Air-to-Water Heat Pump in Heating System

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The subject of the paper is a capability assessment of heat pumps both in the in a classical design with an on / off power control and those with a variable speed control of the compressor to meet variable demands of the heating system during the heating period.

Keywords: heat pump, heating system, heating factor, heating, European reference heating period

The heat pump and the heating system (hereinafter referred to as the HP and the HS) are two separate units with different characteristics. The lower the outside air temperature, the higher the heating system demands on the heat, both on its quantity and the temperature level. For a long time, only heat pumps with constant compressor speed depended on the frequency of the electrical grid 50 or 60 Hz were available, where the HP regulation according to the needs of the heating system was solved by the jumping system on / off. The shortage of heating capacity below the bivalent temperature is covered by an additional heat source, very often an electric boiler. Excess heat has to be accumulated in heating water, whose temperature than rises above the required heating system inlet temperature.

Comparison of heat pumps with constant and variable speeds

An example of the capacity and temperature relationship in the HS during the heating period is shown in the graphs of **Figures 1–4**. The graphs are processed for the average climate conditions according to EN 14825 (minimal ambient temperature −10°C, maximal 16°C), objects with two nominal heat loss of 20 kW and 30 kW, two heating systems represented by a low-temperature one of 35/30°C and a high-temperature one of 55/47°C and the HP with refrigerant R410A. The figures on the left refer to the HP with the constant speed compressor ZH15K1P-TFM of displacement of 11.7 m³/h (heating capacity 16.8 kW at A2/W35), the figures on the right refer to the variable speed compressor ZPV0631E-4E9 of displacement of 11.0 m³/h (at 50 Hz). The monitored quantities are indicated in the figures as follows:

—	Qloss	thermal loss of the building in kW
◆	QHP	heating capacity of the HP in kW
—	QB	heating output of electric boiler in kW
—	THSin	water temperature at the inlet to the HS
—	THSout	water temperature at the HS outlet
▲	THPin	water temperature at the inlet to the HP
■	THPout	water temperature at the HP outlet

If a constant speed HP with the previous mentioned compressor size is used in an object with a nominal heat loss of 20 kW and a low-temperature heating system of 35/30°C (**Figure 1**, left), it results a bivalent operation (bivalent parallel) with the balance point determined by capacity. The balance point temperature is about −3°C and besides the HP, a bivalent heat source with a capacity of up to about 7.5 kW for ambient temperatures of −10°C is required.

