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

The heat pump system planning bottleneck: what data you need for optimal planning and what is accessible

Christian Vering[a,b], Jona Brach[a,b], Laura Maier-Jansen[a], Tim Klebig[a,b], Hannah Vering[a,b], Dirk Müller[a,b]

[a]Heat Pump Academy, Krefelder Straße 197C, 52070 Aachen, Germany
[b]RWTH Aachen University, Institute for Energy Efficient Buildings and Indoor Climate, Mathieustr. 10, 52074 Aachen, Germany

Abstract

A major obstacle to the use of heat pumps in existing buildings is the complex planning process involving the risk that heat pumps may not be able to reach high flow temperatures. In the literature, there are several approaches, identifying the optimal design of a heat pump system for existing buildings. However, input data for optimal design studies differs from real-world available data. This work gives insights into the planning process of heat pump system for existing buildings from both perspectives: Optimal planning with perfect input data in science and best possible planning based on available data in practice. The data analysis captures: (1) general information (e.g., location, behaviour of residents, past energy bills, past modernization, planned modernization), (2) building and weather data, (3) building heat demand calculation, (4) information about the heat transfer system, (5) system integration data (storage, back-up heater, installation site), and (6) heat pump data. The comparison shows that available data in practice is insufficient for optimal planning and even critical for near-optimal planning. The gap between optimal and near-optimal planning can be reduced step by step with just a little additional information. However, today, the additional information is not available in practice and planners must assume data or base their planning either on work experience or on over dimensioning the system. Both ways are not standardized and yield that the heat pump system design for a single building differs based on the planner. Different planning results can confuse end customers, as it is not clear which planned system is best for them. It is therefore necessary to further harmonize the planning process and provide further training for planners, installers, and end customers so that heat pumps can be integrated into existing buildings in a sensible manner.

Keywords: Cold Climate; COP; Heating Capacity ; Natural Refrigerants; Efficiency

1. Heat Pump System Planning in Research and Practice

Modern society spends approximately 90% of their time indoors, a trend reinforced by the COVID-19 pandemic's successful demonstration of remote work capabilities. This lifestyle shift underscores buildings' critical role in daily life and their increasing importance as living and working spaces [1]. Heating, ventilation, and air conditioning systems are essential for maintaining comfortable and productive indoor environments, yet their operation through energy conversion processes contributes significantly to CO2 emissions. Currently, the building sector accounts for up to 40% of total emissions across Europe, presenting a crucial opportunity for emission reductions while directly affecting citizens' daily lives.

Germany's commitment to the Paris Climate Agreement targets a nearly climate-neutral building stock by 2045, addressing approximately 19 million existing buildings with an annual energy consumption of 2,800 PJ and CO_2 emissions of 120 million tons. Air-source heat pumps represent a promising technology for existing buildings due to relatively low installation requirements. Despite higher initial investments compared to gas boilers and potentially elevated operating costs from electricity prices, heat pumps offer significant potential for defossilization. The key challenge lies in optimal system design, which predetermines both acquisition costs through sizing and operating costs through overall efficiency. System efficiency depends on operating temperatures, required loads, and system-specific phenomena such as compressor operating limits, part-load behavior, evaporator frosting, and domestic hot water production for air-source heat pumps. [2]

Current design standards, including VDI 4645 [3] and EN 15450 [4], employ sequential design procedures using simplified heuristics that ensure heating and domestic hot water coverage but fail to explicitly consider system and component interactions [5]. Research demonstrates that simultaneous consideration of multiple system levels and component interactions significantly influences optimal design and, thus, efficient operation. However, these investigations typically lack comprehensive experimental validation or are far too complex and therefore not widely applicable [2]. In pioneering work, Wüllhorst et al. [6] demonstrate easy to apply sizing rules that outperform prior findings from Vering et al., underlining the potential for near-optimal solutions with limited complexity. The occurring bottleneck remains in available data. While Vering et al. [5] assumed perfect information, Wüllhorst et al. [6] reduced the required data. However, the remaining underlying data exceeds publicly available data.

