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EXPERIMENTAL ANALYSIS OF A FIXED-SPEED AND A VARIABLE-SPEED AIR CONDITIONING SYSTEM

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Abstract: *A conventional air conditioning system is designed to satisfy the maximum load, and cycles on/off to match part load demand. A variable-speed or inverter driven system has the ability to regulate its cooling capacity by using a variable-frequency drive which continuously changes the speed of the motor and thus of the compressor. Variable-speed air conditioners are advertised as typically consuming 30 per cent less energy than conventional systems. This investigation is a continuation to a previous experimental investigation by Grech and Farrugia (2012) who used a belt driven open-type reciprocating compressor in both fixed and variable speed operation. In this experimental investigation a series of experiments on a conventional and an off-the-shelf inverter driven air conditioning system were performed. The aim of these experiments was to quantify the advertised part-load efficiency and reduced energy consumption of the off-the- shelf inverter driven air conditioner. The experimental results showed that the cooling coefficient of performance (based on refrigerant cooling effect) is higher for the inverter driven system at all refrigerant condenser out temperatures except at the highest temperatures at which the cooling coefficient of performance for the conventional system was better. This is to be expected since conventional systems are designed to satisfy the maximum load.*

Keywords: Air-conditioning, Inverter, Variable-speed, Part load, Coefficient of performance.

1. Introduction

As a consequence of the continuously rising energy prices, the need to control energy consumption has become a worldwide concern. Inverter driven air conditioners are systems designed with the main target of saving energy. Grech (2008) mentions that variable speed air conditioners are advertised as typically consuming 30 per cent less energy than conventional systems. This low energy consumption is achieved by the use of a variable-frequency drive which continuously changes the speed of the motor and thus of the compressor according to the cooling demand. In simple terms the variable-frequency drive will speed up the compressor when the demand is high and slow it down when the demand is low. Though their low energy consumption might be associated with a much higher initial cost, a well designed system is estimated to have a payback period that ranges between 3-4 years, Zubair et al. (1989). Inverter driven air conditioners both for residential and commercial applications were first implemented in Japan during the 1980s. Since then, variable-speed air conditioners have become widely popular owing to their energy saving and better performance in applications where part load is required. In fact in Japan sales of the inverter driven air conditioners account over 50 per cent of the air conditioning market and are still increasing, Zubair et al. (1989).

2. Experimental Setup

The experimental setup was based on instrumenting the air-conditioning system to have accurate measurements of electricity consumption, the flow of heat on both the hot and cold side, refrigerant flow, refrigerant pressures and many temperatures. The experimental setup used heat exchange to water on both the evaporator and condenser sides to give a better quantification of heat flow rather than cooling and heating of air. This involved the construction of two heat exchangers. The condenser side had the refrigerant coil immersed in a bath of water that was continuously stirred (through circulation) to maintain

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the desired refrigerant condenser out temperature. The heat was rejected from the bath by dumping the necessary amount of hot water and make-up with cold tap water to maintain a stable water level.

The evaporator side heat exchanger had two iterations in design, the first setup used a pipe-in-pipe configuration fed directly by mains water, but at low water flow rates the water froze which led to stagnation and trips. Hence an electrically heated bath setup was later used on the evaporator side as shown in Fig. 1. The cooling load was applied by switching on electrical heaters in the bath of water. This modification gave the added benefit that the temperature of the bath of water could be controlled to simulate the "room" temperature.

The experimental setup included the manufacture of small sized T-type thermocouples to have as little interference as possible with the thermal aspects of the refrigerant piping as detailed by Fenech (2009).

