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FAN PARAMETER ANALYS OF HEAT PUMP AIR CONDITIONING SYSTEMS WITH DIFFERENT HEAT EXCHANGERS CONFIGURATIONS.

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Abstract: *The residential sector accounts for 27% of the EU's total energy consumption, and more than half is used for space conditioning, so improvements in this sector would contribute to achieving the sustainability goals set.*

Heat pumps (HP) have been presented as a good solution, as they are systems capable of satisfying air-conditioning needs in a more efficient way than systems based on fossil fuels; moreover, the REPowerEU Communication established the objective of doubling the current HP deployment rate in the next years.

In this sense, designing and optimizing air conditioning systems is crucial. This study presents a method to determine the power and airflow parameters of a fan in a heat pump air conditioning system. The calculation is performed considering the pressure drop associated with the design of the heat exchangers using the IMST-ART simulation tool. This modeling aims to obtain simulations closer to the real behavior under different design conditions for the development of more efficient air conditioning systems.

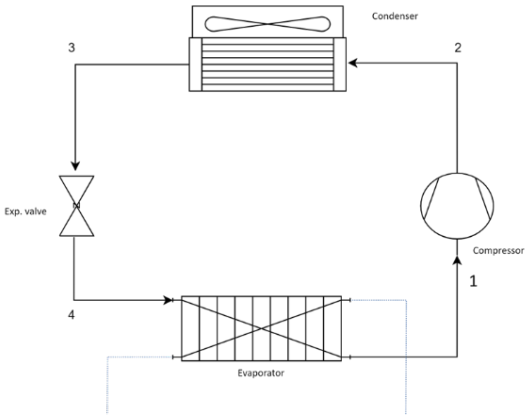

Figure 1 . AWHP schema

Keywords: Heat Pumps, Efficiency, Simulation, Air Conditioning.

1. INTRODUCTION

The European Union has pledged to accomplish ambitious objectives in response to the energy crisis and global warming. In pursuit of this, several strategies have been introduced, including the European Green Pact. This pact outlines a plan to cut CO_2 emissions by a minimum of 55% by 2030. Energy efficiency is a vital component of this plan, with a priority target of reducing total primary energy consumption by 36-39% [1].

On the other hand, energy consumption has been increasing over the years in developed countries. This energy is used to satisfy different necessities, such as comfort, where the residential sector has a significant impact. In the European Union, this sector accounts for 27% of total energy consumption, among which 64.9% [2] of this demand is used to satisfy space conditioning necessities.

Heat Pumps (HP) have garnered considerable attention as sustainable alternatives to conventional heating methods, particularly in residential and commercial buildings, to satisfy the necessities of heating, cooling, and domestic hot water. This technology is attractive due to its high efficiency and support for achieving requirements and goals. Nonetheless, the REPowerEU Communication has aimed to amplify the existing HP deployment rate twice, representing ten million units by 2027[3].

From this perspective, formulating and enhancing air conditioning systems is crucial; furthermore, models are presented as core tools. Afram [4] reviews different models for HVAC systems with heat pumps, classifying them into three main techniques: data-driven, physics-based, and grey box models. The authors claim that models are essential for studying energy consumption and simulating control strategies to enhance energy efficiency in HVAC systems.

In the HP system, the total electricity consumption is determined by the combined usage of the heat exchange fan in the condenser, the evaporator, or both, along with the compressor. Consequently, the performance of the fan is critical to the overall efficiency of the system.

In this line, some research has been done to optimize the fan performance. Soyguder and Alli [5] investigated an HVAC system design where an Adaptive Network-Based Fuzzy Inference System is used to predict fan motor speed, contributing to energy savings by controlling the system more effectively. Liu et al. [6]. discuss various aspects of pumps and fans in HVAC systems, focusing on energy efficiency and design considerations. Regarding design and operation, their work emphasizes the importance of matching fan operation with system requirements and avoiding excessive safety margins in design to prevent efficiency losses. Fernandez et al. [7] analyze a thermal zoning system integrated into an HVAC system based on residential buildings' air-to-water heat pump with a ducted fan coil. The authors detailed an algorithm for optimizing its performance, which includes adjusting the fan coil fan speed.

This paper aims to develop a methodology for determining the operating parameters of a fan in a heat pump system when its configuration is modified. Additionally, it evaluates the impact of these changes on the fan's performance and the overall system efficiency.

2. METHODOLOGY

This work is focused on the modifications of the heat exchangers (HEX), which means a change in the number of rows, the dimension of the tubes, or the arrangement of the circuits. When evaluating the potential of changing the heat exchangers or another component of the secondary circuit, the fan power and airflow are considered constant. When this is done, the system's expected performance could be misestimated.

