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REVIEW ON AIR SOURCE HEAT PUMP FOR WATER HEATING

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Abstract: During the last decade, a number of studies have been conducted by various investigators in the design, modelling and testing of air source heat pump water heating systems (ASHPWHSs). This paper reviews the studies conducted on the ASHPWH systems around the world. The paper, is broadly divided into three main sections, begins with a review of effect of inlet air temperature on performance of heat pumps. This is followed by a review of the major air source heat pump systems with the effect of design on performance of system. Lastly, the paper present heat pump system using new refrigerants.

Keywords: Air source Heat pump, Water heating, Heat pump

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INTRODUCTION

Over the years so far, energy consumption has been increasing day by day and so will it continue to increase hereafter. Then in such a scenario of increasing energy demand, the two options left are either to look for alternative source of energy may it be unconventional, or to use the energy judiciously, by using energy conservation techniques and using energy efficient devices. Hence it becomes essential to think in terms of energy efficiency particularly in refrigeration, air conditioning and heating applications [1].

HP systems are heat-generating devices that can be used to heat water to be used in either domestic hot water or space heating applications. For HP, a basic factor of great importance for its successful application is the availability of a cheap, dependable heat source for the evaporator-preferably one at relatively high temperature. The coefficients of performance 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 [2, 3].

Although a simple heat pump water heating system consists of a compressor, two heat exchangers (condenser and evaporator) expansion valve and tank, many auxiliary components may be used on heat pumps such as valves, thermostats, some measurement tools, pumps, fans, or extra heaters. The main structure and the type of new heat pumps have changed very much due to the improving technology and changing thermal demands all over the world. The components used in heat pump water heater are shown in Fig.1.1 [4, 5].

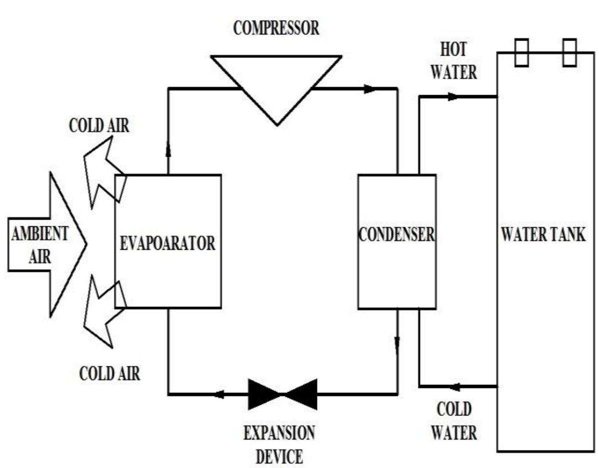

Fig.1 Schematic of a simplified heat pump water heater system [5]

Studies conducted on air source heat pump for water heating

Effect of ambient air on performance of system

Madonna et al. [6] developed a model that simulates the hourly efficiency of air-to-water heat pumps. The model was used to predict the behaviour of air source heat pumps installed in a set of residential buildings located different Italian cities, in both heating and cooling mode. The obtained results showed that the climate plays the leading role on annual performance. The unit has recourse to excessive cycling in the less severe season, causing a seasonal efficiency reduction up 25%. Moreover, the benefits coming from a weather compensation strategy are investigated, showing an annual performance improvement up to 19%.The variation of heating capacity with change in outdoor air temperature is shown in Fig.1.

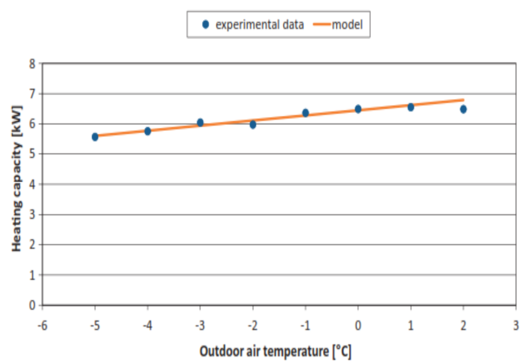

Fig.1 Heating capacity as a function of outdoor air temperature [6].

An experimental set-up and simulation model were constructed by Guo et al. [7]. The recommended outside area ratio of condenser coil to evaporator is 0.14-0.31 when the evaporator outside area is between 6.0 and 6.5 m2 for this set-up. Experimental results indicated that the average COP ranged from 2.82 to 5.51 under typical conditions. 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 ^{o}C in summer and 50 ^{o}C in other seasons.

Palmiter et al. [8] studied the effect of improper airflow and refrigerant charge on the seasonal performance of a typical 10.6 kW, R-410A residential heat pump with a thermostatic expansion valve. Heating and cooling tests were performed on three refrigerant charges of 75%, 100%, and 125% and two airflows of 75% and 100% of rated airflow at six climate zones. Results showed that, in each climate zone, increases in refrigerant charge at the rated airflow could improve the unit's heating seasonal COP by as much as 5%.

EFFECT OF DESIGN ON PERFORMANCE OF SYSTEM

Castro et al. [9] carried out study on an air-to-water reversible heat pump unit using two different fin-and-tube heat exchanger coil designs and propane (R290) as the working fluid. In the coil-2 design, the length of refrigerant circuit is increased about 17% and the refrigerant cross-sectional area decreases approximately 26% with respect to coil-1 design. From the calculation it was found that in both modes of operation coil-2 design gives higher heat transfer coefficient and pressure drops for the refrigerant side. The experimental result indicates that the performance (COP) of the heat pump find an optimal value at a superheat of 6–8 K depending on the heat exchanger design.

Ji et al. [10] introduced a novel air-conditioning product that could achieve the multi-functions with improved energy performance. The results showed that by incorporating a water heater in the outdoor unit of a split-type air-conditioner, so that space cooling and water heating could take place simultaneously, the energy performance could be raised considerably. Two prototypes of slightly different design were fabricated for performance testing. Averaged COP, for space cooling and water heating, water heating only and space heating only, was obtained 4.02, 2.91, 2.00 (ambient temperature at 4.5 ^{o}C) and 2.72 respectively.

Gang et al. [11] established a comparative experiment prototype of an air-source heat pump water heater (ASHPWH) system for the comparative study between instantaneous and cyclic heating modes. It was found that the average COP of the instantaneous heating mode was 25.6, 19.0, 20.0, 21.1, 22.9, and 24.0% higher than that of the cyclic heating mode in the obtained final set temperatures of 30, 35, 40, 45, 50 and 550C of heated water, respectively. The results show that the instantaneous heating mode not only has a higher COP, but also a higher heating capacity, saving power consumption and decreasing heating time.

Rankin et al. [12] presented a study about demand side management for commercial building using an inline HPWH methodology. Rousseau and Greyvenstein [13] also performed enhancing the impact of HPWH in the South African commercial sector.

Kim et al. [14] designed a dynamic model of a WH system driven by a HP to investigate transient thermal behaviour 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.

ALTERNATIVE REFRIGERANTS

Zhiqiang et al. [15] studied the dynamic performance characteristics of the air source heat pump (ASHP) with refrigerants R22 and R407C during frosting and defrosting. The results show that both refrigerant systems have similar performance characteristics, except that the performance of the R407C system deteriorated faster than that of the R22 system under frosting, and the performance of the R407C system attains its steady state faster than that of the R22 system after defrosting. R407C refrigerant can be used in either existing systems or in new systems that were originally designed for R22.

Laipradit et al. [16] investigated theoretical performance analysis of HPWHs using carbon dioxide as refrigerant. For rated capacities of a 4 kW compressor with a 10 kW gas cooler and a 6 kW evaporator, the coefficient of performance is found to be between 2.0 and 3.0. The mass flow rate ratio of water and CO2 between 1.2 and 2.2 is the most suitable value for generating hot water temperature above 60 0C at 15–25 0C ambient air temperature

Fard et al. [17] developed a numerical model for detailed simulation of the air-source residential heat pump. A group of pure refrigerants was selected as potential mixture components and their corresponding refrigerant mixtures are compared. It is seen that the mixture of R-32/CO2 (80/20) has the best performance among the mixtures studied. This mixture has both advantages of the CO2 and R-32; while, the flammability effect of R-32 and high pressure effect of CO2 are minimized. This mixture can increase the heating capacity of a conventional heat pump that runs on R-410A by 30% and it is shown that if the heat exchangers sizes are increased, the heating capacity can be increased by 45% and the COP by 8.5%. Moreover, the GWP of this mixture is 25% of R-410A.

Table1. Summary of studies conducted on air source heat pump for water heating

Year	Investigators	Type of study		Application			Refrigerant	Remark
		Theoretical	Experimental	Heating	A/C	Others		
1998	Harata et al. [18]		✓	✓			R22	By using Thermoelectric technology storage tank water heaters about 13% reduction in energy consumption were achieved.
1998	Neksa et al. [19]		✓	✓			CO_2	COP= 4.3 (for heating water from 9 to 60°C at T_e=0°C); SPF= 4; PEC reduction compared to EWH or GWH: 75%; Temperature up to

							90^0C can be produced.
2000	Rousseau and Greyvenstein [13]	✓		✓		R22	The impact of HPWH in the South African commercial sector
2000	Ito and Miura [20]	✓	✓	✓		R22	Evaporation temperature. Run 1 at an air temperature of 20 ^{o}C; COP = 4.0. Run 2 the temperature of the water and the air 10 ^{o}C; COP = 3.68
2003	Ji et al. [10]		✓	✓	✓	R22	Mode 1: space-cooling and water heating COP = 4.02, COP= 2.91. Mode 2: water heating only; COP= 3.42, 3.25, 2.52, 2.00 (for T w-avg = 31, 25, 15, 4.5 ^{o}C). Mode 3: space heating only COP = 2.72
2003	Fu et al. [21]	✓	✓	✓		R22	Heating mode: T_w = 45^{o}C; Cooling mode: T_w = 7^{o}C; Simulation model is validated
2004	Kim et al. [14]	✓	✓	✓		R22	The reservoir size should be optimized in a design process to minimize both the heat loss and the performance degradation.
2004	Morrison et al. [22]	✓	✓	✓		R22	In Sydney Australia 40 Mj/day peak winter load:= 2.3 and annual energy saving = 56%; COPintegral-condenser= 1.8 and annual energy saving = 44%
2004	Rankin et al. [12]	✓		✓		R22	Demand side management for commercial building using an inline HPWH methodology
2004	Kim et al. [23]		✓	✓		R22	In summer, COP cw-avg = 2.77 (T_a= 35^{o}C); In winter, COP wh-avg = 2.5 (T_a =7^{o}C)
2005	Castro et al. [09]	✓		✓		R290	Two coils were used, in coil-2 design, the length of refrigerant circuit is increased about 17% and the refrigerant cross-sectional area decreases approximately 26% with respect to coil-1 design. From the calculation it was found that in both modes of operation coil-2 design gives higher heat transfer coefficient and pressure drops for the refrigerant side.
2005	Ji et al. [24]		✓	✓	✓	R22	Mode 1: water heating only, COP $_{wh}$ = 2- 2.5 (Ta =2.8^{o}C)

						Mode 2: space-cooling & water-heating; COP_{cw} = 2.8-5 (Ta =35°C)
2007	Zhang et al. [25]		✓	✓	R22	750 W-HP with 150 L and 1125 W-HP with 200 L are more suitable for residential uses; For system (150 L, 1125 W): COP_{winter} = 2.61 (Ta = 0°C); COP_{summer} = 5.66 (Ta=35° C); $COP_{spring/autumn}$ = 4.817 (Ta = 25°C)
2007	Techarungpai-san et al. [26]	✓	✓	✓	R22	The steady state simulation model is quite accurate in predicting important system parameters
2008	Laipradit et al. [16]	✓		✓	CO_2	using CO_2 as refrigerant, 4 KW compressor and 6KW evaporator the COP lies between 2 and 3
2008	Zhiqiang et al. [15]	✓		✓	R22 and R407C	The results show that both refrigerant systems have similar performance characteristics, except that the performance of the R407C system deteriorated faster than that of the R22 system under frosting, and the performance of the R407C system attains its steady state faster than that of the R22 system after defrosting. R407C refrigerant can be used in either existing systems or in new systems that were originally designed for R22.
2009	Huang et al. [27]	✓	✓	✓	R22	Fast response heat pump water heater does not need auxiliary electric heater; For 6 < Ta < 38°C: Temperature response speed of the supply tank,before SMAV opened, changes from 0.714 to 1.234°C/min and that of the holding tank after SMAV opened, changes from 0.483 to 1.1° C/min. Energy consumption lies in the range 0.008-0.016 kWh/l.
2010	Zhifang et al. [28]	✓	✓	✓	R22 and R134a	variable speed hermetic scroll compressor was validated experimentally using R22 and R134a and a control strategy for adjusting the capacity of scroll compressors was suggested
2010	Liang et al.	✓		✓	R22	the latent fin efficiency is generally not equal to the sensible or the overall fin

