TEXTE
22/2025

Sub-Report

Efficiency display of space heaters

by:

Peter Hennig, Joshua Drömer, Hourya Chelh
senercon GmbH, Berlin

Laurenz Hermann
co2online gGmbH, Berlin

Karl Steinjan
Institut für Luft- und Kältetechnik gGmbH, Dresden

Dirk Jepsen, Christian Tebert
Ökopol - Institute for Ecology and Politics GmbH, Hamburg

publisher:
German Environment Agency

German Environment Agency

Umwelt Bundesamt

TEXTE 22/2025

REFOPLAN of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

Project No. (FKZ) 3722 37 308 0
FB001566/ENG

Final report

Efficiency display of space heaters

by

Peter Hennig, Joshua Drömer, Hourya Chelh
senercon GmbH, Berlin

Laurenz Hermann
co2online gGmbH, Berlin

Karl Steinjan
Institut für Luft- und Kältetechnik gGmbH, Dresden

Dirk Jepsen, Christian Tebert
Ökopol - Institute for Ecology and Politics GmbH, Hamburg

On behalf of the German Environment Agency

Imprint

Publisher
Federal Environment Agency
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
buergerservice@uba.de
Internet: www.umweltbundesamt.de

Report performed by:
Ökopol - Institute for Ecology and Politics GmbH
Nernstweg 32-34
22765 Hamburg
Germany

Report completed in:
August 2024

Edited by:
Section V 1.4 Energy Efficiency
Jens Schuberth

Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4804

Dessau-Roßlau, February 2025

The responsibility for the content of this publication lies with the author(s).

Abstract:Efficiency display of space heaters; Efficiency display subproject

Against the background of the amendment to the Ecodesign Regulation (EU) No. 813/2013 on space heaters and combination heaters, this study develops recommendations on how efficiency displays can be taken into account and designed as part of the amendment to the regulation. Efficiency displays are intended to help identify efficiency problems in space heaters and systems as well as defects that reduce efficiency at an early stage. It is based mostly on data collected anyway for control purposes.

A 2023 draft of the amendment to the regulation already contains specifications for measuring or determining actual consumption and the calculated efficiency under the name "self-monitoring". Statements about the output periods, data resolution and accuracy can also be found in the draft document. However, there are currently no requirements for the interpretation and evaluation of efficiency. This study fills this gap and develops a methodology for efficiency displays in space and combination heaters.

Kurzbeschreibung: Wissenschaftliche Begleitung der Umsetzung der Ökodesign-Richtlinie und Energie-verbrauchskennzeichnungs-Verordnung – Viertes Arbeitsprogramm; Teilprojekt Effizienzanzeige

Vor dem Hintergrund der Novellierung der Ökodesign-Verordnung (EU) Nr. 813/2013 zu Raumheizgeräten und Kombiheizgeräten entwickelt diese Studie Empfehlungen, wie Effizienzanzeigen im Rahmen der Novellierung der Verordnung berücksichtigt und ausgestaltet werden können. Effizienzanzeigen sollen dazu dienen, Effizienzprobleme von Heizgeräten und Anlagen sowie effizienzmindernde Defekte frühzeitig zu erkennen. Sie basiert auf mehrheitlich ohnehin für die Steuerung und Regelung erhobenen Daten.

Ein Entwurf von 2023 zur Novelle der Verordnung enthält unter der Bezeichnung „Self-Monitoring“ bereits Vorgaben zum Messen bzw. Bestimmen von Ist-Verbräuchen und der errechneten Effizienz. Auch Aussagen zu den Ausgabezeiträumen, der Datenauflösung und -genauigkeit finden sich in dem Entwurfsdokument. Nicht vorgesehen sind bislang Anforderungen an die Interpretation und Bewertung der Effizienz. Diese Studie füllt diese Lücke und entwickelt eine Methodik für Effizienzanzeigen in Heizwärmeerzeugern.

Table of content

List of figures

List of tables

List of abbreviations

Abbreviation	Explanation
APF	Annual Performance Factor
BAFA	Federal Office of Economics and Export Control
BAM	Federal Institute for Materials Research and Testing
BDH	Federal Association of the German Heating Industry
BEG	German federal funding for energy-efficient buildings (Bundesförderung Energieeffiziente Gebäude)
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
BMWi	Federal Ministry for Economic Affairs and Energy (since 12/2021 BMWK)
BMWK	Federal Ministry for Economic Affairs and Climate Protection
BWP	German Heat Pump Association
COP	Coefficient of Performance
CSV	File format for tables (comma-separated values)
DG ENER	Directorate General Energy of the EU Commission
DIN	German Institute for Standardisation
EAC	Energy analysis from consumption
EHI	EHI Retail Institute GmbH
EN	European Standard
EU	European Union
FAQ	Frequently Asked Questions
FINESCE	Future Internet Smart Utility Services (European research project)
GEG	German Building Energy Act (Gebäudeenergiegesetz)
JIT	Building Energy Act
ILK	Institute for Air Handling and Refrigeration
ISE	Fraunhofer Institute for Solar Energy Systems ISE
ISH	International Trade Fair for Water, Heat, Air in Frankfurt/M
ISO	International Organization for Standardisation
JATL	Japan Air Conditioning and Refrigeration Testing Laboratory
K	Kelvin
kW	Kilowatt
kWh	Kilowatt hour
η_s	Seasonal space heating energy efficiency

Abbreviation	Explanation
η_{wh}	water heating energy efficiency
P_{el}	Electrical power
PV	Photovoltaics
R^2	Coefficient of determination (of regression function)
SCOP	Seasonal Coefficient of Performance
UBA	Federal Environment Agency of Germany
VDI	Association of German Engineers
VZBV	Federal Consumer Centre Germany

Summary

Goal and framework

Efficiency displays are designed to systematically and continuously detect efficiency problems in heating appliances and systems, whether they are of a technical, organisational or planning nature, and to identify efficiency-reducing defects at an early stage. An efficiency display is integrated into a heating appliance or its control system and is shown on the appliance display (optionally also via user portal / app). It is mainly based on data already collected for the control system. Sensors and evaluation routines may need to be added for any additional data required.

The aim of the project was to develop recommendations on how efficiency displays can be taken into account and designed as part of the amendment to Regulation (EU) No. 813/2013 on space heaters and combination heaters (ecodesign).

The draft (Working Document) for the amendment of Regulation No. 813/2013 (EU Kommission, 2023) contains specifications for measuring and determining actual consumption and calculated efficiency under the heading "Self-Monitoring". The working document also contains statements on output periods, data resolution and accuracy. Requirements for the interpretation and evaluation of efficiency have not yet been included. This study aims to provide recommendations on this.

In this context, the authors also looked at relevant legislation in the German context. In their efficiency strategy (BMWi, 2019) the German government defined the goal of providing a minimum level of meters and sensors when installing new heating systems and large air conditioning and ventilation systems - where possible under EU law and economically viable - in order to ensure efficient operation and inspections. For heating appliances, a simple feedback function for consumers should also be provided in addition to the meters in order to achieve transparency regarding the energy status of the systems.

Since 2023, efficiency displays have been a funding requirement for heating systems in the context of the federal funding for energy-efficient buildings (BEG) individual measures (BMWi, 2021). The technical FAQ (BAFA, 2024) focus on consumption displays and a consumption comparison. Information on annual performance factors or degrees of utilisation are not specified. Furthermore, no measurement method is specified for determining energy input and heat output, meaning that comparatively inaccurate estimation methods (see section 4.3) are possible. The estimation methods have a high market share in practice.

The Building Energy Act (GEG), which came into force in 2024, also contains requirements relating to the efficiency calculation of heat pumps. Section 70o (for the protection of tenants) specifies the procedure according to VDI 4650 for determining the "expected annual coefficient of performance". This paragraph is intended to ensure that new heat pump systems in rented residential buildings achieve an annual performance factor of at least 2.5. If not, the apportionability of modernisation costs is restricted. § 60a GEG stipulates that heat pump systems in buildings with at least 6 flats must be inspected two years after commissioning. In this context, the actual annual performance factor must be analysed by measurement. In the event of major deviations from the expected value, recommendations for efficiency improvements are to be made. An efficiency display is not part of the aforementioned GEG regulation, but it could be used for this purpose.

Task and procedure

Based on the results of the so-called "meter study" (Hermann, et al., 2019) which describes the principle of the efficiency display, suitable methods should be identified, evaluated and applied as examples.

As part of a literature review, the status of the preparatory work for the amendment of Regulation (EU) No. 813/2013 and the national implementation of efficiency displays in the Federal Funding for Efficient Buildings (BEG) and the Building Energy Act (GEG) were presented. As part of a comparison of methods, relevant standards and procedures were reviewed and their applicability examined. The methods were presented, evaluated and discussed with experts. This brought further procedures, standards and deviating practical implementations into focus.

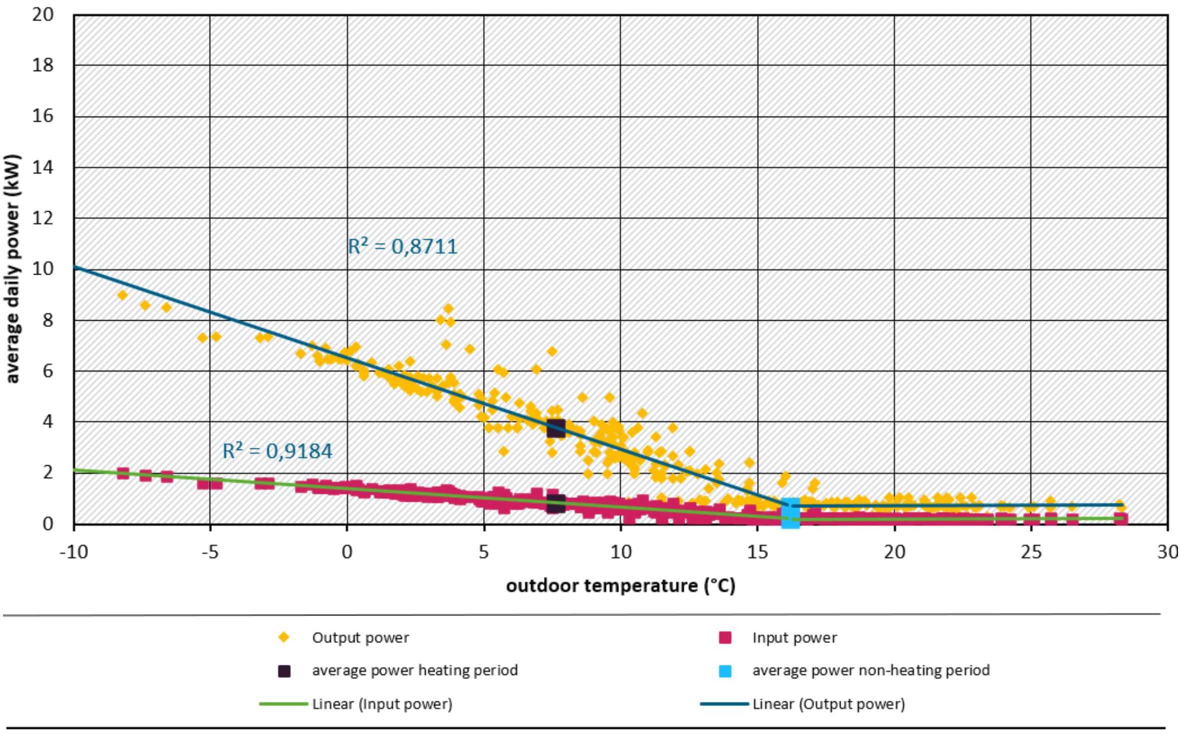
For the subsequent application of the method, an evaluation logic was developed and applied to three heat pumps and one boiler for which corresponding operating data was available. The developed evaluation logic is based on the efficiency criterion "measured annual coefficient of performance or annual utilisation factor", which includes all operating modes (in particular standby, heating and hot water operation). The logic provides for the efficiency to be compared with an "expected efficiency" for the initial assessment after a system has been installed, and then with the measured annual efficiencies on a rolling monthly basis. It should be possible to determine and evaluate the efficiency during the year (before the end of one year after installation).

Results

The key findings and results that are relevant for the design of efficiency displays are summarised below.

- The website of the German Heat Pump Association (BWP) offers an **online tool** that allows the calculation of **the expected annual performance factor** in accordance with VDI 4650 within just a few minutes. The annual performance factor depends, among other things, on the heat source (medium from which heat is extracted), the specific appliance (listed by manufacturer in the tool), the maximum flow temperature of the heating circuit, the hot water temperature and the proportionate hot water consumption.
- Daily values are preferred for the **data resolution of efficiency displays**, although a higher coefficient of determination can be achieved with weekly values. However, this resolution is not sufficient for fault diagnosis (including mapping of switching processes). For this purpose, minute values would be useful.
- **Efficiency displays do not only diagnose efficiency problems**. In general, the efficiency parameters favoured in the study, annual coefficient of performance and annual efficiency factor, also depend on the **usage (change)** and the **climate** during the period under investigation. The efficiency of air-to-water heat pumps in particular depends heavily on the climate. Thermal improvements are also recognised. Deterioration due to ageing may not be identified when using estimation methods.
- In the case of space heating in buildings, there is a **significant correlation between energy input and output and the outdoor temperature** (Figure 1). If this statistical correlation changes (gradient of the curves), the energy efficiency has changed. In the non-heating period, the curves run parallel to the x-axis and represent the hot water demand of the building. Changes in these pairs of values are generally due to changes in utilisation.

Figure 1: Energy analysis of a residential building



Daily values of electricity consumption (input) and heat output of a brine-to-water heat pump (see Appendix B.1) above the outdoor temperature, differentiated by heating and non-heating period. The consumption values are shown as average outputs per day. The procedure is described in section 5. Source: own illustration, co2online/senercon

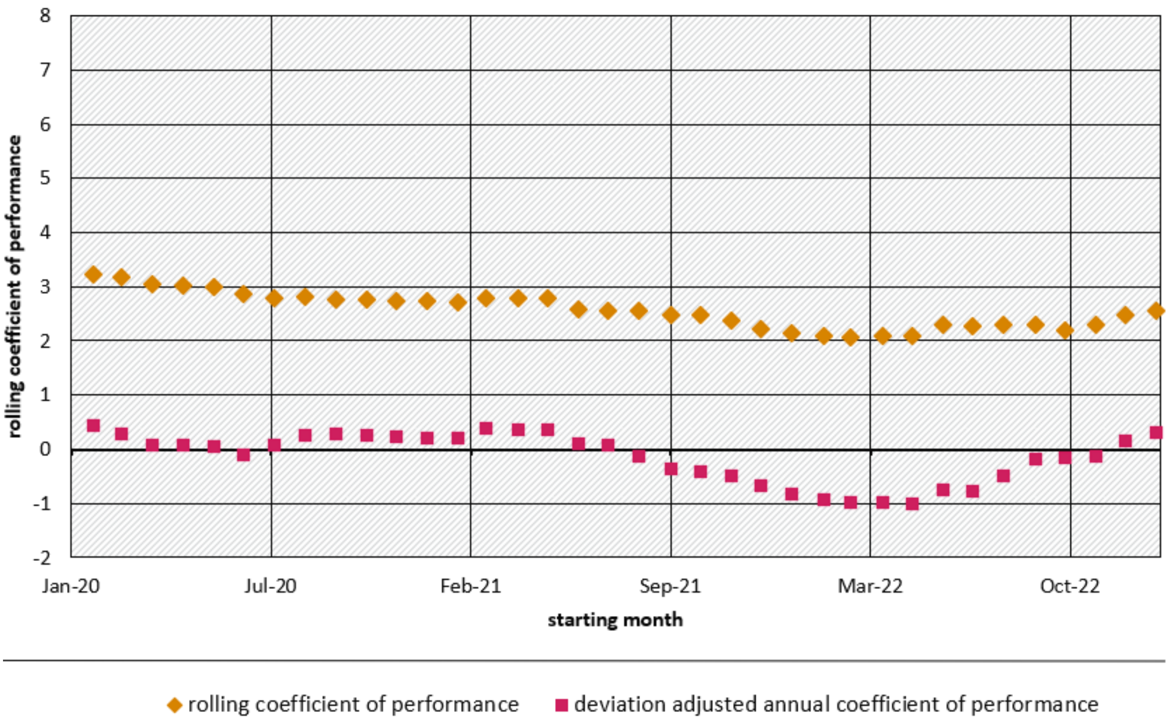
- The **annual coefficient of performance** (or annual performance factor) **and annual utilisation factor** are used to **assess efficiency.** If the energy analysis method is used to calculate these parameters, there is good accordance with the annual values. For this purpose, the pairs of values at average outside temperature in the heating period and in the non-heating period are to be used and the individual heating limit temperature of the building is to be taken into account. The values are weighted using the proportional number of hours.

- As the average outdoor temperature fluctuates from year to year during the heating period, there are climate-related changes in efficiency. A **climate adjustment** can be made by comparing the efficiencies determined via the energy analysis at actual and standard outdoor temperatures.

- A two-stage procedure is proposed for a simple efficiency assessment (Figure 2). Stage 1 comprises the presentation of a summarised efficiency measured as a **rolling annual performance factor** over time. As the periods between the data points only differ by one month, no major climate-related fluctuations are to be expected between two data points. Larger jumps or fluctuations can be recognised as a change in efficiency.

- For stage 2 of the efficiency assessment, a baseline period of one year must be defined for which an energy analysis is prepared. The difference between the summarised efficiency measured for the period and the efficiency determined via the energy analysis (taking into account the respective climate of the period) results in a **zero deviation**. Negative values indicate a deterioration in efficiency. The influence of the climate has already been factored out in this illustration.

Figure 2: Procedure for efficiency monitoring

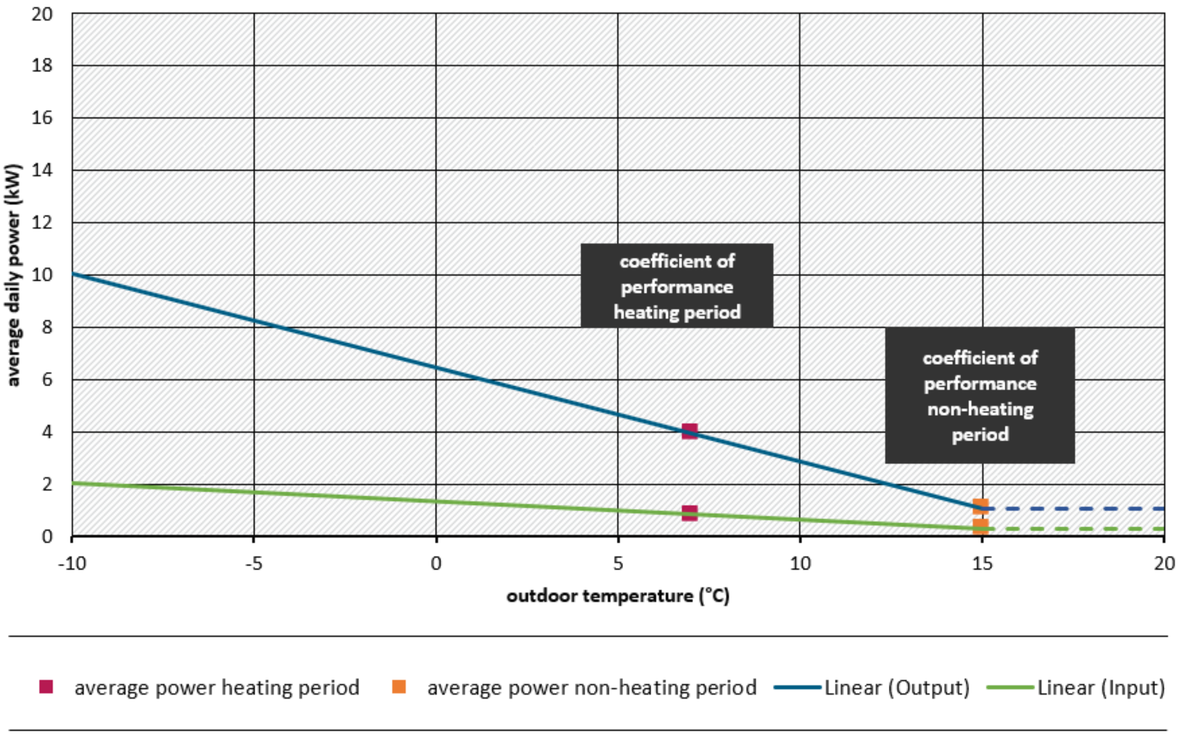


Rolling annual performance factor (orange) and zero deviation (red) analysed over time for the air-to-water heat pump system listed in Annex B.2. Efficiency assessment level 1: The rolling performance factor graph shows annual values calculated from the previous twelve months, with the period under consideration shifting by one month in each case. Efficiency assessment level 2: The zero deviation represents the difference between the summarised measured annual COP and the target annual COP of the baseline period determined via the energy analysis, which depends on the outdoor temperature of the period. Negative values indicate a deterioration in efficiency. Source: own illustration, co2online/senercon

- For the **evaluation of efficiency during the year** (before the end of a year after installation), an estimated annual performance factor can be determined after a few weeks of heating operation during the core heating period. The basic procedure is shown in Figure 3. For this purpose, an expected heating limit temperature (15 °C in the example) must be specified. A determination during the year is only possible on the basis of data from the heating period. Data from the non-heating period cannot be used to determine the efficiency during the heating period. This data can only be used to refine the annual performance factor for hot water supply.
- For the **initial classification of the efficiency of individual heat pump solutions**, "expected annual figures" can be used, which convert standard values from the device data sheet with the help of influencing factors (e.g. source medium, heating system design, hot water volume or number of occupants, hot water temperature, degree day number of the location) to practical comparative values for annual performance figures. In the project, such comparative values were determined both on the basis of VDI 4650 and by means of linear regression of a data sample. The EU-wide applicability of such procedures must be discussed. Individual comparative values are more meaningful than mean values from field tests. However, the methods still need to be refined, as only in one of the cases analysed was a sufficiently good agreement between the comparative value and the practical value found.

- For **boilers**, "**expected annual utilisation rates**" can very probably be specified directly on the basis of the technologies (e.g. condensing boilers, low-temperature boilers and according to the gaseous, liquid or solid fuels used). Orientation values for expected annual utilisation rates could be obtained by applying a discount to the seasonal space heating energy efficiency.

Figure 3: Averaged operating points for determining the SPF of a heat pump during the year



Regression analysis based on daily values of input and output during the year and the corresponding outdoor temperatures, determination of the average output at average outdoor temperature in the heating period, determination of the average output for the non-heating period from the values at the heating limit temperature (see section 5) Source: own illustration, co2online/senercon

In general, the study has shown that there are suitable methods for providing efficiency indicators based on annual performance figures or annual utilisation rates with comparative values. It is possible to calculate a starting value for an "expected efficiency" based on the appliance parameters as well as utilisation and heating system data. It is also possible to determine efficiency values during the year after a few weeks of measurement during the heating period. Data on the outdoor temperature at the building location is also required for the efficiency assessment.

In the authors' view, the study represents a good starting point for technical discussions on the design of efficiency indicators. However, it also shows that the exemplary sample application only allows general statements to be made about the accuracy of the favoured methods for obtaining efficiencies and comparative values.

Ecodesign recommendations

The study provides a basis for discussion on the further development of the requirements for efficiency labelling in the context of the amendment of the Ecodesign Regulation (EU) No. 813/2013 on space heaters and combination heaters. These supplementary proposals could be made available either in the regulation itself or alternatively as part of an EU guideline (not legally binding).

- ► The parameters annual coefficient of performance and annual utilisation factor are suitable as efficiency criteria for heat pumps and boilers.
- ► When assessing efficiency, a distinction must be made between the start-up phase (first year of operation) and subsequent operation.
- ► In the start-up phase, it is possible to generate the efficiencies during the year on the basis of the energy analysis from consumption (EAC) after a few weeks in the heating period. Furthermore, the generation of an individual comparative value for efficiency on the basis of standard values and influencing factors (e.g. temperature levels). In Germany, these comparative values can be determined with the help of VDI 4650.
- ► In subsequent operation, a rolling analysis of the efficiency development alone or additionally taking into account the climate and on the basis of a baseline period is possible. In the second case, it makes sense to visualise the efficiency as the difference between the measured value and the expected value (Figure 2, red line). If this is negative, there is a deterioration in efficiency.
- ► A brief review showed that consumption-based methods, predominantly based on energy analysis, are suitable for making efficiency statements for most appliance groups or that these can be presented as a kind of "utilisation of efficiency".

The procedures for determining individual comparative values must be reviewed and their accuracy improved.

- ► The increased market penetration of heat pump systems for space heating will generally increase the demand for comparative values for efficiency assessment. In Germany, for example, § 60a of the GEG requires new heat pumps in buildings with at least 6 flats to be tested after two years of operation. Within this framework, a metrological inspection and assessment of the annual performance factor is specified.
- ► A method based on VDI 4650 is generally suitable for generating individualised comparative values. However, the results according to VDI 4650 were too positive in three of the applications analysed. The method should therefore be optimised.
- ► Alternatively, it is possible to generate comparative values for annual performance factors using field data by means of a regression analysis of the influencing factors.
- ► As a further alternative for determining comparative values, it would be possible for heat pumps to store standardised values for the seasonal coefficient of performance (SCOP) in the appliances.
- ► As the efficiency of boilers is significantly less dependent on the outside temperature than that of heat pumps, the seasonal space heating energy efficiency can be used as a comparative value by defining a discount factor in order to obtain a practical comparative value.
- ► If standard values are stored, it may be useful to define discount factors (not analysed) in order to obtain practical comparative values.

- A data resolution of daily values is sufficient for the efficiency assessment. In the authors' opinion, the resolution of 15-minute values proposed in the draft version of the amendment to (EU) No. 813/2013 is too fine-grained for a pure efficiency assessment. Daily or possibly even weekly values are sufficient for this purpose. For the purposes of fault diagnosis, higher data resolutions would be required (minute values).
- The draft Ecodesign Regulation requires a differentiation between space heating and hot water when storing input and output data. In the use cases analysed in this study, the consumption data was not available in this differentiation, which is why the authors carried out a statistical breakdown here. This statistical breakdown can be dispensed with if the differentiated measurement data is available. The accuracy will be even higher as a result.

Recommendations beyond Ecodesign

It makes sense to reassess and improve the requirements for efficiency displays applicable in Germany. Efficiency indicators are a funding requirement for heat pumps as part of the federal funding for energy-efficient buildings (BEG) individual measures. Section 60a GEG requires the metrological evaluation of performance figures as part of the testing and optimisation of heat pumps in buildings with at least 6 flats two years after their installation.

- The efficiency indicator as described by the funding authority (BAFA, 2024) in the technical FAQs is currently defined as a consumption display that provides for a comparison of the consumption of different periods that is not climate-adjusted. An update to the efficiency assessment procedure proposed here using annual performance figures or annual degrees of utilisation makes sense.
- The procedure for testing and optimising heat pumps in accordance with § 60a GEG can be significantly simplified if the annual coefficient of performance is determined using the efficiency display. The procedure specified in the GEG in accordance with VDI 4650 can also be integrated into the heat pump control system. This would allow a starting value for an "expected annual performance factor" to be determined during the installation of heat pump systems and made available to the user. Alternatively, this figure can be determined using the annual performance factor calculator of the German Heat Pump Association and stored there by the installer during commissioning.
- The procedure according to VDI 4650 should be improved by including the losses due to defrosting and cycling (see section 4.3.3).

Zusammenfassung

Ziel und Rahmen

Effizienzanzeigen sollen dazu dienen, Effizienzprobleme von Heizgeräten und Anlagen, seien sie technischer, organisatorischer oder planerischer Natur, systematisch und kontinuierlich aufzudecken sowie effizienzmindernde Defekte frühzeitig zu erkennen. Eine Effizienzanzeige ist in einem Heizgerät bzw. dessen Steuerung integriert und wird im Gerätedisplay (optional auch über Nutzer-Portal / App) angezeigt. Sie basiert auf mehrheitlich ohnehin für die Steuerung und Regelung erhobenen Daten. Ggf. müssen für zusätzlich benötigte Daten Sensoren und Auswerteroutinen ergänzt wurden.

Ziel des Projektes war es, vor dem Hintergrund der Novellierung der Verordnung (EU) Nr. 813/2013 zu Raumheizgeräten und Kombiheizgeräten (Ökodesign) Empfehlungen zu entwickeln, wie Effizienzanzeigen im Rahmen der Novellierung der Verordnung berücksichtigt und ausgestaltet werden können.

Der Entwurf (Working Document) zur Novelle der Verordnung Nr. 813/2013 (EU Kommission, 2023) enthält unter der Bezeichnung „Self-Monitoring" Vorgaben zum Messen bzw. Bestimmen von Ist-Verbräuchen und der errechneten Effizienz. Auch Aussagen zu den Ausgabezeiträumen, der Datenauflösung und -genauigkeit finden sich in dem Entwurfsdokument. Nicht vorgesehen sind bislang Anforderungen an die Interpretation und Bewertung der Effizienz. Hierzu will diese Studie Empfehlungen geben.

In diesem Kontext betrachteten die Autoren auch relevante Rechtsetzungen im deutschen Kontext. In ihrer Effizienzstrategie (BMWi, 2019) definierte die Bundesregierung das Ziel, beim Einbau von neuen Heizungen sowie großen Klima- und Lüftungsanlagen – soweit EU-rechtlich möglich und wirtschaftlich vertretbar – eine Mindestausstattung von Zählern und Sensorik vorzusehen, um einen effizienten Betrieb und Inspektionen zu gewährleisten. Bei Heizgeräten sollte neben den Zählern auch eine einfache Feedback-Funktion für die Verbraucher vorgesehen werden, um damit Transparenz über den energetischen Zustand der Anlagen zu erreichen.

Seit 2023 sind Effizienzanzeigen eine Fördervoraussetzung für Heizsysteme im Kontext der Bundesförderung Energieeffiziente Gebäude (BEG) Einzelmaßnahmen (BMWi, 2021). Die technischen FAQs (BAFA, 2024) nehmen vor allem Verbrauchsanzeigen bzw. Verbrauchsvergleiche in den Fokus. Angaben zu Jahresarbeitszahlen oder nutzungsgraden sind nicht vorgegeben. Weiter wird kein Messverfahren für die Ermittlung von Energieinput und Wärmeoutput vorgegeben, so dass vergleichsweise ungenaue Schätzverfahren (vgl. Abschnitt- 4.3) möglich sind. Die Schätzverfahren haben in der Praxis einen hohen Marktanteil.

Auch im 2024 in Kraft getretenen Gebäudeenergiegesetz (GEG) finden sich Regelungen, die die Effizienzberechnung von Wärmepumpen betreffen. In § 70o (Regelungen zum Schutz von Mietern) wird das Verfahren nach der VDI 4650 für die Bestimmung der „erwarteten Jahresarbeitszahl" vorgegeben. Mittels dieses Paragrafen soll sichergestellt werden, dass neue Wärmepumpenanlagen in vermieteten Wohngebäuden mindestens eine Jahresarbeitszahl von 2,5 erreichen. Wenn nicht, wird die Umlagefähigkeit der Modernisierungskosten beschränkt. § 60a GEG schreibt die Betriebsprüfung von Wärmepumpenanlagen in Gebäuden mit mindestens 6 Wohnungen zwei Jahre nach Inbetriebnahme vor. In diesem Rahmen muss die tatsächliche Jahresarbeitszahl messtechnisch ausgewertet werden. Bei größeren Abweichungen vom erwarteten Wert sollen Empfehlungen zu Effizienzverbesserungen gegeben werden. Eine Effizienzanzeige ist nicht Gegenstand der genannten GEG-Regelung, aber sie wäre für diese Zwecke ggf. nutzbar.

Aufgabe und Vorgehen

Auf Basis der Ergebnisse der so genannten „Zählerstudie" (Hermann, et al., 2019), in welcher das Prinzip der Effizienzanzeige beschrieben wird, sollten geeignete Methoden identifiziert, bewertet und exemplarisch angewendet werden.

Im Rahmen einer Literaturrecherche wurde der Stand der Vorarbeiten zur Novellierung von Verordnung (EU) Nr. 813/2013 sowie die nationale Umsetzung von Effizienzanzeigen in der Bundesförderung für effiziente Gebäude (BEG) und im Gebäudeenergiegesetz (GEG) dargestellt. Im Rahmen eines Methodenvergleichs wurden relevante Normen und Verfahren gesichtet und deren Anwendungsmöglichkeit geprüft. Die Methoden wurden dargestellt, bewertet und mit Experten diskutiert. Dadurch gerieten weitere Verfahren, Normen und abweichende Praxisumsetzungen ins Blickfeld.

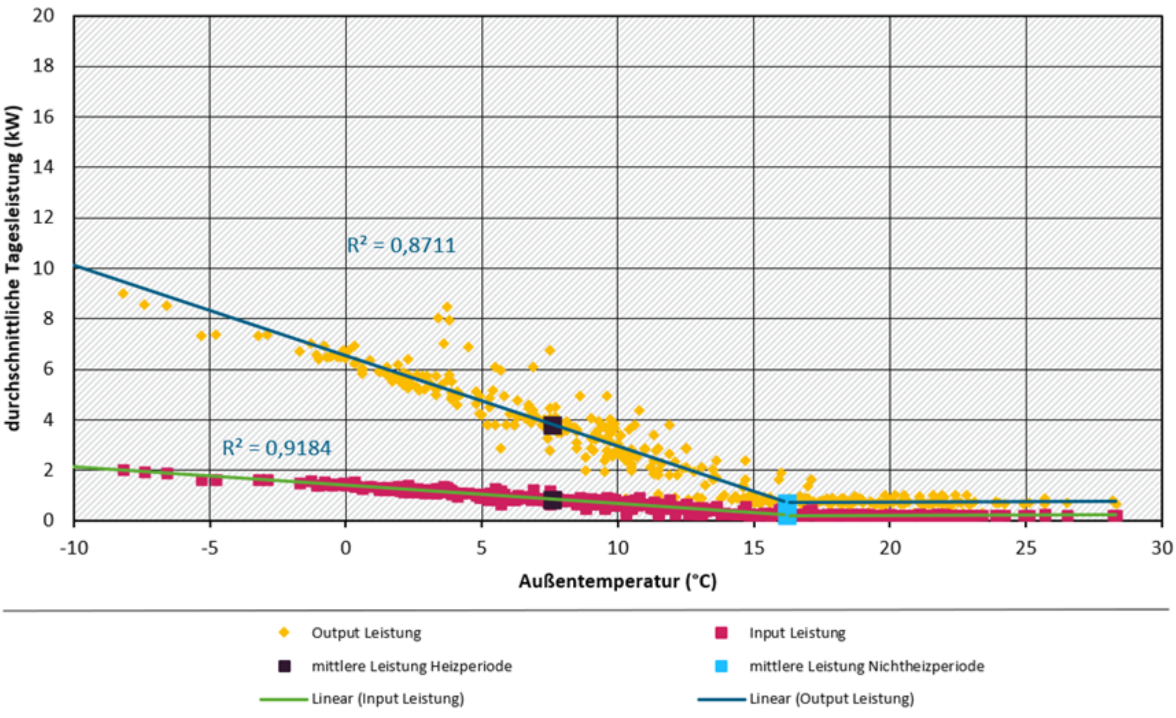
Für die sich anschließende Methodenanwendung wurde eine Bewertungslogik entwickelt und auf drei Wärmepumpen und einen Heizkessel angewendet, für welche entsprechende Betriebsdaten vorlagen. Die entwickelte Bewertungslogik basiert auf dem Effizienzkriterium „gemessene Jahresarbeitszahl bzw. Jahresnutzungsgrad", das alle Betriebsmodi (insbesondere Standby, Heiz- und Warmwasserbetrieb) inkludiert. Die Logik sieht vor, dass für die Erstbewertung nach einem Anlageneinbau die Effizienz mit einer „erwarteten Effizienz" verglichen wird, danach monatlich rollierend mit den gemessenen Jahreseffizienzen. Eine unterjährige Ermittlung und Bewertung (vor Ablauf eines Jahres nach Einbau) der Effizienz sollte dabei möglich sein.

Ergebnisse

Nachfolgend sind zentrale Erkenntnisse und Ergebnisse zusammengefasst, die für die Ausgestaltung von Effizienzanzeigen relevant sind.

- Auf der Website des Bundesverbands Wärmepumpe (BWP) ist ein **Online-Rechner** integriert, der eine Ermittlung **der erwarteten Jahresarbeitszahl** gemäß VDI 4650 in wenigen Minuten ermöglicht. Die Jahresarbeitszahl hängt u.a. von der Wärmequelle (Medium, dem Wärme entzogen wird), dem konkreten Gerät (nach Herstellern im Ratgeber hinterlegt), der maximalen Vorlauftemperatur des Heizkreises, der Warmwassertemperatur und dem anteiligen Warmwasserverbrauch ab.
- Für die **Datenauflösung von Effizienzanzeigen** werden Tageswerte präferiert, obwohl mit Wochenwerten ein höheres Bestimmtheitsmaß erreichbar ist. Für die Fehlerdiagnose (inkl. Abbildung von Schaltvorgängen) reicht diese Auflösung jedoch nicht aus, hierfür wären Minutenwerte sinnvoll.
- **Effizienzanzeigen diagnostizieren nicht nur Effizienzprobleme**. Generell hängen die in der Studie präferierten Effizienzgrößen Jahresarbeitszahl und Jahresnutzungsgrad auch von der **Nutzung(sänderung)** und vom **Klima** im Untersuchungszeitraum ab. Insbesondere die Effizienz von Luft-Wasser-Wärmepumpen hängt stark vom Klima ab. Auch wärmetechnische Verbesserungen werden erkannt. Alterungsbedingte Verschlechterungen können bei der Verwendung von Schätzverfahren ggf. nicht identifiziert werden.
- Bei der Raumheizung von Gebäuden besteht ein **signifikanter Zusammenhang von Energie-Input als auch -Output und der Außentemperatur** (Abbildung 4). Ändert sich dieser statistische Zusammenhang (Steigung der Kurven), hat sich die Energieeffizienz geändert. In der Nichtheizperiode verlaufen die Kurven parallel zur X-Achse und stellen den Warmwasserbedarf des Gebäudes dar. Änderungen dieser Wertepaare sind i.d.R. auf Nutzungsänderungen zurückzuführen.

