INSTANT SUPPLY OF AIR CONDITIONING AND HOT WATER

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Abstract: An innovative lead evaporating air-conditioner (LEA) has been developed to effectively perform multiple thermal applications with high energy efficiency and high environmental performance. For the air-conditioning application, the low-temperature condensate leaving the evaporator is retained to pre-cool the return air and outdoor air to increase the cooling effect. The condensate can also remove suspended particulate matters and airborne microorganisms from the air to improve the indoor air quality (IAQ). The condensate containing contaminants is still at a low temperature. In order to maximize the heat recovery, the condensate is then filtered, disinfected, and circulated for more pre-cooling and purification of the air.

The superheated refrigerant leaving the compressor and entering the condenser possesses high quality waste heat. It can be recovered to produce useful hot water above 55℃. The compressor design has been modified for rapid start-up within seconds so that hot water can be produced instantly. The LEA can supply air-conditioning and hot water simultaneously to achieve the highest overall coefficient of performance (COP).

Key Words: ***cogeneration, waste heat recovery, air purification, indoor air quality***

1 INTRODUCTION

In the 21st century, the serious energy and the environmental issues have raised unprecedented awareness in the whole world. It is urged to make use of more natural resources.

In the field of heating, ventilation and air-conditioning (HVAC), most of the efforts have been devoted to enhance the heating and cooling effects; however, the important ventilation does not receive the attention it deserves. Since the SARS incident in 2003, people become more demanding for a healthy indoor environment with good indoor air quality (IAQ). The indoor pollutants mainly include irrespirable suspended particulates, inorganic gas, and volatile organic compounds (VOC). When the HVAC system cannot effectively remove and dilute the airborne pollutants, the pollutant concentrations will rise above the exposure limits, resulting in poor IAQ. Besides controlling the sources of indoor air pollutants, effective ventilation can improve the IAQ. Insufficient fresh air intake will cause sick building syndromes. The recent surveys show that natural ventilation can provide a comfortable environment. Most occupants prefer natural ventilation and that proves the importance of good ventilation.

2 LEAD EVAPORATING AIR-CONDITIONER (LEA)

2.1 Design and operation

The main components of LEA include the indoor unit, the outdoor unit, the self-cleaning system, and the sophisticated electronic control system (Fig. 1). The LEA system employs a two-stage heat-moisture exchanger. The first stage is a direct evaporative heat exchanger. The multi-layer ripple surface constructed with superposition of fibers performs very well as air pre-cooler and purifier. The actual surface area is 100 times larger than the apparent area. It is a compact, efficient innovative heat-moisture exchanger. The second stage of the LEA system is an efficient finned evaporator that employs an air-cooled refrigerator to further cool the pre-cooled air (i.e. deep refrigeration). These two stages of heat-moisture exchanger use counter flow configuration to ensure maximum temperature difference to effectively reduce the irreversible energy loss.

In order to achieve air disinfection, an ozone generator is installed in the water circulation system. Ozone can degrade odors and pollutants. When ozone is introduced into water, hydrogen peroxide is formed as an oxidizing agent. The pH value is about 5.5. Through a spray shower system, a water fall is formed on the surface of the air purifier/cooler. It can collect the 5-μm or larger airborne particulate matters. It can also dissolve the noxious gas. Therefore, air purification, dust removal, detoxification, and disinfection can be achieved.

2.2 Theory

Evaporative cooling of the outdoor air intake is an air-conditioning method that is environmental-friendly, energy efficient, comfortable, and high-quality. It offers a comfortable indoor environment. The principle of the cooling effect is the evaporation of water. A blower draws the hot outdoor air to the moist fibrous layer. Water is evaporated from the compact fibrous layer and that induces a cooling effect. Simultaneously, the cooling removes the heat from the air. The air is therefore cooled and the humidity is controlled.

