Final Report Demonstration Project Hybrid Heat Pumps

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1. INTRODUCTION AND SUMMARY

Fully in the tradition of experimental physics, it was thus decided to adopt a - measuring is knowing - approach. It is important to note that the saying - measuring is knowing - is actually a corruption of the original: by measuring to know.

This saying was introduced as a slogan and motto by Groningen professor and Nobel laureate Heike Kamerlingh Onnes at the time of his inaugural address in 1882 [2]. The saying indicates that making measurements and studying the measurement results can lead to insight and thus to science. Precisely this study step, which in the saying is wrapped in the word - to - , is essential: **Measurement results often reveal unexpected things that are the opening to discussion and new insights.** The demonstration project is a good example of this; it led to reactions of surprise among internal and external stakeholders.

The word - by - in Onnes's saying indicates that taking measurements is also necessary to arrive at explanations and insights. A condition for this, of course, is transparency: only when others can verify the measurement results and their processing is it possible to speak of a traceable insight. Traceable and thus verifiable results are the basis of science. In the data research community, this has led to concepts such as JupterLab: **an open environment in which data, code, figures and text are linked together so that anyone can check the conclusions.** In this project, the processing of the measured data into insights was carried out in JupyterLab and is therefore traceable for everyone.

The Demo Project

The objective of the demo project is to determine the effect of installing a hybrid in 200 homes that vary in terms of year of construction and type. The main research questions of the project are:

1. how much is the decrease in gas consumption after installation of the hybrid ?
2. what is the consequence for the energy usage and thus bill for the residents ?

The Dutch climate agreement adopted a scope 1 approach, assigning CO_2 emissions to the organization or household emitting it. The decrease in gas use after hybrid installation is therefore 1 to 1 a decrease in CO_2 emissions [17].

The demo project was carried out by the SEF Foundation, which acted on behalf of the six manufacturers that make up the Sustainable Heat Association (VDW). Participants were able to register through the open website, and were able to access the installer network of the manufacturers recruited [8].

Application was through the on-line application form, submission of two energy financial statements prior to placement of the hybrid and an approval by the Netherlands Enterprise Agency.

A measurement set was developed for the project that collects the required measurement data independent of the device's make. Through the measurement set, energy flows and temperatures in the home are measured and transmitted via a mobile LTE-4G network connection to the server cluster where the data analysis was performed. The data analysis was performed using Grafana (looking at the raw data) and the aforementioned JupyterLab.

The vast majority of participants owned the home.
The homes were not structurally altered, and without the intervention of an EPA consultant, the hybrid was selected by occupant and/or installer. In a number of cases, under- or oversizing occurred. In practice, this did not prove to be a problem: **there are homes where the hybrid took over**

the entire gas usage for heating, and there are homes where the central heating boiler tops up relatively quickly.

In about four cases, due to very poor condition or faulty design, the dispensing system was improved by replacing some radiators.

Interest in participation was high. There were several, partly Covid-19 related, teething problems (see Chapter2). For a variety of reasons, the number of participants who provided data for the project lagged behind. In the end, the project had 174 participants with an installed hybrid and a functioning measurement set.

The project actually amounts to a difference measurement. The energy use of the home before installation of the hybrid is compared to the use after installation. This is also the way residents look at it. Due to the extension of the project, for many participants the usage is known two winters prior to placement and over two winters after placement. **In general, home use, such as hot water use and thermostat use, will be fairly constant over time.** This is also evident from the available data. Through a survey of participants, it was confirmed that by far the majority has not changed their heating behavior after placement and almost everyone is satisfied with the hybrid.

Classification

In the following, the setup of the measurement set and data processing are described and observations made are explained. Through images generated by JupyterLab and a generated summary table of all participants, the research results are presented. For quick insight, an overview, of the data and the performance determined from it, of all participants was generated [12].

This is detailed in the following sections:

2. Measurement set and data processing
3. Dates and observations
4. Gas savings, COP and savings performance
5. Conclusions and recommendations

Saving performance

The obvious way is to express the reduction in gas use achieved by the hybrid in relation to the additional use of electrical energy. The concept of savings performance has been introduced for this purpose:

savings performance = (amount of gas saved in kWh) / (additional electrical energy used in kWh)

The savings performance indicates how many kWh of gas are saved by 1 kWh of electricity used by the hybrid heat pump. Where 1 m^3 Dutch gas has an energy value of 9.77 kWh [10]. Assuming a 100% efficiency of the boiler and an unchanged behavior of the heating system and controls after installation of the hybrid, it is expected that the savings performance would be equal to the COP value of the hybrid heat pump. After all, from the energy value of the amount of gas saved, through the COP, the use of electricity by the heat pump would follow. However, it was determined that the average COP value of the hybrids in this project is 3.8 while the average savings performance is 5.7.

Regardless of the exact physical explanation, this is a very remarkable result of the demo project: each m^3 of gas saved, instead of 2.6 kWh, gives only 1.7 kWh more use of electricity. So at current prices of 1.33 for a m^3 of gas and 0.31 euros for a kWh of electricity, that gives an average return of 0.8 euros for every cubic meter of gas saved by a hybrid.

Applying this to the UK context, with lower gas prices and higher electricity prices, the business case is still positive. The savings performance factor shows that every 5.7 kWh gas saved, results in an additional electrical energy usage of 1 kWh. Using current UK energy prices (25.73p per kWh electricity and 6.33p per kWh gas), this would mean that every 36 pence saved on gas means an extra 25p for electrical energy.

Dependent of the heating demand of the dwelling, UK residents can also save hundreds of pounds by installing a hybrid heat pump.[1]

1 https://www.ofgem.gov.uk/information-consumers/energy-advice-households/energy-price-cap#:~:text=Between%201%20July%20and%2030,June%202025%20(%C2%A31%2C849).

New operating range with hybrids

In the tradition of Onnes, the hybrids when measured showed a different, much lower, electricity use than previously predicted. So how is this possible?

Adding the hybrid heat pump to an existing central heating system causes it to operate in a different operating range. The minimum capacity of central heating boilers is on the order of 5-7 kW but for a hybrid heat pump it is on the order of 1-2 kW. An installation with a hybrid can operate at low power and thus at low water temperatures for long periods of time. Much lower than is possible with the boiler. The hybrid increases the operating range of the installation and thus does something other than replace earlier energy use of the boiler. **The hybrid increases the modulation range and lowers the water temperatures. This provides additional energy gains.**

Grid load

The grid load of hybrids in practice is much lower than usually assumed.

The average power load, even on days with temperatures around -5 °C is below 1 kW. Since most low-voltage grids are laid out at 1.5 kW Per dwelling in The Netherlands, grid capacity need not be an obstacle to installing hybrid heat pumps.

Conclusions

The average year of construction of the participating homes is 1974. The gas usage of the homes before participation in the project was around 1900 m^3 (~18.500 kWh).

Apartments are not in the project population. Detached and semi-detached houses are over-represented in the project. The semi-detached houses show the highest absolute savings and the mid-terrace houses the highest percentage savings. Remarkably, the smaller homes show no worse results.

Main conclusion for the average participant is that the hybrid heat pump gives a gas and therefore CO_2 savings of 75% and that the annual energy cost drops around 1,000 euros. This saving is based on the average of the June 2024 tariffs of 1.33 euros for a m^3 gas and 0.31 euros for a kWh electricity [11] . The gas and CO_2 savings are considerably higher than calculated prior to the project. Accounting for increased prices, the decrease in energy costs is higher than anticipated.

The over-the-year measured COP value, also known as SCOP, is around 3.8 and this corresponds well to common numbers [1]. It is often thought that gas savings, heat load of the house and electricity consumption of the hybrid heat pump are related to each other through the SCOP. **This does not appear to be the case. What is remarkable is the much better average energy performance after adding the hybrid heat pump to the installation.** As a result, the use of electricity is also significantly lower than expected.

A figure very different from the Planning Office's 1.7 Mton. In thirty homes, more than 97.5% of the heating demand is met by the hybrid heat pump. For four participants, the hybrid has even completely taken over the heating demand over the past two winters. However, the number of ice days with daily values below zero °C was less than normal. Homes are explained to temperatures down to -10 °C.

The spread in results is wide. A number of homes (10-20%) show much worse than average performance. A significant improvement can probably still be realized in the below-average performing participants by adjusting the installation and/or hybrid. The large spread of measured central heating water temperatures also indicates this.

The wide spread in performance indicates that in addition to proper installation, assessment of the performance of the heating system as a whole will be necessary to achieve good results in all cases. Installers, of course, are not responsible for the distribution system they usually do not install. Furthermore, it is not possible to assess the performance of the system without measurement. Therefore, this is the follow-up task of this project: **how to make sure that all hybrids are properly installed and function properly with the, in the house present, heating distribution system.**

On behalf of the Smart Energy Foundation,
Peter Cool

2. MEASUREMENT AND DATA PROCESSING

A measurement set was developed for the project that functions independently of the hybrid and is used to measure:

- 1 port smart meter: gas, electricity use and feed-in from the home
- Measurement of total heat flow to the delivery system:
    - power
    - water flow
    - supply and return temperatures
- Electrical power consumption by the boiler and heat pump
- Air temperature and humidity in the living room

The technical implementation and accuracy of the measurement set is described in Appendix 2. The following pages schematically show the construction of the measurement set, data storage and data processing (14, 15). Data transport from the measurement sets to the server cluster takes place every 10 seconds. So that all dynamic effects of the heating system are well visible. For the visualization of the raw data, Grafana (grafana.com) was used.

As indicated in the introduction, traceability of results is the fundament of science. The measured data and its processing in this project was performed in JupyterLab and is therefore traceable to all [3,4,5]. The measurement data and the notebooks describing the data processing are released in anonymous form [6]. By installing Jupyterlab as indicated, it is possible to generate the results yourself and conduct further research if desired.

In addition to data coming from the measurement sets, KNMI and Cadastre data (from the official land registry organization) are used. As shown in the diagram, for each manufacturer there is a so-called container with its own data, visualization and analysis environment for the participants connected to it. In addition, there is a global environment that was used for the data processing of all participants for this report and to which the participants' WebApp is connected. Through the WebApp, participants could view the measurement data and performance of their own homes. An example of this is included in Appendix [10].

To secure anonymity, participant measurement data was stored under anonymous, randomly generated, identifiers (ID). Which are also used in this report (e.g., H6PEe0lX). This ensures that in case of unauthorized access to the data or theft of the data, no link can be made to the location of the house or its occupants. Furthermore, property data, such as year of construction and floor area, are categorized to make it impossible to trace the property by matching.

Where there is data there are errors, disruptions and imperfections. So too in this project. Not properly completed registration forms, incomplete energy bills, faltering communication links, partial or temporary failure of measurement sets, residents unplugging in the summer, etc. An important step in the study was data cleansing [7]. The data cleansing steps are described in the JupyterLab project notebooks. Despite the cleansing, some error will still be found. Code is like text in this respect: there is almost always still a form or style error to be found. Given the total number of the project, a data error from a single participating home will not immediately produce a different conclusion. Nor can it be ruled out that there are inaccuracies in the data provided by participants. As was found in 1 case at a very late stage (see note Appendix 7). Experiments have shown that omitting or changing data from multiple participants marginally affects the results (e.g., the table on page 28).

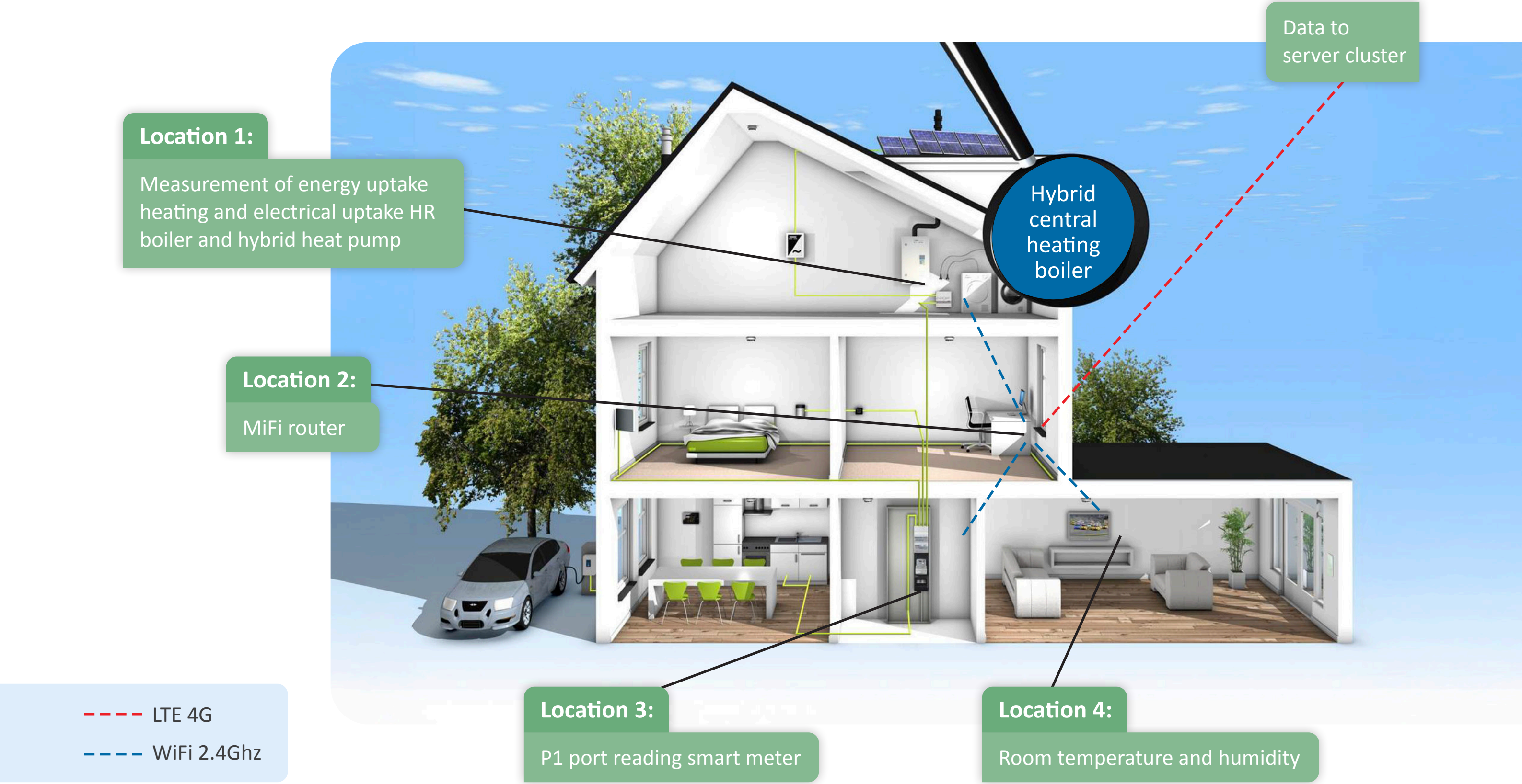
At its inception, the project experienced several delays, partly related to To COVID-19. Chip shortages delayed the Production of the metering sets and also the hybrid heat pumps by many months. As a result, the first homes were not on-line until early 2022.

Then another problem occurred. It was originally planned that the installer of the hybrid would also install the measurement set. That was sent after an approved application. The distribution and proper installation of the measurement sets was very difficult during the first period. During the project, therefore, the choice was made to have the measurement sets installed not by the installer but by the manufacturers’ service department.

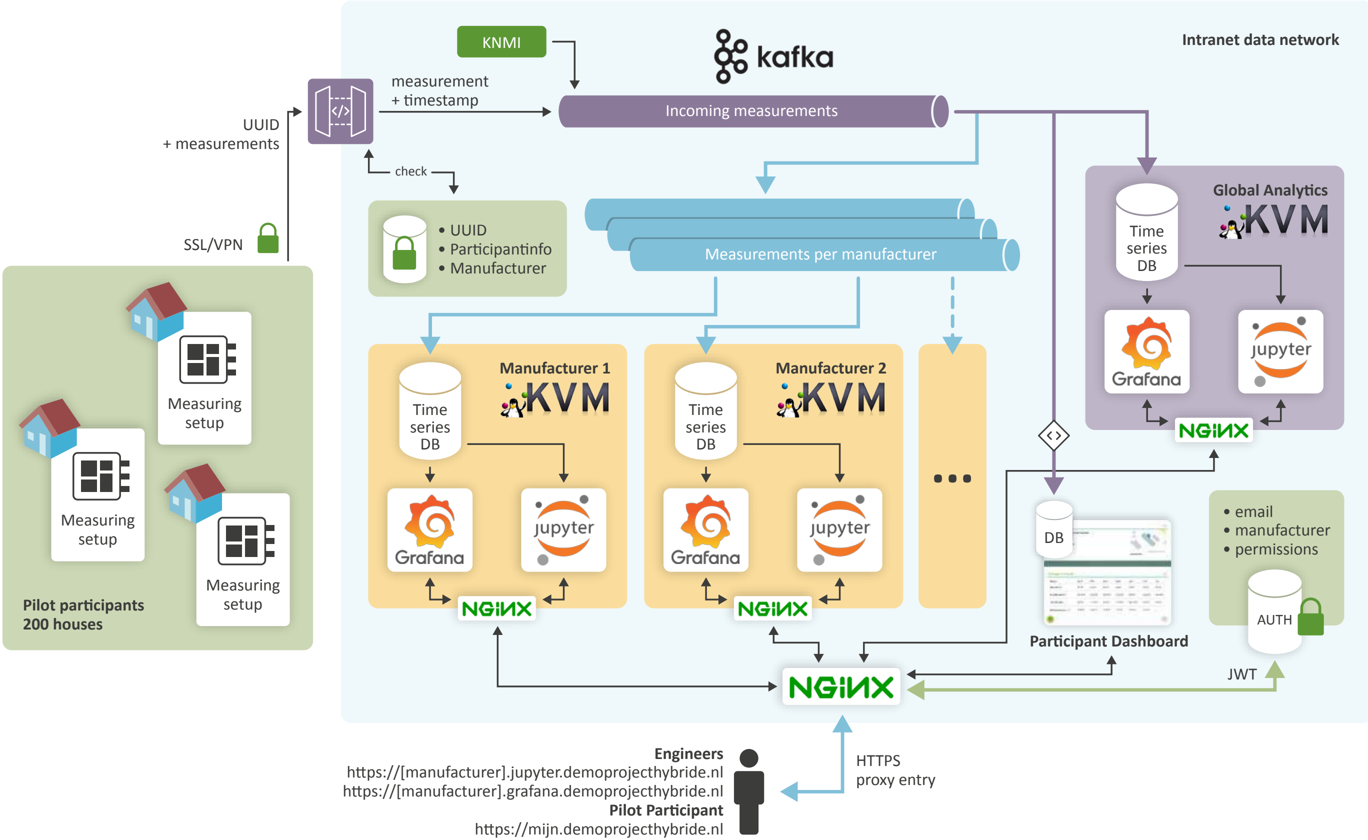
A number of measurement sets were lost or damaged, causing a shortage when the last ones were installed and the two hundred could not be completed. The plan was to make measurement sets in addition. The minicomputer of the measurement set, a so-called Raspberry Pi, was not properly available again until last quarter 2023. Because of the remaining time it was then decided not to make any more measurement sets and to conduct the research with the homes that were on-line at that time.

The application process was through the Netherlands Enterprise Agency. Due to the shortage of measurement sets, the number of participants was limited. In the end, there were 185 participants who went through the application process. A functioning measurement set was eventually installed in 174 participants.