Figure 4: Energieanalyse eines Wohngebäudes



Tageswerte des Stromverbrauchs (Input) und der Wärmeabgabe (Output) einer Sole-Wasser-Wärmepumpe (vgl. Anhang B.1) über der Außentemperatur, differenziert nach Heiz- und Nichtheizperiode. Die Verbrauchswerte sind als durchschnittliche Leistungen pro Tag dargestellt. Das Verfahren wird in Abschnitt 5 beschrieben. Quelle: eigene Darstellung, co2online/senercon

- Für die **Bewertung der Effizienz** werden die Größen **Jahresarbeitszahl bzw. Jahresnutzungsgrad** herangezogen. Wird das Verfahren der Energieanalyse für die Berechnung dieser Kennwerte genutzt, ergibt sich eine gute Übereinstimmung mit den Jahreswerten. Hierzu sind die Wertepaare bei mittlerer Außentemperatur in der Heizperiode und mittlerer Außentemperatur in der Nichtheizperiode heranzuziehen und die individuelle Heizgrenztemperatur des Gebäudes zu berücksichtigen. Eine Wichtung der Werte erfolgt dabei über die anteiligen Stundenzahlen.

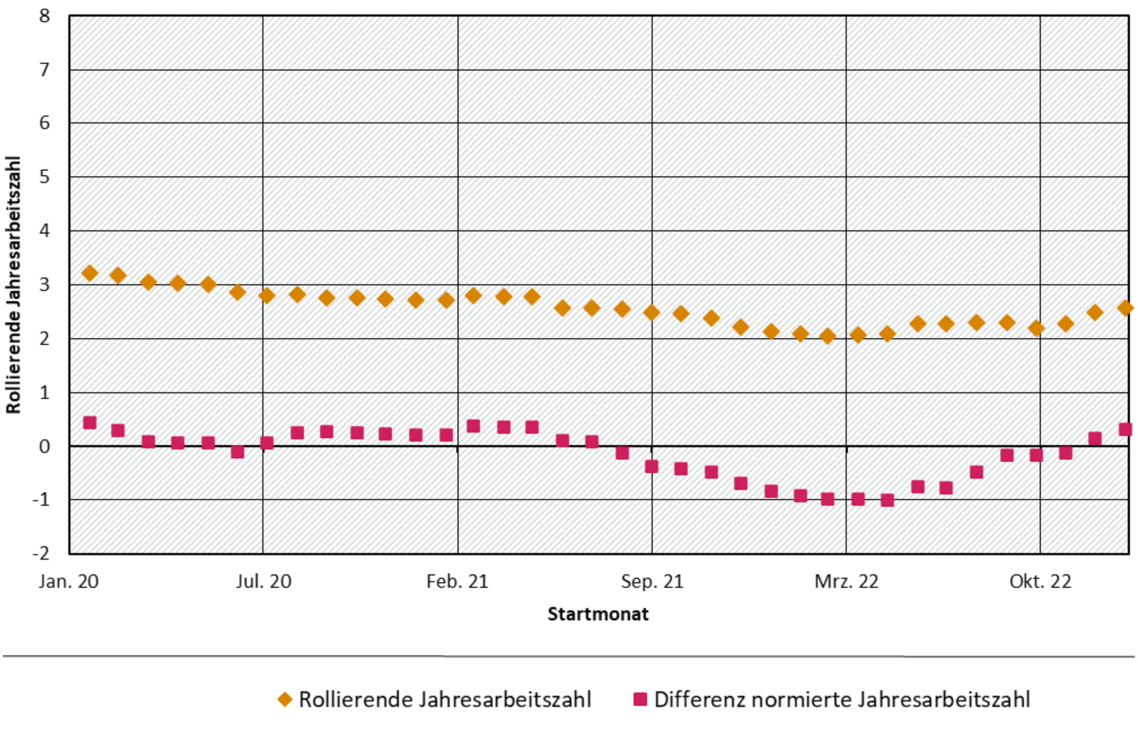
- Da die mittlere Außentemperatur in der Heizperiode von Jahr zu Jahr schwankt, ergeben sich klimabedingte Änderungen der Effizienz. Durch einen Vergleich der über die Energieanalyse ermittelten Effizienzen bei tatsächlicher und Norm-Außentemperatur kann eine **Klimabereinigung** erfolgen.

- Für eine einfache Effizienzbewertung wird ein zweistufiges Verfahren vorgeschlagen (Abbildung 5). Stufe 1 umfasst die Darstellung einer summarisch gemessenen Effizienz als **rollierende Jahresarbeitszahl** im Zeitverlauf. Da sich die Perioden zwischen den Datenpunkten jeweils nur um einen Monat unterscheiden, sind keine größeren klimabedingten Schwanken zwischen zwei Datenpunkten zu erwarten. Größere Sprünge oder Schwankungen sind als Effizienzänderung zu erkennen.

- Für Stufe 2 der Effizienzbewertung ist eine Baseline-Periode von einem Jahr zu definieren, für die eine Energieanalyse erstellt wird. Durch Differenzbildung der summarisch gemessenen Effizienz der Periode mit der über die Energieanalyse ermittelten Effizienz (unter Berücksichtigung des jeweiligen Klimas der Periode) ergibt sich eine

Nullabweichung. Negative Werte weisen auf Effizienzverschlechterungen hin. Der Einfluss des Klimas ist bei dieser Darstellung bereits herausgerechnet.

Figure 5: Verfahren für die Effizienzüberwachung



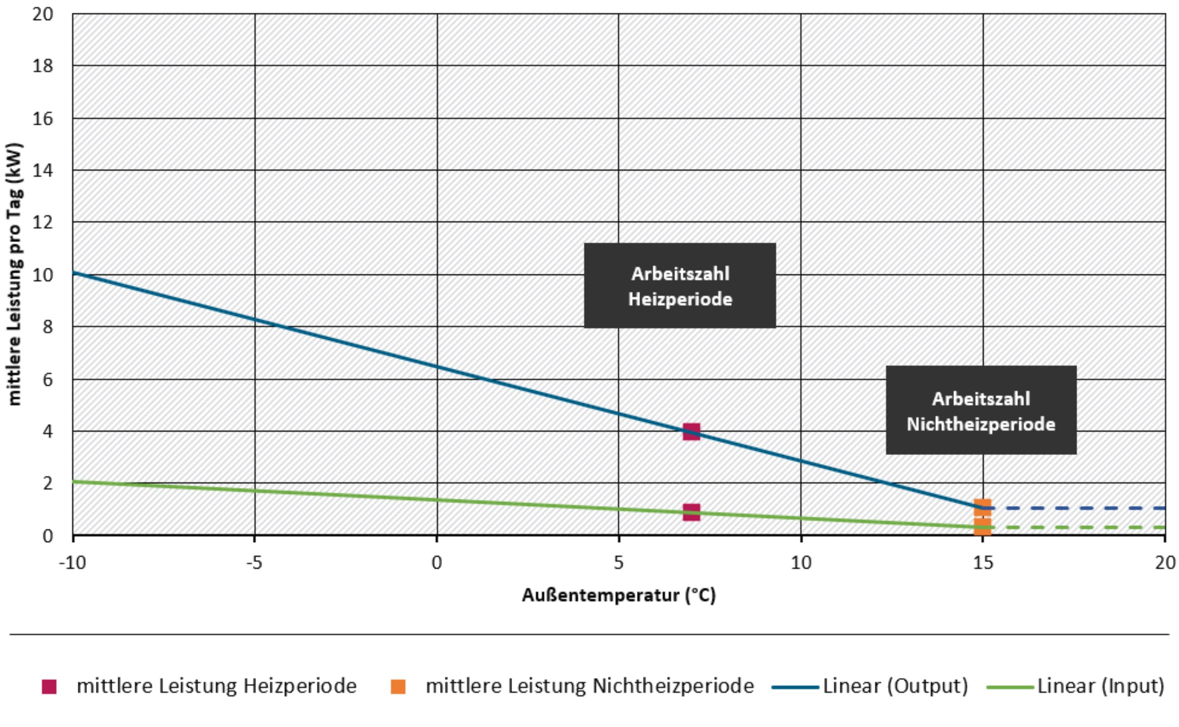
Rollierende Jahresarbeitszahl (orange) und Nullabweichung (rot) der in Anhang B.2 untersuchten Luft-Wasser-Wärmepumpe im Zeitverlauf. Effizienzbewertung Stufe 1: Die rollierende Arbeitszahldarstellung zeigt Jahreswerte, die aus den zurückliegenden zwölf Monaten berechnet werden, wobei sich der betrachtete Zeitraum jeweils um einen Monat verschiebt. Effizienzbewertung Stufe 2: Die Nullabweichung stellt die Differenz zwischen summarisch gemessener Jahresarbeitszahl und der über die Energieanalyse ermittelten, von der Außentemperatur der Periode abhängigen Soll-Jahresarbeitszahl der Baseline-Periode dar. Negative Werte weisen auf Effizienzverschlechterungen hin. Quelle: eigene Darstellung, co2online/senercon

- Für die **unterjährige Bewertung der Effizienz** (vor Ablauf eines Jahres nach Einbau) kann nach einigen Wochen Heizbetrieb in der Kernheizperiode eine voraussichtliche Jahresarbeitszahl ermittelt werden. Das prinzipielle Vorgehen wird in Abbildung 6 dargestellt. Hierfür muss eine zu erwartende Heizgrenztemperatur (im Beispiel 15 °C) vorgegeben werden. Eine unterjährige Bestimmung ist nur auf Basis von Daten aus der Heizperiode möglich. Aus Daten der Nichtheizperiode kann nicht auf die Effizienz in der Heizperiode geschlossen werden. Mit diesen Daten kann die Jahresarbeitszahl bei Warmwasserbezug nur verfeinert werden.
- Zur **Ersteinstufung der Effizienz individueller Wärmepumpenlösungen** können „erwartete Jahreszahlen" herangezogen werden, die Normwerte aus dem Gerätedatenblatt mit Hilfe von Einflussfaktoren (z.B. Quellmedium, Heizungsauslegung, Warmwassermenge bzw. Anzahl Bewohner, Warmwassertemperatur, Gradtagszahl des Standortes) auf praxisgerechte Vergleichswerte für Jahresarbeitszahlen umrechnen. Im Projekt wurden solche Vergleichswerte sowohl auf Basis der VDI 4650 als auch mittels linearer Regression eines Datensamples ermittelt. Die EU-weite Anwendbarkeit solcher Verfahren ist zu diskutieren. Individuelle Vergleichswerte haben eine höhere Aussagekraft gegenüber

Mittelwerten aus Feldtests. Die Verfahren sind allerdings noch nachzuschärfen, da nur in einem der untersuchten Fälle eine hinreichend gute Übereinstimmung zwischen Vergleichs- und Praxiswert festgestellt wurde.

- Für **Heizkessel** können „**erwartete Jahresnutzungsgrade**" mit hoher Wahrscheinlichkeit direkt auf Basis der Techniken (z. B. Brennwertkessel, Niedertemperaturkessel sowie nach verwendeten Brennstoffen gasförmig, flüssig bzw. fest) vorgegeben werden. Orientierungswerte für erwartete Jahresnutzungsgrade könnten durch einen Abschlag auf die jahreszeitlich bedingte Raumheizungsenergieeffizienz gewonnen werden.

Figure 6: Gemittelte Betriebspunkte für unterjährige Bestimmung der JAZ einer Wärmepumpe



Regressionsanalyse auf Basis unterjähriger Tageswerte von In- und Output und den dazugehörigen Außentemperaturen, Ermittlung der mittleren Leistungen bei mittlerer Außentemperatur in der Heizperiode, Bestimmung der mittleren Leistungen für die Nichtheizperiode aus den Werten an der Heizgrenztemperatur (vgl. Abschnitt 5) Quelle: eigene Darstellung, co2online/senercon

Generell hat die Studie gezeigt, dass es geeignete Verfahren gibt, um Effizienzanzeigen, die auf der Basis von Jahresarbeitszahlen bzw. Jahresnutzungsgraden beruhen, mit Vergleichswerten auszustatten. Möglich ist die Berechnung eines Startwerts für eine „erwartete Effizienz" auf Basis der Gerätekennwerte sowie Nutzungs- und Heizanlagendaten. Weiterhin ist eine unterjährige Ermittlung von Effizienzwerten nach wenigen Wochen Messdauer in der Heizperiode möglich. Benötigt werden für die Effizienzbewertung zusätzlich Daten der Außentemperatur des Gebäudestandorts.

Die Studie stellt aus Sicht der Autoren einen guten Ausgangspunkt für Fachdiskussionen zur Ausgestaltung von Effizienzanzeigen dar. Sie zeigt aber auch, dass die exemplarische Beispielanwendung nur tendenzielle Aussagen zur Genauigkeit der favorisierten Verfahren zur Gewinnung von Effizienzen und Vergleichswerten zulässt.

Empfehlungen Ökodesign

Die Studie schafft eine Diskussionsgrundlage für die weitere Ausgestaltung der Anforderungen an eine Effizienzanzeige im Kontext der Novellierung der Ökodesign-Verordnung (EU) Nr. 813/2013 zu Raumheizgeräten und Kombiheizgeräten. Diese ergänzenden Vorschläge könnten entweder in der Verordnung selbst, alternativ im Rahmen einer EU-Leitlinie (nicht rechtsverbindlich) zur Verfügung gestellt werden.

- Die Parameter Jahresarbeitszahl und Jahresnutzungsgrad sind für Wärmepumpen bzw. Heizkessel als Effizienzkriterien geeignet.
- Bei der Effizienzbewertung ist zwischen einer Startphase (1. Betriebsjahr) und dem Folgebetrieb zu unterscheiden.
- In der Startphase ist die unterjährige Generierung der Effizienzen auf Basis der Energieanalyse aus dem Verbrauch (EAV) nach wenigen Wochen in der Heizperiode möglich. Weiterhin die Generierung eines individuellen Vergleichswertes für die Effizienz auf Basis von Normwerten und Einflussfaktoren (z.B. Temperaturniveaus). In Deutschland können diese Vergleichswerte mit Hilfe der VDI 4650 ermittelt werden.
- Im Folgebetrieb ist eine rollierende Betrachtung der Effizienzentwicklung allein oder zusätzlich unter Berücksichtigung des Klimas und auf Basis einer Baseline-Periode möglich. Im zweiten Fall ist eine Darstellung der Effizienz als Differenz zwischen gemessenem Wert und Erwartungswert sinnvoll (Abbildung 5, rote Linie). Wenn diese negativ ist, liegt eine Effizienzverschlechterung vor.
- Eine Kurzprüfung zeigte auf, dass verbrauchsbasierte Verfahren, überwiegend auf Basis der Energieanalyse, geeignet sind, Effizienzaussagen für die meisten Gerätegruppen zu treffen oder diese als eine Art „Ausschöpfung der Effizienz“ dargestellt werden können.

Die Verfahren für die individuelle Vergleichswertermittlung sind zu überprüfen und deren Genauigkeit zu verbessern.

- Durch die stärkere Marktdurchdringung von Wärmepumpensystemen zur Raumheizung wird generell die Nachfrage nach Vergleichswerten für die Effizienzbewertung steigen. Im Deutschland fordert z.B. das GEG in § 60a die Betriebsprüfung neuer Wärmepumpen in Gebäuden mit mindestens 6 Wohnungen nach zwei Betriebsjahren. In diesem Rahmen ist eine messtechnische Überprüfung und Bewertung der Jahresarbeitszahl vorgegeben.
- Ein Verfahren in Anlehnung an VDI 4650 ist grundsätzlich geeignet, individuelle Vergleichswerte zu generieren. Allerdings waren die Ergebnisse nach VDI 4650 in drei untersuchten Anwendungsfällen zu positiv. Das Verfahren ist daher zu optimieren.
- Alternativ ist es möglich, über Felddaten mittels einer Regressionsanalyse der Einflussfaktoren Vergleichswerte für Jahresarbeitszahlen zu generieren.
- Als weitere Alternative für die Vergleichswertbildung wäre es für Wärmepumpen möglich, Normwerte der saisonalen Arbeitszahl (SCOP) in den Geräten zu hinterlegen.
- Da die Effizienz von Heizkesseln deutlich weniger von der Außentemperatur abhängt als bei Wärmepumpen, kann ggf. die jahreszeitbedingte Raumheizungs-Energieeffizienz als Vergleichswert herangezogen werden, indem ein Abschlagsfaktor definiert wird, um daraus einen Praxis-Vergleichswert zu gewinnen.

- Soweit Normwerte hinterlegt werden, ist ggf. die Definition von Abschlagsfaktoren sinnvoll (nicht untersucht), um daraus Praxis-Vergleichswerte zu gewinnen.
- Für die Effizienzbewertung ist eine Datenauflösung von Tageswerten ausreichend. Die in der Entwurfsfassung zur Novelle von (EU) Nr. 813/2013 vorgeschlagene Auflösung von 15-Minuten-Werten ist nach Einschätzung der Autoren für eine reine Effizienzbewertung zu feingranular. Tages oder ggf. auch Wochenwerte reichen für diesen Zweck aus. Für Zwecke der Fehlerdiagnose wären höhere Datenauflösungen erforderlich (Minutenwerte).
- Der Entwurf der Ökodesign-Verordnung fordert bei der Speicherung der In- und Output-Daten eine Differenzierung nach Raumwärme und Warmwasser. Bei den in dieser Studie untersuchten Anwendungsfällen lagen die Verbrauchsdaten nicht in dieser Differenzierung vor, weshalb die Autoren hier eine statistische Aufteilung vornahmen. Auf diese statistische Aufteilung kann verzichtet werden, wenn die differenzierten Messdaten vorliegen, die Genauigkeit ist dadurch noch höher.

Empfehlungen über Ökodesign hinaus

Eine Verbesserung der Ausgestaltung der in Deutschland gültigen Anforderungen an Effizienzanzeigen ist sinnvoll. Effizienzanzeigen sind Fördervoraussetzung für Wärmepumpen im Rahmen der Bundesförderung Energieeffiziente Gebäude (BEG) Einzelmaßnahmen. In § 60a GEG wird die messtechnische Auswertung von Arbeitszahlen im Rahmen der Prüfung und Optimierung von Wärmepumpen in Gebäuden mit mindestens 6 Wohnungen zwei Jahre nach deren Einbau gefordert.

- Aktuell ist die Effizienzanzeige seitens der Förderbehörde (BAFA, 2024) in den technischen FAQ als Verbrauchsanzeige definiert, die einen nicht klimabereinigten Vergleich des Verbrauchs verschiedener Perioden vorsieht. Ein Update auf das hier vorgeschlagene Verfahren der Effizienzbewertung mittels Jahresarbeitszahlen bzw. Jahresnutzungsgraden ist sinnvoll.
- Das Vorgehen bei der Prüfung und Optimierung von Wärmepumpen nach § 60a GEG kann entscheidend vereinfacht werden, wenn die messtechnische Bestimmung der Jahresarbeitszahl über die Effizienzanzeige erfolgt. In das Rechenwerk der Regelung von Wärmepumpen kann auch das im GEG genannte Verfahren nach der VDI 4650 integriert werden. Damit könnte bereits bei der Installation von Wärmepumpenanlagen ein Startwert für eine „erwartete Jahresarbeitszahl" ermittelt und für den Nutzer zur Verfügung gestellt werden. Alternativ kann diese Zahl über den Jahresarbeitszahlrechner des Bundesverbands Wärmepumpen ermittelt und durch den Installateur im Rahmen der Inbetriebnahme dort hinterlegt werden.
- Das Verfahren nach VDI 4650 sollte durch die Einbeziehung der Verluste durch Abtauung und Taktung verbessert werden (vgl. Abschnitt 4.3.3).

1 Background

In practice, many technical building systems, including heating systems, do not work as energy-efficiently as would be technically possible. This means that they generate less useful energy (e.g. space heating, hot water) per unit of energy used (e.g. gas or electricity) than planned. This inadequate energy efficiency leads to both higher operating costs and an increase in greenhouse gas emissions.

In order to systematically and continuously uncover existing efficiency problems in heating appliances and systems, whether they are of a technical, organisational or planning nature, and to identify and rectify efficiency-reducing defects at an early stage, the so-called "meter study" (Hermann, et al., 2019) the **principle of the efficiency indicator** or **efficiency display** was developed.

The efficiency display is integrated into the heating appliances or their control systems and is shown on the appliance display (optionally also via the user portal / app). It is based on the majority of data already collected for control. If necessary, sensors and evaluation routines must be added for additionally required data.

The EU Commission's proposal for the amendment of the Ecodesign Regulation (EU) No 813/2013 on space heaters and combination heaters (EU Kommission, 2023) already contains requirements for operational monitoring, including energy efficiency displays, under the heading of "self-monitoring". At the time the study was prepared, it was still unclear whether the amendment would merely require the energy efficiency to be displayed as a numerical value or whether requirements would also be made for a generally understandable presentation that would inform users that the energy efficiency is too low and that there is a need for improvement - for example, by means of a classification in colour levels.

At national level, the German government defined goals for the efficient operation of heating systems in its Efficiency Strategy 2050 (BMWi, 2019) in individual measure 14 "Meters for heating and air conditioning/ventilation systems". The document defines the goal of providing a minimum level of meters and sensors when installing new heating systems and large air conditioning and ventilation systems - where possible under EU law and economically viable - in order to ensure efficient operation and inspections. For heating appliances, a simple feedback function for consumers should also be provided in addition to the meters in order to achieve transparency regarding the energy status of the systems.

Since January 2023, an efficiency indicator has been mandatory in Germany for heating appliances subsidised as part of the federal funding for efficient buildings (BEG) (BMWi, 2021). Since then, efficiency displays have increasingly been found for heat pumps, as these are currently subsidised by the BEG. Efficiency displays are still the exception for fossil-fuelled boilers, which are not currently eligible for funding.

Many of the efficiency displays implemented on the market only show the energy consumption but not the efficiency of the systems, as the authors discovered during a visit to the ISH trade fair in Frankfurt/M in March 2023. This is sanctioned by technical FAQs published by the subsidisation authority (BAFA, 2024). These set out criteria for the technical implementation of the required efficiency displays, which leave manufacturers a great deal of room for manoeuvre.

2 Goal and task

The aim of the project was to develop recommendations on minimum standards for efficiency displays against the background of the amendment to Regulation (EU) No. 813/2013 on space heaters and combination heaters (Ecodesign). To this end, based on the results of the so-called "meter study" (Hermann, et al., 2019) suitable methods should be identified, evaluated and applied as examples. This methodological preliminary work should create a basis for discussion for the stakeholder exchange on the implementation of efficiency indicators in the context of the Ecodesign Regulation.

The following questions had to be considered:

- Which methods are suitable for determining the energy efficiency of heating appliances in practical operation?
- How should these methods be assessed in terms of accuracy, measurement and evaluation effort?
- Which criteria can be derived for product policy (regulations or supplementary guidelines)?

To begin with, relevant regulations, standards and other sources were analysed to research suitable methods. In the next step, experts from research, industry and energy service companies were consulted on the methods and their suitability. Additional methods that came into focus or deviating practical implementations were taken into account. Together with the client, methods were prioritised and applied on the basis of measurement series from four heating appliances[1] .

Finally, criteria had to be derived and discussed with relevant experts at an expert meeting (June 2024).

[1] Three heat pumps and one gas boiler; processes for solid fuel boilers were not prioritised in this project

3 Legislation, status of research and practice, standardisation

The status quo on the subject of efficiency displays is presented below. Starting with legislation at EU level, as the amendment to the Ecodesign Regulation (EU) No. 813/2013 is the reason for this study. However, German legislation was also considered, as definitions of efficiency labelling or efficiency determination can be found here that may be transferable.

The subsequent section presents the opinions of experts from science, industry and energy service companies with whom interviews were conducted on the subject of efficiency displays, supplemented by statements from trade fair discussions with manufacturers who offer appliances with efficiency displays on the market.

Finally, the relevant standards are considered and the methods used to determine the efficiency of various space heat generators are analysed. The chapter is rounded off with a look at the topic of data resolution.

3.1 Efficiency indicators in the European context

The efficiency of space heat generators and its increase is addressed in European product and building policy in the following legal acts, among others:

- The Ecodesign Regulation (EU) No. 813/2013 on ecodesign of space heaters and combination heaters formulates minimum requirements for seasonal space heating energy efficiency (η_s). This is defined as the quotient of the space heating demand covered by a heating appliance for a specific heating period and the annual energy consumption required to cover this demand in percent.
- The Ecodesign Regulation (EU) No. 811/2013 on the energy labelling of heating appliances defines the requirements for energy labels which, among other things, refer to the energy efficiency of space heating.
- Article 23 of the EU Buildings Directive (2024/1275/EU) specifies intervals for energy inspections of heating and air conditioning systems, depending on their size.

3.1.1 Planned requirements in accordance with the amendment to Ecodesign Regulation No. 813/2013

In the context of the amendment to Regulation (EU) 813/2013, requirements for self-monitoring of space heat generators are to be defined for the first time[2]. A working document on the amendment to the Regulation (EU Kommission, 2023) contains the following requirements in ANNEX II, paragraph 7, under the keyword "self-monitoring"[3] .

1. Determination, storage and visualisation of
   a) Energy input (electricity, gaseous or liquid fuels)
   b) Thermal energy output

[2] Although the term "efficiency indicator" is not used in the context of the draft regulation, the implementation of the envisaged requirements will result in an - albeit simple - efficiency indicator for space heat generators.

[3] As early as March 2018, with reference to interim results of the so-called "meter study" (Hermann, et al., 2019) an official submission from UBA and BAM was made to the EU ecodesign process. The study suggests that the amendment of the relevant ecodesign regulations should include minimum requirements for energy consumption monitoring on the device side and energy efficiency monitoring by means of an efficiency display. The automatic feedback to users or operators of the appliances should also take psychological mechanisms into account so that the efficiency display can have the best possible effect for energy-efficient operation.

c) Energy efficiency (heat output/energy input)
d) Number of on/off cycles (periods with no input)
e) For combination heaters, whether the heater is used for space heating or sanitary water heating.

2. Output periods of the aforementioned information to be displayed to users via device display, website or smartphone; data resolution and duration of data storage (last 3 years: annual values; last 24 months: additional monthly and weekly values; last 10 days: 15-minute values)
3. Maximum permissible deviations when determining or measuring the heat quantities
4. Specification that only the end user is permitted to access the data, unless they grant third parties permission to use the data
5. Requirements for the user manual with regard to data access

ANNEX III to VI of the document stipulate, among other things:

- Calculation specifications for the seasonal space heating energy efficiency (η_s) and the seasonal coefficient of performance (SCOP) (ANNEX III, IV)
- Verification tolerances in the context of market surveillance (ANNEX V)[4]
- Indicative benchmarks (based on the best available technology on the market) for heaters in terms of seasonal space heating energy efficiency (ANNEX VI)

Evaluation of the planned requirements

In summary, the draft amendment to Regulation No. 813/2013 addresses the following elements or aspects of an efficiency display:

- Basic requirements for calculating appliance efficiency
- Obligation to record / calculate of selected operating parameters
- Data retention: output periods, data resolution and storage duration of the data
- Permissible errors for the assessment of hydronic heat energy output
- Indicative benchmarks (based on the best available technology on the market) for seasonal space heating energy efficiency of different appliance types

The following aspects are **not explicitly addressed** - and are therefore left to the discretion of the manufacturer:

1. **Openness to technology**
   The self-monitoring requirements do not include any obligation to use specific technologies, products, services or data sources; the way and means of fulfilling the requirements are at the discretion of the device manufacturer.
2. **Equipment with measurement technology**
   Since heat meters, for example, are not explicitly mentioned, manufacturers have the option of using alternative methods (estimation methods) to determine the quantities of heat generated - provided that the specified accuracy[5] is maintained.

[4] According to a response letter (unpublished) from the EU Commission (DG ENER) dated 20 April 2023 to a list of questions from the EHI Retail Institute, the verification of real operating data in the field should not be subject to market surveillance

[5] The accuracy requirements are +- 5 per cent for the drive energies and ± 7.5-15 % for the heat quantities.

3. **Offline functionality**
   There is no obligation to realise the efficiency display in the context of the device display in order to ensure user information even if there is no internet connection.
4. **Quality / informative value of the user information on the efficiency display**
   There are no specifications on how the data should be processed and presented to the user so that even non-experts can generate relevant information from it; for example**,** it is not required to display the calculated efficiency over time and/or to actively communicate efficiency deteriorations above a certain level (e.g. extent or duration of the deterioration) to the user (e.g. via a warning message on the display or electronic notification).
5. **Benchmarking and evaluation of efficiency**
   Although the draft regulation contains a table with **key figures on the** seasonal space heating efficiency **of the best technologies available on the market**, there are no requirements as to whether and how these are to be used as benchmarks in the context of the efficiency indicator; alternative options for generating comparative values (e.g. against measured values from previous periods) are also not addressed.
6. **Climate adjustment**
   The use of temperature data (outdoor temperature sensors or data from weather stations) for climate adjustment when calculating efficiency is not required.
7. **Fault diagnostics**
   The possibility of manufacturer-side fault diagnostics (as synergy with the efficiency display) is not required; with the required data resolution (no higher than 15-minute values), such fault diagnostics would also not be possible; nevertheless, manufacturers are free to implement such diagnostics voluntarily.

As part of the so-called "meter study" (Hermann, et al., 2019) the aspects described for the implementation of efficiency displays were addressed and initial recommendations for their design were made.

In the context of this study, the **focus was on deepening points 4, 5 and 6** of the above list in order to supplement the requirement to implement an efficiency notice in the draft regulation with rules or recommendations on its specific design**.**

3.2 Efficiency indicators in the German context

A look at German subsidy and regulatory law is also helpful for the development of regulatory options for efficiency indicators within the framework of European ecodesign legislation.

3.2.1 Federal funding for energy-efficient buildings (BEG)

Since 2023, only space heat generators equipped with an energy consumption and efficiency indicator have been eligible for state funding under the BEG individual measures. The following illustrations are based on the guideline for federal funding for efficient buildings (BEG) - individual measures (BMWi, 2021) and the published list of technical FAQs for the funding guideline (BAFA, 2024).

Requirements are placed on the following heating technologies subsidised in the framework of the BEG individual measures:

- Biomass plants
- Electrically operated heat pump systems
- Fuel cell heating

- Innovative heating technology based on renewable energies
- Construction, conversion, extension of a building network
- Connection to a building network
- Connection to a heating network version 8.0 (06/2023).

These requirements relate to the

- Measurement of energy consumption and heat quantities,
- Energy consumption and efficiency display and
- Connectivity of the heating system (internet connection).

"Measurement" according to the BEG means:

- Recording consumption through balancing or measurement technology; recording the quantities of heat generated
- There are no requirements with regard to design and accuracy; calibration is not necessary
- Both external and device-integrated balancing are permitted (device-integrated balancing via control)
- Exceptions:
  - In the case of biomass heating systems and biomass heating systems in building networks, only the quantities of heat generated must be recorded; FAQ BAFA: "The installation of a heat meter must be confirmed for all biomass boilers in the specialist contractor declaration."
  - Heat pumps that heat via air: Measurement of heat quantities is mandatory; energy consumption balancing in accordance with DIN EN 12831, sheet 2, is permissible.
  - Air collectors: no requirements
  - Small solar thermal systems: Function control unit; from 20 m^2 vacuum collector or 30 m^2 flat-plate collector, heat meters or corresponding option in the solar control unit are mandatory

Energy consumption and efficiency display (BAFA, 2024):

- Display of energy consumption and heat quantities via the display/user interface of the device, a higher-level energy management system, an external device or an external application
- Range of functions: Comparison of energy consumption and generated heat quantities with the values of previous heating periods or comparable operating periods
- Exceptions:
  - Efficiency display obligation for biomass heating systems (only generated heat quantities) from 1 January 2025.

- Solar thermal systems: The solar yields and deviations from past periods must be displayed

Furthermore, it is recommended that relevant operating parameters (e.g. energy consumption, heat quantities generated, operating states, outdoor temperature) be stored in hourly resolution (averages) for one year and monthly resolution (average) for ten years and kept in a machine-readable format (e.g. CSV) in order to verify the correct operation of the system:

Table 1: BEG - Subsidised heating technologies - Requirements for efficiency indicators

Heating technologies	Requirements for efficiency monitoring
Solar thermal system	Recording and display of solar yields, visualisation of deviations from previous periods
Biomass heating systems	Recording and displaying heat quantities (from 2025)
Heat pumps	Recording and display of consumption and heat quantities; for heat dissipation via air: recording of consumption, energy consumption balancing in accordance with DIN 12831, sheet 2
All devices (optional)	Storage of relevant operating parameters in hourly resolution
No requirements for	(1 year) or monthly cancellation (10 years)

3.2.2 Building Energy Act (GEG)

The German Building Energy Act (GEG) also contains regulations that address the issue of efficiency indicators and efficiency calculations for heat generators.

GEG draft of 17 May 2023

In the GEG draft of May 2023 (Deutscher Bundestag, 2023) formulated requirements for the measurement equipment of heating systems in Section 71a, which also included the topic of efficiency displays. In analogy to the BEG, the obligation to measure energy consumption and the amount of heat generated was envisaged, with the exception of biomass heating systems and air-to-air heat pumps. In the case of heat pumps, a distinction should also be made between electric immersion heaters and heat sources when recording consumption. The accounting of solar thermal systems was regulated analogue to the BEG requirements.

For non-residential buildings with a rated output of the heating or air conditioning system greater than 290 kW, a building automation system was also specified that recognises efficiency losses in technical building systems and informs the responsible management or staff about possible improvements.

Device-integrated metrological recording was not specified: Alternatively, it was possible to use data from smart meter gateways for metrological recording.

Furthermore, the values should be stored with monthly resolution for three years in a machine-readable format. In the case of hybrid heating systems, the share of the individual producers in the heat supply should also be shown.

The efficiency should be displayed either in the device or the "user interface", in the higher-level building management system or in external devices or applications.

Table 2: GEG draft of May 2023 - Requirements for efficiency indicators

Heating technologies / buildings / technical equipment	Requirements for efficiency monitoring
Biomass heating systems	No requirements
Heat pumps	Differentiation of consumption by heating element and heat pump, no requirements for air-to-air heat pumps
Heat pump hybrid heating	Balancing the shares of the individual producers in the total amount of heat
All devices (optional)	Storage of consumption and heat quantities for 3 years in monthly resolution
Non-residential buildings with heating and/or air conditioning capacity > 290 kW	Building automation that recognises deterioration in efficiency and informs the relevant personnel

GEG final version from 08/09/2023

The version of the GEG adopted by the Bundestag on 8 September 2023 and which came into force at the beginning of 2024 no longer includes requirements for efficiency monitoring. Nevertheless, there are relevant statements on the subject: Section 60a GEG defines requirements for the testing and optimisation of heat pumps two years after commissioning. There, the metrological evaluation of the annual performance factor and its comparison with the expected annual performance factor is required. The result of the test must be sent to the person responsible and also presented to the tenant on request.

Section 60o, which contains regulations for the protection of tenants in the case of modernisations that affect the apportionability of the installation of heat pump heating systems, defines that an appropriate annual performance factor must be determined according to VDI Guideline 4650, Sheet 1. The procedure is described in Section 4.2.3 is presented.

As an interim conclusion on the BEG and rejected GEG requirements, it can be said that

- In both specifications, the analysis and evaluation of heat quantities is at the centre of the efficiency display,
- external meters are always authorised for the collection of data and
- in the case of BEG funding, estimation methods are also permitted in order to determine the heat quantities.

In the GEG, which has been in force since 1 January 2024, the annual coefficient of performance is defined as an efficiency criterion for heat pumps in Section 71o in connection with a regulation for the protection of tenants. The calculation of the expected annual performance factor in accordance with VDI 4650 is specified.

3.3 Interviews with experts and market players

As part of the research, six expert interviews were conducted with a total of eleven interviewees between June and August 2023. Two interviews each took place with representatives from

- Research facilities[6]
- Energy efficiency service providers[7]
- Manufacturers of heating appliances or manufacturer associations[8]

In March 2023, the ISH trade fair in Frankfurt/M was used to gain an impression of the implementation of the BEG requirements regarding efficiency displays for heating appliances. This involved talking to employees of heating manufacturers at their trade fair stands[9] .

The opinions of the experts and manufacturers are summarised thematically below:

In general, the **usefulness of efficiency displays** is not in doubt. There is also agreement that efficiency displays should primarily be aimed at building owners or their technical maintenance personnel.

Requirements regarding efficiency indicators should be specified within the framework of EU ecodesign. Requirements should also be differentiated according to climate zones if necessary. National requirements, such as those in the GEG draft from spring 2023, were felt to be inappropriate. Manufacturers requested that requirements should not be tightened piecemeal (due to the adaptation effort and appliance development cycles), but rather defined in one block. Also, individual heating technologies[10] should not be made disproportionately liable, while others should not be made liable at all.

Efficiency indicators will have an effect if their messages are correct and understandable and motivate action.

In terms of **efficiency evaluation**, the following opinion emerges: Efficiency monitoring during the year, which detects a drop in efficiency after just a few days if possible, is considered sensible. When generating comparative values, however, reference is made to the usefulness of longer periods. Efficiency statements for one day are not possible due to the potentially high variability of the values. Operating modes (e.g. summer operation of heat pumps) or significant deviations in the outside temperature between different periods mean that daily values cannot be compared with average values. User behaviour (e.g. hot water requirements of families with several children compared to households with 1-2 adults) can also have a considerable influence on the average efficiency of a period. A comparison with reference to comparable periods is therefore favoured for the evaluation (e.g. month-to-month previous year, but also periods with approximately the same outdoor temperature conditions). In general, a conflict of objectives can be recognised here between the desire for rapid analysis on the one hand and the requirement for reliable comparative values on the other. This can be remedied by analysing short-term deviations in efficiency, but not evaluating them.

