



14<sup>th</sup> IEA Heat Pump Conference  
15-18 May 2023, Chicago, Illinois

# European heat pump market data – evolution of the state of the art heat pump over time and its possible knowledge gain

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## Abstract

Market data for several thousand heat pumps are available in different databases in Europe. Information therein of different versions over time allow the analysis of the evolution of the state of the art of heat pumps. Contrary to typical investigations of single systems by research groups as kind of “bottom-up approaches” to develop new systems or to argue why a specific refrigerant might be applicable due to reached efficiency etc., we try to gain insights into the state-of-the-art of the European heat pump market with a “top-down approach”. The study begins with a comparison of such available databases and their specific differences. The gained product data are aggregated with additional information usually not part of such databases like the age of equipment, dimensions, etc. Thereby a very comprehensive new database arises. Based on this database we show the course over time of important parameters, such as used refrigerants and efficiency, but also sound emissions and refrigerant charge. Where possible the analysis comprises sensitivity analysis of different parameters linked to the used refrigerants and impacts of the applied refrigerant’s thermodynamics.

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Selection and/or peer-review under the responsibility of the organizers of the 14<sup>th</sup> IEA Heat Pump Conference 2023.

*Keywords: market data; heat pumps; air-to-water; brine-to-water; database; CE-marking*

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## 1. Introduction

Due to the F-gas regulations and the resulting phase down of high GWP (global warming potential) refrigerants such as R407C and R410A, rising effort is spent in academic and industrial research and development towards the use of refrigerants with low GWP [1]. Especially, natural refrigerants like hydrocarbons and carbon dioxide are of interest. However, how fast can a change on the market towards low-GWP refrigerants happen? Beside the choice of refrigerant type, sound emissions of heat pumps become more and more relevant for installation of heat pumps, especially in dense cities. Is there a trend towards less noisy heat pumps visible in the market data? And lastly, an increase in thermal efficiency is a dominant driver for the industry? Is a stagnation of efficiency in sight? Or what is the efficiencies to compete with when new systems are developed? These questions can partly be answered by looking deeply into available market data for heat pumps in public and non-public databases.

The Eastern Switzerland University of Applied Sciences OST publishes every year performance figures of heat pump measurements in their accredited lab. In the last report [2], they show a significant proportion of outdoor installed heat pump units in the lab testing (increase from 17% in 2014 to 32% in 2020) and an increase in their thermal performance (COP increase from 3.5 in 2014 to 4.2 in 2020; operation condition: A2/W35). They state that outdoor installation of heat pumps might increase in future further on. Another finding from OST was that since 2018 the number of heat pumps with low-GWP refrigerants R32 and R290 increased up to 40% of the tested heat pump models in 2020. The authors state that a further increase is probable. Since 2005 OST has measured 249 air-to-water heat pumps and 217 brine-to-water heat pumps according to the

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standard EN 14511, such that this database is a good representative of the heat pump market in Europe. However, local boundary conditions in Switzerland, such as a change in the Swiss quality label for heat pumps [3] affect heat pump design and thus performance in the lab tests accordingly.

In the paper [4] from Park et al., the authors present comparative data that might help policy makers to create more effective air conditioning (AC) efficiency market-transformation programs. The paper explores relationships between the room AC efficiency performance metrics of different regions around the world using performance data for split room AC models, including reversible heat pumps which shows the relevance related to the usage of cross-correlated product databases.

Evaluation reports for subsidization programs for the promotion of heat pumps and thus a decarbonization of heat production are another crucial resource to investigate market dynamics and changes in the state-of-the-art of domestic heat pump. Several countries publish such reports in recent years on a regular basis [5–7] which were main resources on a just recently published meta study from IRENA with a global approach on analyzing costs and markets of heat pumps [8].

