals, structure, and design procedure are presented, also the comparison of it with that without ice storage in aspects of cooling capacities, refrigeration efficiencies and super cooling degrees are illuminated in the paper. An economic evaluation for the system is made and it shows that the return period can be less 3 years.

1. INTRODUCTION

At present, shortage of electric power in daytime electric power has become obstacle of economic development in China. With the development of the industry and economy the power peak load in daytime has been increasing continuously and the peak-to-valley difference becomes more and more large. So how to cut down the power peak load and reduce the peak-to-valley difference scientifically and reasonably has become important project to maintain economy develop rapidly, successively and healthily. It was shown that peak power shift by the way of ice storage system can be realized in air conditioning, instead of the much more costly daytime electric power (William P. Bannfleth and Douglas T. Reind, 1998). Zhang Yongquan (1999) pointed that the ice storage system has been utilized in large buildings, office and retail stores. But the ice storage system is largely limited to the large central air conditioning system, the ice storage system is not spreaded widely in China because of the big space demand and difficult construction project. So developing of ice thermal storage system in commercial buildings and home will be a new field that is worth research and development. Zheng Xiaolei and Liu Chuanju (2001) introduced the efficient energy saving VRV air-condition ice thermal storage system. Zhou Xiaotang *et al.* (2001) studied a household ice storage air conditioning system. Fang Guiyin (2000) analysed and compared the economy of cold storage air conditioning system. Fang Guiyin *et al.* (2005) studied the performance of small cool storage air conditioning system. Ji Changfa and Wang mei (2005) analysed running scheme of small-sized air conditioning system with ice storage. Thus it can be seen that small ice-storage system has arisen many researchers` attention. But the true urgent affairs are to exploit the practical product with the ice-storage system. So a commercial digital multiple variable refrigerant volume air conditioning system with sub-cooled ice storage system has been designed and researched in this paper. The new unit adopts a novel technical with combination of VRV system and ice-storage technology. The system makes ice and stores cold thermal energy directly by using a surplus electric power and utilizes the cold thermal energy to make the refrigerant get high sub-cooling degree for air conditioning systems at the power peak load period of daytime. Design and research were conducted on a nominal 30kW new type multi-connected unit. The system fundamentals, structure, special ice-storage tank and design procedure are presented, also the comparison of it with that without ice storage in aspects of cooling capacities, refrigeration efficiencies and super cooling degrees are illuminated in the paper. An economic evaluation for the system is made and it shows that the return period can be less 3 years.

2. PRINCIPLE OF THE VRV SYSTEM WITH SUB-COOLED ICE STORAGE SYSTEM

In vapour compression refrigeration systems, the sub-cooling degree of refrigerant is about 3~5 ℃ after condenser due to the limit of the cooling air or water temperature. But ice temperature is low to 0℃, which makes it possible for the refrigerant to get bigger sub-cooling degrees. The R22 lgp-h is shown in Fig.1. The standard refrigeration cycle is the 1-2-3-4-1 cycle, the evaporating temperature is 2℃, the superheat degree is 5 ℃, the condensing temperature is 50℃, the super cooling degree is 3℃. When the refrigerant is in the sub-cooling refrigeration cycle 1-2'-3'-4'-1, the condensing temperature is a little reduced while the sub-cooling degree will reach above 35℃, so the unit cooling capacity can increase at 54kJ/kg, EER can increase 25%. It is obvious that the specific refrigerating capacity and refrigerating coefficient of performance increase greatly.

