

RETROFIT HEAT PUMP WITH HIGH ENERGETIC EFFICIENCY BASED ON AN ECO FRIENDLY REFRIGERANT

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Abstract: The intention of this R&D project is the development of an electrical driven heat pump with the refrigerant CO₂ for the retrofit market, which is reaching the demands of existing houses. The main barriers for using heat pumps in old buildings for the retrofit are the high inlet temperatures of 70 °C up to 90 °C. This is too high for the present heat pumps.

The designed heating system with heat pump and electric heater permits to cover the heating demand of a house with 20 kW max. capacity at design temperature. The Seasonal Performance Factor (SPF) target is 3.3. Space heating (90%) and tap water heating (10%) will be realised with an economiser cycle and hot gas injection in the compressor. The bivalent point is fixed at -7 °C (13 kW). The annual energy consumption of the electrical heater amounts to 5% (calculation result).

Also a prototype of a CO₂ compressor with the necessary capacity, high efficiency, high condensing temperatures, a perspective of low production costs and with a long lifespan will be developed during this project.

Key Words: *Retrofit Heat Pump, Scroll-Compressor, Enhanced Vapour Injection, eco-friendly refrigerant*

1 INTRODUCTION

The heat pump is making ever greater inroads into the modernisation market. Compared to new build, this market sector requires high flow temperatures of 70 °C to 90 °C. There are currently only a limited number of commercially available appliances for flow temperatures in excess of 60 °C. Yet there is huge potential for the heating industry in modernising older buildings.

According to that the major barriers for the retrofit market are the high distribution temperature of over 70 °C of conventional heating systems in existing buildings and in many cases the high investment costs.

30 % of approximately 150 million dwellings in Europe are built before 1940, 45 % between 1950 and 1980 and 25 % after 1980 (Annex 30, Retrofit Heat Pumps for Buildings). It is foreseeable that the most of these buildings have to renew their old heating systems during the next years. The market in existing buildings seems to be an excellent chance for heat pumps.

2 REQUIREMENTS FOR A HEAT PUMP IN OLDER BUILDINGS

In addition to high flow temperatures in excess of 70 °C, these heating systems should also provide a correspondingly high mono-energetic heating output heating capacity

of around 20 kW. The bivalent point is set at an outside temperature of -7 °C. This then corresponds to a heating output of approx. 13 kW. The fact that heat pumps for the modernisation market should preferably use outside air as their heat source in order to make subsequent installation as straightforward as possible represents a particular problem. With low outside air temperatures, the heat pump's COP falls and this ultimately has an adverse effect on the annual performance factor. Depending on the construction of older buildings, the heating output is assumed to be made up of 90% heat for heating and 10% for domestic hot water heating.

The need for a low GWP in conjunction with a high annual performance factor in line with the definition of the TEWI (Total Equivalent Warming Impact) is becoming increasingly important due to the current climate situation.

3 HIGH TEMPERATURE HEAT PUMP

The classic cold vapour process essentially comprises an evaporator, a compressor, a capacitor and a throttling device. Water flow temperatures of 55 °C to 60 °C are achieved with current standard refrigerants, e.g. R407C. Such a heat pump is only suitable for modernising older buildings to a certain extent.

The flow temperature can be increased by the so-called EVI process (enhanced vapour injection with an economiser). In this process, vapour is injected into the compressor in the medium pressure stage by means of a centre inlet. This process reduces the hot gas temperature at the compressor outlet, enabling higher water flow temperatures. Pressures of around 29 bar can now be achieved with a discharge temperature of 110 °C compared to a process without enhanced vapour injection. At ambient temperatures of -10 °C, flow temperatures of up to 65 °C can thus be achieved with R407C in an air/water heat pump.

A heat pump process using CO₂ as the refrigerant is supercritical at flow temperatures in above 35 °C. High pressures in excess of 100 bar on the high pressure side and 20 to 30 bar on the low pressure side are typical when using CO₂.

Combining the supercritical CO₂ process with vapour injection and an economiser also results in a reduced hot gas temperature. This ultimately leads to lower pressures on the high pressure side (with the same flow temperature) and thus to better COP values compared to a heat pump without EVI. This can be particularly advantageous with lower evaporation temperatures.

4 REFRIGERANT SELECTION

CO₂ was thus selected as the refrigerant for high temperature heat pumps for modernising old buildings. CO₂ is non-toxic, non-flammable and has a GWP of 1. What's more, a future ban on the hydro fluorocarbons currently used as refrigerants (e.g. 134a, 407C, 410A) cannot be ruled out and there is also a growing trend towards power generation from renewables, thus shifting the balance even more towards the GWP in terms of the TEWI definition.

5 TEST RESULTS

Evaporators and gas coolers were designed and checked by testing as part of a preliminary experiment.

A plate-type heat exchanger, a coaxial heat exchanger and a tube bundle heat exchanger were designed as gas coolers and checked through testing. The results of the gas cooler tests are summarised in a diagram (figure 1). The heating output is shown on the X axis and the mean temperature differential between the heating water and the refrigerant CO₂ (Δt_m) is

shown on the Y axis. The general aim is to achieve as small as possible a Δt_m with the same heat transfer rate.

