

# Air Source Heat Pump Water Heating Systems - A Review

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**Abstract**—Increasing energy demands push us through two options either increase energy production or utilize available energy completely as well as decently. A heat pump water heater follows later way and utilizes waste heat and thus improves energy utilization efficiency. Heat pump technology is briefly explained with comprehensive technical reviews of experimental investigations and developed models of an air source heat pump. And finally conclusions based on literature reviews have been drawn.

**Index Terms**—Air source heat pump, water heater, energy demand, energy utilization efficiency

## I. INTRODUCTION

Water heating is the fourth largest energy user in the commercial buildings sector, after heating, air conditioning, and lighting. It is a major energy user in building types such as full service restaurants, motels and hotels, assisted living centers, and other facilities that do a great deal of laundry or dishwashing [1].

Most residential water heaters (WHs) are equipped with conventional heaters generating heat by consuming fossil fuels or electricity. Those WHs are usually simple, but not desirable in view of energy utilization efficiency. For instance, electric WHs are convenient for installation and operation, however, the overall efficiency in converting a potential energy of fossil fuels into electric energy, then into thermal energy is quite low. Compared to those WHs, heat pump (HP) water heating systems can supply much more heat just with the same amount of electric input used for conventional heaters [2].

HP systems are heat-generating devices that can be used to heat water which is to be used for domestic hot water or for space heating applications. For HP, a basic factor of great importance for its successful application is the availability of a cheap and dependable heat source for the evaporator preferably one at relatively high temperature. The coefficients of performance (COP) of HP systems depend on many factors, such as the temperature of low-energy source, the temperature of delivered useful heat, the working medium used, the characteristics of components of HP systems, etc. Among the above mentioned, the temperature of the evaporator is a key factor [3].

## 2. Heat pump water heating technology

The working principle of air source heat pump water heater (ASHPWH) is shown in Fig.1. Air-source heat pumps remove energy from the air by sucking in and blowing the air across a heat exchanger or evaporator. As the air passes across the evaporator it passes over a set of plates and fins which contain a refrigerant usually at a much lower temperature than the outside air. Some of the heat stored in the air transfers to the refrigerant and the air is then blown back out of the other side of the heat pump unit slightly colder than when it entered. The refrigerant will then be compressed to a much higher pressure and temperature. It then passes across another heat exchanger where it transfers its heat to another fluid, usually water which then feeds a hot water tank.

The system gets the energy from environment which is possibly 3-4 times that of the electric power which it will consume. Totally, it contributes about 4-5 times more energy than that required for water heating using electrical energy. So ASHPWH is preferred by the user due to its virtue such as high efficiency and energy saving [4].

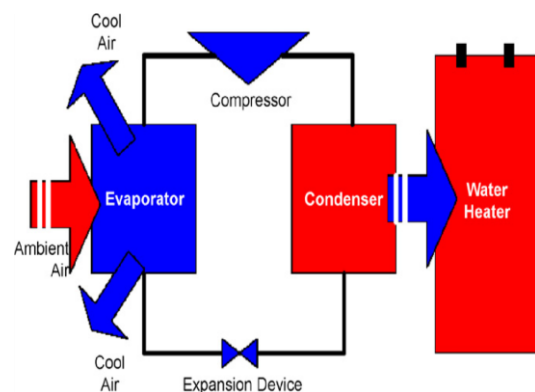


Fig. 1 Air source heat pump water heater

The performance of heat pumps is measured by its COP value which stand for coefficient of performance. This is a measurement or ratio between the amount of energy used and the useful energy produced by the system. COP is equal to the amount of heat energy produced and delivered by the heat pump over the energy required to drive the pumps and compressor.

## II. REVIEW OF AIR SOURCE HEAT PUMP WATER HEATERS (ASHPWHS)

Since the 1950s, several studies were carried out on modeling and experimental investigations of ASHPWHs, including structure, thermodynamics, working fluids, and operation controlling, numerical simulation and economic analysis.

### A. 2.1 Developed models of air source heat pump

Kim et al. [2] designed a dynamic model of a WH system driven by a HP to investigate transient thermal behavior of the system which was composed of a HP and a hot water circulation loop. From the simulation, the smaller size of the water reservoir was found to have larger transient performance degradation, and the larger size caused additional heat loss during the hot water storage period. Therefore, the reservoir size should be optimized in a design process to minimize both the heat loss and the performance degradation.

Fu et al. [7] presented a dynamic model of air-to-water dual-mode HP with screw compressor having four-step capacities. The dynamic responses of adding additional compressor capacity in step-wise manner were studied and compared to experimental measurements that revealed good agreement. MacArthur and Grald [8] put forward a model of vapor-compression heat pumps. The heat exchangers were modeled with detailed distributed formulations, while the expansion device was modeled as a simple fixed orifice. Techarungpaisan et al. [9] presented a steady state simulation model to predict the performance of a small split type air conditioner with integrated water heater and validated it experimentally.