[6] Fraunhofer ISE, Ostfalia University of Applied Sciences

[7] Energy Centre North, Empact GmbH

[8] Federal Association of Heat Pumps (BWP), Federal Association of the German Heating Industry (BDH) and representatives of Vaillant

[9] Discussions were held with personnel from Buderus, Daikin, Mitsubishi, Remeha, Vaillant, Stiebel Elton, Weisshaupt and Wolf

[10] This refers to the BEG requirement for an efficiency indicator, which only applies to heating technologies subsidised by the BEG. As fossil-fuelled boilers are currently no longer subsidised, the BEG requirement does not apply to them either.

Opinions differ on the question of whether the **periphery** should be included in the efficiency assessment or whether it should focus specifically on the product. For the majority of dialogue partners, "less is more". Where manufacturers offer more in-depth statements, this is welcomed.

Several experts raised the question of whether efficiency indicators in times of the energy transition should not refer to the **overall efficiency of the building** or system rather than just the heat generator. A value similar to the energy coefficient is favoured for the efficiency assessment. **Compliance with RE shares**, e.g. in hybrid systems, is also seen as an efficiency criterion. In general, it is questioned whether efficiency monitoring standards should not be weakened in favour of a faster transformation towards renewable energies. In this context, the question was also raised as to whether excessive regulation on the part of the legislator is not counterproductive (keyword: discussion on the GEG). Bonus points on the heating system label (to achieve a higher efficiency class more quickly) or demand calculations if an efficiency indicator is available are seen as an alternative approach here.

There are two schools of thought regarding the **measurement accuracy** of efficiency indicators: One considers precise measurement, e.g. of heat quantities using calibrated meters, to be essential for reliable statements. The other also considers estimates using auxiliary variables, where the efficiency is not overestimated (usually 15 % accuracy is specified here), to be permissible. Others point out that even 15% accuracy will be difficult to achieve in practice or will involve high additional costs. In this context, reference is also made to major errors in calibrated devices, e.g. due to incorrectly or inaccurately positioned temperature sensors.

There are also differing opinions regarding **data resolution and storage** of measured values or parameters on which the calculation is based. While manufacturers consider it a challenge to provide resolutions of 15-minute values and store them over longer periods of time due to the additional storage requirements, from the user's point of view a resolution of minute values would make sense, for example to be able to recognise switching processes. Daily or weekly values seem sufficient for monitoring the efficiency itself. Storing 15-minute values therefore makes little sense. Either daily values are sufficient, or minute values are used. To save storage space, the period for which the data must be stored can be limited (e.g. 1-12 months)

For heating technologies where the efficiency can only be determined with difficulty as a degree of utilisation, the **measurement of the useful energy output** is already considered to be worthwhile (e.g. for solid fuel boilers). In other cases, the measured heat quantity in itself represents the efficiency criterion (e.g. the "utilised collector yield" for solar thermal systems, the actual RE share determined via heat quantity measurement for RE hybrid systems).

Who should take care of the warranty or (re)production of high efficiencies? The experts believe that manufacturers have a duty in this regard; they refer, among other things, to existing concepts for the (paid) involvement of tradespeople, who are currently only rarely commissioned due to the additional costs (e.g. existing recall guarantee in the event of a defective performance factor). Other experts disagree and assume that, due to the existing shortage of skilled labour, no increased efforts on the part of tradespeople are to be expected. In any case, it would make sense to teach such topics as part of HVAC training in the future. Currently, such content does not yet play a role.

Local energy suppliers, especially municipal utilities, are seen as playing an increasingly important role. The trend here is for them to buy up larger installation companies.

Visualisation of efficiency: The suggestions range from the "chimney sweep button" to the use and further development of visualisations that have already been introduced, such as the coloured bars of the EU heating label, which could also be used similarly in a display. Textual explanations of the visualisation are considered useful.

Deviating implementations in practice: In the case of heat pumps in particular, heat meters are generally not installed in the appliances currently available on the market in order to measure heat quantities for efficiency statements. In this context, manufacturers refer to agreements with the funding authority, documented in the technical FAQs (BAFA, 2024) which authorise the auxiliary methods. As a rule, the coefficient of performance is determined via the current consumption of the inverter (frequency control of the compressor motor) and the temperature sensors that are present anyway (see section 4.3.2). Some manufacturers have integrated interfaces into their devices that enable the connection of external heat meters.[11]

Special features for heat pumps: The analogue application of the method for determining an annual efficiency factor in accordance with DIN 18599 (Supplement 1, 2010-01) using consumption values during the year to annual performance factors is questioned, as the relationships for heat pumps are not linear: It should be checked whether the measurement points from the data sheet (at different outside temperatures) are suitable as a reference for efficiency statements when differentiating between air and other heat pumps. Furthermore, attention was drawn to the use of VDI Guideline 4560 (Sheet 1, 2019-03) to calculate annual performance factors or DIN EN 14825, on the basis of which the seasonal coefficient of performance (SCOP) can be calculated.

It was also pointed out that the efficiency of heat pumps may depend on the quality of the compressor, the refrigerant used[12] and, in the case of residential buildings, the hot water requirement. One expert generally recommends installing separate heat pumps for heating and hot water in order to increase the efficiency of the system.

From the expert interviews, the following **aspects** in particular were noted **for further consideration**:

- It should be checked whether the efficiency of appliances or systems should be specified as a 'degree of utilisation' across the board. Examples would be achievement of a specified coefficient of performance and achievement of the previously forecast, desired or specified share of renewable energy. This would enable a standardised classification of efficiencies across all appliances based on different methods and the question of comparative values would also be included in the efficiency statements in this case.
- One school opinion is open to estimation methods, especially for determining heat quantities, as long as a reasonable level of accuracy is maintained.[13]
- Heat quantity determinations that are not based purely on measurements account for a large proportion of practical appliance use. It is therefore important to define sufficient accuracy.
- It must be checked whether the named guidelines and standards are suitable for generating practical comparative values.

[11] All auxiliary methods have the problem that wear and tear is not included in the evaluation (e.g. of motors whose speed is considered constant). The same also applies to the mechanics of heat meters when the calibration period has expired.

[12] According to the ILK Dresden, this concern is unfounded, as only refrigerants suitable for the application are used.

[13] It should be borne in mind here that there is a conflict of objectives between measurement accuracy and cost minimisation; the efficiency indicators frequently found in heat pumps, which use estimation methods, must be considered primarily from the point of view of cost-efficient implementation of the BEG requirements; it is not yet possible to answer the question of whether they sufficiently fulfil the actual goal, namely increasing efficiency through improved operational monitoring and improved information for users or operators; here, questions about the quality of the user interface may be even more important than the quality of the measured or estimated data.

- Daily or weekly values are sufficient for the evaluation of efficiencies, while minute values are required for fault detection. If fault detection is required, the required resolutions must be adjusted, otherwise they can be weakened.
- The possible different data resolutions have an impact on the required storage space. While the storage of daily values over several years or the operating time is probably still possible in the existing memory of the control system, minute-by-minute resolutions probably require additional storage space. In order to limit the storage requirements here, the obligation to store this data should be limited (time span 1-12 months).

3.4 Standardisation

The following section presents the standards that were found via keyword searches on the topic of efficiency assessment of heating appliances. One focus of the search results was on heat pumps. Where procedures or references to assessment approaches could be derived from the standards, these are described below.

3.4.1 Standards for heat pumps

Table 3 summarises the standards researched and their relevance for efficiency displays.

Table 3: Standards for heat pumps with relevance for efficiency displays

Standard	Application on heat pump	Relevance for efficiency indicator	Type of valuation
DIN EN 14511	Air/water heat pumps	Definition of 5 nominal operating points (-15 °C, -7 °C, +2 °C, +7 °C and +12 °C) for the measurement (takes into account temperature dependence of the efficiency of heat pumps)	COP
DIN EN 15879	Water/water heat pumps (ground source)	similar to DIN EN 14511	COP
DIN EN 14825	Air-to-water heat pumps and water-to-water heat pumps (ground source)	Seasonal coefficient of performance and a seasonal space heating efficiency (η_s) for heating and cooling operation based on representative temperature curves for different reference locations Determination of coefficients of performance also for hybrid heat pumps with gas or oil auxiliary heating (efficiency is determined separately using a special formula)	SCOP
DIN EN 16147	Heat pumps for domestic hot water preparation Combi appliances for heating and domestic hot water preparation	Depending on the type of heat pump, 1 to 3 different source temperatures are defined. Different hot water withdrawals are defined depending on the size of the heat pump.	COP
ISO 21978		Analogue DIN EN 14511	COP
VDI 4650 Sheet 1:2019-03	Heat pumps for space heating and domestic hot water supply	Determination of performance figures by correcting the performance figures in accordance with DIN EN 14511 using correction factors obtained empirically. Basis for BAFA funding until 2020. Consideration of the source and downstream heating circuits possible, also combined systems, alternatively overall system efficiency; objective: Determination of maximum coefficients of performance for the evaluation of systems in the field	SCOP
DIN EN 15316-4-2	Heat pumps for heating and domestic hot water systems	Calculation of performance figures for the design and comparison of heating and domestic hot water systems, evaluation on an hourly basis or weighted by temperature classes on a monthly or annual basis. Evaluation of hybrid systems similar to VDI 4650	SCOP
Compensation method, in preparation, leading to standard DIN EN 14511-5: 202x	Heat pumps for heating and domestic hot water systems	Consideration of the improvement in operating figures as a result of intelligent controls	SCOP

The following interim conclusion can be drawn from the standards for efficiency displays for heat pumps:

- The measurement of operating and performance figures on the test bench is carried out for different outside temperature conditions, which take into account the dependence of efficiency on the outside temperature, particularly in the case of air source heat pumps. An efficiency assessment during the year should therefore be carried out depending on the outside temperature.
- For the determination of the SCOP, time resolutions up to hourly values are used, which are available for reference locations.
- VDI 4650 uses conversion factors from field tests to determine coefficients of performance from standardised coefficients of performance. The heat transfer medium of the heat pump and the peripherals (heating system) can also be taken into account.
- The standardisation also determines performance figures and statements on the overall efficiency of hybrid systems. This means that the efficiency of an overall system is taken into account instead of the efficiency of the appliance.

3.4.2 Standards for boilers

The relevant standards for boilers are presented below.

Table 4: Standards for boilers with relevance for efficiency displays

Standard	Application on boilers	Relevance for efficiency indicator	Type of valuation
DIN 4702 Part 8- 1990-03 (withdrawn)		Determination of the standard utilisation factor as the mean value from 5 partial load utilisation factors (12.8 %, 30.3 %, 38.8 %, 47.6 % and 62.6 %) of the boiler output; the starting point for determining the five partial load ranges is the total frequency of the outside temperature (same heat quantities)[14]	Degree of utilisation
DIN EN 15502	Gaseous fuels	Determination of the boiler efficiency depending on the load and the system design: Standard: Full load at 80/60 and partial load 30 % at 50/30[15]	Efficiency
DIN EN 303, Part 5	Various fuels (gaseous, liquid, solid), output ranges, applications	Determination of the boiler efficiency	Efficiency

The following interim conclusion can be drawn from the standards:

[14] Cf. IKZ.de, https://www.ikz.de/ikz-praxis-archiv/p0506/050607.php (Strobel publishing house)

[15] Data sheets for boilers show that the efficiency increases with lower utilisation and lower heating design. If hot water preparation requires full load (e.g. in detached houses), the utilisation factor for hot water preparation is lower compared to the utilisation factor for space heating, which mainly involves partial load.

- The efficiency and thus also the degree of utilisation depends on the capacity utilisation, the design of the downstream heating distribution and the hot water preparation, insofar as this takes place at full load.
- In accordance with the now withdrawn standard, efficiencies for five load ranges, each covering one fifth of the annual heat quantities, were used to calculate an average utilisation factor. This approach is important for evaluating utilisation rates during the year.

3.4.3 Other standards

This section presents standards or supplements to standards (of a non-binding nature) that do not relate to specific heating technologies or appliances but are nevertheless relevant for efficiency displays.

Table 5: Other standards relevant for efficiency indicators

Standard	Description of the	Relevance for efficiency indicator
DIN TS 12831-1: 2020-04 (replaces i.a. DIN 12831, Supplement 1 2008-07)	Method for calculating the space heating load - Part 1: National supplements to DIN EN 12831-1 Chap. 7: Estimation of the heating load from heat quantity measurements Chap. 7.2 Determining the heat loss coefficient from individual values of the generator output and the outdoor temperature ("Energy analysis from consumption")	Determination of the average generation capacity from consumption quantities of heat meters and associated periods during the year
DIN EN 18599	Energy assessment of buildings; calculation of useful, final and primary energy requirements for heating, cooling, ventilation, domestic hot water	Contains reference values for heating appliances and systems (new and existing) in tabular form; based on catalogue and manufacturer specifications as well as measured values from real systems in the field
DIN EN 18599 Supplement 1: 2010-01	Demand/consumption synchronisation: Chap. 5.3 Energy signature for heat consumers (mostly identical DIN TS 12831-1) Chap. 5.4 Energy signature for boilers	Determination of the average useful power output and generator output from consumption quantities of heat meters and associated periods during the year Partial load utilisation factor: Linear regression of the useful power output over the generator output, determination of the annual utilisation factor on the basis of the average useful power output at average outdoor temperature

From Table 5 the following findings emerge:

- The "energy analysis from consumption" (see section 4.4) enables changes in the efficiency of the heating system and downstream peripherals to be recognised. In order to be able to differentiate between the system and peripherals (e.g. also changes of use in residential buildings), both the generation output and the useful heat output must be analysed.

Knowledge gained by the authors in other contexts:

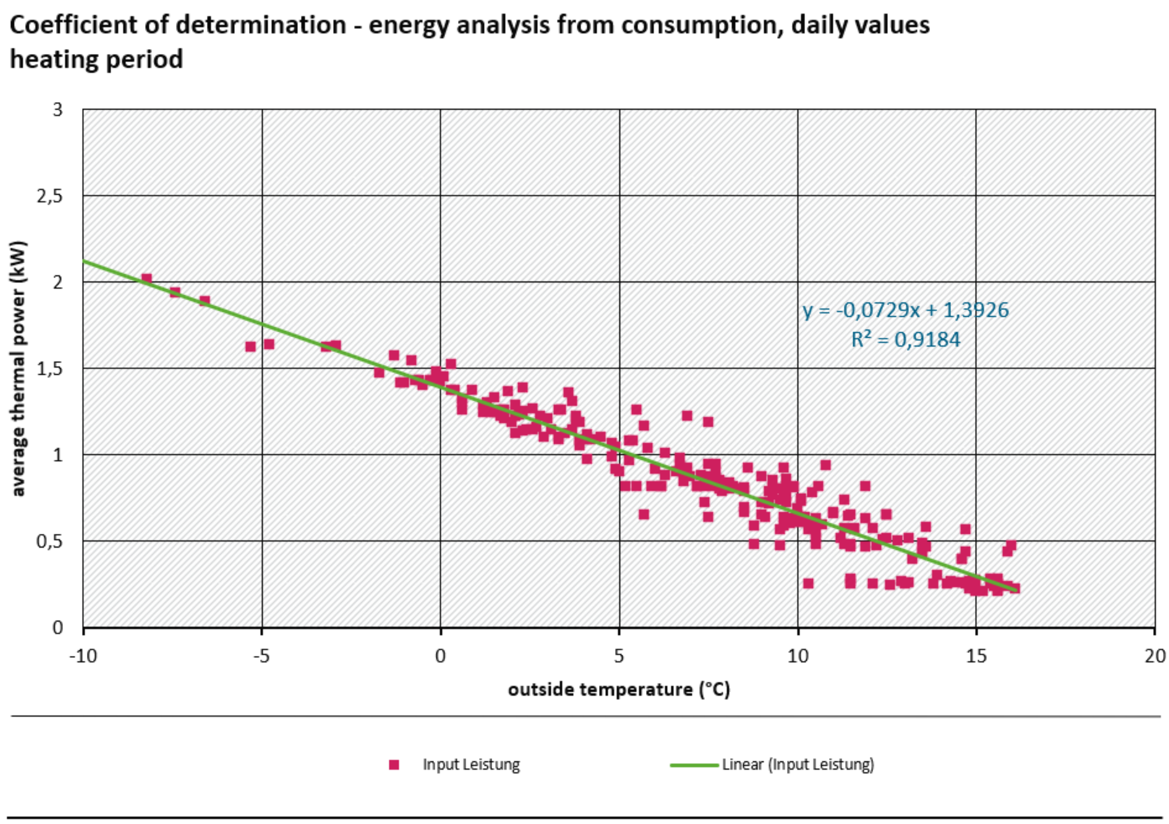
- If the method is applied to boilers and consumption values in the core heating period, a coefficient can be determined after just a few days/weeks.
- The values obtained during the non-heating period ("base output", parallel to the X-axis) that are not dependent on the outside temperature represent the hot water demand for residential buildings. Permanent changes in this proportion represent changes in the efficiency of the hot water system or changes in hot water utilisation. For buildings with a solar thermal system, the base output represents the residual heat demand in the summer months that is not covered by the solar thermal system. An evaluation of the height of the base enables an efficiency assessment of the solar thermal system: Possible permanent changes over time make any changes in efficiency visible.

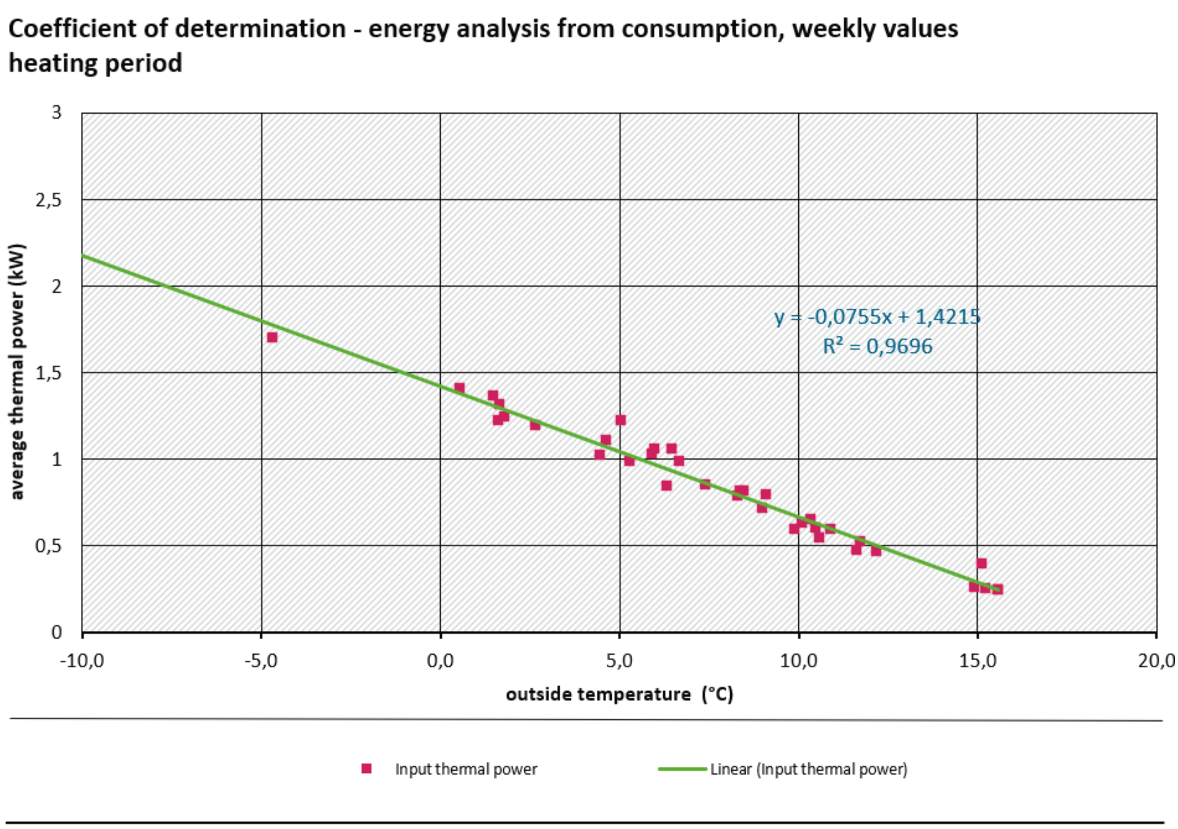
3.5 Data resolution for efficiency diagnostics and fault detection

For the visualisation of efficiencies in heating systems, mainly daily values have become established, for certain applications (e.g. weather forecast control) also hourly values. The associated climate data, in particular outdoor temperatures, are also available in hourly resolution at most, insofar as they are obtained from the weather service. In addition, the heat consumption data on which the efficiencies are based is heavily dependent on the building inertia as well as the outside temperature in the event of short-term weather changes. The building inertia results from the heat storage capacity of the building due to the masses installed. This means that a building reacts with a time delay to a drop in outside temperature, for example, with an increase in consumption. Accordingly, daily values may deviate significantly from the mean value of a regression line, while multi-day or weekly values[16] show a lower dispersion and thus a supposedly higher quality (Figure 7).

[16] According to Prof Dieter Wolff, Ostfalia, resolutions of 2-3 days are optimal

Figure 7: Regression quality as a function of the temporal resolution



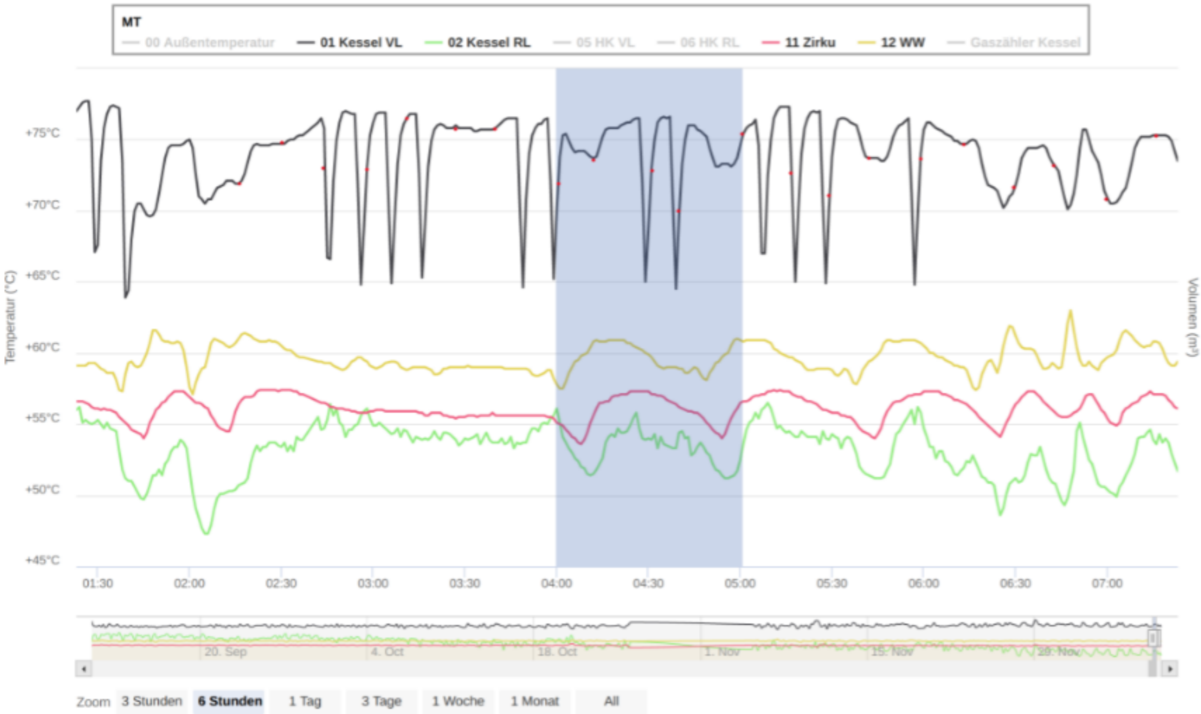


Average output above the outside temperature, daily values at the top, weekly values at the bottom. The higher quality of the lower figure based on weekly values is already visually recognisable. source: own illustration, co2online/senercon

The situation is different when load profile data is used for fault diagnosis, e.g. as part of AI-supported diagnostic tools or for device detection in non-intrusive load monitoring (NILM)[17] . Data with a resolution of two seconds to several kHz is used here. Figure 8 shows that switching processes, which must be recognisable for the diagnosis of faulty control systems, can be recognised with a data resolution of one second. If data from actuators and sensors in heaters is to be stored for such purposes, a resolution of 15-minute values is not sufficient.

Figure 8: Temperature curves with different data resolution

High data resolution



[17] Cf. https://www.ims.fraunhofer.de/de/Geschaeftsfelder/Electronic-Assistance-Systems/Anwendungen/NILM.html

Low data resolution

Progression (six hours) of the flow, return, circulation and hot water temperature of a heating system. The flow temperature (black line) is shown as a minute value in the upper diagram and as a 15-minute value in the lower diagram. The temperature drops in the lower diagram are due to switching processes that are not recognisable as such in the 15-minute curve (Energiezentrale Nord, 2021).

With regard to the data resolution of sensor data, this means that

- the storage of daily or, as a maximum resolution, hourly values is sufficient for efficiency statements. The storage of 8,760 hourly values per year for approx. 5 measured variables appears to be technically feasible without considerable additional effort.
- For fault detection, e.g. using AI, a resolution of at least minute values is required.

4 Presentation of the procedures

The following section presents, analyses and evaluates various methods that can be used to make statements about the efficiency of space heat generators. The focus here is on the calculation processes for determining the actual efficiency values and their evaluation options. In addition, methods found during the research are presented in more detail. [18]

4.1 Degree of utilisation

This section deals with procedures relating to boilers. A distinction must be made between efficiency and utilisation rates. Efficiency rates represent a current state (e.g. measurement on the test bench or by the chimney sweep), utilisation rates are derived from the consideration of heat quantities over periods of time. If the electricity consumption of a boiler is included, this is referred to as "seasonal space heating energy efficiency" in accordance with Regulation 813/2013/EU.

The degree of utilisation results from an evaluation of output (useful heat) to input (heating energy consumption or final energy consumption).

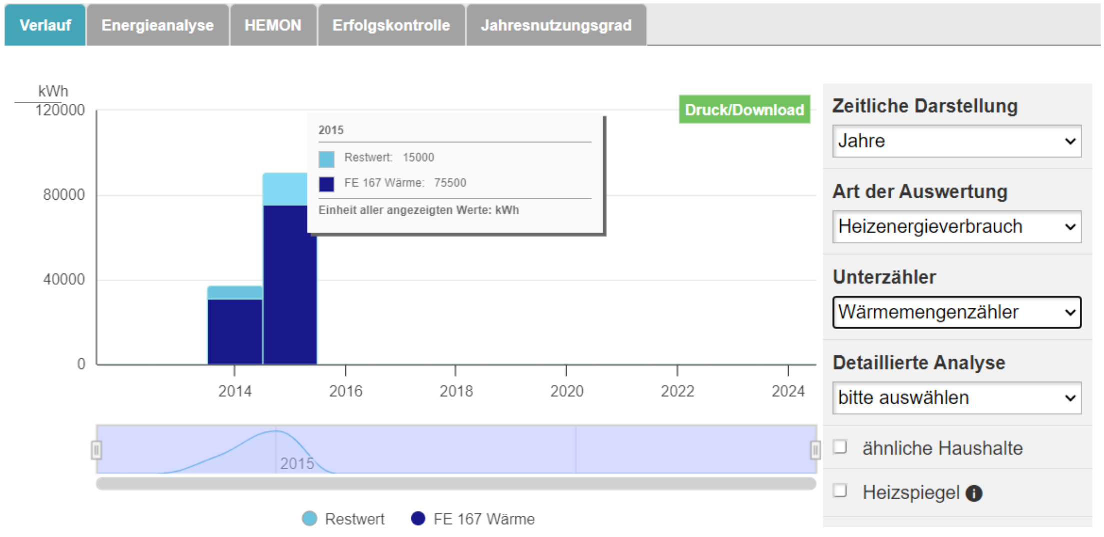
4.1.1 Annual utilisation factor

Typically, the degree of utilisation is determined over an annual period:

$$\eta = Qout_{,a} / Q_{in, a}$$

The following practical example (see Figure 8 and Table 6) illustrates the calculation. Only values for 9 months are available here. In the example, the utilisation factor is based on the net calorific value and is 83.4 %. With reference to the gross calorific value (conversion factor 0.9), this results in a calorific value-related utilisation factor of 75.2 %.

Figure 9: Heating energy and useful heat consumption of a residential building



Heating energy consumption (input: sum of light + dark blue bars) and useful heat consumption (output: dark blue bars) of a residential building (anonymised) from “Energiesparkonto”; source: own illustration, co2online/senercon

[18] The measurement equipment for the methods described below was analysed in the so-called “meter study” (Hermann, et al., 2019). The study also described the need for adaptation when integrating the measurements into the devices or their controls and estimated the accuracy.

Table 6: Calculation of the degree of utilisation

Period	Rest	Output	Input	Degree of utilisation
10-12/2014	6.060	31.100	37.160	83,7
01-06/2015	15.000	75.500	90.500	83,4
Total		**106.700**	**127.760**	**83,5**

The division of output and input [kWh] results in the utilisation rates (here based on net calorific value)

Valuation

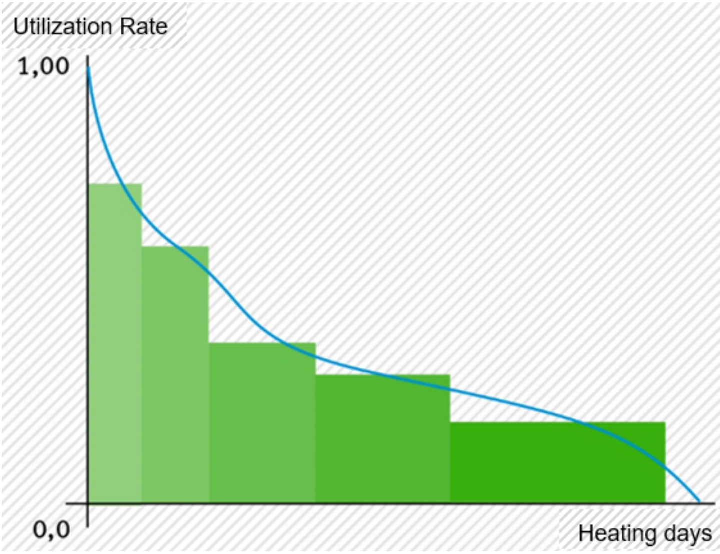
- The method is generally considered to be very robust, as an average value is determined from larger time periods, which includes different operating conditions and outside temperatures. The data required for the method is available when input and output are collected.
- If a distinction is made between heating and non-heating periods for residential buildings with centralised hot water heating, it is also possible to indicate the degree of use for hot water heating (according to draft Regulation No. 813/2013 (EU Kommission, 2023) envisaged).
- An evaluation using annual comparative values is easily possible.
- A major source of error is the correct conversion of gas consumption from m^3 to kWh. This conversion factor is supplier-specific. Natural gas is generally offered in two qualities, depending on the supplier: Natural gas H with a gross calorific value of around 12 kWh/m^3 and natural gas L with a gross calorific value of around 10 kWh/m^3, each with a considerable fluctuation range: natural gas L is no longer to be offered in Germany by the end of 2029.
- The annual utilisation factor represents the characteristic value $\eta_{so,n}$ within the meaning of the Ecodesign Regulation (EU) No. 813/2013.

4.1.2 Standard utilisation factor according to DIN 4702, Part 8

As described in section 3.4.2 the "standard utilisation factor" was determined from the mean value of five efficiencies under partial load conditions in accordance with the former DIN 4702, Part 8. The procedure will be briefly discussed here in order to check whether there are any advantages compared to a consideration of the energy signature for boilers (Section 4.1.3).

Figure 10 shows the logic behind this procedure. The starting point is a typical annual characteristic curve of a building. The partial outputs - rectangles in Figure 10 - correspond to average (theoretical) proportional consumption quantities of the annual energy. The intersections of the rectangles with the duration curve correspond to the partial outputs at which the efficiencies are measured. The standardised efficiency is then determined by averaging the partial load efficiencies.

Figure 10: Annual characteristic curve and partial load ranges according to DIN 4702, Part 8



Typical annual characteristic curve (blue) of a boiler and partial load ranges according to DIN 4702, Part 8; source: Reproduction based on IKZ.de (Strobel Verlag) [19]

Valuation

- In recent years, it has generally been observed that in central Europe sub-zero temperatures only occur at night on a few days a year. In these situations, setback operation with short boiler run times is predominant. When using the process, the typical annual duration characteristic must be adapted to the current climate conditions.
- The data required for the procedure is available if input and output are collected. The consumption shares can be determined via the heat quantity measurement required to determine the degree of utilisation. In addition, the local climate data set is required for the long-term average.
- The principle is similar to the procedure according to DIN EN 14825 for heat pumps (section 4.2.5).

4.1.3 Energy signature for boilers according to DIN 18599, supplement 1[20]

In the method *energy signature for boilers* (or simplified: *boiler signature*) that was already mentioned in section 3.4.2, average generation and utilisation capacities are calculated from meter readings during the year over the intervening time periods. The slope of the equalisation line represents the average efficiency, a point on the line represents the respective part-load efficiency.

The annual utilisation factor is determined using the equalisation curve on the basis of the average useful power output at average outdoor temperature (during the test period).

The process was implemented as a prototype in the „Energiesparkonto“[21]. The result is shown in Figure 11. In the example, daily values of input (Y-axis - "heat output") and output (X-axis "heat output") are available. The intersection of the straight line with the Y-axis represents the

[19] Cf. IKZ.de, https://www.ikz.de/ikz-praxis-archiv/p0506/050607.php

[20] Also developed by Prof Dieter Wolff, Ostfalia University of Applied Sciences

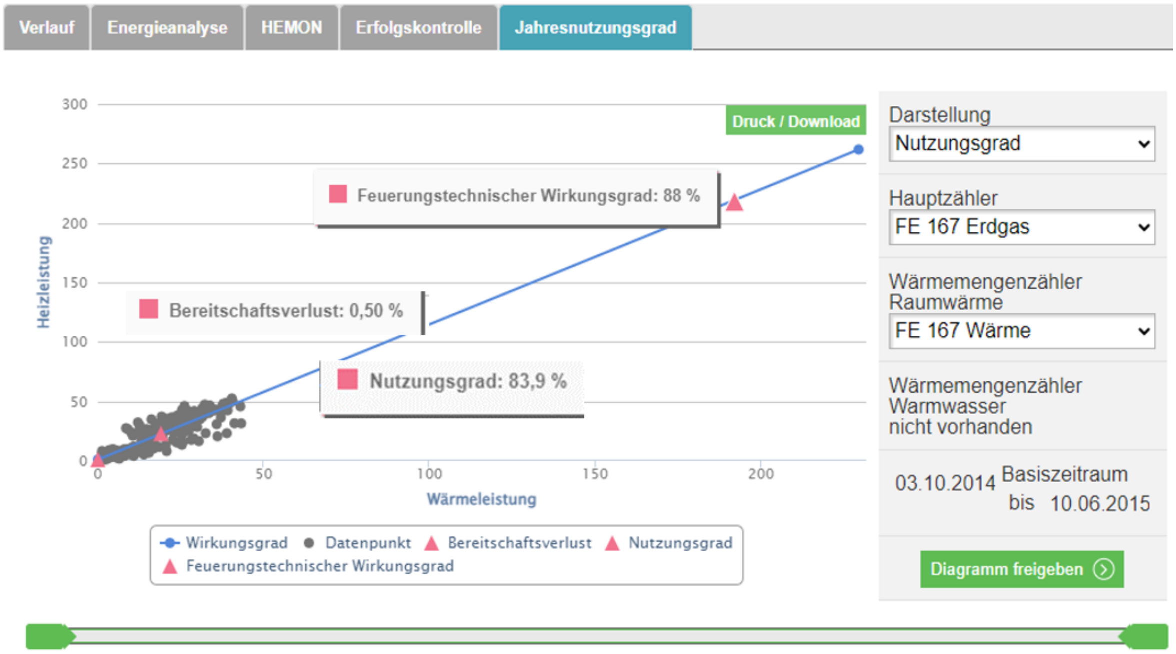
[21] The „Energiesparkonto“ (www.energiesparkonto.de) is a free energy monitoring tool published by co2online and senercon, which offers various options for analysing energy data, including visualisation.

standby losses, which in the example are 1 kW or 0.5 %. The axis division is selected so that the equalisation line covers the entire output range of the boiler. The nominal heat output in the example is 192 kW. The diagram shows that the average output per day is significantly lower than the nominal heat output of the boiler. This is due to the daily outdoor temperatures during the heating period, which are generally well above the design temperature.

Using the boiler data (low-temperature boiler from 1993, nominal heat output 192 kW), a firing efficiency (full load) of 88 % was determined using the corresponding value of the equalisation curve. Unfortunately, the measurement result of the chimney sweep is not available to compare the value with the measurement result.

The average useful power output in the current billing period is around 20 kW. The utilisation factor for this is 83.9 % (based on net calorific value). The result is similar to that described in section 4.1.1 analysed for the same building. Whether this agreement can be generalised is discussed in the method application (Appendix B).

Figure 11: Boiler signature for the gas boiler of a residential building



Graphic representation of the generation output (here heating capacity) over the useful heat output (here heat output), determined from heat quantities (daily values); the method determines the operational readiness loss, the average utilisation factor and the combustion efficiency. Source: own illustration, co2online/senercon

Valuation

- The data required for the procedure is available when input and output are collected,
- In general, the degree of utilisation only fluctuates by a few percentage points depending on capacity utilisation.
- There is a linear relationship between input and output with an expected very high coefficient of determination R^2.
- The average degree of utilisation increases with increasing daily output, as the standby losses then play a less significant role.

- The linear relationship and the point distribution in the example make it clear that the average output represents the annual utilisation factor. This is then also calculated for the heating period on the basis of the average outdoor temperature.
- The equalisation curve determined using measured values appears to make it possible to make statements about the annual degree of utilisation in much shorter periods than over a whole year. It is estimated that after just a few weeks of measurement (during the heating period) it is possible to make statements about the annual utilisation factor.

4.1.4 Determining the seasonal space heating efficiency

If the electricity consumption of a heating appliance is also measured or estimated from product data sheets, a maximum seasonal space heating coefficient η_s can be determined and evaluated. This is done taking into account the annual coefficient of performance determined in section 4.1.1 based on the ecodesign requirement (e.g. Regulation (EU) No. 813/2013 on space heaters and combination heaters). If applicable, the primary energy factor for electricity must be taken into account. The seasonal space heating efficiency also applies to heat pumps.