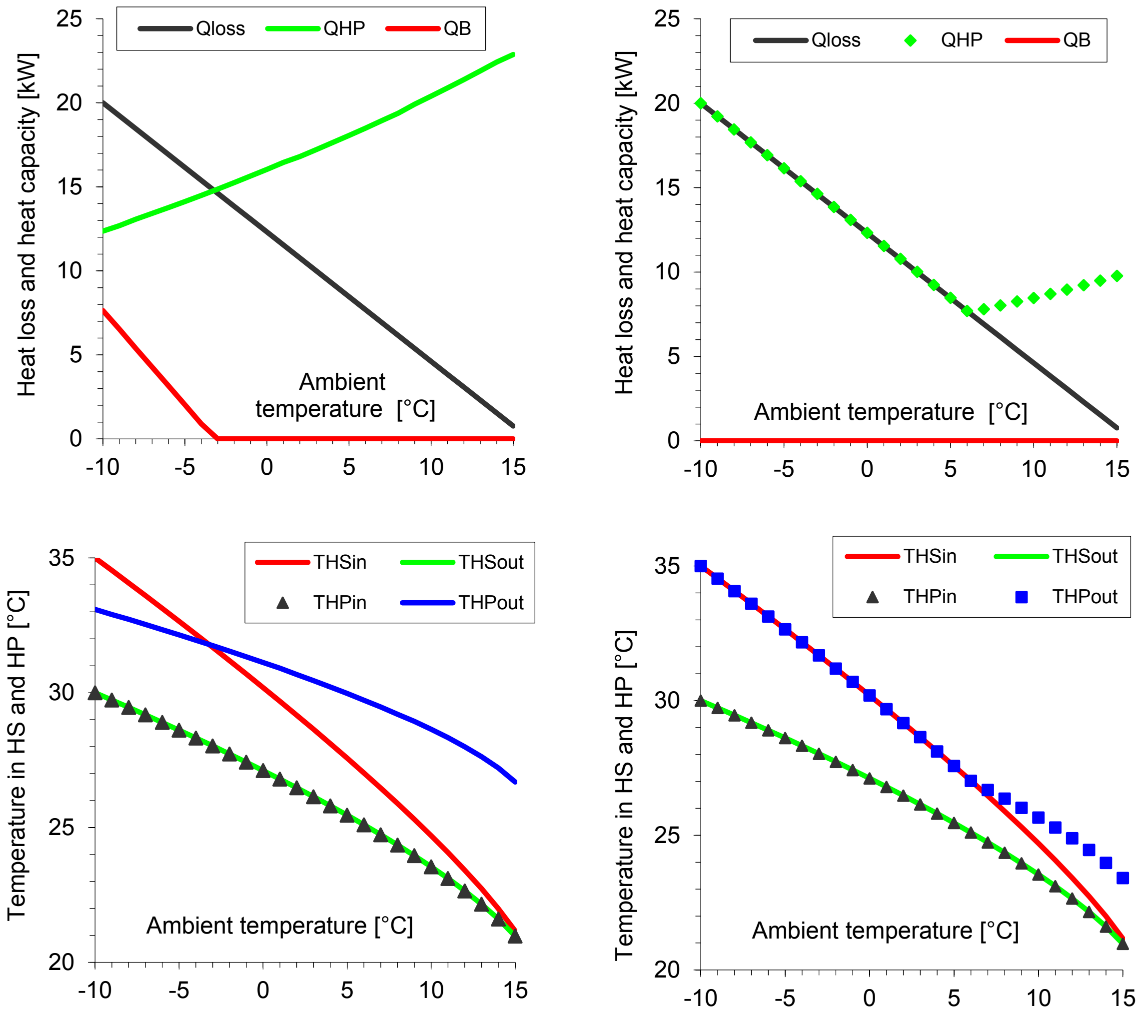

Figure 1. Low-temperature heating system 35/30°C with a heat pump and nominal building heat loss of 20 kW (constant speed compressor on the left, variable speed compressor on the right).

If a variable speed compressor is used, it operates in the frequency range of 20 Hz to 85 Hz and, therefore, still has a capacity reserve, since the maximum frequency is 120 Hz. It can be seen that the temperature of the water leaving the HP exceeds the required inlet temperature to the HS only at ambient temperatures over 6°C because the compressor cannot operate at a frequency below 20 Hz to reduce the heating capacity to the desired HS value. The system can be rated as monovalent.

If the high-temperature heating system 55/47°C was used in this object, the operating conditions would correspond to the state shown in **Figure 2**. A significant change will occur in the HS with an HP with a variable speed generator, where the system converts from monovalent into bivalent – partially parallel. With outdoor air temperatures below −5°C, the heat pump still has sufficient heating capacity (the compressor frequency is only about 59 Hz), but it cannot heat the water to the desired HS temperature because the condensing temperature would go beyond the compressor's operating limits. In order not to exceed the maximum allowable condensing temperature, the compressor speed is gradually reduced at outdoor temperatures of approx. −5°C to −9°C, but the compressor's operating range decreases significantly, especially at speed below 40 Hz (see **Figure 5**), so at the ambient temperature below −9°C, the compressor should be switched off. This is reflected, among other things, by the need to dimension a bivalent heat source to the full nominal object's heat loss.

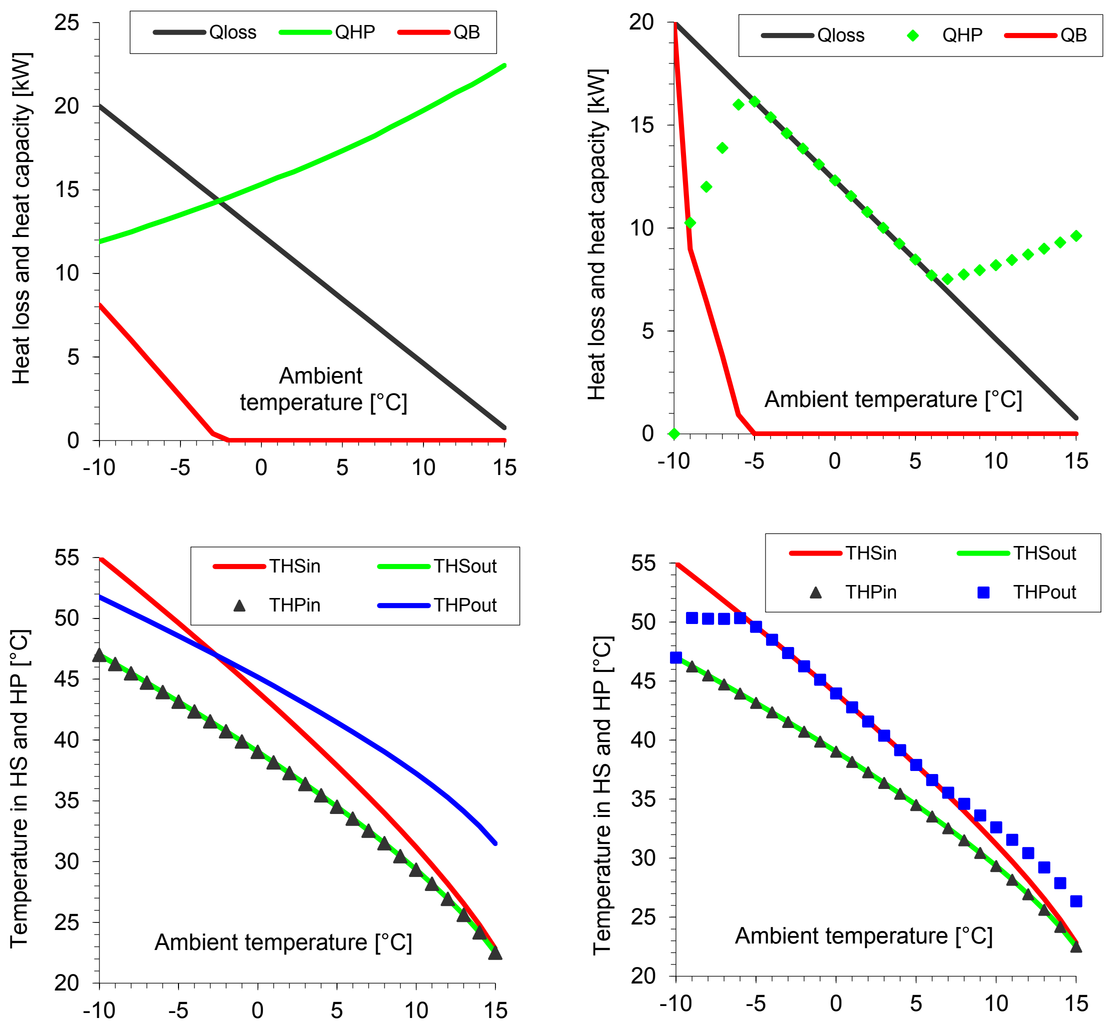

Figure 2. High-temperature heating system 55/47°C with a heat pump and nominal building heat loss of 20 kW (constant speed compressor on the left, variable speed compressor on the right).

In **Figures 3 and 4**, these heat pumps are monitored when used in an object with a nominal heat loss of 30 kW, where the constant speed of the compressor reaches the balance point temperature at +2°C. This temperature is specified in the ČSN EN 14825 and Commission Regulations (EU) No. 811/2013 and 813/2013 as the maximum balance point temperature for the average climate conditions. This size of the heat pump with a compressor ZH15 compressor with constant speed is suitable for objects in the average climatic area up to this nominal heat loss. Therefore, the behaviour of the heat pump is not monitored in buildings with a higher nominal heat loss than 30 kW in this paper.

It is important to note that the HP with a variable speed compressor in the HS of 55/47°C with a nominal heat loss of 20 kW (**Figure 2**) could no longer work at the ambient temperature of –10°C, in that with a heat loss of 30 kW, it works properly with a heating capacity of about 9.7 kW. This is due to the fact that, when demanding higher capacity, it operates at higher speed corresponding to a wider operating range.

In **Figure 5**, the operating areas of both compressors are specified for refrigerant R410A, depending on the evaporation temperature t_o and the condensation t_c. For the cooperation of variable speed compressors with a high temperature HS (e.g. the observed 55/47°C), the slightly lower condensation temperature compared to the fix speed compressor and the reduction of the operating area at high or low frequencies as shown in the right part of **Figure 5** are unfavourable.

For effectiveness description, the Coefficient Of Performance (COP) is used as the ratio of heating

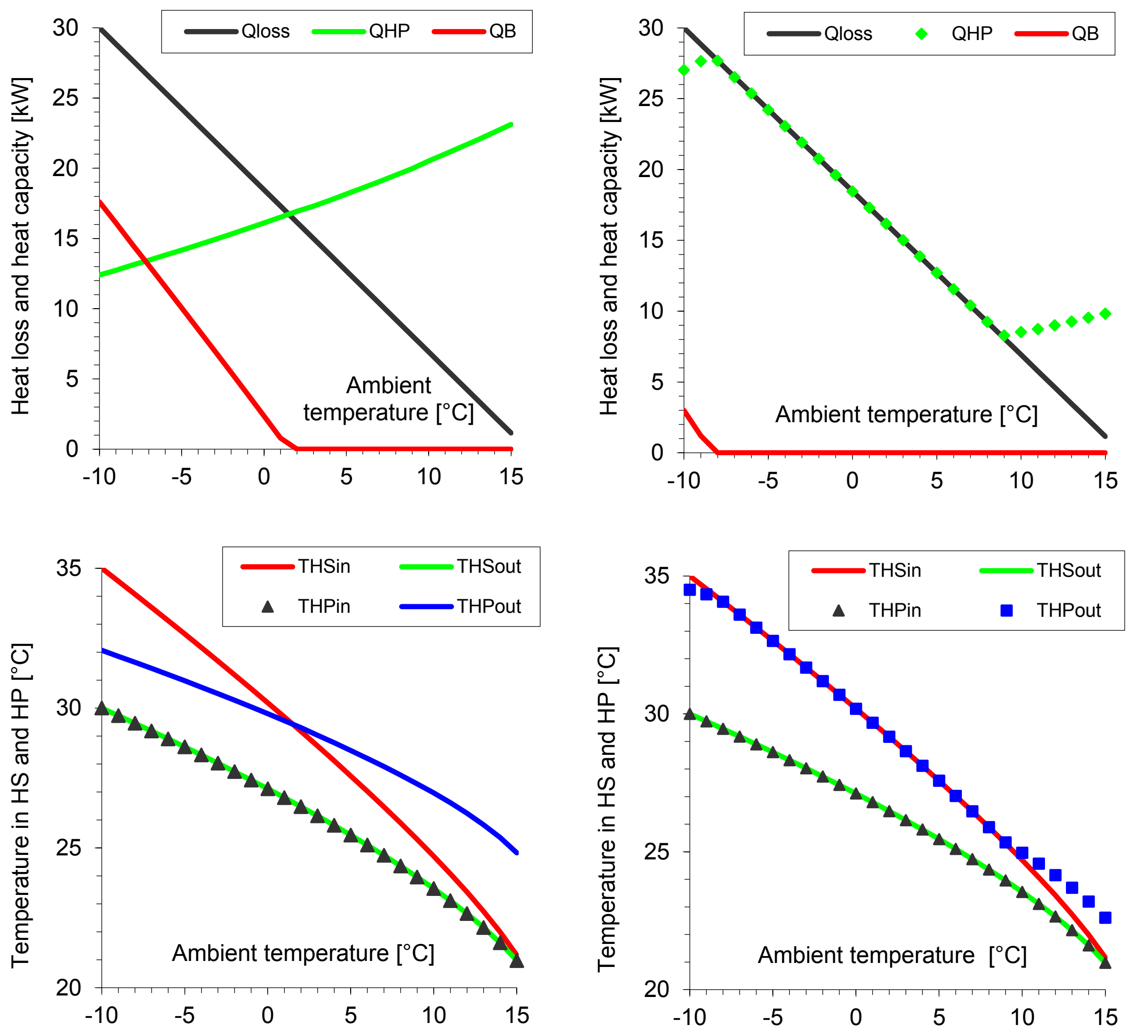

Figure 3. Low-temperature heating system of 35/30°C, heat loss of the building of 30 kW (constant speed compressor on the left, variable speed compressor on the right).