This paper discusses available and required data to identify at least near-optimal heat pump system designs. Based on the analysis, we propose a simplified data-driven approach that enriches available data to match the (near-) optimal heat pump system for a dedicated building. The matching process considers (1) general information (e.g., location, behaviour of residents, past energy bills, past modernization, planned modernization), (2) building and weather data, (3) building heat demand calculation, (4) information about the heat transfer system, (5) heat pump data, (6) system integration data (storage, back-up heater, installation site). The paper is structured as follows: Section 2 discusses the heat pump planning process with perfect information and available information. Section 3 introduces a pipeline to match the (near-) optimal heat pump to a building. Section 4 concludes the findings and outlines future work.

2. From Perfect Information to Available Information

From an academic point of view, it is possible to build up building and heat pump system simulation models to predict their operating behaviour. Such models can be calibrated against experimental data so that the heat pump system can be perfectly matched with a building. On the one hand, this process guarantees optimal design. On the other hand, this process is far too complex to being applied in practice. Even if complexity would become manageable, it would require many data points that are not measured in practice or that simply are not available. If the optimal process at certain execution costs will not be feasible in the future, the question arises as to what is the optimal solution that can be achieved with realistic available data for building and heat pump system. When identifying the (near-) optimal heat pump systems decision, there is a need to know information about the building to serve and heat pump performance. The information is separated into six categories:

(1) general information (e.g., location, behaviour of residents, past energy bills, past modernization, planned modernization),
(2) building (physics) and weather data,
(3) building heat demand calculation procedure,
(4) information about the heat transfer system and required temperature levels,
(5) system integration data (storage, back-up heater, installation site),
(6) heat pump data.

Due to end user interviews, it is possible to get (1) general information about the overall situation helping to set up a model to compute the buildings demand. Based on (2) site visits with individual data collection on the building structure or automated usage of LiDAR systems, it is possible to enrich (3) building performance model to, e.g., predict the heat load at nominal outdoor air conditions following EN 12831 [7]. In addition, analysing the (4) heat transfer system and the recent supply temperature settings helps understanding if conditions are feasible for heat pump systems. Based on EN 15450 or, especially in Switzerland following the "Schweizer Wärmepumpensystemmodul" [8] or especially in Germany following VDI 4645, it is possible to determine (5) the heat pump size, back-up heater size, and storage volumes. The heat pump size can than serve as input into (6) specialist planning software from heat pump manufacturers or for comparison with heat pump data sheets.

While the process is explained straightforward, there are problems that occur due to a lack of data or poor data quality. Figure 1 sums up the general setting when matching a heat pump system with a building [6]. The building load is computed as function of the outdoor air temperature and increases with decreasing ambient air temperature. In contrary, the heat pump capacity decreases with decreasing ambient air temperature, revealing the trade-off between demand and supply. In addition, the heat pump modulates between a minimal and maximal rotational speed, indicated with max. (min.) heat pump power line (dashed). The modulating behaviour separates the heat pump operation into three regimes: (I) Full load, (II) part-load, and (III) on/off-operation. If a bivalence temperature is defined, the area between heat load and gap capacity of heat pump (green area) is served by a back-up heater. On top of the figure, different weather data sets for a cold and a warm year are shown revealing a gap between nominal outdoor air conditions and actual conditions. While only a few points might be served at full load (no/very little back-up heater usage), the modulating and the on/off-regime remain dominant when operating the heat pump systems. This has implications on the heat pump choice:

- Over sizing: Reduction of back-up heater while increasing on/off-regime
- Under sizing: Reduction of on/off-regime while increasing the back-up heater usage

Since the costs for heat pump systems depend on both installation and operation, there is a trade-off for the optimal design. However, based on recent available data, it is coincidence finding the optimal design for a dedicated building, due to:

a. Lack of heat load validation/verification: The head load calculation overestimates the real energy demand, thus, tending to oversize the heat pump system.
b. Lack of defined bivalence point: The planned bivalence temperature must not be in line with the bivalence point integrated into a heat pump system controller.
c. Lack of heat pump data: The minimal and maximal heat pump power are not subject to recent labelling standards and, thus, are not available.
d. Lack of quality in heat pump data: Available data does not take into account heat pump envelope, frosting, domestic hot water and performance degradation due to on/off-operation.