Farouk Fardoun et al. [10] developed a quasi-steady state model using MATLAB and used to predict the system parameters of interest such as hot water temperature, condensing and evaporating pressures, heating capacity, electrical power input and coefficient of performance (COP) of an air source heat pump water heater (ASHPW). Based on the developed model, results showed that about 70% of energy consumption and financial cost is reduced comparing it to conventional electrical water heaters as well as 70% of environmental pollution is reduced based on calculating the amount of CO<sub>2</sub> produced.

Hasegawa et al. [11] proposed a two-stage compression and cascade heating heat pump system for hot water supply. Using R12, it could heat water from 10 °C directly to 60 °C. The inlet and outlet water temperatures of evaporator are 12 °C and 7 °C, and the system COP is 3.73. Fard et al. [12] developed a numerical model for detailed simulation of the air-source residential heat pump. The model is validated by using the experimental

and numerical data available in the literature. A group of pure refrigerants was selected as potential mixture components and their corresponding refrigerant mixtures are compared.

### 2.2 Experimental Studies conducted on ASHP

Zhang et al. [4] studied the system optimization of ASHPWH. The ASHPWH system consisted of a heat pump and a water tank with the condenser coil installed inside the tank to release heat to the water side by natural convection. The capillary tube length, the filling quantity of refrigerant, the condenser coil tube length and system component matching were discussed accordingly. From the testing results, it could be seen that the system performance COP could be improved by optimizing the stated parameters.

Harris et al. [6] and Sloane et al. [19] have developed two HPWH models. One model was designed as a complete unit, consisting of a HP assembly mounted at top a 0.31-m<sup>3</sup> water tank. The second model was a retrofit unit, designed to be used with an existing WH installation. The results obtained are summarized in table 1.

Ma Guoyuan et al. [13] presented an improved ASHP for relatively cold regions. The dynamic performances of the prototype were tested in a laboratory test that could control all the parameters and the outcomes show that this new improved ASHP can work very well under ambient temperatures and great energy can be saved through the improved system with increased efficiency.

M. Mete Öztürk et al. [14] have done an experimental analysis of air source heat pump water heater. They concluded that the performance of entire system is directly proportional with environment conditions. While the highest ambient condition which is obtained with 30 °C and 80% humidity percentages is providing highest performance value, the poor weather which is obtained with 5 °C and 80% humidity percentages causes the performance of the system to diminish.

Hiller [15] led a group studying dual-tank water heating system from 1991. Continuous tests suggest that the efficiencies of 38 kinds of dual-tank water heating systems are higher than single-tank system HPWH with the same volume. Huang and Lin [16] also studied the dual-tank HPWH. The water tank volume was 100 L. Results showed that heating water from 42 °C to 52 °C need 10–20 min, and the all-year COP reached 2.0–3.0. Compared with electrical water, the energy saving fraction was 50–70%, and the hot water discharge efficiency was 0.912.

Ji et al. [5, 17] combined HPWH and conventional air conditioning, and realized a multi-functional domestic

heat pump (MDHP). This equipment could implement multi functions in moderate climate areas, and operate long time with high efficiency. When refrigeration and heating run simultaneously, the average of COP and EER could reach 3.5.

Guo et al. [18] conducted an experimental and simulation research in addition to operation optimization of ASHPWH. Results indicated that; 1) the average COP ranged from 2.82 to 5.51 under typical conditions, 2) the recommended outside area ratio of condenser coil to evaporator is 0.14 - 0.31 when the evaporator outside area is between 6 and 6.5 m<sup>2</sup>. The optimal setting water temperature should be adjusted according to the variation of seasonal ambient temperature. It was suggested that, based on this set-up, setting water temperature should be set higher than 46 °C in summer and 50 °C in other seasons.

Harata et al. [20] used thermoelectric technology. In this thermoelectric technology, they used a HP utilizing the latent heat of the atmosphere. The other characteristic was to collect the heat occurring from the power supply equipment of the thermoelectric technology device in effect a combined heat and power (CHP) device. In this thermoelectric technology, an improvement of the energy efficiency could be expected. Initially they examined for a basis a bench scale model. As for examination condition, the capacity of the tank was 3.7 Litres, the temperature of hot water was 85 °C, the environment temperature was 23 °C and the efficiency of the power supply was 80%.

Ito and Miura [21] investigated the mechanism of HPs for hot water supply using dual heat sources of the ambient air and water and the operating conditions of selecting either one or both heat sources. Then, the performance of a HP, which used water and the ambient air as the heat sources to heat water, was experimentally studied. When the

temperature of the water heat source was decreased, the heat from the water as well as the heat from the air was used for the HP efficiently until its temperature became approximately that of the evaporation temperature of the HP using the ambient air alone as the heat source. When the temperature of the water dropped further, only the heat from the air was absorbed by the evaporators like an ordinary HP, which used only the evaporator of the air heat source at the same ambient air temperature.

