15TH IEA HEAT PUMP CONFERENCE
MAY 26–29, 2026 | HOFBURG
VIENNA 2026
DECARBONISATION THROUGH INNOVATION

Open database with frequency- and directivity-resolved acoustic source data to improve heat pump placement

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Abstract

Heat pumps are gaining popularity due to their high efficiency and carbon-neutral operation, if using renewable energy sources. Among them, air source HPs are particularly favored for their affordability and straightforward installation. However, ensuring optimal placement of outdoor units to minimize receiver noise levels is crucial for the acceptance of HPs. Currently, predicting noise propagation for HPs is challenging due to the lack of frequency- and directivity-resolved acoustic source data.

Standardized acoustic test procedures based on the sound intensity measurement technique (ISO 9614) are employed to obtain frequency-resolved partial sound power levels for the five faces enveloping the HPs. Measurement data gained according to ISO 3744 with a cubic enveloping surface, can be converted to the same format for comparability. These data provide the directivity information needed to improve placement.

In the framework of IEA HPT Annex 63, we extend an open, anonymized database that links directivity- and frequency-resolved sound power data of outdoor units of air source HPs with related data on geometry, operating conditions and measurement methodology. Compared with earlier Annex 63 publications based on 27 units measured at CETIAT and AIT, this paper adds measurements from Fraunhofer IBP and Empa and presents a first cross-laboratory statistical analysis of five comparable units that quantifies how the orientation of fan, heat-exchanger and blind faces affects directional sound radiation. The analysis reveals patterns, such as approximately 10 dB higher radiation at the heat-exchanger face above 2 kHz and about 5 dB shielding by blind faces below 2 kHz, which can be directly translated into placement recommendations. The database is open for additional contributions and can include data of sound intensity measurements, measurements according to ISO 3744 using a cubic enveloping surface and other measurements performed in free field over a reflecting plane with arbitrary microphone positions.

Keywords: Air-to-water heat pumps; Source directivity; heat pump placement; Open acoustic database

1. Introduction

The growing number of air source heat pumps, as an essential component of a decarbonized future, requires robust prediction of receiver noise levels in residential and mixed residential-industrial areas to improve their placement. Aggregate metrics such as the A-weighted overall sound power level are of limited use for this purpose, as a robust prediction often requires frequency- and directivity-resolved source data.

For this reason, within IEA HPT Annex 63 an open and anonymized database has been established that links directivity- and frequency-resolved sound power data of outdoor units of air source heat pumps with related data on geometry, operating conditions and measurement methodology [4], [5]. Annex 51 provides groundwork on the acoustic signatures of heat pumps [6]. Earlier Annex 63 and Annex 51 publications mainly described the concept of the database and initial measurement campaigns [4] - [7]. This contribution summarizes the current content and structure of the database, the relevant measurement methods and their harmonization, and presents a preliminary statistical analysis of five comparable units with respect to the influence of face positions.

2. Background and Related Work

Certification-oriented acoustic testing of outdoor units of air source heat pumps is often based on the sound intensity method according to ISO 9614-1/-2 [1], [2]. Alternatively, measurements according to ISO 3744 (in the free field over a reflecting plane) using a cubic enveloping surface are employed. Lastly, ring- or dome-shaped microphone arrays in the free field over a reflecting plane are used. Within the context of Annex 63 a converter has been developed to integrate measurements gained with the ring- or dome-measurement method. So far, several measurements using different methods have been integrated in the database [7].

3. Objectives and Research Question

The database is intended to provide publicly accessible, frequency- and directivity-resolved acoustic source data for heat pumps with a standardized format and with documented provenance [4], [5]. It should be curated and extensible within the framework of Annex 63 [4], [5]. Optionally, additional metadata (e.g., refrigerant used) can be systematically encoded in accordance with ANSI/ASHRAE 34 [8]. Building on the initial description in [7], this paper documents the current content of the database including additional datasets, outlines the conversion procedures used to harmonize different measurement methods, and evaluates a subset of five comparable units. This paper will address the question of how the positions of fan, heat-exchanger and blind faces influence the radiation of sound. The following sections provide an overview of the available data, followed by an initial statistical analysis of the database, which is then presented and discussed.