All research articles and reports listed above show significant trends of performance categorized e.g. for types of heat pumps. Their results can help policy makers and industry to learn from past trends and to estimate future trends. Our work will continue this trend analysis with heat pump data from large European databases and own data collection and adds the time of market introduction into perspective as another relevant figure. It helps to gain knowledge about heat pumps and is a figure which wasn't used before to the best knowledge of the authors.

## 2. Databases

For the following analysis of the European heat pump market several different databases have been used. These databases are listed in Table 1.

Table 1. List of databases

No.	Database	Country of origin	Number of heat pumps in database	Year	Used as eligibility list for e.g.	Reference	Used in this paper for...
1	<b>HP Keymark database</b>	Europe	428 btw hps; 4271 atw hps	11.2022	-	[9]	Efficiencies
2	<b>SAP Q database</b>	GB	4010 atw hps; 650 btw hps	11.2022	GB	[10]	Market introduction
3	<b>GET product database</b>	Austria	1453 atw hps; 578 btw hps	11.2022	Austria	[11]	Sound power
4	<b>BAFA database</b>	Germany	4221 atw hps; 1212 btw hps	11.2022; 12.2020	Germany	[12]	Efficiencies
5	<b>HARP database</b>	Ireland	605 atw hps; 163 btw hps	03.2022	Ireland	[13]	Market introduction
6	<b>Eurovent Certita Certification database</b>	Europe	12324 atw hps; 394 btw hps	11.2022	France	[14]	-
7	<b>Propane heat pump database Fraunhofer ISE</b>	Europe	120 atw hps; 5 btw hps	11.2022	-	this paper	Efficiencies, dimensions, market introduction
8	<b>Other national databases (IT, DK, CDN, NL)</b>	Europe, Canada	110 to 25500 (all types)	2020 to 2022	EU members, Canada	[15–18]	-
9	<b>TOPTEN databases (CH, A)</b>	Europe	110 to 190 (all types)	2022	-	[19]	-

atw: air-to water; btw: brine-to-water; hps: heat pumps

According to the website the Heat Pump Keymark is a *voluntary certification mark that supports the quality and performance of heat pumps on the European market. It can apply to all heat pumps, combination heat pumps and hot water heaters. The certification is based on independent third-party testing and is compliant with efficiency requirements as set by Ecodesign Lot 1, 2 and 10<sup>2</sup>*. The European heat pump sector is pinning

<sup>2</sup> See website [www.ehpa.org/heat-pump-keymark](http://www.ehpa.org/heat-pump-keymark), last accessed 30.11.2022

hopes into the idea to have in the future a standardized eligibility framework within the EEA based on the HP Keymark.<sup>3</sup> The database is of good quality due to the strict work based on test reports.

The GET product database is mainly *for installers to find product lists for boilers and collectors to help them prepare the system design declaration required for grant submissions.*

The BAFA database is a set of heat pump models listed as being eligible in terms of the legal and technical constraints in the framework of the German heat pump subsidization scheme. It comprises EN 14511 efficiencies, heating capacities and certain system and circuit specifications (in versions until 14<sup>th</sup> December 2020). In recent versions publicly available data were minimized and harmonised towards other product databases being compatible to implementing directives (mainly 206/2012 and 813/2013) of the ecodesign regulation rules which made the list less attractive for statistical purposes as within this study.

The SAP Appendix Q Database provides individual branded product performance information that can be accessed and used as an adjunct to the SAP calculation. A product's performance information is determined by testing against a specification agreed by different stakeholders in England.

The HARP database provides information on the efficiency of heating appliances available in Ireland for use in domestic funding schemes. Product submissions include product test data, product identification documentation and HARP submission forms. The database has been in operation since 2006.<sup>4</sup>

The Eurovent Certita Certification database is the largest and most professional database but more dedicated to commercial appliances and less used for heat pumps in residential houses. Its objectives are in the range of serving R&D departments of participating member companies as well as using the data to participate in bids for public orders.