The advantages of evaporative cooling are:
(1) to reduce the air temperature, reduce the discomfort due to great temperature difference between the indoor and outdoor environments, increase the air flow rate to adjust the indoor air current, improve thermal comfort;
(2) to save electricity because the evaporative cooling can reduce the electricity consumption by 25% compared with conventional vapor compression refrigeration method;
(3) to enhance the ventilation effect, shorten the air change cycle; higher outdoor air intake can dilute CO_2, discourage the growth of bacteria and viruses, and, at the same time, supply more oxygen;
(4) to facilitate effective heat-moisture treatment and purification of the outdoor air to improve its quality;
(5) to supply air with a proper humidity to the indoor environment.

According to the abovementioned principle, LEA first makes use of the evaporation to pre-cool the air and allows the moisture in the air to reach the saturated condition. Through the use the refrigeration evaporator, further cooling of the air is performed. The relative humidity of the supply air is more comfortable. A better quality of cooled air can be supplied. Cooling, purification, and humidity control are accomplished by the single system. In the refrigeration cooling process, the saturated moisture in the indoor air will be condensed to low-temperature condensate. The cooled water continuously produced is treated by filtration and then ozone disinfection. Clean cooled water is spray to evaporative cooler for cooling the hot outdoor air intake. In the continuous circulation, the pre-cooling is prepared for the refrigeration cooling. The condensate from the refrigeration cooling is used to pre-cool the air. The two coolers operate separately, but mutually support each other. The energy is consumed efficiently. The low air flow resistance and large area of evaporative cooling and large air flow rate increase the energy efficiency.

2.3 Application and innovation

2.3.1 High energy efficiency for supply air temperature above evaporation temperature

According to the natural heat absorption characteristic of water evaporation, LEA air-conditioning employs a special design of high air flow operation. For example, in the CX200 model, the cooling effect of the compressor of the refrigeration cooling is 11.2 kW. The air flow rate is 14,000 to 18,000 m^3/h. The wind speed reaches 9 to 13 m/s. The temperature of the supply air is slightly higher than that of conventional air-conditioner. However, the supply air is more comfortable. Even though standing in front of the air supply grill, the person will not feel too cold. It is less likely for an occupant to get cold.

2.3.2 How to use condensate effectively?

The condensate is normally at about 11 to 18°C. Discharging the condensate is a waste of energy. The LEA system uses the low-temperature condensate produced in the refrigeration cooling stage to pre-cool air by evaporative cooling.

2.3.3 Self-cleaning function

When the LEA system is not operating, the system will automatically collect the cooling water and discharge it along with the particulates, microorganisms, and VOCs. The water collection system will not store any noxious substances. Still water is a potential source of Legionnaires' disease and other bacteria.

2.3.4 Self-disinfection function

Normally when an air-conditioning system is shut down, the system becomes a place for the growth of bacteria as it is warm and humid. For example, when you turn on an air-conditioner after it has been shut down for quite some time, you often smell abnormal odors and particulates may be blown out through the supply. News have reported that mouse hair, bones, cockroaches etc. were found.

In order to avoid these unwanted incidents, the LEA system has a special design for disinfection after it is shut down. A UV-C germicidal device is installed inside the LEA system. Living organisms cannot grow in places that are irradiated by UV-C. It is because UV-C can penetrate cell walls and destruct the reproductive systems of the cells.

2.3.5 Effective heat exchanger

LEA applies the water evaporative cooling technology and refrigeration cooling for integrated heat exchange to achieve heat recovery from the condensate. Such heat transfer design can increase the overall heat transfer rate up to 201.36%. The sensible heat transfer is increased by 177.6%. The results of the experimental studies conducted are summarized in Table 1.

3 INSTANT-HEAT REFRIGERATION WATER HEATER

3.1 Design and operation

Instant-heat refrigeration water heater mainly consists of a heat recovery unit (condenser), refrigeration cooling circulation system, hot water temperature control system, and precision electronic control system.
Cold water enters the heat recovery unit. Using a specially designed refrigerant/water multiple-channel fine tube heat exchanger, water rapidly absorbs most of the heat from the hot refrigerant and the water temperature rises to 55 - 70°C.