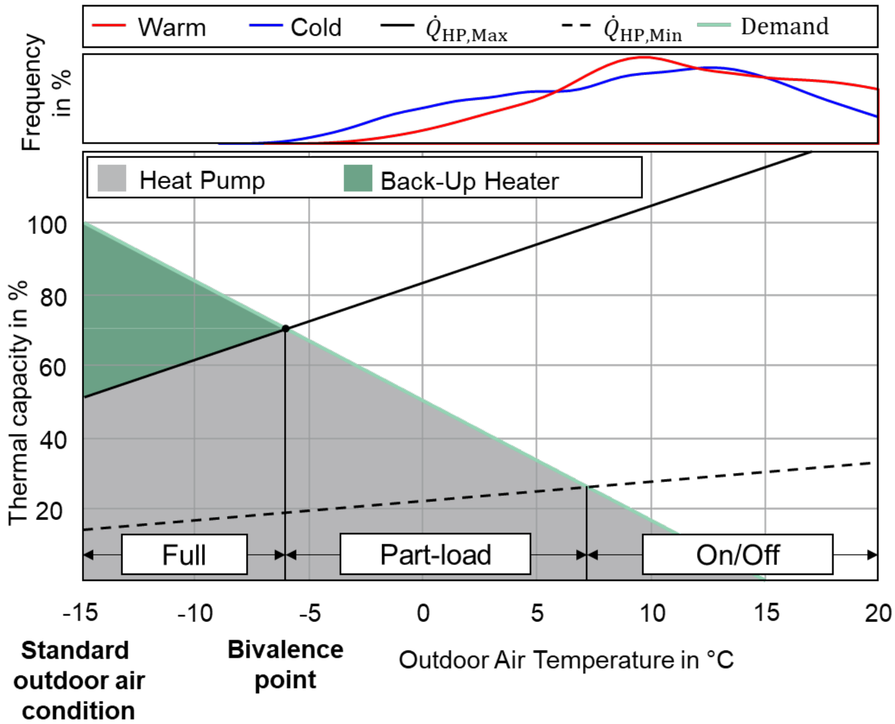

Figure 1: Heat pump system design for residential buildings.

When now rethinking the designing process, it becomes evident that, even if the system is perfectly commissioned and hydraulic balancing was executed perfectly, available information and perfect information are different, thus, yielding suboptimal heat pump system choices. While (a) and (b) are already discussed in the literature, this paper focuses on information regarding (c) and (d).

3. Data-Driven Heat Pump Models

To overcome the lack of available heat pump data, this work investigates a data-driven modeling approach that captures:

- Minimal and maximal heat pump power
- On/Off penalty

Compared to the lacks (c) and (d), the working envelope and domestic hot water provision as well as frosting is neglected in a first step. Based on available heat pump data shown in the energy efficiency label and the keymark data-base, the data-driven modeling approach builds up a continuous mathematical description of the heat pump model. The continuous formulation is important to match the heat pump with a building in a second step. The data-driven modelling approach uses input data from the label to identify the best model fit. The results are shown in Figure 2.