4. Database Overview

The database contains measurements of outdoor units of air source heat pumps. Each database entry contains information on five standardized unit faces (the parts of the enveloping surface to determine the sound power level), partial sound power levels in one-third-octave bands for each face, the overall sound power level and metadata on geometry, operating conditions and measurement methodology. The face nomenclature (i.e. ‘fan face’, ‘heat-exchanger face’, ‘blind faces’, ‘top face’) is standardized to enable comparisons of single units and across laboratories [7].

4.1. Measurement conditions and data sources

The database contains data, measured with different methods. Some of them are based on sound intensity measurements according to ISO 9614-1/-2: intensity is sampled on a grid over an enveloping surface around the unit and integrated over defined surface segments (faces). This yields frequency-resolved partial sound power levels for each face (typically: fan-, heat-exchanger-, blind/top-faces) [1], [2].

In addition, datasets obtained according to ISO 3744 with a cubic enveloping surface are included [3]. Measurements using ring- or dome-shaped microphone arrays in a free field over a reflecting plane are also applied to measure radiation with high angular resolution. The computation of total and face-resolved sound power levels from dome measurements is described and validated [4].

Measurements were conducted in certification-relevant environments. The documented test standards specify the geometry of the enveloping surface, measurement distances, microphone/probe calibrations and relevant environmental boundary conditions.

Operating points are also set according to relevant standards. Where available, fan speed, compressor frequency, supply/return temperatures, ambient temperature and supplementary electrical metrics are recorded.

The current database includes heat pumps in top-blow and side-blow configurations, monobloc and split units, as well as a range of capacities and years of manufacture. The five standardized unit faces are defined consistently within the data structure, enabling analysis across units and laboratories. Method-specific differences (ISO 9614, ISO 3744 with conversion, and ring- or dome-shaped microphone arrays with conversion) are indicated in the metadata, enabling both method-consistent subsets and comparative analyses [1] - [5].

This face-wise decomposition is directly applicable to the prediction of receiver noise levels and is generally available at one-third-octave-band resolution between 100 Hz and 10 kHz. To ensure comparability, all spectra are harmonized to a common one-third-octave band raster. A glossary defines the standardized face assignment, including units with multiple fans or complex heat-exchanger geometries.

4.2. Dome-measurement data conversion

To be able to consider datasets obtained in a free field over a reflecting plane with a ring- or dome-shaped microphone array, a converter has been developed by Empa. The current converter prototype discretizes the enveloping surface with the microphones into finite elements, estimates the sound power radiated through each finite element (Figure 1a) and assigns the element to one of the five target segments, i.e. faces (Figure 1b). Lastly, the sound powers of the finite elements belonging to the same face are summed, leading to the sound power of each of the five target faces. From this the spatial averages of sound intensity can be estimated (Figure 1c). Further research and validation are needed to verify the conversion results.

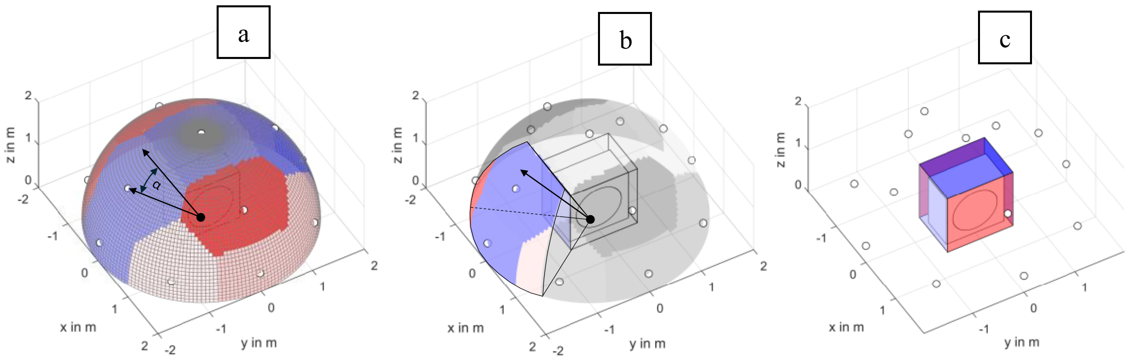

Figure 1: (a) Each finite element is assigned to the microphone with which it forms the smallest angle α. The colors represent the measured sound pressure and intensity levels assigned to the finite elements (blue: low, red: high). (b) Each finite element is assigned to the face of the virtual box which intersects with the element vector. The assignment of the elements to one face is shown as an example. (c) Estimated sound intensities through the five faces of the enveloping surface.

