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Scroll Compressors for Dedicated Heat Pumps: Development and Performance Comparison

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ABSTRACT

Heat pump systems have to operate at high efficiency levels to be an economical alternative to the traditional heating systems. The requirements for the compressors are derived from the heating system design parameters (air or ground source) as well as from the ambient conditions which are not uniform through-out Europe. Therefore dedicated compressors were developed with adaptations to the standard air conditioning models to achieve the required coefficients of performance as well as the necessary operating range. Two types of scroll compressors for dedicated heat pumps are described in this paper. The first type is developed based on basic scroll design for an increased operating map and performance at high condensing. The second type of compressor for high condensing and low evaporation operation integrates an injection port to allow the heat pump to use a cycle with economizer. The main advantages are then a higher COP, increased operating map and higher capacity at low evaporation. These dedicated compressor designs make it possible to achieve the required high condensing temperatures. A performance comparison with the standard compressor designs is finally presented.

1. INTRODUCTION

Heat pumps for space heating have a long tradition already, but for many years they could not win substantial market share versus the conventional fossil heating systems in Europe. Meanwhile however, technically highly developed heat pumps are available and a growing usage of heat pumps in space heating is taking place also due to the constantly increasing gas price.

Climatic conditions and designs of the buildings define the requirement for the operation of a heat pump and in particular for the compressor. The compressor in particular has to meet the requirements of a very wide operating range and high energy efficiency ratios (EER), since in the end a heat pump does not only have to be ecologically beneficial but it also has to be economically viable.

This can only be achieved if in comparison to the conventional European heating systems the higher first costs of a heat pump can be compensated by substantially low operating costs. In this respect, it will be shown that the compressor can make a noticeable contribution.

Generally, all compressor technologies that are known from the air conditioning and refrigeration sector can be found in heat pumps. Scroll compressors however, have demonstrated their superior position from a technical and economical point of view. Therefore, the following text is dedicated only to this kind of compression technology.

2. HEAT PUMP SYSTEMS

Heat pump type and performance is characterized by the nature of the source, i.e. the medium from which heat is extracted by the evaporator, and the sink, i.e. the distribution of heat in the building. The two main sources of heat are ground (sometimes called geothermal) and air. Below a certain depth, ground temperatures remain relatively stable and the ground source heat pump (GSHP) has a typical source temperature of 5° - 10°C. Brine is circulated in a sealed loop via a bore hole to gain the necessary heat. Drillings of 50 m depth and upwards are typical. An alternative method is to circulate a glycol solution through plastic pipes, laid in trenches. It is also possible to circulate the refrigerant directly by inserting the copper tube evaporator in the drilling. This eliminates one of the heat barriers, but increases refrigerant charge and there is always the issue of underground refrigerant leakage, which can be costly to rectify. The factory assembled heat pump unit itself is quite compact and contains the complete refrigeration circuit and pumps for circulating the cold and warm secondary fluids,

Air temperatures are within the range 5 to 15 °C for a large part of the heating season, higher than with ground source for much of the year, resulting in excellent performance. With no drilling or trenching the installed cost of such a unit is usually much less, and there is also much less disruption. The ASHP contains the complete refrigeration circuit and is similar in this respect to the GSHP, but with an air coil evaporator and fan instead of a plate heat exchanger and water pump.

However there are some drawbacks with air source. Outdoor temperature variation significantly affects the capacity and efficiency. In particular, low outdoor temperatures result in poor performance, and bring the additional problem of ice formation on the outdoor coil. Defrosting can be done by using a reversing valve to temporarily deliver hot gas to the outdoor coil, although this may have the undesirable effect of suddenly cooling the hot water supply! Another method is to divert some discharge gas to the evaporator using a hot gas bypass valve. Whilst the duration of very low outside air temperature conditions may be relatively short, their occurrence coincides with the most acute need for heating, and so it is critical that the ASHP can cope. Sufficient capacity requires a larger unit than would be needed for ground source, or an alternative is to use back up heating during cold spells.

One of the most efficient ways of delivering space heating is an under-floor water distribution system. This consists of plastic coils embedded in a solid floor, above a layer of insulation. The water may be circulated at a relatively low temperature of say, 35 to 40°C and this system is almost exclusively applied to new build. Wall hung radiators result in lower COPs than under-floor coils because higher water temperatures are required.