4.2 Coefficients of Performace

Coefficients of performance characterise the efficiency of heat pumps. Here, too, a distinction is made between instantaneous and average values based on output and consumption. COP (Coefficient of Performance) and SCOP (Seasonal COP) are commonly used in the standards for performance figures. The SCOP is usually a calculated value that includes operational and standby losses. Very often, SCOP values only describe space heating operation.

4.2.1 Annual coefficient of performance

The annual coefficient of performance is calculated in the same way as the annual efficiency according to section 4.1.1:

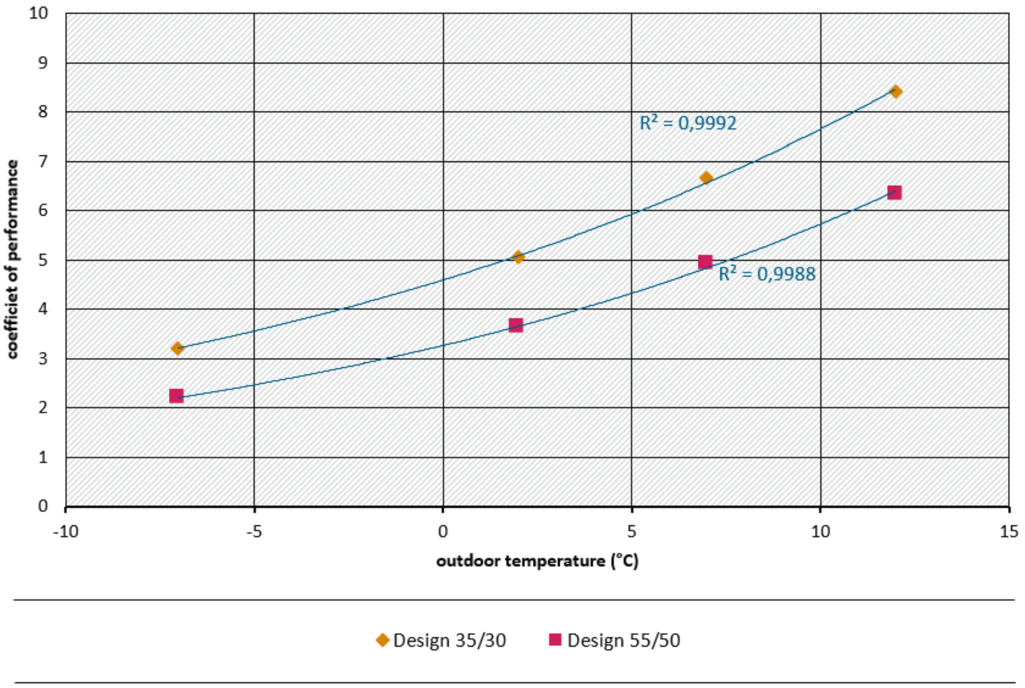
Annual coefficient of performance = $Qout_{, a} / Q_{in, a}$

The balance limit is the entire appliance including all auxiliary energy consumption as well as the consumption of any existing heating element. The data required for the procedure is available when input and output are collected.

4.2.2 Coefficients of performance as a function of the outside temperature

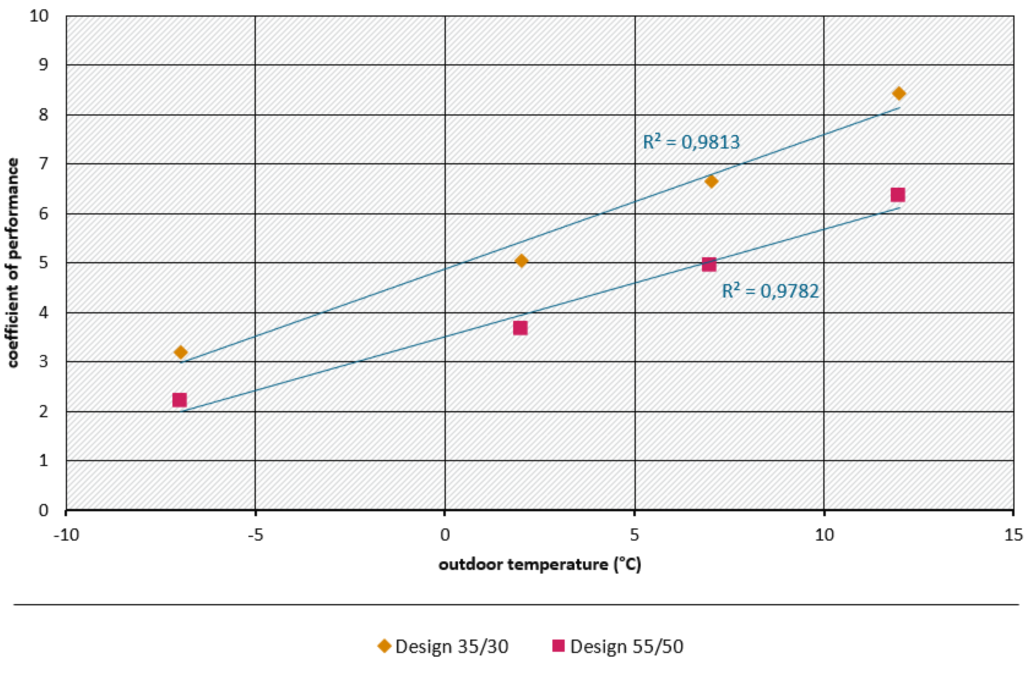
Unlike the efficiency or utilisation rates of boilers, the coefficients of performance of an air source heat pump, in which air is used as the heat transfer medium, are heavily dependent on the outside temperature. There is also a strong dependence on the design or operating temperature of the heating circuit. Both relationships can be explained by the Carnot process. The relationship is illustrated by Figure 12 and Figure 13. By inserting a trend line, it was also checked whether the relationship is non-linear (as assumed) or can also be considered linear with restrictions.

Figure 12: Performance figures of an air-to-water heat pump as a function of the outdoor temperature, non-linear



Trend formation (non-linear) of the performance figures based on the measuring points of the test bench / data sheet, for two different heating system designs. Source: own representation co2online/senercon based on the data sheet information of a heat pump manufacturer (Vaillant, 2023)

Figure 13: Performance figures of an air-to-water heat pump as a function of the outdoor temperature, linear

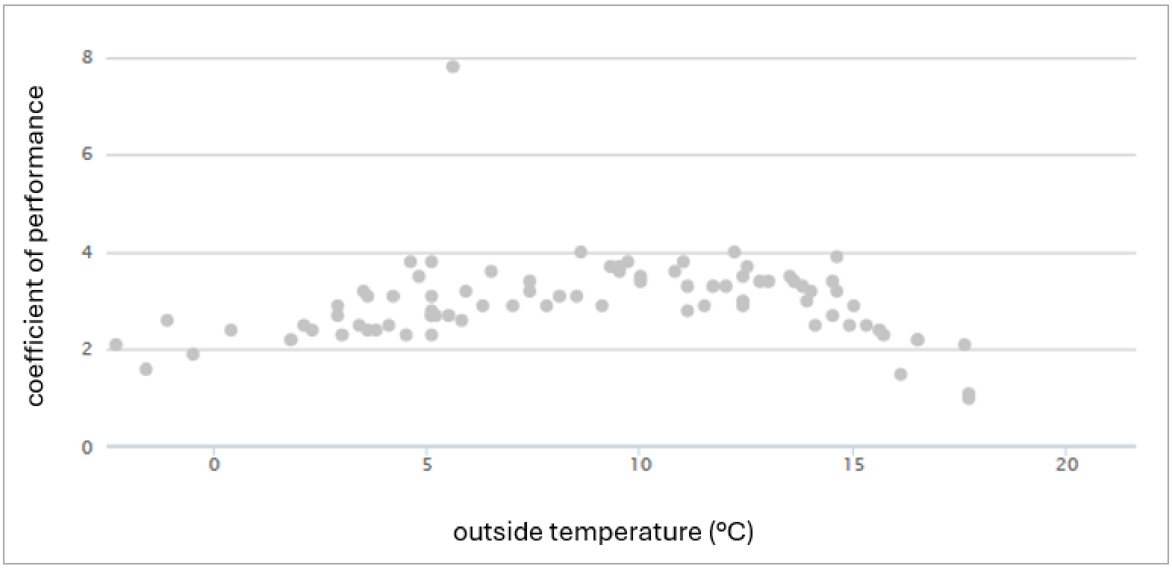


Trend formation (linear) of the performance figures based on the measuring points of the test bench / data sheet, for two different heating system designs. Source: own representation co2online/senercon based on the data sheet information of a heat pump manufacturer (Vaillant, 2023)

From Figure 12 and Figure 13 it can be seen that the relationship for the air-to-water heat pump shown in the example can also be approximated linearly with sufficient accuracy.

From the FINESCE project[22] , input and output data from an air-to-water heat pump for the years 2014/15 were available as daily values for a Danish building, from which the daily energy figure was determined in each case. Figure 14 shows the coefficients of performance over the outdoor temperature.

Figure 14: Daily coefficients of performance of a heat pump



Data point of the daily coefficient of performance of a heat pump from the FINESCE project as a function of the outside temperature; the data point with a coefficient of performance of almost 8 is probably due to a measurement error; source: senercon's own illustration

From Figure 14 it can be seen that the daily coefficient of performance in the temperature range from 7 to 14 °C is largely constant above 3. The coefficient of performance decreases towards sub-zero temperatures. The figure clearly shows that during the heating period there are only a few days with average outdoor temperatures below 0 °C, when the coefficient of performance is around 2. It is also clearly recognisable that the coefficient of performance drops significantly in the summer with pure hot water operation (outside temperature > 15 °C).

Nevertheless, Figure 14 shows that data from the field does not show a similarly strong linear relationship as the test bench values (Figure 13) suggest.

It can be deduced that further data analysis is possible:

- It is possible to display an average degree of utilisation over the outdoor temperature during the year using the input and output data collected. In addition, the average outdoor temperature for the period is required, which can be obtained from the data of the outdoor temperature sensor of the control system.
- That data from newer heat pumps (with possibly more advanced efficiency) should be analysed in order to verify the facts. Both an air and a brine heat pump should be analysed (cf. B Appendix 2).

[22] In a sub-project involving senercon, the consumption data of 11 heat pumps was mapped in the „Energiesparkonto“

- The performance figures from the data sheet should also be compared with the achieved performance figures.

4.2.3 Determination of the expected coefficient of performance according to VDI Guideline 4650, Sheet 1

VDI Guideline 4560 Sheet 1 specifies how a practical coefficient of performance is calculated under standardised conditions for planning purposes. The procedure according to the guideline is specified in § 71o GEG for checking compliance with tenant protection requirements. It specifies a metrological check of the annual performance factor and a comparison with an "expected annual performance factor" of at least 2.5. From this it could be concluded that the expected annual performance factor according to § 60a GEG, which provides for the testing and optimisation of newly installed heat pumps after an operating period of 2 years, must also be determined according to VDI 4560.

The method described in the VDI guideline for determining the annual performance factor is implemented by the German Heat Pump Association (BWP) as an online calculator[23] free of charge. The starting point for calculating the coefficient of performance in the VDI guideline are performance figures for the operating point of the appliance, which were determined in accordance with DIN 14511 and can usually be taken from the manufacturer's data sheets. If the type designation is known, data sheets are not necessary, as all newer heat pumps from the most common manufacturers are already stored here. The following parameters are used to determine the annual performance factor:

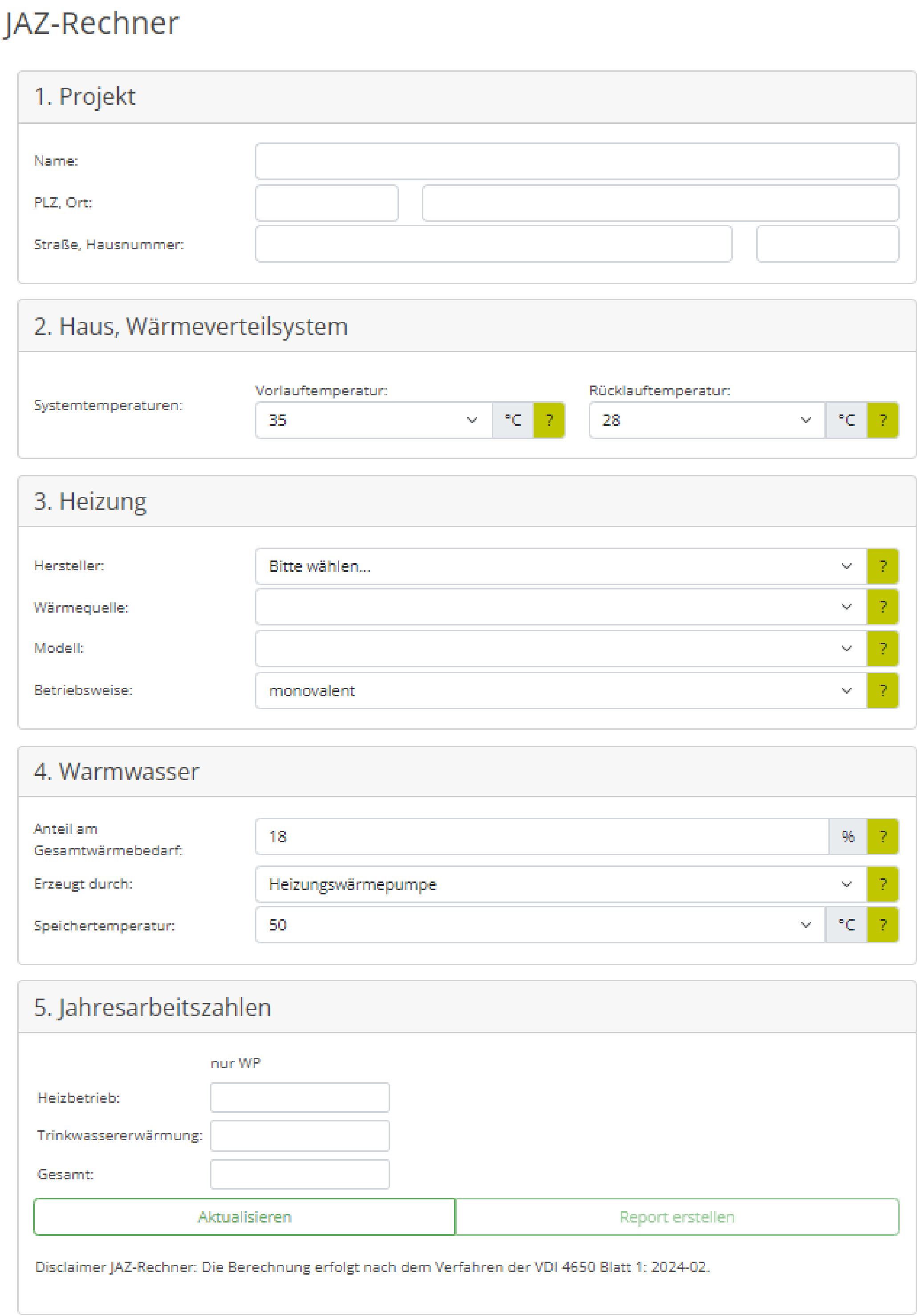
- Type of medium from which heat is extracted and the average expected medium temperature (e.g. soil 10 °C, air 2 °C),
- Temperature design of the heating system (maximum flow temperature/return temperature in the design case, e.g. 35/28 °C for panel heating or e.g. 50/40 °C[24] for radiators),
- Expected annual heat consumption (e.g. from the energy consultancy report) and proportionate hot water consumption and hot water temperature.
- The location of the building and therefore the design temperature and the associated climate data (determined in the online guide based on the postcode),
- For hybrid systems, additionally the bivalence temperature, the output of the heat pump and the total heating load (heat output).

Figure 15 shows the input screen of the BWP heat pump calculator.

[23] Cf. https://www.waermepumpe.de/jazrechner

[24] The actual (set) heating design is used for the calculation. The example represents a heating system design suitable for heat pumps, as was the case in the three buildings with heat pumps examined in the field test (see Appendix B.1 to B.3)

Figure 15: Online calculator for determining the annual performance factor



Input screen of the online calculator and output of the expected annual performance figures. A report with the stored data and COP used can be downloaded. (BWP)

The process therefore takes into account the typical test bench COP at 0 °C for space heating and 7°C for hot water, the average medium temperature, the flow temperature of the heating system and the hot water temperature. These parameters are important for assessing efficiency according to the Carnot process. Partial performance figures are calculated for hot water heating and space heating, which are weighted by the consumption shares for space heating and hot water. For single-family houses in particular, the correct proportion for hot water (as a percentage value in the calculator) must be specified. Hot water consumption depends heavily on the number of people in the household and their habits. It also has a strong influence on the energy coefficient. The default value of 18 % stored in the calculator should be adjusted to the actual values. As hot water consumption is not usually measured in single-family homes, a heat consumption of 800 kWh[25] per person per year can be estimated. The unadjusted annual consumption can be used to determine correct percentage values.

For the heat pump described in section 4.2.2, Figure 12 and Figure 13 the annual coefficient of performance determined using the online calculator is 4.82. A heating design of 35/28, a hot water temperature of 50 °C and a proportionate hot water consumption of 25 % were assumed (location Berlin, postcode 10829).

It can be deduced from the above:

- A heat pump calculator based on VDI 4560, Sheet 1 can be used to determine a case-specific, expected annual performance factor with the aid of a small amount of data, e.g. that is available to the heating installer. This data is also available for the applications shown in Appendix 2. On this basis, measured annual performance factors could in any case be evaluated approximately.
- When using the coefficients of performance, the calculator takes into account that the medium temperature for brine and water heat pumps is comparatively constant over the heating period. Therefore, only one coefficient of performance is used to determine the comparative value for these heat pumps.
- The benchmark calculated in this way could be used to be stored as a comparative value in the efficiency display of a heat pump. It seems possible to determine this during the commissioning of heat pump systems, as the effort involved is low.
- For the calculation of comparative values at EU level, the procedure in accordance with VDI 4650, Sheet 1 must be adapted, or national procedures are generally authorised.

4.2.4 Determination of the expected COP using a regression model

A regression is a statistical method which, in the simplest case, visualises the relationship between data points in an x/y diagram. The variable y is dependent on x. If the relationship is linear (straight line), this is referred to as linear regression. In multivariate regression, y is dependent on several parameters.

In section 4.2.3 the method according to VDI 4650 was presented, which uses selected performance figures from the appliance data sheets and the influencing variables caused by the Carnot process to determine practical annual performance factors. In the following, we will examine whether it is also possible to determine annual performance factors using a regression model when using the same/similar influencing variables if the actual annual performance factor is known for the respective data set.

In the so-called heat pump consumption database[26] , registered users publish their heat pump operating data, in particular electricity and heat consumption data and the corresponding coefficients of performance. Master data is available for each data set, which, in addition to the

[25] Corresponds to 30 litres of hot water consumption at 45 °C on 330 days per year with a system efficiency of 50 % for hot water preparation.

[26] Cf. https://www.waermepumpen-verbrauchsdatenbank.de (Brockmann, 2024)

product name of the heat pump, also shows parameters influencing the annual performance factor of heat pumps. The following parameters were used for the regression:

- Type of heat pump (air or brine)
- Measured annual performance factor for the year 2022
- Flow temperature heating system in the design case
- Hot water temperature
- Number of people in the household
- Researched coefficient of performance (determined from data sheets or via BWP annual coefficient of performance calculator at outside temperatures of -7, 0 or 7 °C and underfloor heating (W35))
- Degree days figures in 2022 at the location (own research)

The regression was carried out for a selection of 21 heat pumps from the 3,600 data records contained in the heat pump database. The result has a coefficient of determination of R^2=0.77[27] .

Table 7, column J shows the estimated result, column K the deviation from the measured annual performance factor. All estimated values (exception: 8) are in the range +- 20 %.

Table 7: Data set regression analysis

Para metre No.	A Type of constr uction	B Users	C VL °C	D WW °C	E A-7/ W35	F A2/ W35	G A7/ W35	H GTZ 2022	I JAZ	J JAZ gesch.	K Decre ase %
1	2	2	45	47	3,27	3,73	4,46	3450	3,2	3,7	-17
2	1	4	35	50	4,33	4,51	4,69	3327	3,8	3,9	-2
3	2	2	38	55	2,78	3,84	4,79	2715	2,9	3,1	-7
4	1	3	30	45	4,33	4,51	4,69	2932	3,4	3,6	-5
5	2	4	35	50	3,30	3,80	4,50	2873	3,3	3,3	0
6	2	4	35	47	3,30	3,80	4,50	2799	3,6	3,5	4
7	2	2	35	50	3,14	3,74	4,59	3405	3,6	3,1	15
8	2	4	35	46	2,77	3,37	3,94	3596	2,4	3,3	-37
9	2	4	35	48	3,30	3,80	4,50	3402	3,7	3,5	5
10	2	2	35	49	3,20	3,80	4,30	3740	3,6	3,1	13
11	2	3	33	43	2,61	3,74	4,74	3275	3,8	3,6	5
12	2	7	30	52	3,27	4,10	5,22	3351	4,0	4,0	0
13	2	4	30	43	3,35	4,34	5,02	3919	4,3	4,1	5

[27] The coefficient of determination is acceptable considering the limited time available for this study. It should be possible to increase the coefficient of determination by including additional plants with a higher willingness to vary the analysed parameters or by using other calculation models.

Parametre No.	A Type of construction	B Users	C VL °C	D WW °C	E A-7/ W35	F A2/ W35	G A7/ W35	H GTZ 2022	I JAZ	J JAZ gesch.	K Decrease %
14	2	3	35	44	2,61	3,74	4,74	3236	4,2	3,7	11
15	2	4	35	46	3,00	4,43	5,07	3055	4,4	4,2	4
16	2	4	35	43	3,20	3,80	4,30	3588	3,6	3,8	-6
17	1	4	65	55	2,96	2,96	2,96	2779	4,2	3,9	6
18	2	4	37	50	3,77	4,75	5,94	3087	4,5	4,4	1
19	2	2	38	50	2,75	4,20	5,33	3152	3,2	3,8	-19
20	2	4	35	48	3,14	4,31	5,41	3328	4,2	4,2	0
21	2	2	45	44	3,45	4,40	5,61	3449	4,6	4,6	1

Regression parameters (columns A to I) and result (columns J and K). Type 1: brine/water, type 2: air/water.

The regression model is based on the following formula, which is derived from Table 8 results:

Y (annual COP) = -0.189210827 * A + 0.191488388 * B +... + 0.013258388

The coefficients determined are shown in Table 8 are shown.

Table 8: Coefficients of the regression function and P-value

Parameters	Coefficients	P-value
Constant link [28]	0,013258388	0,99696668
A (type)	-0,189210827	0,76811751
B (number of users)	0,191488388	0,05520233
C (Pre-run C)	0,053937016	0,01786894
D (WW temperature)	-0,049909193	0,19965626
E (A-7/W35)	-0,253434130	0,57843953
F (A2/W35)	0,657702558	0,52936676
G (A7/W35)	0,303109189	0,63920956
H (GTZ 2022)	0,000176839	0,66460820

Coefficients of the regression formula of the linear equation that enable the annual performance factor to be estimated. The larger the P value, the more dependent the annual COP is on the respective parameter

[28] Displacement of the straight line

For the heat pump described in section 4.2.2, Figure 12 and Figure 13 the annual coefficient of performance determined using the regression is 4.86, assuming the same parameters. For comparison: The coefficient of performance determined according to VDI 4650 is 4.82.

The P value[29] shows that the design, the climate and the COP database values have a significant influence on the annual performance factor. With 20 cases and very homogeneous data sets, e.g. with regard to the flow temperature, the sample is not suitable for making general statements about the influence of individual parameters on the annual performance factor. The aim here was to illustrate that such methods are interesting for determining comparative values.

4.2.5 Seasonal coefficient of performance according to DIN EN 14825

In DIN EN 14825, the seasonal coefficient of performance (seasonal COP, SCOP) is calculated from the COP or performance values determined on the test bench at outdoor temperatures of -7, 2, 7 and 12 °C and standardised climate data[30] . For each outdoor temperature (so-called BIN temperatures) in the heating period, it is defined how many hours it occurs in the year.

In the first step, the proportionate heating load to be covered by the heat pump is determined using the total heating load and the respective bin temperature. The COP values are then interpolated from the standard values for each BIN temperature. The expected heat consumption per BIN temperature level (-10 to 15 °C) is determined using the heating load and the BIN temperature hours. The predicted electricity consumption is then calculated using the COP value. The average $SCOP_{on}$ (SCOP when the appliance is running) is then calculated from the sums of the consumption values for all bin temperatures.

Table 9 shows the procedure in principle. Line 3 illustrates the interpolation of the COP value for -6 °C (from lines 2 and 5). Line 11 shows the total values including the hidden lines (...). Line 12 shows the $SCOP_{on}$ determined on the basis of the total values.

Table 9: Calculation $SCOP_{on}$

No.	BIN temperature °C	Hours h	Heating load kW	COP	prognosis heat consumption kWh	prognosis electricity consumption kWh
1	...	49				
2	-7	24	8,8	3,21	212	66
3	-6	27	8,5	3,42	575	168
4	...	1.106				
5	2	320	5,4	5,06	1.723	341
6	...	1.346				
7	7	326	3,5	6,65	1.128	170
8	...	1.213				
9	12	169	1,5	8,41	260	31
10	...	330				

[29] Probability that the observed result will occur (1 to 0)

[30] The calculation is to be carried out for the climate zone "Average or A" (corresponds to Strasbourg), which is also most comparable to the German climate. There are also the climate zones "Warmer or W" (corresponds to Athens) and "Colder or C" (corresponds to Helsinki).

No.	BIN temperature °C	Hours h	Heating load kW	COP	prognosis heat consumption kWh	prognosis electricity consumption kWh
11	Total	4.910			26.298	5.281
12	SCOPon					4,98

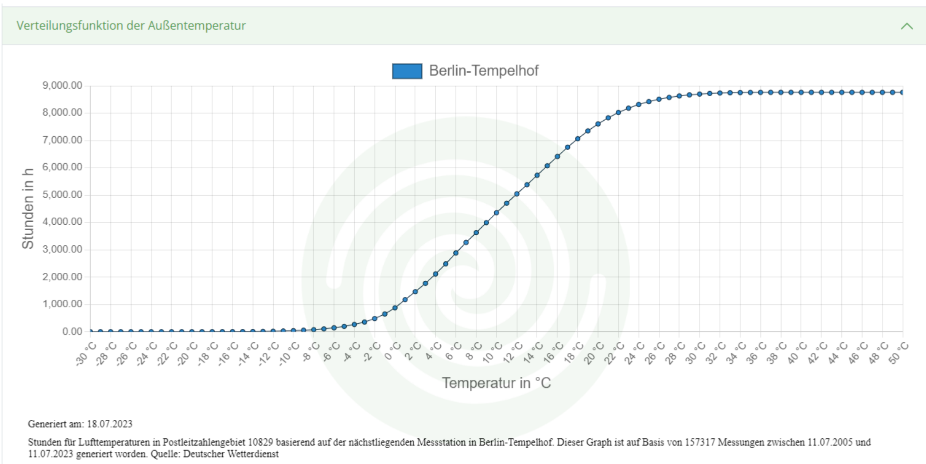
Calculation of the SCOPon based on the standard COP and BIN temperature hours, total values incl. temperature ranges not shown

The SCOP is then determined from the SCOPon, taking into account operational and standby losses for selected operating states and modes. Because the losses are taken into account, the SCOP is lower than the value for $SCOP_{on}$.

The following conclusion can be drawn from the above:

- The calculation process takes into account temperature conditions at the Strasbourg site that correspond to today's conditions in Central Europe (e.g. only a few hours < -7 °C).
- The SCOP takes into account various operating cycles and their losses for heating operation.
- The costs for water heating are not included. The value is therefore only suitable to a limited extent for assessing the efficiency of combi appliances in practice.
- In general, the calculation procedure for determining the $SCOP_{on}$ using the BIN temperature hours appears to be suitable for forecasting the annual performance factor during the year. In this case, the average real outdoor temperatures at the location, which are available from the German Weather Service, should be used (Figure 16).

Figure 16: Hours of outdoor air temperature for Berlin-Tempelhof



Graphical representation of the annual hours at which a specific outdoor temperature occurs. The figure refers to a rolling 18-year period. In times of climate change, it may make sense to look at a shorter period in the past. Source: Bundesverband Wärmepumpen e.V.; German Weather Service[31]

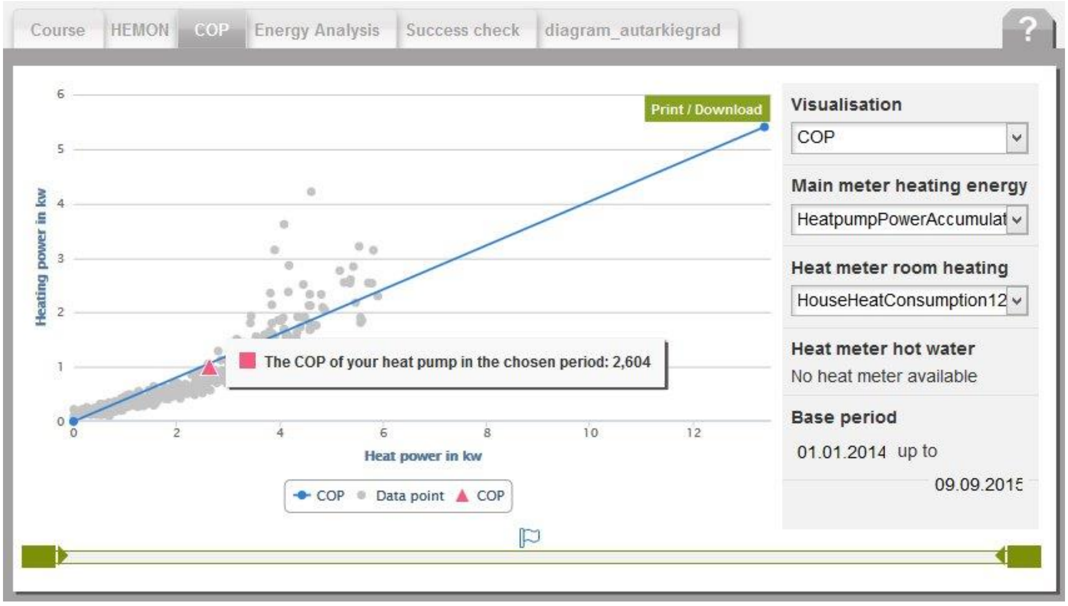
[31] Cf. https://www.waermepumpe.de/normen-technik/klimakarte/ (BWP)

4.2.6 Application of the boiler signature to heat pumps

The boiler signature graphically displays the input and output data of a boiler in a diagram. Input and output data from heat pumps can be displayed in the same way. The process name "boiler signature" (see section 4.1.3) is retained, as the method was first described in Supplement 1 of DIN 18599.

In Figure 17 the annual performance factor of a heat pump is determined using the output at average outdoor temperature. Here too, the output values were determined from the daily consumption in kWh, divided by 24 hours.

Figure 17: "Boiler signature" of a heat pump

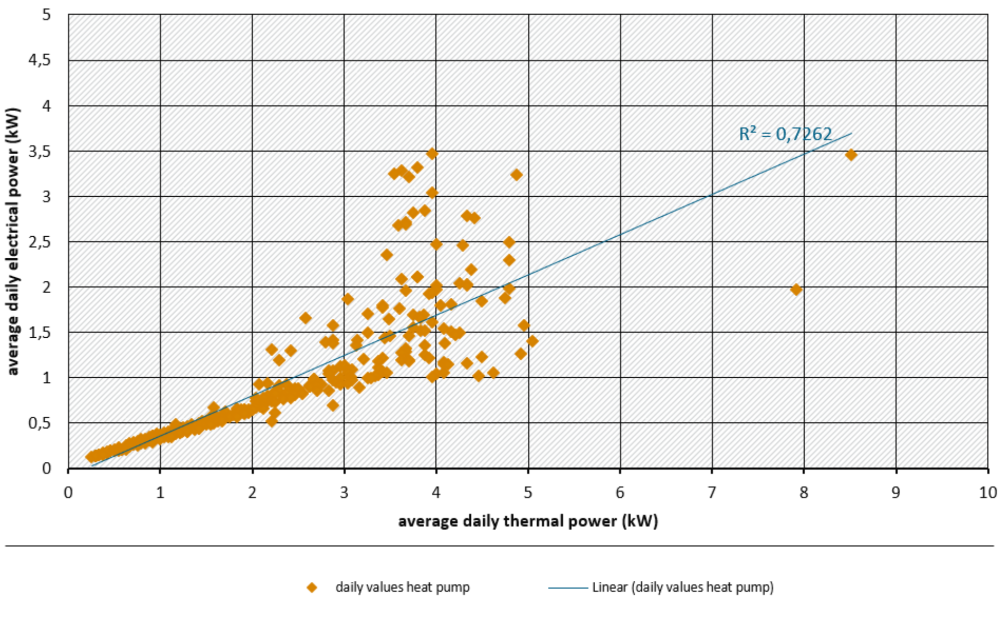


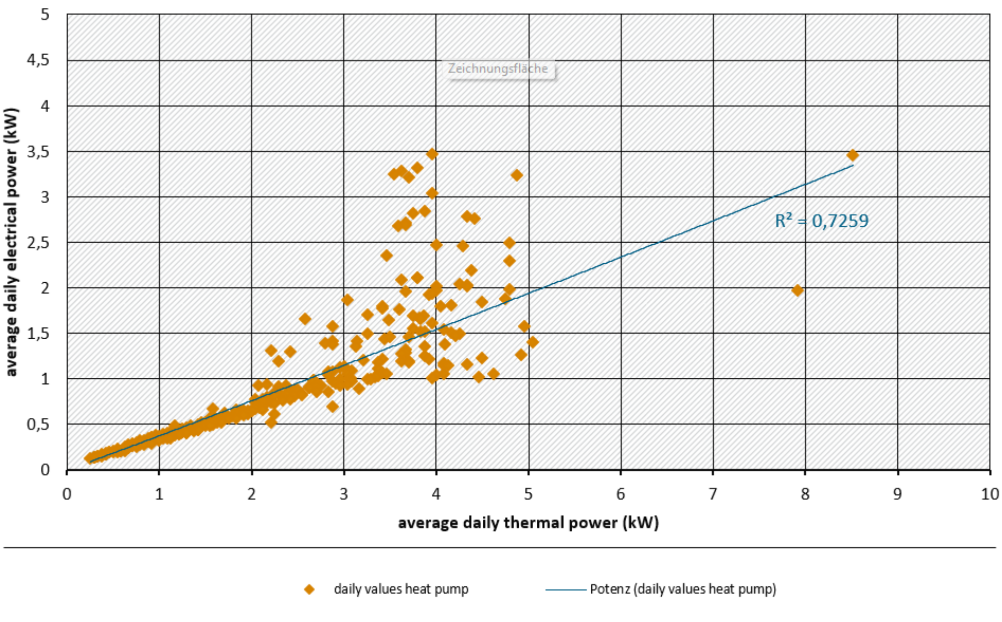
Graphic representation of the power consumption (here "Heating Power") over the useful heat output (here "Heat Power") for a heat pump (source medium unclear). Source: FINESCE project, own illustration co2online/senercon

The linear relationship between power consumption and useful heat output is clearly recognisable in the partial output range up to 3 or 3.5 kW. This range should cover both the non-heating period and the outdoor temperature range between 7 and 14 °C. The high scatter range of the values at higher outputs (lower outdoor temperatures) is striking.

The recalculation for another FINESCE system, also based on consumption data from 2014 and 2015, shows why a linear relationship was chosen to determine the average coefficient of performance (Figure 18).

Figure 18: Test coefficient of determination (linear, potential) "Boiler signature" of a heat pump





Test of the coefficient of determination for an air-to-air heat pump: Linear (upper diagram) and potential trend (lower diagram) have the highest coefficient of determination of the tested models[32] . Source: own illustration co2online/senercon

Off Figure 18 it can be seen that the linear correlation is slightly more accurate. No other tested trend lines were shown. However, an approximation based on a trend function is generally not very high and far from a typical coefficient of determination of high correlation (>0.85-0.95).

For the application of the boiler signature to heat pumps, it can be deduced that

- general applicability is given with the available input and output data.

[32] Linear, quadratic, polynomial, potential

- For the example of an air-to-water heat pump shown, the correlation with the regression function drops significantly with high daily power demand (cold outside temperatures) and the application of a non-linear trend does not bring any improvement.
- When using the method (B Appendix 2), it is investigated whether, despite the quality problems described, annual performance factors can be calculated via the boiler signature that do not deviate too much from the annual values according to Section 4.2.1 determined via annual values.

4.3 Estimation method for determining input and output

4.3.1 Determining the cooling capacity of air-to-air heat pumps

It is possible to estimate the cooling capacity of a split air conditioning system (heat pump) with an error in the range of 5 %[33] using four simple temperature sensors on the cooling circuit and an AI (here "artificial neural network") (Figure 19), as was determined in a research project in 2020 (Sholahudin, 2020). The method can be transferred to the heating output.

The research project was prompted by the fact that split appliances lose performance over the course of their service life due to soiling or refrigerant leaks and then no longer operate at maximum efficiency.