	[29]						efficiencies.
2011	Guo et al. [07]	✓	✓	✓		R22	COP ranged from 2.82 to 5.51, condenser coil to evaporator area ratio is 0.14-0.31 and evaporator outside area is between 6.0 and 6.5 m2
2011	Zalil et al. [30]	✓		✓		R22 and R407C	R407C can be a suitable alternative for replacing R22 in all the refrigeration systems with low evaporation temperature.
2011	Byrne et al. [31]	✓	✓	✓	✓	R407C	air-source heat pump for simultaneous heating and cooling,using R407C,results obtained are compared with those obtained by software
2011	Gang et al. [11]	✓	✓	✓		R22	the coefficient of performance (COP) of the ASHPWH system, it was found that the average COP of the instantaneous heating mode was 25.6, 19.0, 20.0, 21.1, 22.9, and 24.0% higher than that of the cyclic heating mode in the obtained final set temperatures of 30, 35, 40, 45, 50 and 55^0C of heated water, respectively. The results show that the instantaneous heating mode not only has a higher COP, but also a higher heating capacity, saving power consumption and decreasing heating time.
2011	Palmiter et al. [08]		✓	✓	✓	R410A	Results showed that, in each climate zone, increases in refrigerant charge at the rated airflow could improve the unit's heating seasonal COP by as much as 5%. However, combined decreases in airflow and refrigerant charge could penalize the unit's heating seasonal COP by as much as 10%.
2011	Jiang et al. [32]	✓	✓	✓	✓	R22	proved that both stability and efficiency of the ASHPWH can be improved significantly by using the EEV.
2012	Huchtemann and Müller [33]		✓	✓	✓	R22	Analyzed data from air-to-water heat pumps showed that the majority of investigated systems used more primary energy and produced higher CO emissions, when compared with a gas-condenser boiler with a 0.96-annual fuel utilization efficiency. Mean SPF_{ASHPs} = 2.3; Max SPF_{ASHPs} = 3
2012	Wu et al. [34]	✓	✓	✓		R22	Single stage: COP = 1.5-3.05 Cascade mode: COP = 1.74-2.55

2012	Li et al. [35]		✓	✓		CO_2	The results show that the coefficient of performance (COP) is within the range 3.3-3.8, which is 5-30% higher than that of the 1ASHPWH system using the hot-gas defrosting method.
2013	Cakir et al. [36]	✓	✓	✓		R22	R22 as working fluid, $COP_{water-air}$ =3.94, $COP_{water-water}$ =3.73, $COP_{air-air}$ =3.54, $COP_{air-water}$ =3.40 exergy efficiency, water to air = 30.23%, air to air = 30.22%, air to water = 24.77% and water to water =24.01%
2013	Madonna et al. [06]	✓	✓	✓	✓	R410A	The obtained results show that the climate plays the leading role on annual performance. The unit has recourse to excessive cycling in the less severe season, causing a seasonal efficiency reduction up 25%. Moreover, the benefits coming from a weather compensation strategy are investigated, showing an annual performance improvement up to 19%.
2013	Liu et al. [37]	✓	✓	✓		R22	Gray water as heat source and sink, The COP of the system in the space heating plus hot water supply mode increases in all heat source combinations,
2014	Fard et al. [17]	✓	✓	✓		mixture of R-32/CO_2	It is seen that the mixture of R-32/CO_2 (80/20) has the best performance among the mixtures studied. This mixture has both advantages of the CO_2 and R-32; while, the flammability effect of R-32 and high pressure effect of CO_2 are minimized. This mixture can increase the heating capacity of a conventional heat pump that runs on R-410A by 30% and it is shown that if the heat exchangers sizes are increased, the heating capacity can be increased by 45% and the COP by 8.5%. Moreover, the GWP of this mixture is 25% of R-410A.

CONCLUSION

In this study, a detailed review of different air source heat pump water heating systems existing worldwide was conducted. Therefore, further experimentation for selecting compact components and optimizing system as well as testing system should also be performed to offer useful guidelines. With abundant amount of heat available in various natural sources and waste heat generated in various process industries, HP becomes an indispensable technology that can contribute towards a cleaner environment. It is observed that ambient temperature has significant effect on the performance of the system, i.e COP of the system increases with rise in temperature.

Also the composition of refrigerant also effects system performance. Much work has been done but more is still required to integrate HP in innovative systems. It is hoped that this review will help increase awareness and efforts in exploring and maximizing the potential of HP to realize greater energy efficiency.

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