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Performance Analysis on Developed EVI Air Source Heat Pump with Seasonal Heat Demand

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ABSTRACT

An optimised air source heat pumps (ASHP) using an economised vapour injection (EVI) compressor is integrated in a residential house for field trial and aimed to replace fossil-fuel boiler heating system. Due to the complex of operation strategy and ambient conditions, a good understanding of the EVI-ASHP performance under different operation conditions is essential. This study investigates and analyses the heating capacity and performance of the developed EVI ASHP in field trials for space heating and hot water supply for whole year with variable operation strategies and issues in details. The results of this study provide a solid basis for system operation improvement and scaling up applications of this kind of heat pump in the future.
Keywords: Domestic Air Source Heat Pump, COP, Field Trial, Heat Supply, Domestic Hot Water.

1. INTRODUCTION

In the UK energy use in domestic sector accounted for 29 % of the total energy consumption and 80 % of which is used for space heating and hot water (ECUK, 2017). In the European Union 14% of total energy consumption in the residential sector is for hot water production while in the UK 17% for the water heating. Retrofitting the existing domestic heating system using renewable energy sources, it could potentially reduce the energy consumption and carbon emission. Air source heat pumps (ASHP) utilise energy stored in the surrounding ambient at low temperatures and convert it to high temperature useful energy which is good practice for meeting buildings' heating demand in marine climate like UK because of high efficiency and lower cost (Hewitt et al., 2011; Chua et al., 2010). Studies have revealed that the efficiency of energy production equipment is influenced by the particular characteristics of heat consumption profile.
The ASHP using an economised vapour injection (EVI) compressor has the capability to overcome some of the difficulties of the high temperature lift operation (namely reduced heating capacity) that allows low liquid subcooling to be attained in the compression cycle while maintaining the high evaporator capacity to provide adequate heating during the cold ambient air period (Hewitt et al., 1991; Zhang et al., 2016). A research programme was developed to optimise the components and operating regime of an ASHP using the EVI compressor (Hewitt and Huang, 2008; Huang and Hewitt 2013). The results showed that the EVI-ASHP improved the heating capacity and COP by up to 23% and 5.4%, respectively under the standard test conditions in the lab.
An optimised Air source heat pumps (ASHP) using an economised vapour injection (EVI) compressor is integrated in a residential house for field trial and aimed to replace fossil-fuel boiler heating system. Due to the complex of operation strategy and ambient conditions, a good understanding of the EVI-ASHP performance under different operation conditions is essential. In is also, in order towards a more sustainable behaviour for energy and heat usage, studying the realistic energy consumption with the heat supply are necessary for optimizing the design and control operation of energy systems (Fuentes et al. 2018). Characterization of domestic heat demanding with supply performance would allow for designing innovative control strategies for heat supply systems based on consumption. This study investigates and analyses the heating capacity and performance of the developed EVI ASHP in field trials for space heating and hot water supply in a residential house in Belfast, Northern Ireland, UK for whole year with variable

operation strategies and issues in details. The results of this study provide a solid basis for system operation improvement and scaling up applications of this kind of heat pump in the future.

2. DESCRIPTION OF THE EVI ASHP HEATING SYSTEM FOR FIELD TRIAL

The operated EVI-ASHP system in the field trial has a nominal capacity of 12 kW heat (Copeland, 2016). The selected heating system retrofit house heated by the EVI ASHP is a typical UK semi-detached 3 bed-roomed family house with 105 m^2 in Carrickfergus, Northern Ireland. The household space heat distribution system and domestic hot water supply would be met by circulating pump transferring heat directly from the ASHP to the household, as shown schematically in Fig. 1. Circulating pump has a constant flow rate of 0.385 l/s. More detail description about the principle of EVI ASHP can be found in our previous work (Huang and Hewitt, 2013). The ASHP system has been operated through all year. Three particular periods have been chosen to study the performance of the ASHP aiming to have a close study on the heat supply to meet the space heating and hot water supply with variable demanding: 1) Feb/March for combined space heating and hot supply in the coldest ambient temperature period; 2) May for combined space heating and hot supply in the mild ambient period; and 3) Aug/ Sep for hot water supply only. The performance of the ASHP with energy consumption have been monitored and the data were recorded by a ΔT logger at 30 second intervals and stored for later analysis. Only the repeatable data for operating under similar ambient conditions were used for analysis.

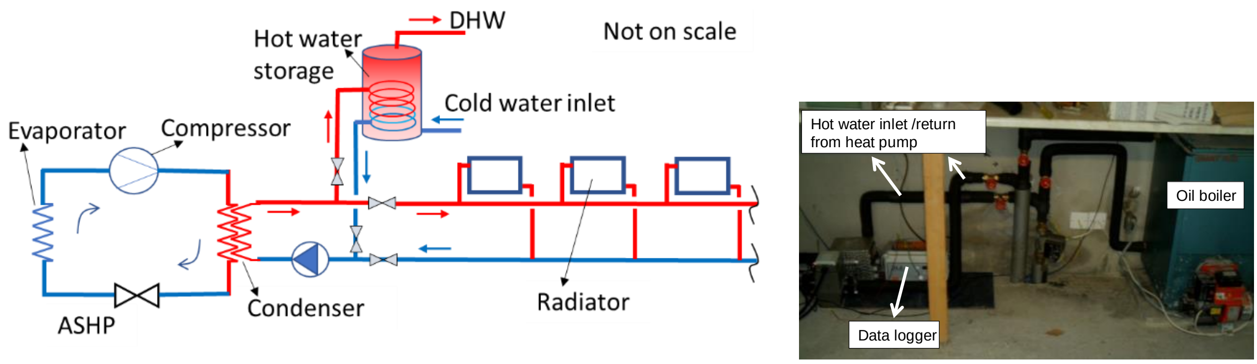
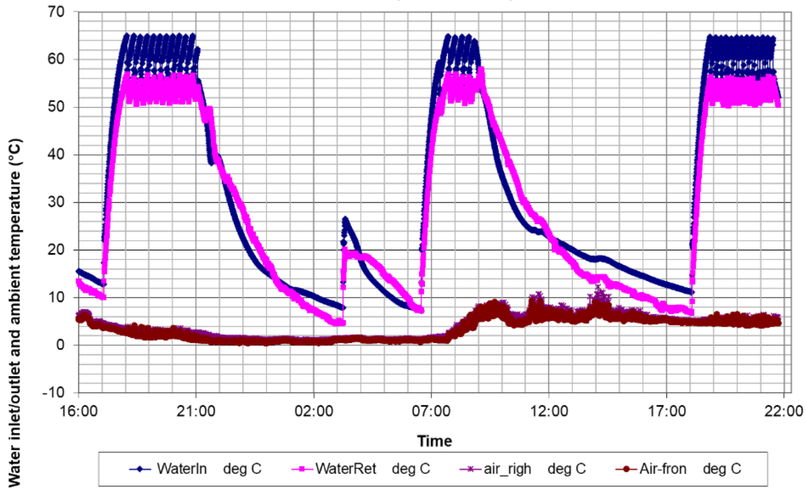


Figure 1: Schematic representation of ASHP integrated into a conventional domestic heating system