The refrigerant is condensed to low-temperature liquid and enters the large-area finned heat exchanger. Under a high air flow rate, the refrigerant cools down the air significantly. The refrigerant turns to low-temperature vapor and then compressed to high-temperature superheated refrigerant vapor in the compressor. One refrigeration cycle is completed.

3.2 Theory

Instant--heat refrigeration water heater is a instant heating device. That means water inside the effective tubular heat exchanger is heated from 25°C to 45 °C within 1 min. The hot water supply can be used directly.

The water heater can heat up water to such high temperature within such short period of time because the newly developed tubular heat exchanger can evenly distribute the refrigerant and increase pressure in the heat transfer process. The high-temperature, high-pressure refrigerant can evenly passes through the heat exchanger tubes. Not only the heat transfer area is increased, but also the heat transfer rate between the refrigerant and water is increased.

The film condensation heat transfer implies high heat exchange rate that can heat up water to 55-70°C within a short period of time.

3.3 Innovation

3.3.1 Instant start-up for instant heating

The time delay for turning on a compress is commonly 3 minutes. The water temperature fluctuates from 1-3°C when a compress is switched on. In order to overcome this problem, the compressor should be able to switch on after 1.5-3 seconds after it is shut down. This can be accomplished by adding a device in the refrigeration circuit that can balance the high and low pressures rapidly within 1.5 s after it is shut down. This device has been tested for two years. The tests have shown that the new device makes the compressor operation safer.

3.3.2 Variable air flow design

The refrigeration water heater can be used all year round. The system can also perform multiple functions, i.e. space cooling and space heating. The compressor can adapt the outdoor environment from 40 to -10^{o}C and the temperature of incoming water from 4 to -35^{o}C. Using precision electronic control, the air handling unit can vary the air flow rate in response to the changes of the outdoor environment. The compressor can operate in a more uniform manner.

3.3.3 Adjustment of water temperature and flow rate

The hot water supply will vary with the ambient temperature.

4 LEAD EVAPORATIVE AIR-CONDITIONING + INSTANT-HEAT REFRIGERATION WATER HEATER

4.1 Design schematics

A complete system consists of an LEA evaporative air-conditioning (indoor unit), instant-heat refrigeration water heater (outdoor unit), hot water temperature control system, and precision electronic control system. The system as illustrated in Fig. 1 can perform different modes of operation.

Simultaneous cooling and heating

The heat of the high-temperature refrigerant vapor produced by the compressor can be rapidly absorbed by incoming water via a special multi-tube heat exchanger (see Fig. 2). The temperature of the hot water produced is 55-70^{o}C.

After condensation, the liquid refrigerant will be diverted to the finned heat exchanger of the LEA system. The high air flow can extract a lot of cooling from the refrigerant. The refrigerant becomes low-temperature vapor. The compressor will increase the pressure of the refrigerant for the next cycle.

Spacing heating

As shown in Fig. 2, the high-temperature refrigerant vapor leaving the compressor flows to the flow diverter. The refrigerant will directly enter the finned heat exchanger of the LEA system. Under the condition of high air flow, the air extract a lot of heat for spacing heating. After condensation, the refrigerant is diverted and turns to low-temperature refrigerant. It immediately enters the condenser of the instant-heat refrigeration water heater. The refrigerant cycle is operating as a space cooling system.

Water heating

When hot water is required and neither air-conditioning nor spacing heating is needed for the LEA, the compressor produces high-temperature refrigerant vapor and the heat is transferred to the water by a multi-tube heat exchanger. The incoming water rapidly absorbs the heat from the high-temperature refrigerant vapor. The hot water temperature is 55-70^{o}C.

After condensation, the refrigerant flows through a diverter, turns to a low-temperature liquid refrigerant, and enters the condenser of the instant-heat refrigeration heat exchanger. The refrigerant reject a lot of cooling to the ambient air as the air flow is high. The refrigerant turns to a low-temperature vapor. The compressor increases its pressure for the next refrigeration cycle.