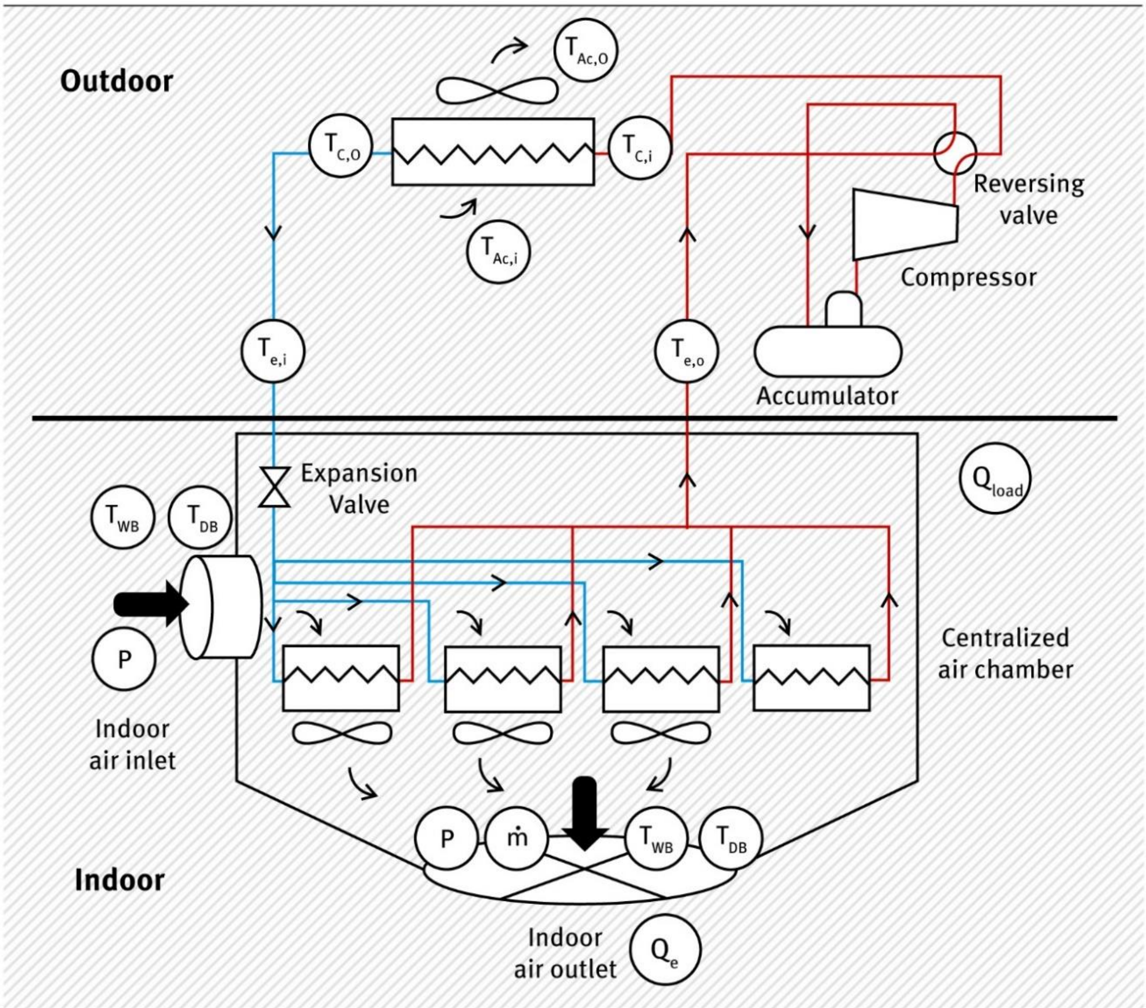
The model is based on the black box principle and on the principle that the system performance is defined by the thermodynamic states of the refrigerant during the operating cycle. (see outdoor unit $T_{e,i}$, $T_{e,o}$, $T_{c,i}$, and $T_{c,o}$).

Similar methods are used, for example, to determine the cooling capacity of cars. Analyses in this area show accuracies of the same order of magnitude. The method was tested and certified on the basis of Japanese JATL standards. [34]

[33] However, the model does not currently take soiling of the heat exchangers into account, which can be an issue, particularly in the case of air-operated systems.

[34] https://www.jatl.or.jp/en/ (JATL, 2024)

Figure 19: Schematic diagram of split system with measuring points



Schematic representation of the split system: The cooling capacity of the indoor unit Q_e , which can be determined for comparison and training purposes with high measurement effort via air pressure (P), mass flow ($\dot{m}$)and dry bulb temperature (T_{DB}) as well as wet bulb temperature (T_{wB}), is determined on the basis of the temperatures of the outdoor unit $T_{e,}$ i, $T_{e,o}$, $T_{c,i}$, and T $_{,co}$, as well as an AI. Source: Replica based on Sholahudin et. al (Sholahudin, 2020)

Valuation

- The accuracy of the procedure is higher than demanded in the draft of the new Ecodesign Regulation (EU) No. 813/2013 (EU Kommission, 2023) required. Application therefore seems generally possible.

4.3.2 Determining the electrical power consumption of heat pumps

In practice, it is common practice not to measure the electrical power consumption of heat pumps, but to calculate it via the operating point using polynomials. To calculate the power consumption, a data map (Table 10) of a measured compressor is used and the electrical power consumption is determined as a function of the pressures at the inlet and outlet as well as the temperature at the inlet and possibly also at the outlet and the specified speed. However, this approach takes little or no account of wear or missing refrigerant.

In practice, the power consumption of electrical components such as heating elements, pumps and other electronics is currently only calculated or estimated in most cases, but not measured.

Table 10 : Characteristic curve of the power consumption of a compressor

		to[°C]	-15	-10	-5	0	5	10	15	20	25
	tc[°C]										
P [W]	15		1127	-	-	-	-	-	-	-	-
	20		1217	1185	1158	1142	1143	1166	-	-	-
	25		1311	1281	1250	1227	1215	1220	1249	1307	-
	30		1409	1385	1356	1328	1308	1300	1311	1347	-
	35		1511	1496	1473	1446	1422	1406	1404	1421	-
	40		1614	1614	1601	1579	1556	1536	1525	1528	-
	45		1718	1737	1739	1727	1709	1689	1674	1668	-
	50		1822	1866	1886	1889	1880	1865	1850	1840	1841
	55		1926	1998	2042	2063	2069	2063	2053	2043	2039
	60		2028	2132	2204	2250	2274	2282	2281	2275	2271
	65		2127	2269	2374	2447	2494	2521	2533	2537	2537
	70		2223	2407	2549	2654	2729	2779	2810	2826	2835

The power consumption depends on the evaporation temperature to and condensation temperature tc. Source: own illustration ILK Dresden

Valuation

- Methods for the substitute determination of input and output values for efficiency monitoring via other system parameters are widely used for heat pumps.
- Sufficient accuracy of efficiency statements based on such parameters has been proven in individual cases. These methods can be recommended for use if they can comply with the maximum deviation of 7.5-15 % proposed in the draft Ecodesign Regulation. Estimating the power consumption of the peripherals therefore also provides comparatively accurate values. In general, the accuracy of the determination could be certified as part of an additional test (during the approval test on the test bench).
- System wear and missing refrigerant cannot be mapped. These should only be recorded if measurement of input and output were mandatory.

4.3.3 Estimation function for heat output and efficiency based on electrical power consumption and compressor load

It appears possible to determine the heat output and efficiency of electric heat pumps using the maximum electrical power consumption of the compressor and the compressor load. In an as yet unpublished manuscript (Jagnow, Wolff, & Gebhardt, 2024) the heat output of heat pumps $\dot{Q}_{WP}$ is defined as a function of the electrical power consumption P_{el} on the basis of the ideal efficiency according to Carnot ε_c compared to real efficiency by introducing an exergetic efficiency factor ζ_{EX}.

Based on the coefficient of performance *COP* determines

$$\dot{Q}_{WP} = P_{el} * \ COP$$

By introducing the exergetic efficiency ζ_{EX} the COP can be replaced by $COP = \zeta_{EX} * \varepsilon_c$. From this follows:

$$\dot{Q}_{WP} = P_{el} * \ \zeta_{EX} \ * \varepsilon_c$$

$$\dot{Q}_{WP} = P_{el} * \ \zeta_{EX} \ * \frac{T_c}{\vartheta_c - \vartheta_0}$$

Taking into account the compressor load φ applies:

$$P_{el} = P_{el,max} * \varphi$$

By introducing the correlation obtained by graphical representation

$$\zeta_{EX} = a * \varphi^2 + b * \varphi + c$$

the heat output is a function of the load and, if applicable, the flow *(T_c; ϑ_c)* or source temperature of the heat pump ϑ_0 to

$$\dot{Q}_{WP} = P_{el,max} * \ \varphi * (a * \varphi^2 + b * \varphi + c) * \frac{T_c}{\vartheta_c - \vartheta_o}$$

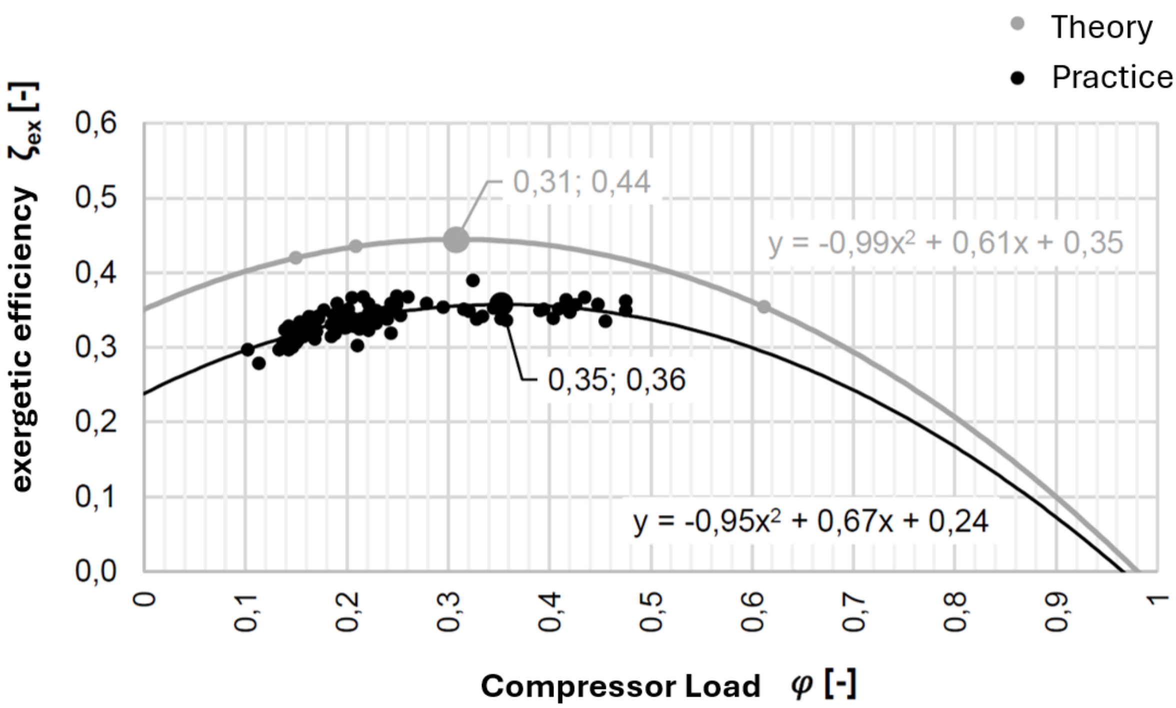
The calculation procedure for the example analysed by the authors is shown in Table 11 and Figure 20 respectively. Table 11 shows how the load and the exergetic efficiency can be calculated from the manufacturer's data sheet values. The results are shown in Figure 20 assuming a quadratic correlation. There they are compared with the measured data of the real installed heat pump of the same type.

Table 11: Calculation of load and exergetic efficiency from manufacturer data

Point	ϑ_{Source} or ϑ_0	$\vartheta_{forward\ flow}$ or ϑ_C	ε_C	P_{el}	$P_{el,max}$	φ	$\dot{Q}_{WP}$	COP	ζ_{ex}
	°C	°C	-	kW	kW	-	kW	-	-
	*	*	**	*	*	**	*	*	**
1	-7	35	7,33	2,08	3,4	0,612	5,40	2,60	0,354
2	2	35	9,33	0,51	3,4	0,150	2,00	3,92	0,420
3	7	35	11,00	0,71	3,4	0,209	3,40	4,79	0,435

Data sheet values * and calculated values **; The ideal Carnot efficiency results from the source and flow temperature, the load from the electrical power consumption and the maximum electrical power consumption. The exergetic efficiency is the result of the quadratic function of the load. (Jagnow, Wolff, & Gebhardt, 2024)

Figure 20: Exergetic efficiency as a function of the compressor load



Comparison of the theoretical values (grey dots or line) from Table 11 with measured values (black dots or line) of the installed heat pump of the same type. It can be seen that the exergetic efficiency has a maximum value in a load range of 30-40 %. (Jagnow, Wolff, & Gebhardt, 2024)

The difference between the characteristic curves represents the difference between the test bench and reality. The deviation is explained by the fact that defrosting processes and the timing of the compressor are not or not sufficiently taken into account on the test bench. According to the authors (Jagnow, Wolff, & Gebhardt, 2024) the approach is suitable to fulfil the requirements described in section 4.2.3 to improve the VDI 4650 method for forecasting actual COPs. In the authors' opinion, this requires further investigations (including analysing other systems, measuring the characteristic curve of the exergetic efficiency for the entire compressor load on the test bench).

Valuation

- The method makes it possible to estimate the heat output as a function of the load and, if applicable, the measured media and flow temperature[35] .
- A temperature data set for the location of the measured system could be used to determine an average discount value for the exergetic efficiency, which could be used to forecast real operating figures from manufacturer data. This could improve the procedure according to VDI 4650, sheet 1.

[35] For air heat pumps, the medium temperature is the outside temperature.

4.4 Energy analysis (from consumption) according to DIN 12831 supplement

The energy analysis described in the supplements to DIN 12831 represents the average power requirement (e.g. gas or electricity consumption) over the outside temperature (Figure 21 energy analyses from the „Energiesparkonto"). Here, too, the average power is determined over the energy quantity of a time interval. In general, an energy analysis can also be created for the energy output.

There is a linear relationship for boilers and heat pumps. The heating load of the building can be determined by extending the trend line to the design temperature. By separating the data on the basis of the heating limit temperature (usually 15 °C for existing buildings), statements can also be made about the average hourly power requirement for hot water preparation in buildings with centralised hot water preparation via the heating system.

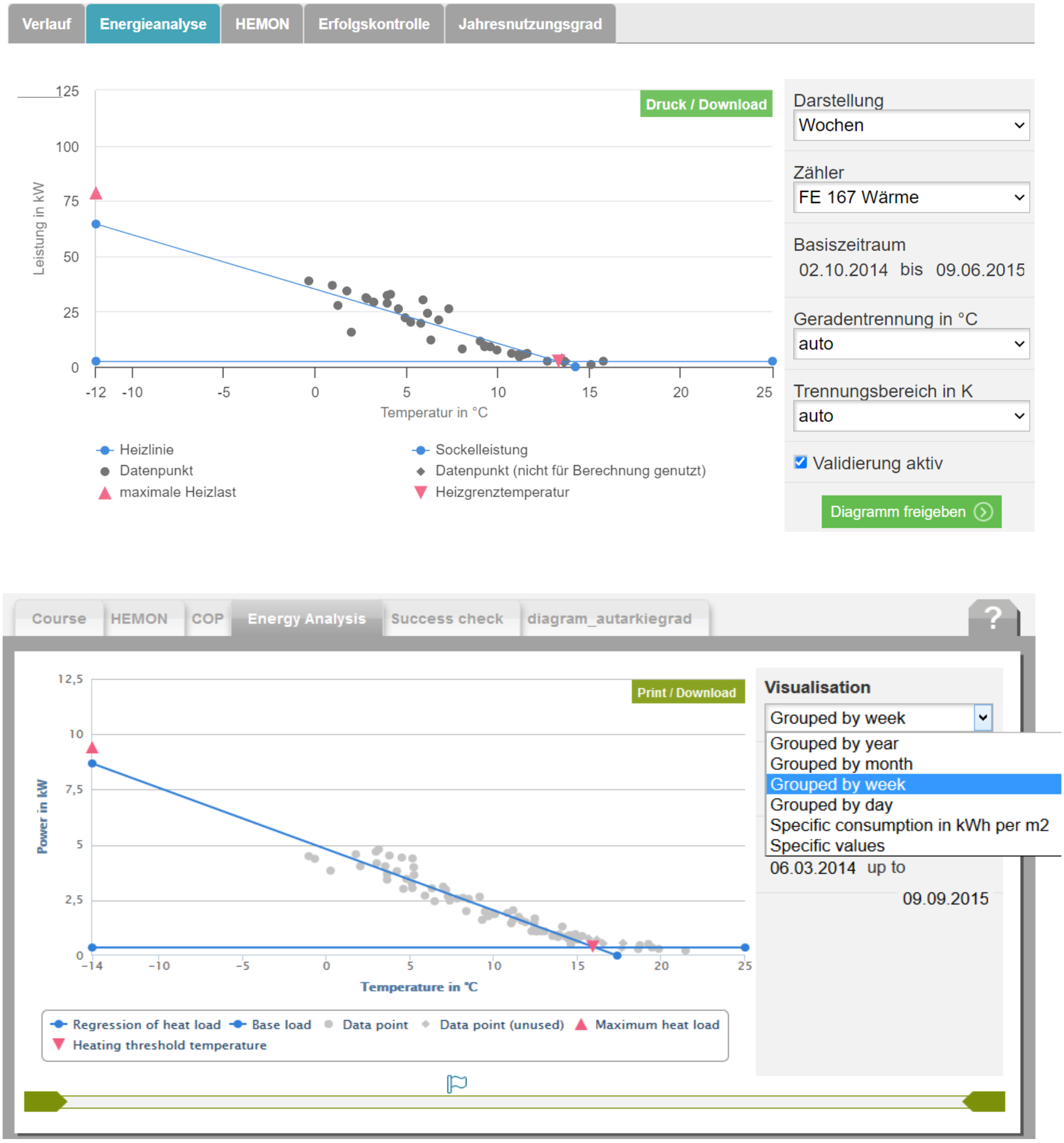
Changes in the correlation between power demand and outdoor temperature allow conclusions to be drawn about changes in efficiency. If the energy analysis is applied to the useful energy demand (output), changes in the efficiency of the heating appliance are no longer included.

Investigations by senercon have shown that the regression line can be determined with sufficient accuracy if daily values of energy input and output are available for the heating period of around 3 months. Approximate statements are already possible after 14 days. The same applies to the base load in the non-heating period. The trend should not be formed from periods where the outside temperatures are at the heating limit. Experience has shown that there is a wide range of variation in the values here, due to the daily temperature change between the heating and non-heating periods and corresponding usage behaviour (e.g. frequent window opening during the day when the temperature is above the heating limit temperature, in the morning and evening the temperature is lower and heating is used).

The efficiency is determined from the gradient of the straight line. In addition to the efficiency of the heating system, the gradient also includes the thermal insulation of the building and the average usage behaviour. When interpreting changes in the gradient, it may therefore be necessary to differentiate between causes that are not system-related.

The average heating load for heating and non-heating periods can be determined from the linear equations. With the help of these values and statistical data on the number of heating days, the annual consumption can be forecast during the year. In this way, for example, the success of thermal modernisation measures can be estimated after just a few weeks.

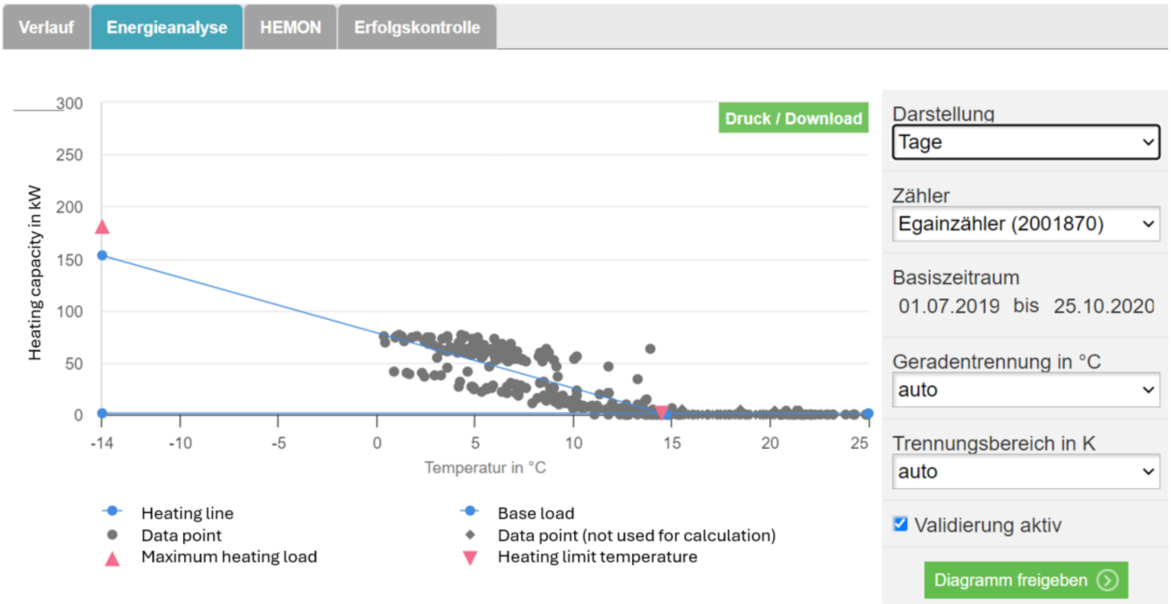
Figure 21: Energy analysis of boiler and heat pump in comparison



Energy analysis for the energy sources described in section 4.1.2 (above, boiler) and 4.2.6 (below, heat pump).
Source: own illustration co2online/senercon

Figure 21 shows that the method can be applied to systems with boilers as well as heat pumps.

Figure 22: Influence of changes in utilisation



Change in the thermal capacity (y-axis) requirements of a cultural institution after the outbreak of the coronavirus pandemic. Source: own illustration co2online/senercon

Figure 22 clearly illustrates how changes in efficiency or utilisation are noticeable in practice. In the example, the room temperatures were lowered due to non-utilisation during the COVID pandemic. A new regression line is formed (bottom point cloud), which differs significantly from the fully heated state (top point cloud). The "heating line" in the figure refers to the entire period. An efficiency display would have to recognise this deviation automatically (e.g. by regularly forming new regression lines) and update the baseline for an evaluation in the event of longer-lasting changes in the gradient of the heating line.

The advantages and disadvantages of the process can be summarised as follows:

- The procedure is based on consumption values that are to be recorded in accordance with the draft amendment to the Ecodesign Regulation (EU) No. 813/2013 (EU Kommission, 2023). The outdoor temperature is also available in the heater if an outdoor temperature-guided control system is installed in the appliance, or the heater communicates with the Internet.
- By using outdoor temperatures and thus climate data, the consumption-based method is much more accurate than simply analysing consumption over different periods (e.g. comparing the month with the month of the previous year).
- It can be applied to both boilers and heat pumps. An analogue evaluation of the useful energy consumption of solid fuel boilers or the power consumption of air-to-air heat pumps is also possible.
- The entire system is always evaluated. Changes in the increase indicate changes in efficiency. Other changes (utilisation, thermal refurbishment) can also cause changes in the increase.
- Changes in the gradient and thus the ratio of output (or consumption) to the outside temperature indicate a deterioration in efficiency (increase in the gradient) or an improvement in efficiency (reduction in the gradient), e.g. due to energy refurbishment. Changes in utilisation can also cause a change in the gradient.

- The correlation between output and outside temperature is stable after a few weeks of measurement (during the heating period).
- An assessment based on the level of base load (constant demand) would also be conceivable for electrically or gas-fuelled hot water storage tanks and solar thermal systems as well as for pure hot water heat pumps.
- By analysing energy input and output at the same time, it is also possible to make statements about the efficiency of the heating appliance by calculating average efficiency levels or coefficients of performance on this basis.

4.5 Analysing system temperatures

By storing and analysing data from the sensors already present in the heating appliance, it is possible to assess the efficiency of heating appliances or systems. The assessments can be further improved if additional sensors are installed. An important evaluation parameter in this context is the return temperature[36].

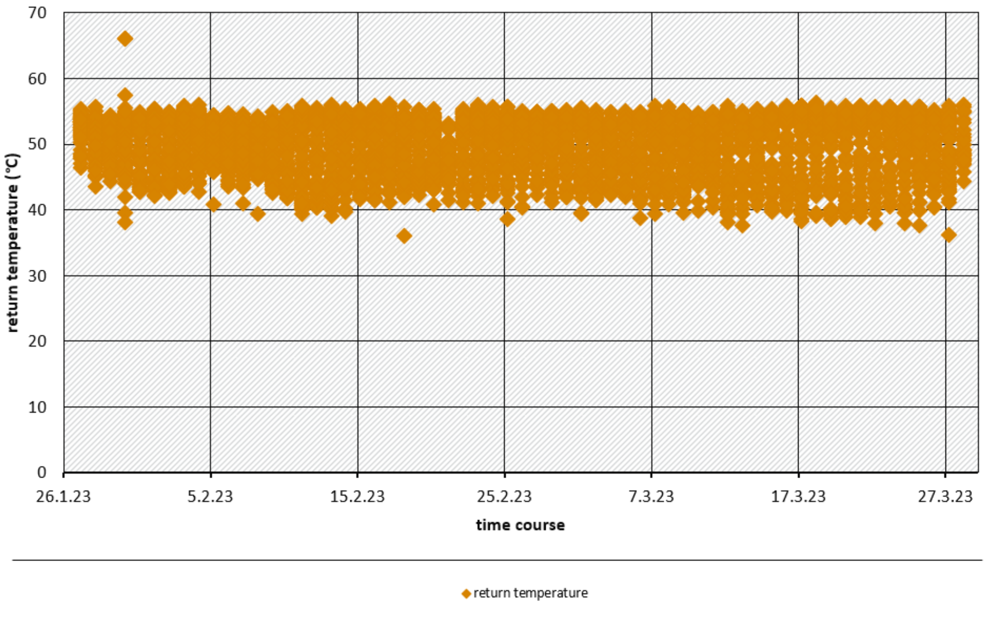
The importance of this variable is illustrated below using the example of heat meters from district heating systems, as these continuously measure the return temperature.

If such meters are installed, it is possible, for example, to detect errors in the appliance's control settings without having to access the appliance's control system directly.

The easiest way to read return temperature data is from heat meters. On the one hand, it is possible to read heat meters at the desired intervals (minutes, hours, days...) via standardised interfaces implemented in the meter or retrofittable interfaces (usually M-Bus). For this purpose, the meter must be equipped with a power supply unit, as the built-in battery is only designed for monthly readings with a calibration period of 5 years. Figure 23 shows the quarter-hourly return temperatures of a district heating system read from a heat meter. It can be seen that the average return temperature in the core heating period from the end of January 2023 to mid-March 2023 is around 50 °C.

[36] While the flow temperature in heating appliances is measured regularly for control purposes, this does not apply to the return temperature,

Figure 23: Use of heat meter for system temperature analysis: After optimisation



Analysis of the return temperature (1/4 hourly values) of a heating circuit based on the values of a continuously read heat meter. Source: own illustration co2online/senercon

Most meters store monthly values for heating energy consumption, as well as maximum values (hourly values) for temperatures, water quantities and outputs with a time stamp. These values can be read out via the operating display or the optical interface (as a CSV download). The digital output (optical interface) of heat meters from some manufacturers already contains a visualisation of the values as a diagram over time.

Figure 24: Memory contents (data) of a heat meter

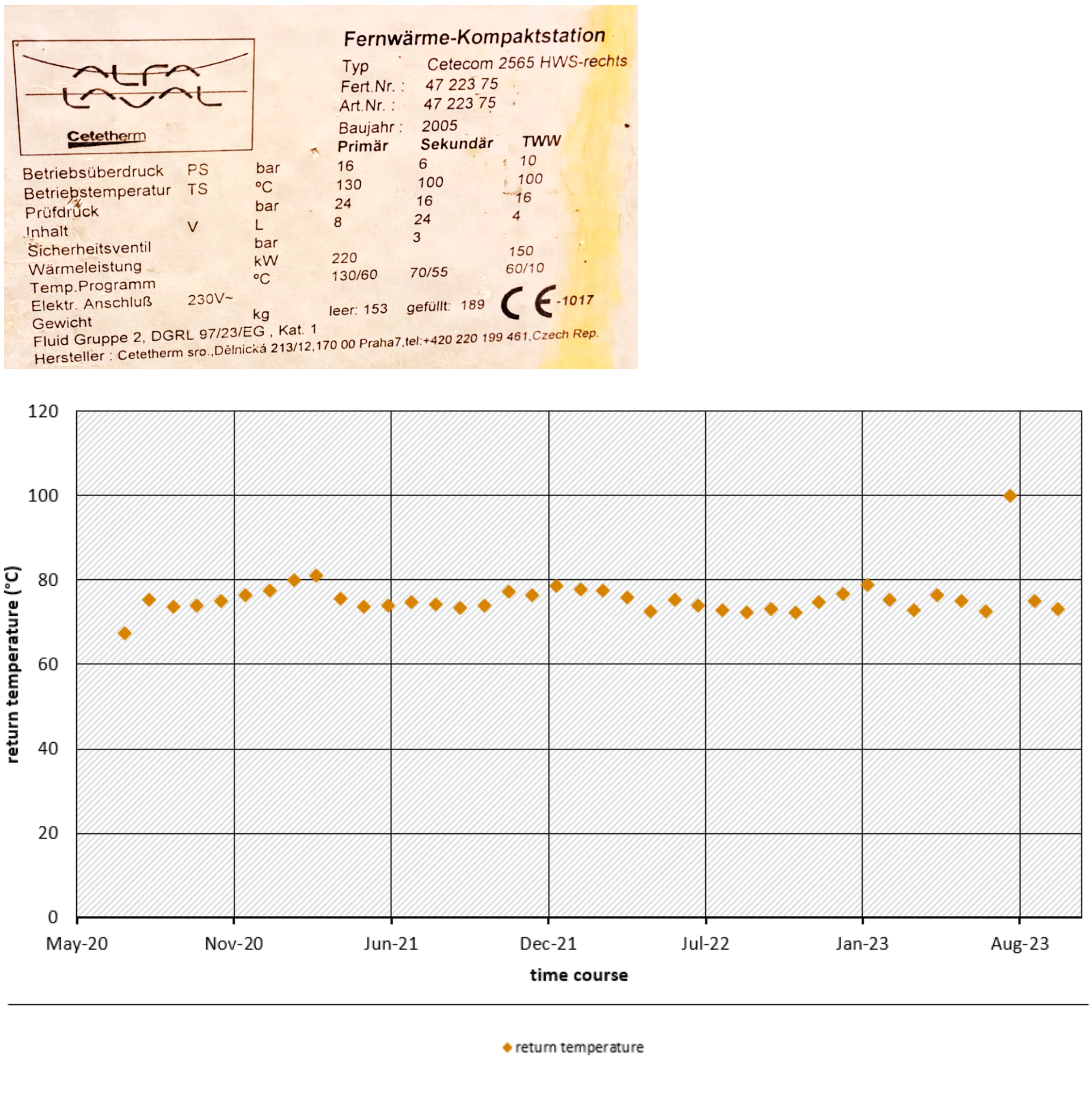
Datum	Energie		Volumen		Max. Temperatur warme Seite (MV)		Zeitpunkt	Max. Temperatur kalte Seite (MR)		Zeitpunkt	Max. Temperatur differenz		Zeitpunkt	Max. Durchfluss		Zeitpunkt	Max. Leistung		Zeitpunkt
01.10.2023 00:00	964,820	MWh	17753,40	m^3	103,9	°C	01.09.2023 05:07	73,1	°C	12.09.2023 05:40	63,8	K	02.09.2023 22:16	1,080	m^3/h	20.09.2023 2	39,5	kW	13.09.2023 20:00
01.09.2023 00:00	956,427	MWh	17526,48	m^3	102,6	°C	31.08.2023 07:52	75,0	°C	10.08.2023 10:48	62,0	K	26.08.2023 23:36	1,584	m^3/h	02.08.2023 0	72,8	kW	02.08.2023 08:00
01.08.2023 00:00	949,490	MWh	17351,59	m^3	100,5	°C	27.07.2023 12:55	100,1	°C	28.07.2023 12:25	57,5	K	03.07.2023 22:24	2,784	m^3/h	30.07.2023 1	56,5	kW	30.07.2023 05:00
01.07.2023 00:00	942,290	MWh	16893,06	m^3	102,3	°C	03.06.2023 08:28	72,5	°C	10.06.2023 01:42	61,0	K	23.06.2023 11:15	1,140	m^3/h	13.06.2023 0	41,7	kW	01.06.2023 20:00
01.06.2023 00:00	934,089	MWh	16689,63	m^3	109,2	°C	03.05.2023 07:07	75,0	°C	09.05.2023 19:50	63,3	K	03.05.2023 07:38	1,308	m^3/h	26.05.2023 1	52,0	kW	03.05.2023 07:00
01.05.2023 00:00	918,476	MWh	16313,44	m^3	111,9	°C	05.04.2023 06:40	76,5	°C	04.04.2023 19:00	64,2	K	03.04.2023 06:04	1,440	m^3/h	08.04.2023 0	79,3	kW	03.04.2023 07:00
01.04.2023 00:00	891,400	MWh	15811,92	m^3	115,1	°C	06.03.2023 12:00	73,0	°C	03.03.2023 19:48	71,0	K	06.03.2023 15:03	1,584	m^3/h	05.03.2023 1	95,0	kW	05.03.2023 16:00
01.03.2023 00:00	856,812	MWh	15207,57	m^3	115,8	°C	08.02.2023 08:53	75,4	°C	27.02.2023 20:50	67,0	K	08.02.2023 18:07	1,668	m^3/h	27.02.2023 0	107,5	kW	27.02.2023 08:00
01.02.2023 00:00	820,900	MWh	14610,55	m^3	114,3	°C	23.01.2023 08:00	78,9	°C	24.01.2023 14:35	68,3	K	22.01.2023 11:51	1,632	m^3/h	22.01.2023 1	97,0	kW	22.01.2023 17:00
01.01.2023 00:00	781,471	MWh	13945,82	m^3	119,4	°C	16.12.2022 10:31	76,7	°C	19.12.2022 08:58	73,2	K	18.12.2022 00:13	1,764	m^3/h	18.12.2022 1	120,6	kW	18.12.2022 11:00
01.12.2022 00:00	736,575	MWh	13225,30	m^3	114,2	°C	20.11.2022 05:47	74,7	°C	23.11.2022 19:49	66,3	K	24.11.2022 08:50	1,488	m^3/h	20.11.2022 1	90,0	kW	20.11.2022 18:00
01.11.2022 00:00	707,963	MWh	12720,82	m^3	107,8	°C	12.10.2022 07:54	72,3	°C	28.10.2022 17:07	60,7	K	12.10.2022 06:15	0,888	m^3/h	04.10.2022 0	46,7	kW	04.10.2022 07:00
01.10.2022 00:00	691,222	MWh	12372,53	m^3	105,7	°C	30.09.2022 10:00	73,1	°C	08.09.2022 20:07	56,4	K	28.09.2022 18:53	0,828	m^3/h	07.09.2022 0	40,9	kW	30.09.2022 20:00
01.09.2022 00:00	680,329	MWh	12115,28	m^3	94,9	°C	09.08.2022 05:29	72,4	°C	13.08.2022 04:19	57,6	K	28.08.2022 07:09	0,984	m^3/h	13.08.2022 0	41,5	kW	13.08.2022 05:00
01.08.2022 00:00	673,905	MWh	11938,80	m^3	99,7	°C	01.07.2022 09:36	72,8	°C	23.07.2022 04:03	67,8	K	01.07.2022 07:59	0,936	m^3/h	15.07.2022 0	39,7	kW	01.07.2022 09:00
01.07.2022 00:00	666,445	MWh	11739,03	m^3	104,7	°C	02.06.2022 06:22	74,0	°C	28.06.2022 06:19	63,4	K	13.06.2022 19:17	0,864	m^3/h	11.06.2022 0	42,7	kW	11.06.2022 01:00
01.06.2022 00:00	658,041	MWh	11553,30	m^3	107,1	°C	02.05.2022 12:15	75,3	°C	10.05.2022 22:32	62,4	K	25.05.2022 19:47	1,176	m^3/h	12.05.2022 2	53,4	kW	10.05.2022 23:00
01.05.2022 00:00	644,303	MWh	11257,11	m^3	117,0	°C	04.04.2022 06:39	72,6	°C	15.04.2022 07:10	70,3	K	02.04.2022 08:55	1,296	m^3/h	08.04.2022 0	79,6	kW	04.04.2022 07:00
01.04.2022 00:00	614,510	MWh	10744,82	m^3	115,6	°C	01.03.2022 09:57	75,9	°C	03.03.2022 07:34	68,8	K	06.03.2022 10:30	1,752	m^3/h	03.03.2022 0	108,8	kW	03.03.2022 08:00
01.03.2022 00:00	575,615	MWh	10100,44	m^3	113,8	°C	28.02.2022 11:00	77,5	°C	07.02.2022 07:39	68,1	K	24.02.2022 21:44	1,716	m^3/h	28.02.2022 0	105,2	kW	28.02.2022 08:00
01.02.2022 00:00	536,301	MWh	9460,26	m^3	115,4	°C	21.01.2022 08:21	77,8	°C	17.01.2022 06:20	69,8	K	18.01.2022 20:44	1,872	m^3/h	17.01.2022 0	108,8	kW	17.01.2022 07:00
01.01.2022 00:00	489,046	MWh	8708,77	m^3	117,7	°C	26.12.2021 17:17	78,7	°C	21.12.2021 08:01	70,9	K	25.12.2021 20:49	1,776	m^3/h	21.12.2021 0	113,3	kW	21.12.2021 08:00
01.12.2021 00:00	441,261	MWh	7959,34	m^3	116,4	°C	29.11.2021 18:42	76,3	°C	29.11.2021 08:04	68,9	K	12.11.2021 18:46	1,584	m^3/h	29.11.2021 1	99,9	kW	29.11.2021 08:00
01.11.2021 00:00	403,554	MWh	7331,80	m^3	112,8	°C	18.10.2021 07:37	77,3	°C	03.10.2021 19:57	65,3	K	18.10.2021 07:04	1,620	m^3/h	26.10.2021 2	71,3	kW	25.10.2021 07:00
01.10.2021 00:00	376,854	MWh	6825,04	m^3	108,4	°C	20.09.2021 11:01	74,0	°C	15.09.2021 05:20	61,4	K	30.09.2021 06:07	1,116	m^3/h	21.09.2021 0	46,5	kW	23.09.2021 18:00
01.09.2021 00:00	364,509	MWh	6550,74	m^3	106,1	°C	27.08.2021 16:32	73,3	°C	08.08.2021 18:03	59,6	K	16.08.2021 16:49	1,212	m^3/h	13.08.2021 0	46,6	kW	13.08.2021 04:00
01.08.2021 00:00	354,202	MWh	6293,42	m^3	106,4	°C	01.07.2021 20:16	74,3	°C	08.07.2021 04:08	57,3	K	02.07.2021 19:21	1,260	m^3/h	19.07.2021 0	49,4	kW	19.07.2021 06:00
01.07.2021 00:00	345,860	MWh	6072,84	m^3	105,2	°C	01.06.2021 06:35	74,7	°C	06.06.2021 04:30	60,7	K	01.06.2021 20:32	1,068	m^3/h	22.06.2021 0	51,8	kW	01.06.2021 21:00
01.06.2021 00:00	337,259	MWh	5860,50	m^3	109,2	°C	07.05.2021 08:23	74,0	°C	10.05.2021 22:36	61,2	K	03.05.2021 11:04	1,260	m^3/h	04.05.2021 0	69,2	kW	04.05.2021 08:00
01.05.2021 00:00	314,719	MWh	5400,99	m^3	115,5	°C	06.04.2021 08:26	73,6	°C	01.04.2021 16:49	69,8	K	06.04.2021 07:42	1,524	m^3/h	10.04.2021 0	89,0	kW	17.04.2021 09:00
01.04.2021 00:00	279,837	MWh	4799,44	m^3	115,9	°C	20.03.2021 09:51	75,7	°C	30.03.2021 17:07	69,0	K	19.03.2021 21:40	1,752	m^3/h	09.03.2021 0	107,1	kW	09.03.2021 07:00
01.03.2021 00:00	236,907	MWh	4071,74	m^3	121,7	°C	12.02.2021 08:10	81,0	°C	13.02.2021 10:36	78,1	K	07.02.2021 17:55	2,352	m^3/h	15.02.2021 1	144,2	kW	10.02.2021 10:00
01.02.2021 00:00	189,468	MWh	3325,31	m^3	117,5	°C	15.01.2021 09:45	79,9	°C	13.01.2021 09:33	71,4	K	18.01.2021 07:25	1,800	m^3/h	11.01.2021 0	115,9	kW	16.01.2021 10:00
01.01.2021 00:00	136,231	MWh	2483,83	m^3	116,3	°C	02.12.2020 15:42	77,5	°C	03.12.2020 06:05	73,2	K	06.12.2020 19:49	1,620	m^3/h	28.12.2020 1	103,8	kW	28.12.2020 11:00
01.12.2020 00:00	89,995	MWh	1747,97	m^3	114,1	°C	25.11.2020 10:19	76,3	°C	27.11.2020 19:44	66,2	K	26.11.2020 23:22	1,740	m^3/h	30.11.2020 0	104,0	kW	30.11.2020 09:00
01.11.2020 00:00	53,276	MWh	1112,00	m^3	110,9	°C	11.10.2020 21:42	75,0	°C	18.10.2020 09:41	62,4	K	14.10.2020 20:21	1,380	m^3/h	17.10.2020 1	71,7	kW	17.10.2020 10:00
01.10.2020 00:00	27,893	MWh	633,33	m^3	108,4	°C	29.09.2020 18:19	74,0	°C	17.09.2020 02:08	66,4	K	03.09.2020 18:10	1,044	m^3/h	18.09.2020 1	52,4	kW	18.09.2020 19:00

Data table of the readout of the heat meter (billing-relevant meter) of a district heating station; the maximum values of the return temperature (hourly values) are marked with a time stamp. Source: own illustration co2online/senercon

Figure 23, Figure 24 and Figure 25 show how inefficient operation of a district heating system can already be recognised from the maximum return temperatures stored in the meter. The projected return temperature of the system in the design case (coldest day) is 55 °C (Figure 25, rating plate, temperature spread 70/55). In the standard case, the maximum return temperature is exceeded by 20 K over the year. With reference to Figure 24 the average return temperature should therefore be 15 K above the maximum return temperature projected and required by the supplier in the technical connection conditions.