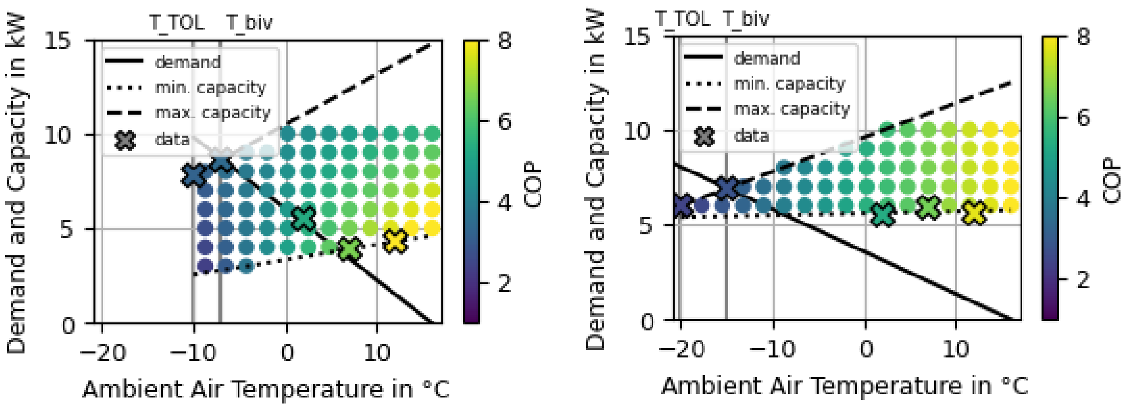

Figure 2: Data-driven model fits.

Based on the declared data points available in EN 14825 [9], the model development procedure is able to identify minimal and maximal heating power which show a reasonable behavior in line with Figure 1. It is obvious, that compared with a building demand, that on/off-behavior is reached. A penalty can be implemented to account for efficiency losses under that conditions that are not part of the recent labeling. Thus, the modelyields a more realistic approximation for the SCOP and a more reasonable assessment of operating costs compared to standard procedures. Finally, the heat pump and building match can be fully automated yielding the identification of the best solution from an end-users point of view. However, the data-driven modeling approach does not work out for all available heat pump data sets. Hence, making available data insufficient. Therefore, it is promising to rethink which data points should be a must-have in a labelling standard from a planner's point of view and not only from a manufacturers point of view helping to accelerate the energy transition in the building sector. In addition, the COP-penalties have been drawn from the literature. If recent labelling standards would already account for operating conditions like, e.g., frosting or on/off-operation, it would be even more accurate to estimate the SCOP and, thus, evaluate the expected overall costs.

4. Conclusion

The practical paper shows the difference between planning with perfect information and planning with available information. Using a data-driven modelling approach overcomes the lack of heat pump data to some extent underlining the potential of such planning processes. However, from a manufacturer-independent heat pump system planning point of view, it is highly recommended to align the planning process with the product rating process since recent data is insufficient when aiming at identifying the best near-optimal solution for an end-user.

Acknowledgements

The authors gratefully acknowledge the financial support by the Deutsche Bundesstiftung Umwelt (DBU), promotional reference 35507/21.

References

[1] European Commission (2003). Indoor Air Pollution: New EU Research Reveals Higher Risks than Previously Thought. Joint Research Center.

[2] Vering, C., Optimal Design of Heat Pump Systems in Existing Buildings, Dissertation, RWTH Aachen University, 2023.

[3] VDI 4645 Blatt 1 - 2018-03 – Heizungsanlagen mit elektrisch angetriebenen Wärmepumpen in Ein- und Mehrfamilienhäusern - Planung, Errichtung, Betrieb - Schulungen, Prüfungen, Qualifizierungsnachweise.

[4] DIN EN 15450 Heizungsanlagen in Gebäuden – Planung von Heizungsanlagen mit Wärmepumpen; Deutsche Fassung EN 15450:2007.

[5] Vering, C., Wüllhorst, F., et al., Towards an integrated design of heat pump systems: Application of process intensification using two-stage optimization, Energy, Conversion & Management, 250:114888.

[6] Wüllhorst, F., submitted PhD Thesis, RWTH Aachen University.

[7] DIN EN 12831-1: Energetische Bewertung von Gebäuden – Verfahren zur Berechnung der Norm-Heizlast – Teil 1: Raumheizlast, Modul M3-3; Deutsche Fassung EN 12831-1:2017.

[8] Das Schweizer Wärmepumpensystemmodul, https://www.wp-systemmodul.ch/de/, last access: 17.11.2025.

[9] EN 14825 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance.