Simulation and Analysis of an Air Source Heat Pump Used for Washing Machine

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Abstract: This research looks into the performance of a heat pump used in washing machine without heating technology of its own. Analysis of a washing machine found in the market was also studied in the research. Then the comparison is done in order to understand how either of the two systems can be an ideal for a small family. During the experiment time, there are a couple of parameters to be considered, so the final unknown parameters can be estimated. This is how the behaviour of a system can be explained and understood. The experiment stands on the data collected at the period of two hours with each sample foreseen at every minute. The behaviour and performance of heat pumps has been analyzed in this paper. During the trial, the ambient temperature was between 26.5 - 27.9 ºC by setting the highest temperature the heat pumps to be at 55 ºC. Washing machine which can be bought from the market has also been analyzed to check the performance in terms of consumption of electric power. And finally the comparison of this two systems has been taken place.

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1. Introduction:

Heat pumps generally draw heat from the cooler external air (Bengtsson, Bergheland, & Renström, 2014). In other word, a heat pump is a machine or device that moves heat from one location (the 'source') at a lower temperature to another location (the 'sink' or 'heat sink') at a higher temperature using mechanical work or a high-temperature heat source (Cengel, Yunus, Michael, & Boles, 2008). As the principle of a heat pump is to move heat from one place to another, it is capable of heating (warming) substances in what is called a heat sink as well as of cooling a hot material, thus can work both as a heater and a cooler! In the both cases, theoretically the operating criteria are same (Dieckmann, Roth, & Brodrick, 2004). So there gets two cycles of a heat pump – heating cycle and cooling cycle. In heating cycle, heat is input from the outdoor air, and then pumped more efficiently into where more heat is necessary. In the cooling cycle, it works reverse – heat pumped to outdoor air from where it needs heat to take out.

For washing machine, the concern is how to reduce the use of the different inputs it takes. But rationally, power consumption becomes the major of all of those. Historically, there has not been any significant reduction in the usage of electricity for washing machines (dryers), vented and condensers (Energy Saving Trust, 2014). The only major improvement in electricity usage was when heat pump technology was introduced (Garner, 2015). Experiment with washing machine using a hot-water circulation loop transferring the heat using a heat exchanger showed that it is possible to replace up to 90% of the electricity usage (Ha, & Janda, 2012). This is a very important fact of devising a system that how small it consumes power, so that the overall cost for a user is mitigated. The user of US were conducted a survey on choosing low power using refrigerator, and the report convey us the message that they were willing to pay an extra 250-350 for the system that has been awarded an ENERGY STAR label (Handbook, 2005). Why? The users wanted a safe and secure use of power so that the ultimate cost of the system and the system-use can reduce the overall cost. Again, a research reveals that, in South Korea, the buyers had a significant positive trend towards purchasing energy-efficient products like TVs, ACs and washing machines (Höjer, 2014). Besides these, there are many researches done worldwide, that drive increasing support of the users for cost-effective products, even to pay some 'more' for buying price. So, for washing machines, compared to other household appliances, it is laid to consider more experiment of how it can be devised for less usage of power consumption.

At the moment of heating mode, a heat pump usually exhibits three to four times more efficiency in terms of using electric power compared to conventional electrical heaters. This research went on using ambient air for analysis. Heat pump of this kind known as Air Source Heat Pump (ASHP) is proved to be efficient in hotter environment. Though geothermal heat pumps can reduce energy consumption up to 44% compared with air-source heat pumps (Maytag, 2015), still ASHP works better, as it shows a COP of 3 to 4 in summer weather. Due to Carnot efficiency limit, when the ambient temperature decreases significantly, COP for an ASHP reduces even to 1.0 at zero degree Celsius, though a standard air source heat pump used in domestic affairs can extract useful heat down to about -15C (Persson, 2007). This trend may help the future researchers to go for experiment of using an ASHP for washing machines in order to understand the cost-effective behaviours. Research shows that effective performance in cold climates can also be determined by the working fluid (Persson, 2007). It has also been revealed in many researches that, the lower the temperature of the ambient air, the more energy is needed to extract heat from it (U. S. Department of Energy, 2014). External heat pump heating water for washing machine thus may be a way to analyze in the context of different environment, and this may help understand simulating and devising a new integrated system.

2. Principles of Heating Cycle:

As stated before, during heating cycle, outside air heat (ambient temperature) is taken as input to produce a multitude of final heat for using that heat in different purposes. The steps can be described as follows:

2.1. Step 1:

The liquid refrigerant (here R22) is let to passes through the expansion valve. This changes the liquid into a low pressure liquid or vapour mixture. It then comes up to the evaporator where the coils are responsible for giving the liquid refrigerant a chance to absorb heat from the ambient air. The refrigerant then boils, and turns to vapour of low temperature.

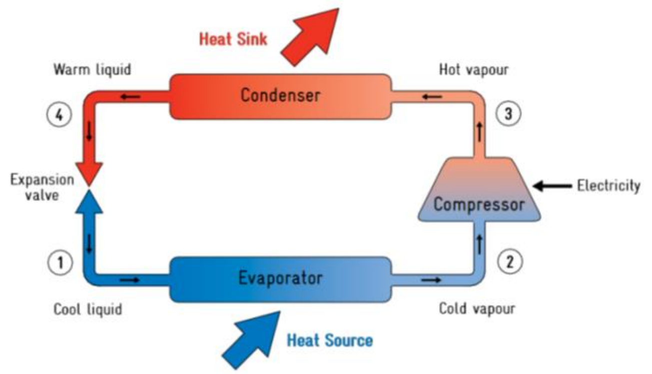

Figure 1. Heat Pump (Evaporation/Condensation Cycle) (Ward, Clark, Jensen, Yen, & Russell, 2011)

2.2. Step 2:

The low temperature refrigerant vapour is then passed through the reversing valve to the accumulator, which collects any remaining liquid. Then it enters into the compressor. Here the vapour is compressed, and thus getting more pressure reducing its volume causing it to be heated up.

2.3. Step 3:

The heated refrigerant now turns to vapour with high temperature. The reversing valve sends the gas, which is now hot, to the indoor coil. This device is called as condenser. The heat from the hot gas is condensed here, causing the refrigerant to lower it temperature, and makes it liquid again. This liquid refrigerant comes again to the expansion valve and the cycle is thus repeated.

3. Data Analysis:

This research includes total electric power consumption in the home to produce hot water when using this hot water to wash clothes in the washing machine. It needs to look into how washing machine of this type consumes electricity than conventional washing machine without water heating system. The importance of using hot water to wash clothes is that, cleaning this way also helps in eliminating germs. It is to investigate that, the use of heat pumps to separate the production of hot water to wash clothes consumes how much power. It has been primarily supposed that as heat pumps use heat from the outside air which in general needs less power to produce heat can sum up a low power consumption that the conventional washing machine system. The current research would reveal the fact of this assumption.

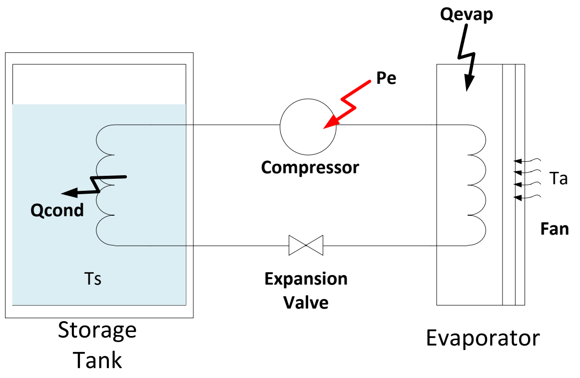

Figure 2. The heat pump system using ambient air

Cleaning clothes with hot water at a temperature higher than or equal to 54 ºC is the best choice for clothes that are white. For a dirty diaper and high through dyeing fabrics, it needs to be careful of using hot water that, certain species of germs cannot withstand the heat required to read labels to separate the clothes of those out of the way. Naturally water with higher temperature increases the efficiency of washing machines (Ward, Clark, Jensen, Yen, & Russell, 2011). However, it is not suitable to let the washing machine removing blood red wine and coffee stains, for which the machine will experience more difficulties than ever (Zhang, 2014). The system tested was to produce hot water from an outside heat pump instead of an integrated water heating system. The working principle of the heat pump is shown in Figure 1 above.

This research tests the heat pump system with a hot water with the tank size of 100 Liters. Actual ambient temperature (Ta) when data was collected is equal to 26.5 - 27.9 degree Celsius at the time of 19:32 to 20:25 hrs. By the hot water temperatures of up to 55 degree Celsius in the tank, a Thermocouple was connected to the Data logger to record the test results to a computer using Multi-meter to measure voltage and Clamp meter to measure the electricity to the technical use of the pump system.

Table 1: *Detail of the washing machine.*

Brand	Fisher & Paykel	
Model	WA80T65GW1	WL80T65CW2
Water Heating System	Yes	No
Water Usage (Liter)	82	82
Capacity (kg)	8.0	8.0
Energy Usage (kWh/365uses)	664	369

Then analyzing the data helps creating a mathematical model by defining the purpose of the model to be applied to the washing machine with outside hot water system, and of size of 8 kg, which demand for hot water of 80 Liter. This modelled system is then let to compare with the washing machine holding an integrated water heating system. Table 1 above shows the specification of the washing machine in a home of a small family (3-4 members).

Now, the following picture would give an idea of how to use and attach a heat pump to the washing machine in a house. Connecting pipes from the hot water tank to the washing machine would enable a user to use the hot water when it is needed.

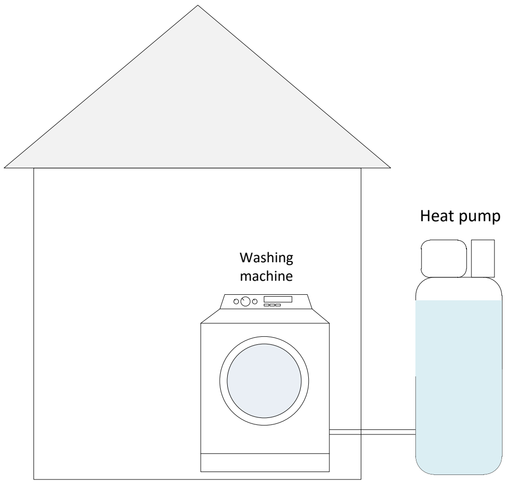

Figure 3. Heat Pump and Washing Machine in a House

The question is why heat pump is established outdoor. This is because the device relies on the ambient air temperature, and at outdoor which is relatively high.

3. Results:

This analysis considers the hot water with a tank size of 80 and 100 liters to bring hot water to the washing machine with no integrated hot water system. In Figure 3, the temperature inside the bucket compared to the time calculated from the mathematical model. It can be seen from the figure that, the temperature inside the tank is increasing in a steady way for both the experiment and simulation criteria.

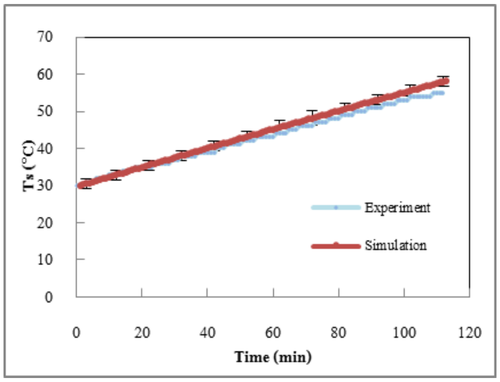

Figure 4. Water temperature in the storage tank for simulation vs. experiments with respect to time.

Compared with the temperature in the water tank of the experiment involved with environmental temperature causes heat transfer systems are slow and limit the surface temperature is 55 degree Celsius to produce hot water within 1 hr. 53 min (113 min).