The propane heat pump database from Fraunhofer ISE, used within this paper, contains market available heat pumps with the refrigerant R290 (propane) in order to show evolution and trends in the market of propane heat pumps. The database is based on the BAFA database but extended with data provided from the manufacturers. The database is non-public and lists more than 100 different types (vapor compression circuits) of propane heat pumps resulting several hundred individual models as variants from those different cycles.

Other national databases are available from different countries that are operating a heat pump funding scheme. Without being complete these are for example Canada, Belgium, Denmark, Spain, Austria, Switzerland, Belgium, Czech Republic as well as Poland.

Topten databases are usually a subset of the large portfolios of heat pumps available in the European Economic Area (EEA). Usually, products are relatively new to serve the aim of solely offering highly efficient, modern and environmentally friendly products to the market.

### 3. Evaluation

Based on this preliminary work to evaluate the existing databases and to generate a new database an analysis of relevant parameters started.

#### 3.1. Refrigerant charge

The refrigerant charge is strongly dependent on the heating capacity of the heat pump. An increase in capacity usually corresponds to an increase in component size (e.g. heat exchangers) and thus yields higher absolute but not necessarily to higher specific refrigerant charges. The ratio of charge and capacity is shown in Figure 1 and referred to as "specific charge". The figure shows heat pump models from the BAFA database (No. 4 in Table 1). The year is based on the CE-marking dates (market introduction date) of the individual models. The data is separated into heat pumps with heating capacities below (a) and above (b) 12 kW. Comparing graph (a) and (b) regarding the increase in charge it is visible that the baseline is not strongly differing between smaller and larger systems. The inter decile range (between 10-90% of all models) for the smaller systems is in the range of 0,33-0,63 kg/kW and the inter decile range of the larger systems is in-between 0,1-0,52 kg/kW. This means that smaller systems have a faint larger specific charge amount than larger systems. But this strongly depends on the type of the used heat exchangers.

<sup>3</sup> Personal communication to several CEO's of heat pump manufacturer in November 2022.

<sup>4</sup> See website [www.seai.ie/home-energy/building-energy-rating-ber/support-for-ber-assessors/software/harp-database/](http://www.seai.ie/home-energy/building-energy-rating-ber/support-for-ber-assessors/software/harp-database/), last accessed 30.11.2022