Locations, measurement equipment and dates



Data infrastructure setup



3. DATES AND OBSERVATIONS

The participants’ raw data was made visible through Grafana dashboards.

Page 18 shows such a dashboard for a 1960s home, with participant identification H6PEe0lX, which is numerically typical of the project.

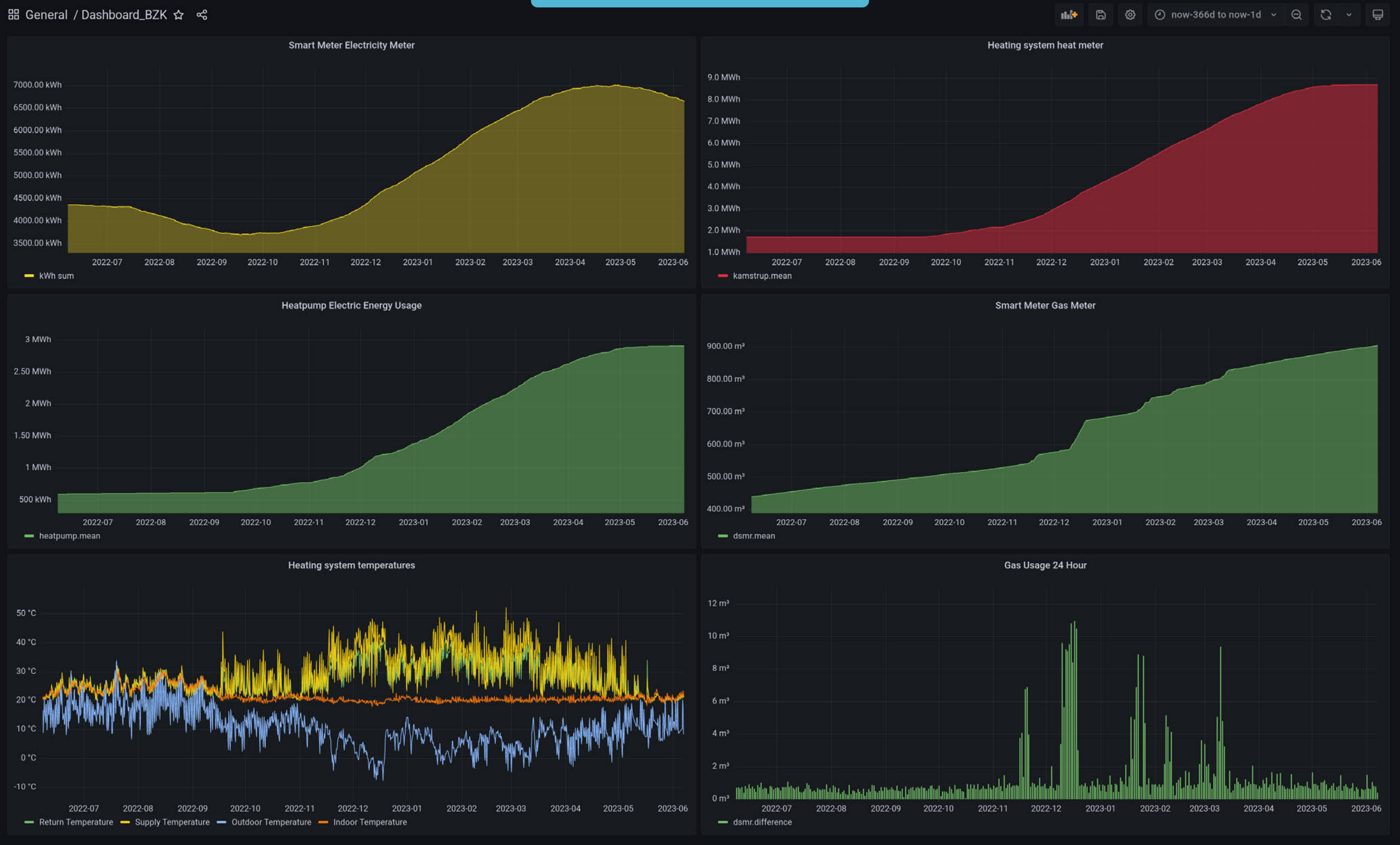
This dashboard shows over the period of one year:

- The cumulative electricity use of the home (top left), which is the balance of off-take and feed-in of electricity per 24-hour period. Many participants have solar panels, so backflow meter data are visible in the summer months.
- The amount of heat that entered the home, cumulatively per 24-hour period (top right).
- The position of the gas meter in the meter box (center right). This is the cumulative gas usage: heating plus hot water and cooking. Visible is that the meter rises continuously due to daily use of hot water and/or cooking and rises more sharply during winter days.
- The gas usage per 24-hour period (bottom right), the constant decrease in tap water/cooking can be seen and spikes that occur during cold winter days.
- Bottom left, the temperature of the supply, the return, the sensor in the living room and the outside temperature (KNMI data per hour). Clearly visible is that water temperatures, even on severe winter days, are much lower than what is usually assumed.
- The measured power consumption of the hybrid heat pump (left middle, cumulative)

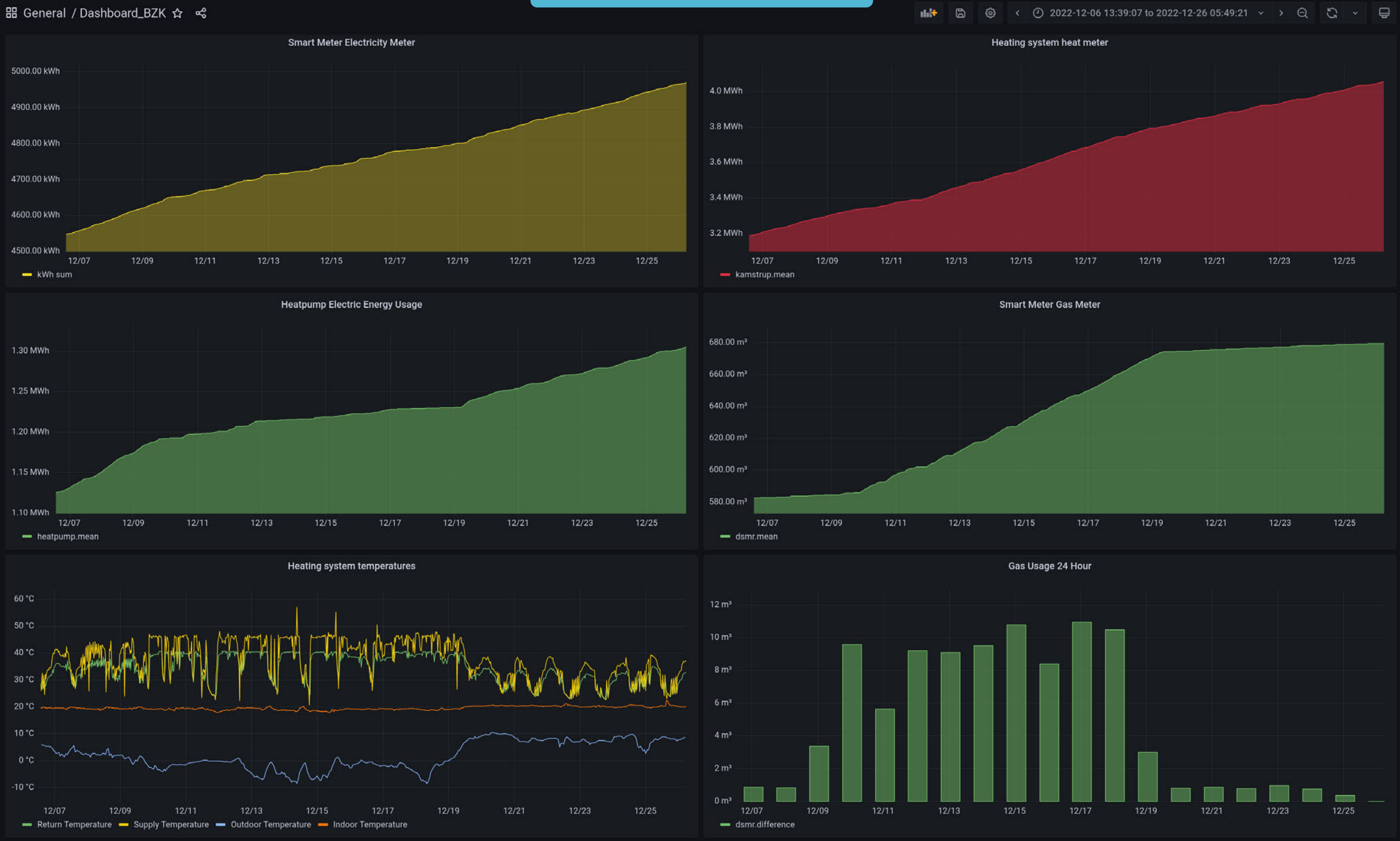
A page further (19) is zoomed in on a severe winter week in the month of December 2022. Outdoor temperatures as low as -10°C. You can clearly see how gas consumption and water temperature increases to keep the home warm. On the other hand, the hybrid's electricity use decreases, which is beneficial to the grid. After the winter period, gas use drops again because gas is only used for hot water and cooking.

Another page further (20), with other subplots, is further zoomed in on twice 24 hours in the month of December. Visible are the low water temperatures, of around 35 °C, with an outside temperature of around 7 °C. It can be read that over the period 100 kWh of heat was generated and the hybrid used 22 kWh of electricity. This gives a COP of 4.5. It can be seen that the hybrid runs continuously for long periods, using 600 to 800 watts of power. The supply and return temperatures are around 35 and 30 °C.
This prolonged running at low power and low temperature is impossible in an installation with only a boiler. Because of the higher minimum power of central heating boilers (5-7 kW). Thus, the hybrid increases the modulation range of the installation. The behavior of hybrid installations is more continuous. Some participants came up with the appropriate comment that the heat is distributed more evenly on a comfortable level. The hybrid operates the system differently than the boiler.

H6PEe0lX - 1960s home



H6PEe0lX - winter week



H6PEe0lX - twice 24 hours (December month)

Appendix 6 includes images of dashboards as before for a number of participating homes. Differences in water temperatures, behavior of the hybrid and gas usage of the homes are explained. Also included in the appendix is the dashboard, in a slightly different form, of a number of participants over a two-year period. This shows the limited differences between winters and occurring issues such as: data interruptions, switching a smart meter and incomplete electrical connection of the hybrid.

Heat loss is driven by the difference of indoor and outdoor temperatures. With that in mind, it is obvious to plot the energy use for heating per 24 hours against the average temperature difference between indoors and outdoors. On the next page (23) are the graphs created by Jupyterlab showing the heat demand, energy use, COP and water temperatures in relation to the difference of indoor and outdoor temperatures for participant H6PEe0lX. A summary of the available measurement data used for this purpose is given on page (18).

Each point in the graph is composed of 24 hours of data. The lines are the, in mathematical terms, best fit lines to the points and show the energy consumption of the house per 24-hour period in relation to the difference between indoor and outdoor temperatures. The dispersion of the points is caused by the fact that in addition to outdoor temperature, sun, wind and rain also affect the heat loss of the house.

Because it is based on the average difference between indoor and outdoor temperatures over 24 hours, effects such as whether or not there is a night reduction, going on vacation for a while and setting the thermostat low, a more or less harsh winter does not influence the trends.

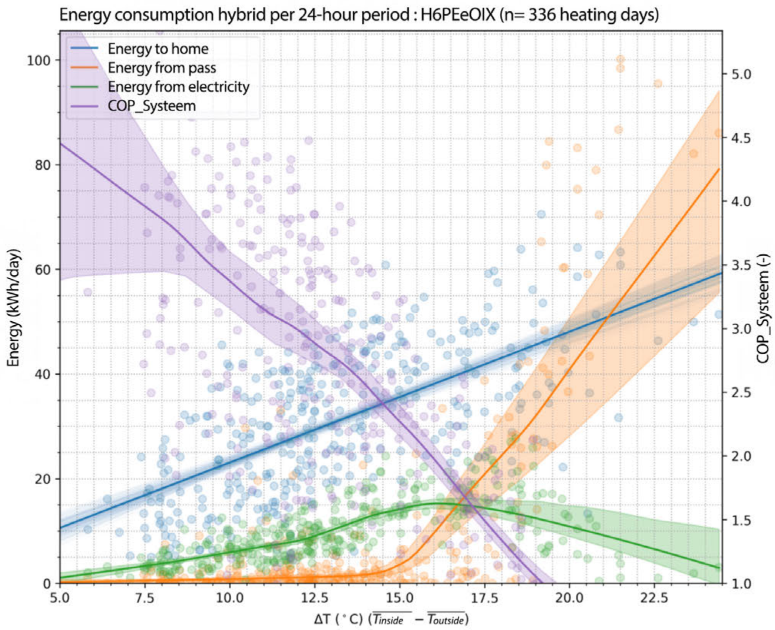
The plot on page 18 shows that the average gas consumption for things other than heating is 0.7 m^3 /day. This was determined for all homes by averaging over a period in the summer. The result of this is made visible by a blue dotted line in the middle left subplot. Incidentally, gas consumption for making hot tap water increases in winter due to lower cold water pipe temperatures. Actual gas usage for domestic hot water will be slightly higher as a result.

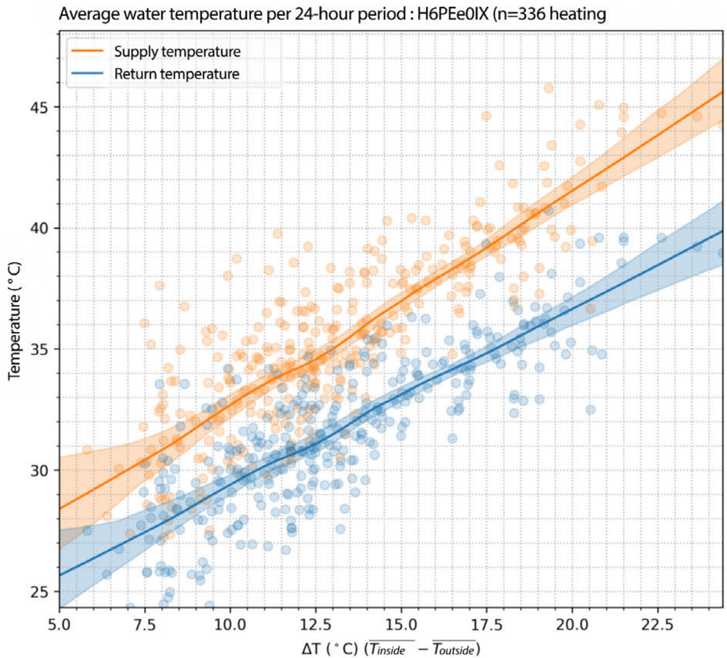
Using Jupyterlab, the plots for all participants were generated. This is a large file and therefore processed as a separate file [12]. The graphs of all participants, as shown on pages 18, 19 and 20, are included herein alongside other house and measurement data.

The plots show, among other things:

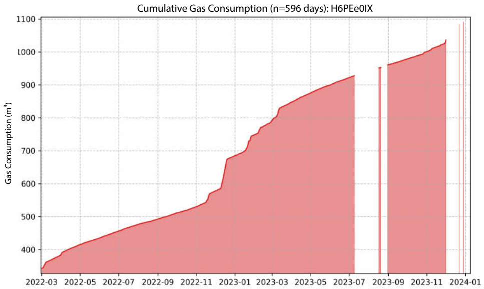
- Many homes at low delta T generally no longer need heating. This means that on those days the home's own heating (glass) but also the heat produced by appliances and occupants is sufficient to keep the home warm. Over a 24-hour period, it can also be the case that the temperature during the day is higher than during the night. This off-set effect is incorporated into the definition of degree days.
- Worth noting is the decline in the COP line on days with high outdoor temperatures in some homes.
  This is because the hybrids generally show high electrical downtime losses. Around 0.2 kWh per day. This is 73 kWh per year (23 euros with current electricity price!).
  On days with hardly any heat demand, this negatively affects the COP.

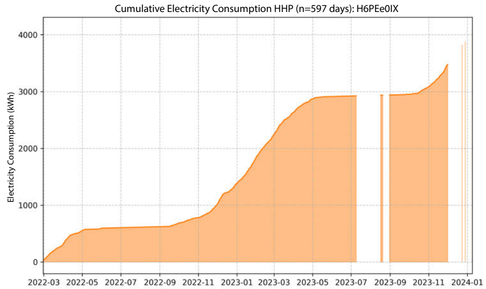
Participant H6PEe0lX

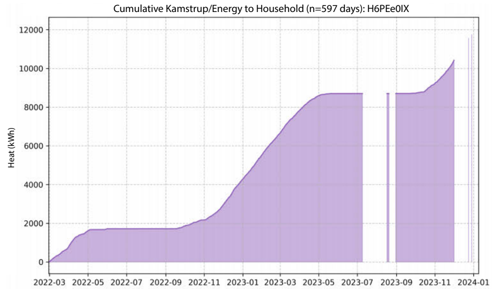


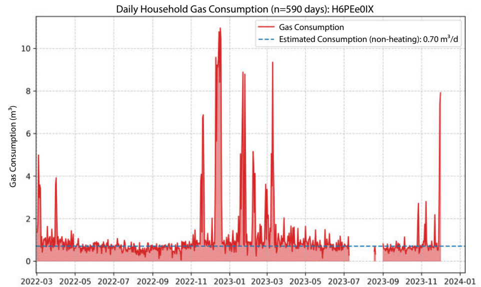


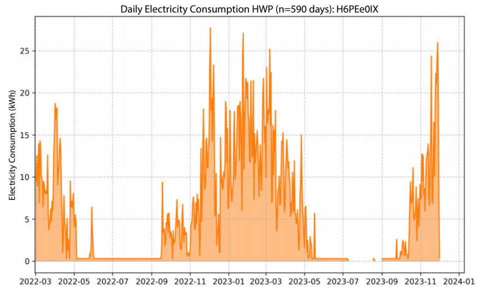
Participant H6PEe0lX

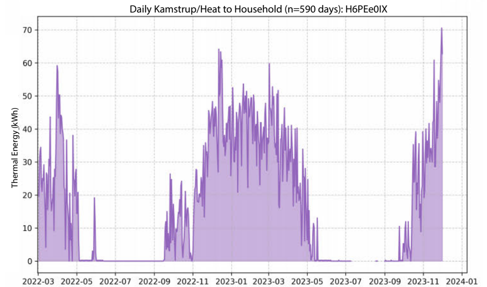


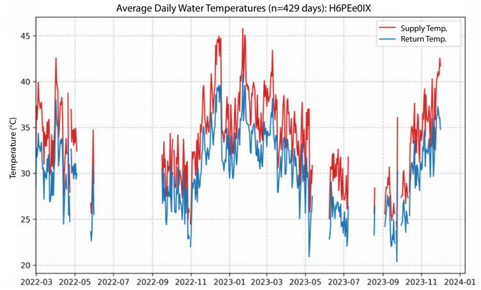


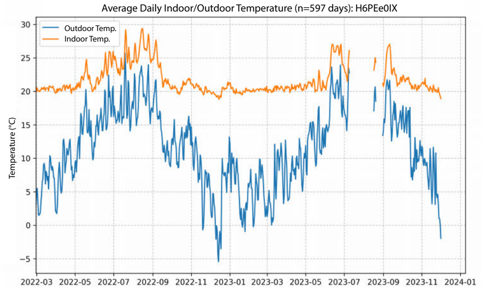


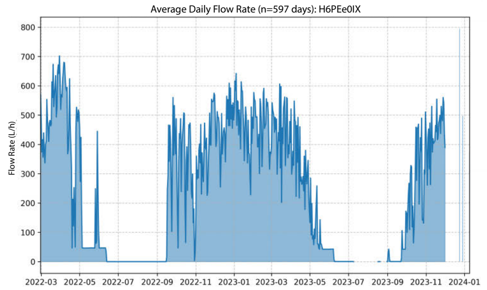




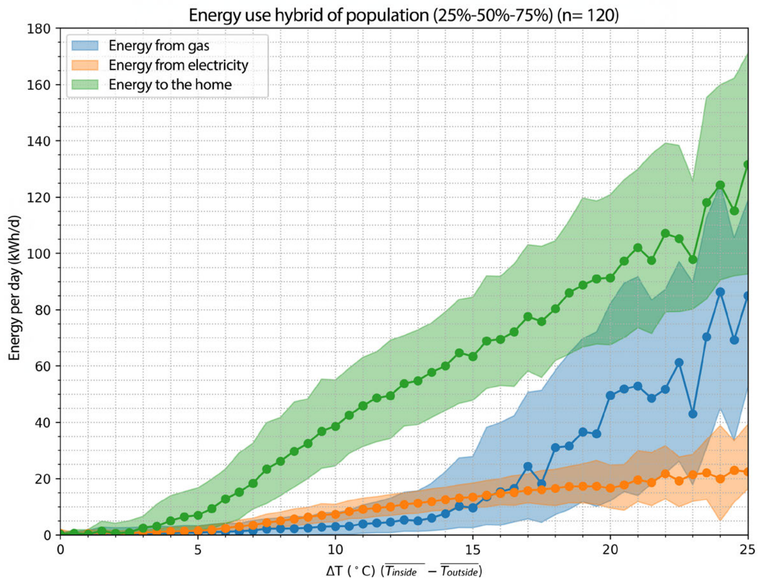








In addition to overviews per participant, aggregate plots were made showing the data of all participants over time (Annex 4). These show energy consumption, water temperatures and their distribution among the participants. As a relevant example, the plot below. Which shows the average energy use and its distribution, for all 120 participants, for which this determination could be done. The 25 and 75 per cent limits of the population are indicated.