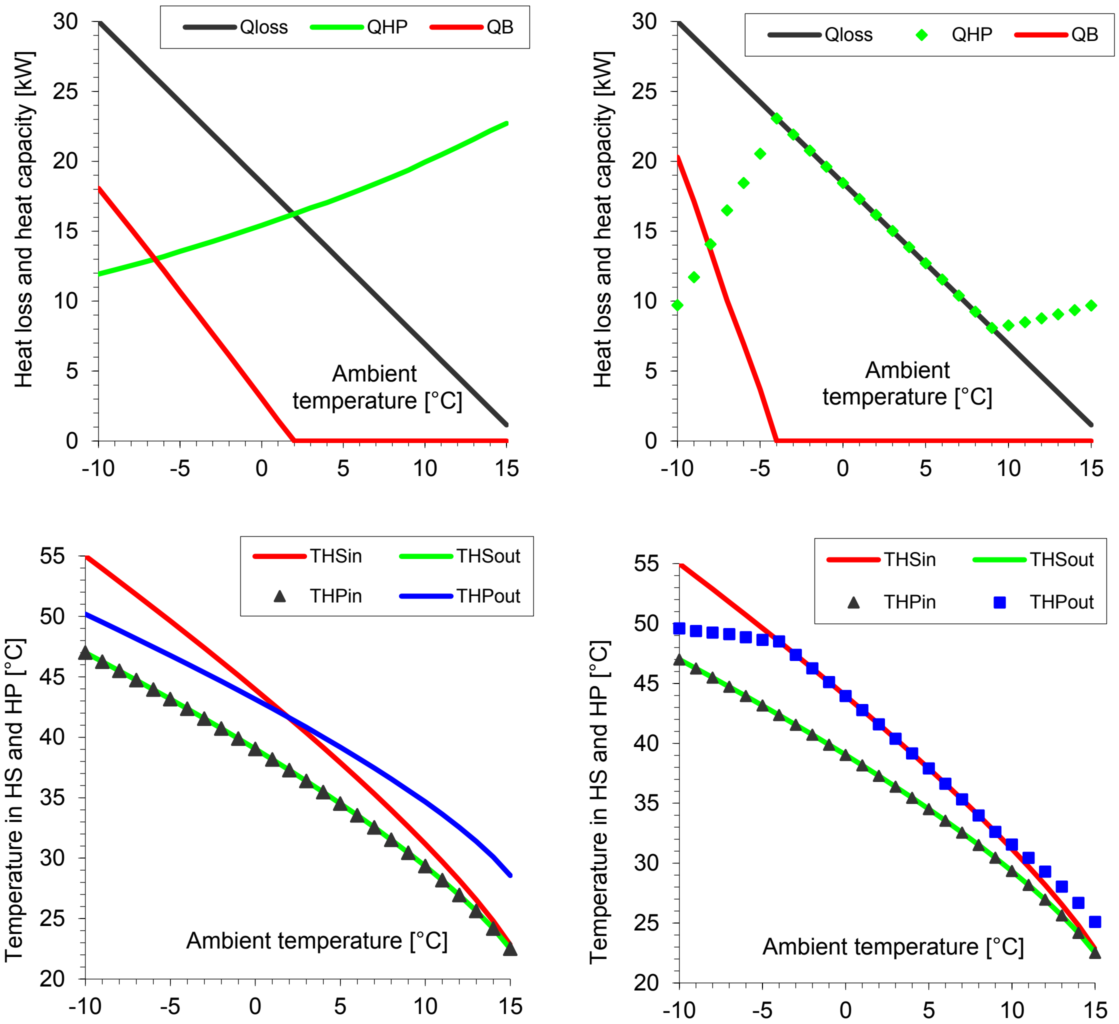

Figure 4. High-temperature heating system of 55/47°C, heat loss of the building of 30 kW (constant speed compressor on the left, variable speed compressor on the right).