The coaxial heat exchanger transfers the heat slightly better than the plate-type heat exchanger. The plate-type heat exchanger tested is also a special design that only achieved the pressure resistance by means of a solid clamping device. The coaxial heat exchanger was selected for further tests for this reason.

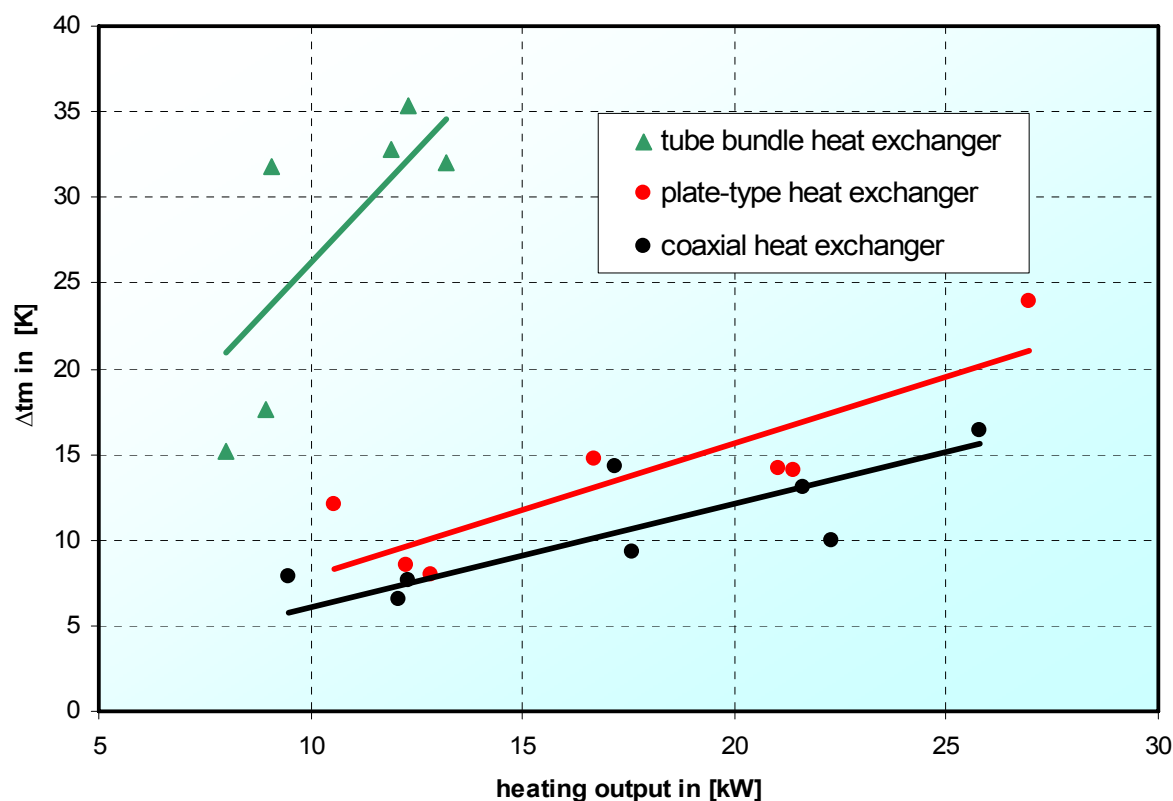


Figure 1: Results of the gas cooler tests

The evaporator was supplied with circulating air as standard. The air quickly lost its moisture content and can be described as dry during the test process. To record the influence of the moisture, additional test in this respect were performed under real conditions. A significantly lower air flow was achieved in this process with the same output. This is shown in table 1.

Table 1: Results of the evaporator tests

Nr.	Temperature outside air	Evaporating temperature	Mass flow CO ₂	Volume flow air	Comment
	[°C]	[°C]	[kg/h]	[m³/h]	[-]
I	DX- evaporator (first prototype)				
I.1	-11.6	-15.4	171	5850	Dry air
II	DX- Evaporator (CO2 optimized: high pressure resistance, higher heat transfer rate)				
II.1	-11.8	-13.7	173	5600	Dry air
II.2	-12.0	-13.9	173	4500	Moist air

The CO₂ compressor was tested by Copeland. The second generation prototype has an isentropic efficiency of over 60%. First results are shown in table 2. All these measurements were done without hot gas injection.

Table 2: Results of the compressor tests

Nr.	Evaporating temperature	Discharge temperature	High pressure	Isentropic efficiency
	[°C]	[°C]	[bar]	[-]
1	-7	95	85	0.55
2	0	110	80	0.61
3	-16	150	110	0.53

6 EFFICIENCY OPTIMISATION

A notable feature of the supercritical process, unlike the subcritical process, is the high enthalpy differential that goes hand in hand with a wide temperature differential. The isobar heat capacity reaches a maximum at the isotherm turning point above the critical point. The gas cooler should be operated in this range. The isotherm turning points shift towards the right as the pressure and temperature rise. The high pressure value should be adjusted as a function of water temperature and the outside air temperature in line with the course of the isotherms. If the gas cooler is designed correctly and with optimum pressure and temperature conditions, the temperature spread on the water side can thus be reduced to a considerable extent, as can the mass flow rate of CO₂. At the temperature constellation as shown in figure 3, 120 bar may be the optimized pressure.