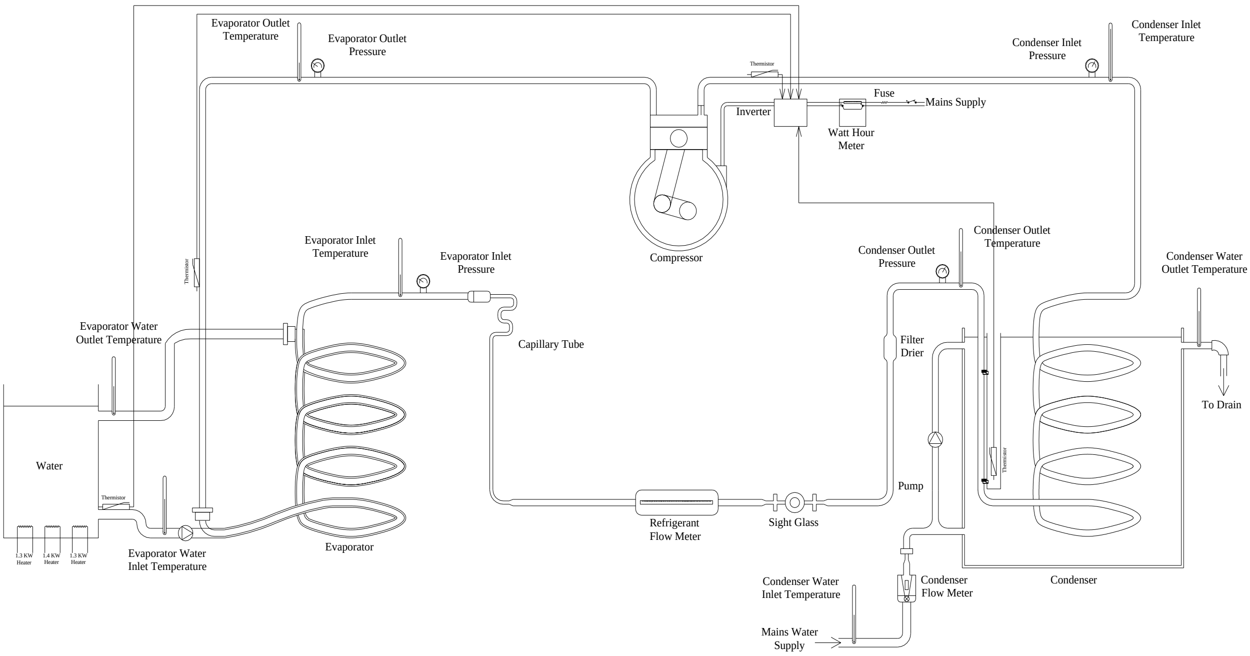

Fig. 1: Schematic diagram of the inverter driven air conditioning system.

3. Cooling Capacity

The variations of the cooling capacity with the refrigerant condenser out temperature obtained during experimentation are represented graphically in Fig. 2. As can be seen from the trends of Fig. 2 the cooling capacity exhibits a decrease as the refrigerant condenser out temperature is increased. This results from the fact that the enthalpy of the refrigerant at evaporator inlet increases at high condensing temperatures, thus the enthalpy difference across the evaporator decreases resulting in a lower refrigerant cooling capacity at high temperatures. The refrigerant mass flow rate also affects the cooling capacity. The refrigerant mass flow rate decreases as the refrigerant condenser out temperature increases. The decrease in refrigerant mass flow can be explained due to the fact that higher condenser out temperatures cause higher condenser pressures. Hence the compressor has to overcome a larger pressure rise which leads to a lowering of refrigerant flow. Thus the cooling capacity continues to decrease at the higher condenser temperatures. This decrease in the cooling capacity manifests itself as a low system coefficient of performance as will be discussed further in the next section.

Comparing the trends of the fixed-speed and variable-speed system, the former has a higher refrigerant cooling capacity due to the high volume of refrigerant that is delivered by the compressor. Considering the curves of the variable-speed system at the different loads, the largest cooling effect is obtained when the highest load was applied. Since the compressor had a larger load against which it had to work in order to maintain the "room" at the desired temperature, thus more refrigerant had to be delivered by the compressor. With the same argument the 1.4 kW load resulted in the lowest cooling capacity.

Grech's (2008) scaled trend also follows the same concept *i.e.* the cooling capacity decreases as the condensing temperature increases. This shows that the results of Grech's and those obtained from this study are in agreement. Additionally, the cooling capacity drop with condenser temperature rise for R 410 compared favourably to that given by Motta et al. (2000).

A comparison between the refrigerant and water cooling capacities was performed. Both show a decrease in cooling capacity as the refrigerant condenser out temperature is increased, thus it was concluded that a good energy balance was achieved between the refrigerant side and water side of the system. However there was a difference in magnitude between the refrigerant and water cooling capacity and this anomaly was attributed to the large amount of condensation that resulted on the outside of the evaporator heat exchanger. Additionally, the 1.4 kW, 2.0 kW and 2.7 kW trend lines should ideally have been horizontal representing the fixed loads to which the system is subjected. This would have indicated that no losses by convection were present during experimentation. It must also be pointed out that the losses for the case when 2.7 kW load was applied are much greater than for the other loads, since the change in temperature between the water temperature in the tank due to the heat source (heaters) and ambient conditions was larger.

