Residential Heat Pump Design
for Low-GWP Refrigerants

A System-Level Approach for OEM Manufacturers

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1. Introduction

Under the new EU F-gas Regulation (EU) 2024/573, virgin HFCs are set to be phased out by 2050 through a steadily declining quota system. This new regulation is designed to shift heating and cooling systems toward using natural, low-GWP refrigerants, such as propane (R290), CO_2 and ammonia, wherever feasible. While the exact timing and thresholds vary according to application, equipment, and the GWP of the refrigerant, these regulations will prohibit certain new equipment that contains fluorinated greenhouse gases from being placed on the market.

In addition to the F-gas Regulation, the EU is also evaluating restrictions on PFAS (per- and polyfluoroalkyl substances). Since certain low-GWP HFO refrigerants, including those based on R-1234yf and R-1234ze, may fall within the proposed PFAS definition, future PFAS legislation could further influence refrigerant selection. While the final scope of these restrictions is still being determined, this provides an additional incentive to consider natural refrigerants such as propane (R290), CO_2 and ammonia where technically feasible.

For small refrigeration, air conditioning, and heat pump systems with a capacity of up to 12 kW, the new regulations effectively prohibit the use of refrigerants such as R410A in new equipment, beginning in 2026. The regulations also set a long-term objective of phasing out F-gases in most applications by 2032, replacing them with refrigerants that have a much lower GWP.

Due to its excellent thermophysical properties and low GWP, propane (R290) has emerged as the preferred refrigerant for new heat pumps. However, because propane is flammable, with a low minimum ignition energy and a wide flammable range, the potential for leaks must be carefully managed and every system must undergo a detailed safety and risk assessment. A large refrigerant charge increases the potential consequences of a leak, making charge one of the most important design parameters considered in the safety assessment.

Leaked propane can accumulate inside enclosed spaces, which makes it particularly important to limit the refrigerant charge in indoor installations. Safety standards, including EN 378 and IEC/EN 60335-2-40 define the maximum allowable propane charge based on the size of the room where the equipment is installed.

Charge limits for outdoor installations are much less restrictive. Since outdoor installations can accommodate higher refrigerant charges, propane has been successfully adopted in monobloc air-to-water heat pumps, and a variety of R290 system designs are now available on the market. While indoor propane heat pumps are limited by the amount of refrigerant that can safely be contained inside a building, outdoor monobloc heat pumps largely avoid this problem because the refrigerant remains outside.

The remaining safety concern for outdoor air-to-water heat pumps is failure of the refrigerant-to-water heat exchanger, where propane could potentially dissolve into the circulating water and be transported indoors. Modern safety standards therefore allow higher refrigerant charges if protective measures are incorporated into the system, such as double-walled heat exchangers, venting systems, or leak detection.

Reducing the refrigerant inventory in the condenser and evaporator makes it easier to comply with EN 378 and IEC/EN 60335-2-40, reduces the consequences of a potential leak, and increases the feasible heating capacity of indoor R290 heat pumps, without resorting to complex safety measures.

However, indoor installations may still require permanent ventilation to prevent leaked propane from reaching a flammable concentration. Unfortunately, continuous ventilation increases energy consumption, which can reduce seasonal efficiency (SCOP), particularly in smaller heat pumps.

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2. **The role of heat exchangers in low-charge systems**

Managing refrigerant charge depends largely on how effectively the refrigerant is distributed, evaporated, condensed, and returned throughout the system, making heat exchangers central components in low-charge heat pump design.

Reducing refrigerant inventory in components such as evaporators and condensers is an important strategy for low-charge heat pump design. In practice, however, achieving a low refrigerant charge requires optimization of the entire refrigeration circuit. Heat exchanger design must therefore be considered together with factors such as compressor-oil carryover, refrigerant distribution, piping layout, pressure drop, and the sizing and placement of other components, including filter driers. These trade-offs are particularly important for A3 refrigerants such as propane, where charge limitations are generally more restrictive than for A2L refrigerants.

Achieving a low total refrigerant charge through system-level optimization makes it easier to design an indoor R290 heat pump that complies with EN 378 and IEC/EN 60335-2-40 while still here delivering useful heating capacity.