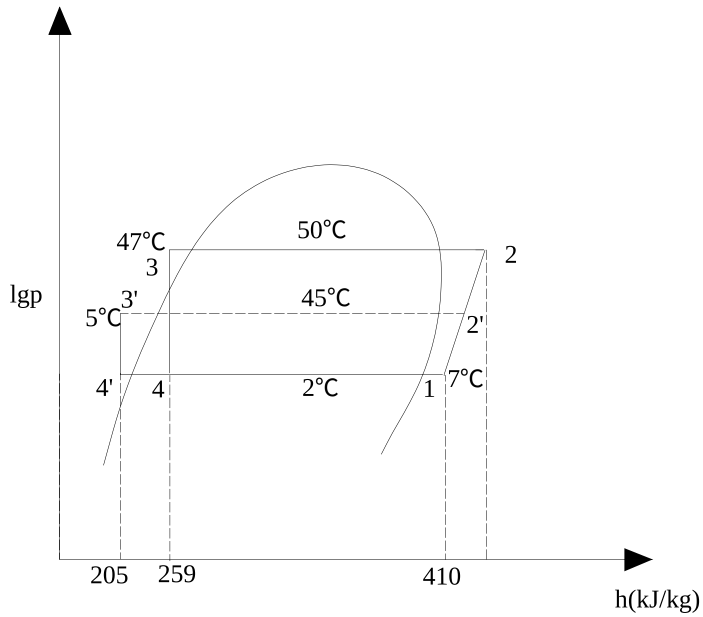

Fig.1 The log p-h schematic diagram of the sub-cooling system

3. SYSTEM CONFIGURATION AND OPERATING MODES

3.1 System Introduction

The designed and researched 30kW new type multi-connected unit consists of one outdoor unit and several indoor units. As shown in Fig.2, the outdoor unit adopts a digital scroll compressor. The system consists of the ice storage tank, a high pressure liquid receiver, vapour liquid separator. To control the switch of the six operating modes check valves, 2,4,5,8,9 solenoid valves and 1,3,6,7 electronic expansion valves were chosen and connected on different pipes. Refrigerant type is R22, unit consists of some electronic expansion valves that can automatically control the refrigerant flow for each indoor unit and the ice storage tank. Also unit can achieve the demand of different operating modes through the switch of some solenoid valves and check valves.

3.2 Operating modes

The designed and researched new type multi-connected system can operate at six operating modes: ice charging mode, ice discharging mode, common refrigeration mode, heat charging mode, heat discharging mode and common heating mode. In the ice charging operation, the ice will be made to store cool energy in the ice tank by the off-peak power with preferential price at night. The period of the operation is about 8 hours and 378,000 kJ of cool capacity will be stored. The thickness of ice outside of tube is 35mm, before icing there is obvious thermal stratification in the ice-storage tank and in the course of icing cool storage increases linearly. In the ice discharging operation, the ice-storage tank works as a subcooler in the power peak load period of daytime, the cold thermal energy makes the refrigerant get bigger sub-cooling degree, which increases specific refrigerating capacity and decreases the power consumption, so increases refrigerating coefficient of performance, and the cooling capacity can rise in air conditioning system, the period of ice discharging is about 8 hours. When the air-conditioning load is small, the system can turn to the common refrigeration mode, where the ice-storage tank is bypassed and the refrigerant will not flow pass the ice-storage tank in the common refrigeration operation. In the heat charging mode, the water will be heated to store heat energy in the ice tank by use of off-peak power with preferential price at night. In the course of heating, heat storage increases linearly. In the heat discharging mode, the refrigerant will flow across the ice-storage tank where the temperature of water is about 50℃ and so the evaporating temperature will arise above the common heating mode, which increases specific heating mode and COP largely, and also decreases the power consumption and can ease frosting at the same time. When the air-conditioning heating load is small, the system can turn to the common heating mode where the refrigerant will not flow across the ice-storage tank and the ice-storage tank is bypassed. In all the modes control of the valves 1~9 is shown in tab.1 in details.