Morrison et al. [22] presented a procedure for annual load cycle rating of ASHPWHs where two condenser designs were studied, a separate heat exchanger design with water pumped to it from the storage tank and a wrap-around condenser coil on the tank. The results showed that the second design had a higher annual COP (coefficient of performance). Furthermore, the study indicated that the effect of ambient temperature on the system performance is more significant than the effect of initial water temperature during the heating process.

Mei et al. [23] studied, experimentally, different HPWHs with natural convection immersed condensers. The described set of experiments demonstrated the viability of this type of HPWHs that is aimed to eliminate the application of electric resistance heating completely.

Ji et al. [24] presented a distributed model of an ASHP (air-source heat pump) system and its experimental setup using an immersed water condenser. Dynamic performance of the ASHP was then evaluated by both simulation and experiment. The results indicated that the system COP (coefficient of performance) decreased as the condenser temperature increased, ranging from 4.41 to 2.32.

Table 1. Studies conducted on air source heat pump

Sr. No.	Investigator	Year	Type of study	Results
1.	Sloane et al. [19]	1979	Modeling (Simulation)	COP=2.0 to 2.8 (ambient air=18-35 °C, 27 and 4.4 °C source water)
2	Harata et al. [20]	1998	Experimental	Thermoelectric technology storage tank water heaters about a 13% reduction in energy consumption were achieved
3	Ito and Miura [21]	2000	Theoretical (Simulation)	COP = f (Te) Te: evaporation temp. Run 1 at an air temperature of 20 °C; COP = 4.0. Run 2 the temperature of the water and the air 10 °C; COP = 3.68.
4	Ji et al. [17]	2003	Experimental	Mode: water heating only; COP <sub>w-avg</sub> = 3.42, 3.25, 2.52, 2.00 (for T <sub>0</sub> = 31, 25, 15, 4.5 °C).
5	Morrison et al. [22]	2004	Theoretical (Simulation) &	In Sydney Australia 40 MJ/day peak winter load:

			Experimental	COP <sub>integral-condenser</sub> = 2.3 and annual energy saving = 56%; COP <sub>external-condenser</sub> = 1.8 and annual energy saving = 44%
6	Zhang et al. [4]	2007	Experimental	COP <sub>winter</sub> = 2.61 for T <sub>o</sub> = 0 °C COP <sub>summer</sub> = 5.66 for T <sub>o</sub> = 35 °C COP <sub>spring/autumn</sub> = 4.817 for T <sub>o</sub> = 25 °C
7	Guo et al. [18]	2011	Modeling (Simulation) & Experimental	COP <sub>avg,summer</sub> = 5.51 (T <sub>a</sub> = 35 °C); COP <sub>avg,winter</sub> = 2.82 (T <sub>a</sub> = 5 °C)

Zali et al. [25] studied thermodynamic properties of refrigerants, condenser and evaporator Secondary fluid using artificial neural network. They used Wilson-Plot method to compare performance of refrigeration cycle with R22 and R407C refrigerants. The result shows that decreasing evaporator temperature, behaviour of R407C approach to R22. Therefore R407C can be a suitable alternative for replacing R22 in all the refrigeration systems with low evaporation temperature.

### III. SUMMARY:

The main points of summary, which may be drawn from the literature review, are listed below:

1. HPWHs, unlike conventional WHs that use either gas burners (and sometimes other fuels) or electric resistance heating coils to heat the water, are devices, which operate on an electrically driven vapor-compression cycle and pump energy from the air in its surroundings to water in a storage tank, thus raising the temperature of the water. Its primary advantage is a significant increase in point of use operating efficiency over alternative electric water-heating systems.
2. With water heating the second largest use of home energy in most locations, there has been renewed interest in the development and use of energy-conserving domestic WHs.
3. The performance of heat pump depends on various parameters such as evaporator design, type of refrigerant, fin spacing, operating conditions etc.
4. The literature review points out that both temperature and relative humidity of the outdoor air affects the frost formation process; however the relative humidity plays a leading role in determining the amount of frost that can be accumulated.
5. However, all theory and practice have shown that the ASHP has a shortcoming that prevents its application such as, the heating capacity of the ASHP decreases sharply as the outdoor temperature falls, thus in extremely

cold climates-where the most heat is needed - heat pumps are least able to supply enough heat.

6. ASHP does not work reliably if the ambient temperature is below -5 °C because the COP of the ASHP becomes smaller under this circumstance than in the warmer outside temperature, and the discharge temperature of the refrigerant will continue to increase, leading to the destruction of the compressor unless the ASHP is stopped.

Energy analysis method was used in many studies, while the number of studies conducted on exergy analysis was very low.

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