From the plot it can be seen that:

- Gas consumption for heating only comes to a 1 m^3 (10 kWh) for the average participant at a delta T of 15 °C, or 20 degrees inside and 5 degrees outside. Visible is a kind of tipping point. Gas consumption goes up hard at lower outdoor temperatures. This is explainable. Around that point, the heat pump's outdoor unit freezes and will have to be periodically defrosted. This causes performance to drop and consumption to rise. The boiler will need to contribute a lot from that point onwards.
- The average use of electricity by the hybrid heat pumps barely exceeds 20 kWh on cold days with 24-hour temperatures of -5 °C (delta T 25 °C). This implies an average 24-hour output of less than 1 kW. Since most low-voltage grids are laid out at 1.5 kW per dwelling, it seems possible to apply the hybrid heat pump widely without grid reinforcement [16]. The electricity grid cannot provide the extra 80 kWh per twenty-four hours required on average for this population, as read right on cold days, and provided by the boiler.

4. GAS SAVINGS, COP, AND SAVINGS PERFORMANCE

In order to answer the research questions, the following terms were used. Here everything is expressed in kWh and 1 m^3 Dutch gas has an energy value of 9.77 kWh [10].

- **gas_before:** two-year average gas usage before placement of the hybrid
- **gas_after:** measured annual usage of gas after placement of the hybrid
- **gas_tapwater:** from measured data determined annual usage of tap water and cooking [12]
- **heat:** measured annual usage of heat after placement of hybrid
- **gas_hybrid:** determination by: gas_after - gas_tapwater
- **elek_hybrid:** measured annual usage of electricity by hybrid

- **gas savings:** (gas_before - gas_after) / gas_before
- **gas loss factor:** heat / (gas_for - gas_water)
  effectiveness of gas conversion to heat
- **SCOP_ lower limit:** (heat - gas_hybrid) / elek_hybrid
  if the gas is 100% effectively converted to heat
- **SCOP:** (heat - gas_hybrid*gas loss factor) / elek_hybrid
  efficiency ofgas conversion to heat included
- **SCOP_system:** heat / (gas_hybrid + elek_hybrid)
  efficiency of total system
- **Coverage performance:** (heat - gas_hybrid*gas loss factor) / heat
  effectiveness ofgas conversion to heat included
- **Saving performance:** (gas_before - gas_after) / elek_hybrid
  this is how residents will view it

The table generated by JupyterLab on the next page shows the outcome of the above concepts for a number of houses (22). The entire table is included in Annex 7.

Year usage was determined for as many homes as possible over the period from May 2023 to May 2024. For homes where this was not possible, the previous year or other appropriate year period was chosen. In a number of cases (21) there was no complete years of data and, where this was readily possible, this was extrapolated. Unfortunately, in a number of homes (40), the hybrid's use of electricity was not properly measured due to a connection error. These residences were not included in terms of electrical use of the hybrid heat pump.

Annual usage was determined for as many residences as possible over the period from May 2023 to May 2024. For residences where this was not possible, the previous year or other appropriate annual period was chosen. In a number of cases (21) there was no complete year of data and, where possible, this was extrapolated. Unfortunately, in a number of homes (40), the hybrid's use of electricity was not properly measured due to a connection error. These residences were not included in terms of electrical use of the hybrid heat pump.

Participant_id	Year built [years]	House Type	Gas_for_2 [m³]	Gas_for_1 [m³]	Gas_after [m³]	Gasbsp [–]	Elek_hyb [kWh]	Deck_degree [–]	Gas loss [–]	SCOP_below [–]	SCOP [–]	SCOP_sys [–]	Bsp_pres [–]	Netto bsp [euro]
kKi5OIGx	[1960-1979]	semi-detached	2189	1834	294	0,85	5264	0,92	0,99	3,15	3,15	2,69	3,19	652,37
A0JoUuz-	[1980-1999]	freestanding	1129	1107	349	0,69	1925	0,74	0,96	3,68	3,74	2,11	3,9	425,49
bW_iJrKG	2000=>	semi-detached	1867	1759	390	0,79	3753	0,96	0,94	3,47	3,48	3,14	3,71	729,56
wv6qC56z	[1980-1999]	semi-detached	1321	1208	338	0,73	2314	0,78	0,91	3,47	3,57	2,18	3,91	514,46
SDIPnuVt	[1980-1999]	freestanding	1675	1521	861	0,46	1801	0,51	0,89	3,16	3,57	1,44	4	422,07
RHON9wor	[1920-1939]	semi-detached	1316	954	373	0,67	1698	0,81	0,87	3,68	3,81	2,3	4,38	487,08
fEQuZl6P	[1960-1979]	semi-detached	1275	1506	300	0,78	3137	0,89	0,85	2,82	2,88	2,28	3,39	477,27
hRPmkwLs	[1960-1979]	semi-detached	1075	1071	216	0,8	1895	0,88	0,83	3,54	3,65	2,56	4,42	551,94
CbPETsjw	2000=>	corner house	941	1062	110	0,89	1961	1	0,82	3,66	3,66	3,66	4,44	578,23
VF54k5wO	[1920-1939]	freestanding	2910	2898	916	0,68	4310	0,74	0,82	3,39	3,68	1,92	4,51	1307,94
SZphemL4	[1980-1999]	freestanding	1433	1469	261	0,82	2254	0,86	0,81	4,01	4,17	2,67	5,16	883,82
aQ1RbqD6	[1980-1999]	freestanding	1280	1443	79	0,94	2265	0,98	0,81	4,44	4,47	4,04	5,53	1003,51
3voUJ8cb	[1920-1939]	semi-detached	2746	2855	1236	0,56	3624	0,62	0,8	2,87	3,38	1,52	4,22	957,67
3c1fUm5M	[1980-1999]	freestanding	1650	1824	507	0,71	2450	0,83	0,78	3,59	3,81	2,3	4,91	876,7
d7dbrO23	2000=>	semi-detached	1106	1146	128	0,89	2221	0,91	0,78	3,32	3,42	2,59	4,39	638,43
wEqq3ifR	<1900	freestanding	4317	4012	2883	0,31	5360	0,33	0,76	0,64	1,79	0,94	2,34	43,19
TkMyAOp1	[1980-1999]	freestanding	1850	1790	302	0,83	3264	0,92	0,75	3,32	3,42	2,67	4,54	1006,8
GdemEVzZ	2000=>	semi-detached	1265	1302	524	0,59	1736	0,7	0,74	2,71	3,18	1,61	4,27	471,68
e-V7pn_P	[1940-1959]	freestanding	2171	2307	1112	0,5	1650	0,54	0,74	3,37	4,91	1,35	6,67	987,58
aGIM-uhc	2000=>	freestanding	1680	1580	160	0,9	2685	0,92	0,73	3,8	3,93	2,91	5,35	1122,49
ez7d4xNY	[1940-1959]	corner house	1717	1742	167	0,9	2536	0,98	0,73	4,37	4,4	3,97	6,02	1291,77
cXHtdNjQ	[1980-1999]	freestanding	1863	2037	94	0,95	4519	0,98	0,72	2,85	2,87	2,73	4,01	1067,35
uTJqSvxx	2000=>	freestanding	1778	1554	462	0,72	2237	0,76	0,7	3,2	3,7	1,82	5,26	907,98
xSDmm63y	[1960-1979]	terraced house	1199	1391	799	0,38	745	0,42	0,7	1,79	4,53	1,08	6,49	427,99
5NNgThim	[1920-1939]	freestanding	3727	3718	811	0,78	4218	0,81	0,68	4,05	4,56	2,2	6,74	2565,16
h57Wozww	[1920-1939]	terraced house	2089	1886	200	0,9	2540	0,95	0,66	4,39	4,52	3,46	6,88	1590,1
vAibnS26	[1960-1979]	semi-detached	2489	2458	375	0,85	3234	0,89	0,65	3,85	4,12	2,62	6,34	1788,69
6-gOUJps	[1960-1979]	semi-detached	1809	2135	470	0,76	2590	0,84	0,64	3,22	3,63	2,05	5,67	1194,45
QtE_uvEX	[1960-1979]	terraced house	1098	1022	114	0,89	1491	0,9	0,62	3,6	3,86	2,53	6,2	795,93
eTBI5kYm	[1980-1999]	semi-detached	1589	1425	173	0,89	1831	0,96	0,61	4,22	4,35	3,43	7,12	1206,6
rC_pkM3K	2000=>	terraced house	1312	1275	349	0,73	1416	0,9	0,6	3,61	3,89	2,52	6,52	816,98
lVK0bORa	[1960-1979]	freestanding	2198	2377	921	0,6	1870	0,71	0,58	2,95	4,17	1,49	7,14	1238,3
e9WTomef	[1980-1999]	freestanding	2237	2000	462	0,78	2388	0,82	0,57	3,22	3,85	1,91	6,78	1462,73
yxOWx66O	[1980-1999]	freestanding	1560	1466	140	0,91	1465	0,92	0,57	4,86	5,21	3,13	9,16	1372,21
6oWZr5LM	[1980-1999]	freestanding	2558	2235	1256	0,48	1395	0,52	0,56	1,27	4,47	1,03	7,99	1084,45
9SiQCg0b	2000=>	semi-detached	1585	1305	284	0,8	1601	0,85	0,56	3,42	3,95	2,1	7,09	1048,19
MPjpuY8a	[1960-1979]	terraced house	1300	1049	310	0,74	1001	0,78	0,52	3,32	4,42	1,7	8,44	839,31
UigJRsPF	[1980-1999]	freestanding	2372	2195	659	0,71	2360	0,76	0,5	2,32	3,39	1,42	6,73	1428,98
l7_BBT0u	[1980-1999]	freestanding	4226	3945	1390	0,66	2728	0,75	0,5	3,16	4,81	1,5	9,65	2739,13
141Q2Shj	[1980-1999]	semi-detached	1444	1349	700	0,5	2370	0,55	0,49	0,22	1,4	0,76	2,87	191,64
sNLALR1w	[1920-1939]	freestanding	3658	3201	177	0,95	3881	0,97	0,49	3,88	4,02	3,27	8,19	3122,48
1Y5XKgSd	2000=>	freestanding	1282	1400	52	0,96	1432	0,96	0,48	4,09	4,26	3,32	8,8	1270,37
GjGxfcOD	[1920-1939]	freestanding	1973	1790	216	0,89	2230	0,89	0,48	3,01	3,47	2,08	7,3	1523,99
H6PEe0lX	[1960-1979]	-	1951	1814	409	0,78	2534	0,91	0,48	2,4	2,71	1,88	5,68	1173,62
Average			**1914**	**1850**	**507**	**0,748**	**2504**	**0,81**	**0,70**	**3,26**	**3,78**	**2,29**	**5,69**	**1051,97**
Quantity			44	44	44	44	44	44	44	44	44	44	44	44
Project avg.			**1914**	**1835**	**483**	**0,748**	**2514**	**0,83**	**0,75**	**3,34**	**3,82**	**2,27**	**5,67**	**1017,88**
No. of projects			168	170	168	158	132	152	152	120	117	120	120	120

By installing Jupyterlab and running the published notebooks, it is possible to generate the complete table of the previous page [6]. An explanation of the terms introduced and included in the table:

Gas savings

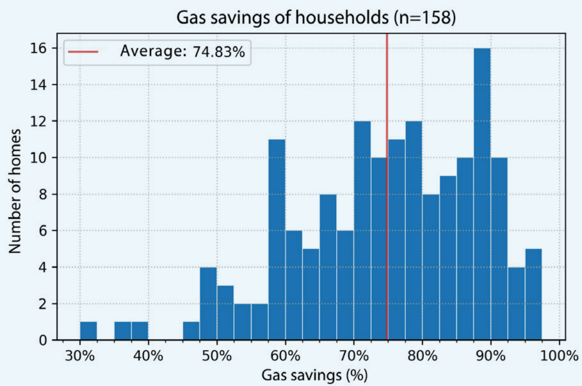
The average gas savings of 168 participants is 75%. The spread is from 31 to 97%. There are 25 participants where the savings are less than 60%. Among these are homes with low SCOP values. Even some below 2. This indicates a heat pump not properly installed (amount of F gas) or not functioning properly. In addition, in this group there are poor installations that limit the heat pump portion of the hybrid resulting in low gas savings. For example, the 6oWZr5LM shows unnecessarily high water temperatures. The control behavior of the xSDmm63y was so strange that the house was visited (see also plot in Appendix 6 or find participant in [12]). The radiators of this cooperative house appeared to be built away in a low air permeable casing. A construction that for aesthetic reasons is used more often. Especially in older homes quite often visible.

Moreover, a number of homes in this less than 60% group, performs excellent in terms of financial returns. As a result, residents think the installation is working as it should and do not consult their installer. For example, the e-V7pn_P which shows gas savings of 50% on a starting value of the around 2200 m^3 and where the hybrid yields €987 annually. A poor performance compared to the UigJRsPF which also started around 2200 m^3 but shows a savings of 71% and saves 1482 euros per year. Or even better the vAibnS26 which started around 2500 m^3 and uses 85% less gas and saves the occupant 1789 euros per year.

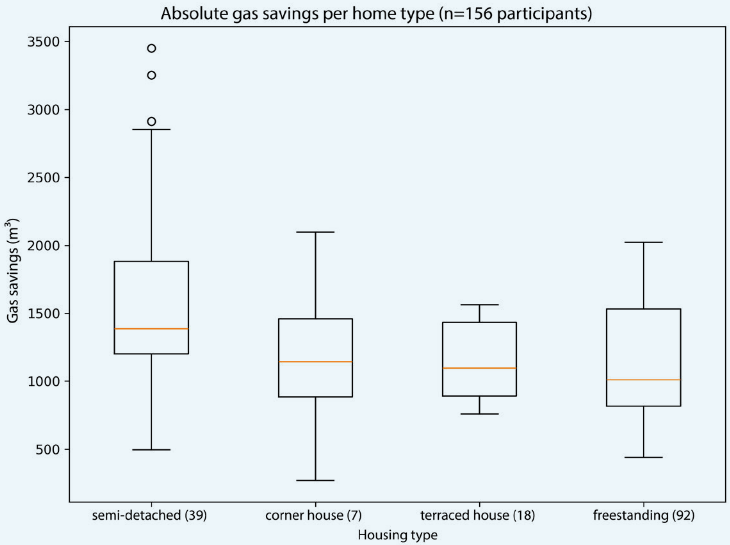
Finally, the wEqq3ifR which shows only 31% savings from a starting value of around 4200 m³. The l7_BBT0u which started from 4000 m³ and which with 66% savings gives the resident 2739 euros per month shows what is possible. The hybrids used in the project had between 5 and 7 kW of power. Even with an initial use of 4000 m³ gas, a very good performance is still possible with a hybrid of around 6 kW.

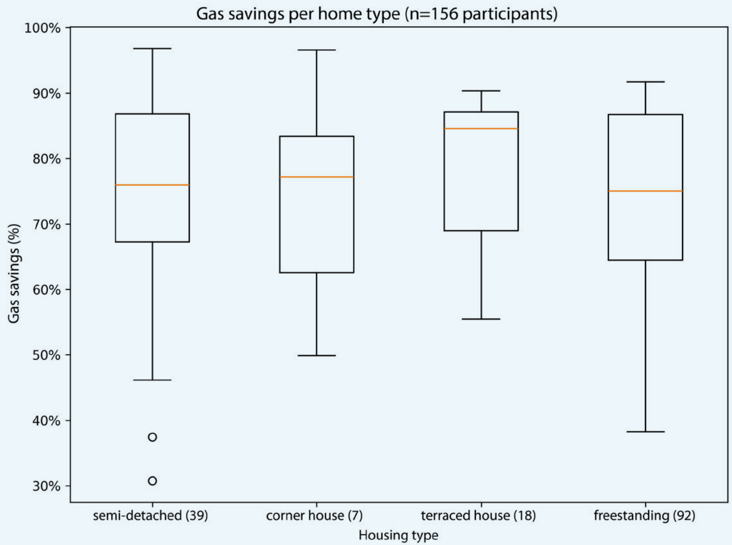
Remarkably, small homes did not do worse in terms of gas savings (see plots page 31). A few homes with very high gas savings were found to have shower heat recovery or were using hot water very sparingly (plot page 31).

Like the other terms in the table, gas usage, as indicated, was determined over the period from May 2023 to May 2024. For verification, shifting the annual period to a different start and end month was examined. This gave no different result (plot Appendix 3).



Gas gaving per type of home





Gas saving quatation

People sometimes speak of a warm winter but that is a statement with limited meaning (at least in the short term of years). The difference between winters in recent years is not that big. One way to relate gas use heating to winter weather is to use so-called degree days or effective degree days [13, 14]. Appendix 2 shows the degree days for recent years. No major differences are visible.

It is known that homes show fairly constant energy use over the years. This was also evident in almost all cases from the pre-reported usage over two energy years.

The measured tap water use and measured heat demand of the home can be related to the gas use before installation of the hybrid. This then gives an impression of how the gas use for heating and the heat demand are related. This is expressed in the gas loss factor. The amazing thing is that on average only 75% of the energy value of the gas (from top calorific value) was useful to the occupant. The purity of this calculation could possibly be questioned but the gap is so large and so wide across the population that surely there is a substantial loss.

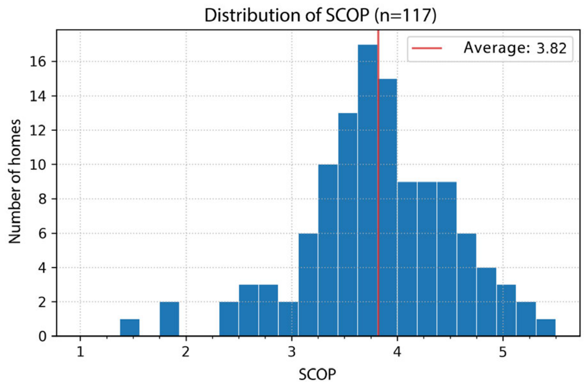
Thus, it has been assumed that the use of the property is constant over the years. In general, this will be true. Many residents also stated this in the survey conducted (Appendix 11) The average value of all living room temperature sensors also indicates constant use (Appendix 2 page 46).

SCOP_lower limit

The most obvious way to look at the SCOP of the hybrid is to subtract energy value of the gas portion, still needed for heating, from the measured heat demand. Then by dividing by the hybrid's measured electricity use, the SCOP follows. This then includes the assumption that all the heat potentially contained in the gas also arrives at the occupant as heat. The previous consideration of the gas loss factor indicates this is not the case. This approach to the SCOP does give a minimum under-value: a value that is correct if all the energy of the gas is converted to heat. The average SCOP under-value over 120 participants was determined to be 3.34.

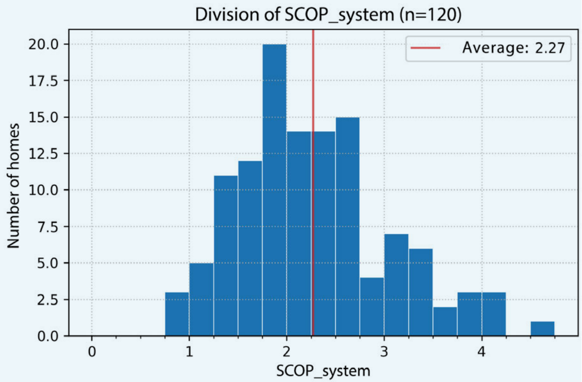
SCOP

From the SCOP lower bound, the SCOP follows by taking into account the gas loss factor of the house in question. Indeed, the gas loss factor can be seen as an estimate of the efficiency of gas conversion to heat. Because in most homes the remaining gas part heating after hybrid installation is not that large, the difference of this determination with the lower value of the SCOP is limited. This is not the case in the previously discussed cases with less than 60% gas savings. The difference between the SCOP and its lower bound can be significant there. The average SCOP value across 120 participants is 3.82. This number is very close to the certificate values used at the time [1].



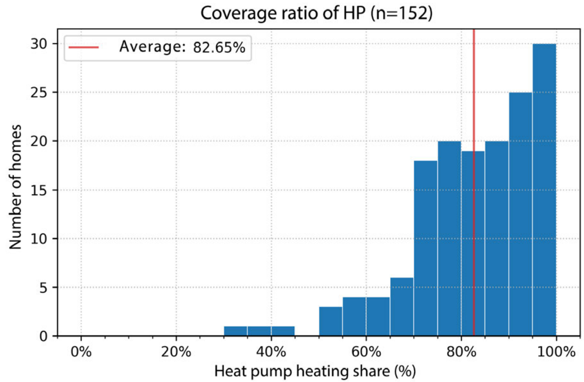
SCOP_system

The hybrid heats the home by using gas and electricity. With this in mind, the SCOP for the system was defined. The average system SCOP over 120 participants is 2.27. In some cases, the system SCOP equals SCOP. In those cases, the gas heating part is zero. The heat pump part of the hybrid was then able to supply the full heating demand (coverage ratio=1).



Coverage ratio

The degree of coverage indicates which part of the heat demand for heating is met by the heat pump component. The gas loss factor takes into account the incomplete conversion of gas into heat. The average degree of coverage over 152 participants is 83% In a number of houses (30) the hybrid covers more than 97.5% of the heat demand for heating (plot page 31). There are 4 participants where the heat pump generated the full heat demand, or a coverage ratio equal to 1 (in 3 other cases, coverage ratio 1 is a rounded value).

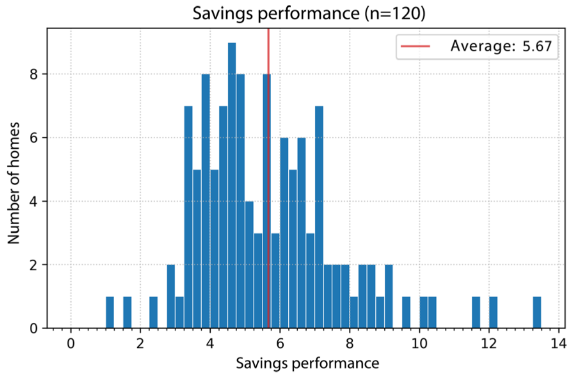


Savings performance

From the perception and financial perspective of residents, the assessment of the hybrid heat pump is about the saving of gas and the additional usage of electricity. In other words, how effective is the addition of the hybrid to the installation? This is why the concept of saving performance was introduced. The savings performance is the energy value of the amount of gas saved divided by the electricity required for it.

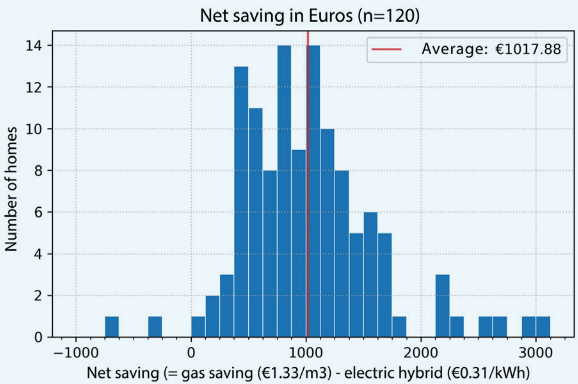
It is quite often assumed that a boiler converts all the gas into useful heat. Based on this, the savings performance should be (almost) equal to the COP. After all, the energy value of the amount of gas saved is now generated by the heat pump. The curious thing now is that the savings performance is a much larger number than the SCOP. Averaged over 120 homes, the savings performance is 5.7. This compares to a SCOP value of 3.8. The savings performance shows that the average participant saves 5.7 kWh of gas with 1 kWh of electricity. Or 1m^3 (9.77 kWh) gas savings gives 1.7 kWh use of electricity. With the current June 2024 energy rates for gas and electricity, that gives an average revenue of 0.8 euros (1.33-1.7*0.31) for every cubic meter of gas saved by a hybrid [11].

Appendix 1 shows how the annual savings from the hybrid can be calculated using the savings performance and the price ratio. It also shows the sensitivity of the savings to changes in the price ratio and savings performance.



Financial savings

From the average gas savings and electricity use by the hybrid, the annual financial savings can be calculated directly. This is indicated in the last column of the table and is 1017 euros. This assumes the market average of the June 2024 rates: 1.33 euros for a m^3 gas and 0.31 for a kWh [11].



Notes

- The obvious idea is that the savings performance should be approximately equal to the SCOP. Similarly, it is thought that the gas loss factor should be approximately equal to 1. **Both the savings performance and the gas loss factor show that there is an energy gap between the situation prior to and the situation after installation of the hybrid.** Where could this better-than-expected performance come from? The obvious explanation is the increase in modulation range. Most installations equipped with a central heating boiler modulate for heating between a minimum output of 5-7 kW and a maximum output of about 20 kW. With the addition of the hybrid, the minimum power goes back to the 1-2 kW range. This will result in the installation being able to run at totally different temperatures as before. It is therefore noteworthy in this context that it is visible that many installations run almost the entire year below 35-40 °C and sometimes even below 30 °C supply. With the higher minimum output of a boiler, this would be impossible. In addition, of course, the control of the hybrid plays a role.

In any case, the measured water temperatures are much lower than what was thought possible. In fact, the dispensing systems involved in this study can be seen as low-temperature systems. Thereby it is also true that almost all participants have radiators and in about 30% of the cases only radiators. The hybrid is capable of running at low power with low water temperatures for long periods (as also visible in the plot of Chapter 3).

- **Because of the lower water temperatures and higher modulation range, the systems switch less.** The lower water temperatures also produce less heating of the structural environment of pipes and radiators, reducing premature heat leakage (loss of heat before it has reached the living space). The less switching has been noted by residents who indicated that the heat from the hybrid produced a more comfortable heat because it is more evenly divided over the room.
- **There has been much discussion about whether or not buffer tanks are useful.** There are installers who argue that in combination with a hybrid, a buffer tank is always necessary. While others believe it is only necessary with in-market zone control systems where all zones can shut down. Because then the flow rate drops which causes the hybrid to shut down. The manufacturers of zone systems have now also realized this and are coming up with solutions that always guarantee enough flow (e.g., hydraulic abgleich in floor heating or control valves instead of open-close valves).
- In many homes there are relatively long pipes to the living room and kitchen where the radiators are always open. The supply pipes quite often run partially through unheated rooms.
- **Through so-called radiator fans or blown convectors, heat can be dispersed much faster.** Previous studies have already questioned the effectiveness of this type of solution [19]. It was found that with well-designed radiator fans, considerable reductions in heat demand can be achieved (order 15-20%) at constant room temperatures. Despite the wall and thus the insulation of the house remaining the same, the heat demand decreases. This is possible due to better heat dispersion. Appendix 9 illustrates how lower water temperatures and better heat dispersion can contribute to a lower delta T, while maintaining the same temperature in the center of the room.

- **Whether or not the boiler was replaced when the hybrid was installed could affect the readings.** It cannot be fully ascertained but it is the case that in the vast majority of dwellings the existing boiler stayed in place when the hybrid was installed.
- A number of datapoints do require comments. For example, there are participants who reported very different energy consumption over two years or other questionable usage numbers. Only in a few exceptional cases where it was obvious or known that the data were not correct, the participant was removed from the results.

The above points led to a research issue that is included in Appendix 5.

In the process, it was determined that:

- Heat losses from transmission lines between generation and distribution can be very large (order 15% and more).
- The best solution for small delivery systems is a heat pump with a low minimum power (1 kW) and the use of delivery improvement (radiator fans or convectors). Even in a small setup with two radiators, the system then runs continuously at 35 °C supply temperature.
- Small buffer vessels help only very little against cyclic on-off behavior. Especially compared to release enhancement.
- Buffer vessels, no matter how switched, give a heat loss on the order of 10%.
- There is still much room for Improvement on the system and the distribution of heat.

5. CONCLUSIONS AND RECOMMENDATIONS

The main research questions are:

1) **How much is the decrease in gas consumption after installation of a hybrid heat pump.**
2) **What is the effect on total energy usage and thus bill for the residents.**

The answers to these questions and the surrounding context have been discussed in the previous chapters.

Conclusions

- The participating homes had a prior two-year average gas use of 1875 m^3. **Installation of the hybrid reduced gas use by an average of 75% to 478 m^3 for 158 households.** On average, the hybrid required 2514 kWh of electricity for this reduction.
- Calculated with June 2024 energy prices: 1.33 euros for a cubic meter of gas and 0.31 euros for a kWh of electricity, **this results in an annual reduction in energy bills amounting to 1018 euros.**
- The average 75% reduction in gas use is much more than the 55% previously assumed [1]. A 75% reduction was considered feasible only for homes equipped with LT (low temperature) heating systems. Almost all participants have radiators and 30% have only radiators. **The hybrid can heat the home well for long periods of time with low water temperatures. Even with radiators.** A remarkable result.
- It was previously thought that the reduction in gas use and the electricity required to do so are related through the COP. This turns out not to be the case. **The reduction in gas use and the increased use of electricity are related to each other by a factor of 5.7.** This is called the savings performance. While the COP is 3.8. The measured COP value agrees well with known values from certificates [1].

The hybrid increases the modulation range and lowers water temperatures of the heating system.

- Re-calculating the measured heat load and gas use for showering and cooking to previous years, and comparing to prior energy use, shows a surprisingly large gap (the gas loss factor) for many participants. Inevitable conclusion is that **heating systems equipped with a hybrid, as a whole, perform better than those equipped with a boiler alone.**
- The spread in the results is wide: there are participants with more than 90% gas savings but also participants with less than 40%. This also applies to the electricity use of the hybrid. **A relatively low gas savings may be accompanied by a relatively high electricity use.** The group of participants with 60% or less gas savings is quite large at 20%. In almost all cases, it can be seen directly from the measurement data that there is room for improvement.
- If out of a total of 158 participants, the group with gas savings of 60% or less is removed (i.e., these low values can still be improved), **then the average of the remaining 133 participants rises to 80% gas savings.** The spread in water temperature values is also appreciable. Homes with low temperatures do much better (Appendix 3). There is still much room for improvement.
- The mindset of the market has always been focused on comfort and no complaints (often resulting in high supply temperatures) and not on high efficiency of the heating system as a whole (though in parts). The surprise of the savings performance, the gas loss factor and the partial study conducted show that efficiency of the distribution and dispensing system is uncharted territory. **The quality of the distribution system and controls are critical to achieve good performance in all cases.** In order to successfully implement the hybrid in large numbers, a "through measurement to knowledge approach" will be needed.
- In 30 of the 174 participants, the hybrid took over 97.5% of the heating demand and in four cases completely. The nuance here is that recent winters have shown few so-called icy days with low daytime temperatures. Still, depending on circumstances such as available space for a domestic hot water tank, **the quality of the heating system and the degree of insulation, the next step to completely decarbonized systems** seems relatively easy for these participants.

Recommendations

- **The research has shown that the performance of the heating system as a whole is an unknown area where much remains to be gained.** This will require the measuring and comparing of the performances of heating systems.
- **The dispersion in results and especially the relatively large number where the hybrid and/or installation are not functioning properly is of concern.** A quality improvement is certainly needed in the coming years to ensure that all hybrid installations are functioning properly.
- **Meanwhile, new developments are seen, included hybrid domestic hot water, cooperation with storage and integration with energy management systems.** In some cases, participants had experimented successfully with the distribution system (fan strips and LT radiators [19]). There are also participants where the dwellings have shower water heat recovery systems. Social housing organizations also use these systemd more frequently. The summation of the hybrid with these types of improvements, which are apparently already being applied, can further shape the transition of the built environment. It sometimes seems that this more pragmatic approach does not get the attention of the more model-driven regulations. It therefore deserves further investigation and encouragement.
- **The new EU data act requires manufacturers to make usage data fully and easily accessible.** A number of devices on the market already have the data used in this study on board as standard. On-line recording, measurement and comparison of performance, should become the standard.

ATTACHMENTS

Appendix 1	Calculation of annual saving through savings performance
Appendix 2	Degree Days and Indoor Temperature
Appendix 3	Population distributions
Appendix 4	Behavior over time of the population
Appendix 5	Sub-study performance buffer tank and dispensing
Appendix 6	Graphana dashboards of some participants
Appendix 7	Jupyter table of all participants
Appendix 8	Measurement set description and specifications.
Appendix 9	Water temperature, delta T and warm air dispersion
Appendix 10	Screenshots WebApp - H6PEe0lX
Appendix 11	Participant survey

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[16] https://dacs-hw.nl/

[17] Program_acceleration_sustainability_built_environment-1.pdf - page 19 - https://www.klimaatakkoord.nl/actueel/nieuws/2022/06/02/hoofdlijnen-klimaatbeleid-voor-de-gebouwde-omgeving

[18] pbl-2023-climate-and-energy-research-2023-part-1-5108.pdf - page 49 - 2.5e6*1.8*378*1e-9 = 1.7 Mton

[19] Scientific_verification_HR_hybrid_practice_tests_UT_final4.0.pdf

Appendix 1: Calculating annual saving through savings performance

As indicated on the next page, based on the concepts in Chapter 4, with the savings performance and the price ratio, the ratio of gas to electricity prices, a relationship for the annual saving of the hybrid can be written down:
earning in euros = gas savings∗gas price∗h_factor

The relationship indicates through the correction factor what part of gas savings is lost due to the more use of electricity by the hybrid. Currently, the gas price is 1.33 and the electricity price is 0.31 [11]. The price ratio is then 0.31/(1.33/9.77)=2.28. With a savings performance of 5.7, a correction factor of 0.60 then follows from the graph or formula on the next page.

Suppose the estimate is that 1000 m3 of gas will be saved by installing the hybrid. Then for annual saving follows:
1000∗1.33∗0.60 = 798 euros

The average participant in the demo project saved 1400 m^3. Then for the average savings amount of the project follows:
11400∗1.33∗0.60 = 1117 euros

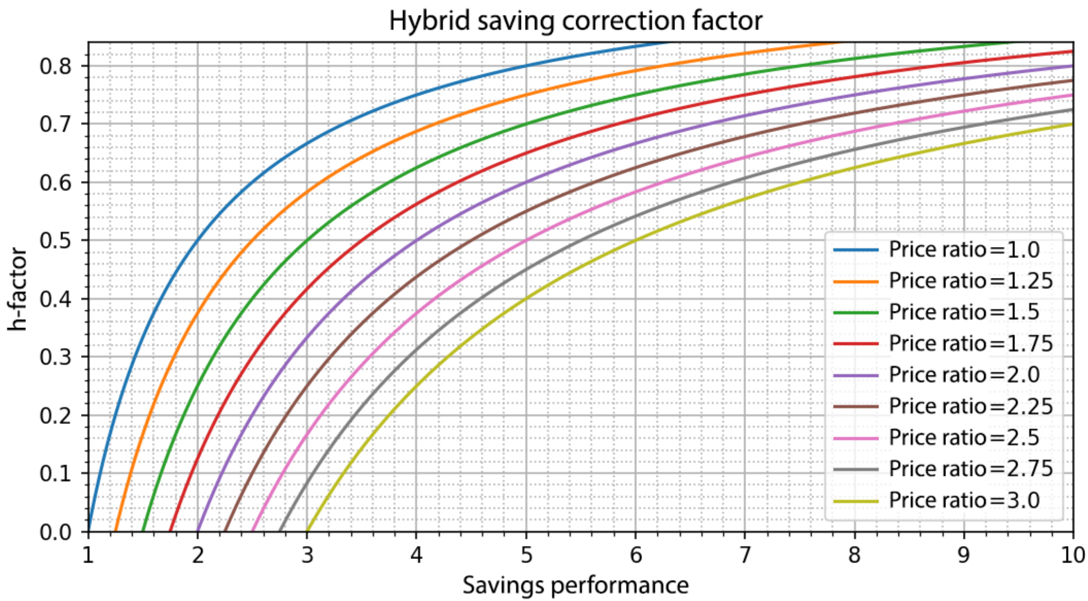
The graph on the next page shows that savings performance can have a strong knock-on effect. Especially if it is much too low. The price ratio has a less strong knock-on effect. Historically, the electricity price to gas price ratio has been indicated by the gas plant. More and more electricity is coming from non-fossil sources. The fluctuations of generation from natural sources is large. Clearly, both the fossil ratio in the price ratio and also the constancy of energy prices are coming under pressure.

