FIELD TEST STUDY ON THE PERFORMANCE OF AIR SOURCE HEAT PUMP IN LOW TEMPERATURE IN BEIJING

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Abstract: Under the abnormal weather, such as -16.5°C~-6°C of low temperature and snow, air source heat pump (ASHP) unit was tested continuously for 80 hours in Beijing. The unit's operation characteristics in low temperature were analyzed in the aspects of operation performance, heating performance and heating effects. The results shown that in the average outdoor temperature of -11°C, average COP reached 2.21 and heating demands were satisfied. It was pointed out that the mal-defrost operations together with the frequent start-stop operations were the key problems to influence the stability of system's heating performance.

Key words: ASHP, low temperature, field test, heating performance

1 INTRODUCTION

The performance of air source heat pump (ASHP) was not agreeable in low temperature environment. Following the environment temperature dropped, the suction specific volume of the compressor increased, and the compressor displacement decreased. The heating capacity of the ASHP decreased at the moment. However, it is the critical time for the heating requirement. Furthermore, the increased compression ratio will lead to high discharge temperature. If the discharge temperature got the extreme value, the unit stopped because of the self-protection rules. The compressor might be easily damaged when runs in such conditions. A lot of researches have been conducted to improve the performance of the air source heat pump in low temperature environment. (Arai 1983) reported a scroll compressor applying in packaged air conditioner, and the test results indicated the heating performance could be improved 15% in low air temperature environment. A new Hi-Re-Li cycling technology was used by Westing-House Company, which can promise the unit running normally in environment temperature of -28°C. (Sami and Tulej 1995) presented a developed Combined Cycle Fully Integrated Air/Air Heat Pump (CFIA) system which combines the proven efficiencies of heat pump technologies with heat regenerative technologies to bring the most efficient heating/cooling system with capabilities to produce domestic hot water. And the field testing revealed an average COP of 2.4 at - 13.5°C outside temperature. The Copeland Company proposed a new design of double stage compression and capacity adjustable scroll compressor which can improve the heating capacity of the unit in low temperature environment (Chai Q.H. and Ma G.Y. 2002). Aiming at improving the heating efficiency of ASHP in cold regions, (Ma Z.L. et al. 2001) put forward a double-stage heat pumps heating system, which consisted an ASHP and a water source heat pump. A one month field test for this double stage coupled heat pump system applying in Beijing was conducted by (Wang et al. 2005), the tested results indicated the performance of the unit was ideal when it operated in double stage mode in cold regions. (Ma G.Y. and Shao, S.Q. 2002; Ma G.Y. et al. 2003) presented a new heat pump cycle which can secure heating capacity under low ambient temperature by employing the scroll compressor with supplementary inlets. The tested results of the heat pump prototype demonstrated that the heat pump could output high temperature water and high capacity even under the low ambient temperature of -10°C ~-15°C. The developed double stage heat pump heating system can be used in cold regions. (Tian, C.Q. and Shi W.X. 2004) developed a two-stage compression air source heat pump (TV-ASHP) combining variable frequency. The experiment shows this system runs safely and steadily, which can be used in the cold regions where outdoor temperature falls lower than -18°C.

Though abundant works have been done to improve the performance of ASHP in cold climate, most of them were conducted in laboratory, few literatures reported the field test results of the performance for ASHP operating in cold environment. With the aim to reveal the performance of the ASHP under low environment temperatures, a field test for an ASHP with economized liquid injection technology operating in -16.5°C to -6°C and snow conditions was presented in this paper. The operation performance, heating performance and heating effects of this unit was analyzed.

2 TESTED ASHP HEATING SYSTEM

2.1 Field Test

Field test was conducted in an office building in Beijing, China, which included 11 rooms with the total heating area of 185m^2. An air source heat pump connecting the radiant floor heating system was applied in this work. The ASHP with nominal heating capacity of 28.07kW and nominal power of 8.48kW was applied as the heating source in this test. It is equipped with two scroll compressors, one was constant speed compressor (CSC) acted as a primary unit, and the other was variable speed compressor (VSC) acted as a backup unit. The VSC would not start until the water supply temperature is below 41°C, and it would stop operating once the water supply temperature reached at 45°C. Fig 1 showed the schematic of the experimental system, due to the symmetrical structure of the CSC and VSC unit, Fig 1 displayed the schematic of the CSC side.

