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Impact of nozzle material and integration practices on defrost efficiency and system compliance in heat pump fans

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Abstract

The performance of heat pump systems is closely tied to the efficiency of their fan units - both operation and defrost cycles, which significantly affect seasonal performance factors. This contribution investigates the influence of different nozzle materials on defrost speed and overall energy requirement. A comparative analysis between metal and polymer-based nozzles reveals the differences and consideration regarding chances and risks in airflow guidance, weight, manufacturing costs, and thermal behavior. Special attention is given to the nozzle's role during defrosting, where optimized designs can reduce cycle duration and energy consumption.
A second focus addresses the growing responsibility of heat pump manufacturers in ensuring proper fan integration. Driven by the requirements of the Ecodesign Directive (ErP), system manufacturers will become accountable for the aerodynamic and acoustic performance of the fan assembly. This shift necessitates a deeper understanding of the interactions between nozzle, grille and fan, as well as their impact on system efficiency and regulatory compliance.
The paper presents practical insights into selecting suitable nozzle technologies and highlights how targeted material choices and design strategies can enhance both defrost performance and economic viability. Furthermore, it discusses how regulatory developments are transforming traditional supplier relationships. These findings aim to support more informed design decisions in the development of next-generation heat pump units.

Keywords: fan; nozzle; noise; ErP;

1. Introduction

Condensation and icing phenomena are unavoidable in air-source heat pumps, especially under cold and humid weather conditions. Ice formation on the evaporator and on the fan components (impeller and nozzle) reduces airflow, increases pressure drop, increases acoustics and reduces system efficiency. Regular defrost cycles are therefore essential to restore normal operation. Both design and material of the nozzle play a decisive role in achieving low acoustics, high system efficiency and uncritical icing behavior. Generally, there are three major options for material which will be discussed: Sheet Metal, Glass fiber reinforced Polypropylene (PP) Expanded Polypropylene (EPP)

Simultaneously, the regulatory landscape is evolving. The new Regulation (EU) 2024/1834 (ErP2026) imposes stricter efficiency and documentation requirements, shifting more responsibility to system integrators. This paper combines experimental, theoretical, and regulatory perspectives to provide actionable guidance for manufacturers.

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2. ErP 2026 (EU) 2024/1834

On 24th of July 2024, the European Commission published Regulation (EU) 2024/1834 [1], commonly referred to as ErP2026 for fans, which replaces the long-standing Regulation (EU) 327/2011 (ErP2015). This new regulation sets ecodesign requirements for fans driven by electric motors with an input power between 125 W and 500 kW. It marks a significant step forward in the EU's strategy to reduce energy consumption and support the transition to climate neutrality by 2050 (European Green Deal).

ErP2026 introduces several fundamental changes that pose both technical and organizational challenges for manufacturers and integrators [1]:

Higher Efficiency Requirements

The regulation raises the minimum efficiency thresholds for fans, requiring performance at the declared Best Efficiency Point (BEP) to meet or exceed a calculated target. This shift demands improved aerodynamic design, optimized motor selection, and precise system integration.

Extended Documentation Obligations

Manufacturers must now provide an even more detailed package of product information, including technical datasheets, user manuals, and with that being compliant to European law (EC Declaration of Conformity) and by that mark it with CE (Conformité Européenne) mark. These documents must be accessible via a free website and remain available for up to 20 years after product withdrawal.

Partial load performance data: already a market standard, soon a regulatory requirement

Although performance data at partial load is already widely used in the market, it will not become mandatory until the implementation of ErP2026. This upcoming requirement supports more accurate system design and improved energy efficiency under real-world operating conditions. However, it also brings increased complexity in testing and documentation.

The inclusion of partial load efficiency in ErP2026 reflects a growing recognition of its importance - especially given that fans are increasingly operated at controlled partial load duty points in actual applications like heat pumps.

Spare Parts and Spare Part Fans

In support of the circular economy, ErP2026 introduces rules for the availability and documentation of spare parts. Fans compliant with ErP2015 may be sold as spare part fans until 2037, provided they meet specific conditions. This ensures continuity for maintenance while encouraging gradual transition to more efficient systems.

ErP2026 opens the field of mandatory spare parts availability for fans sold under ErP2026, two years after putting into service and for 10-years after phasing out of the fan. Although leading the way into a sustainable future, this is a huge hurdle for fan manufacturers.