The finned heat exchanger of the LEA unit does not take part in this mode of operation. The instant-heat refrigeration water heater performs all the operation.

4.2 Theory

This system makes use of the advantages of the LEA (indoor unit) and the instant-heat refrigeration water heater (outdoor unit). The two units can be jointly operated to support each other; they can also operate separately.

4.2.1 Pressure-enthalpy analysis

Different refrigeration cycles are presented in a pressure-enthalpy (P-h) diagram as shown in Fig. 3:

Mode 1: Simultaneous cooling and heating (red)
Mode 2: Air-conditioning (dark blue)
Mode 1: Space heating (light blue)
Mode 1: Water heating (green)

4.3 Technical problem solving

4.3.1 Operation at high and low ambient temperature

In the summer time or when the ambient temperature is 40^{o}C or above, the temperature of the incoming water is nearly 30^{o}C. The hot water temperature can reach 60^{o}C or above. If this system is design in a conventional manner, the low pressure of the R417a refrigerant is 0.68-0.88 MPa and the high pressure is 2.3-2.6 MPa. The suction temperature is 20-30^{o}C. Under these circumstances, the compressor operation is overloaded. The exceedingly high temperature reduces the operation limit of the compressor. Long-term operation in such condition will shorten the compressor life.

In the winter time, the temperature is low. When the system is operating for water heating, the evaporating pressure is low (about 0.3-0.45 MPa). If hot water at 55^{o}C is needed, R417a refrigerant should have a high pressure of 2.0-2.2 MPa. The compressor ratio will become very high and possibly exceed the safety limit.

In order to adapt the above two adverse conditions, variable speed indoor air handling unit is selected. The condensing air flow rate can vary to adapt different ambient temperature and different modes of operation. The compressor can be running within a safe operating condition.

4.4 Innovation

4.4.1 Multiple functions

The indoor air handling unit, outdoor fan, compressor, multiple-way valves are controlled by precision electronic controller. The LEA and instant-heat refrigeration water heater have multiple functions: integrated operations, individual operation, cooling, space heating, water heating.

1. Cooling, heating, humidity control, moisture removal, and water heating
2. Cooling, heating, humidity control, and moisture removal
3. Water heating only

The system is available all year round to fulfill all the thermal requirements.

5. TECHNOLOGICAL AND ECONOMIC DEVELOPMENT

5.1 Effective use of natural resources and renewable energy

Water is used as a coolant in the LEA system. For the whole system, the output of a compressor can be maximized. The electricity consumption can be reduced. The operation is also simple. Evaporative cooling required low energy consumption to perform much cooling. The efficiency is 2.5-5 times high than that of conventional vapor compression refrigeration systems. The output of conventional a vapor compression refrigeration system is about 50 W/m^2. Evaporative cooling can achieve 10 W/m^2, i.e. 80% energy saving.

Evaporative cooling air-conditioning system can save energy by about 30%. It can reduce the peak power demand for air-conditioning in the summer time to lower the risk of seasonal electrical power overload.

5.2 Heat recovery to prevent thermal pollution of the atmosphere

Instant-heat water heater recovers the heat discharged to the atmosphere and turns the waste heat into useful hot water. That can reduce the heat released to the atmosphere and lessen the global warming problem. The Instant-heat water heater also saves energy.