The uncertainty analysis showed that the error associated with the volume measurement contributed the most in the final uncertainty value compared to the error in time measurement which were used in the water flow rate calibration. The error in temperature measurement was constant and determined by the grade of thermocouple wire used.

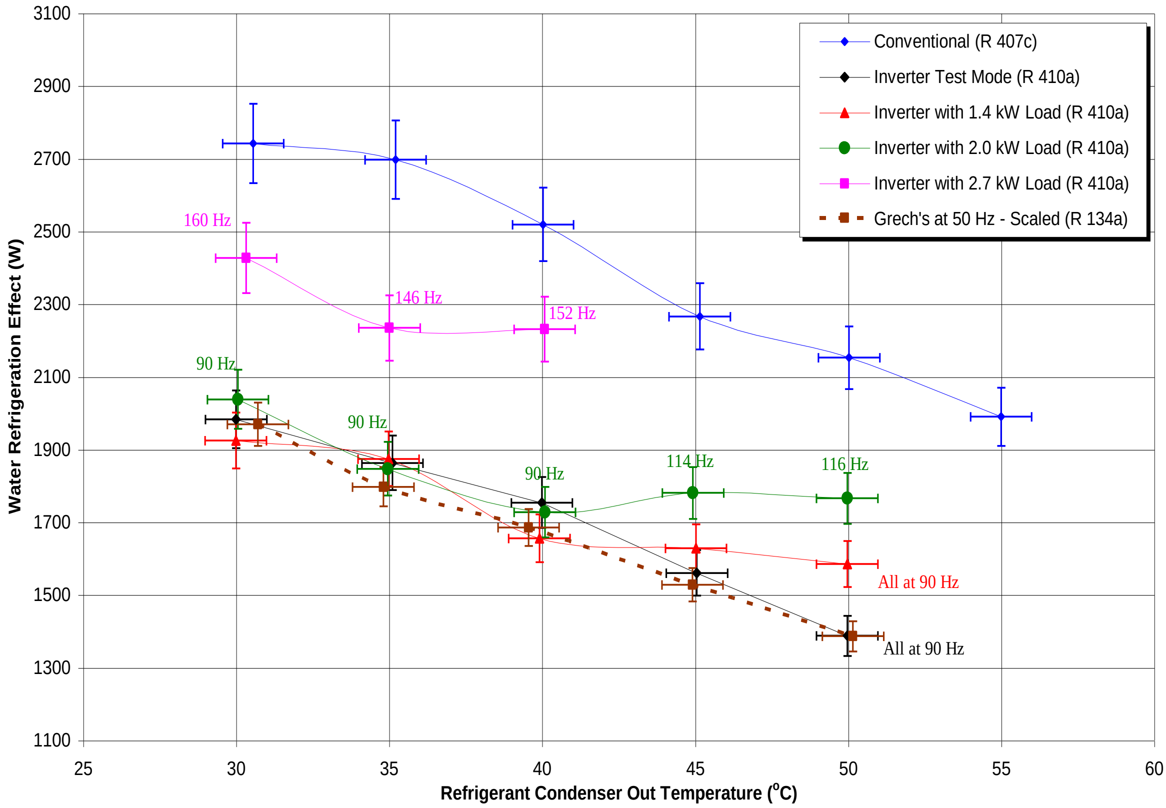

Fig. 2: Variation of water cooling capacity with refrigerant condenser out temperature.

4. Coefficient of Performance, COP

The trend of the electrical COP shown in Fig. 3 indicates that the electrical COP for all experiments performed worsens as the condensing temperature increases. From the figure it can be noted that the electrical COP of the conventional system is the lowest. This is mainly attributed to the large electrical power input that the conventional system requires all the time. It should be noted that the COP is dependent on the cooling capacity and hence it its expected that the COP falls just like the cooling capacity does.

