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Performance of heat pump unit with capillary heat exchanger*

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Abstract: The heat pump system utilizes shallow geothermal energy in the coastal areas, which not only uses clean energy but also contributes to energy conservation and environmental protection. This paper studies the performance of a heat pump system applied a capillary heat exchanger as an energy collection device. The numerical performance of capillary heat pump showed a good agreement with the experimental data in the winter heating mode and the summer cooling mode. It was concluded that the COP of the heat pump unit using the capillary heat exchanger was 5.32 in winter and 4.32 in summer.

1. Introduction

The heat pump unit system could be used for heating and refrigeration. The heat pump unit absorbs heat from the environment and transfers the energy to the building [1].High thermal efficiency heat pump had been proposed as a new heating apparatus [1]. Heat pumps are preferred widely used in many applications [2].The most commonly used coefficient of performance (COP) to evaluate the efficiency of GSHP [2]. In the horizontal loop system, the horizontal loop system required large of land areas [3]. However, the performance of the GSHP system depended on many other parameters, such as geological conditions, heat exchanger material, carrier fluid, pipe diameter, mass flow rate of heat exchanger fluid [4].

Hence, research on the performance of heat pump is important to reduce the investment and operation cost. Bazkiaei et al.[5] proposed a method to optimize a horizontal GHX system by using homogenous and non-homogenous soil profiles. Esen et al.[6] studied the performance of GSHP system and its economic benefits. Ramni et al. [7] observed that the condenser outlet temperature played a major role in controlling the COP for space heating applications. Noorollahi et al. [8] studied the economic analysis of a ground source heat pump for supplying energy for a greenhouse in Iran. Based on reviewing the recent literature, the COP of studies on heat pump systems shows an increase in the literature but still it is not adequate. Recently, studies focued on heat pump systems with capillary heat exchanger. Mariem Lazaar [9] placed capillary heat exchanger in greenhouses soil, capillary heat exchanger provided 12 ℃ at night. Mejdi Hazami et al. [10] investigated the capillary heat exchanger extracted from seawater, which could be used as the cold source of the Salammbo Museum aquarium in Tunisia.

However, the performance of a heat pump unit with a capillary heat exchanger was not studied. In this paper, the COP and EER of capillary heat exchanger heat pump were calculated. The theoretical and experimental comparison of performance analysis of capillary heat exchangers was presented.

2. Method

The capillary heat exchanger grids consist of outside diameter is 4.3 mm, a wall thickness is 0.8 mm and tube spacing is 20 mm. [12]. Capillary heat exchanger was applied in coastal areas. In summer, the capillary outlet temperature was 34 ℃. The condensate temperature of the refrigerant was 35℃. The glycol was heated 37℃ flow into the condenser. The circulation pump completes the heat transfer. The theoretical study of heat pump unit performance is necessary. The heating cycle and the cooling cycle are basically the same. Therefore, the refrigeration cycle are selected as a typical analysis. When operate for heating, the thermal load of heat pump is expressed in Eq (1) [11].

$$Q_h = Q_b\left(1 - \frac{1}{COP}\right) \tag{1}$$

While in the cooling mode, the thermal load of heat pump is given in Eq (2).

$$Q_c = Q_b\left(1 + \frac{1}{EER}\right) \tag{2}$$

3. Results and discussion

When the coefficient of refrigeration was analyzed, the working medium was R22 [14]. The condensation

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temperature of the condenser was the sea water temperature plus 10°C [13]. $t_1=4℃$; $P_1=562.342kPa$; $h_1=407.228kJ/kg$; $h_2=423.256kJ/kg$; $t_e=40℃$; $h_3=h_4=236.257kJ/kg$; $\varepsilon_0=11.05$; $q_c=184.6kJ/kg$; $\omega=16.04kJ/kg$; $t_2^{'}=44℃$; $h_2^{'}=417.128kJ/kg$; $h_3^{'}=255.210kJ/kg$. $h_1=406.948kJ/kg$; $P_1=562.342kPa$; $\varepsilon_H^{'}=6.2$; $\varepsilon_H=12.5$; $\varepsilon_0^{'}=\frac{q_0^{'}}{\omega_0^{'}}=5.2$; $\frac{\varepsilon_0}{\varepsilon_0^{'}}=2.21$; $\frac{\varepsilon_H}{\varepsilon_H^{'}}=2.02$.

From the above calculation results, it could be seen that the refrigeration coefficient of the capillary refrigeration heat pump unit was 2.21 times that of the ordinary refrigeration unit. In summer, ordinary refrigeration equipment consumed large amounts of energy. If a capillary heat pump refrigeration unit was used, the cooling efficiency of a capillary heat pump refrigeration unit was twice that of an ordinary refrigeration unit. It greatly reduced energy consumption.

3.1 Power consumption

As shown in Fig.1, the monthly space heating ranged from 103.45kW/h to 135.45kW/h. While the corresponding electricity consumption ranged from 19.37kW/h to 28.11kW/h. At the end of the test period, the total space heating and electricity consumption were recorded 1501.12kW/h and 284.97kW/h, respectively.

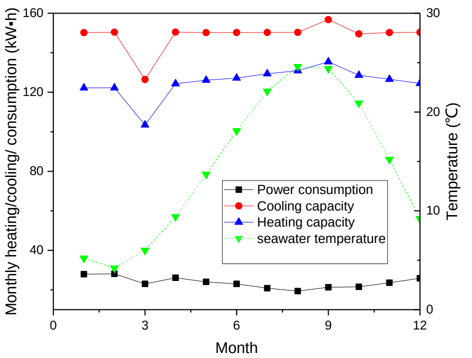

Figure 1. GSHP monthly heating/cooling/consumption

It was assumed chilled water temperature was 7°C, the evaporation temperature was 5°C. The ordinary air conditioning system condensing temperature was 35°C. It could be concluded that the COP was 5.26. The monthly heating ranged from 126.49kW/h to 156.78kW/h. While the corresponding electricity consumption ranged from 19.37kW/h to 28.11kW/h. At the end, the total heating and electricity consumption were recorded 1785.44kW/h and 284.97kW/h. The EER was 6.26[14]. Due to the application of shallow geothermal energy, the condensing temperature reduced to 20°C. The air conditioning energy consumption was lower than 50%.