Redefining Fan Manufacturer

One of the most impactful changes is the new definition of "what is a fan" and the assignment of responsibility. According to ErP2026, a fan is defined as a rotary bladed machine designed to maintain a continuous flow of gas, typically air, and includes at least a motor, an impeller and a stator. The definition of a stator in the regulation is not a part of the electrical motor, it is the stationary part of the fan, interacting with the airstream. As an example, the mounting of the impeller and motor with the nozzle is a part of the stator.

Strategic Decision for Integrators

For companies integrating fans into their heat pumps this regulation presents the strategic decision whether they want to become a fan manufacturer (e.g. by assembling motorized impeller to a nozzle).

Stepping into this role, means taking over full responsibility for efficiency, documentation, and compliance. While this offers control and potential for optimization, it also introduces regulatory burden and technical complexity. To avoid stepping into this role sourcing a fully assembled fan is a possible solution.

3. Ice formation at fan and nozzle

While there is plenty of publication on fan icing behavior of aero-engine fans [2; 3] and on evaporator icing behavior [4; 5] literature on icing behavior of fans and nozzles of evaporator in heat pump cannot be found. However, in practical operation of heat pumps formation of ice at these parts can pose a major risk for reliable and silent operation.

There are two different ways of ice formation at nozzle and fan:

1. During heating operation: Subcooled air streams over fan and nozzle and deposits frost on both parts. However, the majority moisture is in such cases deposits on the heat exchanger as the coldest component within the system
2. During defrosting cycle: During defrosting ice is removed from the heat exchanger. Regardless the used process the heat exchanger is heated up and moisture rises from the heat exchanger while fan and nozzle remain unheated and become the coldest components within the system. This leads to a depositing of moisture which can result as ice.

To remove the ice from these surfaces obviously temperatures above melting point (0°C) must be achieved. In many cases the heat of the moisture which rises during defrosting cycle or longer standstill of the heat pump with sufficient high ambient temperatures are sufficient to remove the ice. Nevertheless, at prolonged cold and humid condition combined with a high operational time there is necessity to remove the ice from nozzles proactively to avoid the fan blade brushing on the formed ice by a resistance heating band on the nozzle. A brushing of the fan blade on ice leads to noise and can on the long term destroy the blade. Alternatively, fan tip clearance can be chosen big enough initial to take such phoneme into consideration during design phase. However, this comes with downsides on the acoustic behavior [6].

Obviously, the ice formation during defrosting is dependent on thermal conductivity and capacity of the nozzle material. Table 1 compares typical properties of glass fiber reinforced PP, EPP and sheet metal.

Table 1. Material properties

Nozzle Material properties	Thermal Conductivity [W/m K]	Thermal Capacity [J/kg K]	Density [kg/m³]	volumetric thermal capacity [kJ / K m³]	typical material thickness [mm]
PP LGF-40 [7]	0,33	1400	1220	1708	3
EPP [8]	0,046	-	20-30	-	>100
Sheet metal [9]	45	470	7850	3390	2

In direct comparison to the metal nozzle, the PP nozzle (figure 1) has a significant weight saving. With identical geometry, the density difference between polypropylene with 40% long glass fiber content (PP-LGF40, 1,22 g/cm³) and steel (7,8 g/cm³) results in a weight advantage in favor of the composite by a factor of >6.

Figure 1. llustration of the plastic nozzle.

Another advantage of the composite is its corrosion behavior: While metallic components usually require an additional coating to ensure corrosion resistance, this process step is completely omitted for plastic components, which leads to a simplification of production and potential cost reduction. Due to the inherent corrosion resistance of composite, there is also no risk of corrosion-related material damage. This allows for permanently reliable joints, whereas metallic materials such as steel can become corrosion due to coating defects or mechanical damage to the protective layer, which can affect the structural integrity of the joint in the long term.

In the context of energy efficiency in the active defrosting process with a resistance heating band, the low thermal conductivity of plastic compared to metal poses a potential challenge. While steel has a thermal conductivity of about 45 W/(m·K), this value for polypropylene is only about 0,33W/(m·K), which corresponds to a difference of a factor of 130. At the same time, PP has a specific heat capacity that is about three times as high. Active defrosting with EPP is not possible as it usually has large wall thicknesses and therefore heat transfer is very low.