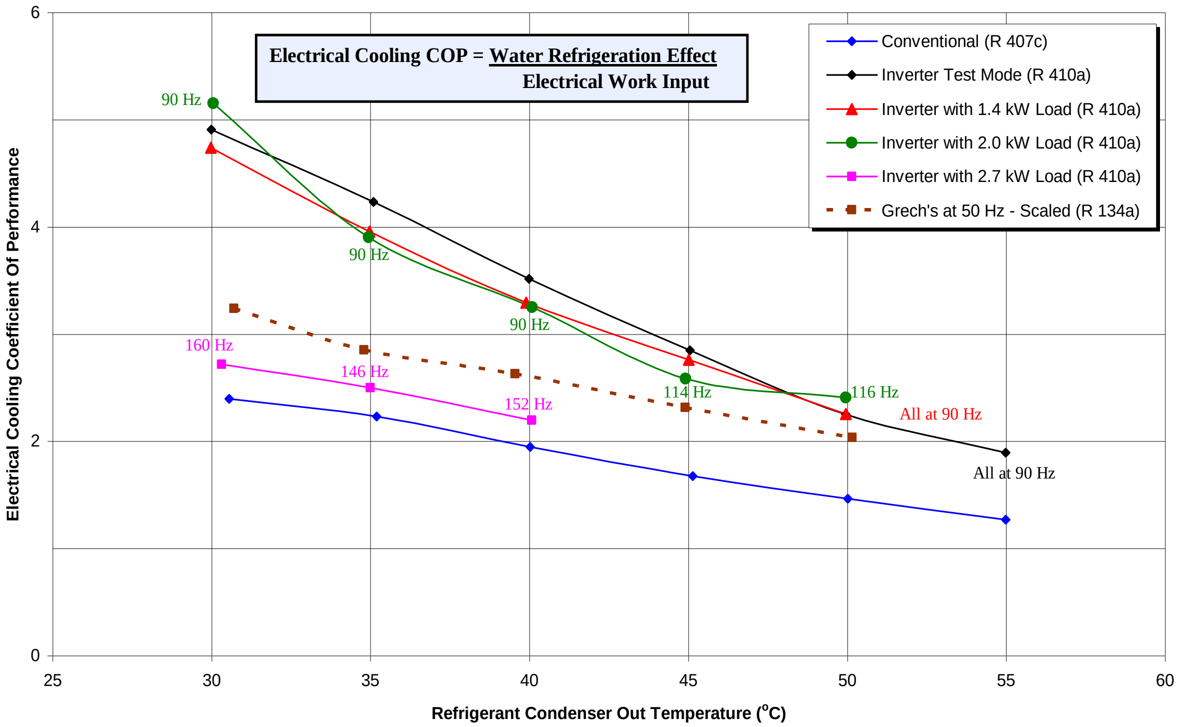

Fig. 3: Variation of electrical COP with refrigerant condenser out temperature.

5. Conclusions

The COP's from the experiments showed that larger COP's are obtained at lower condenser out temperatures. This is as expected as the reverse Carnot COP is higher for smaller temperature differences between the inside (evaporator) and outside (condenser) temperatures. This finding is also in agreement with observations by Motta et al. (2000). A comparative calculation based on the measured COP's for the off-the-shelf fixed-speed unit *vs* the off-the-shelf variable speed unit, at 20°C room temperature and a an outside temperature of 35°C, and assuming the user switches on the air conditioner for 6 hours daily for an entire summer month, showed that a 30% reduction in electricity consumption by an inverter air conditioner is indeed a good ball park figure.

References

Fenech, G. (2009) Experimental analysis of a fixed and variable speed air conditioning system, B.Eng. Dissertation, University of Malta, Malta.

Grech, N. (2008) Investigation on variable speed operation of air conditioning, B.Eng. Dissertation, University of Malta, Malta.

Grech, N & Farrugia, M. (2012) Experimental investigation on variable speed operation of air conditioning, In: Proc. 9th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics, Malta.

Motta, S. F. Y. & Domanski, P. A. (2000) Performance of R-22 and its alternatives working at high outdoor temperatures, In: Proc. National Institute of Standards and Technology, pp. 47-54.

Zubair, S., Bahel, V. & Arshad, M. (1989) Capacity control of air-conditioning systems by power inverters, Energy, Vol. 14, No. 3, pp. 41-151.