Saving performance: **gas saving / elek_hybrid**

Saving: **gas savings*gas_price - elek_hybrid*elek_price**

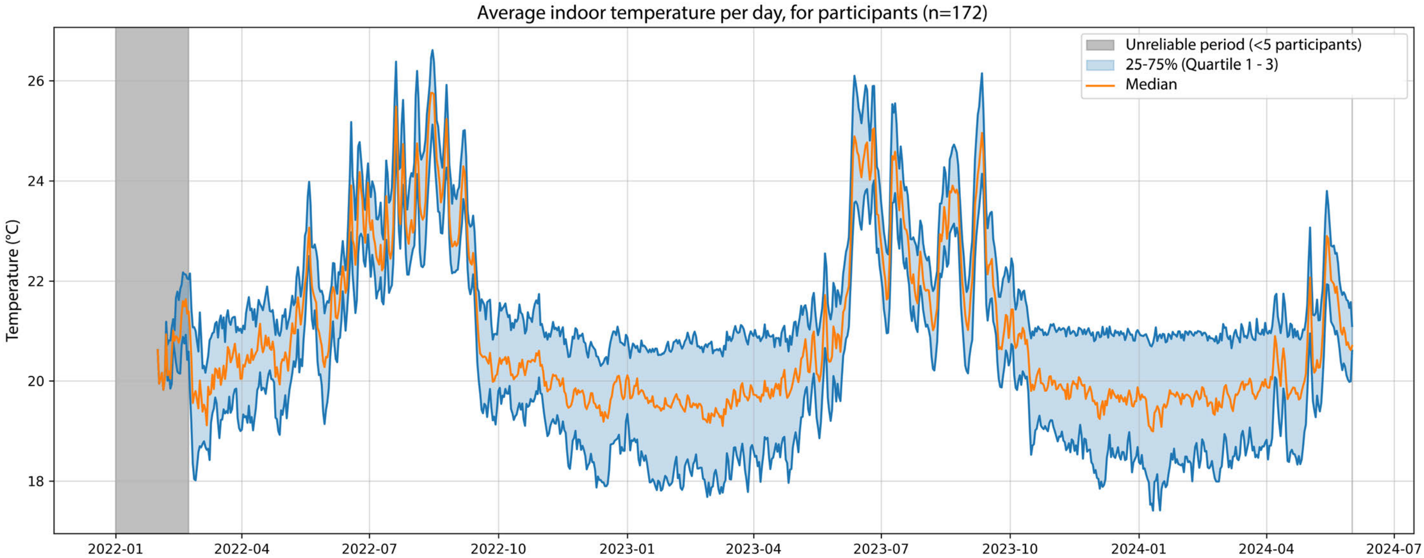
Earnings: **gas savings*gas_price*(1 - price ratio/savings performance) | price ratio=elek price/gas price**

Price Earnings: **gas savings*gas_price*h_factor**

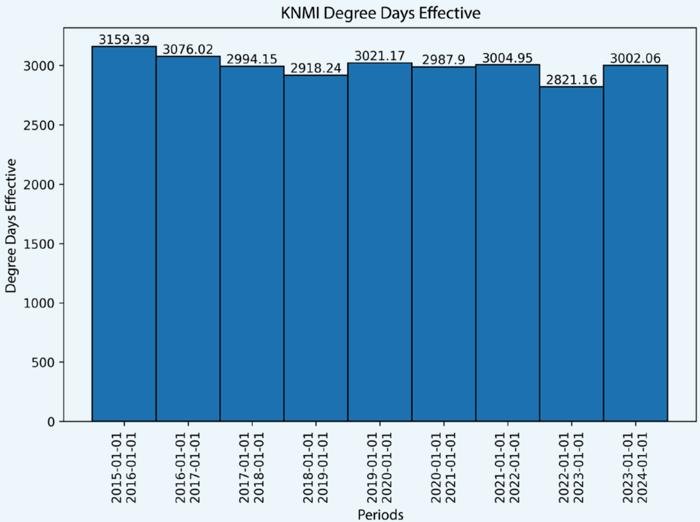


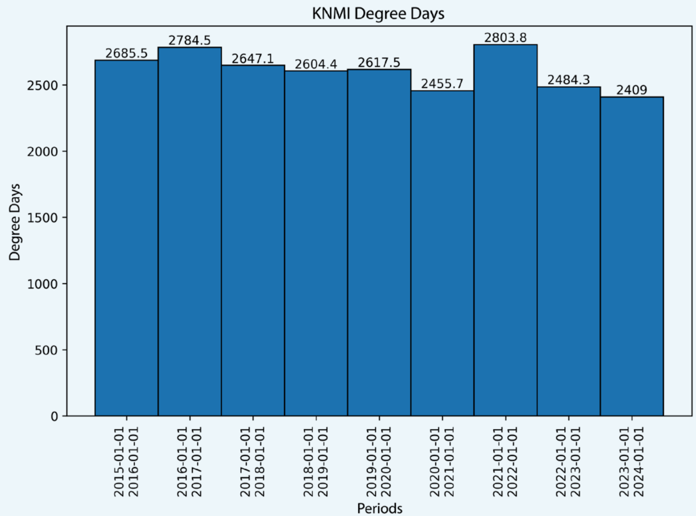
Appendix 2: Degree Days and Indoor Temperature

The figure below shows that the average temperature across all participants has been in the range of 19 to 20 °C for the past two winter seasons. The measurement sensor in the living room was placed randomly. Since spread of temperature in rooms can be quite a few degrees, and can depend strongly on the position in the room, an individual value has no exact meaning. An average of 19.5 does not seem strange. More than half of the participants indicated that they had not changed their heating behavior in recent years.

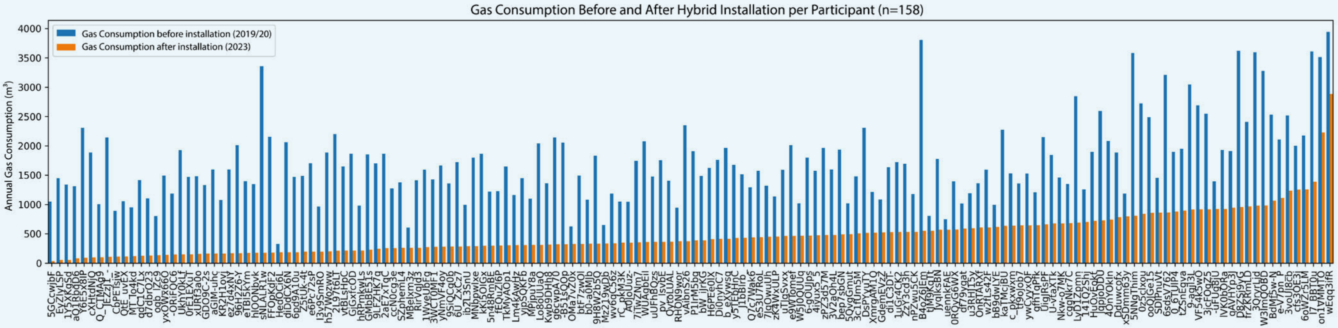


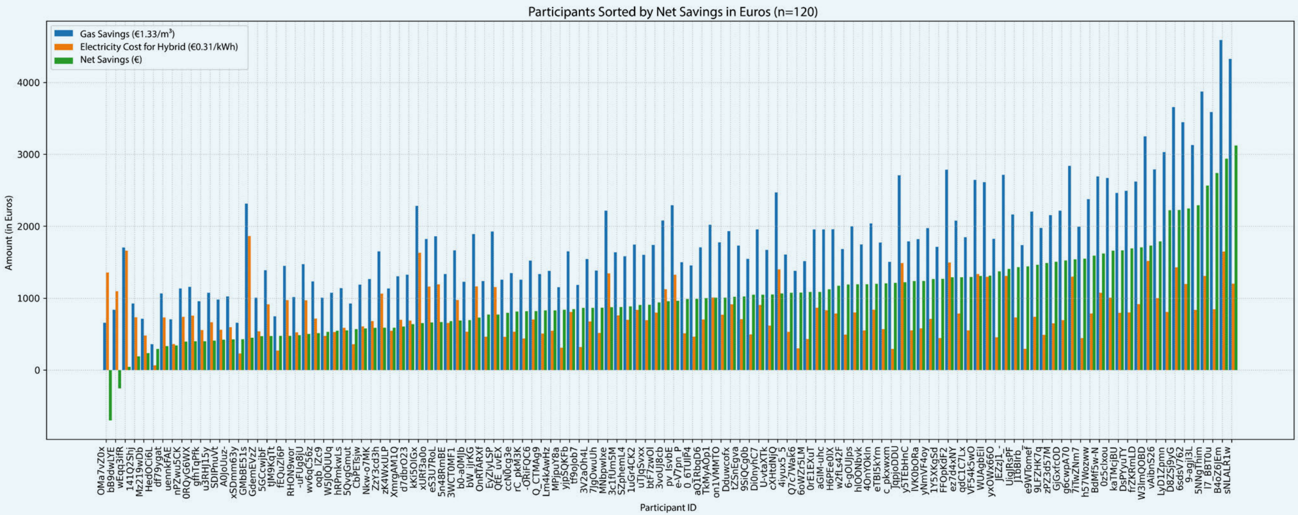
The The graphs below shows the degree days and effective degree days over the past few years. The effective degree days were developed as a concept to compare the gas use over the years [13] . The period of the annual energy use accounts do not correspond to calendar years. In any case, a difference between participants' statements for 2019-2020 and 2020-2021 is not strongly visible (no big difference between columns gas_for1 and gas_for2, table page 28).

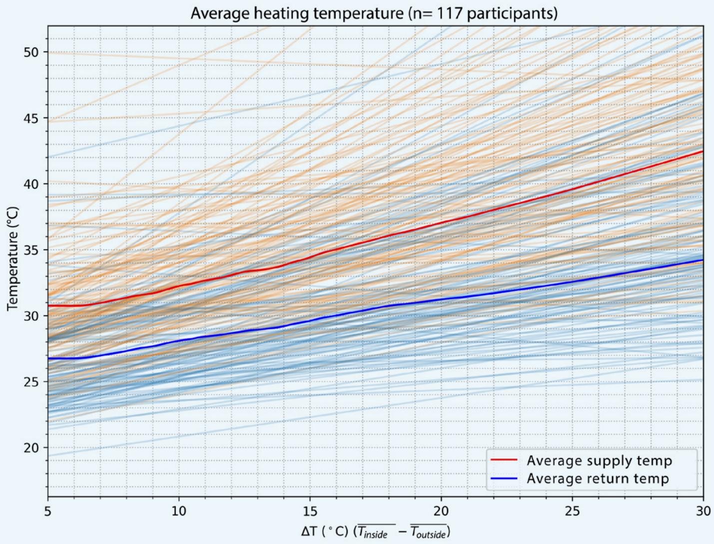


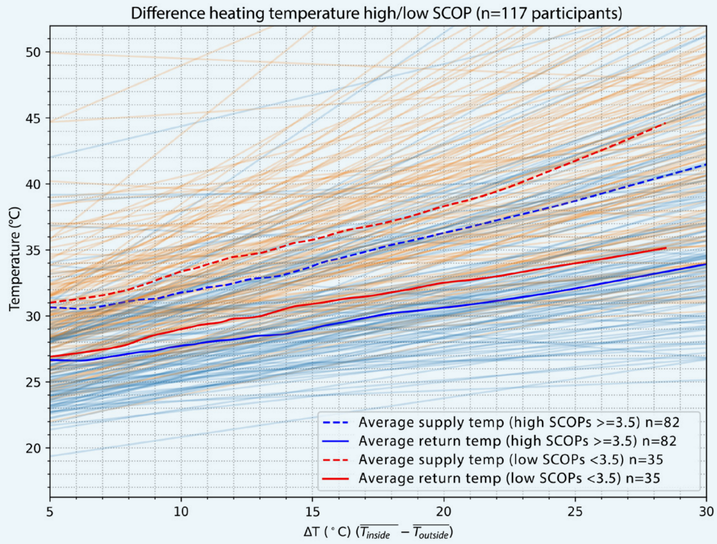


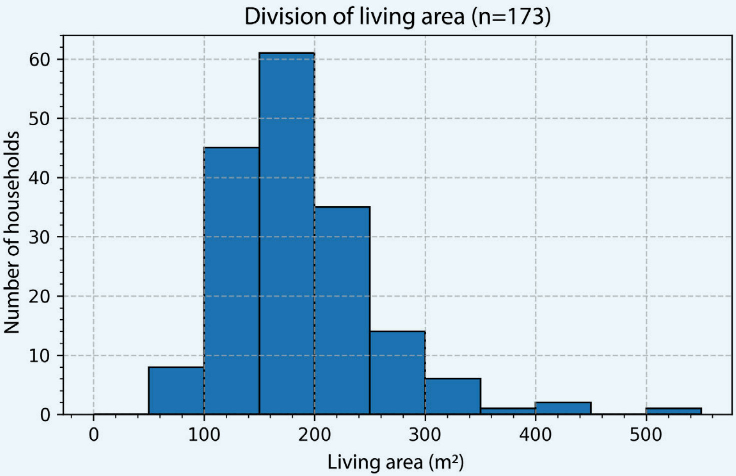
Appendix 3: Population distributions

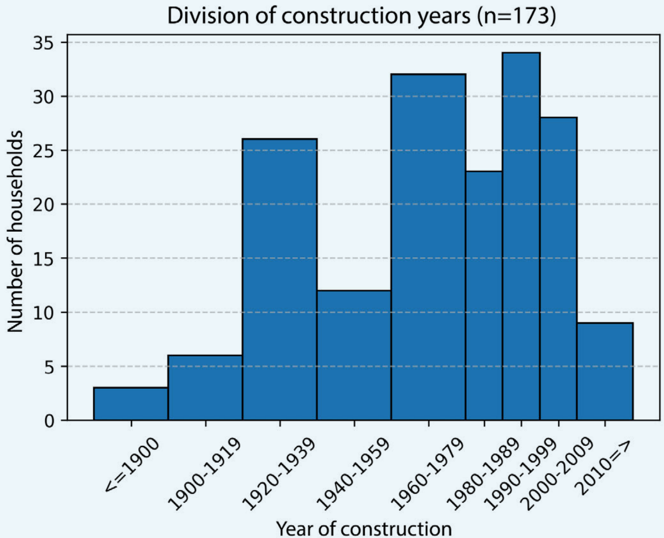


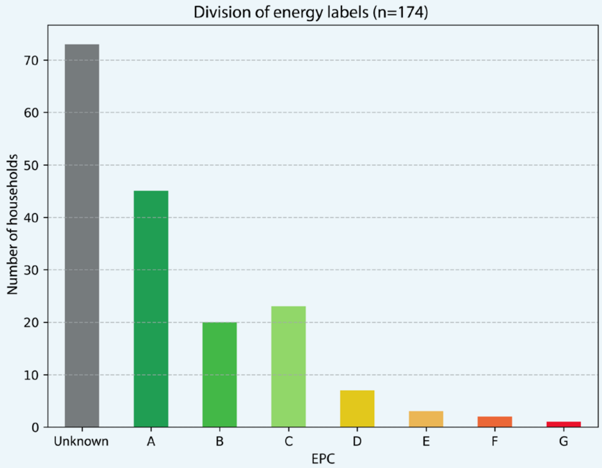


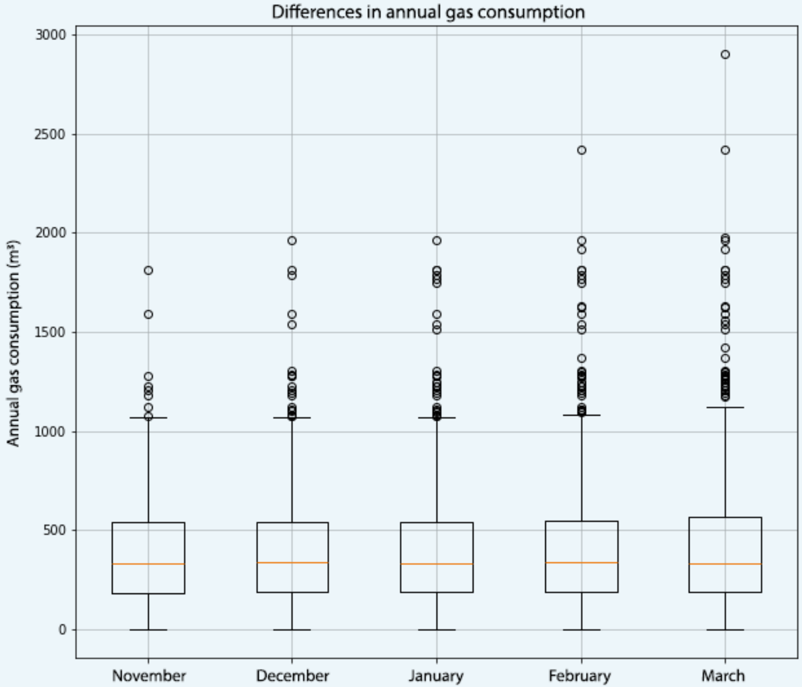

Average heating temperature (n= 117 participants)
Temperature (°C)
ΔT (°C) ($\overline{T_{inside}} - \overline{T_{outside}}$)
Average supply temp
Average return temp

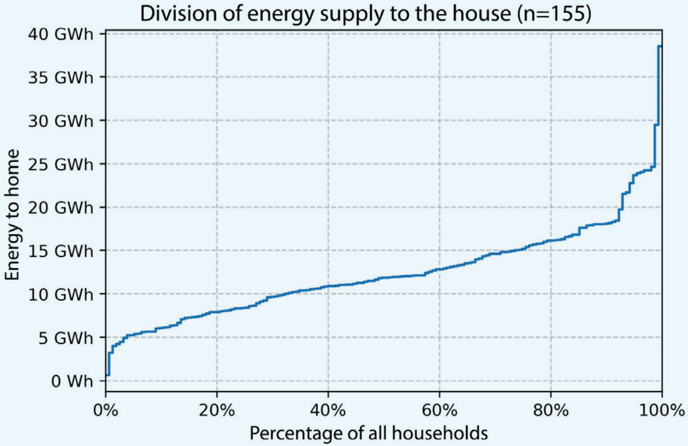

Difference heating temperature high/low SCOP (n=117 participants)
Temperature (°C)
ΔT (°C) ($\overline{T_{inside}} - \overline{T_{outside}}$)
Average supply temp (high SCOPs >=3.5) n=82
Average return temp (high SCOPs >=3.5) n=82
Average supply temp (low SCOPs <3.5) n=35
Average return temp (low SCOPs <3.5) n=35

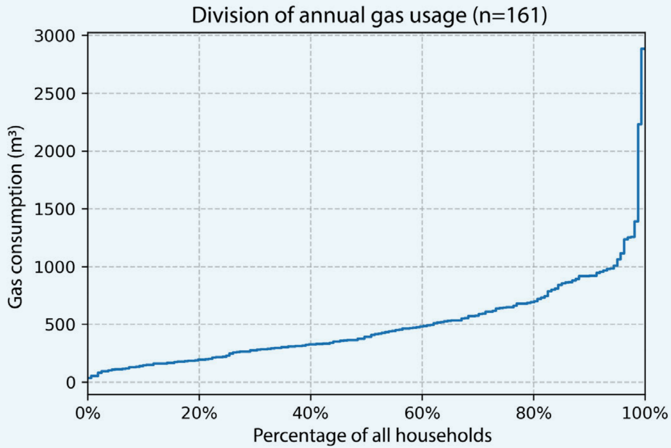

Division of living area (n=173)
Number of households
0
10
20
30
40
50
60
0
100
200
300
400
500
Living area (m²)

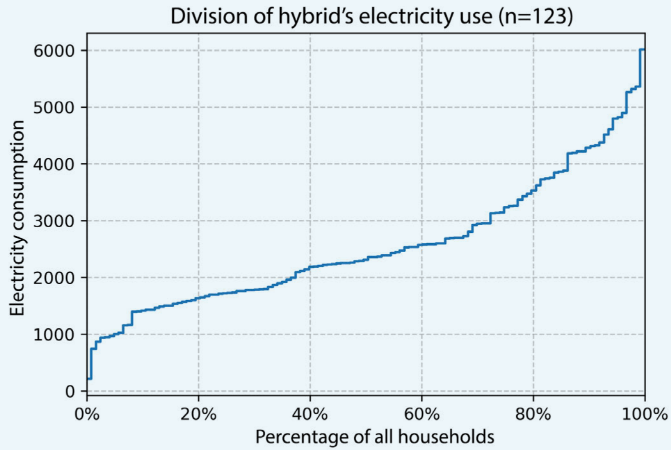

Division of construction years (n=173)
Number of households
0
5
10
15
20
25
30
35
<=1900
1900-1919
1920-1939
1940-1959
1960-1979
1980-1989
1990-1999
2000-2009
2010=>
Year of construction

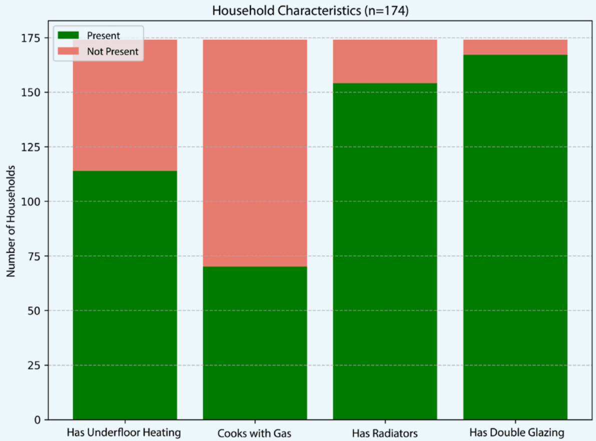

Division of energy labels (n=174)
Number of households
0
10
20
30
40
50
60
70
Unknown
A
B
C
D
E
F
G
EPC

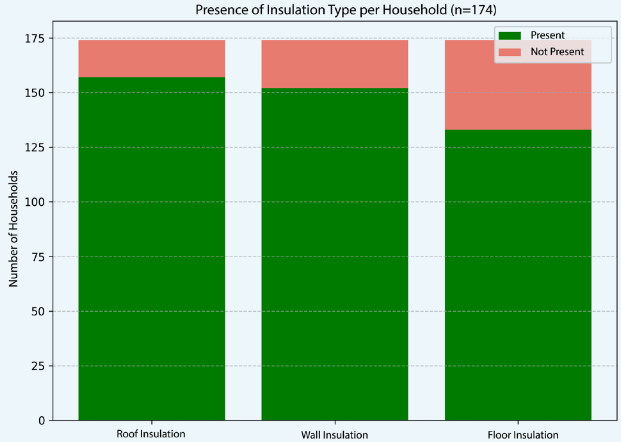

Differences in annual gas consumption
Annual gas consumption (m³)
0
500
1000
1500
2000
2500
3000
November
December
January
February
March

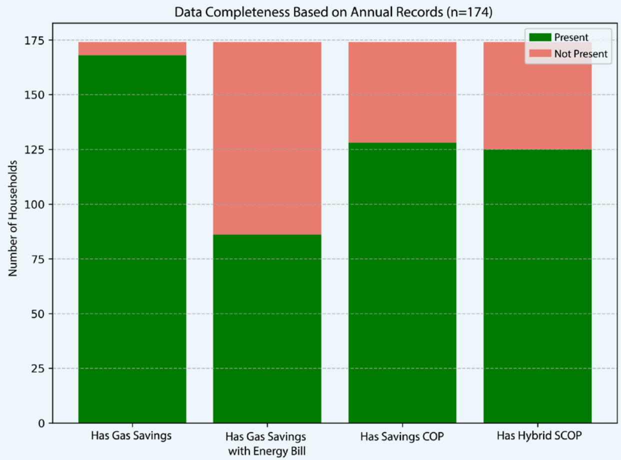

Division of energy supply to the house (n=155)
Energy to home
40 GWh
35 GWh
30 GWh
25 GWh
20 GWh
15 GWh
10 GWh
5 GWh
0 Wh
0%
20%
40%
60%
80%
100%
Percentage of all households

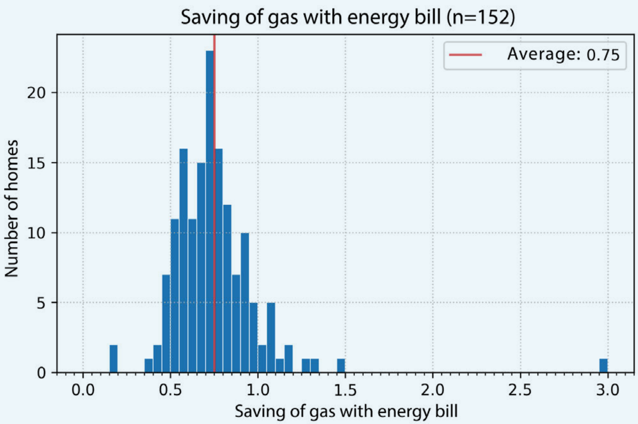

Division of annual gas usage (n=161)
Gas consumption (m³)
3000
2500
2000
1500
1000
500
0
0%
20%
40%
60%
80%
100%
Percentage of all households

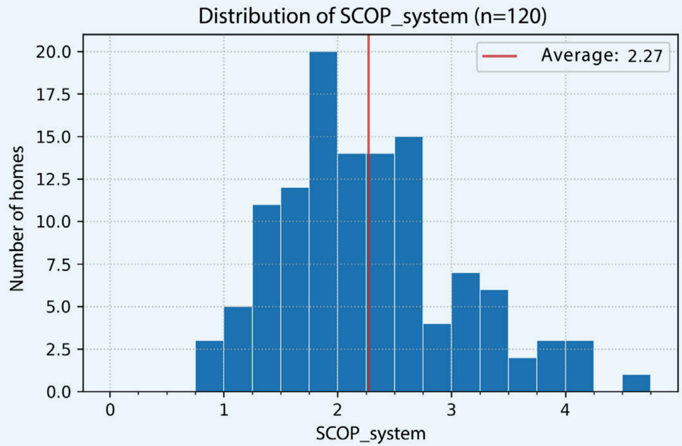

Division of hybrid's electricity use (n=123)
Electricity consumption
6000
5000
4000
3000
2000
1000
0
0%
20%
40%
60%
80%
100%
Percentage of all households

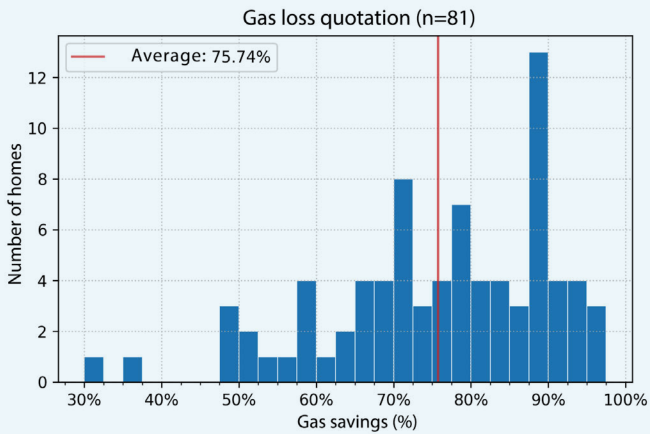

Household Characteristics (n=174)
Present
Not Present
Number of Households
0
25
50
75
100
125
150
175
Has Underfloor Heating
Cooks with Gas
Has Radiators
Has Double Glazing

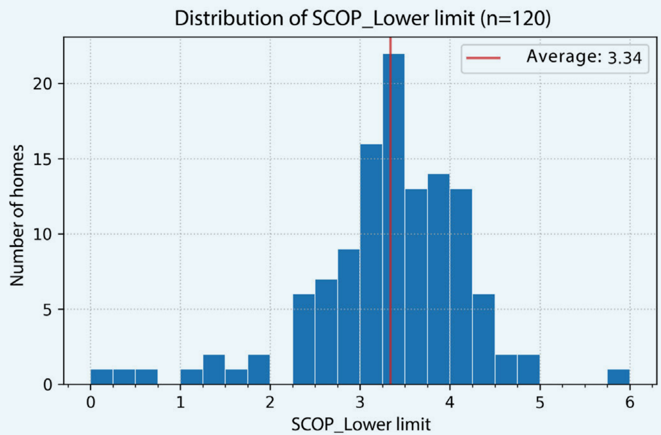

Presence of Insulation Type per Household (n=174)
Present
Not Present
Number of Households
0
25
50
75
100
125
150
175
Roof Insulation
Wall Insulation
Floor Insulation


Data Completeness Based on Annual Records (n=174)
Present
Not Present
Number of Households
0
25
50
75
100
125
150
175
Has Gas Savings
Has Gas Savings with Energy Bill
Has Savings COP
Has Hybrid SCOP

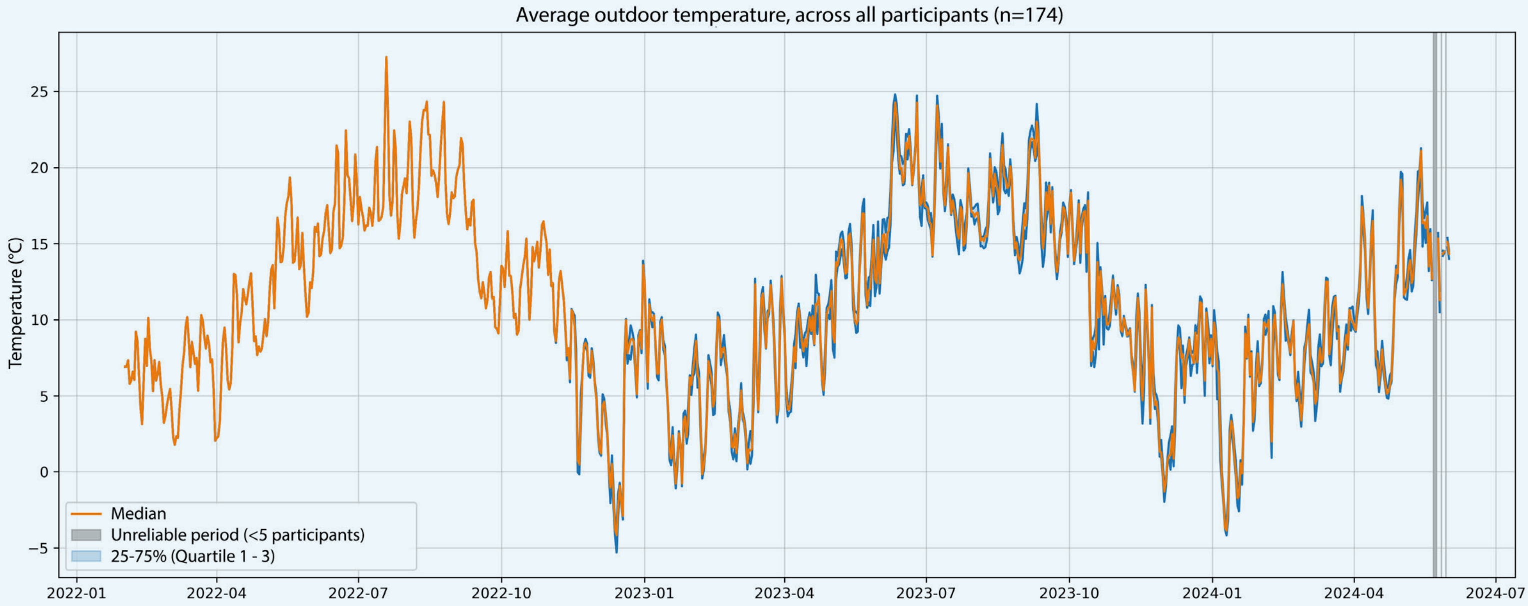

Saving of gas with energy bill (n=152)
Average: 0.75
Number of homes
Saving of gas with energy bill
0
5
10
15
20
0.0
0.5
1.0
1.5
2.0
2.5
3.0

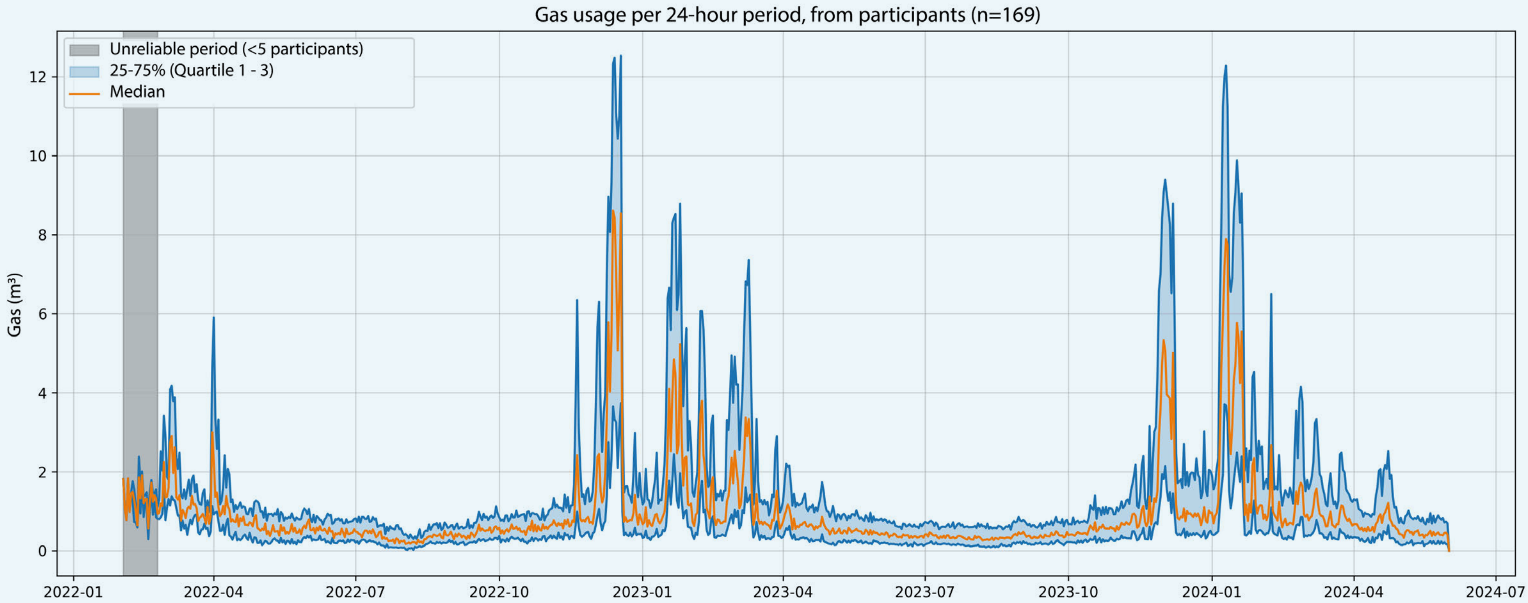

Distribution of SCOP_system (n=120)
Average: 2.27
Number of homes
SCOP_system
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
0
1
2
3
4

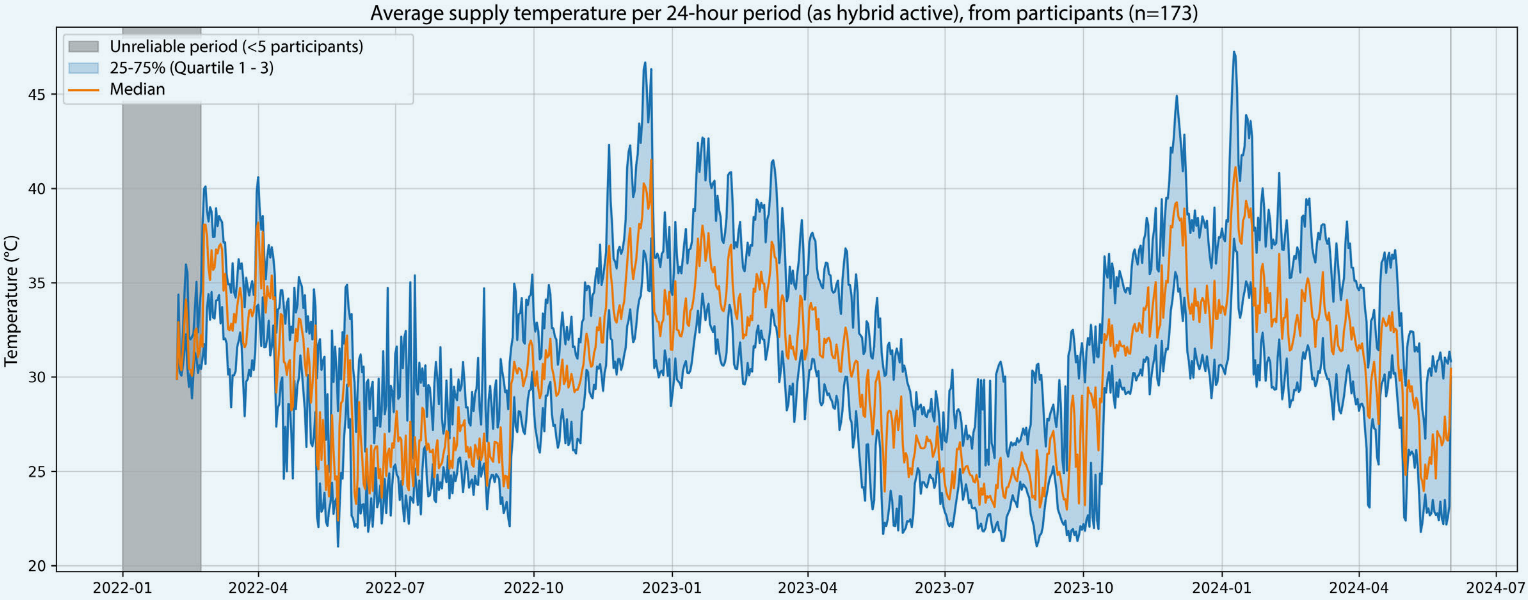

Gas loss quotation (n=81)
Average: 75.74%
Number of homes
Gas savings (%)
0
2
4
6
8
10
12
30%
40%
50%
60%
70%
80%
90%
100%

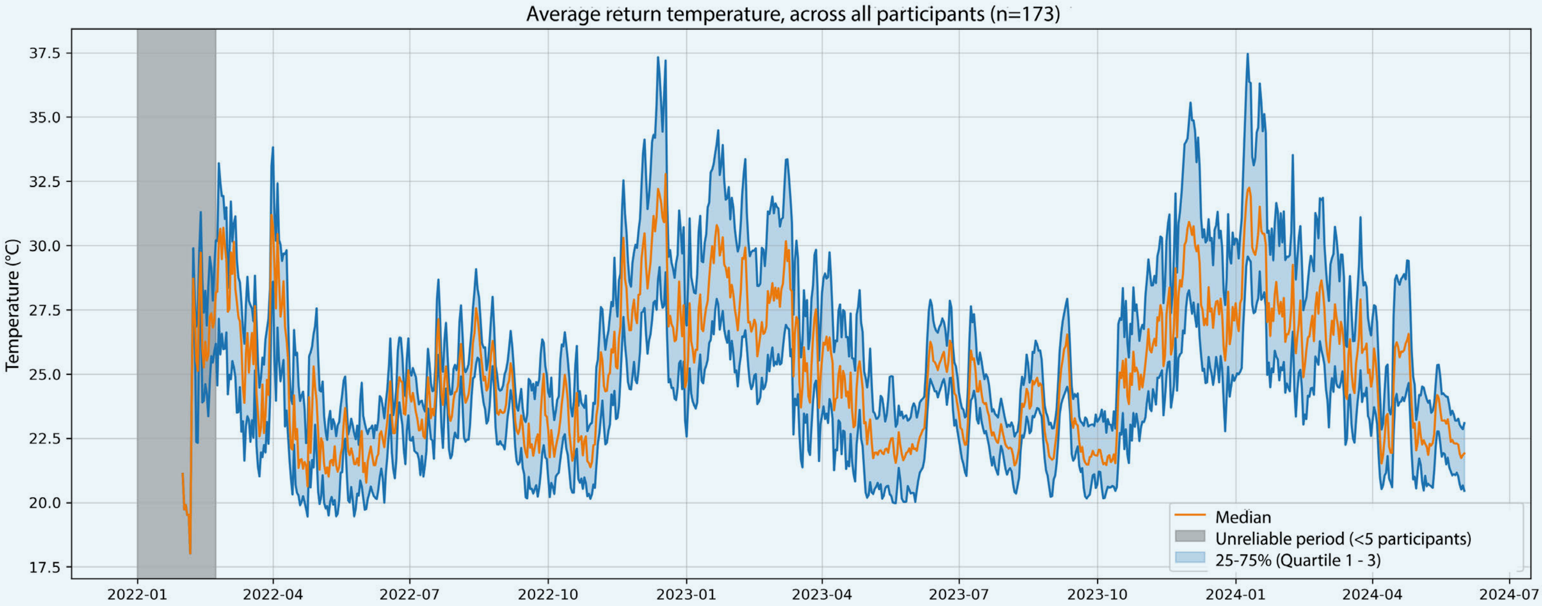

Distribution of SCOP_Lower limit (n=120)
Average: 3.34
Number of homes
SCOP_Lower limit
0
5
10
15
20
0
1
2
3
4
5
6