3.2 The energy efficiency ratio with load rate

The EER and COP were selected to represent heat transfer performance of heat pump units in summer and winter. As shown in Figure2, the energy efficiency ratio was higher in summer than that in winter. The load rate of the heat pump unit was changing. It could be seen that COP and EER of heat pump had a change for different load rate. It changed strongly with load rate from 0.3 to 0.6. The value of COP ranged from 3.40 to 5.32. The value of EER ranged from 3.82 to 6.32.

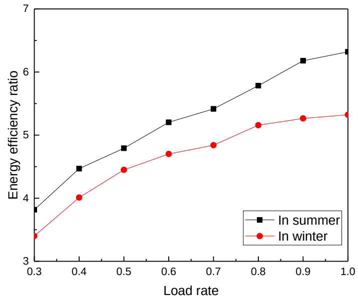

Figure2. Variation of energy efficiency ratio with load rate

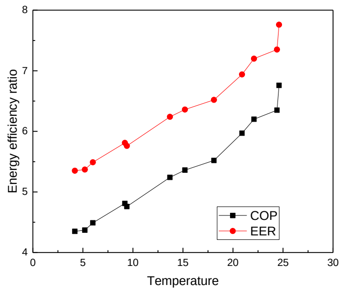

Figure 3. **V**ariation energy performance ratio

As shown in Figure.3, it illustrated that the COP going up with the seawater temperature larger. The temperature difference was smaller between the heat source and the load, the COP was higher. It showed that the EER rose, when seawater temperature larger. The difference temperature smaller between cold source and load, the EER was higher.

3.3 Refrigerating capacity and heating capacity

Through the COP changed, the cooling capacity and heat supply of the heat pump were introduced. It would be more accurate when took into account the impact of COP and energy efficiency. The heat supply and cooling capacity of the heat pump varied with the building load. For a fixed heat pump, the cooling capacity and the efficiency of the heat supply vary with the energy efficiency ratio and the COP, respectively.

As shown in Fig 4. When the building load was increased, the refrigerating capacity of the heat pump unit rose. The EER was ascended, the refrigerating capacity of the heat pump unit larger. The increase in refrigerating capacity of heat pump unit had little rise. As shown in Fig 5, when the building load was increased, the heating capacity of the heat pump unit rose. The COP was ascended, the heating capacity of heat pump unit larger. The increase in heat production of heat pump unit was not significant.

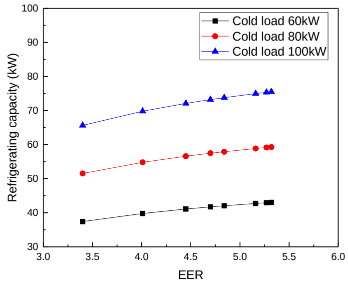

Figure 4. Variation of refrigerating capacity with EER.

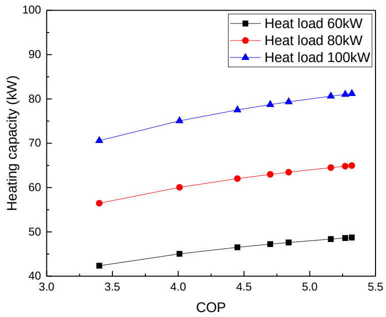

Figure 5. Variation of heating capacity of different building load units with COP

3.4 Comparison of calculation and experimental

Zhou et al.[13] investigated a new medium-sized seafood hotel, with the hotel installation of a capillary water source heat pump system in Qingdao.

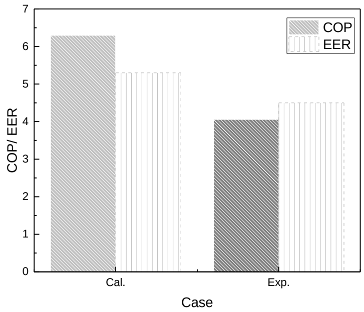

Figure 6. Comparison in calculation and experimental data.

The construction area was 500 m^2. The rated refrigerating capacity was 60kW. The average value of refrigeration coefficient EER was 4.50. The average value of heat pump unit COP was 4.06. As shown in Fig.6, the calculated COP/EER was compared with the experimental data. It could be observed that the theoretical calculation EER/COP was higher than experimental data. The theoretical calculation value EER was 5.32. The COP was 6.32 in heating mode. The reason might be that the system power was lower. The capillary heat exchangers were buried too long.

4. Conclusion

This paper proposed the capillary heat exchangers application scheme in buildings. The energy-saving characteristics of the capillary heat pump system were calculated. Through the actual operation test of the capillary heat exchanger, the COP and energy efficiency ratio of the system were studied. In this paper, working conditions in winter and summer were considered. The following conclusions are drawn.

(1) The application of heat pumps in buildings would greatly reduce building energy consumption, especially in the summer. Compared with ordinary air conditioners, the power consumption was reduced to 1/2, the benefits were significant. (2) The COP of the system ranged from 3.40 to 5.32. The energy efficiency ratio of this system ranged from 3.82 to 6.32. (3) This dissertation is helpful to understand the winter COP value and summer effective value, and provides an entry point for further research in this field.

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