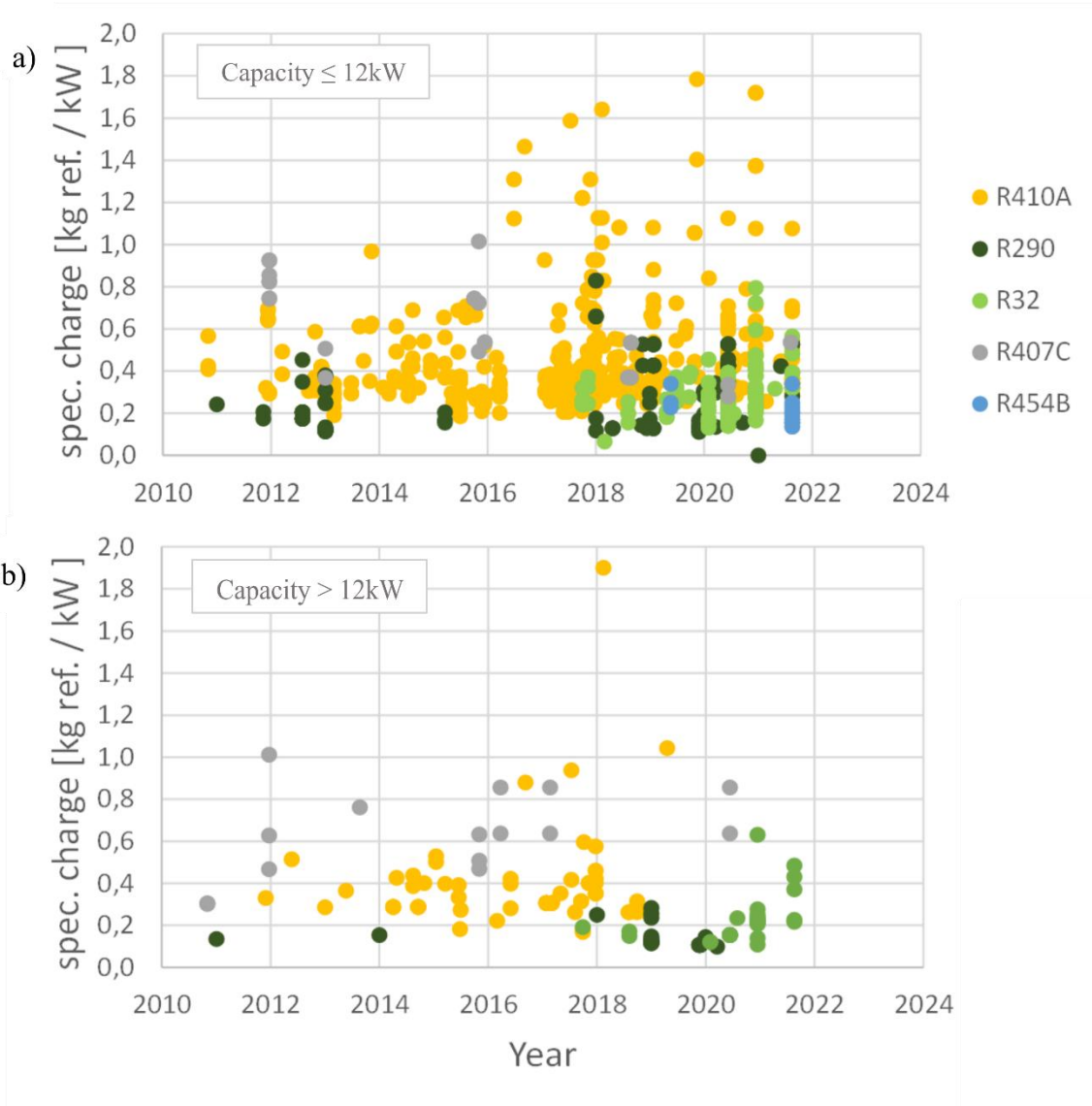


Figure 1. Refrigerant charge in kg per heating capacity in kW for different refrigerant types for air-to-water heat pumps. Operation point is A7/W35. a) for a heating capacity below 12 kW; b) for a heating capacity above 12 kW. Source: Own data and BAFA database (No. 4 in Table 1).

Different reasons for a specific charge higher than ca 0.8 kg/kW can be listed. For the authors, the most probable one is the usage of larger components in order to get a high COP.

A specific charge below 0.1 kg/kW is reached in less than 5% of the data. For these models the authors assume a design of the refrigeration circuits, optimized for low charge operation. Even though there are manufactures on the market with these low refrigerant charge heat pumps, a trend towards low charge cannot be seen from the analysis in Figure 1. At the same time the authors see strong R&D activities of the heat pump manufacturers with the flammable refrigerant R290. A safe operation is thereby linked strongly to the amount of refrigerant used. A reduction of R290 supports the safe operation. As Figure 1 shows the air-to-water heat pump models only, an assertion for brine-to-water heat pumps is not possible. The authors see for these systems market available low charge heat pumps and ongoing R&D activities<sup>5</sup>, such that specific charge for brine-to-water heat pumps will further decrease.