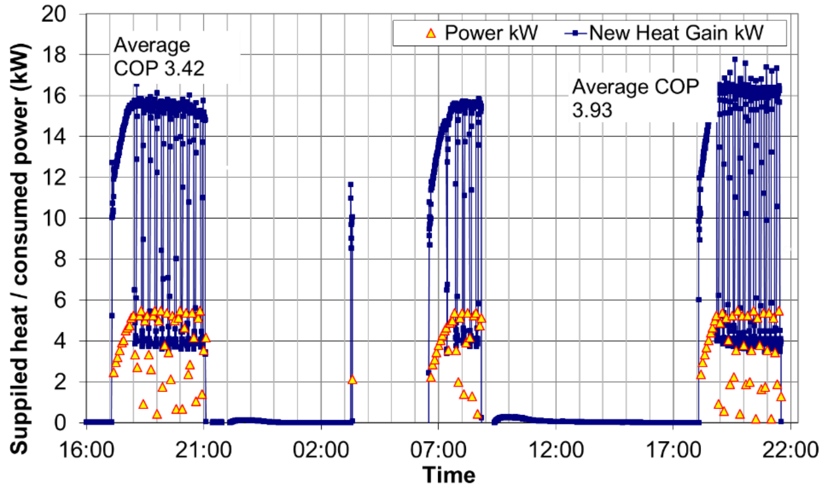
3. RESULTS AND DISCUSSIONs

3.1. EVI ASHP Performance in the Winter Operation

Fig. 2 presents the hot water inlet and return temperatures and heat supply to the household in continued 30 hours during March with an ambient temperature varies from around 0°C to 4°C. The ASHP is engaged during the early morning and late afternoon. It can be seen that the heat supply has been affected with the ambient temperature variation. The COPs are 3.42 and 3.93 respectively on the same period of the two days to reflect the influence of the ambient temperatures. More detailed temperature variations can be seen respectively in the two afternoon sessions (Fig. 3). When the ambient temperature is lower at the first day, the heating demand is higher but the supplied hot water temperature from ASHP takes longer time to reach the setting point 65/55 °C during the ramp up and on-off periods comparing to the higher ambient temperature in the second day. In order to keep the setting points with the system operation, the discharge temperature is higher and suction temperature is lower with the lower ambient temperature in the first day comparing the higher ambient temperature in the second day.



Hot water inlet / return with ambient temperature



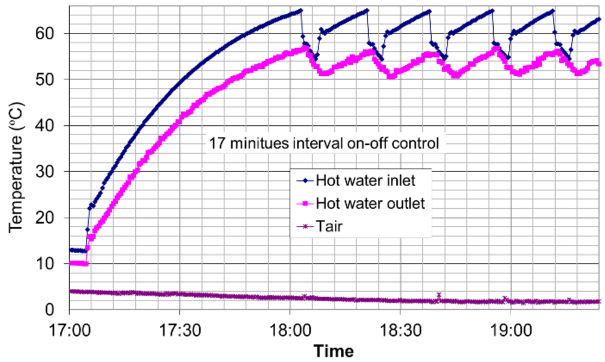
Heat supplied to the house by the ASHP

Figure 2: ASHP operated within 30 hours on March with hot water inlet/return temperatures and heat supply

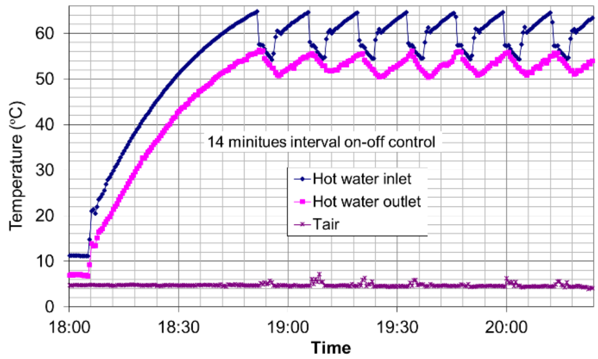
3.2. Heat Supply by ASHP for Hot Water only Demand with and without Hot Water Withdraw

During summer there is no space heating demand but only for domestic hot water. The heat supplied by the ASHP is extracted by the water in the existing hot water tank with 1000 l capacity then used for hot water discharge in the household (see Fig. 1). The heat pump operated at the on-off setting points of 65/45 °C.

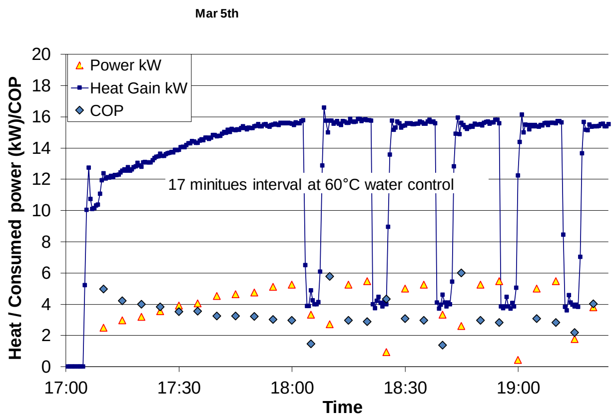
Comparisons of ASHP performance for the DHW supply only have been carried out with different hot water withdraw period by occupancies during charging the storage tank in Fig. 4. In order to limit the influence from other factors, the two situations are under the same ambient conditions. The blue lines with symbols represent hot water frequently withdrawn by the occupancies, by contrast, the yellow symbol lines represent a lack of water withdrawn. The ASHP performs similar on the discharge and condenser temperatures, but energies for longer time in the situation of the frequent hot water usage. The heat extracted by the hot water tank is increased when there is hot water withdraw from the hot water tank by the occupancies. It can be seen that the water withdrawn can cause an increase of heat extraction. The heat stored in the hot water tank is increased with higher COPs when there is hot water frequently withdrawn by the occupancies.