4.3. Envelope-based sound pressure measurement conversion

Some methods determine the sound power level with measurements of either sound pressure (e.g., DIN EN ISO 3744) or sound intensity (DIN EN ISO 9614, all parts), using a cuboid as the enveloping surface. While the intensity method handles integration over segments of unequal area in a physically consistent manner, the sound-pressure method does not. Ambiguities in assigning areas to measurement points arise particularly when points lie on edges or corners of the cuboid (in accordance with the standard) and when increased point density is used in regions of elevated radiation. Building on Wittstock’s approach [9], a scheme that explicitly accounts for non-uniform segmentation and corner/edge positions was applied.

5. Statistical metadata and data analysis

5.1. Data preparation and selection

For the comparative analysis presented here, a subset of five heat pumps with comparable operating conditions was selected. The selection criteria were fan and heat-exchanger on opposite faces; three closed (‘blind’) faces (plus the ground); comparable outdoor temperature (A = 7 °C) and water return temperature (W = 55 °C); and availability of the fan rotational speed and compressor frequency.

The selected measurements are shown in Figure 2a, which shows the fan rotational speed (x-axis) and compressor frequency (y-axis) of the database entries. The orange-highlighted measurements represent the operating point 'A7W55' with comparable unit designs (Figure 2b): all devices feature one face with a fan, a (rear) face with a heat-exchanger, and three faces closed on the sides and on the top. Notably, the rotational speeds/frequencies of the fan and compressor differ, which may lead to different acoustic signatures while the temperature conditions are the same.

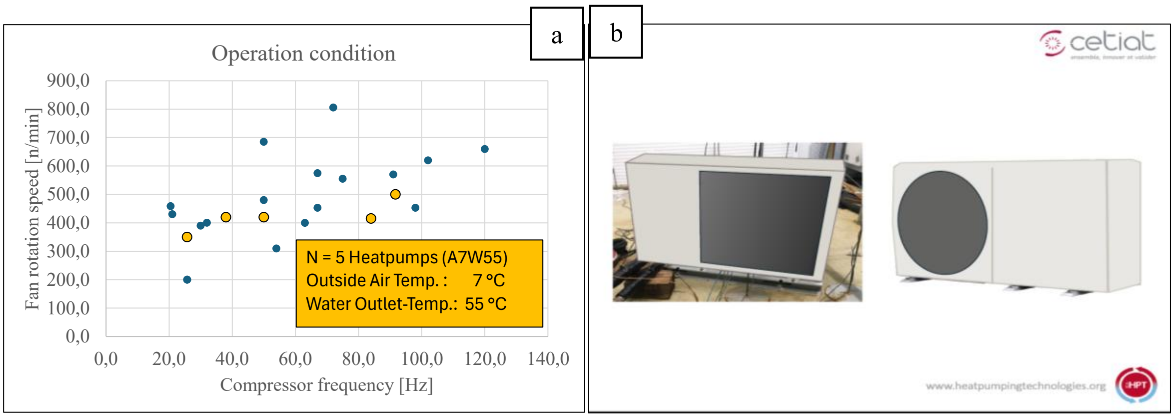

Figure 2: (a) Fan and compressor operating conditions available in the database in terms of fan rotational speed (x-axis) and compressor frequency (y-axis). (b) image of device configuration; one face with a fan, a (rear) face with a heat-exchanger, and three blind faces on the sides and on the top.

5.2. Results

The following three diagrams summarize the results of the analysis of the five units. Figure 3a shows the average of the sound power levels L_w (dB) of the fan faces of all five units per one-third-octave band. Figure 3b shows the mean difference of the sound power level of the heat-exchanger face relative to the sound power of the fan face; positive values mean higher radiation at the heat-exchanger face. Figure 3c shows the mean difference of the sound power levels of the three blind faces relative to the sound power levels of the fan face; negative values indicate shielding by the blind faces. The standard deviation as an uncertainty indicator shows the variability among the five devices.