Appendix 4: Behavior over time of the population

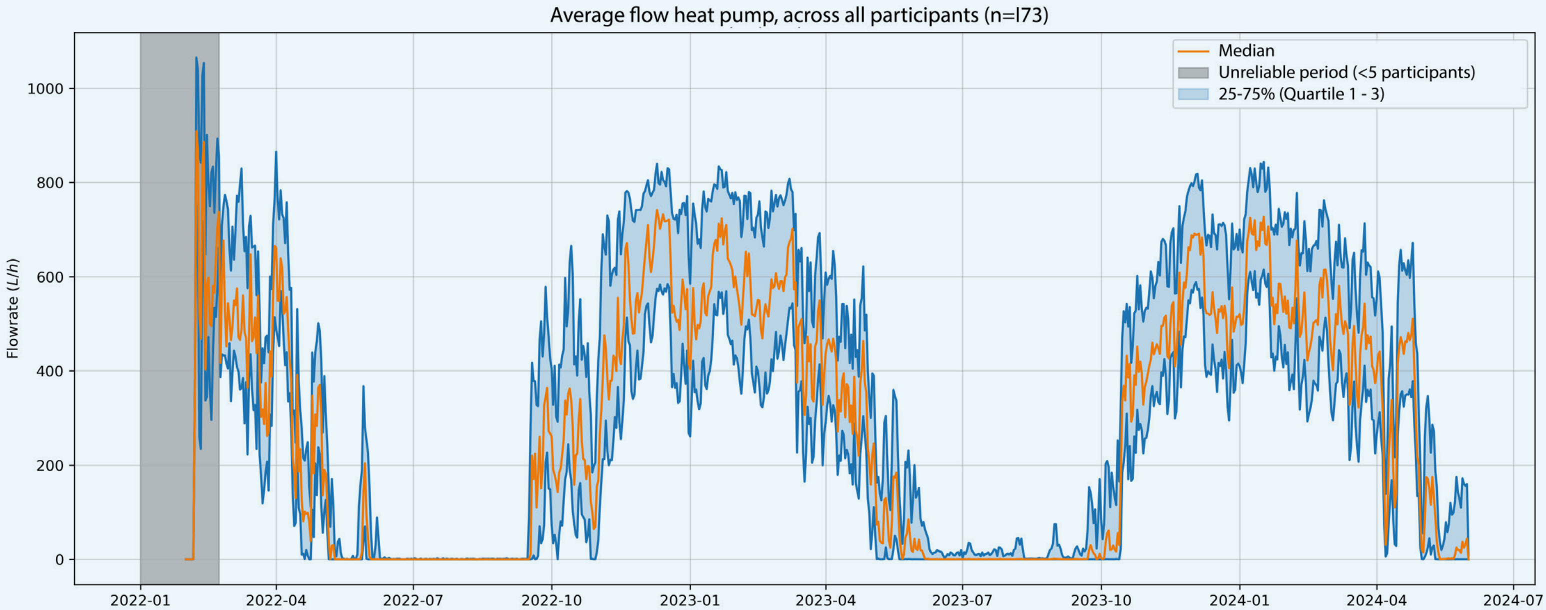



Gas usage per 24-hour period, from participants (n=169)
Unreliable period (<5 participants)
25-75% (Quartile 1 - 3)
Median
Gas (m³)
0
2
4
6
8
10
12
2022-01
2022-04
2022-07
2022-10
2023-01
2023-04
2023-07
2023-10
2024-01
2024-04
2024-07

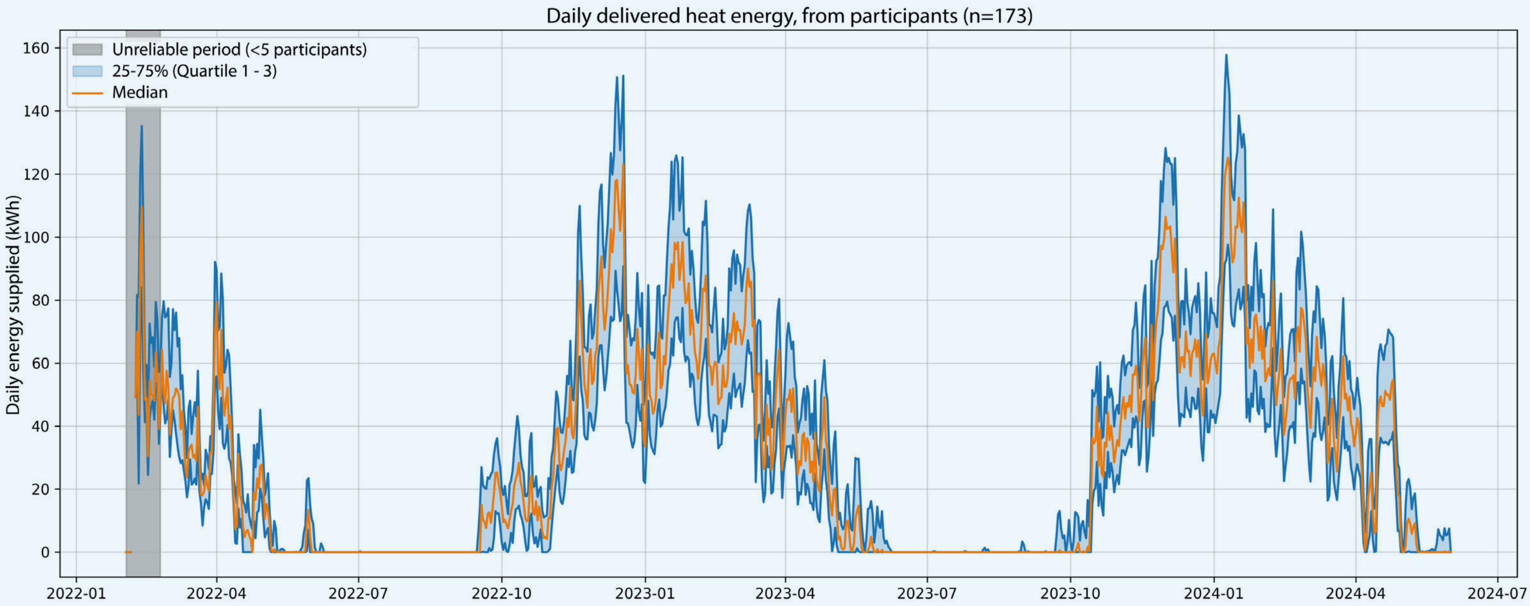

Average supply temperature per 24-hour period (as hybrid active), from participants (n=173)
Unreliable period (<5 participants)
25-75% (Quartile 1 - 3)
Median
Temperature (°C)
45
40
35
30
25
20
2022-01
2022-04
2022-07
2022-10
2023-01
2023-04
2023-07
2023-10
2024-01
2024-04
2024-07



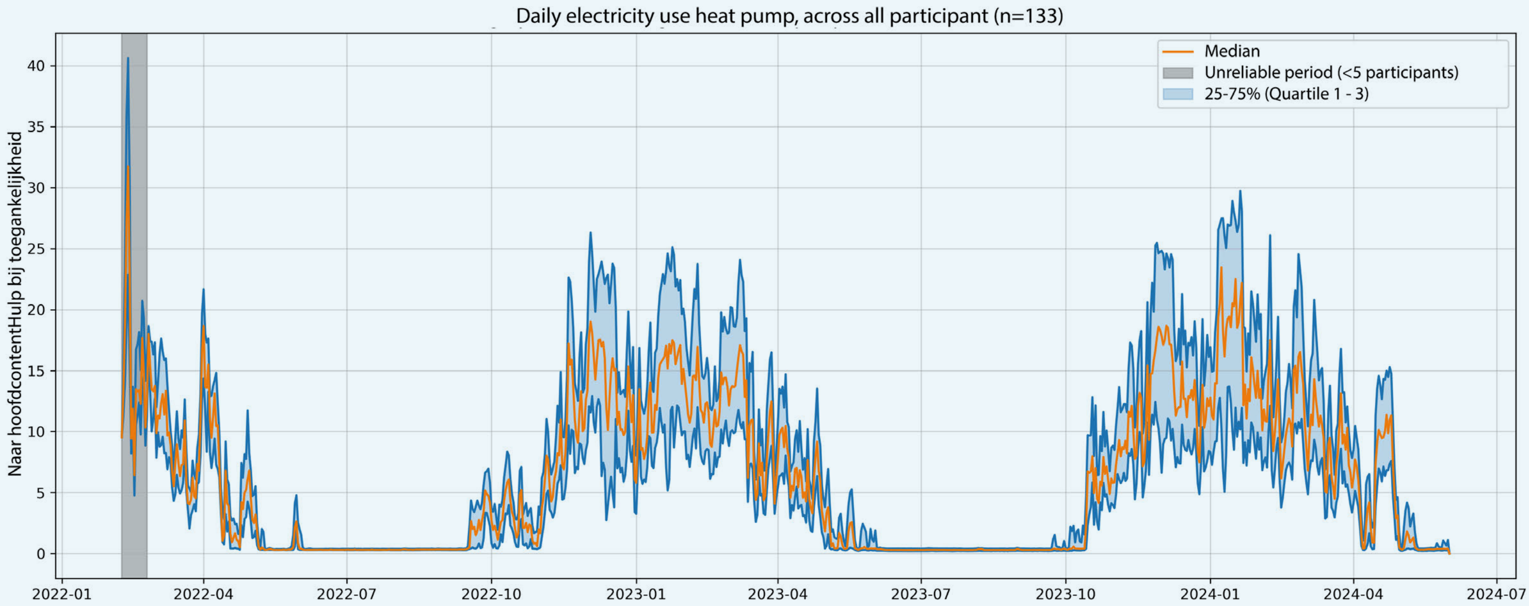
Average return temperature, across all participants (n=173)
Temperature (°C)
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
2022-01
2022-04
2022-07
2022-10
2023-01
2023-04
2023-07
2023-10
2024-01
2024-04
2024-07
Median
Unreliable period (<5 participants)
25-75% (Quartile 1 - 3)



Average flow heat pump, across all participants (n=173)
Median
Unreliable period (<5 participants)
25-75% (Quartile 1 - 3)
Flowrate (L/h)
1000
800
600
400
200
0
2022-01
2022-04
2022-07
2022-10
2023-01
2023-04
2023-07
2023-10
2024-01
2024-04
2024-07



Daily delivered heat energy, from participants (n=173)
Unreliable period (<5 participants)
25-75% (Quartile 1 - 3)
Median
Daily energy supplied (kWh)
160
140
120
100
80
60
40
20
0
2022-01
2022-04
2022-07
2022-10
2023-01
2023-04
2023-07
2023-10
2024-01
2024-04
2024-07



Daily electricity use heat pump, across all participant (n=133)
Median
Unreliable period (<5 participants)
25-75% (Quartile 1 - 3)
Naar hoofdcontentHulp bij toegankelijkheid
0
5
10
15
20
25
30
35
40
2022-01
2022-04
2022-07
2022-10
2023-01
2023-04
2023-07
2023-10
2024-01
2024-04
2024-07

Appendix 5: Sub-study performance buffer tank and dispensing

The following pages show a setup that accurately examined the influence of the minimum compressor speed, adding a buffer tank and applying radiator fans.

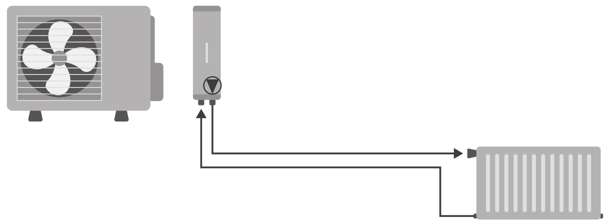
The setup consists of a heat pump equipped with means of measurement for the electric power absorbed, for the amount of heat generated (flow, temperature, power, by means of combrup as indicated in appendix measurement set), and for the heat arriving at the radiators is placed (by means of two heat meters according to appendix).

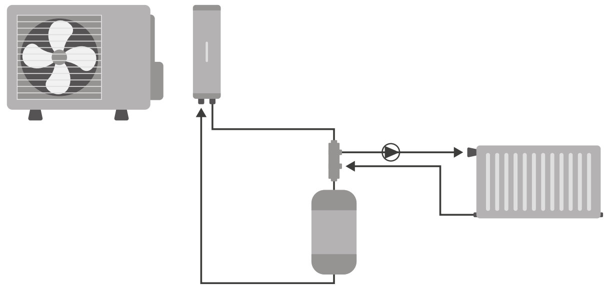
The setup is built with two radiators typical of a small porch house. Between the radiators and the heat pump is several meters of hose equipped with couplings. The couplings allow switching between the buffer tank solutions visible in the photo without further changes. The installation has a generation part and a delivery part. Different configurations are visible on the next page. A second pump is used, which of course is also measured.

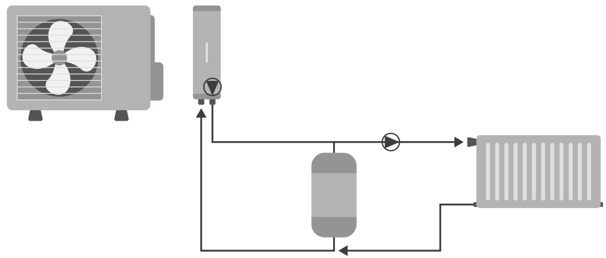
In order to exclude the influence of a control system, the set-up was examined for several hours at a constant supply temperature. Thereby, it was possible that the system started switching because the generated heat was not completely dissipated. The switching was with several degrees around the supply temperature.
Long-term measurements were made in each case and a large number of circuits in steady-state were selected in order to make the measurement as pure as possible in a comparative sense.
For the supply temperature, the values 35,45 and 55 °C were taken in order to map the whole operational range.

Here are the configurations:

- **Above** is the original configuration with couplings in the middle of the two hoses so that the configurations below can be made without further addition.
- **Middle** is the configuration with open distributor.
- **Below** is the configuration in parallel.
- **Not shown** is the configuration series where the buffer vessel is serially placed in the return.







In this way, the following confugurations were examined in comparison:

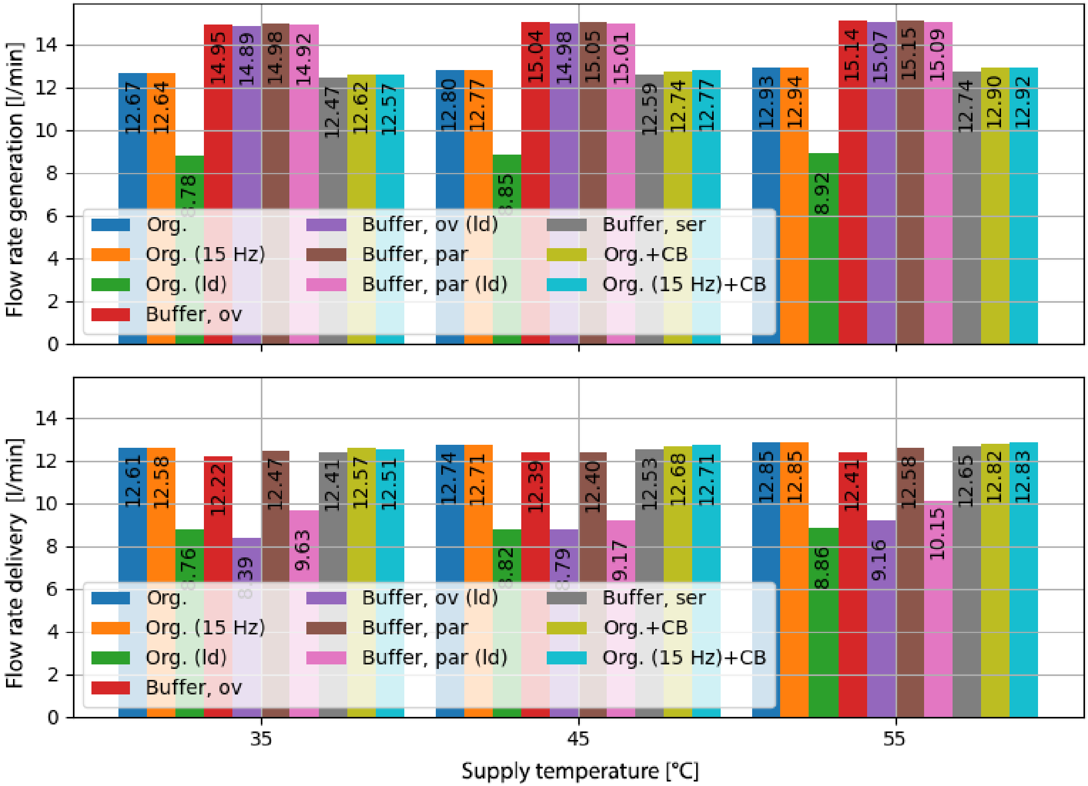
a) Org - the arrangement as described
b) Org (15 Hz) - as a) but with reduced minimum compressor speed
c) Org (ld) - as a) but with reduced flow rate
d) Buffer ov - see drawing
e) Buffer ov (ld) - if d) with low flow rate
f) Buffer par - see drawing next pagine
g) Buffer par (ld) - as f) with low flow rate
h) Buffer ser - buffer serial in the pipeline
i) Org +CB - as a) with radiator fans
j) Org (15 Hz) +CB - as b) with radiator fans

Buffer tank and dispensing

Consideration of the measurement results on the following pages provides the following conclusions:

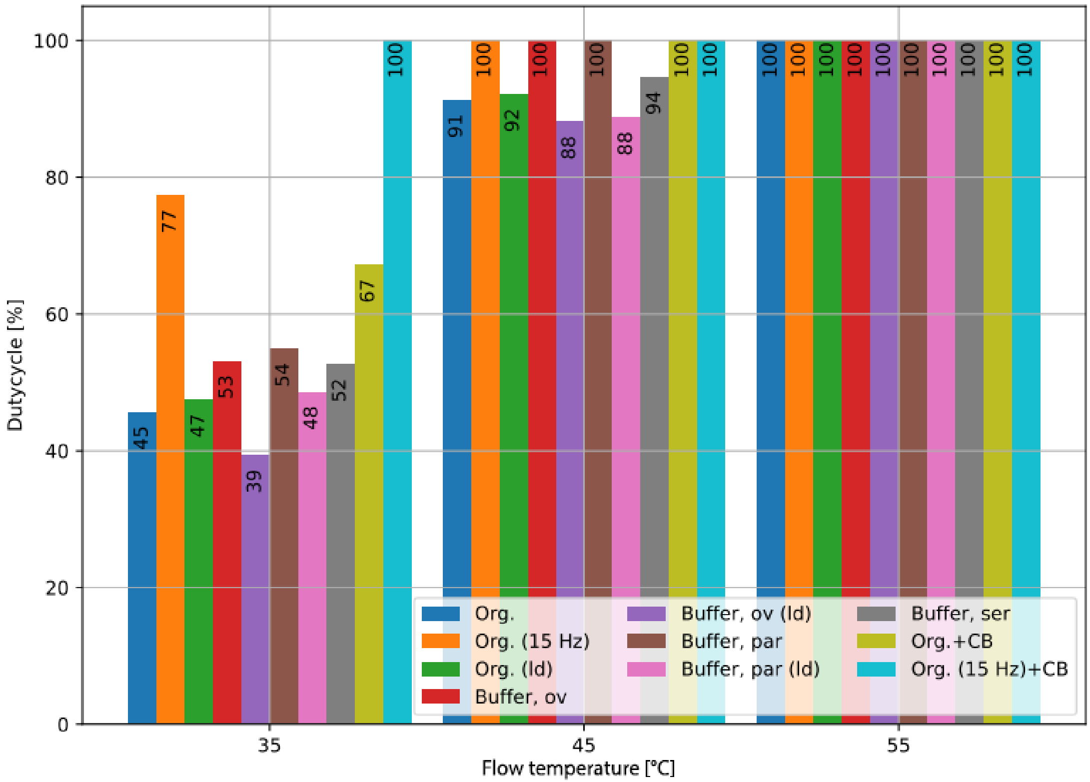
1) Heat losses from pipes between generation and distribution can be very large (order 15% and more). A buffer tank further increases this loss significantly (order 10%). This is visible in the plot efficiency of solution, which shows the ratio between the roomrup generation and output. Now the installation situation in homes will be different than in the test setup but it is generally hard to imagine that the losses are less there. Possibly a kitchen setup will do better.
2) The best solution is to run the heat pump continuously by applying dispense improvement and reducing the compressor speed. This is configuration j. At 35°C delivery, the COP of the delivery increases from 3.88 to 4.76. An increase of 22% that affects the energy bill one to one.
3) Small buffer vessels are of limited help against cycling. After the first cycle, the vessel has warmed up and is running in the on/off control band of the supply. Only the slightly larger volume that the buffer vessel gives to the system helps extend the switching time a bit. Lowering the compressor speed, and thus increasing the modulation range of the heat pump, helps more in this regard. If a release improvement is then added, the cycling in this example disappears altogether (configuration j).
4) Buffer vessels, no matter how switched, give a heat loss on the order of 10%.