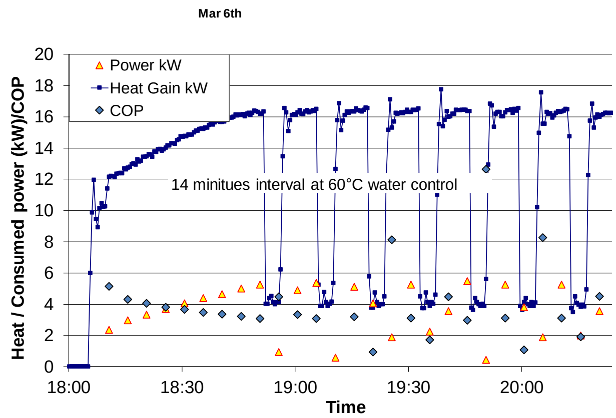
Hot water inlet/ return temp. on the First day



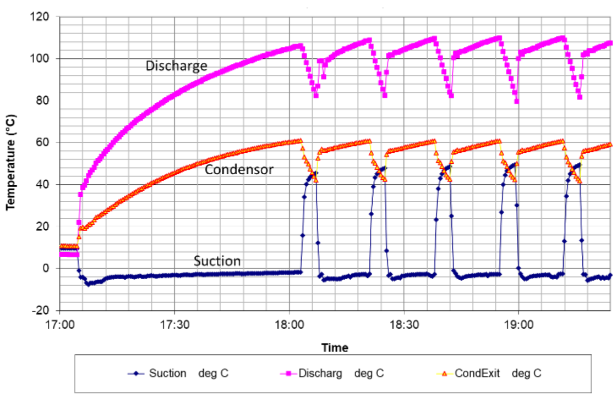
Hot water inlet/ return temp. on the Second day