<sup>5</sup> See [https://www.lc150.eu/more\\_info/](https://www.lc150.eu/more_info/)

### 3.2. Acoustics

Several of the databases includes sound power levels (database No. 1, 3, and 6). We focus on database No. 3 which is the Austrian GET product database. The GET database includes nominal and maximum sound power levels. A lot of models and thus entries in the database show a zero difference which means nominal and maximum sound power level are declared identical. This represents about 40% of all models listed in the database. The considered amount of listed air-to-water heat pumps is 1453 models. This leads to the conclusion that the data is not sufficiently reliable to investigate the sound power trends according to the time of market introduction. This is one of the reasons why for the revision of LOT 1 of the Ecodesign directive it was suggested to define operating conditions stricter than in the past. The taken recommendations are strongly linked to the recommendations and conclusions of the Swedish project on the acoustics of heat pumps to identify more reliable testing conditions [20]. This project was running in parallel to the IEA Annex 51 about the Acoustic Signatures of Heat Pumps [21].

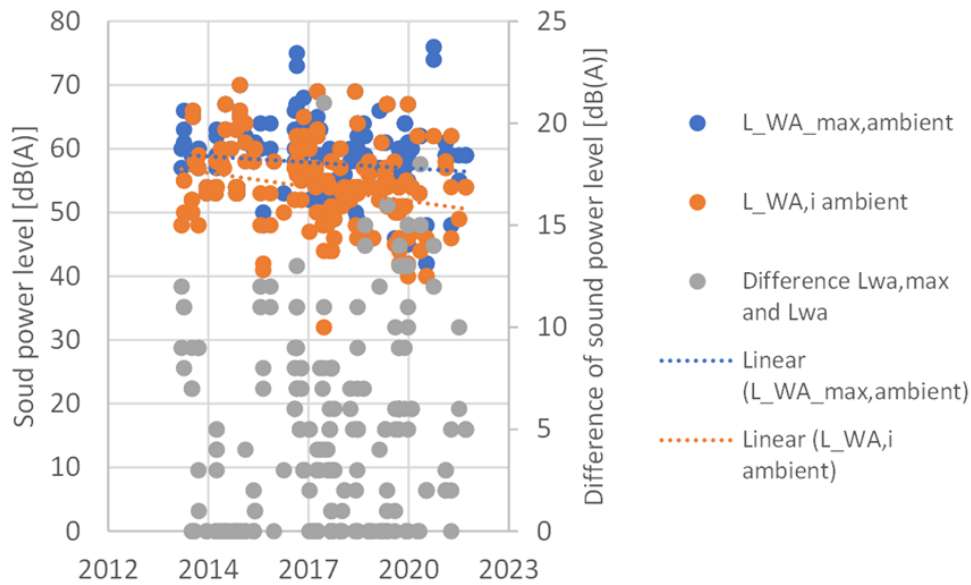


Figure 2: Sound power level of air-to-water heat pumps; L\_WA: sound power level. source: get database (No.3 in Table 1).

### 3.3. Performance

Based on the BAFA database No. 4 from Table 1, an analysis of the eligible heat pumps in Germany is done with focus on performance of heat pumps for different types of refrigerants. Figure 3 shows the coefficient of performance for six different refrigerants for all low-GWP air-to-water heat pumps in the BAFA database. The figure differentiates between four operation points of the heat pump. COPs for the lowest ambient air temperature of -7°C (blue bars) differ from 2.7 to 3.1 as a refrigerant-specific mean value. The variation within a refrigerant category can be more than one COP point (see the error bars) at this operating point; e.g., R32 reaches values up to 4 for a specific heat pump model and down to 2.5 for another model. For ambient conditions of +10°C (yellow bar) the mean COPs are highest, reaching values up to 5.6. Model-specific COPs reach values up to 6 at this operating point.

The number of heat pump models in each refrigerant category (grey boxes) ranges from 4 for R454C to more than 200 for R32. Thus, a comparison of performance should be done with caution for the categories with low number of models. Nevertheless, for the three refrigerants R32, R290 and R454B there are a large number of models and manufactures in the BAFA database, such that Figure 3 can give a good impression on performance.