The provision of domestic hot water (DHW) in addition to space heating necessitates a control system so that the HP can deliver lower temperature heat for space heating once the DHW demand is satisfied. Alternatively a top up electrical immersion heater or inline heater can bring the water temperature up to 60°C.

It can be seen that there are a number of possible heat pump configurations and each application requires careful consideration of source, sink and use pattern.

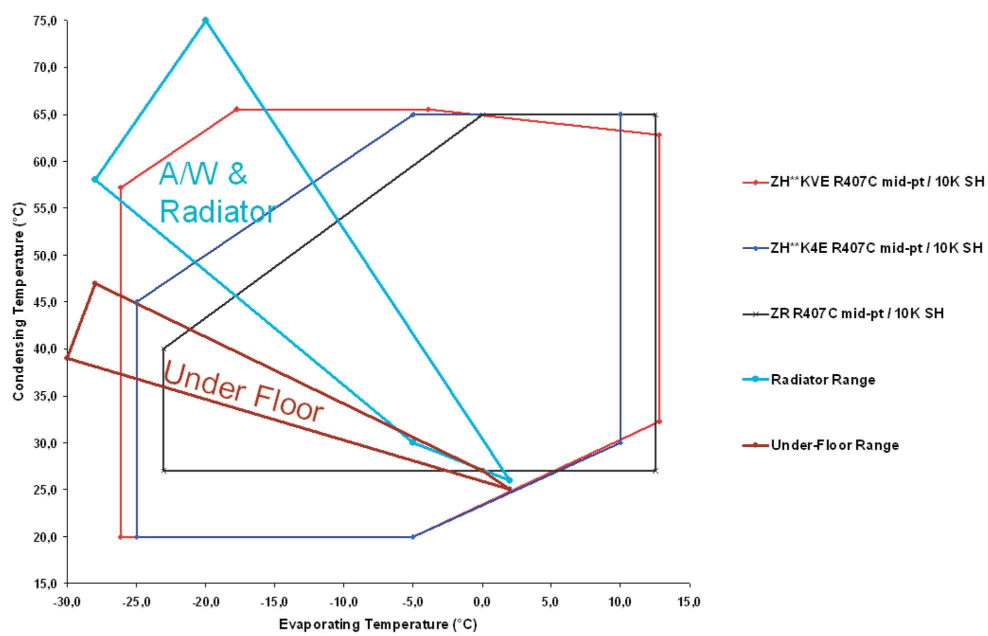

Figure1. Operating map of Air Source Heat Pump Applications

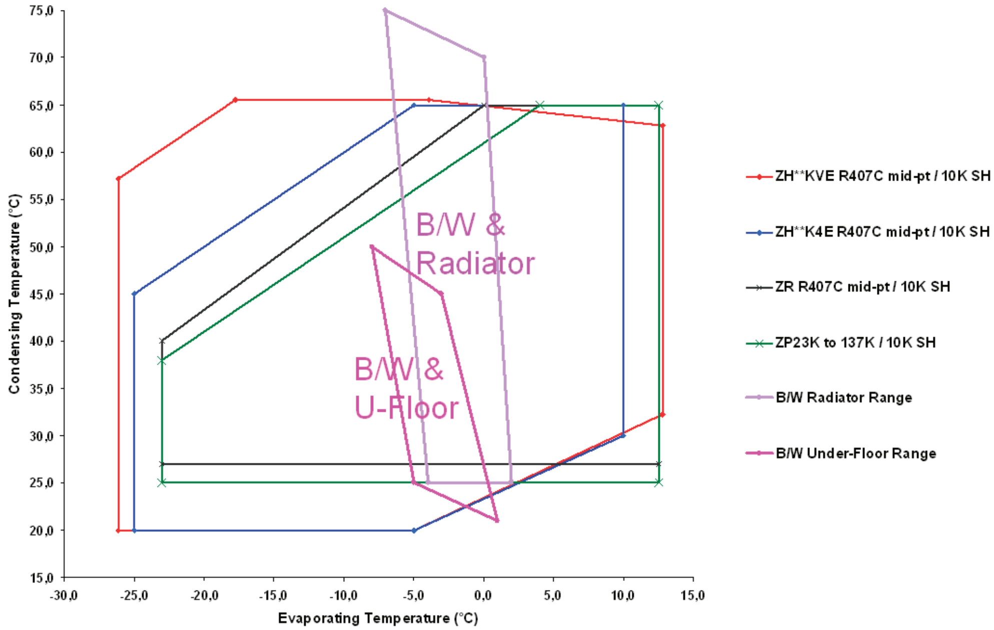

Figure2. Operating map of Ground Source Heat Pump Applications

3. COMPRESSOR DESIGN CONSIDERATIONS

The basis of all derivative developments of scroll compressors is given by the scroll air conditioning compressor which is produced in very large quantities, and therefore in a very cost effective manner. This design is referred to as ZR compressors in this paper.