Even in the summer months, when the return temperature may sometimes be 57 °C as a result of the connected hot water preparation if hot water is not drawn off due to the requirement for legionella prophylaxis, the return temperature is significantly higher.

Figure 25: Return flow temperature analysis with heat meter storage data: before optimisation



Heating design 70 °C/55 °C of a district heating transfer station according to the type plate (top image) and maximum values (hourly values) return temperature, which are above 70 °C on average (bottom image). Source: own illustration co2online/senercon

This was caused by the control being set too high to counteract an undersupply due to leakage. The ongoing effects on the efficiency of the heating system are increased distribution losses due to higher system temperatures. At the same time, a higher connected load is required, as significantly less output is provided for the same amount of water.

The consequences for the district heating network are insufficient cooling of the network. This reduces the efficiency of district heating generation and distribution (higher pump power requirement). More capacity is tied up than necessary, which could otherwise be made available to new customers.

The example illustrates that it is possible to assess the efficiency of heating systems by analysing the system temperatures. The analysis logic can be transferred to other parameters such as operating hours or switch-on times for hybrid systems or pressures for ventilation systems. Possible applications to heating technologies are shown in Appendix 1.

The temperature analysis allows qualitative, but less quantitative statements and is limited to the following applications:

- Evaluation of systems as part of temporary efficiency checks (e.g. during inspections or on-site investigations or as part of remote maintenance); this includes checking control settings and, for example, detecting "external interference" (e.g. adjusted controls by unauthorised persons with access to the boiler room)
- Further investigation of causes when efficiency deficiencies are identified; access to historical data records is helpful here if these are available, as shown in the heat meter example above.

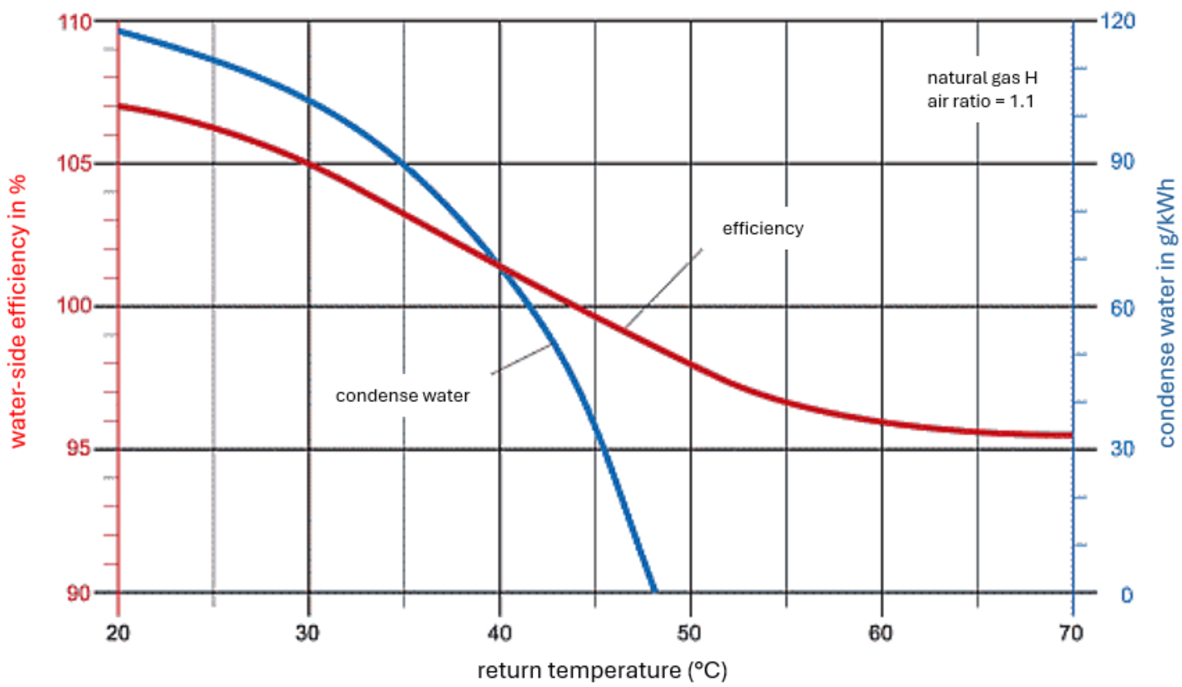
Section 4.3.1 makes it clear that quantitative statements on efficiency can also be made if system temperature data is linked to an AI. The KINERGY project[37] , among others, is currently testing whether automated fault detection and optimisation recommendations for heating systems and their downstream peripherals, which go far beyond the detection of incorrect heating curve settings, are also possible on the basis of measured system temperatures and AI alone. Results are expected at the end of 2024.

4.6 Checking the calorific value effect

The calorific value effect of condensing boilers can be estimated by analysing the return temperatures or measuring the amount of condensate (cf. Figure 26). Physically speaking, one kWh of natural gas, for example, has up to 10 % more energy content if the flue gases condense in the burner chamber or a downstream heat exchanger and this condensation heat benefits the downstream heating system. In addition, condensing boilers work with significantly lower flue gas temperatures (approx. 60 °C) than low-temperature boilers (approx. 160 °C). The condensation effect has a significantly greater influence on the additional energy yield than the reduction in the return temperature due to the change in aggregate state from gaseous to liquid.

[37] see "KINERGY" research project: Starting signal for more efficient heating systems in Germany **An invalid source is indicated.**

Figure 26: Dependence of condensate quantity and efficiency on return temperature



Dependence of the heating system efficiency and the amount of condensate on the return temperature.
Source: Ruhrgas (Beitzke, 2018)

Figure 26 clearly shows that condensation only occurs in the boiler if the return temperature is well below 50 °C. Condensation physically begins at 57 °C. It can also be seen that the efficiency or utilisation factor can be improved by around 10 percentage points (calorific value reference) due to the calorific value effect.

Analysing the return temperatures or measuring the amount of condensate therefore allows conclusions to be drawn about the calorific value effect and thus indirectly about the annual efficiency.

In the project "Aktion Brennwertcheck", the German consumer advice centre (VZBV, 2011) investigated from the mid-2000s the condensing effect for around 1,000 boilers and found that the potential of the higher efficiency of condensing boilers was largely not being utilised.

In general, it is possible,

- analysing the return temperatures or measuring the amount of condensate to make qualitative statements about the use of the condensing effect. There are likely to be limitations to the accuracy of condensate quantity measurement, e.g. due to evaporation. Application to oil and solid fuel boilers is likely to be even less accurate due to the smaller amount of condensate produced.
- Since statements on the efficiency or utilisation factor can only be made indirectly or proportionately, there is no added value, especially of the condensate quantity measurement method, compared to the direct determination of the efficiency factor via heat quantities, as described in section 4.1. Furthermore, the approval of this method would stand in the way of the desired standardisation.

4.7 Conclusion

In the previous sections, input-output methods for the assessment of boilers based on the annual utilisation factor and heat pumps based on the annual performance factor were considered. It was shown how the assessed parameters relate to the product efficiency parameters specified in the EU Ecodesign Regulation, namely the seasonal space heating coefficient η_s (Section 4.1.4) and the coefficient of performance SCOP (section 4.2.5).

The starting point for determining measured efficiencies are input and output values. In the sections 4.3.1 to 4.3.3 three estimation methods for heat pumps are described, which determine these values using auxiliary variables and in some cases utilising AI instead of meters.

VDI Guideline 4650, Sheet 1 can be used to obtain comparative values for the efficiency of heat pumps (expected annual performance factor) (Section 4.2.3), even if these may be too optimistic in some cases. The basis for this is the standardised performance figures determined in accordance with DIN EN 14825, taking into account individual building location, heating system and usage parameters. Alternatively, a regression method (section 4.2.4) was tested that enables the determination of an expected annual coefficient of performance based on the data set used in VDI 4650.

Furthermore, the method *energy analysis from consumption* (section 4.4) was described, which analyses the relationship between the average output resulting from consumption and the outside temperature. Significant changes in this correlation can indicate possible deteriorations in efficiency. However, this method cannot diagnose a poor efficiency of a system from the outset.

Selected parameters from sensors, which are collected anyway for appliance control or can be retrofitted with little effort, also allow efficiency statements to be made and help to analyse deviations between planning and reality if these are available over time. This was illustrated using the example of return temperatures available in heat meters (section 4.5).

In addition, the procedure for evaluating the condensing effect was presented, in which the amount of condensate produced can be used to make statements about condensing utilisation and thus the efficiency of condensing boilers (section 4.6).

The applicability of the procedures described in the EU context may be limited by the fact that some procedures are only described in non-binding or national supplements to standards or directives.

All consumption and heat quantity-based methods are characterised by the fact that the peripherals (in particular the heating system design, and in the case of the energy analysis also the thermal condition of the building) and the usage are included in the statements. As a result, the analysis is not based purely on appliance efficiency, but always on system efficiency.

5 Methodology for efficiency displays in heat generators

In the following chapter, the information presented in chapter 4 are first evaluated and checked for suitability with different space heat generators. Subsequently, in agreement with the client, the methodology was focussed on the efficiency monitoring of electric heat pumps and boilers for liquid and gaseous fuels.

5.1 Method for measuring efficiency by heat generator

The general applicability of the methods described in section 4 for a wide range of heating technologies and appliances and their combinations was summarised (see section A Appendix 1), presenting for each technology an

- Assessment of the future significance of the respective technology
- Efficiency criteria that need to be monitored
- Measurement effort
- Possible alternative methods (instead of heat quantity measurement) that could be used.

It was not possible to analyse all heating technologies in depth within the scope of this project, which is why the focus below is on a methodology for monitoring the efficiency of electric heat pumps and boilers.

5.2 Methodology for heat pumps and boilers

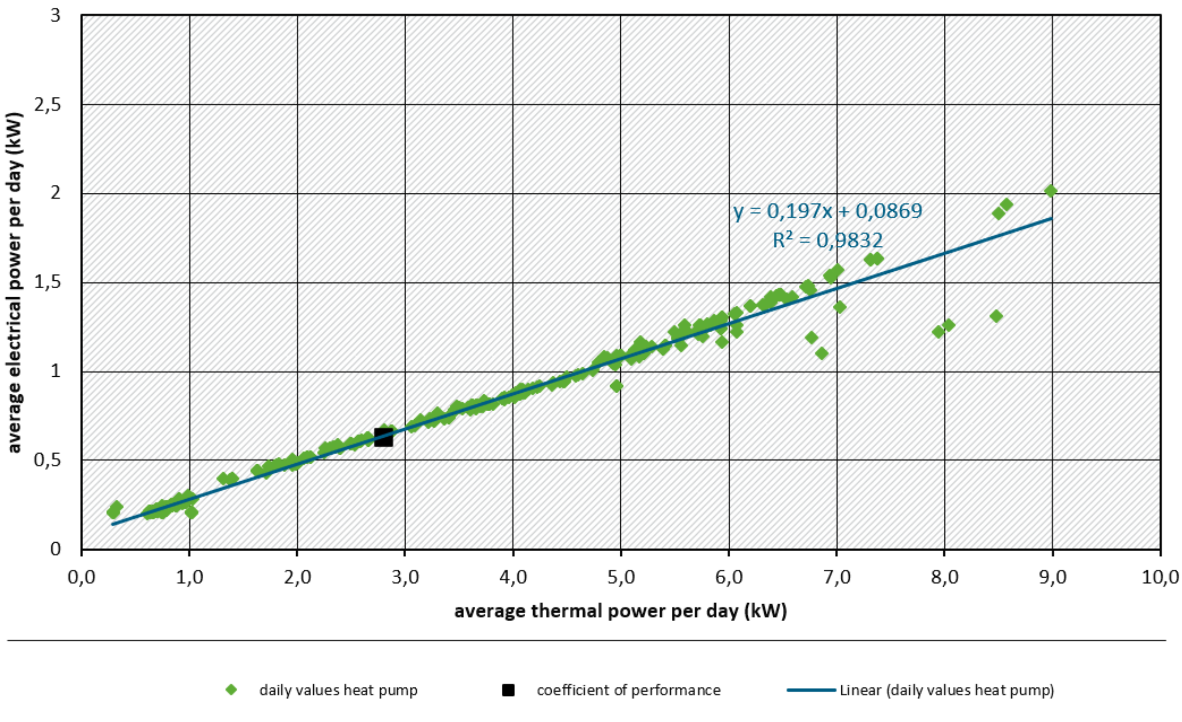
For electric heat pumps, a methodology for (intra-year) benchmarking was developed and prototypically tested on three heating systems B Appendix 2 (see use cases in Appendix B.1 to B.3). The methodology is based on selected methods (see section 4). It is also applicable to heating systems fuelled by gaseous and liquid fuels (see use case Annex 0).

The methods were further adapted in the context of their application to the measurement series of the four selected example buildings. The central elements of the methodology are described below and illustrated with exemplary analyses from the use cases.

5.2.1 Efficiency analysis

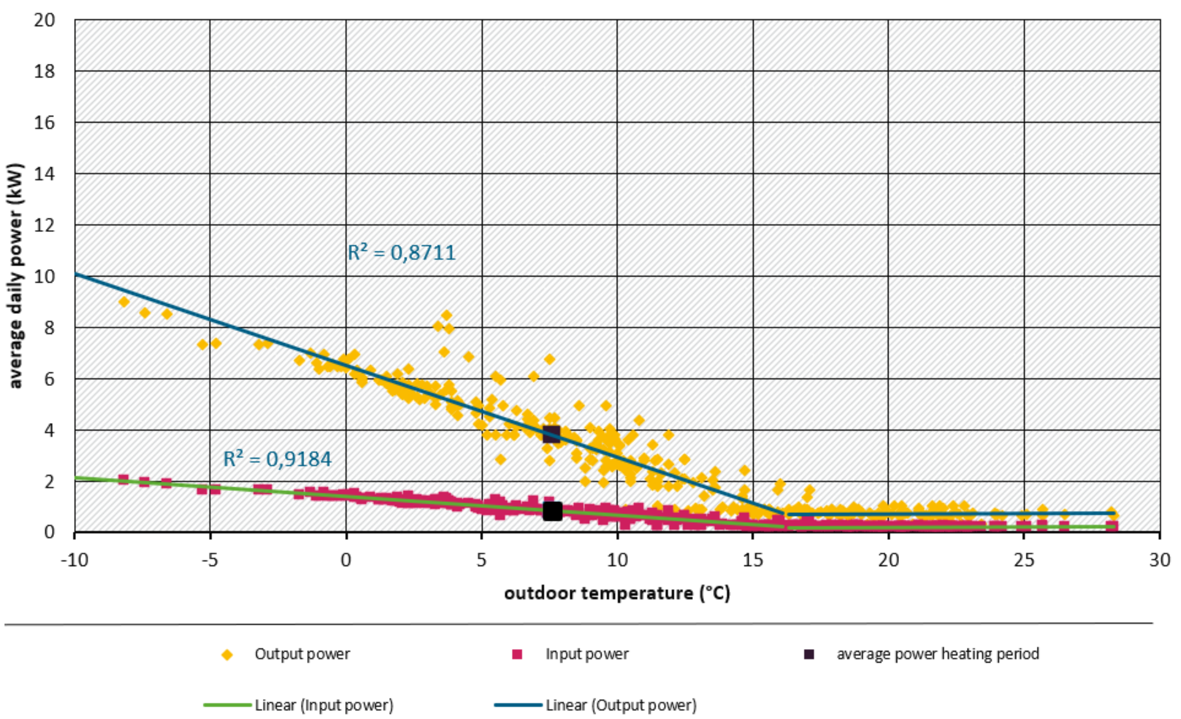
- The energy analysis (see section 4.4) is the starting point for determining the boiler signature (see section 4.1.3), which can also be applied to heat pumps (see section 4.2.6). The boiler signature represents the ratio of input to output as a straight line in the X/Y diagram (Figure 27). The annual coefficient of performance (heat pumps) or annual utilisation factor (boilers) is calculated at the point of average output. The average output in the heating period can be determined based on the linear relationship from the energy analysis at average outdoor temperature (Figure 28).

Figure 27: Boiler signature (use case 1)



Boiler signature with data point for average output in the heating period, determined from energy analysis in Figure 28. To determine the annual performance factor for space heating, output and input must be divided at the marked data point. Source: own illustration co2online/senercon.

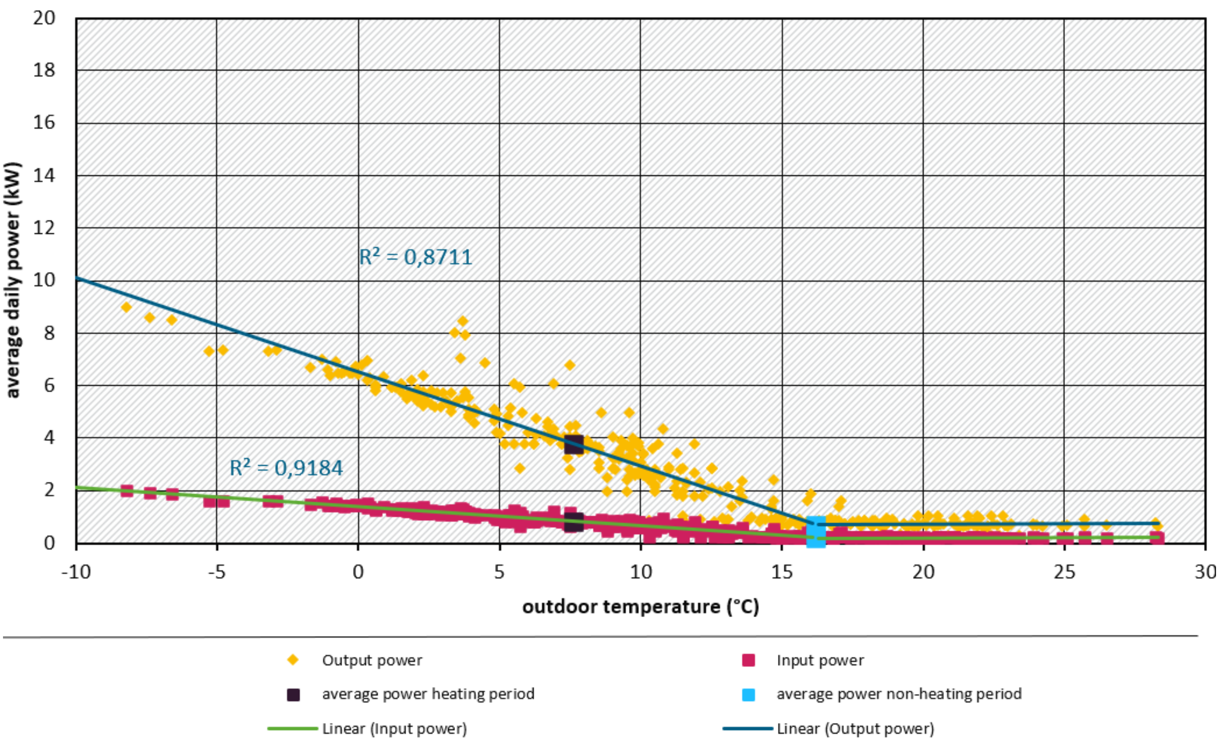
Figure 28: Energy analysis for determining the annual COP (use case 1)



Energy analysis with data point for determining the annual COP for space heating; average outdoor temperature during the heating period in the reporting period 7.7 °C. Source: own illustration co2online/senercon.

- From VDI 4650 (section 4.2.3), an annual coefficient of performance for space heating and domestic hot water preparation should be calculated using the proportional consumption quantities and the respective partial coefficients of performance.
- In DIN EN 14825 (section 4.2.5), the annual coefficient of performance for space heating ($SCOP_{on}$) is determined using the sums of predicted heat and electricity consumption for periods of the same outdoor temperature.
- From the information presented in the previous two paragraphs, it can be deduced (and has been verified by calculation) that the annual performance factor for space heating and hot water preparation is calculated from the proportional annual performance factors for space heating at the point of average output in the heating period and the proportional annual performance factor for output in the non-heating period (base output, corresponds to consumption for hot water preparation) if these are weighted by the proportional hours in the heating or non-heating period. The proportional hours are to be determined from the climate data set of the respective location, taking into account the heating limit temperature. The heating limit temperature resulting from the graphical representation is used to differentiate between the heating and non-heating periods[38] (intersection of the outside temperature-dependent straight line with the base output).
- The boiler signature can be omitted if the input and output are entered directly in the energy analysis and the respective proportional annual performance factors for space heating and domestic hot water preparation are determined at these points (Figure 29).

Figure 29: Energy analysis (use case 1)



Energy analysis with data points for determining the annual performance factor for space heating and domestic hot water heating, heating limit temperature 17 °C. The annual performance factor is determined from the annual performance

[38] This neglects the fact that there are days in the transition period that are partly in the heating and partly in the non-heating period.

factors for space heating and hot water heating using the proportionate hours in the heating and non-heating periods. Source: own illustration co2online/senercon.

When compared with the summarised values for the annual performance factor, it was found that the values determined via the energy analysis can in principle be regarded as consistent with the summarised values (Table 12), even if the deviation is greater for other applications than for application 3.

Table 12: Results Comparison of operating figures (use case 3)

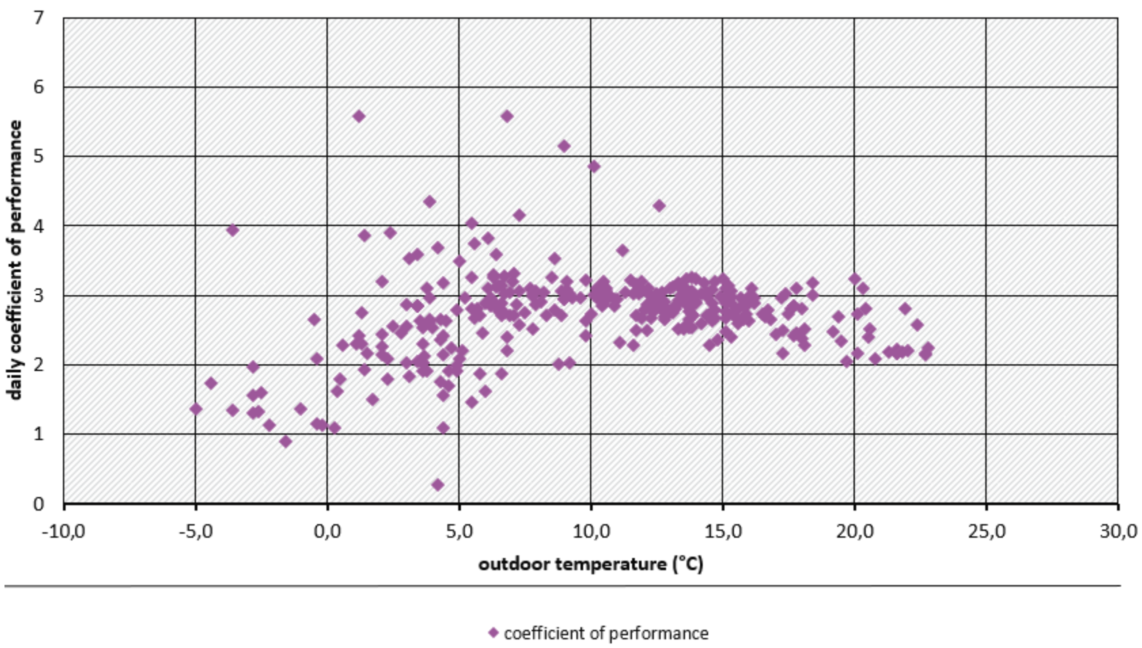
Description of the	Annual Performance Factor (APF) (from totals, measured value)	APF from Energy Analysis (outside temp. 10.5 °C) (measured value)	APF boiler signature (output/input 2.20/0.89 kW) (measured value)	Expected APF VDI 4650 (comparative value)	Expected APF regression (comparative value)	COP at 2 / 7 °C (design 55/50) (comparative value)
Value	2,56	2,60	2,47	3,61	4,60	3,22 / 4,61
Absolute deviation	-	-0,04	0,09	1,05	2,04	0,66 / 2,05
Deviation %		0,0	-3	41	80	26 / 80

5.2.2 Consideration of outdoor temperature, rolling representation of efficiency

For a better understanding of the outdoor temperature dependence of the annual performance factor (Section 4.2.2), especially for air source heat pumps, the daily coefficient of performance is shown above the outdoor temperature (cf. Figure 30).

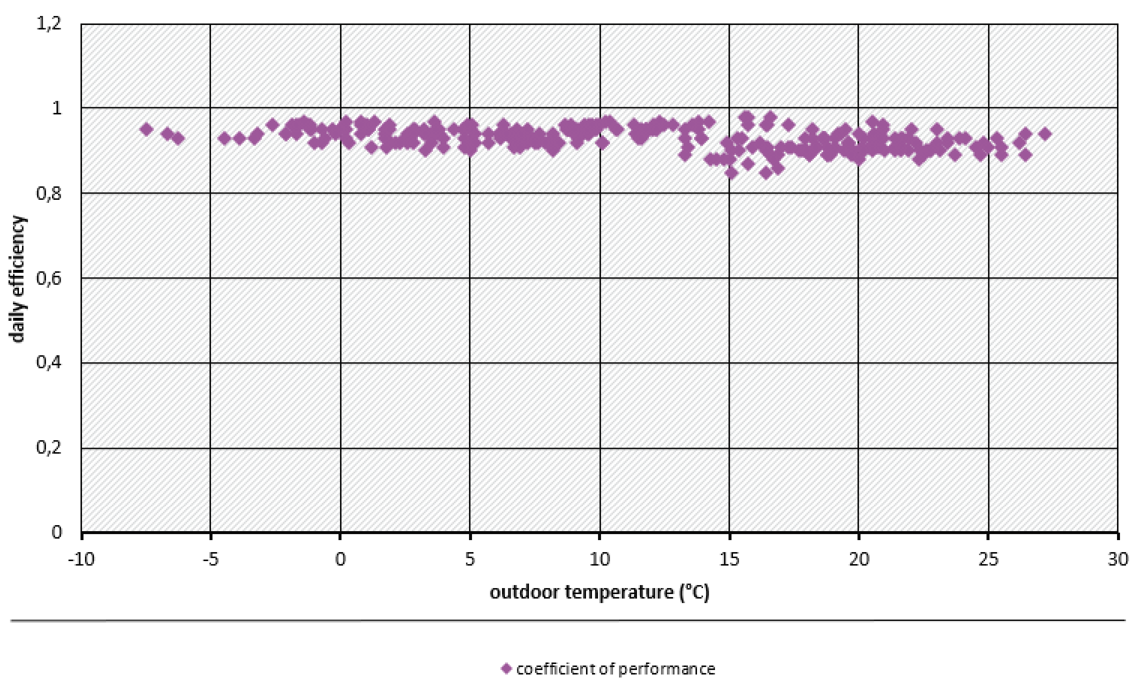
Off Figure 30 it can be deduced that annual coefficients of performance change, particularly for air source heat pumps, when the average outdoor temperatures change during the heating period. Annual performance factors are therefore dependent on the climate. This dependency does not exist for the analysed boiler (cf. Figure 31). The outdoor temperature dependency is also much less pronounced for the brine heat pump (see Appendix B.1).

Figure 30: Daily energy figures via outdoor temperature (use case 3)



The data set for an air source heat pump installed in 2014 is shown: It is easy to see how the daily coefficient of performance drops at outside temperatures below freezing. The effect can also be recognised at outside temperatures > 15 °C. This is probably due to operation in hot water only mode. The heat pump has to generate a high hot water temperature, which is at the expense of efficiency. Source: own illustration co2online/senercon.

Figure 31: Daily utilisation factor over outdoor temperature (use case 4)



The daily utilisation factor is not dependent on the outside temperature. The slight increase in the degree of utilisation at low outside temperatures is probably due to the higher power requirement and consequently lower cycling. Source: own illustration co2online/senercon.

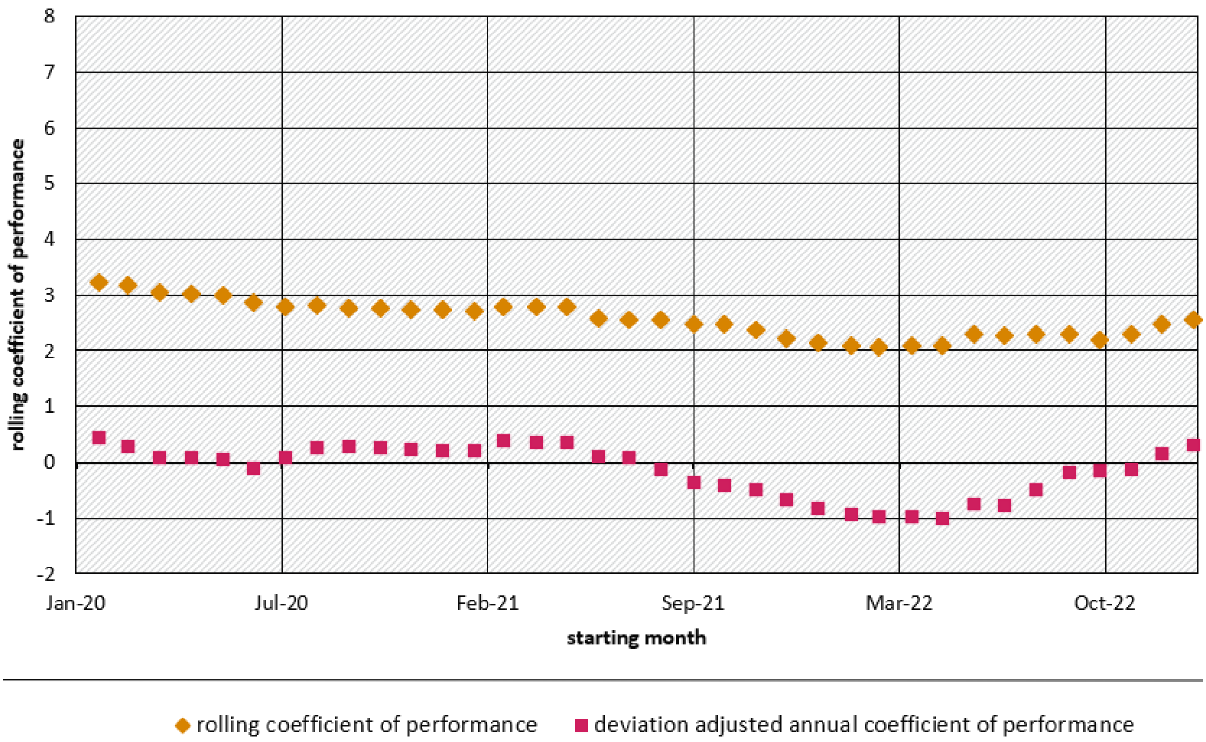
In order to compensate for climate dependency, it would be possible to adjust the annual performance factors. This could be done via the energy analysis by using average outdoor temperatures and average hourly figures for heating and non-heating periods at the site to calculate the adjusted annual performance factor. However, adjusted annual performance factors are likely to be difficult to understand, which is why they were not calculated or used.

A **rolling annual performance factor**, which considers 12-month periods and differs by one month between two data points, is easier to understand[39] (Figure 32). No major climatic differences are then to be expected between two data points.

5.2.3 Presentation of efficiency deterioration

Efficiency losses are easier to visualise if a baseline is defined for which an energy analysis is created. This energy analysis is then used as a reference to determine a target annual performance factor based on the actual outdoor temperatures and hours in the year under consideration. This target coefficient of performance is compared with the summarised annual coefficient of performance by subtracting the summarised annual coefficient of performance from the target annual coefficient of performance (red dotted line in Figure 32). This results in a value that fluctuates around the zero point. Climate changes are included in this illustration. Negative values indicate a deterioration in efficiency.

Figure 32: Rolling representation (use case 2)



Rolling representation of the annual performance factor (orange dotted line). The monthly figure represents the starting month for the respective 12-month period. The red dotted line represents the deviation from the target annual performance factor. Negative values represent a deterioration in efficiency. In the case shown, there was an efficiency problem with the heat pump that was recognised and rectified (start: start month August 21, end: start month September 22). Source: own illustration co2online/senercon.

[39] Example: Data point 1: Period 01.01.2022-31.12.2022, data point 2: 01.02.2022-31.01.2023.

5.2.4 Determination of efficiency during the year

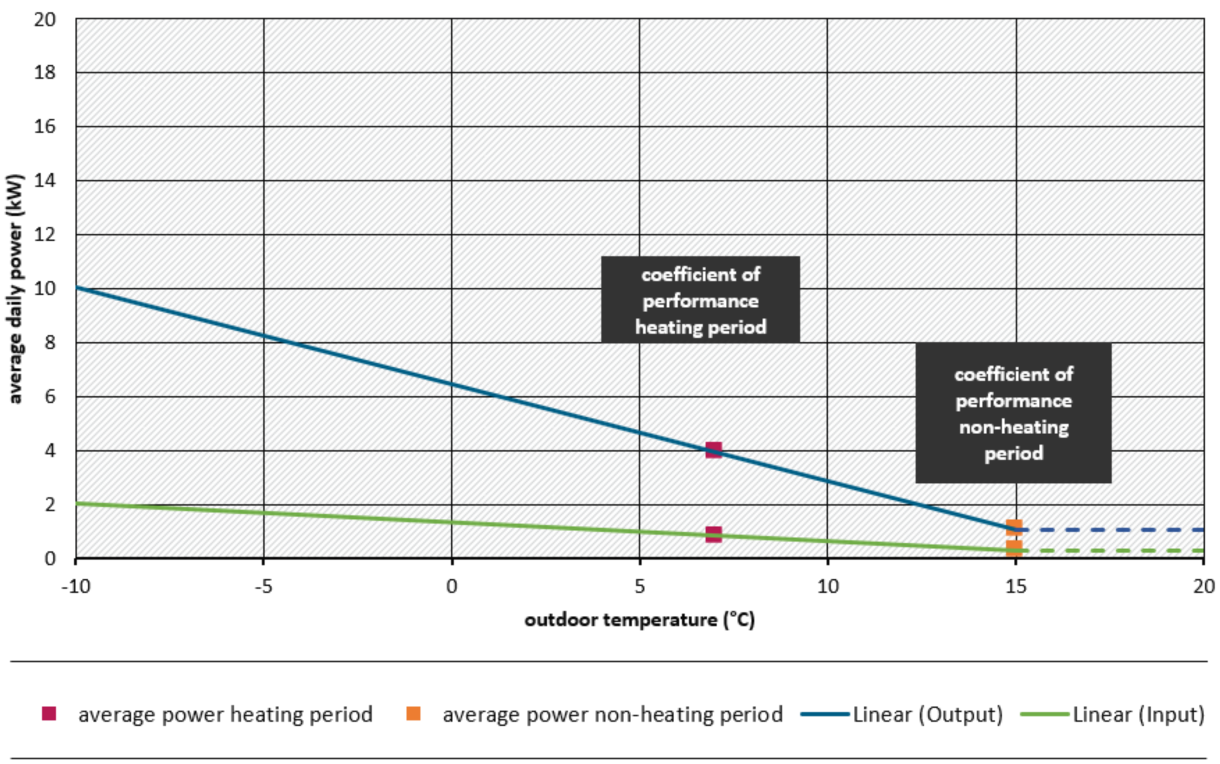
Based on a linear relationship between outdoor temperature and output in the energy analysis, the following procedure was derived to determine the annual performance factor during the year (after the installation of a new heating system, if data for a whole year is not yet available) (Figure 33):

According to section 4.4 it is possible to create an energy analysis within a few weeks during the heating period when using data with a resolution of daily values.