2.2 Test Facilities

The measurement system is built up to monitor the outdoor and indoor environment, performance of the tested ASHP, the images of frost on the heat exchanger. Table.1 presents the detail information about the test instruments of the measurement system. Temperature and humidity sensors are widely applied in this test to get the following parameters, indoor and outdoor temperature and humidity, refrigerant evaporating and condensing temperature, compressor suction and discharge temperature, water inlet and outlet temperature, and fin surface temperature. The test range of these sensors is, temperature -40~100°C, humidity 0~99%RH, and the accuracy is, ±0.5°C for temperature, ±4.5%RH for humidity. A power sensor YD2000 with the accuracy of ±0.5% is used to monitor the power input to the ASHP. A water flow-meter LZB-50, with an accuracy of 1.5 levels in the range of 0.6m^{3}h^{-1} to 6m^{3}h^{-1}, is used to measure the water flow rate. The images of frost are captured by a video camera (10 Megapixels) and a digital camera (12 Megapixels). Data collected from above sensors are automatically recorded by a computer via a data acquisition switch unit.

3 TESTED RESULTS

3.1 Environment Conditions

The snowfall in Beijing is very abundant in the winter 2009 to 2010. So, the weather is quite unusual compared to the previous years. The ambient temperature decreased dramatically. It's beginning to snow at 1:00am of January 3, 2010 and last for 22 hours. The average snowfall per hour amounted to 1 mm. Then, the abnormal weather of low temperature and snow in Beijing appears during the next few days. It is a good chance to test the actual operating performance of ASHP in the low temperature and snow conditions. The ambient temperature, humidity and velocity during 9:00am of January 3 to 14:00pm of January 6 are shown in Fig 2. The lowest temperature in the 80 hours test period reaches -16.5°C, and an average value is -11°C. These ambient conditions are much lower than the design temperature -9°C for house heating in Beijing. As the result of snow, high relative humidity with an average of 84% and the maximum of 87% appear at the first 16 hours. Then, the humidity reduces quickly when the snow stops. The minimum relative humidity is 24%. The average air velocity is 3.0 m s^{-1} during the 80 testing hours.

3.2 Operating Characteristics

Fig.3 shows the variation of compressor suction, discharge, fin and distribution tube surface temperatures in the 80 hours testing period. The discharge temperature of the compressor varies from 70°C to 90°C with the average value 80°C. Compared to the fluctuating discharge temperature, the suction temperature is stable, and the average value is at -10°C. It can be found that following the environment temperature, the temperature of fin and distribution tube surface periodically changed. At the time of 30^{th}h, 54^{th}h, and 78^{th}h, the fin and distribute tube surface temperature reaches the maximum (Fin, -7.5°C, -6°C, -6°C; Distribute tube, -10°C, 8°C, -8°C). The minimum of the surface temperature (Fin, -9°C, -12°C, -10°C; Distribute tube, -11.5°C, -10°C, -12.5°C) appears at the time of 23^{th}h, 45^{th}h, 70^{th}h when the environment temperature is relative lower.

From the discontinuity of fin and distribution tube surface temperature, defrost operations can be determined. Totally 32 times defrost operations appear in 80 hours, averaging 0.4 time/h. During the time of 0~38h, 48~64h, 72~79h, the time interval between two defrost cycles is about 2 hours. According to field observations, there is almost no frost on the fins in the period after 60^{th}h. This attributes to the extreme low ambient temperature and humidity. However, 8 defrost operations still appear in the 61~80h. These are unnecessary defrost operations. This means nearly 25% of the input power for defrosting process serves for the mal-defrost. Therefore, it is required to develop new technologies method to monitor the frost thickness directly and accurately, which is required for the defrost control strategy.

3.3 Heating Performance

The inlet and outlet water temperature, heat capacity, power consuming of the ASHP and COP in 80 hours testing period are shown in Fig 4. It is found that an average COP of 2.21 is reached in the average environment temperature of -11°C. A higher EER is assured by the tested ASHP with economized liquid injection technology. But the heating capacity is not very stable because of the frequent start-stop of the variable speed compressor. The outlet water temperature varies from 40°C to 44.5°C, average value is 42°C and the inlet water temperature varies from 37°C to 41°C, average value is 39°C. The heating capacity of the unit varies from 5kW to 17.6kW, average value is 10.39kW and the power input to the ASHP varies from 2.9kW to 6.4kW, average value is 4.16kW. As the frequent start-stop operations break the stability of the heating capacity, efficient methods should be developed to optimize the control strategies. During the period 38h-48h, no defrost operations appear, but the average environment temperature is -13.8°C, the average COP is only 1.83 (dropped 17%

compared to the average value). This indicates that prolonging the defrost intervals can not promise an ideal performance for the unit when the environment temperature is extremely low. The air temperature is the dominant factor affecting the heating performance of the ASHP.

3.4 Heating Effect

Two rooms are selected as the typical rooms to test the heating effect in this experiment. The indoor air temperature in the 80 hours testing period is shown in Fig 5. The maximum and minimum temperature value of room 204 is 22.4°C and 17.6°C, and the 209 is 20.5°C and 17.1°C respectively. The average temperature of 204 is 19.2°C which slightly higher than room 209, 18.5°C. The temperature of the typical room has small fluctuations following the environment temperature but the average value is higher than 18°C. This result demonstrates that the tested ASHP can satisfy the heating demand in such low temperature and snow weather.

4 CONCLUSION

Abnormal weather with -16.5°C~-6°C of low temperature and snow appeared in Beijing in January 2010. Air source heat pump unit was tested continuously for 80 hours with economized liquid Injection technology. The operation characteristics of the unit in low temperature were analyzed in the aspects of operation performance, heating performance and heating effects. The following conclusions are achieved,

(1) In the 80 hours testing period, the environment temperature reached -16.5°C with an average value of -11°C. The average COP of the unit in the testing period reached 2.21. And the average temperature of two typical rooms reached 19.2°C and 18.5°C respectively. These results illustrate that the ASHP with economized liquid injection technology has an ideal heating performance in low temperature environment.

(2) There are two essential problems influenced the unit's heating stability. The first one, unit defrosts while there is almost no frost on the fins, and the second one, the unit frequently experiences start–stop operations. To improve the unit operating stability and enhance the COP in low temperature conditions, technologies of testing the frost thickness directly and accurately, together with the defrost control strategy is needed. Moreover, methods to optimize the start-stop of the unit are also required.

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5 TABLES AND FIGURES

Table 1: Information of the experiment instruments

Device	Number	Accuracy of Reading	Full Scale	Model
Temperature Sensor				
Refrigerant side	5	±0.5°C	-40~100°C	ADL
Water side	2	±0.5°C	-70~150°C	SDB-Tn10
Outdoor air	2	±0.5°C	-40~100°C	ADL
Indoor air	11	±0.5°C	-40~100°C	ADL
Humidity sensor	2	±4.5%RH	0~99%RH	ADL
Power sensor	1	±0.5%	50~600 V 0~6 A 50/60 Hz	YD2000
Flow-meter	1	±0.5%	0~10 m^3 h^{-1}	LWY-25

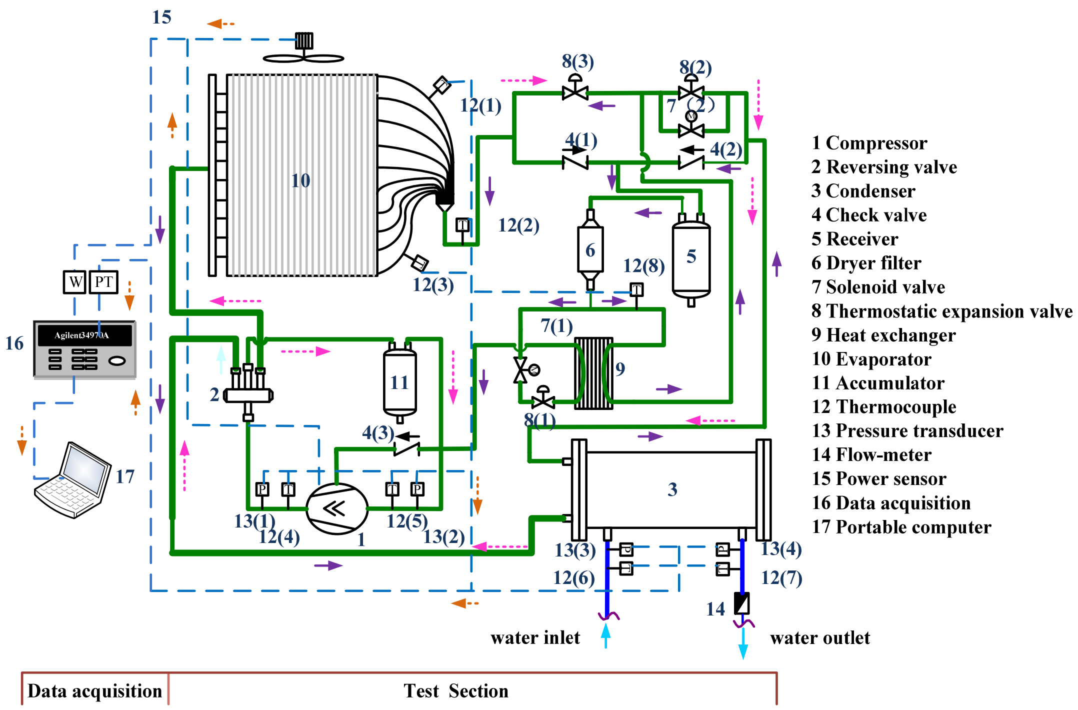
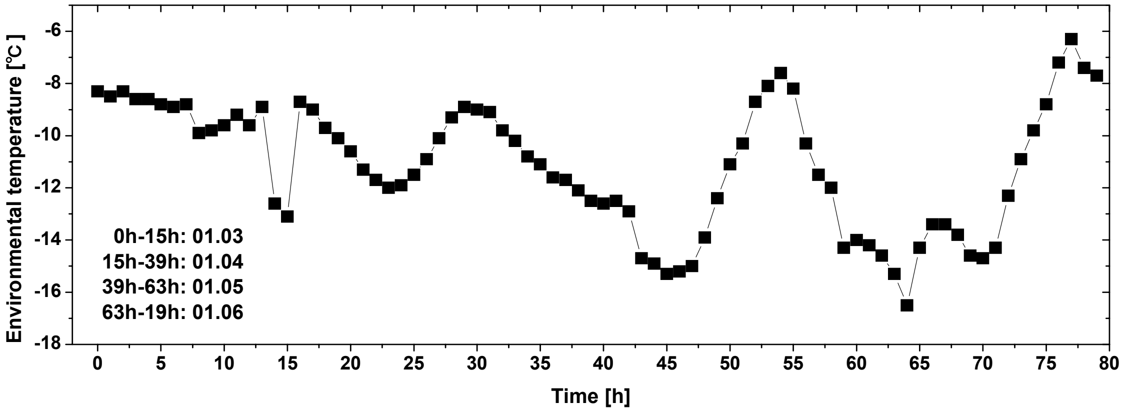
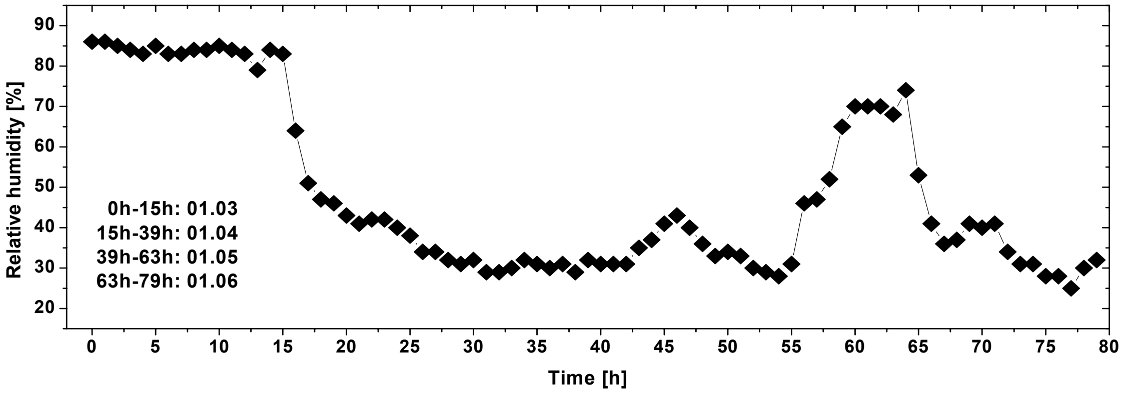


