HIGH PERFORMANCE AIR-WATER HEAT PUMP WITH EXTENDED APPLICATION RANGE FOR RESIDENTIAL HEATING

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ABSTRACT

A new type of air-water heat pump has been developed with the aim to cover an extended application range in high temperature residential heating (for retrofitting existing oil or gas boilers in hydronic heating systems). The base heat output is about 10 kWth. Based on a commercial heat pump, the refrigerant cycle was modified with two main components: A hermetic scroll compressor with a specially designed vapor injection port and an internal "economizer" heat exchanger. Performance tests were carried out in the laboratory over a wide range of injection mass flow rates and at external conditions covering air temperatures down to -12°C. At A-7°C/W60°C an increase of heat output of 28% and a COP improvement of 15% compared to the tests without injection flow have been observed. The heat output at A2°C/W50°C (standard operating conditions without injection) and at A-12°C/W65°C (extreme heating point with injection) are about the same.

Considering these promising results and with the aim to further improve the seasonal COP and the heat output curve, a second compressor prototype based on a different compressor model, is being tested in phase two of this project.

1. INTRODUCTION

The market penetration of heat pumps for residential heating (<20kWth) shows an important increase in most of the European countries (sales growth rate of 11 to 25% in 2000, Rivoalen 2001), but the market share is still low in absolute terms in most of the countries. The most successful market share for new buildings is shown in Sweden and Switzerland, essentially for new houses with low temperature floor heating. The much more demanding and potentially interesting retrofit market is still negligible due to heat pump technologies with low efficiency, inadequate heat output characteristics and a very restricted temperature range.

With high temperature lifts single-stage heat pumps tend to suffer from high compressor loads and discharge temperatures, high expansion losses in the expansion valve and reduced specific evaporator capacity due to the relatively high vapor quality downstream of the expansion valve. Potential solutions include two-stage expansion with economizer separator (Granryd 1992) and a compressor equipped with economizer port(s), multistage expansion with multistage compressors or dual cycles either superposed or interconnected cycles. The latter has recently been theoretically and experimentally studied (Zehnder et al. 1999) with good results for high temperature glides on the heating water, but with a complexity deterring broader application so far. Two stage expansion and compression cycles, which are extensively used in large heat pumps (Makise 1993) suffer from oil migration and control in domestic units with hermetic compressors and are not yet applied in spite of their excellent performance (Favrat et al. 1997). Figure 1 shows schematically the range of heat supply characteristics, which could potentially be covered by two-stage heat pumps with capabilities to use compressors in a two-stage mode, or one-stage modes with either the first or second stage compressor in use. Concepts with two stage expansion and a compressor equipped with economizer ports are well known with screw compressors in the mid size range, but have not been applied for domestic heat pumps due to the lack of suitable compressors. Earlier attempts have been made to use refrigeration scroll compressors with liquid intermediate injection ports but the size of the ports was too small to significantly increase performance (Zehnder et al. 2000).

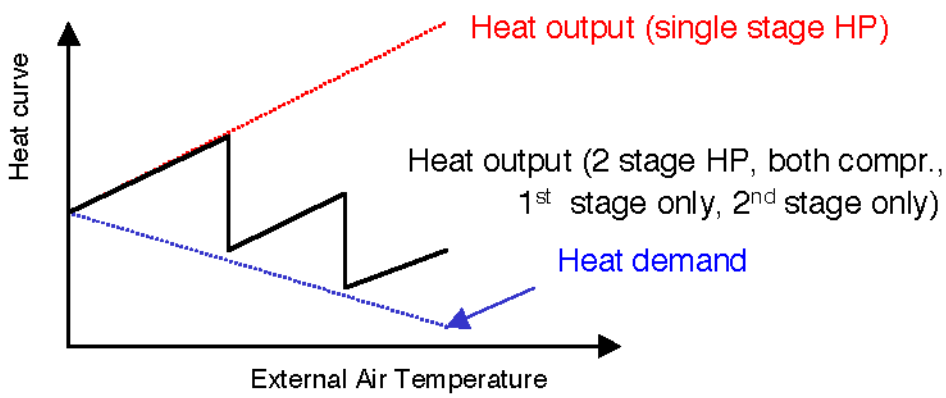

Figure 1: Comparison of heat demand and heat output curves for a single-stage and a two-stage heat pump.

This paper presents the first tests of a domestic heat pump prototype using an orbiting scroll compressor with specially designed economizer ports together with an internal economizer heat exchanger. Figure 2 shows a comparison of expected range from this new unit compared to its single-stage counterpart.

Due to the reduction of the end of compression temperature by injecting saturated or even moist vapor during compression, the application range of the heat pump is strongly extended.

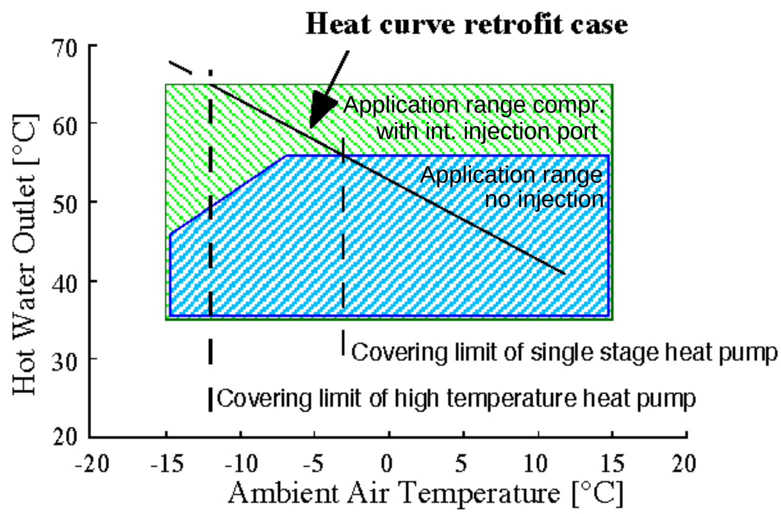

Figure 2: Extended application range for high temperature heating in residential application.

2. EXPERIMENTAL SETUP

A commercially available heat pump, among the best performing in a series of heat pumps tested in the Swiss Heat Pump Test Center of Töss (ZH/CH) was selected for the new prototype and easy comparison with the state-of-the-art. Figure 3 shows a picture of the test rig at EPFL with its computer controlled air conditioning chamber in the back. Humidity up to 95% and temperature down to –12°C can be realized.