This combination of low thermal conductivity and high heat capacity means that the heat in the PP is stored efficiently and thus has low heat losses, but is transported more slowly to the inner surface, which can delay the defrosting process compared to the metal nozzle. Nevertheless, this disadvantage can be compensated by the targeted local heat input as measurements show. The lower thermal conductivity of the plastic enables effective use of the energy input, as an axial heat transport is more difficult to achieve in comparison to sheet metal.

To evaluate the energy efficiency in the defrosting process, the required heating energy per area was calculated taking the typical wall thickness into account assuming that nozzle surface area and provided heating power identical in both cases (Eq 1).

$$C' = \rho \cdot c \cdot s \tag{1}$$

with

C': heat capacity per surface area in kJ/ (K·m²)
ρ: Density in kg/m³
c: specific heat capacity in kJ/ (kg·K)
s: typical wall thickness in m

In this theoretical approach PP would require 31% less time to achieve any given identical temperature rise at identical energy input in comparison to steel. If the deviating material thickness would be neglected and same thickness is assumed PP would require even 54% less energy than required to achieve the same temperature rise with steel. However, this approach (Eq 1) completely neglects the fact that heat is not only transported in radial direction (from out nozzle surface to inner surface) but as well in axial direction (nozzle height). Considering this it is obvious that high thermal conductivity will lead to a more homogeneous heated nozzle heating as well areas which are not required to be heated for defrosting.

For testing and evaluation purposes the heating up process of PP and sheet metal was compared to each other. The results show that the metal nozzle heats up evenly over its entire height but only reaches moderate local maximum temperatures. In contrast, the PP nozzle can achieve significantly higher temperatures locally with the same heat supply. This allows targeted and energy-efficient defrosting, as the heat can be concentrated at relevant points.

The temperature curves along the axial cross-section of the plastic and metal nozzles are compared in fig 2. The temperature values shown are to be understood as examples and are based on an identical heat input and the same environmental conditions. In figure 2, the left nozzle and the gradient P1 represent the metal nozzle whereas the right picture and the gradient P2 represents PP. The picture was taken as a comparison during an equilibrium state at -5°C ambient temperature. The results make it clear that compound nozzles despite their lower thermal conductivity can achieve very high local temperatures at the (>40°C) at ambient temperatures of -5°C at the chosen heating power. Further defrosting tests with 1700 W/m² area related heating power of the heating band as well showed that with PP nozzles defrosting would be possible down to -20°C ambient temperature whereas steel does not achieve temperatures higher than 0°C at all.

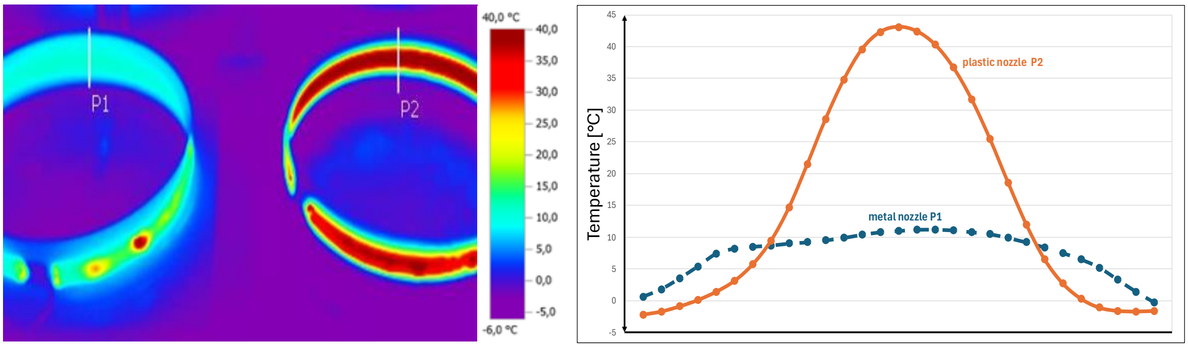

Figure 2. Left: Thermal image of metal (P1) and PP (P2) at -5°C ambient temperature. Right: Temperature curve above nozzle height

In addition to the steady state measurements dynamic measurements of the temperature of the inner nozzle surface have been conducted to check on the time until 0°C is achieved and actual defrosting starts. The results in Table 2 and Figure 3 show the time which was required to measure any temperature rise at all and the time which was required to achieve 0°C after switching on the resistance heating band. The later parameter represents the starting point of actual ice removal. In both cases a 1700 W/m² area related heating power resistance heating band was applied to the nozzles for same fan sizes. The results show that steel reacts 15s quicker but the melting temperature is achieved 25s faster with PP.