Heat exchangers have traditionally been evaluated in terms of thermal performance. In low-charge systems, selecting the right heat exchangers is especially important, since they will impact the oil return, the system’s pressure drop, and the refrigerant mass. A heat exchanger that performs well in isolation may not deliver optimal results if surrounding components introduce losses or hamper distribution. In addition to meeting safety requirements for low-charge systems, heat exchanger selection must also support compliance with the EU Ecodesign (ErP) framework (Directive 2009/125/EC and Regulation (EU) No 813/2013), which evaluates heat pump performance over a full range of operating conditions through seasonal efficiency metrics (SCOP) rather than at a single nominal operating point.

To meet these new demands, a new generation of ultra-low-charge propane heat pumps is emerging. SWEP has contributed by developing heat exchanger designs that maximize thermal efficiency across all operating points, while minimizing refrigerant inventory. This significantly simplifies compliance with safety standards and reduces the need for additional protective measures. New heat pumps with system charges approaching those used in domestic refrigerators represent an important milestone toward making indoor propane heat pumps both practical and commercially attractive.

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3. Refrigerant charge as a system-level constraint

Heat pumps with total refrigerant charges around 150 g are now feasible for systems up to approximately 8 kW. Achieving such low refrigerant inventories requires minimizing the hold-up volume of every component while maintaining heating capacity, efficiency, and stable operation. In addition to compressor and lubrication design, the brazed plate heat exchangers play a critical role by maximizing the effective use of every gram of refrigerant across the full operating range of the heat pump.

For heat pump OEMs, this shift to low-charge R290 requires more than refrigerant substitution. It changes system design fundamentally, requiring system architecture, refrigerant selection, and component design to be treated as interconnected, rather than independent, decisions. As the charge is decreased, performance will increasingly depend on the distribution of the refrigerant, control strategy, and manufacturing-based variations in the components.

The commonly referenced 150 g engineering threshold (approximately 152 g for propane) is derived from the methodology defined in EN 378 for A3 refrigerants. Above this initial threshold, the maximum allowable refrigerant charge is determined using installation-specific calculations that consider factors such as room size, installation height, and equipment location.

Consequently, refrigerant charges below approximately 150 g are often viewed as attractive during early-stage product development because they simplify the safety assessment. However, compliance with EN 378 and other applicable standards must always be verified for the final system design.

3.1 Operating regimes

Heat pump performance does not degrade gradually as refrigerant charge is reduced. Instead, systems tend to operate within distinct operating regimes characterized by differences in efficiency, stability and control behavior.

These regimes range from undercharged conditions, where capacity and stability are reduced, to overcharged conditions, where excess refrigerant negatively affects the system's efficiency. Between these extremes lies an optimal operating range that balances performance and stability.

This operating window also defines a stability boundary. As systems operate closer to refrigerant charge limits, sensitivity to operating conditions, manufacturing tolerances, and control tuning increases.

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4. Pressure drop

In addition to refrigerant charge and heat exchanger design, pressure drop is also a central constraint. The flow rate of the refrigerant mass affects the pressure drop, distribution, and system stability.

As the charge is decreased, the entire circuit, including heat exchangers, piping, valves, and fittings become more sensitive to pressure losses. Suction-side losses are particularly critical due to their direct impact on the efficiency of the compressor.

Pressure loss on the suction-side may lead to reduced pressure at the compressor inlet. Under low-charge conditions, pressure losses in the liquid line may reduce the available liquid subcooling, increasing the risk of flash gas forming before the expansion device. Too little superheat can potentially result in droplets of refrigerant reaching the compressor, reducing its reliability and, in severe cases, causing damage.

Piping design can therefore become a key factor in performance. Long suction lines, unnecessary bends, or restrictive fittings may make it necessary to increase the refrigerant charge in order to compensate for pressure drops that do not improve thermal performance.

Within heat exchangers, pressure drop is governed by geometry, such as chevron angle, channel depth, and plate corrugation design. These parameters define a trade-off between heat transfer performance and flow resistance.

Pressure drop also affects transient behavior, including superheat control, expansion valve response, start-up, and defrost operation. These effects become more pronounced at low charge due to reduced system buffering.