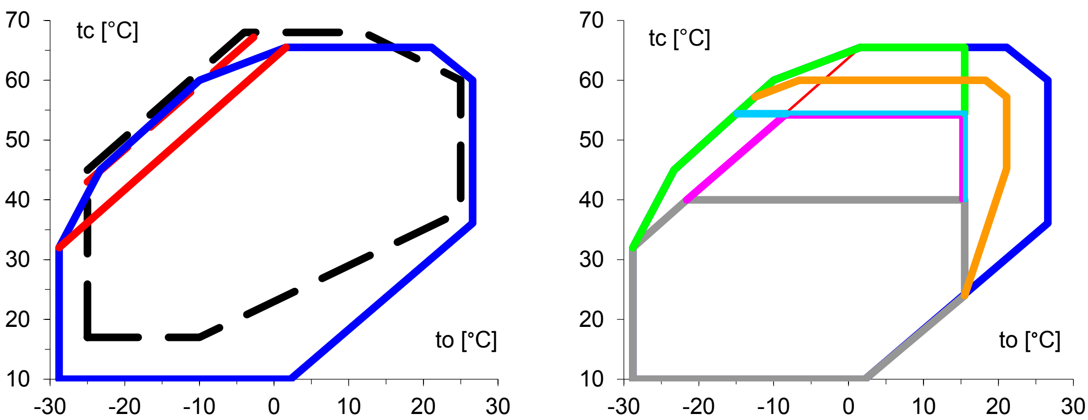

Figure 5. The operating zone of the employed compressors (valid for overheating at the inlet at 5K; the zone is limited by red line for overheating at 10 K): dashed line for the ZH15K1P-TFM compressor with constant speed; solid line for the ZPV0631E-4E9 compressor with variable speed (dark blue 43 Hz to 100 Hz, grey 20 Hz, purple 30 Hz, green 40 Hz, orange 110 Hz, light blue 120 Hz).

capacity to the input power. Today, ČSN EN 14825 defines a total of 8 types of numerals that distinguish between the indices with the abbreviation *COP* or (if associated with a certain period of time) it has the *SCOP* designation and specifying the added index if it is only for the HP (then *SCOP*net) or includes the power consumption by an additional source (*SCOP*on). At the same time, for the purposes of calculating the reference *SCOP*, three reference climate conditions are established: average, warmer and cooler. For these conditions, the range of ambient temperatures and the corresponding heating hours are given. The heating period in all three condition types uniformly ends at an outdoor air ambient temperature of 16°C.

Climate conditions in the Czech Republic are best reflected by the average climate conditions [5]. Therefore, they were used in the calculation of *SCOP*on values and for the determination of the annual energy savings. For simplification, this is understood as the difference between the thermal energy delivered to the HS and the electricity required for the operation of the compressor and an electric heater as the additional bivalent heat source. Results are shown in **Figures 6 and 7** for the assumed use of the heat pump in buildings with a nominal heat loss of 10 kW to 30 kW where COP also reaches their maximum.

A large heat pump in a building with a low heat loss means a large investment cost, but according to **Figure 7**, has a small energy saving, i.e., a long payback period. Besides that, there is also a risk for a variable speed compressor in high-temperature heating systems that the low compressor speed restricts the permissible operating limits below temperatures required by heating system, so the heat pump cannot be operated for a major part of the heating period although it is oversized. This is the reason for the missing data of around 10-11 kW for heating the system of 55/47°C in **Figures 6 and 7**. It is, therefore, necessary to install a heat pump of appropriate capacity relative to the size of the object and to operate it at the higher speed of the compressor.

Although, in **Figures 1–4**, a heat pump with a variable speed compressor better follows the needs of the heating system, the improvement of the seasonal *SCOP*on is only about 10% relative to a compressor with a constant speed in buildings with a heat loss of 15 kW to about 22 kW (for a heating system of 55/47°C, approx. 8% only). The explanation can be found in the weaknesses of the variable speed compressor, namely its working area (see **Figure 5**), as well as the higher energy demand of its operation, which is illustrated in **Figure 8** by comparing the specific compression work based on the manufacturer's data shown.

It should be noted that **Figure 8** does not compare the parameters of the HP, but only the compressors. For a variable speed compressor, this variable also depends on the frequency and its values fill the area defined in the figure with red lines.

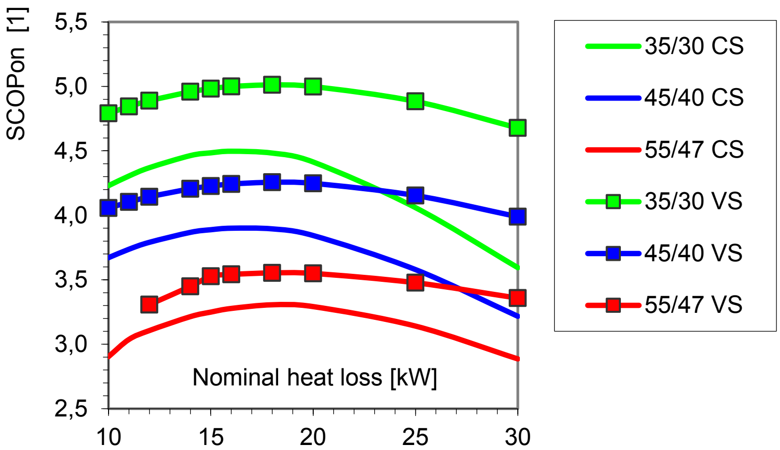

Figure 6. Seasonal Coefficient of Performance SCOPon for different heating systems: CS – constant speed compressor; VS – variable speed compressor.