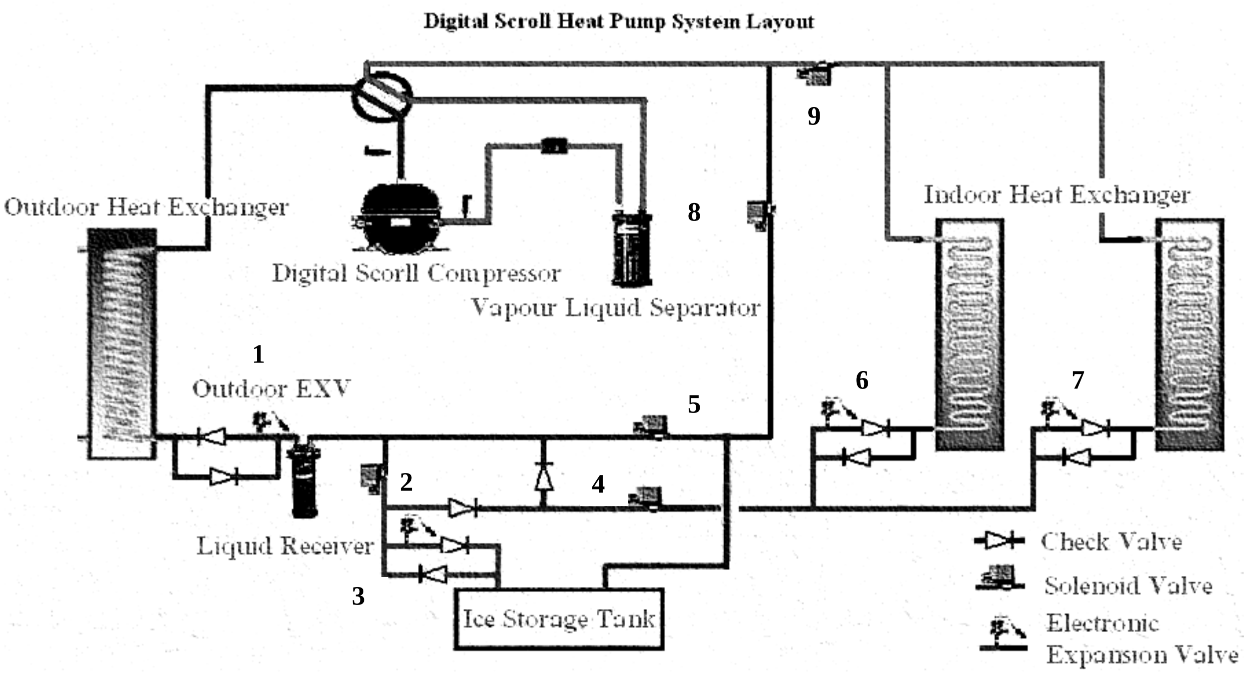

Fig.2: Schematic diagram for the new type sub-cooled ice storage multi-connected system

Table 1: The state control of the 1~9 valves in six operation modes

Valves \ Operation	Ice charging mode	Ice discharging mode	Common refrigeration mode	Heat charging mode	Heat discharging mode	Common heating mode
Valve 1	by-pass	by-pass	by-pass	throttle	full open	throttle
Valve 2	open	close	open	open	open	close
Valve 3	throttle	close	close	close	close	close
Valve 4	close	open	open	close	open	close
Valve 5	close	open	close	close	open	close
Valve 6		throttle	throttle		throttle	throttle
Valve 7		throttle	throttle		throttle	throttle
Valve 8	open	close	close	open	close	close
Valve 9	close	open	open	close	open	open

Note: The blank shows that the valve can be operated at the state of open or close.