The power values of input and output for the base power can be determined from the approach of a typical building heating limit temperature (e.g. 15 °C).

The average outdoor temperature of the location during the heating period and the average number of hours of heating and non-heating periods (depending on the heating limit temperature) can be used to calculate the annual performance factor from the determined annual performance factors for space heating and hot water.

Figure 33: Averaged operating points for determining the annual performance factor of a heat pump during the year



Regression analysis based on daily values of input and output during the year and the corresponding outdoor temperatures, determination of the average output at average outdoor temperature during the heating period, determination of the average output for the non-heating period from the values at the heating limit temperature. Source: own illustration co2online/senercon.

5.2.5 Evaluation of the methodology

The following procedure was used to evaluate the annual performance figures determined in summary or via the energy analysis:

- By using the annual performance factor calculator of BWP (section 4.2.3), the expected annual performance factor was determined in accordance with VDI 4560.
- At the same time, the regression method described in section 4.2.4 was used to determine the expected annual performance factor.
- All values were compared with each other (Table 12). In addition, the coefficients of performance (COP) from the data sheet were compared at 2 and 7 °C outside temperature
- Forecasting methods based on COP values from the data sheets, heating circuit and hot water temperatures and proportional consumption quantities for space heating and hot water in accordance with VDI 4650 or using the regression method are a possible approach for determining "expected coefficients of performance" for an initial classification of the efficiency of heat pumps. [40]
- However, no plausible comparative values could be determined for the three heat pumps analysed as part of the method application. Neither the method according to VDI 4650 nor the regression according to section 4.2.4 provided sufficiently accurate results for the "expected coefficient of performance". Both are significantly higher than the values actually measured. It remains the task of subsequent investigations to improve the methods by including larger samples of actually measured annual performance factors so that they provide more suitable comparative values.
- A direct comparison of the annual performance factors with the COP values from the data sheets shows that the actual annual figures lie between the COP values at 2 °C and 7 °C.
- An improvement of VDI 4650 seems possible if, as described in section 4.3.3 the defrosting processes and the compressor cycle are taken into account when determining the standard values for the COP or in the procedure for determining the annual performance factors from the standard values.

5.3 Summarising the methodology

- The **annual coefficient of performance**[41] **and annual utilisation factor** are used to **assess efficiency.** If the energy analysis method is used to calculate these parameters, there is good agreement with the annual values. For this purpose, the pairs of values at average outside temperature in the heating period and average outside temperature in the non-heating period are to be used and the individual heating limit temperatures of the building are to be taken into account. The values are weighted using the proportional number of hours.
- As the average outdoor temperature fluctuates from year to year during the heating period, there are climate-related changes in efficiency. A **climate adjustment** can be made by

[40] If they provide plausible values, individual comparative values are more meaningful than mean values from field tests, such as those from the WPSmart project (Günther, et al., 2020)

[41] The measured variables for input and output include all operating modes of the heat pump (standby, heating mode, possibly with heating element activation, hot water mode).

comparing the efficiencies determined via the energy analysis at actual and standard outdoor temperatures.

- A two-stage procedure is proposed for a **simple efficiency assessment** (Figure 33). Stage 1 comprises the presentation of a summarised measured efficiency as a **rolling annual performance factor** over time. As the periods between the data points only differ by one month, no major climate-related fluctuations are to be expected between two data points. Larger jumps or fluctuations can be recognised as a change in efficiency.

- For stage 2 of the efficiency assessment, a baseline period of one year must be defined for which an energy analysis is prepared. The difference between the summarised efficiency measured for the period and the efficiency determined via the energy analysis (taking into account the respective climate of the period) results in a **zero deviation**. Negative values indicate a deterioration in efficiency. The influence of the climate has already been factored out in this illustration.

- For the **evaluation of efficiency during the year** (before the end of a year after installation), an estimated annual performance factor can be determined after a few weeks of heating operation during the core heating period. The basic procedure is shown in Figure 33. For this purpose, an expected heating limit temperature (15 °C in the example) must be specified. A determination during the year is only possible on the basis of data from the heating period. Data from the non-heating period cannot be used to determine the efficiency during the heating period. This data can only be used to refine the annual performance factor for hot water supply.

- For **the initial classification of the efficiency of individual heat pump solutions**, "expected annual figures" can be used, which convert standard values from the device data sheet with the help of influencing factors (e.g. source medium, heating system design, hot water volume or number of occupants, hot water temperature, degree day of the location) to practical comparative values for annual performance figures. In the project, such comparative values were determined both on the basis of VDI 4650 and by means of linear regression of a data sample. The EU-wide applicability of such procedures must be discussed. Individual comparative values are more meaningful than mean values from field tests. However, the methods still need to be refined, as only in one of the cases analysed was a sufficiently good agreement between the comparative value and the practical value established.

- For **boilers**, "**expected annual utilisation rates**" can very probably be specified directly on the basis of the technologies (e.g. condensing boilers, low-temperature boilers and according to the gaseous, liquid or solid fuels used). Orientation values for expected annual utilisation rates could be obtained by applying a discount to the seasonal space heating energy efficiency ($\eta_{s,on}$).

6 Recommendations and outlook

The planned specifications for self-monitoring of heating appliances based on the current draft document for the amendment of Ecodesign Regulation No. 813/2013 (DG ENER, 2023) provide a good basis for starting to monitor the efficiency of heating systems. It specifies the monitoring of energy input and output, energy efficiency (heat output/energy input), number of switching cycles and, in the case of combined appliances, information on whether an appliance is used to generate space heating or hot water.

As the requirements of the draft regulation were formulated relatively openly with regard to efficiency, there is room for manoeuvre when it comes to implementation by manufacturers.

In general, the draft lacks specifications for the interpretation and evaluation of efficiency. The figures published there for the best technologies available on the market are not sufficient, especially as the best technology is not likely to be installed everywhere and the technology installed must be assessed.

This study contributes to closing this gap for the important technologies of heat pumps and boilers heated with liquid or gaseous fuels.

6.1 Ecodesign recommendations

The study creates a basis for discussion for the concretisation of the requirements of the future EU Ecodesign Directive for heating appliances. This concretisation could be made available as part of a non-binding EU guideline.

The focus of the concretisation is on the procedure for calculating and evaluating the presentation of energy efficiency (heat output/energy input) for heat pumps and boilers heated with liquid or gas fuels required as part of self-monitoring.

- The parameters annual coefficient of performance and annual utilisation factor are suitable as efficiency criteria for the above heating technologies.
- When assessing efficiency, a distinction must be made between the start-up phase (first year of operation) and subsequent operation.
- In the start-up phase, it is possible to generate the efficiencies during the year on the basis of the energy analysis from consumption after a few weeks in the heating period. Furthermore, the generation of an individual comparative value is possible for the efficiency on the basis of standard values and influencing factors (e.g. temperature levels). In Germany, these comparative values can also be determined with the help of VDI 4650.
- In subsequent operation, a rolling analysis of the efficiency development alone or additionally taking into account the climate and on the basis of a baseline period is possible. In the second case, it makes sense to visualise efficiency as the difference between the measured value and the expected value. If this difference is negative, there is a deterioration in efficiency.
- A brief review showed that consumption-based methods, predominantly based on the method energy analysis from consumption, are suitable for making efficiency statements for most appliance groups or that these can be presented as a kind of "degree of utilisation" (fulfilment of the efficiency criterion).

The procedures for determining individual comparative values must be reviewed and their accuracy improved.

- The increased market penetration of heat pump systems for space heating will generally increase the demand for comparative values for efficiency assessment. In Germany, for example, § 60a of the GEG requires new heat pumps in buildings with at least 6 flats to be tested after two years of operation. Within this framework, a metrological inspection and assessment of the annual performance factor is specified.
- A method based on VDI 4650 is generally suitable for generating individualised comparative values. However, the results according to VDI 4650 were too positive in three of the applications analysed. The method should therefore be optimised.
- Alternatively, it is possible to generate comparative values for annual performance factors using field data by means of a regression analysis of the influencing factors.
- As a further alternative for determining comparative values, it would be possible for heat pumps to store standardised values for the seasonal coefficient of performance (SCOP) in the appliances.
- As the efficiency of boilers is significantly less dependent on the outside temperature than that of heat pumps, the seasonal space heating energy efficiency ($\eta_{s,on}$) can be used as a comparative value.
- If standard values are stored, it may be useful to define discount factors (not analysed) in order to obtain practical comparative values.
- A data resolution of daily values is sufficient for the efficiency assessment. In the authors' opinion, the resolution of 15-minute values proposed in the draft version of the amendment to (EU) No. 813/2013 is too fine-grained for a pure efficiency assessment. Daily or possibly weekly values are sufficient for this purpose. For the purposes of fault diagnosis, much higher data resolutions would be required for shorter periods (minute values).
- The draft Ecodesign Regulation requires a differentiation between space heating and hot water when storing input and output data. In the use cases analysed in this study, the consumption data was not available in this differentiation, which is why the authors carried out a statistical breakdown here. This statistical breakdown can be dispensed with if the differentiated measurement data is available. The accuracy is thus even higher.

6.2 Recommendations beyond Ecodesign (DE)

It makes sense to improve the requirements for efficiency displays applicable in Germany. Efficiency indicators are a prerequisite for heat pump subsidies. The detailed requirements are explained in the BAFA's technical FAQ on the BEG. Section 60a GEG requires the metrological evaluation of performance figures as part of the testing and optimisation of heat pumps in buildings with at least 6 flats two years after their installation.

- An efficiency indicator is mandatory in the funding guidelines for the BEG individual measures program. In the BAFA FAQs, which were subsequently supplemented, the efficiency indicator is interpreted as a consumption indicator, according to which a non-climate-adjusted comparison of the consumption of different periods is sufficient. An update of the technical FAQ on the BEG to the efficiency assessment method proposed here using annual performance figures or annual utilisation rates is advisable.

- The procedure for testing and optimising heat pumps in accordance with § 60a GEG can be significantly simplified if the annual coefficient of performance is determined using the efficiency display. The procedure in accordance with VDI 4650 can also be integrated into the heat pump controls. This would allow a starting value for an "expected annual performance factor" to be determined during the installation of heat pump systems and made available to the user. Alternatively, this figure can be determined using the annual performance factor calculator of the German Heat Pump Association and stored there by the installer during commissioning.
- The method according to VDI 4650 should be improved by including the losses due to defrosting and cycling (see section 4.3.3).

6.3 Outlook

- In terms of appliances, the study focussed on heat pump systems and boilers. The application to hybrid systems was not considered. Here it is necessary to discuss and test whether cross-appliance efficiencies, as partly determined by the standards, should be aimed for, or whether an individual assessment of the individual heat generators is not more sensible.
- The question of the extent to which the estimation approach described in section 4.3.2 and which has been introduced widely on the market, is sufficiently accurate for determining heat quantities and thus assessing efficiency has to be further addressed. The prerequisite for a metrological comparison would be systems that generate and store the data required for calculating the equivalent value internally and that are also equipped with precise external electricity and heat meters. It seems possible to clarify this issue as part of the test bench measurements for appliance approval.
- The procedure described in section 4.3.1 for determining the heat output of air source heat pumps with the aid of AI makes it clear that such procedures could also be applied to other appliances, e.g. solid fuel boilers. The aim would be to generate statements on annual efficiency for this group of appliances based on estimated data and, if necessary, with the aid of the measured heat output when standardising efficiency statements. It might make sense to initiate or promote projects that develop such procedures.

7 List of references

BAFA. (2024). Bundesförderung für effiziente Gebäude - Liste der technischen FAQ - Einzelmaßnahmen; Version 6.0. Retrieved 07 30, 2024, from https://www.bafa.de/SharedDocs/Downloads/DE/Energie/beg_liste_technische_faq.pdf?__blob=publicationFile&v=6

Beitzke, D. (2018, 10 29). *Was bedeuten Brennwert und Heizwert?* Retrieved from Heizungs-Betrieb: https://www.heizungsbetrieb.de/de/brennwert.html

BMWi. (2019). Energieeffizienzstrategie 2050. Retrieved 07 30, 2024, from https://www.bmwk.de/Redaktion/DE/Publikationen/Energie/energieeffiezienzstrategie-2050.pdf?__blob=publicationFile&v=1

BMWi. (2021). Richtlinie für die Bundesförderung für effiziente Gebäude – Einzelmaßnahmen (BEG EM). *BAnz AT 18.10.2021 B2*. Bundesanzeiger. Retrieved 07 30, 2024, from https://www.bafa.de/SharedDocs/Downloads/DE/Energie/beg_richtline_beg_em_20231221_PDF.pdf?__blob=publicationFile&v=2

Brockmann, H. (2024). *Wärmepumpen Verbrauchsübersicht*. Retrieved 07 30, 2024, from https://www.waermepumpen-verbrauchsdatenbank.de/

Bundesanstalt für Materialforschung und -prüfung. (2023). *Test guideline for a load-based performance testing - Preliminary Draft.* Retrieved 08 14, 2024, from https://netzwerke.bam.de/Netzwerke/Content/DE/Downloads/Evpg/Heizen-Kuehlen-Lueften/bam%20test%20guideline%20-%20load-based%20testing%20of%20heat%20pumps%202023.pdf.html

BWP. (n.d.). *Webseite des BWP: JAZ-Rechner.* Retrieved 07 30, 2024, from https://www.waermepumpe.de/jazrechner/

BWP. (n.d.). Webseite des BWP: Klimakarte. Retrieved 07 30, 2024, from https://www.waermepumpe.de/normen-technik/klimakarte/

Deutscher Bundestag. (2023). Entwurf eines Gesetzes zur Änderung des Gebäudeenergiegesetzes, zur Änderung der Heizkostenverordnung und zur Änderung der Kehr- und Überprüfungsordnung. *Drucksache 20/6875*. Berlin. Retrieved 07 30, 2024, from https://dserver.bundestag.de/btd/20/068/2006875.pdf

Deutsches Institut für Normung. (1990). *Heizkessel; Prüf- und Kennzeichnungsverfahren für die Bestimmung des Wirkungsgrades und des Norm-Nutzungsgrades - Teil 8: Zusatznutzungsgrad (DIN 4702-8:1990-03, zurückgezogen).* Beuth Verlag.

Deutsches Institut für Normung. (2010). *Energetische Bewertung von Gebäuden - Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung - Beiblatt 1: Bedarfs-/Verbrauchsabgleich (DIN V 18599 Beiblatt 1:2010-01).* Beuth Verlag.

Deutsches Institut für Normung. (2011). *Prüfung und Leistungsbemessung von erdreichgekoppelten Direktübertragung-Wärmepumpen mit elektrisch angetriebenen Verdichtern zur Raumbeheizung und/oder -kühlung, Teil 1: Direktübertragung/Wasser-Wärmepumpe (DIN EN 15879).* Beuth Verlag.

Deutsches Institut für Normung. (2017). *Energetische Bewertung von Gebäuden - Verfahren zur Berechnung der Energieanforderungen und Nutzungsgrade der Anlagen - Teil 4-2:*

Wärmeerzeugung für die Raumheizung, Wärmepumpensysteme, Module M3-8-2, M8-8-2 (DIN EN 15316-4-2:2017-09). Beuth Verlag.

Deutsches Institut für Normung. (2020). *Verfahren zur Berechnung der Raumheizlast - Teil 1: Nationale Ergänzungen zur DIN EN 12831-1 (DIN/TS 12831-1:2020-04).* Beuth Verlag.

Deutsches Institut für Normung. (2023). *Heizkessel - Teil 5: Heizkessel für feste Brennstoffe, manuell und automatisch beschickte Feuerungen, Nennwärmeleistung bis 500 kW - Begriffe, Anforderungen, Prüfungen und Kennzeichnung (DIN EN 303-5:2023-07).* Beuth Verlag.

Deutsches Institut für Normung. (2023). *Heizkessel für gasförmige Brennstoffe - Teil 1: Allgemeine Anforderungen und Prüfungen (DIN EN 15502-1:2024-08).* Beuth Verlag.

Deutsches Institut für Normung. (2023). *Luftkonditionierer, Flüssigkeitskühlsätze und Wärmepumpen für die Raumbeheizung und -kühlung und Prozesskühler mit elektrisch angetriebenen Verdichtern - Teil 1: Begriffe (DIN EN 14511-1:2023-08).* Beuth Verlag.

Deutsches Institut für Normung. (2023). *Luftkonditionierer, Flüssigkeitskühlsätze und Wärmepumpen für die Raumheizung und -kühlung mit elektrisch angetriebenen Verdichtern – Teil 1: Begriffe (DIN EN 14511-1:2018).* Beuth Verlag.

Deutsches Institut für Normung. (2023). *Luftkonditionierer, Flüssigkeitskühlsätze und Wärmepumpen mit elektrisch angetriebenen Verdichtern zur Raumbeheizung und -kühlung, gewerblichen Kühlung und Prozesskühlung [...] (DIN EN 14825:2023-10).* Beuth Verlag.

Deutsches Institut für Normung. (2023). *Wärmepumpen mit elektrisch angetriebenen Verdichtern - Prüfungen, Leistungsbemessung und Anforderungen an die Kennzeichnung von Geräten zum Erwärmen von Brauchwarmwasser (DIN EN 16147:2023-12).* Beuth Verlag.

Energiezentrale Nord. (2021, 12 10). Der digitale Heizungskeller: Energie und Kosten sparen durch Heizungsmonitoring. Retrieved 07 30, 2024, from https://www.vodafone.de/immobilienwirtschaft/media/pdf/2021_Webinar_Heizungsmonitoring.pdf

Ericsson GmbH et al. (2024, 07 30). *Webseite des Forschungsvorhabens FINESCE*. Retrieved from www.finesce.eu

EU Kommission. (2023). *Working document supporting the discussion of the revision of regulation (EU) 813/2013 (unveröffentlicht).* Brüssel. Retrieved 08 14, 2024, from https://circabc.europa.eu/ui/group/418195ae-4919-45fa-a959-3b695c9aab28/library/afcc9b1a-8dea-4e36-b0b4-fd540cb75832/details

Fraunhofer IMS. (n.d.). Webseite des Fraunhofer IMS. *Nonintrusive Load Monitoring (NILM)*. Retrieved 07 30, 2024, from https://www.ims.fraunhofer.de/de/Geschaeftsfelder/Electronic-Assistance-Systems/Anwendungen/NILM.html

Günther, D., Wapler, J., Langner, R., Helmling, S., Miara, M., Fischer, D., . . . Wille-Hausmann, B. (2020). *Wärmepumpen in Bestandsgebäuden: Ergebnisse aus dem Forschungsprojekt "WPsmart im Bestand".* Fraunhofer ISE, Freiburg. Retrieved 07 30, 2024, from https://www.ise.fraunhofer.de/content/dam/ise/de/downloads/pdf/Forschungsprojekte/BMWi-03ET1272A-WPsmart_im_Bestand-Schlussbericht.pdf

Hermann, L., Hennig, P., Metzger, S., Köhrer, M., Pauser, L., Yanev, D., . . . Knauff, M. (2019). *Energiemonitoring und Informationsaustausch bei Geräten und Anlagen (Zählerstudie).*

Berlin: BfEE. Retrieved 07 30, 2024, from https://www.bfee-online.de/SharedDocs/Downloads/BfEE/DE/Effizienzpolitik/zaehlerstudie.html?nn=1444228

International Organization for Standardization. (2023). *Luft-Wasser-Wärmepumpen - Prüfung und Leistungsbemessung unter Teillastbedingungen und Berechnung der saisonalen Leistungszahl für Raumbeheizung (ISO 21978:2023).*

Jagnow, K., & Wolff, D. (2017). *Manuskript für Recknagel/Sprenger "Taschenbuch Heizungs- und Klimatechnik", Ausgabe2017.* Retrieved 07 30, 2024, from https://www.delta-q.de/wp-content/uploads/Recknagel-Energiekennwerte.pdf

Jagnow, K., Wolff, D., & Gebhardt, K. (2024). *Wärmepumpenplanung auf Basis von Verbrauchsdaten mit einfachen Exceltools:.* Manuskript für den Bauphysikkalender 2025 (unveröffentlicht).

JATL. (2024). *Webseite des Japan Air Conditioningand Refrigeration Testing Laboratory*. Retrieved from https://www.jatl.or.jp/en/

senercon GmbH . (2019, 12 15). *Forschungsprojekt KINERGY: Startschuss für mehr Efficzienz von Heizungsanlagen in Deutschland*. Retrieved from Webseite der senercon GmbH: https://www.senercon.de/forschungsprojekt-kinergy-startschuss-fuer-mehr-effizienz-von-heizungsanlagen-in-deutschland/

Sholahudin, G. e. (2020). Experimental implementation of artificial neural network for cost effective and non-intrusive performance estimation of air conditioning systems. *Applied Thermal Engineering, Volume 181*. doi:https://doi.org/10.1016/j.applthermaleng.2020.115985

Strobel Verlag. (n.d.). *IKZ: Sanitär | Heizung | Klima - Planung Bau und Betrieb.* Retrieved 07 30, 2024, from IKZ Praxis: Normnutzungsgrad: https://www.ikz.de/ikz-praxis-archiv/p0506/050607.php

Vaillant. (2023, 12 14). Product data sheet (in accordance with EU regulation no. 811/2013). Retrieved 07 30, 2024, from https://www.vaillant.de/documents/download/591104

Verein Deutscher Ingenieure. (2024). *Berechnung der Jahresarbeitszahl von Wärmepumpenanlagen - Elektrowärmepumpen zur Raumheizung und Trinkwassererwärmung (VDI 4650 Blatt 1:2024-02).* Beuth Verlag.

VZBV. (2011). *Die „Aktion Brennwertcheck" der Verbraucherzentralen.* Retrieved 07 30, 2024, from https://verbraucherzentrale-energieberatung.de/wp-content/uploads/2019/01/2019_aktionbrennwertcheck_langfassung.pdf

Wolff, D., & Jagnow, K. (2017). Energiekonzepte. In *Loseblattsammlung "Energie 2020".* Berlin: Beuth-Verlag.

A Appendix 1: Overview of applicability procedures for various heating technologies

The methods described in chapter 4 and their suitability for assessing the efficiency of various heating technologies and appliances and their combinations are summarised in Table 13. It begins with an assessment of the future significance of the technology. Next, the efficiency criteria that need to be monitored and whether these can be measured with reasonable effort are presented. The "Possible alternative methods" column shows whether alternative methods or different estimation methods (instead of heat quantity measurement) can be used.

A comprehensive systematisation is checked in the columns overwritten in **blue**. Firstly, whether it makes sense to additionally record and store system parameters, in particular flow and return temperatures. In the right-hand column, it is checked whether consumption-based methods could be used for the efficiency assessment across all technologies. In particular, whether the method energy analysis from consumption as described in section 4.4 is suitable. The last column examines whether compliance with a device-specific efficiency criterion can also be presented across all devices as a kind of "utilisation of efficiency". For example, compliance with a predicted annual performance factor (comparative value) of 3.5 for an air-to-water heat pump with a measured annual performance factor of 3.4 can also be presented as 97 % utilisation of efficiency. The achievement of predicted solar yields or compliance with renewable energy shares can also be shown as "utilisation of efficiency" (e.g. solar yield 4,800 kW, predicted yield 5,000 kWh, corresponds to 96 %).

Applying the methods to the appliances shows that - with some exceptions - a heat quantity-based efficiency analysis is possible for all appliances. Insofar as heat quantities are only considered over time to analyse efficiency, as currently specified in the German BEG, the energy analysis (from consumption) is the highest quality method due to its reference to outdoor temperature.

By including comparative values, efficiencies determined on the basis of different methods can be presented - with some reservations - as a kind of "utilisation of efficiency" across all appliances.

Table 13: Examination of standardised procedures and standardised presentation of efficiencies for heating technologies

No.	Heating technology	Assessment of future significance	Efficiency criterion	Measurement technically determinable	Possible alternative procedure	Analyse system parameters (supplementary/ partial)	Alternative methods for evaluating consumption/utilisation energy/yield	Efficiency can alternatively be presented as "utilisation of efficiency"
1	Boilers (liquid, gaseous fuels)	decreasing	Degree of utilisation	Yes	Condensate measurement, return temperature analysis	Flow and return and outside temperatures	yes (energy analysis)	Yes
2	Boiler (solid fuels, automatically loaded)	low	Degree of utilisation	Yes	Determination of fuel consumption via screw conveyor	Oxygen content, if applicable	yes (energy analysis)	Yes
3	Boiler (solid fuels, manually loaded)	low	Degree of utilisation	only useful heat	AI (to be developed)	Oxygen content, if applicable	If applicable, only useful energy (energy analysis)	if a replacement procedure is
4	Heat pump air / air	EU high	Work figure	Partial	AI (section 4.3.1) and selected temperatures	Flow and return and outside temperatures	If applicable, only electricity consumption (energy analysis)	Proceed on the basis of replacement
5	Heat pump air / water	high, strongly increasing	Work figure	Yes		Flow and return as well as external tempera	yes (energy analysis)	Yes
6	Heat pump with PV system[42]	high, strongly increasing	Labour figure, PV yield, Compliance[43] EE share	Yes			yes (energy analysis, PV yield)	Yes
7	Hybrid heat pump) Combination boiler / (air) heat pump	high, strongly increasing	Overall efficiency, Compliance with EE share	Yes	Evaluation of part efficiencies instead of overall efficiency	Flow and return as well as outside tempera tures, operating times of individual components	yes (energy analysis, proportionate consumption and heat quantities)	yes, all criteria

[42] Not covered by EU Ecodesign, but of high practical relevance, therefore listed here
[43] Comparison with the forecast share of PV yield

No.	Heating technology	Assessment of future significance	Efficiency criterion	Measurement technically determinable	Possible alternative procedure	Analyse system parameters (supplementary/ partial)	Alternative methods for evaluating consumption/utilisation energy/yield	Efficiency can alternatively be presented as "utilisation of efficiency"
8	Solar thermal systems	EU for hot water	Solar yield	Yes	Function control devices, if applicable	Temperatures collector tor circuit, storage tank, solar radiation if applicable	yes (solar yield)	Yes
9	Combination of boiler or heat pump with solar thermal system	DE low, increasingly replaced by combinations with PV	Overall efficiency Compliance with EE share	Yes	Evaluation of part efficiencies instead of overall efficiency	Sum no. 1 or 5,6 and 8	yes (energy analysis, solar yield)	Yes
10	Electric boiler	DE low, EU unclear	Consumption	Yes	-	Flow and return as well as outside temperatures	yes (consumption)	difficult, possibly as a percentage overrun
11	District heating	DE medium	Consumption, temperature spread	yes (available)	-	Flow and return temperatures available in the WMZ, outside temperatures	Yes	difficult, possibly as a percentage overrun
12	Hot water tank (gas/electric)	constant	Consumption	Yes			Yes	difficult, possibly as a percentage overrun

Heating technologies and their future significance, examination of the applicability of standardised procedures (heat quantities, system temperatures) or standardised identification of different efficiency criteria as degrees of utilisation

B Appendix 2: Detailed results of the method application

As part of the project, the prioritised methods were applied, verified and checked for plausibility using the measurement series from four buildings. The application of the methods focussed on heat pumps. In addition, the method described in section 5 for determining and evaluating efficiencies during the year is also applied to a boiler. Despite the increasing use of heat pumps, it was difficult to find suitable data providers that had data sets with a resolution of daily values. In particular, it was not possible to include a larger heat pump system in the project. The methods are applied to the following projects:

- Detached house in Kaiserslautern with brine-to-water heat pump
- Detached house near Karlsruhe with air-to-water heat pump
- Detached house in Denmark with air-to-water heat pump
- Gas-fired apartment block in Würzburg

B.1 Brine-to-water heat pump - detached house in Kaiserslautern

In the first case, a brine-to-water heat pump is evaluated in a detached house in Kaiserslautern. The building is equipped with underfloor heating. Selected building and system data are shown in Table 14 and Table 15. The heat pump dates back to 2009, when efficiency data was not yet mandatory. There is only an indication of the annual coefficient of performance estimated according to VDI 4650. Data from the period 01.01.2022 to 31.12.2022 was evaluated.

Table 14: Building and heating system data (use case 1)

Location postcode	Year of construction Building	Usable area m²	Number of users	Flow heating °C	Hot water temperature °C
67659	n.a.	280	4	38	55

Source: Owner

Table 15: Heat pump data (use case 1)

Year of construction Heat pump	Type of heat pump	Power kW	ηs	ηwh
2009	Brine water	12	-	-

Source: Owner, own research co2online/senercon

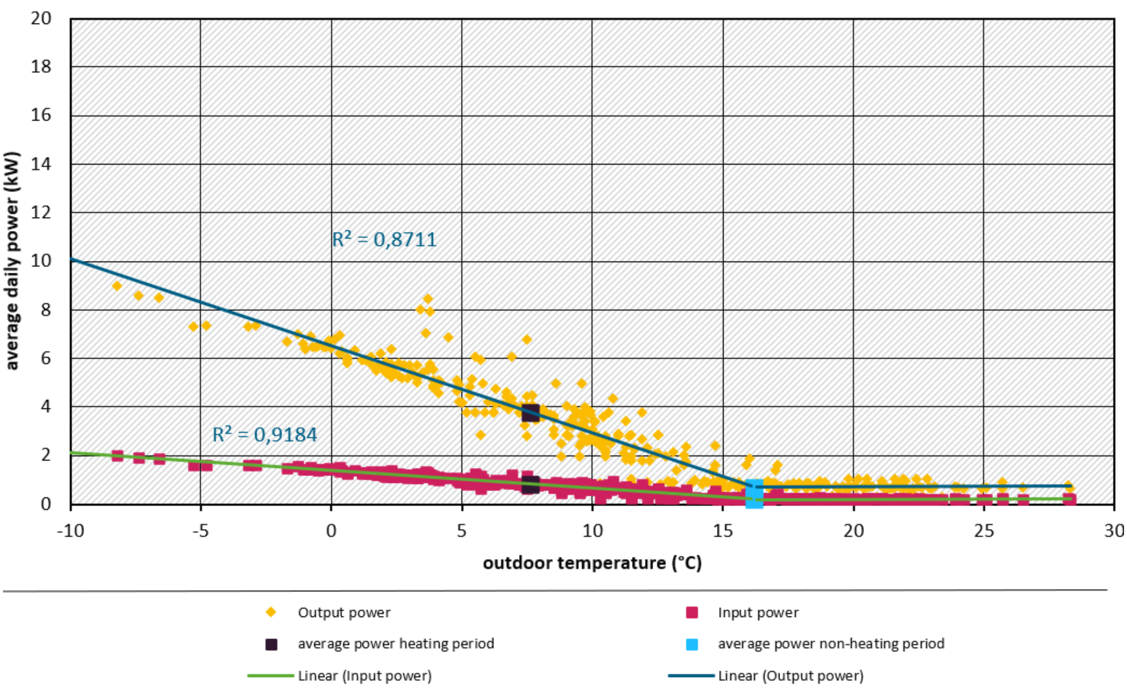
The results of the study are presented in Table 16.

Table 16: Results of use case 1

Description of the	Annual Performance Factor (APF) (from totals, measured value)	APF from Energy Analysis (AT 7.7 °C) (measured value)	APF boiler signature (output/input 2.83 / 0.64 kW) (measured value)	Expected APF VDI 4650 (comparative value)	Expected APF regression (comparative value)	COP at 2 / 7 °C (design 35/30) (comparative value)
Value	4,39	4,18	34,39	4.4 (manufacturer information MAP 2008)	-	-
Absolute deviation	-	0,20	0,0	0,01	-	-
Deviation %	-	+5	-0	0	-	-

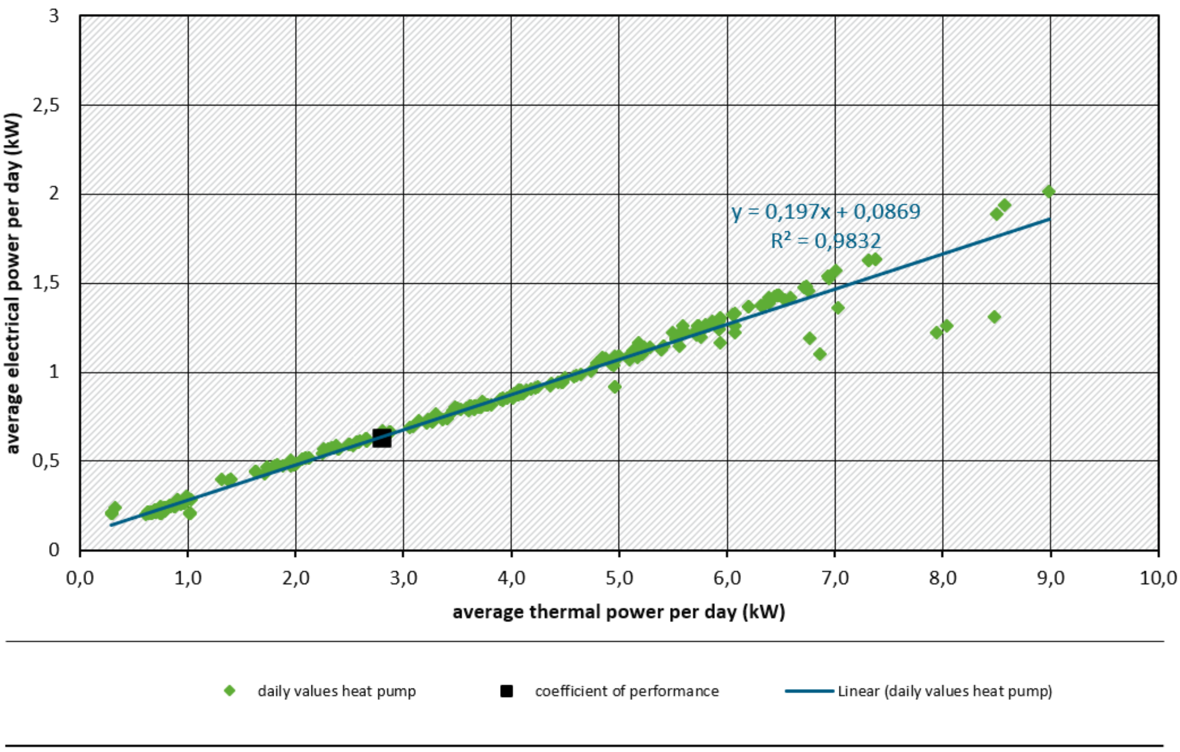
Figure 34 to Figure 37 show the results graphically. The rolling representation (Figure 37) shows that the annual performance factor has remained largely constant over the observation period. By calculating the difference with the standardised annual performance factor (red dotted line), actual efficiency deviations (negative values) can be differentiated from climate-related deviations. The standardised coefficient of performance was calculated using the energy analysis for the respective outdoor temperature in the period and the corresponding hours.

Figure 34: Energy analysis (use case 1)



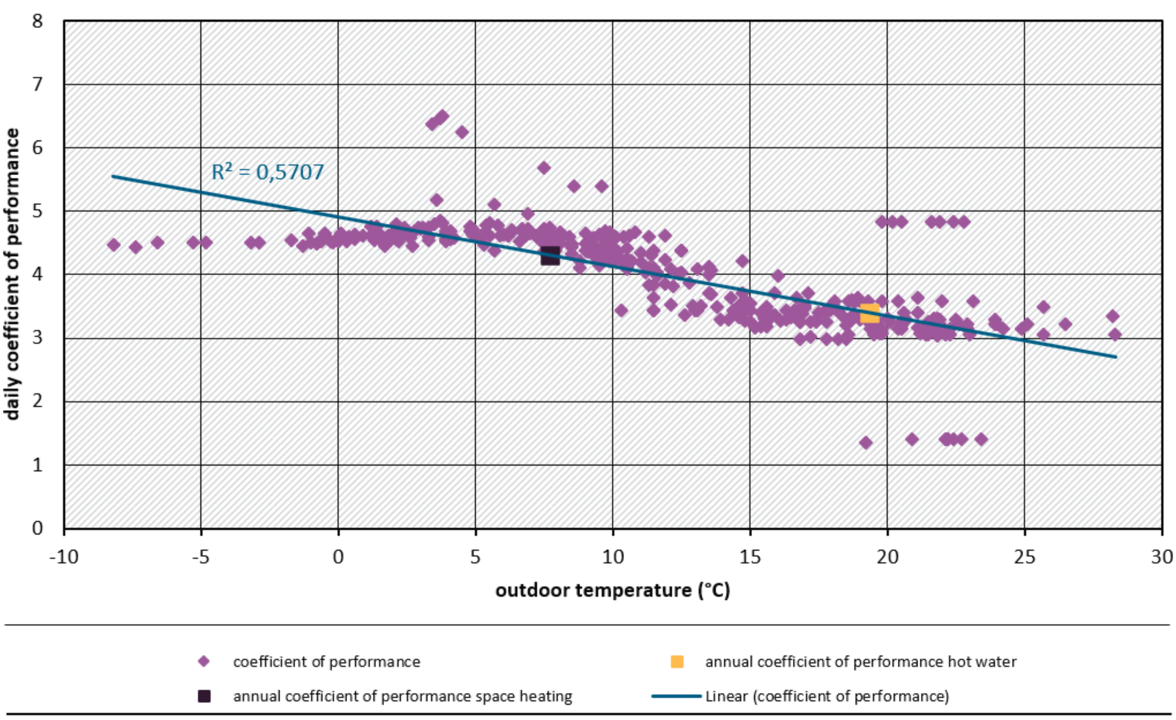
Energy analysis with data points for determining the proportional annual performance factors; average outdoor temperature during the heating period in the reporting period 7.7 °C; heating limit temperature 17 °C. Source: own illustration co2online/senercon.