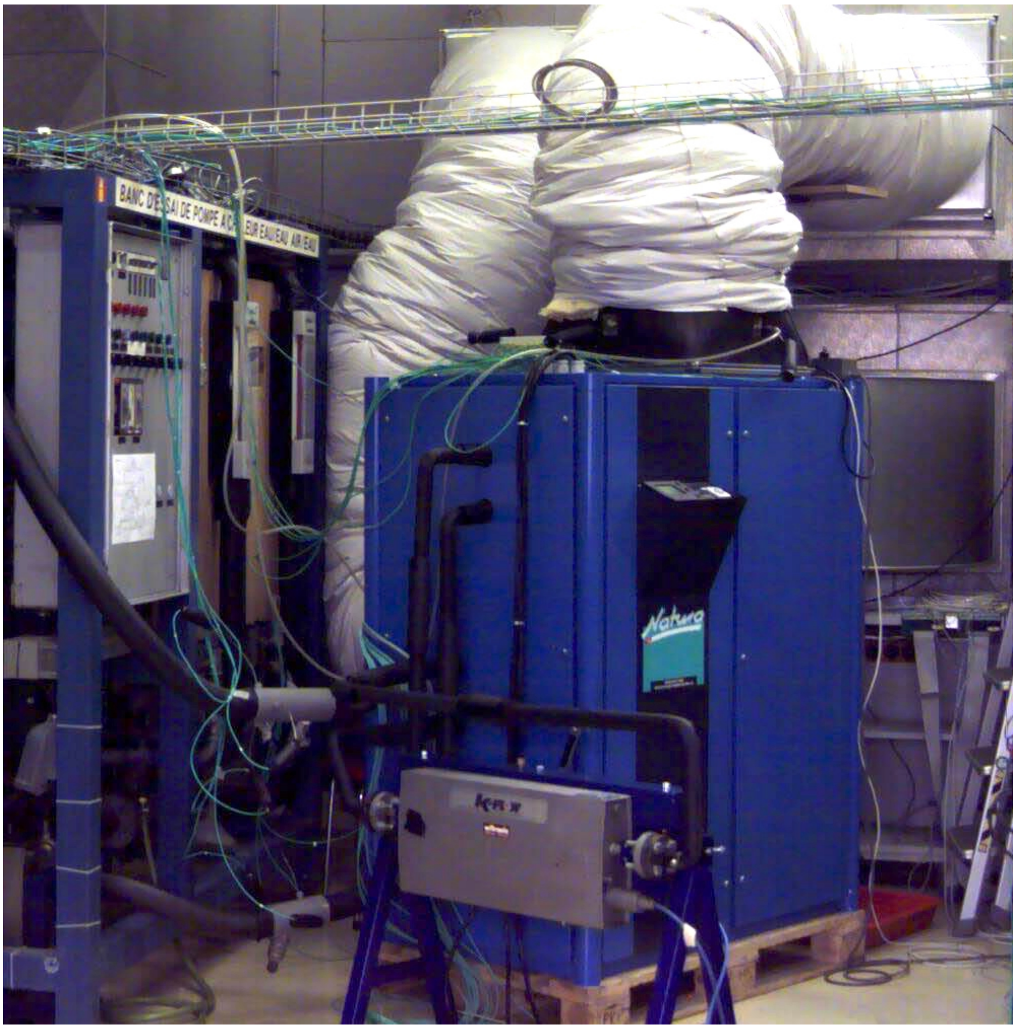

Figure 3: Air-water heat pump test rig at the Laboratory of Industrial Energy Systems at EPFL.

Figure 4 shows the flowchart of the heat pump. At the outlet of the plate condenser the refrigerant is separated into: a) The economizer flow which is expanded to an intermediate pressure stage with an electronic expansion valve and then partially evaporated in an internal heat exchanger (commonly called economizer). b) The main flow which is subcooled before going to the main thermostatic expansion valve leading to the evaporator.

The economizer flow at the intermediate pressure level is injected into the modified hermetic scroll compressor with symmetric injection ports.