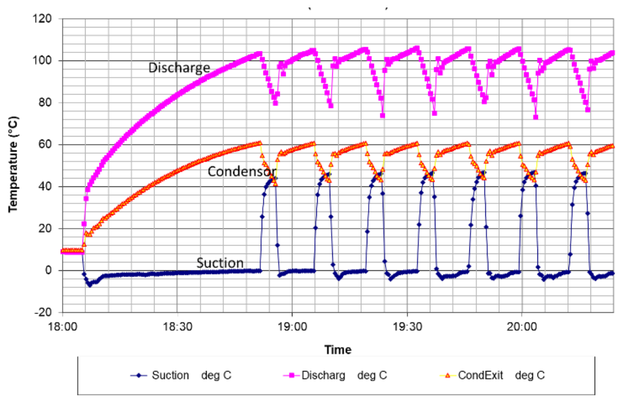
Heat /Power/COP on the First day



Heat /Power /COP supply on the Second day

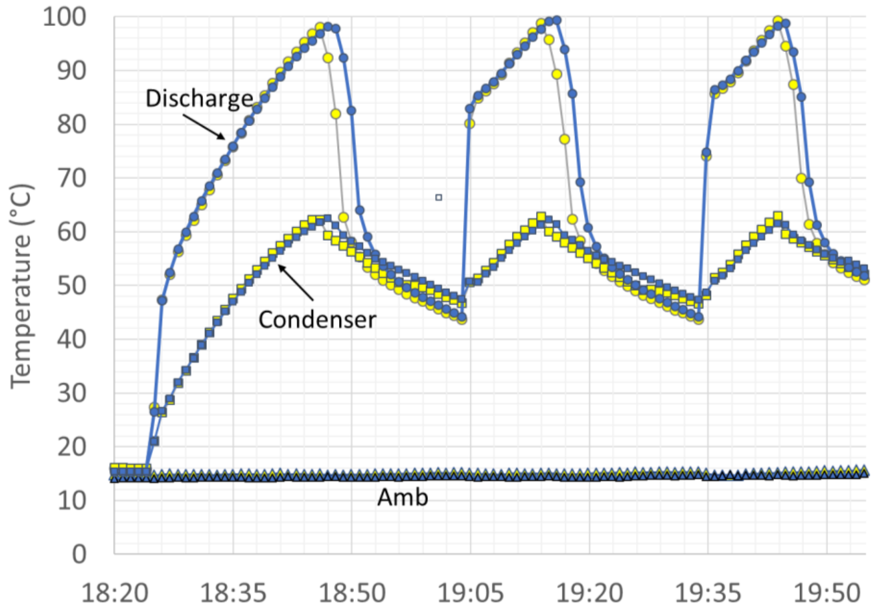


ASHP performance on the First day

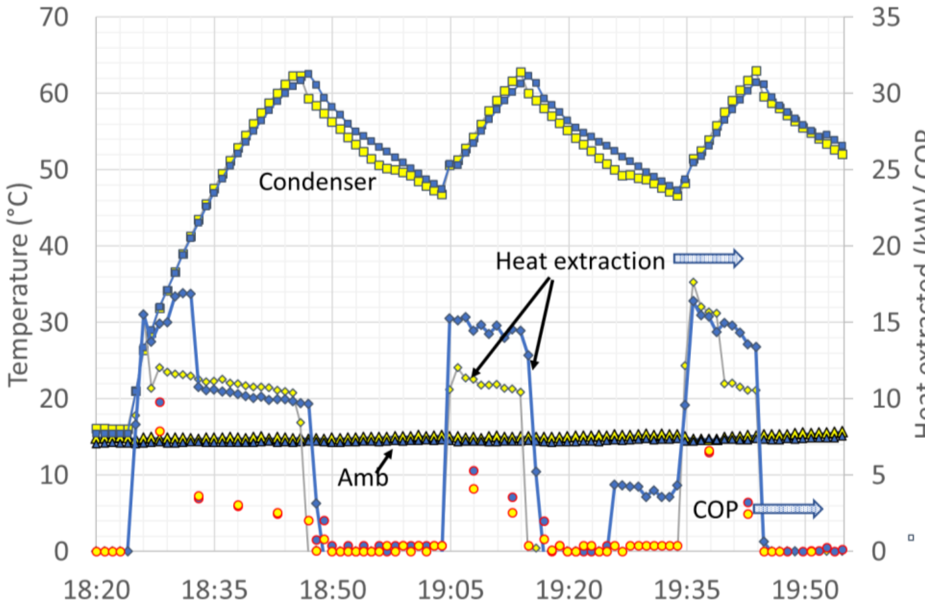


ASHP performance on the Second day

Figure 3: Detailed comparison of hot water inlet / return, heat supply to the household and ASHP performance along the cycle for the two days with respective time periods



Discharge/Condenser temperature variations with same ambient temperatures



Condenser temperature variation along with heat extraction and COP during ASHP operation

Figure 4: Comparison of ASHP performance under different water discharge period for DHW supply only during summer with same ambient temperatures

3.3. Heat Supply by ASHP for Space Heating and Domestic Hot Water during Winter Period

During winter period the heat supplied by the ASHP is used for the house space heating and hot water withdraw (Fig. 1). The effect of ambient temperature to the performance of ASHP has been studied on the period in February. Fig. 5 represents the performance of the ASHP at the ambient temperatures at around 3 and 6 ℃. The AHSP is operated at the setting point of 60/40 ℃. The periods of the ramp up and on-off cycle are shorter while the discharge temperature is lower with higher heat extraction for the household when the ambient temperature is at 6 ℃ than at 3 ℃. Meanwhile the temperature rising rates are higher for the discharge and condenser temperatures at 6 ℃ than at 3 ℃.