Table 2. Dynamic heat up with identical area related input power (1700 W/m²)

Nozzle Material	Time until starting temperature (-5°C) is exceeded	Time until 0°C is achieved
PP LGF-40 [7]	23s	104s
Sheet metal [9]	8s	129s

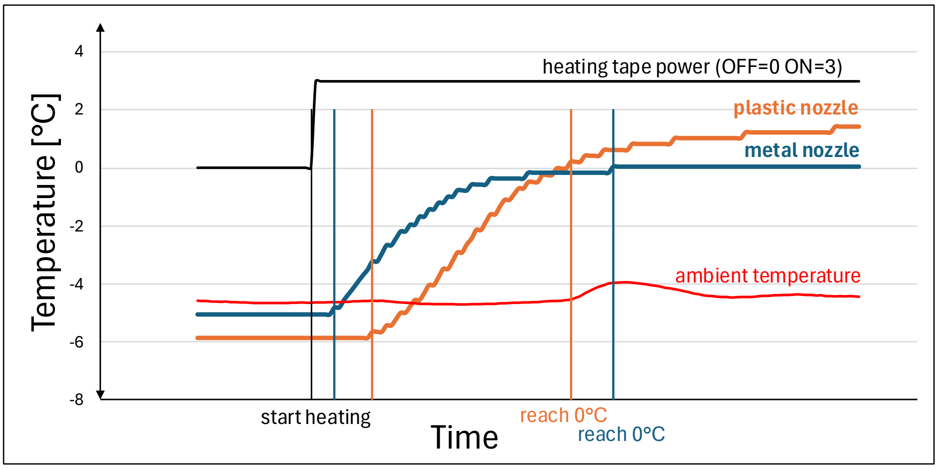

Figure 3. Temperature profile of metal and plastic nozzle over time during defrosting process

Both the steady state and dynamic measurement show that PP nozzles show superior properties when it comes to defrosting with external resistance heating band which supports the initial theoretical results with the simplified approach.

4. Performance and acoustic behavior

Undoubtedly low acoustics, high pressure rise, and high efficiency of fans are most important to contribute to a quiet and performant heat pump outdoor unit. Considering high performance blades engineered to purpose the major criteria is the technical alignment of fan blade and nozzle to achieve best values. However, considering identical blades, a small tip clearance (radial distance between blade and nozzle) and the right nozzle geometry (axial direction) are the most important parameters. Both sheet metal and PP nozzles can be designed and manufactured for both parameters in a way that identical performance can be achieved within the accuracy of the used test bench (DIN EN ISO 3745 (Class 1)). EPP nozzles on the other hand must be manufactured with higher tip clearance both due higher requires assembly tolerances and to hold a reserve to the unlikely event of icing on the nozzle. Consequently, EPP nozzles with the same blade will both loss efficiency and will provide higher acoustic signature [6].

5. Conclusion

ErP2026 not only increases the threshold for efficiency of fans but as well redefines and codifies the definition of a fan and who is the fan manufacturer. It further enforces obligations ensuring fans are compliant to the new regulation not only for efficiency but as well for spare part considerations. Although heat pump manufacturers pass through multiple testing and certification make or buy decisions for must be made even more consciously due to ErP.

The measurements show that PP nozzles show superior properties when it comes to defrosting as defrosting in the conducted measurements starts 25s earlier and achieves higher temperatures (up to 30K, depending on axial height) at the critical nozzle areas. These aspects should accelerate a defrosting under similar conditions. However, tests with identical ice loads using standardized test procedures could not be performed as there isn't such a procedure. This can be a future field of research action as well as comparative field measurements. Further a variation of nozzle material (e.g. a combination of metal and plastic) to improve deicing behavior seems promising from a research standpoint.

As one-stop shop solutions are more required in future a compound nozzle made from PP was developed and tested. Theoretical considerations and measurements show that icing behavior of PP is better than of sheet metal and close to the properties of EPP. Active defrosting of PP is possible and shows slightly better results than sheet metal. As far as performance (e.g. acoustic, efficiency) is concerned PP and sheet metal are identical and superior to EPP versions.

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