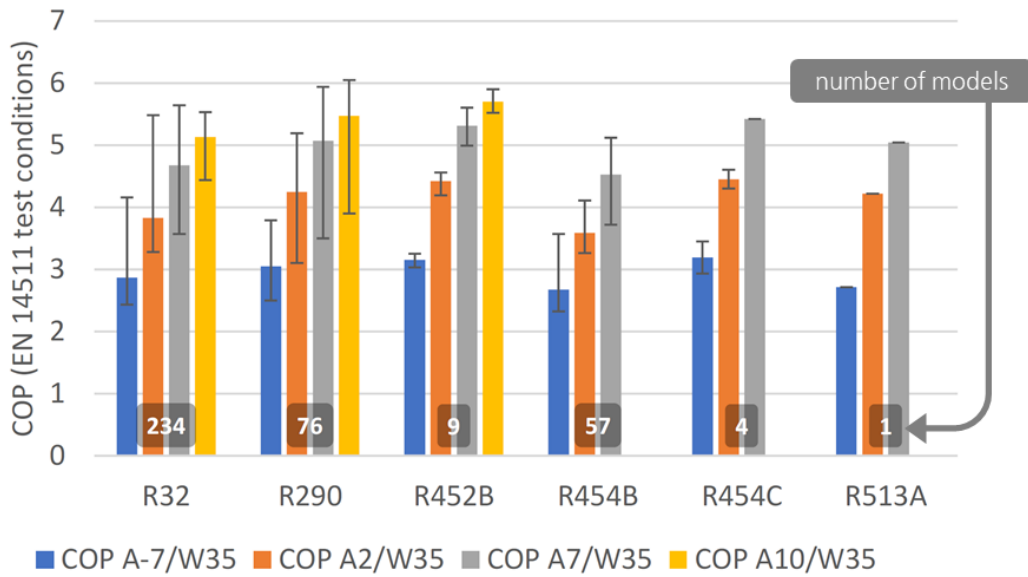


Figure 3. Performance of heat pumps, categorized by type of refrigerant; source: BAFA database (No.4 in Table 1).

Based on the data, we can conclude, that primarily the choice of a specific heat pump model leads to a higher impact on the performance than the secondary choice of a specific low-GWP refrigerant. But in combination best case situations occur. And this situation can be found at the German market. There were high sales numbers until the evaluated subsidization scheme MAP where we concluded that for R290 systems the share of sold units is much larger as for other low-GWP refrigerants, see Annex of [5] for the evaluation and the Annual Report 2021 of IEA Annex 54 [22]. However, R454B shows significant lower COP values than R32 or R290. This is in accordance with the material properties of the refrigerants.

### 3.4. Proportion of refrigerant type

The date of the CE marking of a heat pump is one criterion to estimate the date of the heat pump release into the market, other resources are for example the SAP Q database No. 2 as well as the HARP database No. 5 in which the assignment of a new model within these funding schemes is monitored. However, it can on the other hand express a revised heat pump which got changes. Therefore, a CE marking date expresses a constant working or improvement process.

Figure 4 shows the type of refrigerant in heat pumps in relation to the date of the last CE marking. The data is based on the BAFA list 2020 and extended by the CE marking date. It can be seen that the proportion of high-GWP refrigerants (GWP > 1500) such as R404A, R407C and R410A is decreasing the last 5 years. However, there is still a proportion of 50% in 2020 and thereafter with high-GWP refrigerants.