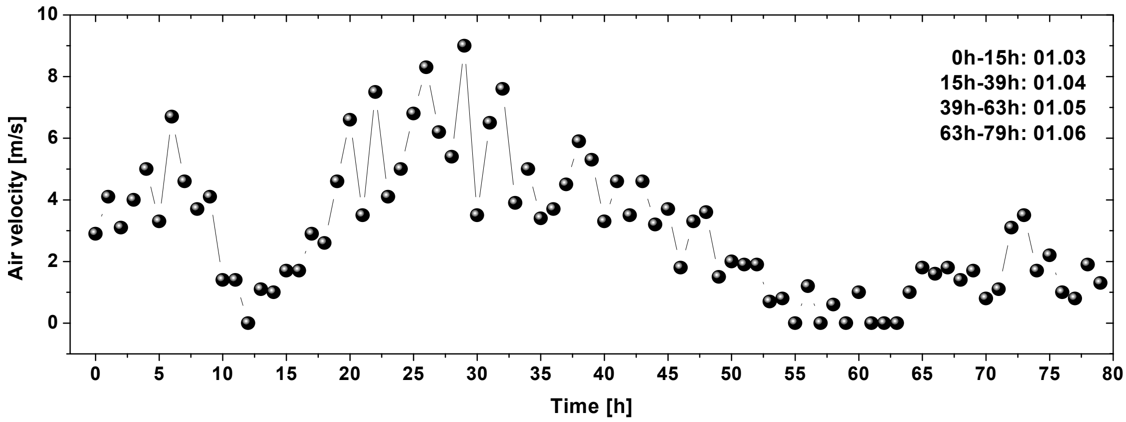
Figure 1: Schematic of the field test system