3.3 Unit figures and system analysis

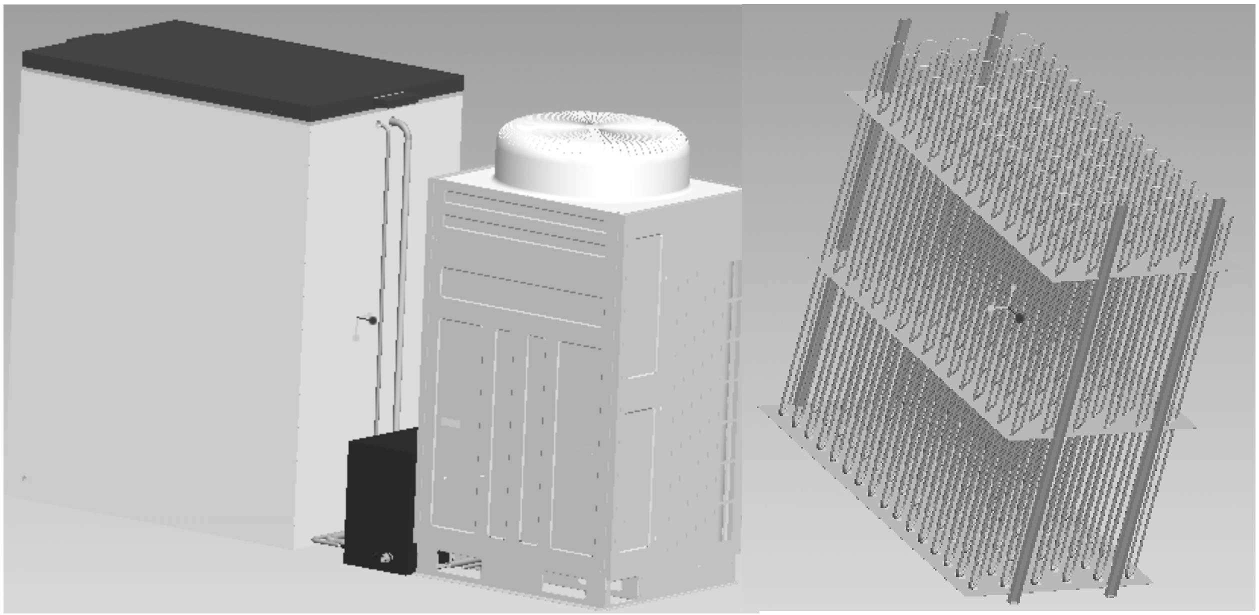

Figure 3: Lay of the whole sub-cooled VRV ice-storage system and the evaporating coils of the ice-storage tank

Figure 4: Figure of the VRV unit

The whole sub-cooled VRV ice-storage system and the lay of the evaporating coils are shown in Fig.3, the outline dimension of the ice-storage tank is about 1440×970×1725 mm (Length×Width× Height)，while the outline dimension of the VRV unit is 990×840×1715 mm (Length×Width× Height), the refrigerant charge volume is about 20kg. The ice-storage tank was special designed, is cuboids and the height is almost same as the VRV unit shown in Fig.4. In the design of ice-storage tank, the cool storage capacity and the thickness of ice layer were key points in the system, which influence several economic and technical problems such as the system matching and outline dimension, first cost, operating cost and so on. As shown in Fig.2 and Tab.1, there is convenient ice charging, ice discharging,, heat charging, and heat discharging through the designed system, and the whole unit can be controlled flexibly and operated simply. The system shows the merits of ice storage technology: Peak load shifting, balance of electric power load, save of power cost and compact construction.

4. SYSTEM ECONOMIC EVALUATION

Cool storage technology can help the electrical utilities reduce on peak loads and increase the load during off peak periods. The shifting of load improves the utilization of base load generating equipment, thereby reducing the reliance on peaking units which have higher operating costs. Electric utilities benefit from a reduction in peak, and customers also benefit with lower electricity bills, which depends upon the electrical rate structures, as the cool energy system allows customers to take advantage of lower off peak rates for electric energy and reduced peak demand billing charges. But in practice because the cost for the ice-storage system is higher than the common system, the system can be economic for customers when the payback time for customers should be shorter than 5 years. Office and emporium buildings are ideal for cooling storage installations, so the system economic evaluation and payback time here used an emporium in Shanghai, the results were shown in Tab.2.

Tab.2 Economic evaluation and payback time for the designed VRV Sub-cooled system

	Peak load (kw)	Full day load (kw.h)	VRV cooling capacity (kw)	First cost (yuan)	Charged bills (Yuan/Year)	Saved money every year (yuan)	Payback years (Years)
General system	41	469	42	32000	15039.3	2001.8	2.3
Ice-storage system			31	36600	13037.5		

Note:

a. Used the Shanghai electric price
Peak: 06:00 ～ 22:00；0.962yuan/Kw.h; Off-peak: 0:00 ～ 6:00, 22:00～24:00; 0.433yuan/kW.h

b. Operation time in summer adopts 110 days

c. Calculation adopts static economic evaluation.

5. CONCLUSIONS

A digital multiple variable refrigerant volume air conditioning system with sub-cooled ice storage system has been designed and researched. Design and research were conducted on a nominal 30kW new type multi-connected unit. The system fundamentals, structure, and design procedure are presented, it is shown that the digital VRV multi-connected units with sub-cooled ice storage system can attain 40kWcooling capacities and run stably for 8hs in day. It is an effective method to combine the ice-storage technology with VRV system in commercial central air conditioning system and the system has the merits of flexible controls, simple operation and compact construction, which need not the big space and difficult construction like the big central ice-storage system. An economic evaluation for the system is made and it shows that the return period can be less 3 years. In the meantime, the experimental research and analysis for the designed system will be related in next work because of the time limit.

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