For this purpose, the IMST-ART v4.1[8] software simulates a commercial air-to-water heat pump for air conditioning and sanitary hot water demand. Simulation results are the system performance and the pressure drop due to the heat exchanger.

Figure 2 shows the software interface, which also presents the main components of the heat pump. Furthermore, it presents the configuration window for the coil heat exchanger, where design parameters can be customized. The fan is positioned in front of the coil, which works as a condenser or evaporator, depending on the mode of functioning, cooling, or heating, respectively.

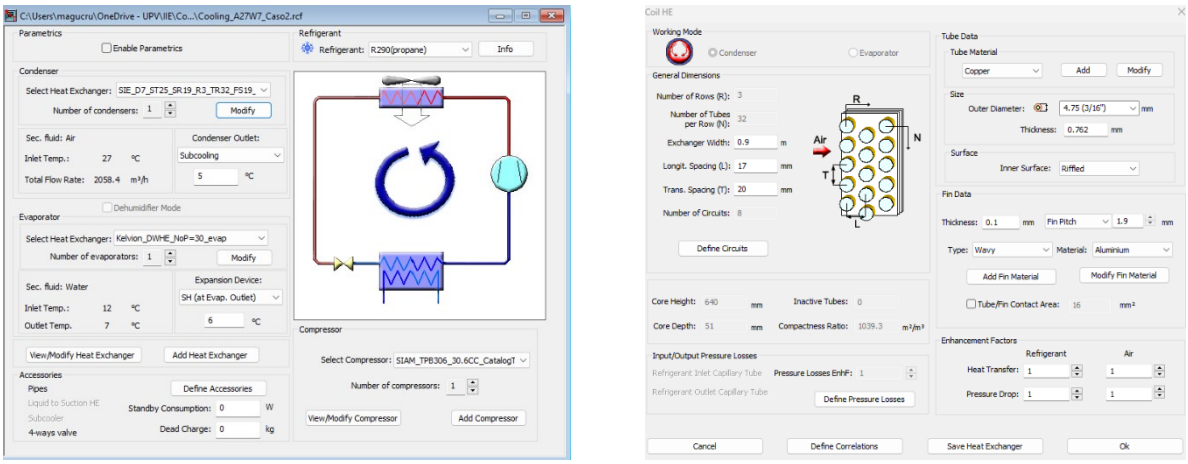

Figure 2 . IMST-ART main interface(a) and heat exchanger configuration (b).

The heat pump design is derived from commercial equipment, and the fan datasheet is readily available. Additionally, the operating conditions attach to the manufacturer's specifications.

The following assumptions were made for the simulations.

- Coil design: 3 rows, 8 circuits, 7 mm tube diameter.
- Heat pump works with Air 27ºC and water 7ºC values with 5 and 6 ºC of Subcooling and Superheat, respectively.
- There are no obstacles between the fan and the coil.
- Air is blown from the fan at 27ºC and 55% RH.

With these considerations, the analysis was planted. The working parameters of the simulation on IMST-ART were obtained using a base model of the air-to-water heat pump. The more important results of this first simulation were the airflow and the fan power.

A series of changes in the coil were defined:

- An increasing and decreasing number of rows.
- A change in the diameter of the tubes or fin space.
- A combination of them.

Figure 3 presents a diagram of the two methodologies compared in this study. Using the standard methodology, the airflow and fan power were kept constant to simulate the new Heat Exchangers (HEX), and the results were reported directly. However, it is worth noting that the results may not be entirely accurate due to changes in the fan performance caused by the alteration in the coil geometry, which can lead to a difference in flow resistance.

The methodology proposed in this study involves obtaining precise airflow and fan power values to simulate heat pump performance. IMST-ART provides pressure drop values in the heat exchangers, enabling the conduct of parametric simulations with different airflow values to obtain the resistive curve of each coil configuration. By using the characteristic curve of the fan and finding the cross point between both curves, the flow rate the fan can provide after modifying the HEX can be determined. However, the fan new power consumption can be calculated by knowing the airflow value.