Figure 35: Boiler signature (use case 1)



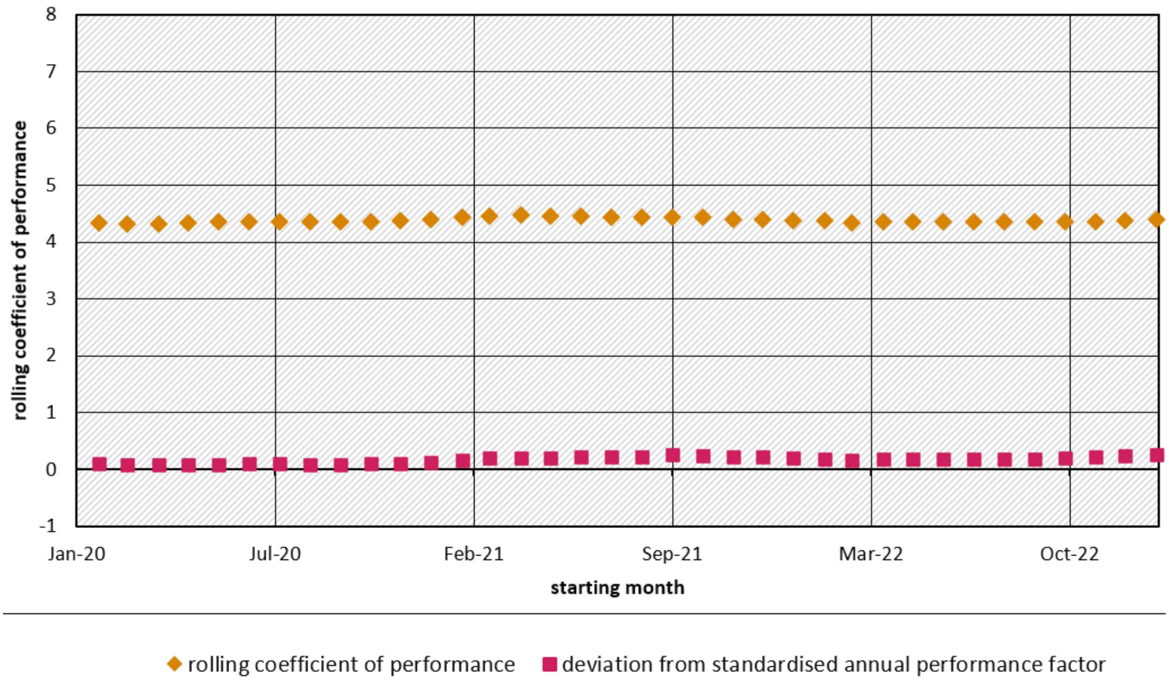
Boiler signature with data points. Source: own illustration co2online/senercon.

Figure 36: Daily energy figures via outdoor temperature (use case 1)



Daily energy figures above the outside temperature. Source: own illustration co2online/senercon.

Figure 37: Rolling representation (use case 1)



Rolling representation of the annual performance factor determined on the basis of available monthly values. The red dotted line represents the deviation from the standardised annual performance factor. Negative values represent a deterioration in efficiency. Source: own illustration co2online/senercon.

The example clearly shows that the boiler signature of this brine-to-water heat pump has a high coefficient of determination, as does the energy analysis. This is probably due to the largely constant brine temperature throughout the year. It can also be seen that the daily coefficient of performance drops noticeably at > 10 °C outside temperature. This could be due to increasing hot water operation and possibly high standby losses. In general, the annual coefficient of performance of 4.4 can be rated as good for a model that was already more than 12 years old at the time of measurement. The efficiency corresponds to the manufacturer's specification. As no COP values were available, it was not possible to determine the expected annual performance factors (according to the VDI calculator).

B.2 Air-to-water heat pump - detached house near Karlsruhe

In the second case, a heat pump in a detached house in Baden-Württemberg, built in 1976 and modernised in 2019, is examined. Selected building and system data are shown in Table 17 and Table 18. Data from the period 16/09/2019 to 15/09/2020 was analysed.

Table 17: Building and heating system data (use case 2)

Location postcode	Year of construction Building	Usable area m²	Number of users	Flow heating °C	Hot water temperature. °C
75334	1976, 2019 EH85	320	4	50	42 [44]

Source: Owner

Table 18: Heat pump data (use case 2)

Year of construction Heat pump	Type of heat pump	Power kW	ηs	ηwh
2019	Air-water	12	144	-

Source: Owner, own research co2online / senercon

The results of the study are shown in Table 19.

Table 19: Results of use case 2

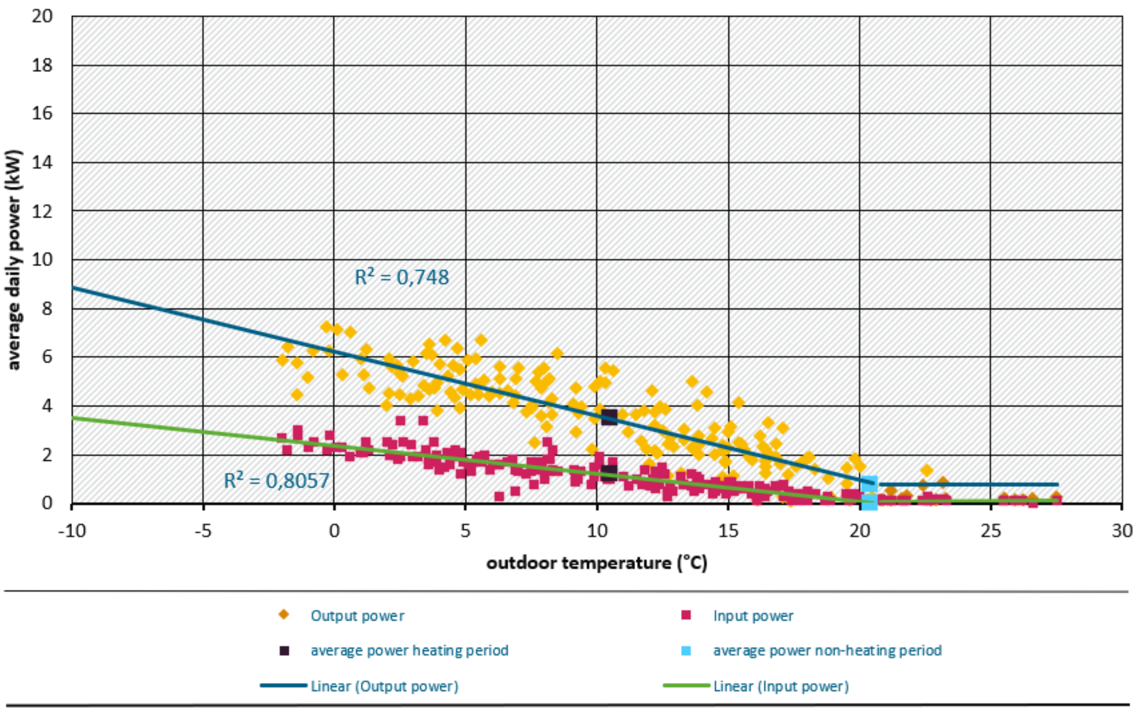
Description of the	Annual Performance Factor (APF) (from totals, measured value)	APF from Energy Analysis (outside temp. 10.5 °C) (measured value)	APF boiler signature (output/input 3.26;1.11 kW) (measured value)	Expected APF VDI 4650 (comparative value)	Expected APF regression (comparative value)	COP at 2 / 7 °C (design 55/50) (comparative value)
Value	3,16	3,07	2,95	4,1	4,9	3,57 / 4,83
Absolute deviation	-	0,09	0,19	0,94	1,74	0,41 / 1,67
Deviation %		0,03	-7	+30	+55	13 / 53

Figure 38 to Figure 41 show the results graphically. The rolling representation (Figure 41) shows that there were efficiency problems between August 2022 (start month: September

[44] Hot water temperatures below 57 °C are permissible for hot water systems with a cylinder volume of less than 300 litres, as legionella protection requirements do not apply to such systems. It is generally recognisable from the data records of the use cases that these were provided by convinced energy savers.

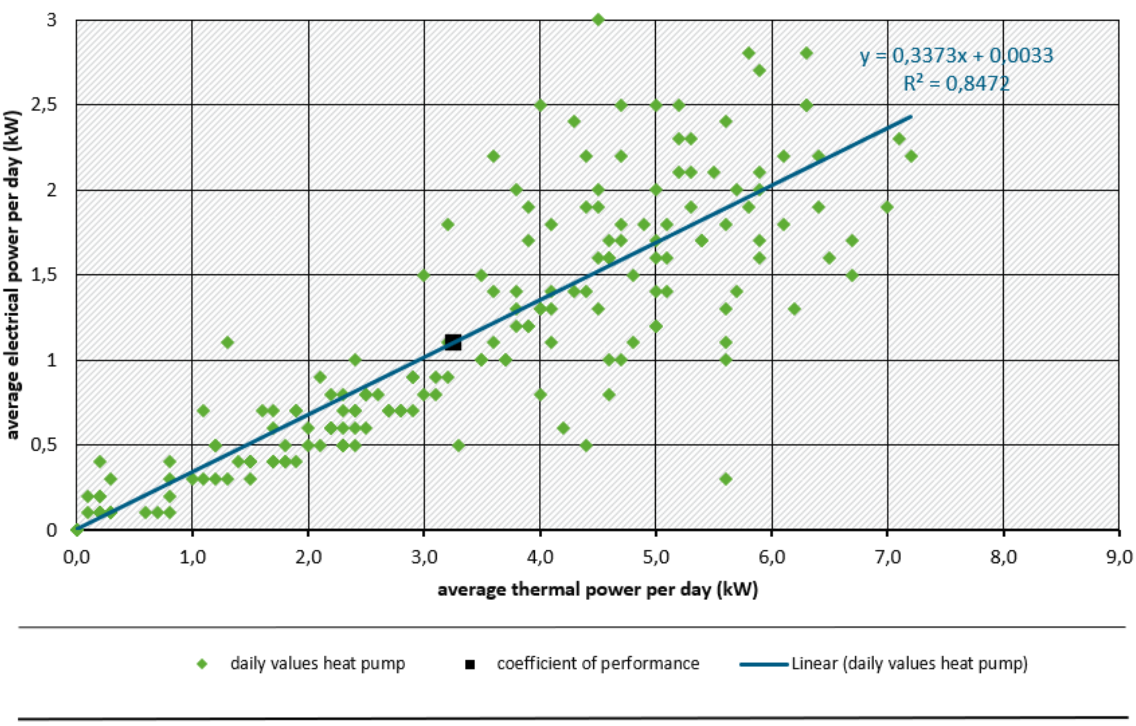
2021) and September 2022 (start month: September 2022), which were confirmed by the building owner.

Figure 38: Energy analysis (use case 2)



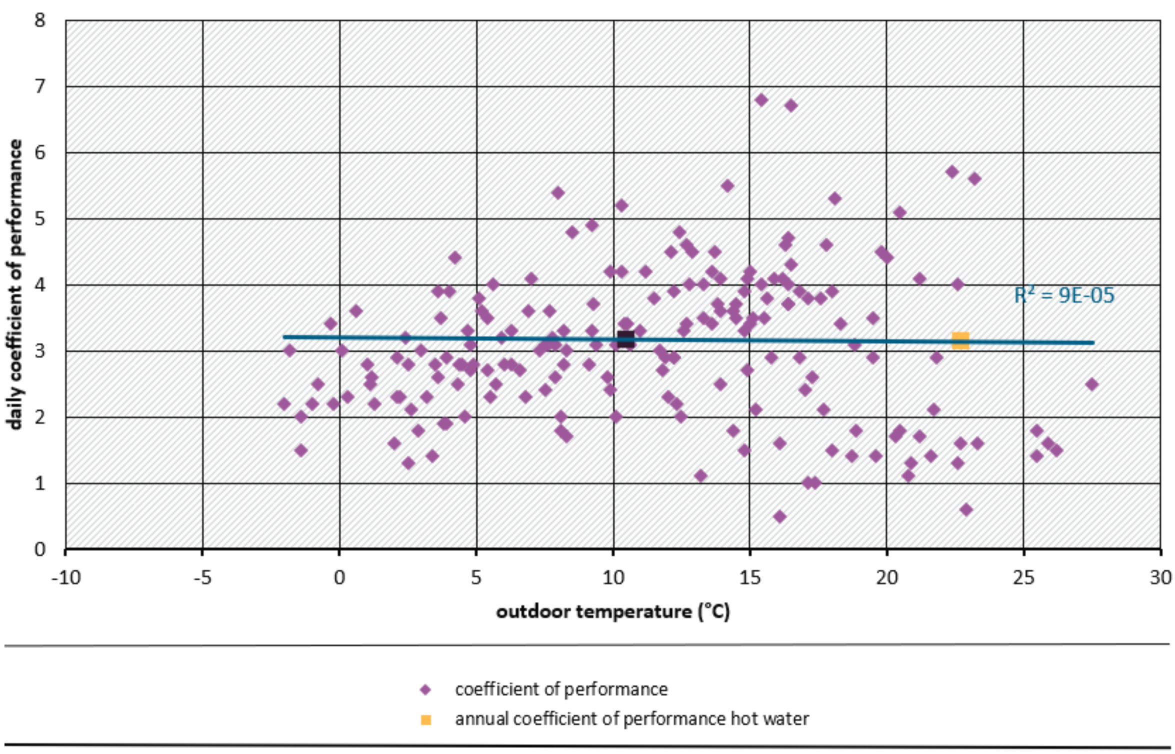
Energy analysis with data points for determining the pro rata annual performance factors; average outdoor temperature during the heating period in the reporting period 10.5 °C; heating limit temperature 20 °C. Source: own illustration co2online/senercon.

Figure 39: Boiler signature (use case 2)



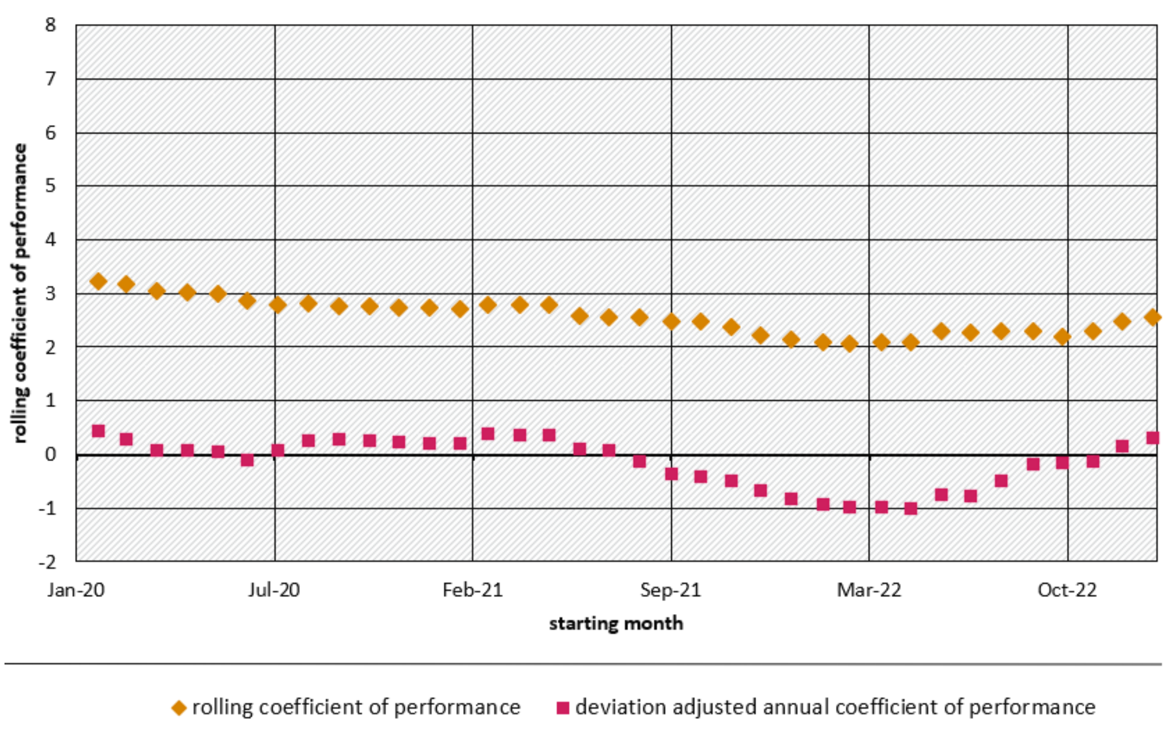
Boiler signature with data points. Source: own illustration co2online/senercon.

Figure 40: Daily energy figures via outdoor temperature (use case 2)



Daily energy figures above the outside temperature. Source: own illustration co2online/senercon.

Figure 41: Rolling representation (use case 2)



Rolling representation of the annual performance factor determined on the basis of available monthly values. The red dotted line represents the deviation from the standardised annual performance factor. Negative values represent a deterioration in efficiency. Source: own illustration co2online/senercon.

The example shows that the energy analysis can be used to determine annual coefficients of performance that correspond to the total annual value with a high degree of accuracy. The strong deviation of the COP from the expected value (COP 4.1 according to VDI 4650) is not due to efficiency problems of the heat pump (defective contactor), as this problem only occurred later. The exact cause of the deviation could not be determined.

B.3 Air-to-water heat pump - detached house in Denmark

In the third case, a heat pump for a detached house in Denmark[45] , built in 1986, is examined. Building and system data are shown in Table 20 and Table 21. Data from the period 09.03.2014 to 08.03.2015 was analysed.

Table 20: Building and heating system data (use case 3)

Location postcode	Year of construction Building	Usable area m²	Number of users	Flow heating °C	Hot water temperature. °C
DK-8781	1986	217	6	55	60

Source: Owner

Table 21: Heat pump data (use case 3)

Year of construction Heat pump	Type of heat pump	Power kW	ηs	ηwh
< 2014	Air-water	13	132	98

Source: Owner, own research co2online / senercon

The results of the study are shown in Table 22.

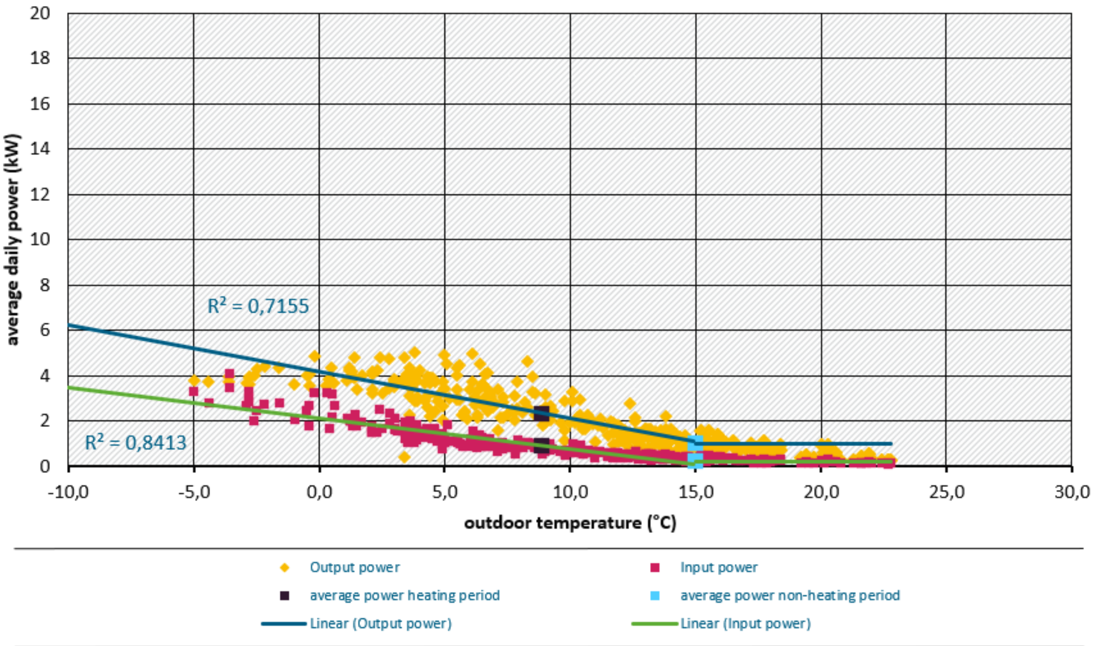
Table 22: Results of use case 3

Description of the	Annual Performance Factor (APF) (from totals, measured value)	APF from Energy Analysis (outside temp. 10.5 °C) (measured value)	APF boiler signature (output/input 2.20/0.89 kW) (measured value)	Expected APF VDI 4650 (comparative value)	Expected APF regression (comparative value)	COP at 2 / 7 °C (design 55/50) (comparative value)
Value	2,56	2,60	2,47	3,61	4,60	3,22 / 4,61
Absolute deviation	-	-0,04	0,09	1,05	2,04	0,66 / 2,05
Deviation %		0	-3	+41	+80	+26 / +80

[45] Source: FINESCE project

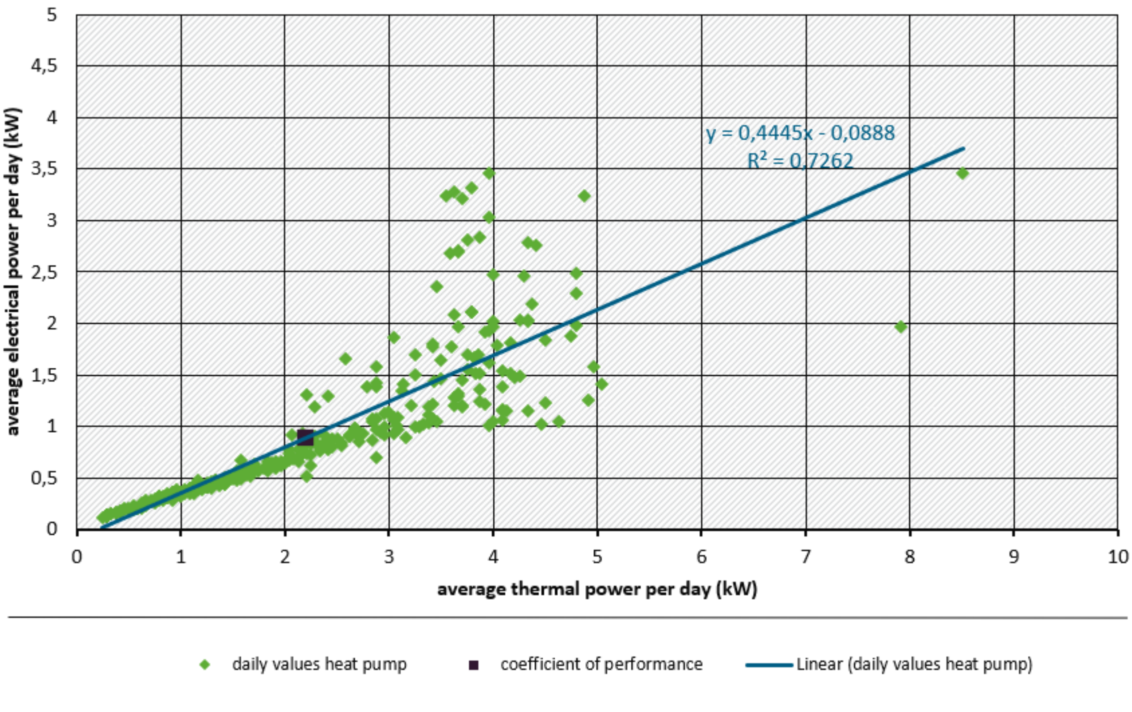
Figure 42 to Figure 44 show the results graphically. A rolling representation is not available as only measurement data for one year is available.

Figure 42: Energy analysis (use case 3)



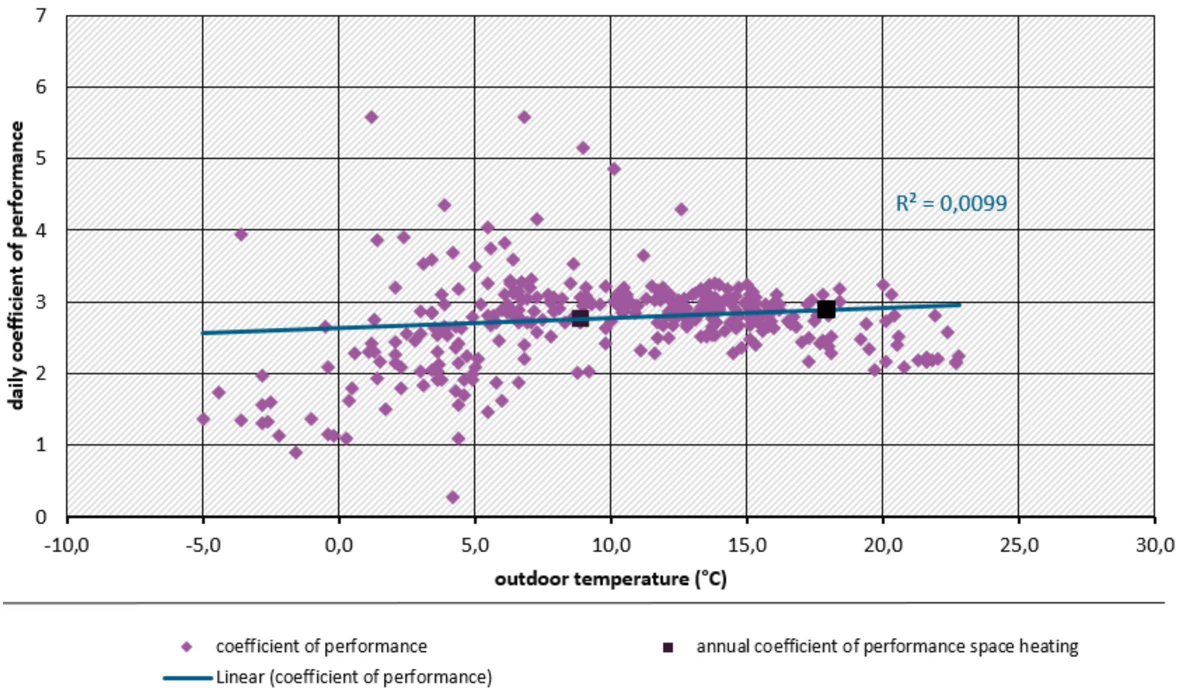
Energy analysis with data points for determining the pro rata annual performance factors; average outdoor temperature during the heating period in the reporting period 8.9 °C; heating limit temperature 15 °C. Source: own illustration co2online/senercon.

Figure 43: Boiler signature (use case 3)



Boiler signature with data points. Source: own illustration co2online/senercon.

Figure 44: Daily energy figures via outdoor temperature (use case 3)



Daily performance factor above the outside temperature. Source: own illustration co2online/senercon.

In general, the example shows that the energy analysis can be used to determine annual performance figures that correspond to the summary annual value with a high degree of accuracy. It is unclear why the comparative values determined deviate so greatly from the measured values. As data from a project completed in 2015 was used for the analysis, it was no longer possible to find out the reasons for the deviations by contacting the building owner.

B.4 Gas heating - Apartment block in Würzburg

The data set for the building was provided by the KINERGY project[46] . The building was constructed in 1972 and underwent energy efficiency improvements in 2016. As part of this, the heating system was replaced, and a gas condensing boiler was installed. Domestic hot water is provided with support of a storage tank. The heat output of the system was determined from the sum of the heat meter values for space heating and hot water (before storage tank). Data from the period 16.11.2022 to 13.09.2023 was evaluated.

Table 23: Building and heating system data (use case 4)

Location postcode	Year of construction Building	Usable area m²	Number of users	Flow heating °C	Hot water temperature. °C
97074	1972	615		55	60

Source: Owner

Table 24: Boiler data (use case 4)

Year of construction Boiler	Type of boiler	Power kW	ηs	ηwh
2016	Calorific value	27	94	82

Source: Owner, own research co2online / senercon

The results of the study are shown in Table 25.

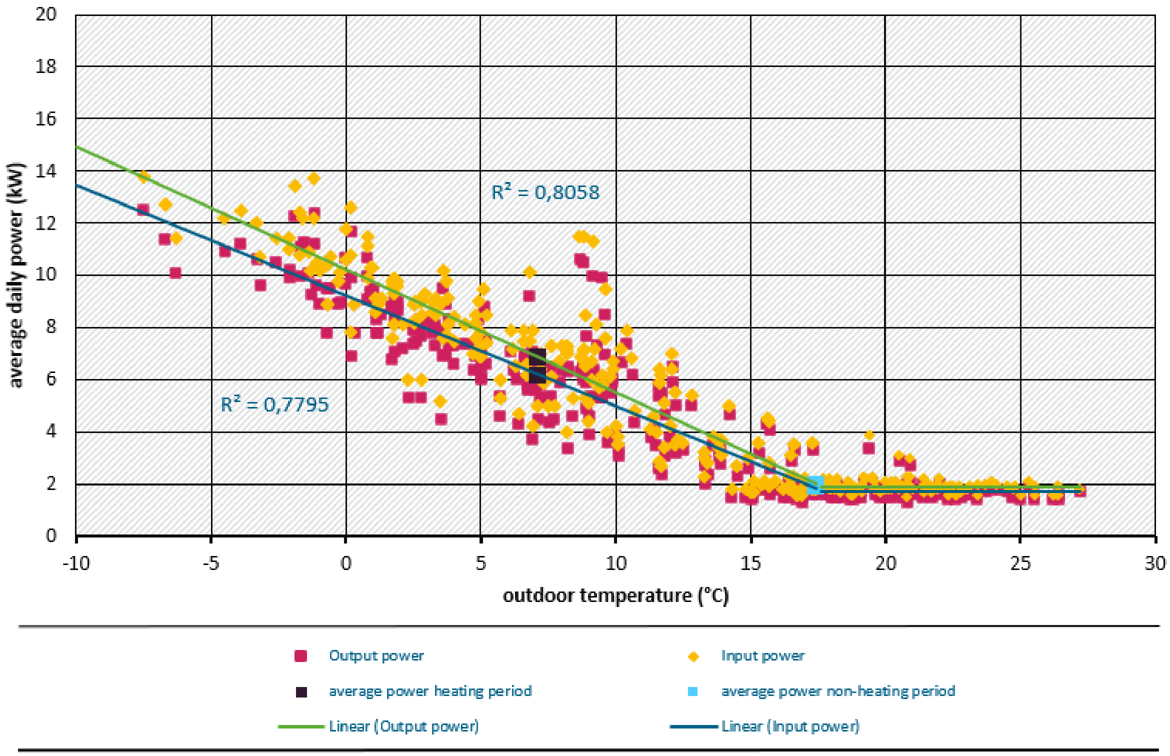
Table 25: Results of use case 4

Description of the	Annual utilization factor - AUF) (from totals, measured value)	AUF Energy Analysis (AT 7.1 °C) (measured value)	AUF boiler signature (output/input 4.88 / 5.41 kW) (measured value)	Space heat (η_s) (comparative value)	Hot water (η_{wh}) (comparative value)
Value	0,90	0,91	0,90	94	82
Absolute deviation	-	0,00	0,00	-0,04	0,08
Deviation %		0	0	-4,3	9,0

Figure 45 to Figure 47 show the results graphically. A rolling representation is not available as only measurement data for one year is available.

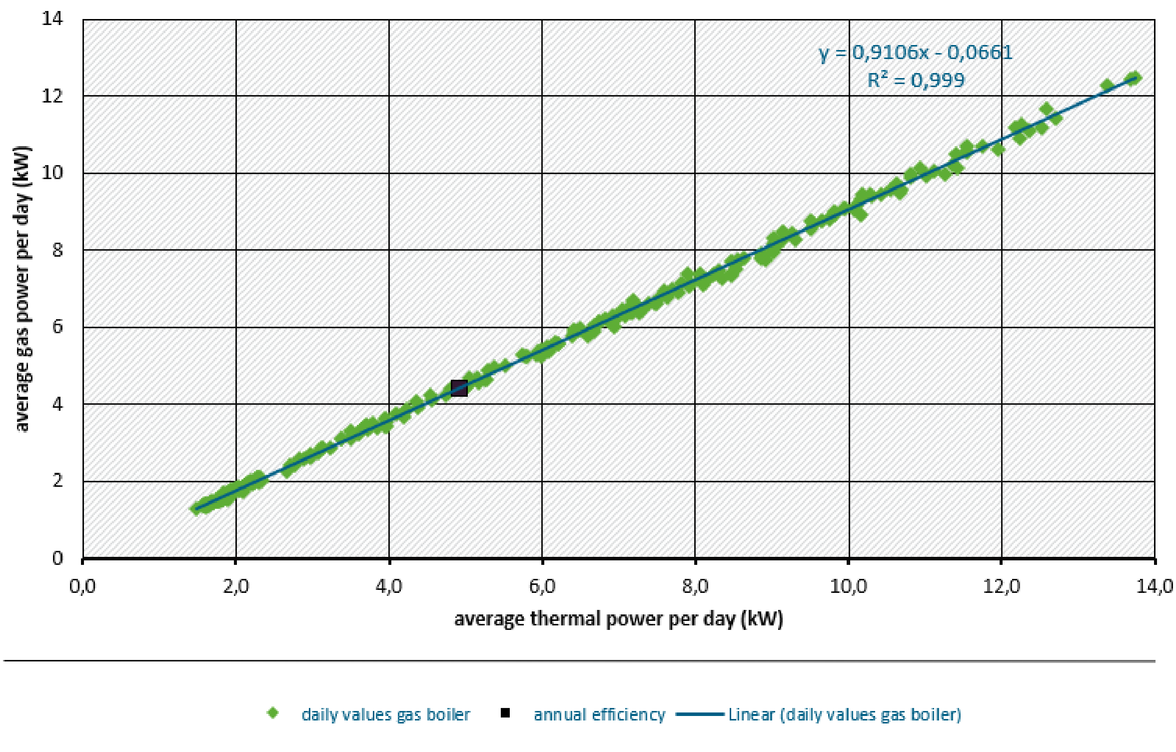
[46] Cf. https://eneriq.com/2019/11/forschungsprojekt-kinergy-startschuss-fur-mehr-effizienz-von-heizungsanlagen-in-deutschland <19.03.2024>

Figure 45: Energy analysis (use case 4)



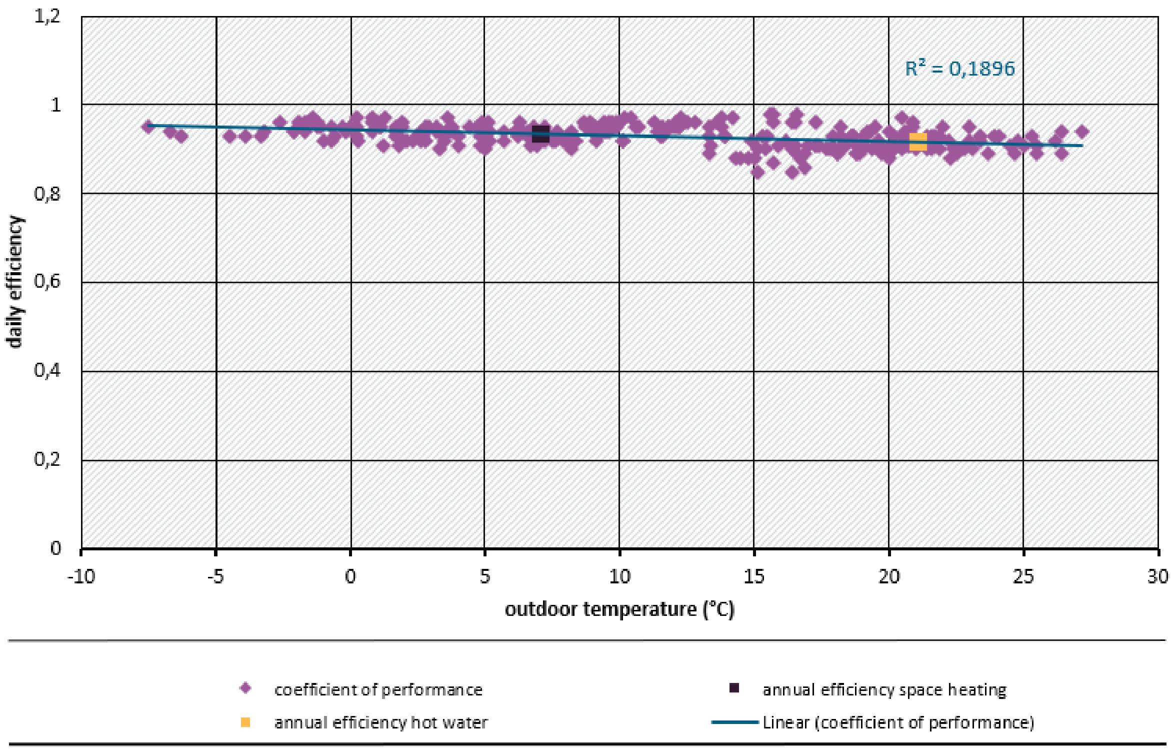
Energy analysis with data points for determining the pro rata annual performance factors; average outdoor temperature during the heating period in the reporting period 7.1 °C; heating limit temperature 17.6 °C. Source: own presentation co2online/senercon.

Figure 46: Boiler signature (use case 4)



Boiler signature with data points. Source: own illustration co2online/senercon.

Figure 47: Daily utilisation factor over outdoor temperature (use case 4)



Daily utilisation factor above the outside temperature. Source: own illustration co2online/senercon.

The use case clearly shows that all methods for boilers work very well, as the degree of utilisation does not depend on the outside temperature. The boiler signature has a high coefficient of determination. A slight drop in the efficiency at high outside temperatures is recognisable, but this is due to the fact that the boiler cycles more frequently in partial load operation.