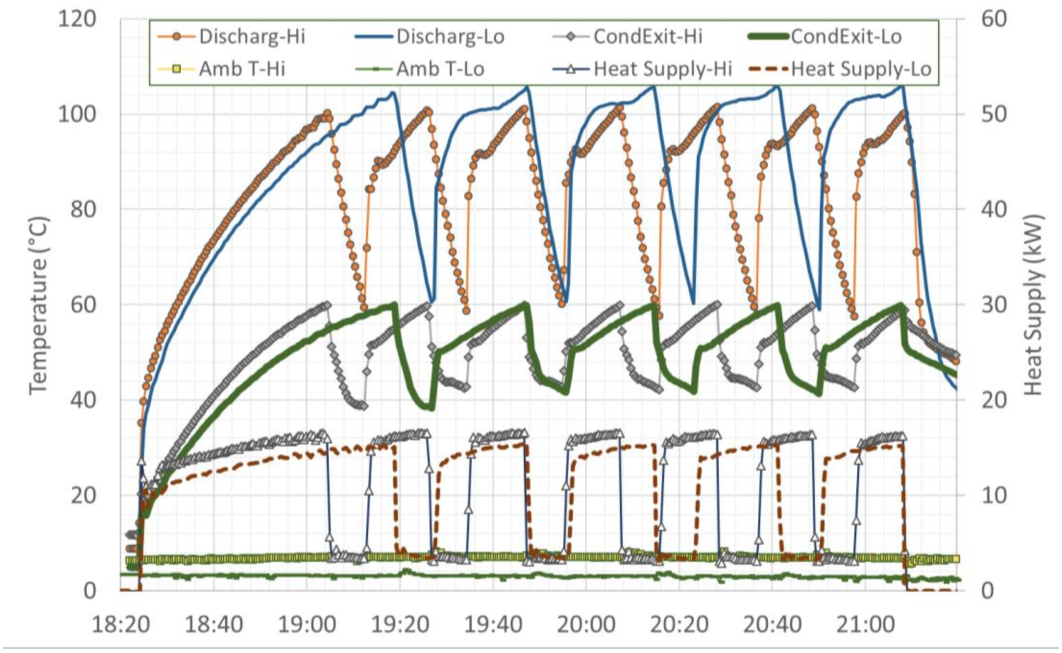


Figure 5: Ambient temperature influence onto the ASHP performance during winter operation between 3 and 6 ℃

3.4. Heat Supply by ASHP for Space Heating and Domestic Hot Water during Mild Period

Ramp up has some influence, but during on-off cycle, there is no significant difference.

The EVI ASHP performance during mild period of the year has been presented and compared with different ambient temperatures in Fig. 6. The hot water inlet temperature rising is quicker in the higher ambient temperature than in the lower ambient temperature. During off cycle period the heat is still extracted from the water. The heat extracted by the space heating system and hot water tank from the supplied hot water reaches to around 12 kW during the engaged period for both of the ambient temperatures at around 9C and 14 ℃. During the off cycle the circuit pump is still running and the heat extracted for space heating system can be seen at around 3kW. The heat extraction is a bit higher for the low ambient temperature situation than the high ambient temperature situation, but there is no significant difference with the ambient temperature at 9 ℃ and 14 ℃. However the discharge temperature in the vapor compression cycle is higher above 3 ℃ when the ambient temperature difference is 5 ℃.