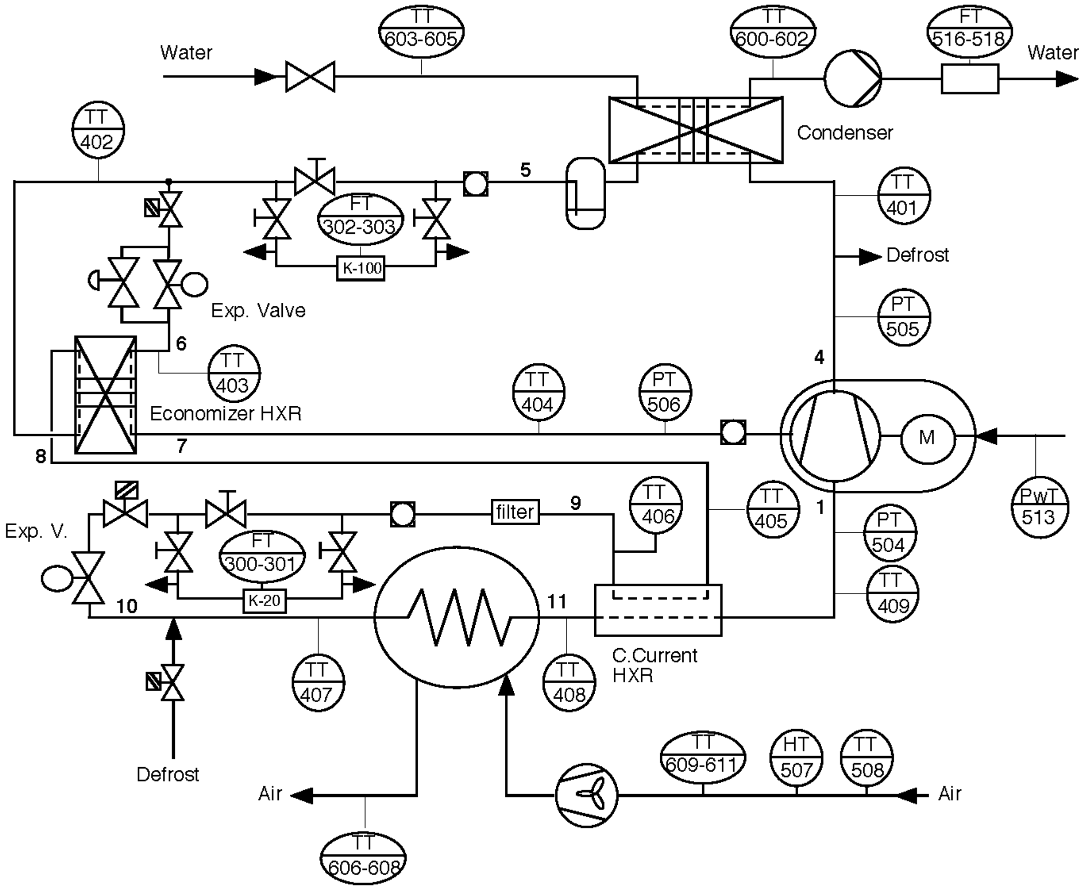

Figure 4: Flowchart and test data points of the modified heat pump.

Several test runs at steady state conditions were performed in the laboratory:

- Air inlet temperatures of -12°C, -7°C, 2°C and 7°C , with air flow at 3500 m3/h. All tests are without humidification of the inlet air.

- Heating water outlet temperatures of 50°C, 60°C and 65°C, with a constant volumetric flow of 13 l/min.

The injected refrigerant flowing through the intermediate injection port was controlled by an electronic valve and varied within in the range of 0 – 45 g/s.

The heat pump was equipped by two Coriolis mass flow meters (relative precision ±0.2%). The values of absolute pressure (±1 kPa), temperatures (±0.1 K) and electric power (±0.25%) completed the measurements on the refrigerant cycle and also in the auxiliary part of the test section.

3. RESULTS

In several test runs (specific test conditions, see previous chapter) the behavior and the capacities of the prototype compressor with adapted injection port implemented in a refrigerant cycle with economizer heat exchanger were examined and compared to a standard running mode without injection.

Figure 5 shows the performances of the heat pump for optimized injection flow rate and in comparison with the tests without injection. Due to injection the COP is slightly increased (the most significant raise is achieved at the highest temperature lift) and a significant improvement of the heat output over the whole test range is observed.

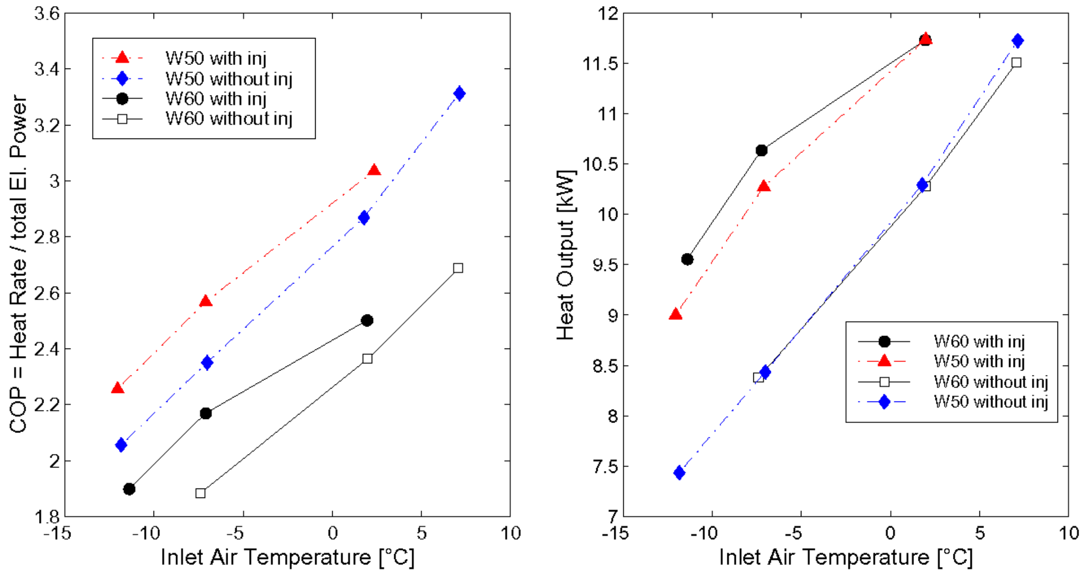

Figure 5: Performance comparison for the first prototype of high temperature air-water heat pump.