(a) Air temperature

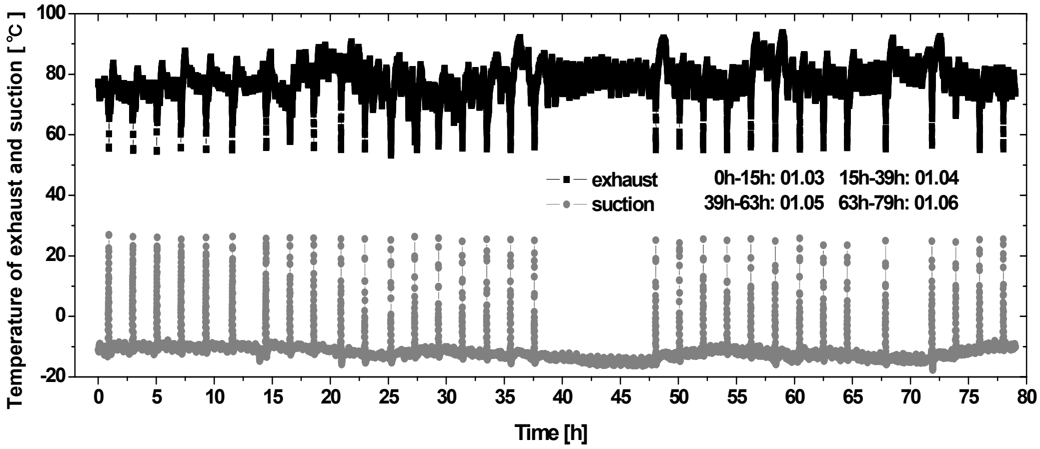


(b) Air relative humidity

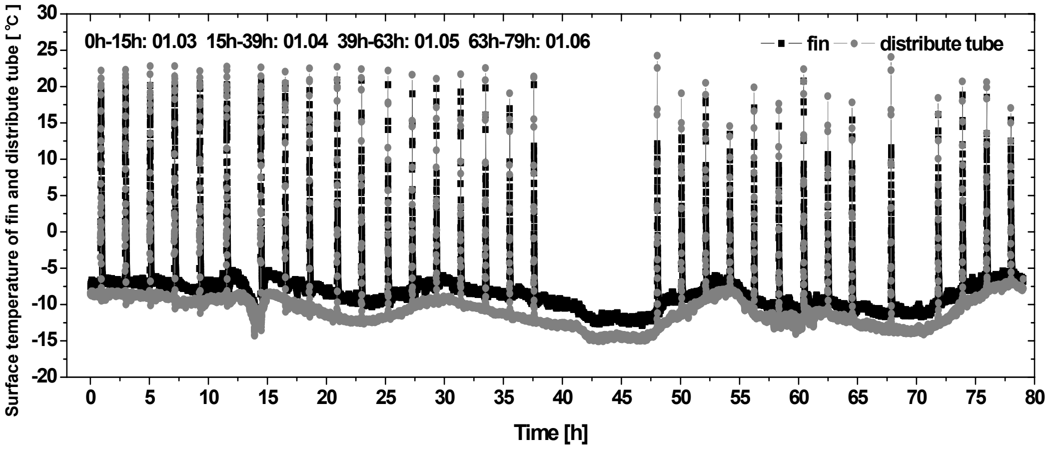


(c) Air velocity

Figure 2: Ambient environment parameters from January 3 to 6, 2010 in Beijing

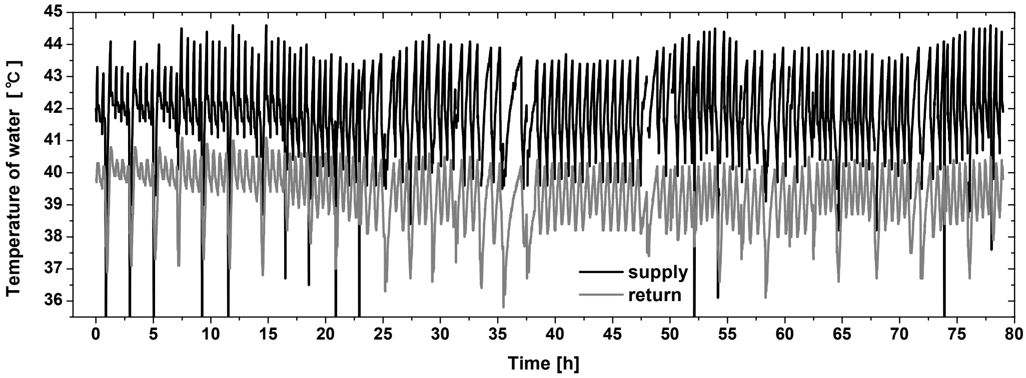


(a) Suction and discharge temperature of the compressor

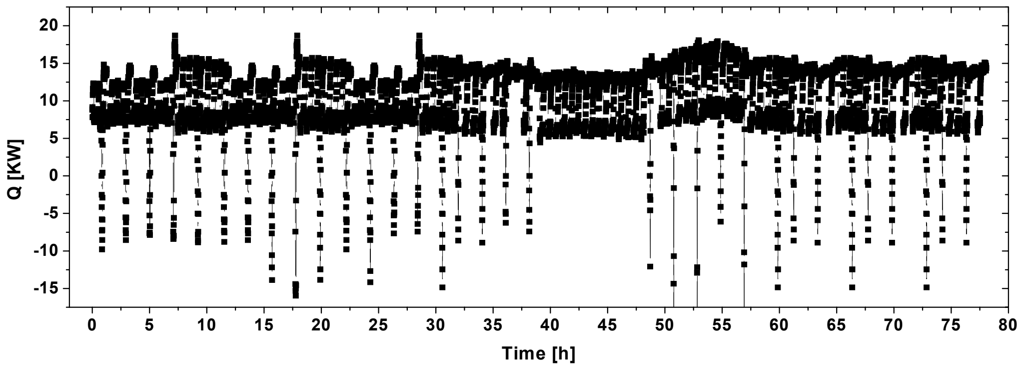


(b) Temperature of fin and distribute tube surface