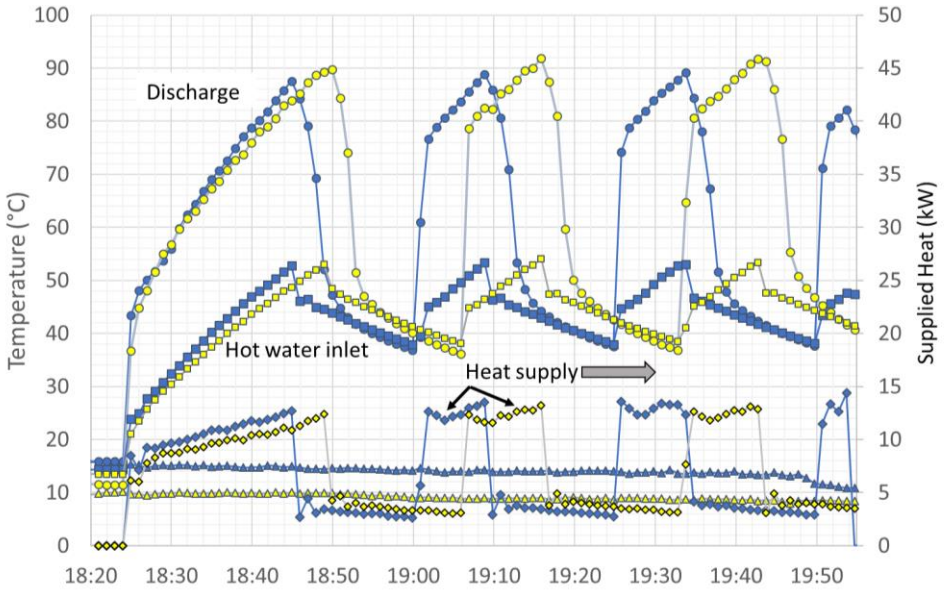


Figure 6: The performance of EVI ASHP for space heating and domestic hot water during mild period

3.5. Performance Comparison of the ASHP for Combined Space Heating and Domestic Hot Water and for Hot Water only

The hot water supplied by the heat pump is delivered to the house to meet the heat demand with constant water circuit pump. The performance of the ASHP with the supplied heat for hot water only and for the combined hot water and space heating with the heat pump operation setting points at 65/45 ℃ are analysed. The system under the ambient temperatures at 7°C and 3°C are selected to reflect the two cases respectively. The hot water inlet and outlet and heat supplied by the ASHP with ambient temperatures are presented in the Fig. 7. From the figure it can be seen that during the cold ambient temperature at around 3 ℃, the heat delivered by the ASHP to the house used for hot water and space heating is higher than the warm ambient temperature at around 7 ℃. The temperature ramp up rate of the water inlet is lower with the ambient temperature at 3 ℃ than at 7 ℃, i.e it takes longer time for the inlet water reaching the set point of 65 ℃ during the ramp up and on-off cycle. The inlet water temperature rising ratio keeps lower during the on-off cycle with the high heat demanding situation than for the low heat demanding which is only for hot water supply.

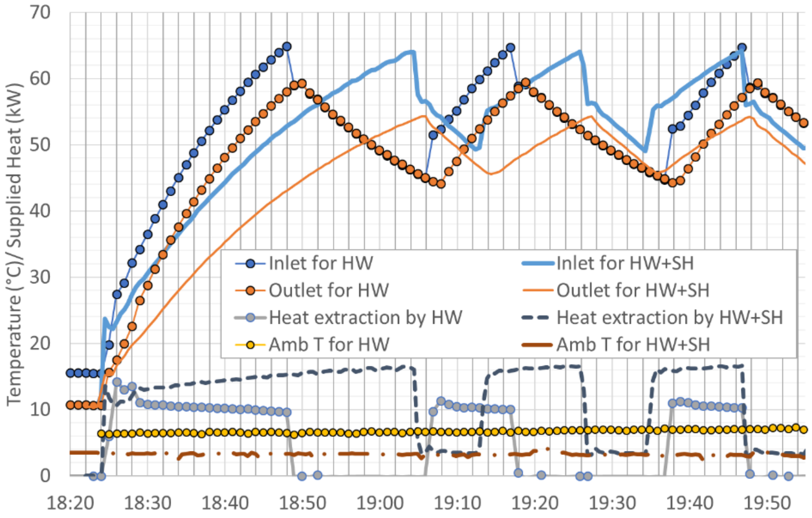


Figure 7: The comparisons of ASHP performance with the hot water supply only and combined hot water and space heating supply with 65/45 ℃ setting points

4. CONCLUSIONS

A laboratory evaluated EVI ASHP system has been integrated into a typical UK residential house for field trials. The issues and performance of the system on variable ambient conditions and operation conditions have been analysed and discussed in detail. The performance of the EVI ASHP with the heat demanding by the space heating and hot water have been analysed. It is expecting that these information can provide support information to optimise the system operation in the future. It has shown that such an EVI ASHP unit is capable of heating a typical N. Ireland family home and contributes the carbon emission reduction in the building sector, although more data from field trials needs to be collected to consolidate the optimised operation strategies.

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