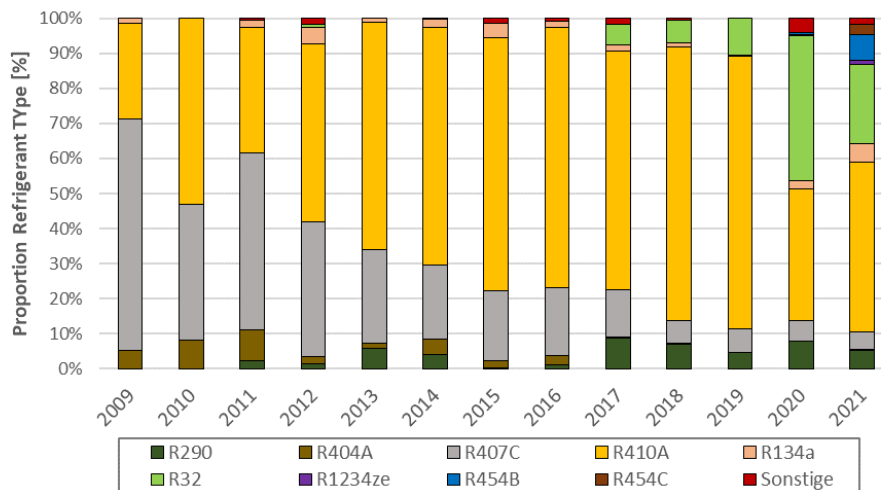


Figure 4. Proportion of refrigerant type for heat pumps based on CE marking date in data sheets; source: extended BAFA Database (No. 4 in Table 1)

In Figure 4 it can be seen that within the last five years heat pumps with R290 are constantly marked with the CE marking, but stay below 10% of all heat pump CE markings in the BAFA database. Caution must be taken with the interpretation of Figure 4 for the heat pump market. The figure does not show sales numbers of heat pumps. A link between refrigerant and sales number needs additional data (e.g. [8]) besides the databases in Table 1. Data from before 2009 can be looked up in [2].

### 3.5. Focus Propane

In order to understand the market of propane heat pumps better, the database No. 4 and 7 from Table 1 (BAFA list and propane heat pump database Fraunhofer ISE) is used to show possible trends. Therefore, Figure 5 shows the efficiency in terms of the seasonal space heating energy efficiency  $\eta_s$  for air-to-water heat pumps with four different refrigerants. The mean efficiency (black line) increased between 2007 and 2021 by more than 10%<sup>6</sup>. However, scattering of data is by a factor of two larger than this mean increase. Remarkably, there are two strong impacts on the data of this graph.

1. On the right side close to 2020 there are cluster-like structures which is the result of identical CE marking documents which were all updated and provided publicly at the same time from individual manufacturers. This is of course not the market introduction but more a consequence due to the changes/revision anywhere within the legal framework of these conformity declared product.
2. The same effect shows updates and pseudo-market introduction dates for R407C systems within the year 2018 which definitely is not resulting from newly introduced equipment (since no new R407C system should have been developed after about 2012 or earlier) but more to this issue of changes of the legal framework which might leads to regular CE marking updates for individual models. This has also a large impact on Figure 4.

Nevertheless, the dataset for Figure 5 is huge and it is assumed that tendencies and relations between the data are real and can be analyzed.

<sup>6</sup> This is the consequence out of different definitions being used for SCOP (with changes at about 2018/2019) together with an unclear situation if all used resources to digitize and use SCOP values were updated based on the current understanding of this figure. Furthermore, the listed SCOP in product and especially eligible heat pump lists should have change in the time window of end of 2021 beginning of 2022 when BAFA for example at the last one has switched from system-wide calculations of  $\eta_s$  to product-based values and it is not clear if entries of SCOP done by manufacturers themselves is always provided based on the one or the other then valid definition and it is best declared together with the value.