Figure 3 highlights the particular design modifications of a heat pump compressor (referred as ZH in the paper) versus a scroll compressor for air conditioning application (ZR).

Main design changes are scroll set, floating seal and the addition of a dynamic discharge valve. Heat pump scroll compressors have a particularly adapted scroll set coming from the fact that the design optimization points (HP1 & HP2) required for heat pump operation mode have a higher pressure ratio than the air conditioning design points, ARI & CHEER (see comparison in Figure 4). The larger operating envelop is also dictating some design considerations in terms of reliability at conditions where the scroll vanes see higher differential pressures in case of heat pump.

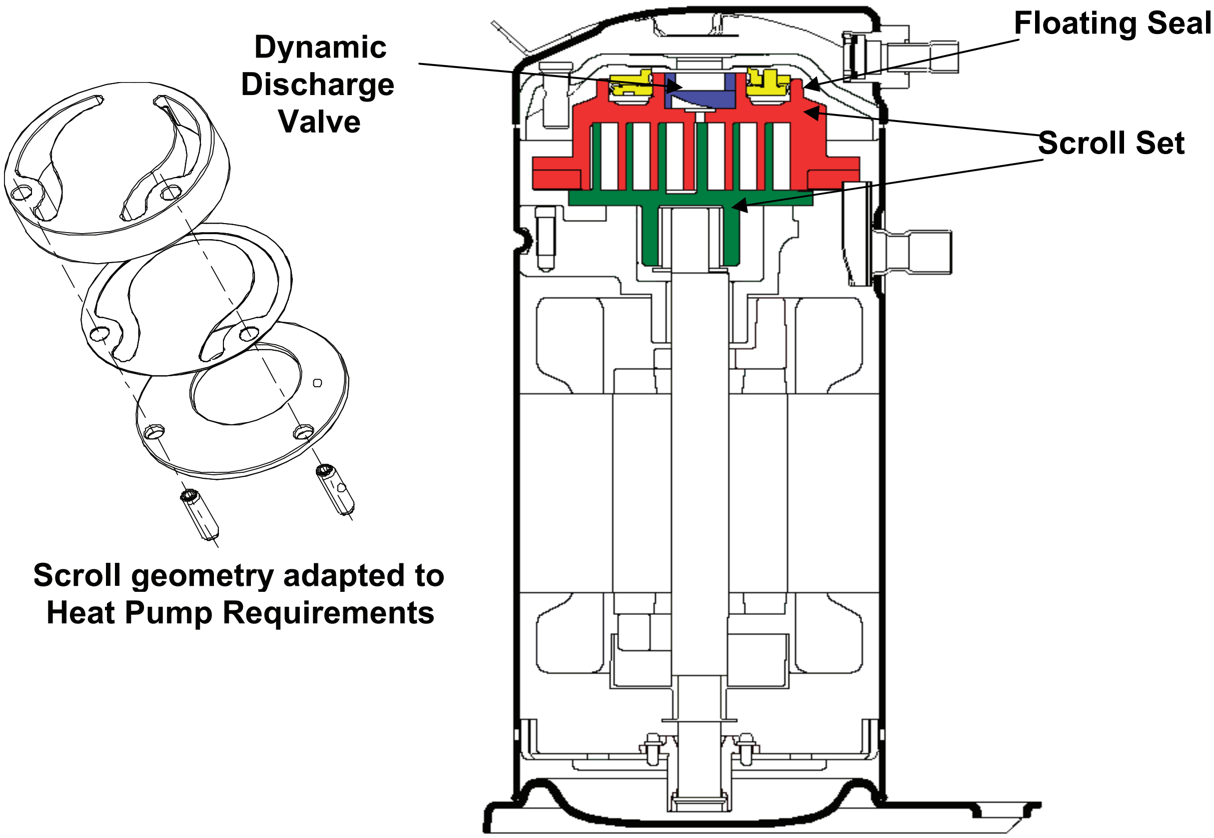

Figure 3. Component Changes for Heat Pump Compressor Vs A/C Baseline

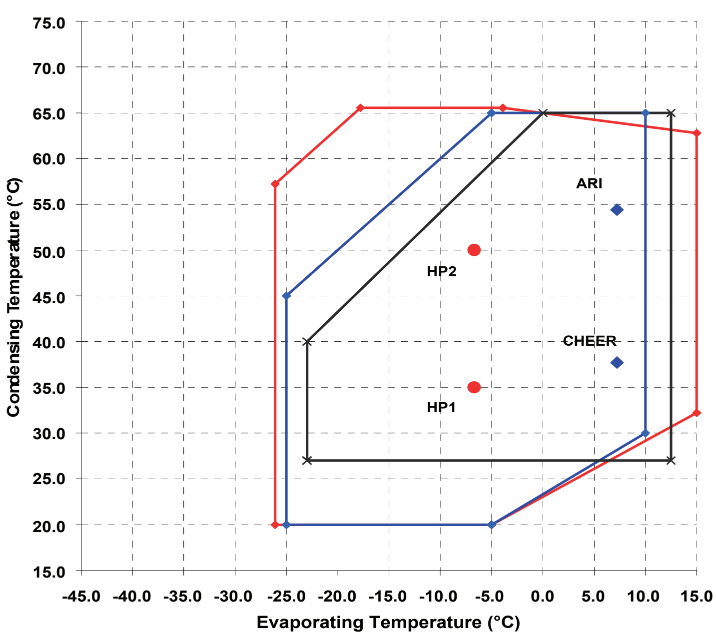

Figure 4. Optimization Points for Heat Pump Vs. A/C Scrolls

Pressure ratio seal change is a consequence of scroll design change, resulting in different axial balance forces and thus requiring different diameters on the pressure ratio seal. Also, the orbiting scroll mass change might induce in some cases the resizing of the counterweights (upper and lower) in order to keep good balancing.

Like scroll compressors used in refrigeration applications, heat pump scroll compressors have a dynamic discharge valve in order to minimize the fixed volume losses resulting from the built-in volume ratio of this machine. The discharge volume flow in heat pump compressors is larger than that of refrigeration compressors and this required an enlargement of the dynamic discharge valve so that flow losses would be minimized. The benefit of such valve is only valid for the upper left portion of the operating envelop of the compressor (very high pressure ratio's). Nevertheless, the discharge valve is also useful across the full operating map to prevent the compressor from running in reverse direction at shutdown, which usually creates unpleasant noise.

4. VAPOUR INJECTION

Unfortunately, the operating map from the ZH compressor (operating map in blue, see Figure 1) does not encompass all required heat pump operating points, and in particular it does not encompass the operating point required for an air-to-water heat pump in a retrofit for existing buildings (using radiators). To achieve that Figure 5 presents a design with vapor injection (referenced as "ZH-KVE" compressor). This injection gives a larger cooling and respectively heating capacity, while the power consumption of the compressor increases proportionally less, thus resulting in an improved EER. Furthermore, injection also produces a cooling effect for the discharge gas and therefore a lower discharge temperature, which enlarges the operating map in the area needed by heat pump (low evaporating and high condensing temperature area).

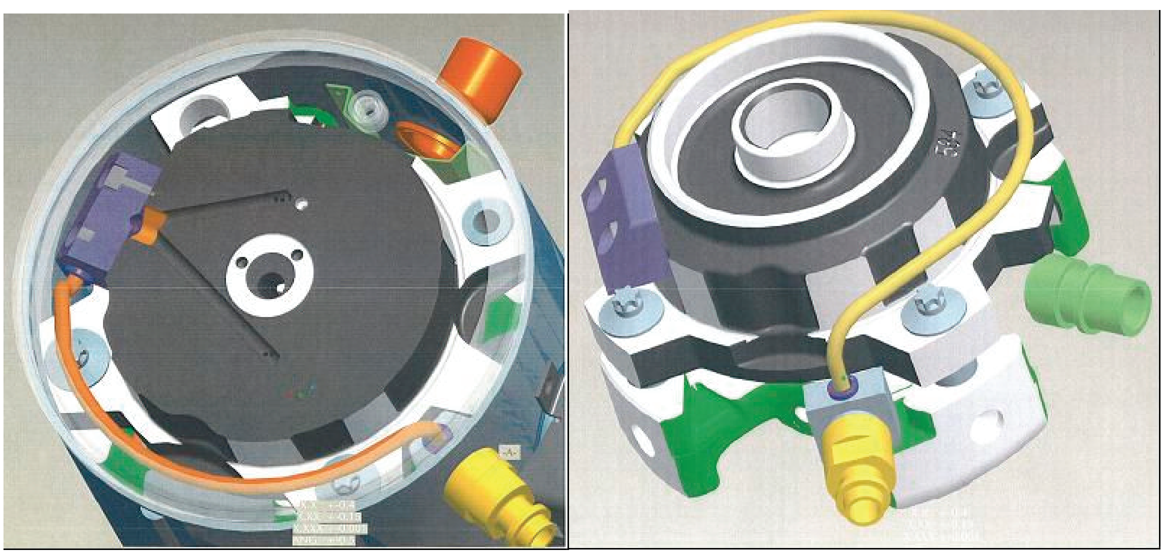

Figure 5. Injection Tube in ZH-KVE Compressor and Scroll Injection Ports

The principle of vapor injection is identical to the one used in refrigeration scrolls and is illustrated in Figure 6. To utilize these advantages of an enlarged operating envelope and an improved coefficient of performance, some extra elements have to be added to the design of the system, such as a subcooler, additional expansion valve, piping, etc.

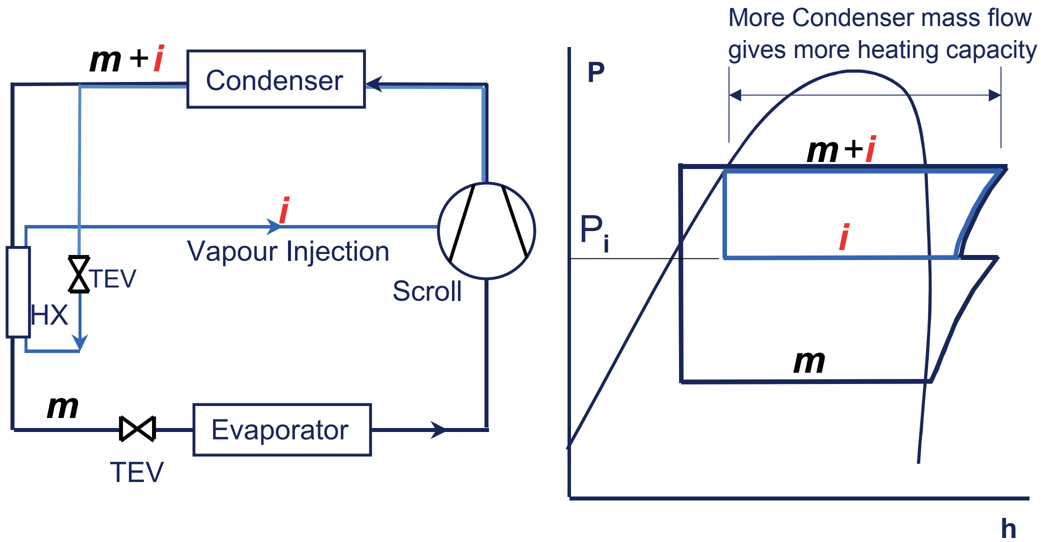

Figure 6. Vapour-injected scroll compressor with enhanced vapour compression cycle

This now encompasses the particularly important operating points for the practical application of the maximum design condition for an air-to-water heat pump in a retrofit installation at –15 / 60°C. This shows that the modified scroll geometry and the modified integrated dynamic discharge valve already gave rise to a substantial enlargement of the operating range versus the standard air conditioning compressor. Moreover, the injection of refrigerant vapor allows a substantial further enlargement of the operating envelope to lower evaporating and high condensing regions, that is at high compressor ratios. These operating maps then encompass the largest portion of what is required in the retrofit market.

An economical operation of the heat pump does not only require to meet the extreme operating conditions, but also it is equally important to achieve high energy efficiency ratios to give low operating costs.