In terms of relative improvement, the performances of the heat pump at steady state conditions and without frosting of the evaporator coil are:

- COP +13% at A-7°C/W60°C and +6% at A2°C/W50°C.
- Heat output: +28% at A-7°C/W60°C and +18% at A2°C/W50°C.

The diagrams in Figure 6 show the evolution of the heat pump's performance at several mass injection points for heating water outlet temperatures of 60°C. The coefficient of performance passes through an optimum, where the thermodynamic benefit of the injection is still much more important, than the losses due to friction in the injection lines. At higher injection flow rates these losses are strongly increasing, resulting in a lower COP. For injection rates higher than a certain limit the heat output is nearly stable. It is not recommended to try to modulate the heat output with the injection flow.

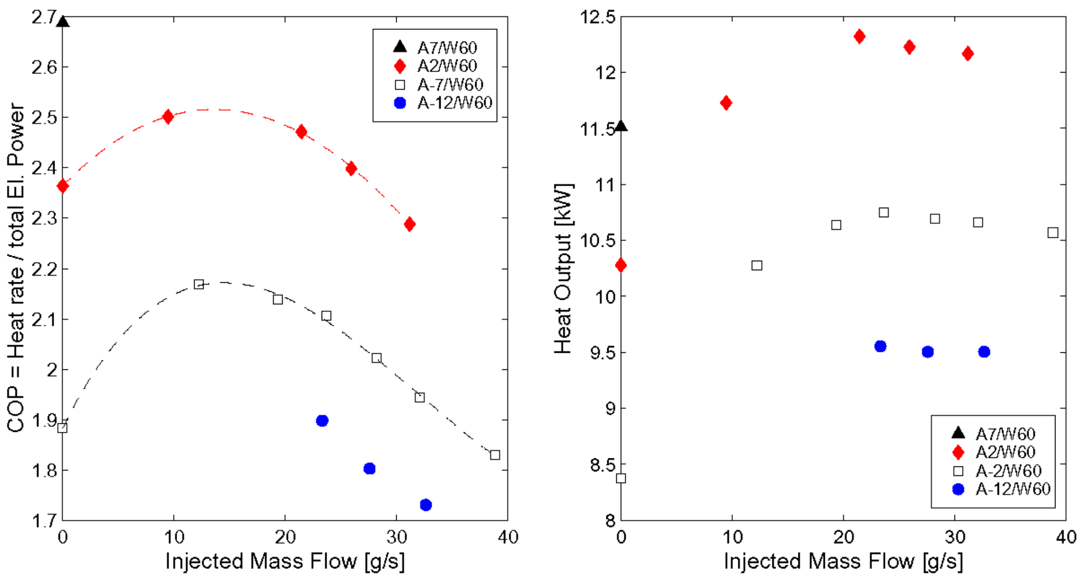

Figure 6: COP and heat output for variable injection mass flow rate at heating water outlet temperature of 60°C.

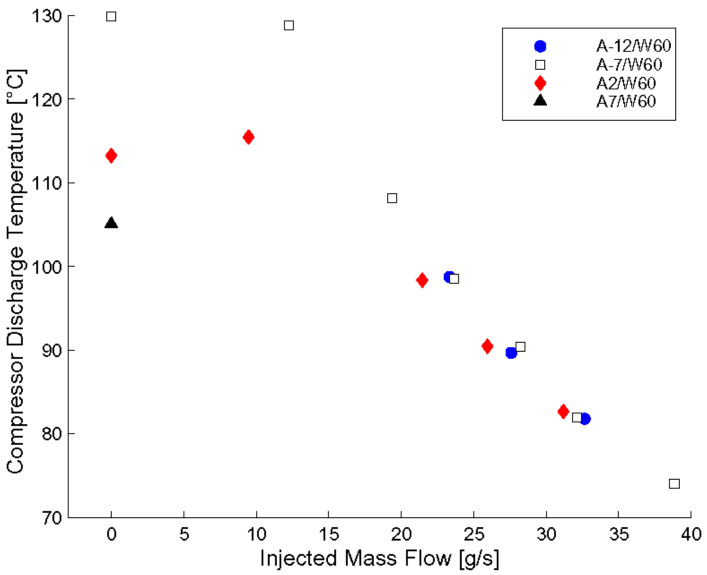

Figure 7: Compressor discharge temperature for variable injection mass flow rate at heating water outlet temperature of 60°C.