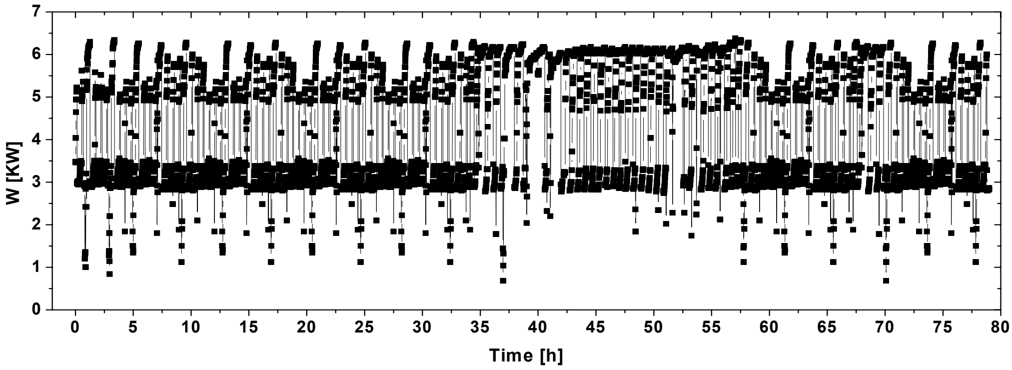
Figure 3: Operating characteristics of the ASHP



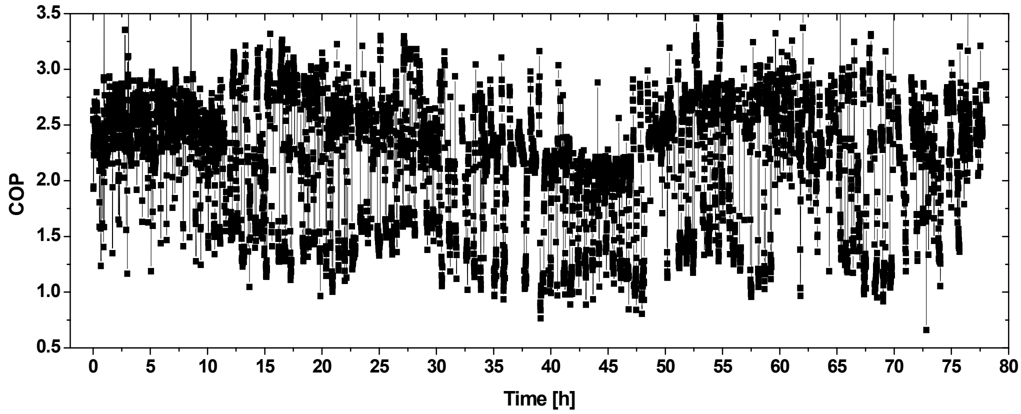
(a) Inlet and outlet water temperature



(b) Heating capacity of the unit



(c) Power input to the ASHP



(d) COP of the system

Figure 4: Heating performance of the ASHP

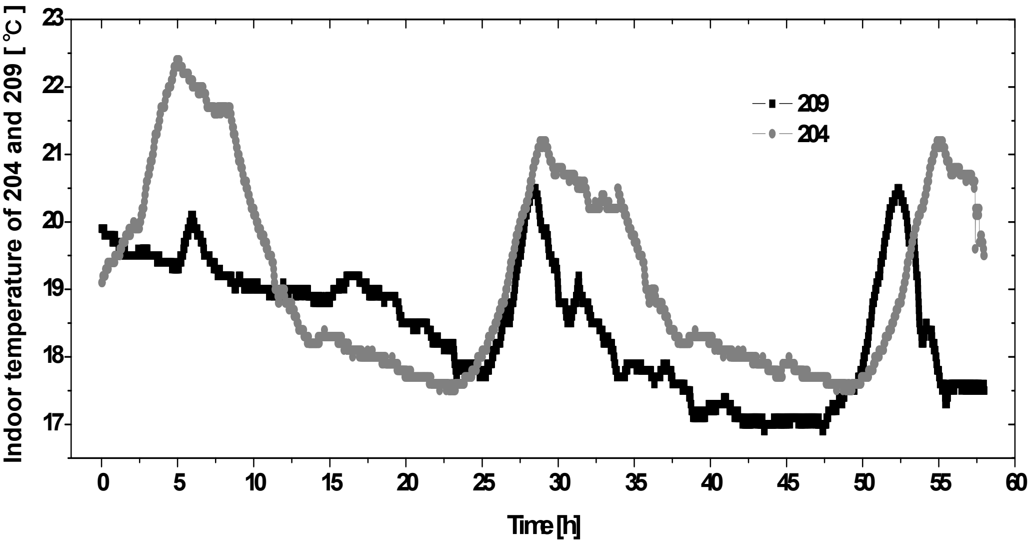


Figure 5: Indoor temperature of typical rooms of 204 and 209

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