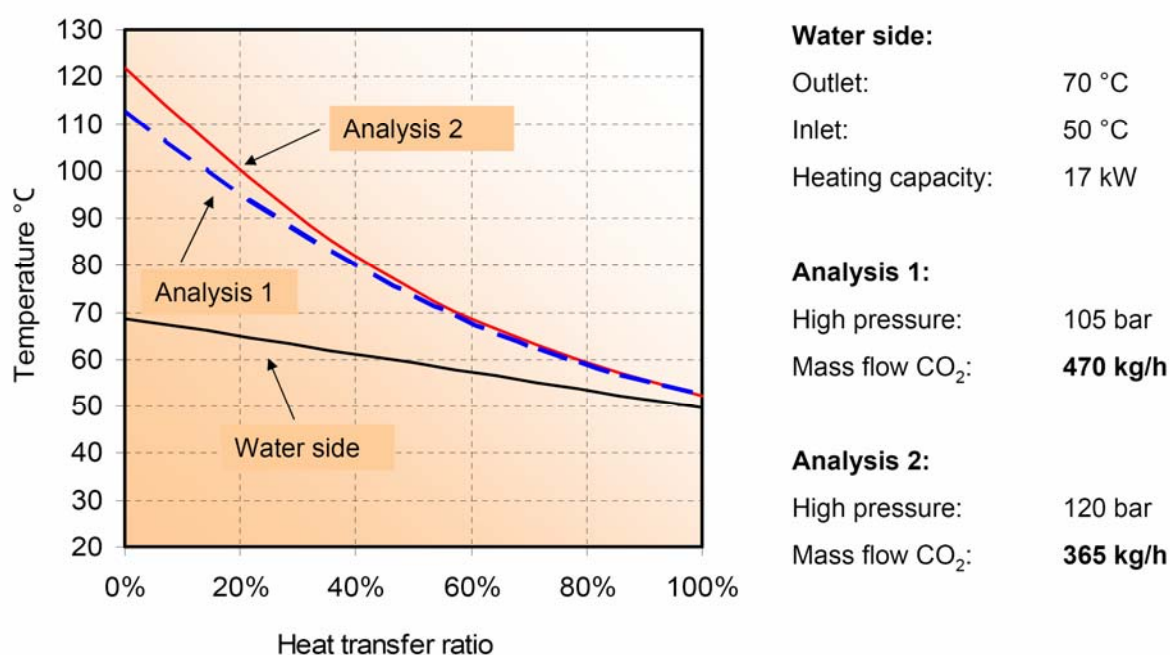


Figure 3: Typical temperature course at gas cooler at different pressures and by the same heating capacity of 17 kW

The heat pump also needs to be operated subcritically in order to achieve an annual performance factor of more than 3.0. In addition to high pressure control, this also requires traditional overheating control.

7 PROTOTYPE

Outwardly, the CO₂ heat pump is only slightly different from the appliances available on the market at present. A standard Viessmann casing has been used to create the heat pump prototype. Figure 3 gives a look inside the prototype heat pump.

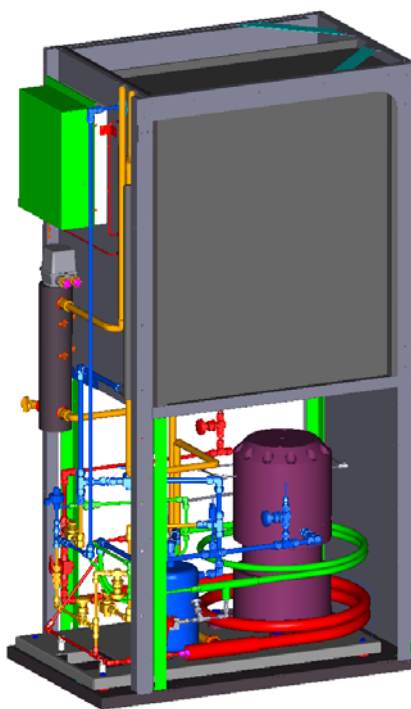


Figure 4: Prototype

8 CONCLUSIONS

The first prototype of the retrofit heat pump with high energetic efficiency is build up and the first tests were done. First measurements are done without the hot gas injection. Further measurements will be done with the activated so called EVI-Process.

Certainly, air is not the most efficient heat source for heat pumps. But the installations of ground probes are often not possible in existing buildings. To use air means low installation costs and make the installation himself easier. In our calculations the CO₂ heat pump reaches a seasonal performance factor (SPF) over 3.0 and has ecological advantages.

Furthermore, there are a lot of technical challenges for the CO₂ heat pump technology. The biggest problem is the high working pressure related to the supercritical CO₂ circle. For example, there is no plate-type heat exchanger as gas cooler available for pressures higher than 120 bar.

9 LITERATURE

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