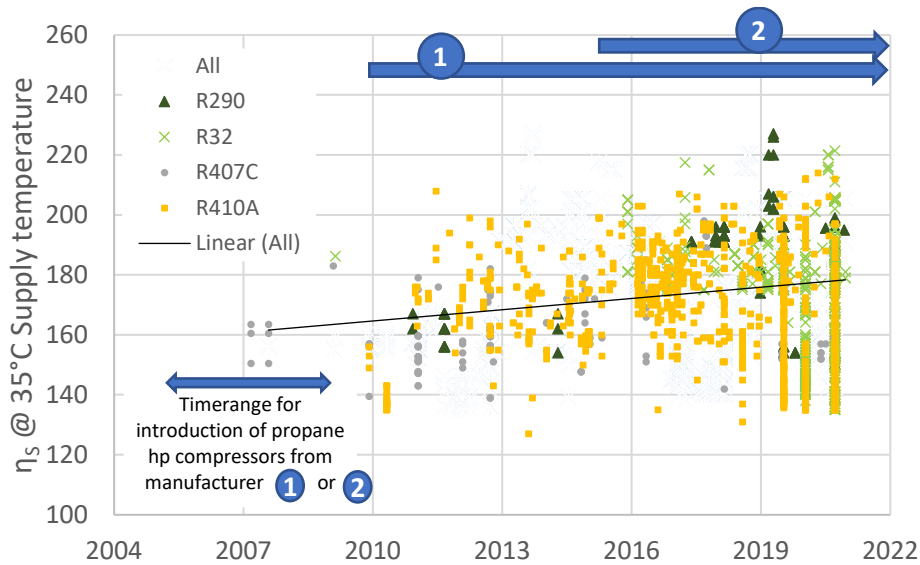


Figure 5. Evolution of  $\eta_s$  at the supply temperature level of 35 °C of BAFA database and additional individual R290 HP specifications for air-to-water heat pumps.

For R290 the evolution shows a clear picture. With the introduction of a new compressor designed for propane and for heat pump application starting from 2010 the first propane refrigerant circuits show similar performance than those of other heat pumps. With the ongoing development improvements of propane-specific compressors on the market in 2016, performances increased strongly, and the propane heat pumps show performance values significantly above average.

#### 4. Summary and Outlook

Several thousand heat pump models are listed in European databases with information such as performance and capacity. An evaluation of these databases individually can help for a view on current market available heat pumps. However, to express trends in performance, usage of refrigerant, acoustics, etc, additional information have to be collected for these datasets. This extension has been done by the authors. Especially the date of market introduction is a meaningful parameter which the authors included. They depicted the date by the CE-marking of the heat pump model as well as listing dates from database No. 2 and 5. Trends based on this representation show reasonable data point progression, with limitations based on revision of the CE-marking. A comparison of the efficiency among each database is difficult due to the different operation points used in the databases.

The main conclusions of the evaluation of these databases are:

- Specific refrigerant charge (in kg refrigerant per kW heating capacity) for air-to-water heat pumps shows a large scattering from 0.1 kg/kW up to 0.8 kg/kW with additional outliers. A clear trend towards reduced amount of refrigerant cannot be seen in the data up to the year 2021. The flammable refrigerant R290 shows lower specific charge than the other refrigerants within the database.
- A trend toward more silent heat pumps can be found in the data. However, a large proportion of the data points shows inconsistencies in terms of nominal and maximum sound power level, which reduces the informative value of the evaluation. Further filtering would be helpful to separate the dataset from non-modified fan blades and serrated trailing-edge fan blades which are nowadays the de-facto standard for quite axial fans.
- The performance of heat pumps (COPs) shows a recognizable dependency on the type of refrigerant. Market available heat pumps listed in the BAFA database show best performance for R290, followed by R32 and R454B (evaluation only for more than 50 different models per refrigerant type). The individual heat pump model has a stronger impact on the performance than the type of refrigerant.

- A large bandwidth of COPs shows large quality or design differences among the models; Simultaneously these differences show potential for performance increase among the majority of heat pumps.
- For R290 new components (e.g. compressor platforms) yielded a significant change in performance in the past. The authors assume still some more performance increase based on improved components in the future for R290 refrigerant circuits before an expected asymptotic final technical maturity level will be reached.

## Acknowledgements

The financial support by the German Federal Ministry for Economic Affairs and Climate Action for the Project SafeSENSE [23] under grant no. 03EN2030A is gratefully acknowledged.

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