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5. **Oil management**

During normal operation, compressor oil and refrigerant are somewhat miscible, depending on the temperature and pressure. A drop in pressure or increase in temperature will reverse this process, causing the refrigerant to evaporate and separate from the oil. However, if the superheat at the evaporator outlet is too low (5 – 8 K) the oil may remain saturated with refrigerant as it returns to the compressor.

When this refrigerant-rich oil reaches the compressor, the pressure drops, and the dissolved refrigerant evaporates rapidly. This can cause the oil to foam, reducing its ability to lubricate the compressor and increasing the risk of wear or damage.

To prevent this, an evaporator must be able to combine uniform refrigerant distribution across all evaporator circuits with reliable oil return and sufficient oil drying to prevent foaming in the compressor. When operating with low superheat, achieving this balance can be challenging.

Superheat has a strong influence on these processes. Lower superheat improves evaporator performance because a larger part of the heat exchanger operates under two-phase conditions, making better use of the available heat transfer area.

However, if the superheat is too low, more refrigerant remains dissolved in the oil. This refrigerant cannot contribute to evaporation and therefore does not participate in useful heat transfer. In addition, the oil may form a thin insulating film on the heat transfer surface, reducing the heat transfer coefficient.

Higher superheat has the opposite effect. It promotes better oil drying by releasing more refrigerant from the oil before it returns to the compressor. This reduces the risk of compressor foaming and can reduce the refrigerant charge required for stable operation. However, excessive superheat reduces the area available for evaporation and may lower the overall efficiency of the system.

For this reason, superheat must be carefully balanced. It should be low enough to achieve good evaporator performance but high enough to ensure adequate oil drying and reliable compressor lubrication.

This balance is particularly important in low-charge systems. An internal heat exchanger (IHX) can help achieve this balance by increasing the suction-gas superheat to improve oil drying, while also providing liquid subcooling. As a result, the risk of compressor foaming is reduced, and a larger portion of the refrigerant can be used effectively for evaporation.

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6. Evaporator – condenser alignment

The evaporator and condenser should be designed as a coordinated pair rather than as independent components. Matching the heat exchanger pair improves sub-cooling performance at the condenser, contributing to increased heating capacity and overall efficiency. Seasonal efficiency (SCOP) is strongly influenced by the balance between the sub-cooling and condensing temperatures.

A well-matched condenser and evaporator can provide sufficient liquid subcooling while maintaining an appropriate condensing temperature. Adequate subcooling helps ensure that only liquid refrigerant reaches the expansion device, increasing the available cooling capacity and improving the overall performance of the system. However, achieving greater subcooling generally requires more refrigerant to be stored in the condenser, so the level of subcooling must be balanced against the total refrigerant charge.

This balance is particularly important in low-charge systems. Because there is less refrigerant circulating in the system, its performance becomes more sensitive to how well the evaporator and condenser are matched. Small changes in heat exchanger performance or refrigerant distribution can have a large impact on efficiency and operating stability. As a result, the selection and coordination of the two heat exchangers are key to the overall system design.

The physical layout of the system can also influence this balance. In some layouts, for example, placing the condenser at a higher elevation can make use of the hydrostatic pressure difference in the liquid line, helping to maintain liquid flow while reducing the required refrigerant charge. The diameter of the liquid line is also a factor. The challenge lies in achieving sufficient subcooling with the lowest possible refrigerant charge, while maintaining stable operation throughout the system.

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7. Conclusion

The transition to propane heat pumps represents a shift from component optimization toward system optimization. Success depends on balancing refrigerant charge, heat exchanger performance, pressure drop, oil management, and controls as an integrated design. Heat exchangers play a central role by influencing refrigerant distribution, pressure drop, oil return, and refrigerant inventory, making them fundamental to both efficiency and system stability. Early cross-disciplinary collaboration between OEMs, heat exchanger specialists, and compressor manufacturers is essential.

SWEP

SWEP has extensive experience working with OEM heat pump manufacturers to develop architectures for low-charge propane systems. We can dimension and deliver optimized evaporator and condensers that support stable operation and high system capacity, guaranteeing excellent Seasonal Coefficient of Performance (SCOP).