6 Conclusion

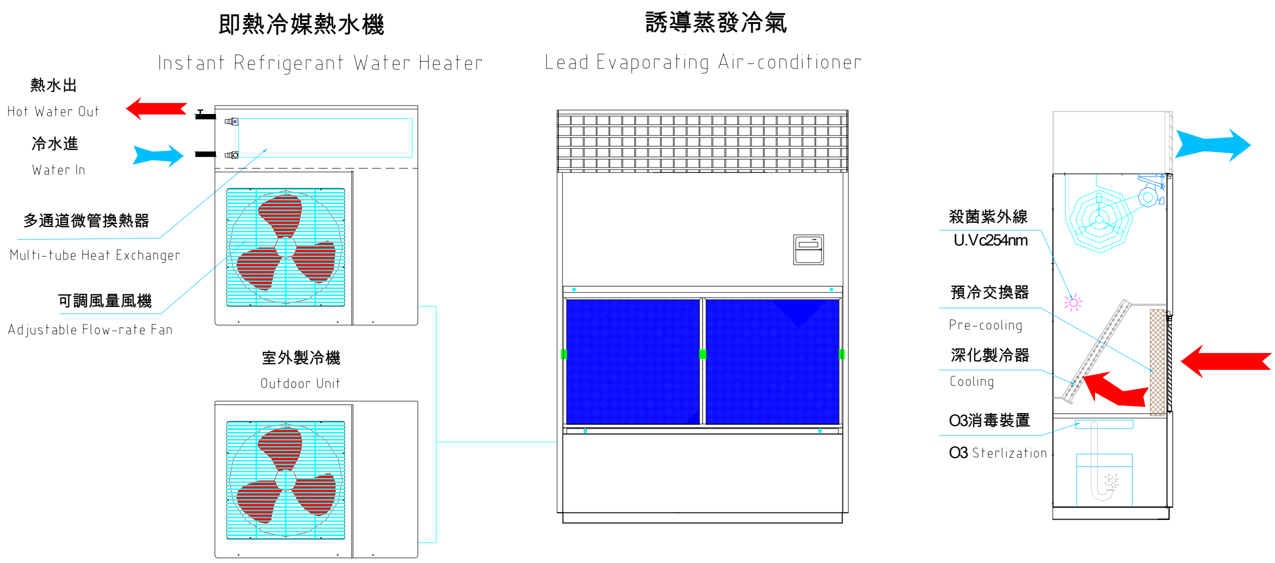
The innovative lead evaporative air-conditioning (LEA) makes use of the evaporation of water and low-temperature condensate to produce a cooling effect. The integration develops new cooling/ heating and renewable techniques. After continuous research and development, more technologies are incorporate into the LEA system. The product is now multi-functional, energy efficient, environmentally friendly, effective, and practical. A list of products of various capacities and applications are already available in the market.