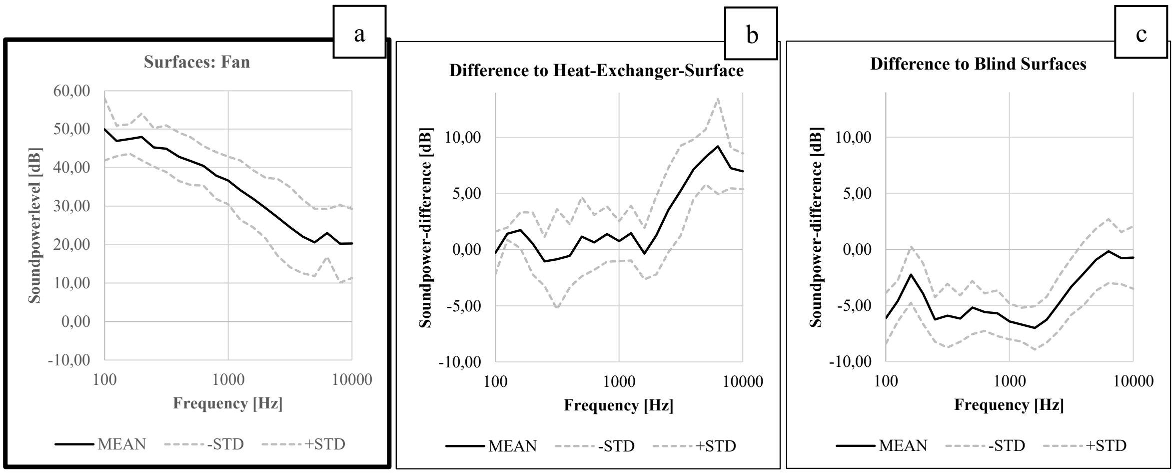

Figure 3: (a) Line plot of the mean L_w spectra of Fan-face (100 Hz–10 kHz) with standard deviation, (b) L_w-difference between fan-face and heat-exchanger face, (c) L_w-difference between fan- and blind faces.

Up to roughly 2 kHz, the blind sides show a broadband shielding effect of about 5 dB relative to the fan face, indicating effective attenuation towards the lateral directions. Above 2 kHz the heat-exchanger face radiates approximately 10 dB more than the fan face. This trend is consistent across the five units and needs further investigation.

The reported standard deviations apply to the devices considered here, selected regarding their design and operating conditions (A7W55). Extrapolation to other types of heat pumps or operating conditions requires additional investigation. For this type of heat pump, the direction- and frequency-resolved measurement data allow a preliminary estimate of radiation towards the heat-exchanger direction and of the shielding effect of the heat pump housing. This already allows decisions on improved placement of this type of heat pump.

6. Discussion

An open, standardized database with frequency- and directivity-resolved sound power data provides immediate added value for installation, planning and assessment. The directivity information directly supports improved installation of heat pumps and the planning of shielding measures, while the frequency information improves the prediction of sound propagation. Openness to multiple measurement procedures increases coverage but requires explicit labelling of conversions and method-sensitive analyses. Two conversion methods were used to enhance comparability with ISO 9614 and ISO 3744 references. In this way, the present work extends [7] by including additional datasets and by carrying out a comparative, face-resolved analysis for a subset of five units.

The comparison of only five typical heat pumps is already of practical use: above 2 kHz, the heat-exchanger face is, on average, roughly 10 dB louder than the fan face; below 2 kHz, the three blind faces, i.e. the lateral and the top sides of the heat pump housing, provide a broadband shielding of approximately 5 dB relative to the fan face. Validity is limited to the type of heat pumps considered and the operating point A7W55; extrapolation of the results requires further investigation. Annex 63 provides the organizational framework and infrastructure for this effort [4], [5], while Annex 51 contributes the conceptual foundation [6]. Overall, the database complements existing certification practices and establishes a robust basis for comparative analyses.

7. Conclusion and Outlook

The database closes a central gap in the acoustic assessment of air source heat pumps: publicly accessible, frequency- and directivity-resolved source data with documented provenance. Compared with previous Annex 63 and Annex 51 publications [4], [7], this contribution summarizes the harmonized data structure, the applied conversion procedures and a first comparative evaluation of five units with comparable operating conditions. By considering measurements according to ISO 9614, ISO 3744, and with ring- or dome-shaped microphone arrays and by harmonizing input data, it establishes a solid foundation for planning, evaluation, and research. The database can substantially improve predictions of receiver noise levels.

In the future, the database will be extended with additional measurements. In parallel, definition of the input data will be further consolidated. Based on the frequency- and directivity resolved source data, source models for propagation calculations will be developed, with a focus on the interface between the database and standard prediction tools. Further research will provide generic spectra and directivities for certain classes of heat pumps, cross-checks of database entries and the validation of conversion procedures — particularly those for measurements with ring- or dome-shaped microphone arrays — alongside investigations of the transferability to additional geometries and operating states and the improved estimation of uncertainties.

1. References

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