Figure 7 shows the coefficients of performances (COP) for these two heat pump compressor types in comparison to the standard air conditioning compressor ZR. The "COP heat" is the ratio between the heating capacity (equals to cooling capacity plus 95% of electrical power) divided by the electrical power consumed. Even in the condition – 6.7°/ 35°C which is a reference point (representing the brine to water application for underfloor heating, see Figure 2), these special heat pump compressors give higher COP's (5 to 6%) than the air conditioning compressor. In this condition, vapour injection gives marginal advantage due to the low pressure ratio.

A more important operating point for heat pump operations generally speaking is – 6.7°/ 50°C and it shows here that vapour injection gives a noticeable increase of the COP with respect to the heat pump compressor without vapour injection.
To better illustrate the advantage of the heat pump without and with vapour injection versus the air conditioning compressor, Figure 8 shows the relative gains in % between the different compressors. Clearly, the higher the pressure ratio the bigger is the advantage of heat pump compressors in comparison to the air conditioning compressor and also the higher the benefit of vapour injection is.

For more extreme operating condition at – 15°/ 55°C, which is at a rather low ambient temperature for air source, only heat pump compressors are able to operate at that condition, data given for the A/C compressor is extrapolated for the sake of comparison.

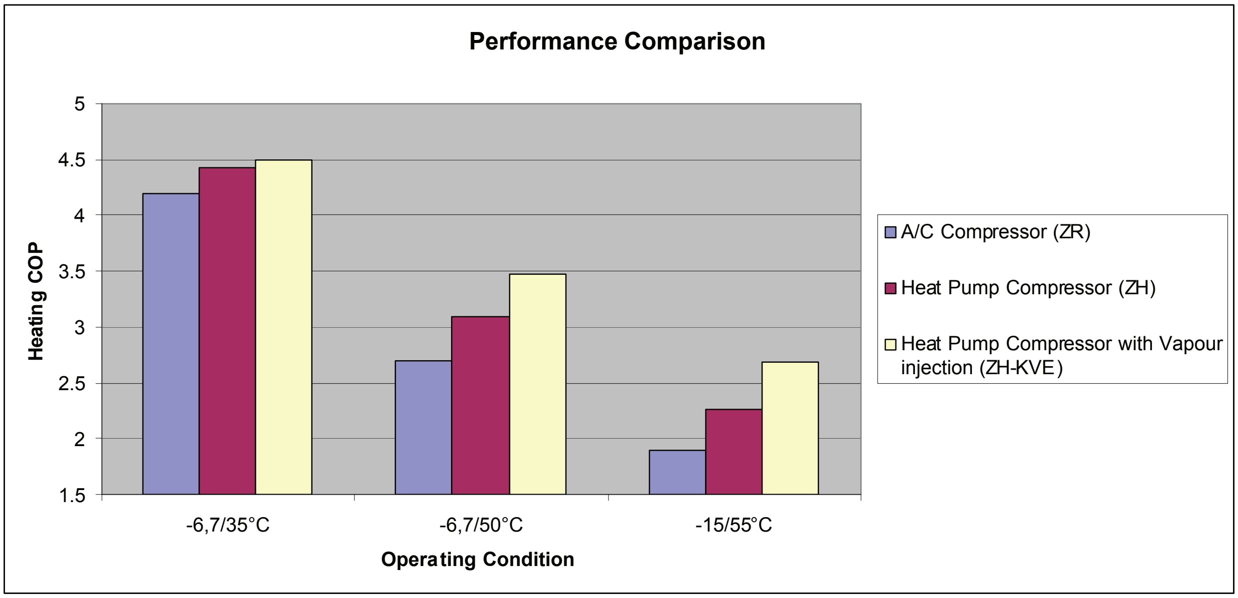

Figure 7 : Performance Comparison

Of course, due to the high pressure ratios in this operating condition, the COP values on an absolute scale are particularly low, but the relative improvement from vapor injection is the highest. In the end, one has to make a trade-off between the additional investment costs when using vapor injection and the low operating conditions, whether or not to use vapor injection or to use a non-injected heat pump compressor.