7 TABLES AND GRAPHICS

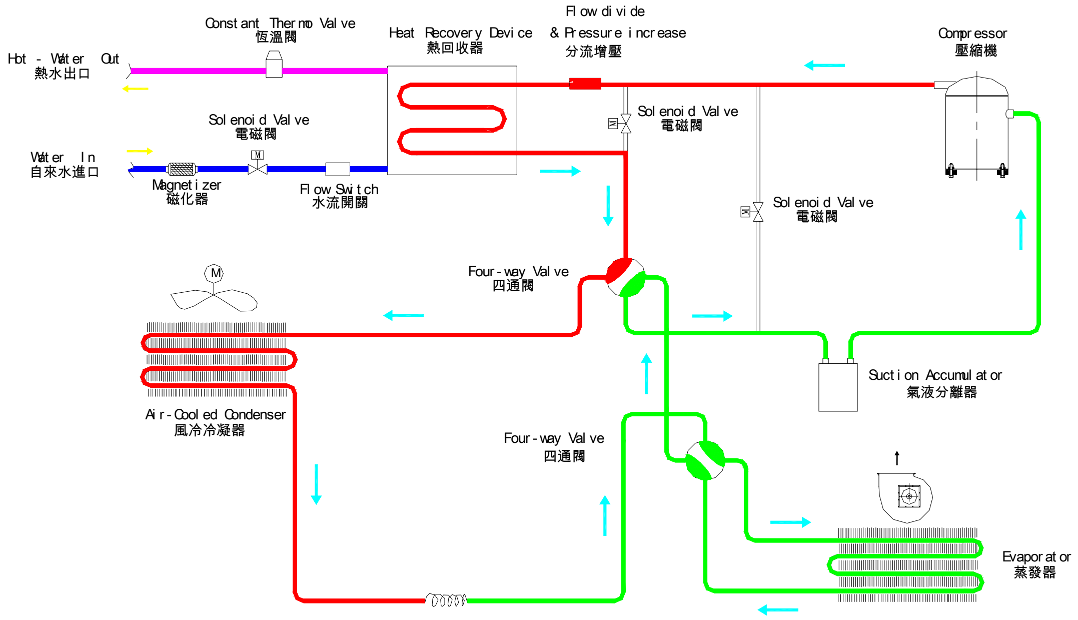
Table 1: Cooling effects of LEA system

誘導蒸發冷氣 LEA	預冷段 Pre-cooling	深冷段 Cooling	預冷段+深冷段 Overall cooling
進風溫度 DB/WB ℃ Indoor Air Inlet	26.98 / 19.08	26.97 / 19.11	26.92 / 19.01
出風溫度 DB/WB℃ Indoor Air Outlet	23.51 / 19.18	24.21 / 17.89	19.55 / 17.89
顯 冷 量 KW Total cooling capacity	12.420	9.420	38.799
製 / 全 冷 量 KW Total cooling capacity	0	12.615	25.402
輸入功率 KW Power input	2.200	5.848	5.949
能效比 C O P	0	2.157	4.270

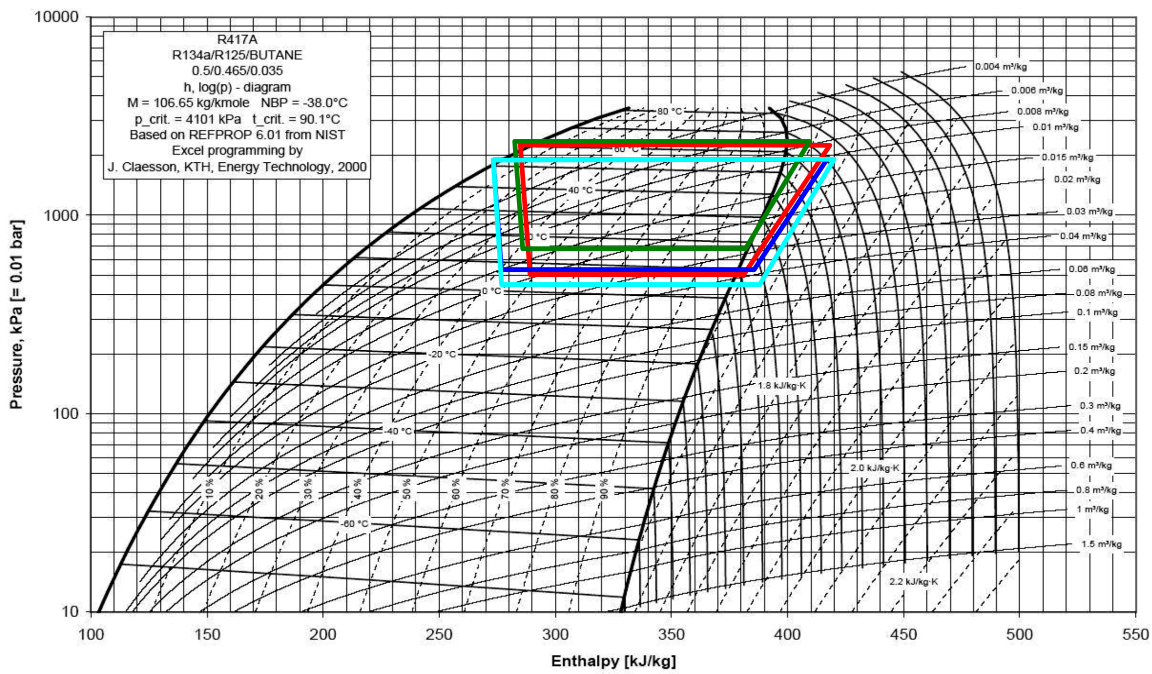
Note: Lead Evaporating Air-conditioner CX200D.



Figur. 1. LEA system



Figur. 2. Simultaneous cooling and heating operation



Figur. 3. Pressure-enthalpy diagram