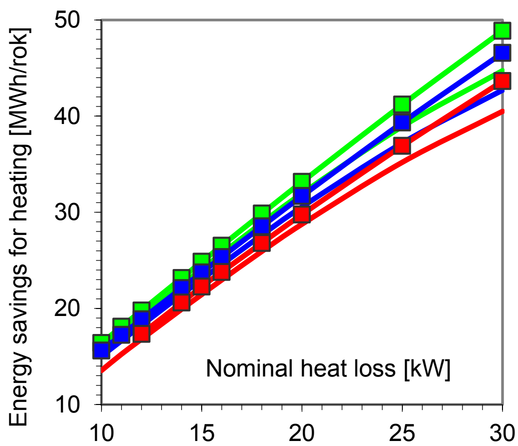

Figure 7. Energy savings for heating: CS – constant speed compressor; VS – variable speed compressor.

In buildings with a nominal heat loss of above approx. 22 kW, the *SCOP*on of a given heat pump with a constant speed compressor is continuously decreasing. This is due to the gradual increase in the balance point temperature and, hence, the longer operation of the bivalent heat source of higher capacity. On the contrary, a heat pump with a variable speed compressor can increase the capacity due to a higher frequency and has a flatter characteristic of the seasonal *SCOP*on, which can be up to 16% till 30% higher than the constant-speed heat pump of the same performance. To improve the heating factor of a constant speed compressor system in such large buildings, it would be necessary to choose a higher performance compressor.

Conclusion

In this paper, heat pumps differing only from compressors (constant speeds and variable speeds varying in the range of 20 to 120 Hz, but approximately equal displacement of 11.7 and 11.0 m^3/h at 50 Hz) were compared. The heat exchangers were identical in both designs (with the same characteristics). Any heat losses due to the heat accumulation have not been considered. This may, in fact, handicap the variant with a constant speed compressor, as the heat accumulation often occurs.

For objects with a nominal heat loss of about 15 kW to 22 kW, a heat pump with variable speed can achieve a better seasonal *SCOP*on by about 10%. In those of 30 kW, this can even be by 16 to 30% depending on the heating system. Due to the increase of the heating capacity by increasing the speed, a heat pump with a compressor of a similar displacement (at 50 Hz) can cover larger objects, but smaller objects (due to the compressor size) may have problems in connection with the significant reduction of the working range (especially heating systems with high water temperatures). A smaller variable speed compressor (with smaller displacement) than for a heat pump with a constant speed compressor will suffice for such an object. ■

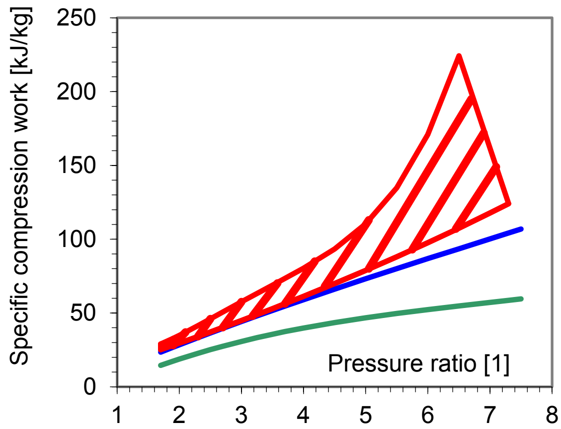

Figure 8. Specific compression work in dependence on the discharge to inlet pressure ratio for the isentropic compression (green) and for the ZH15K1P-TFM (blue) and the ZPV0631E-4E9 (red; hatched area for permissible speed range) compressors.

Acknowledgement

The authors wish to thank doc. Ing. Tomáš Matuška, Ph.D., for reviewing the article.

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