The compressor's discharge temperature is found to be very easily controllable by variation of the injection mass flow rate (see Figure 7). A linear correlation can be admitted for mass flow rates higher than a limit corresponding to approximately the optimal COP operating condition. This capacity of temperature reduction has given the opportunity to test the heat pump also at water temperatures of 65°C with limited compressor discharge temperatures.

4. DISCUSSION

The tested heat pump shows very promising performance characteristics over the whole application range. Although at very high temperature lifts a significant injection mass flow rate is required to remain within the required discharge temperatures. For very low air inlet temperatures the required injection can reach flow rates in the order of magnitude of the suction flow. The lifetime of this type of compressor at limiting operating conditions (high economizer flow rates) is not yet known and specific lifetime tests will be performed after system optimization.

In this project phase the injection mass flow rate is controlled with an electronic expansion valve, but this relatively expensive solution could be avoided by the implementation of a capillary tube. First estimations show that with a capillary tube at the economizer stage the mass flow rate can be held near to the optimum performance over a large application range.

5. CONCLUSION

A new type of compressor with specially designed economizer ports, implemented in a air-water heat pump refrigerant cycle with internal economizer heat exchanger was tested successfully. Substantial heat output gains due to the economizer flow were obtained for typical high temperature conditions occurring in the retrofit application of hydronic heating systems. A heat output increase of about 28% for the base heating point (at A-7°C/W60°C) was measured. For the same conditions a COP gain of 15% has been achieved, compared to the same test without injection flow.

Discharge temperatures can be easily reduced with increasing injection flow rate. With this measure the maximum system temperature can be controlled allowing a larger application range at imposed temperature limits. At higher injection flow rates the coefficient of performance drops again and the injection must therefore be kept as small as possible.

It is important to note that the modified compressor model was not specifically designed for a high temperature lift applications. Further improvements in terms of higher seasonal COP and more appropriate heat output curve are expected with the implementation of a second prototype compressor based on a hermetic scroll compressor with a higher built in volume ratio.

ACKNOWLEDGMENTS

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REFERENCES

BRAND F., FAVRAT D., ZEHNDER M. 2000. *Pompe à Chaleur Haute Température, Phase 1: Solution avec Compresseur à Injection Vapeur*, final report in French, Swiss Federal Office of Energy.

FAVRAT D., NIDEGGER E., REYMOND D., COURTIN G. 1997. *Comparison between a single-stage and a two-stage air to water domestic heat pump with one variable speed compressor*. IIR Conference on heat pump systems, energy efficiency and global warming, Linz.

GRANRYD E. 1992. *Energy Savings in Vapor Compression Refrigerating Systems*. Proc. Int. Symp. On the NTH Refrigerating Engineering, Trondheim Norway.

MAKISE Y. 1993. *Future Vision of Heat Pump Technology and Global Environment*. 4th IEA Heat Pump Conference, Maastricht.

RIVOALEN H. 2001, EDF R&D. *Heat Pump Market Overview Europe,* European Heat Pump Association (http://www.ehpa.org).

Swiss Heat Pump Test Center Winterthur-Töss 2001. *http://www.wpz.ch.* Axpo and EKZ.

ZEHNDER M., FAVRAT D. 2000. *Oil migration in single and two-stage Heat Pumps, Phase 1: Design and Concept*, intermediate report, LENI-EPFL Lausanne, Swiss Federal Office of Energy.

ZEHNDER M., REINER G., FAVRAT D., CIZMAR J. 1999. *Wärmepumpe mit Hilfskreislauf zur Kondensatunterkühlung, Phase 2: Experimentelle Untersuchung*, final report in German, LENI-EPFL Lausanne, Swiss Federal Office of Energy.

ZEHNDER M., TRÜSSEL D., ZAHND E., CIZMAR J., FAVRAT D. 2000. *Wärmepumpe mit Zwischeneinspritzung bei Scrollkompressoren*, final report in German, LENI-EPFL Lausanne, Swiss Federal Office of Energy.