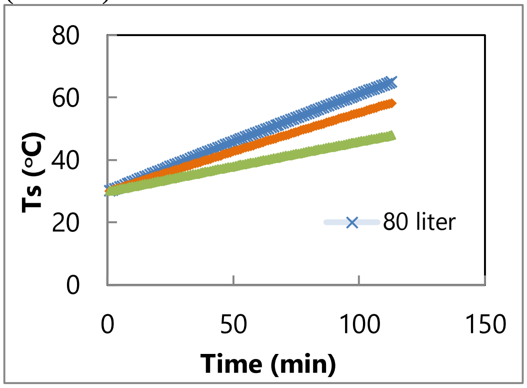

Figure 5. Comparison of the temperature of hot water in the hot water storage tanks of various sizes.

The graph above is for building a mathematical model, that hot water tank temperature of approximately 55 degree Celsius to various sizes can be seen that the water tank size of 80, 100 and 160 liters can heat water to the desired temperature at the time 37, 43 and 55 minutes, respectively. For 80 liter tank, it is being seen that Ts to Time graph line is steeper than the others. This is because, the increased water temperature helps heating up the smaller tank water more quickly.

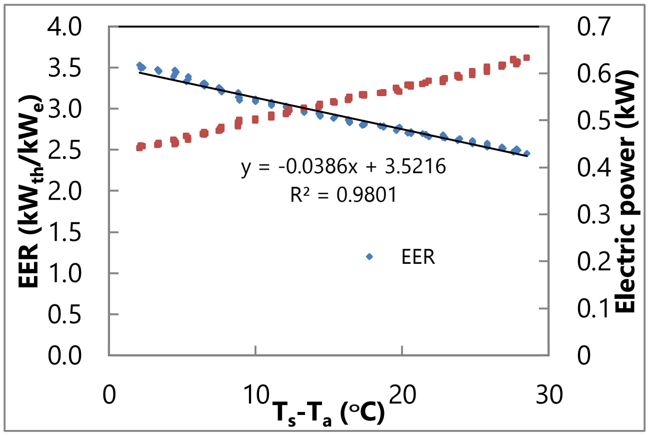

Figure 6. Performance of the heat pump during experiments with mathematical models compared with the environmental temperature, water temperature in the tank.

From the plot above, trial for getting EER shows a reduction in value, which is due to environmental temperature, and the temperature inside the tank as well. During this experiment, the trial of error is 3.5% when compared to the mathematical model. Again, the table as follows needs to analyze to further understanding of electricity consumed.

Table 2: *Power consumption of the devices*.

Equipment's	Power (kWh/year)
Heat Pump	142.4
Washing machine with no hot water heat pump system.	511.4
Washing Machine with integrated heat pumps	664.0

The table above shows the amount of power to produce hot water by a stand-alone heat pump keeping the temperature up to 55 ºC with the tank size of 80 liters spends less, thus saves energy.

4. Discussion:

The research covers the small family (3-4 people total membership) to analyze the test results with the appropriate size of the hot water tank. It found that the use of heat pumps to produce hot water at a temperature of 55 ºC spent 37 min with a water tank of 80 liter capacity. The performance ratio of the heat pump (EER) of 10 has been found for applied washing machine system. Hot water measuring 8 kg consumed electricity was 511.4 kWh / year compared to the washing machine with hot water system in its body. This can save electricity 152.7 kWh/year which is equivalent to a less power consumption of 22.9% in terms of yearly usage. EER of the heat pump measured in the experiment though doesn't certify the performance of all air source heat pumps used in washing machines general, but still this experiment gives the idea of how to make sure of having a general manufacturer's rating that can give the idea of how efficient it might be of using an air source heat pump for heating water for washing machines. Performance of a device may vary in of different types and of different components of a system.

5. Conclusion:

This research was laid down to analyze the performance of a heat pump used in a washing machine. It shows that an air source heat pump consumes significantly less power than a washing machine found in the market. Data were taken in the summer only. If winter data can be explained, it might help understand the system behaviour in more diverse way. For different seasonal data for the experiment may tell different performance of the system. Some few minor specifications should be out of the studies, and may be overlooked. In this research, the researchers used a particular situation to compare all the possibilities of how a heat pump can do for a washing machine in terms of energy consumptions.

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