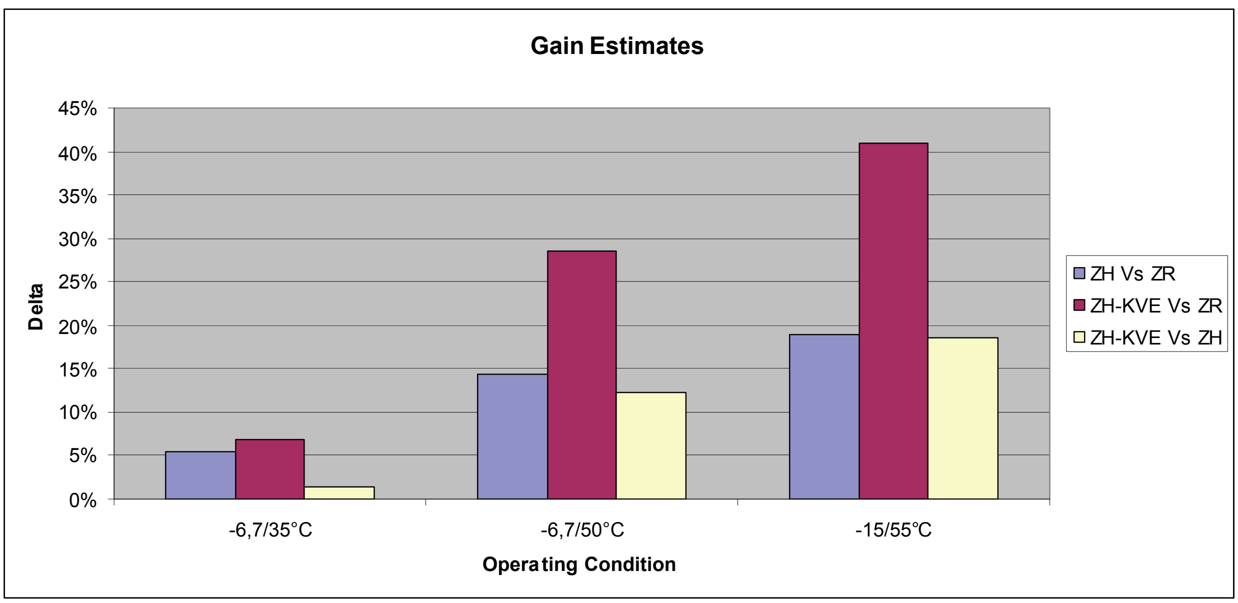

Figure 8. Performance Comparison in Percentage Variation

The performance of the new heat pump compressor family ZH presented is now offering a displacement range between 5 and 40 m³/hr. For an operating condition of – 6.7°/ 50°C, this gives capacities between 5 kW and 40 kW. However, when using vapor injection in this condition, a considerable increase in heating capacity of about 26% is achieved and one can reach a maximum value of 40 kW.

One can show that the performance of the compressor without vapor injection is equivalent to that performance of the compressor which is equipped with the capability for vapor injection (called ZH-KVE) but without utilizing this injection capability. This offers the possibility for capacity control by either activating or de-activating vapor injection, and therefore operating on either one of the two curves shown. Applying this modulation capability, the delivered heating capacity can be better adapted to the heating demand. This is particularly important for the non-coherent behavior between heating capacity demand and available heating capacity in an air-to-water heat pump.

5. CONCLUSION

Electrically operated heat pumps for space heating offer a good alternative to the prevailing fossil fuel space heating in Europe with regard to the reduction of primary energy consumption as well as CO2 emissions. This effect is even increased further now because more and more electrical energy is produced without burning fossil fuel, such as wind energy, solar energy, etc...

A very large portion of today's heating market is the replacement of existing older type heating systems in Europe representing a large potential for heat pump applications. Although several heat pump concepts exist, the air-to-water heat pump which uses ambient air as heat source is the most useful heat pump concept for a replacement of existing fossil fuel heating systems.

However, this system presents the most difficult operating conditions for the operating heat pump, since in this case particularly high water inlet temperatures are combined with a substantial variation of the heat source temperature. In this case, the design point for a compressor is the extreme point of this application, which is a particularly low evaporating temperature in combination with a high condensation temperature.

These operating points can be achieved when utilizing dedicated modifications to existing scroll compressors. In conjunction with vapour injection this achieves a substantial increase of the energy efficiency ratio as compared to the standard air conditioning compressor. For this purpose, two dedicated heat pump compressor product lines were generated. These compressor product lines are able to satisfy a heating requirement between 5 and 40 kW at –6.7°/50°C.

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