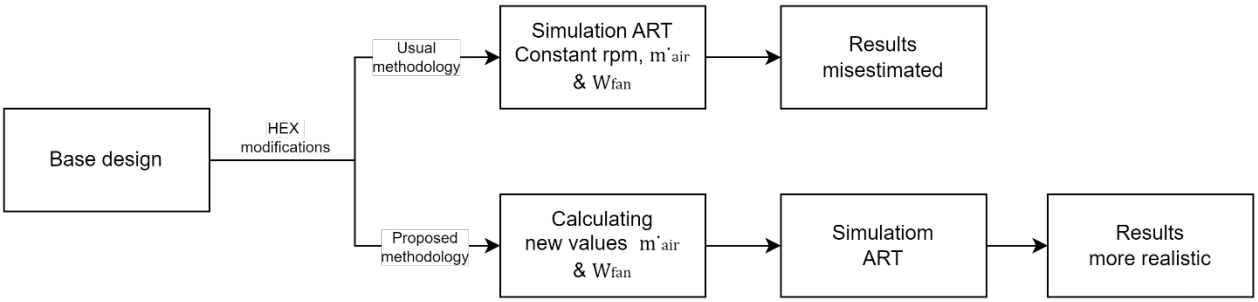

Figure 3 . Typical and proposed methodology to evaluate changes in heat exchangers.

The next step is simulating the Heat Pump using the updated configurations. These simulations use the previously calculated airflow. After this, the COP values are obtained based on the compressor consumption, and the fan power is recalculated.

Figure 4 shows the crossing point between the fan base curve and the HEX resistive one.

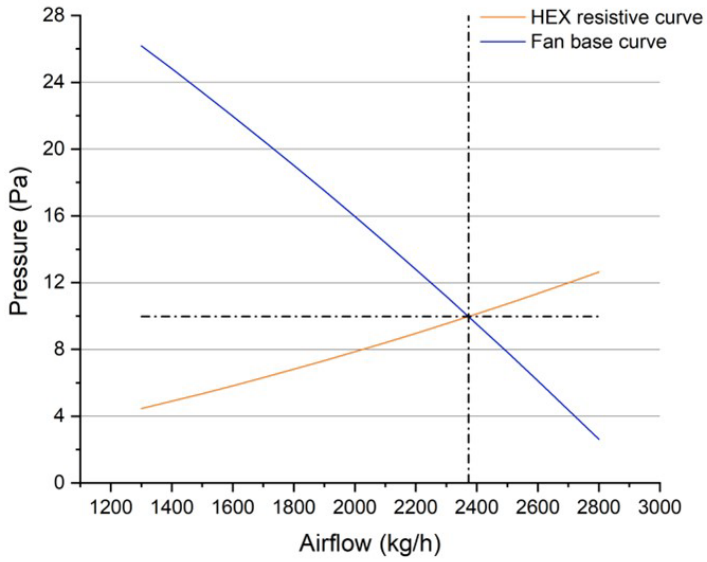

Figure 4 . Crossing curves.

The methodology developed using the laws of fans enables the calculation of fan airflow and power when there is a change in rpm. Additionally, if there is a need to achieve maximum airflow, whether for design or noise considerations, it is possible to determine the required rpm and power for that specific airflow.

3. RESULTS

The results of simulations performed with varying row numbers are presented in Table 1. The "Typical methodology" column indicates the simulation results when the airflow and fan power remain constant, while the "Proposed" column shows the results obtained with the methodology developed in this work. The fan values exhibit a significant decrease of around 20%, while the COP values vary slightly by about 1.5%. A similar trend was observed when the diameter of tubes varied and when the fin changed from wavy to plane.

Table 1. Variation on rows number.

Methodology		Base model	Typical	Proposed	Typical	Proposed	Typical	Proposed
Rows		3	2		4		5	
Flowrate	m³/h	2055.30	2055.30	2110.65	2055.30	1965.34	2055.30	1895.96
W_{fan}	W	58.39	58.39	45.72	58.39	45.90	58.39	45.93
Cooling Capacity	kW	4.00	3.91	3.92	4.03	4.02	4.05	4.03
COP (fan included)	-	4.10	3.86	3.93	4.19	4.21	4.25	4.24

Table 2 presents the results of the combined variations of row numbers and tube diameters of the coil, and Figure 5 shows the fan power and COP of each variation. The proposed methodology shows a decrease of around 22% in power consumption compared to the expected values under these conditions. In the case of COP, the results obtained with the proposed method present a reduction of around 5%.

Table 2. Combined variation, row number, and tube diameter.

Methodology		Base model	Typical	Proposed	Typical	Proposed	Typical	Proposed
Rows		3	2		4		5	
Tube diameter	mm	7	9.52		9.52		9.52	
Flowrate	m³/h	2055.30	2055.30	1970.90	2055.30	1658.54	2055.30	1540.50
W_{fan}	W	58.39	58.39	45.89	58.39	45.77	58.39	45.54
Cooling Capacity	kW	3.997	3.93	3.92	4.03	3.97	4.04	3.96
COP (fan included)	-	4.10	3.91	3.93	4.19	4.06	4.25	4.04

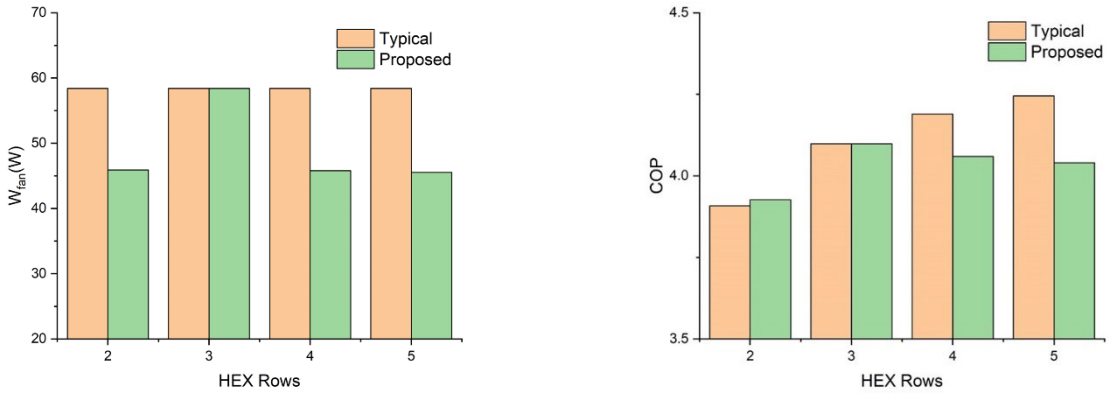

Figure 5. Fan power (a) and COP (b) of the system with combined variations.

4. CONCLUSION

A new method has been developed to determine the consumption and performance of a fan under different conditions. The study analyzed the fan performance in cooling mode in a commercial heat pump using the manufacturer-recommended working parameters. Modifications to the heat exchangers were made and evaluated using IMST-ART.

The results from the new methodology were compared with those obtained from the conventional approach to determine the extent of improvement in the calculated parameters.

The following conclusions can be drawn from the analysis carried out:

- The methodology developed allows for the calculation of changes in airflow resulting from modifications in pressure drop caused by the HEX design.

- When the HEX design is changed, there is an important difference in the power values of the fans when considered constant and when calculated as being lower by about 22%.

- The COP is not significantly affected by minor HEX changes, but more considerable changes, such as rows and tube diameter combined, can result in a variation of around 5%.

- This methodology can also be applied to evaluate other conditions where there is a bigger pressure drop, such as ventilation ducts in combination with the HEX.

- It is possible to conduct a more comprehensive study to evaluate HP performance in both cooling and heating modes, considering different types of fans.

REFERENCES

[1] European Comission, "Delivering the European Green Deal," https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en.

[2] European Comission, "In focus: Energy efficiency in buildings," https://commission.europa.eu/news/focus-energy-efficiency-buildings-2020-02-17_en.

[3] EUROPEAN COMMISSION, "REPowerEU Plan," 2022.

[4] A. Afram and F. Janabi-Sharifi, "Review of modeling methods for HVAC systems," *Applied Thermal Engineering*, vol. 67, no. 1–2. Elsevier Ltd, pp. 507–519, 2014. doi: 10.1016/j.applthermaleng.2014.03.055.

[5] S. Soyguder and H. Alli, "Predicting of fan speed for energy saving in HVAC system based on adaptive network based fuzzy inference system," *Expert Syst Appl*, vol. 36, no. 4, pp. 8631–8638, May 2009, doi: 10.1016/j.eswa.2008.10.033.

[6] L. Liu, Y. Liu, and J. Liao, "Issues of pumps and fans in HVAC systems," *World Pumps*, vol. 2015, no. 1, pp. 26–29, Jan. 2015, doi: 10.1016/S0262-1762(14)70345-1.

[7] F. Fernández Hernández, A. Atienza-Márquez, J. Miguel Peña Suárez, J. Antonio Bandera Cantalejo, and M. Carmen González Muriano, "Analysis of a HVAC zoning control system with an air-to-water heat pump and a ducted fan coil unit in residential buildings," *Appl Therm Eng*, vol. 215, Oct. 2022, doi: 10.1016/j.applthermaleng.2022.118963.

[8] J. M. Corberan *et al.*, "Purdue e-Pubs ' ART' A Computer Code To Assist The Design Of Refrigeration and A/C Equipment R9-4 'ART' A COMPUTER CODE TO ASSIST THE DESIGN OF REFRIGERATION AND A/C EQUIPMENT." [Online]. Available: http://docs.lib.purdue.edu/iracc/570