Flow rate

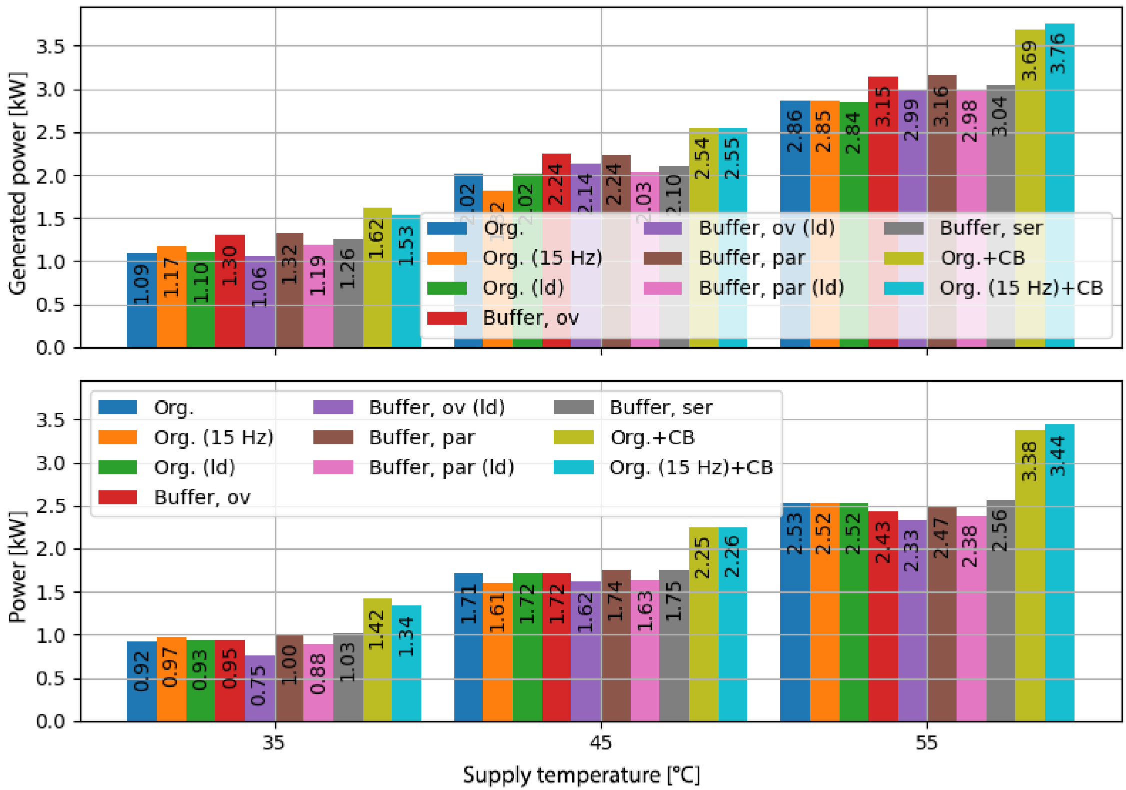


Flow rate generation [l/min]
12.67
12.64
8.78
14.95
14.89
14.98
14.92
12.47
12.62
12.57
12.80
12.77
8.85
15.04
14.98
15.05
15.01
12.59
12.74
12.77
12.93
12.94
8.92
15.14
15.07
15.15
15.09
12.74
12.90
12.92
Flow rate delivery [l/min]
12.61
12.58
8.76
12.22
8.39
12.47
9.63
12.41
12.57
12.51
12.74
12.71
8.82
12.39
12.40
8.79
9.17
12.53
12.68
12.71
12.85
12.85
8.86
12.41
9.16
12.58
10.15
12.65
12.82
12.83
Org.
Org. (15 Hz)
Org. (ld)
Buffer, ov
Buffer, ov (ld)
Buffer, par
Buffer, par (ld)
Buffer, ser
Org.+CB
Org. (15 Hz)+CB
35
45
55
Supply temperature [°C]

Relative On-Time

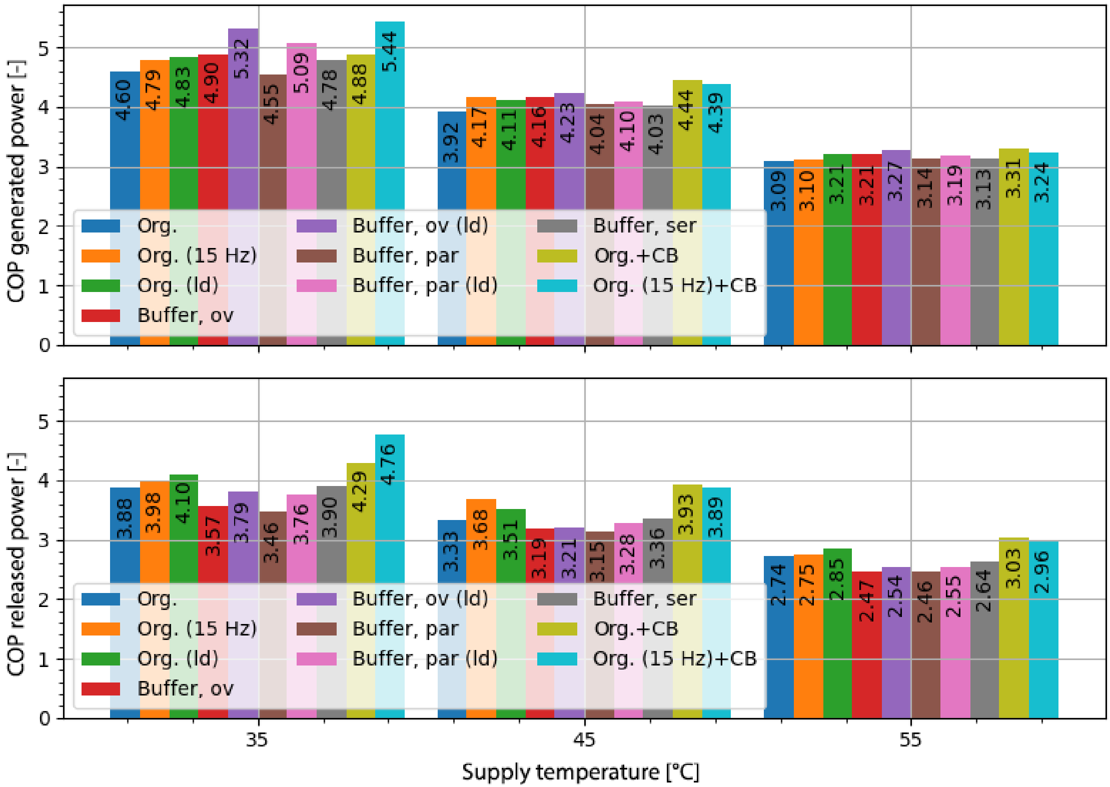


Power



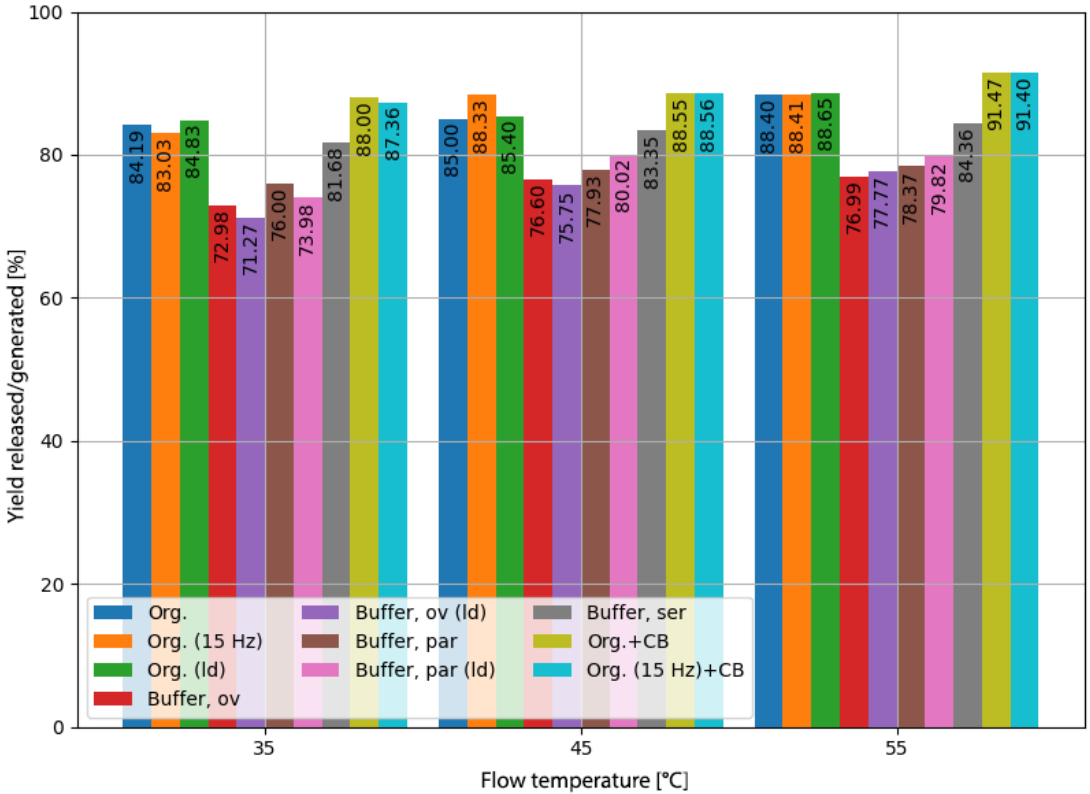
Generated power [kW]
Power [kW]
Supply temperature [°C]
35
45
55
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Org.
Org. (15 Hz)
Org. (ld)
Buffer, ov
Buffer, ov (ld)
Buffer, par
Buffer, par (ld)
Buffer, ser
Org.+CB
Org. (15 Hz)+CB
1.09
1.17
1.10
1.30
1.06
1.32
1.19
1.26
1.62
1.53
2.24
2.14
2.24
2.10
2.54
2.55
2.86
2.85
2.84
3.15
2.99
3.16
2.98
3.04
3.69
3.76
0.92
0.97
0.93
0.95
0.75
1.00
0.88
1.03
1.42
1.34
1.71
1.61
1.72
1.72
1.62
1.74
1.63
1.75
2.25
2.26
2.53
2.52
2.52
2.43
2.33
2.47
2.38
2.56
3.38
3.44

COP



COP generated power [-]
COP released power [-]
Supply temperature [°C]
35
45
55
Org.
Org. (15 Hz)
Org. (ld)
Buffer, ov
Buffer, ov (ld)
Buffer, par
Buffer, par (ld)
Buffer, ser
Org.+CB
Org. (15 Hz)+CB
4.60
4.79
4.83
4.90
5.32
4.55
5.09
4.78
4.88
5.44
3.92
4.17
4.11
4.16
4.23
4.04
4.10
4.03
4.44
4.39
3.09
3.10
3.21
3.21
3.27
3.14
3.19
3.13
3.31
3.24
3.88
3.98
4.10
3.57
3.79
3.46
3.76
3.90
4.29
4.76
3.33
3.68
3.51
3.19
3.21
3.15
3.28
3.36
3.93
3.89
2.74
2.75
2.85
2.47
2.54
2.46
2.55
2.64
3.03
2.96

Yield of solution



Appendix 6: Graphana dashboard of some participants

The following pages show the behavior of some of the participating homes characteristic of the project.

The measured values of the homes are visualized in a Grafana dashboard. The homes are also included in the table in Chapter 4.

This dashboard shows over the one-year period:

- The **total electricity** use of the home (top left), which is the balance of off-take and feed-in per 24-hour period. Many participants have solar panels, as in the case of the six of the seven example homes, so feed-in is visible.
- The **amount of heat** that entered the home, cumulatively per 24-hour period (top right).
- The **position of the gas meter** in the meter box (center right). This is the total gas usage: heating plus hot water and cooking.
- The **gas usage** per 24-hour period (bottom right), constant decrease in tap water can be seen and spikes that occur during cold winter days.
- The **temperature** of the supply, the return, the temperature sensor in the living room and the outside temperature (KNMI data per hour).
- The **measured power consumption** of the hybrid heat pump (left middle, cumulative).

By considering the successive plots and the too table in ch. 3, the following observations can be made for these participants:

GdemEVzZ – This **mid-corner house from around 2005** with the original radiators saved 59% gas. The additional gas usage, on top of the tap water usage, during the more severe weeks in winter is clearly distinguishable. The savings performance is on the low side at 4.27. The water temperatures are on the high side. Note here especially the difference between the Grafana plots that show peak values while the collector file [12] shows average values.

H6PEe0lX – This **semi-detached house from around 1965** with radiators and later installed underfloor heating (living room, milled in) shows the average project residual: gas savings 78% with a savings performance of 5.68. Compared to the previous home, the annual savings are quite higher. As with the first home, winter periods are clearly distinguishable in the 24-hour gas graph.

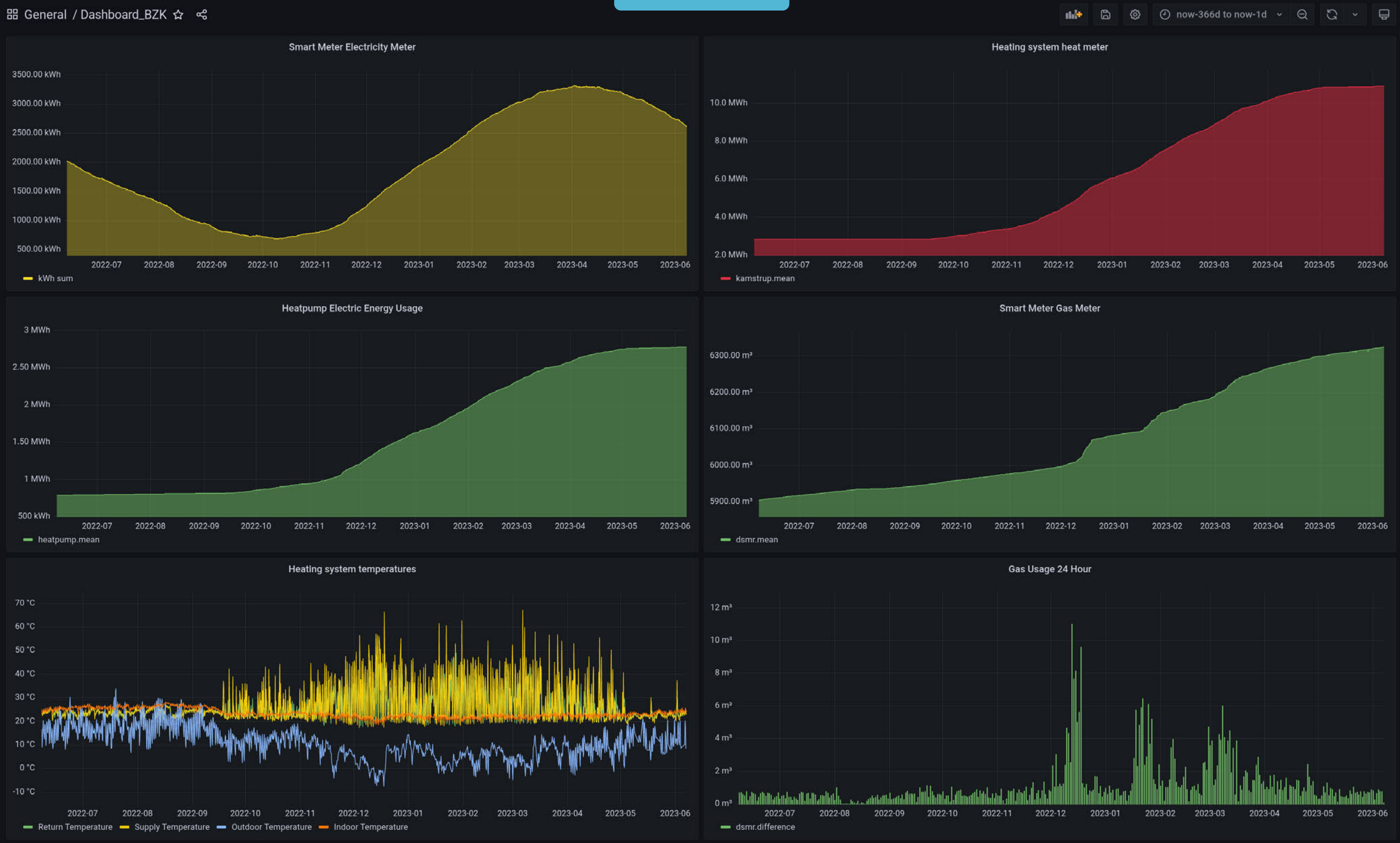
lVK0bORa – This **detached from home built around 1965** with radiators gives a below average savings (60%) but has a high savings performance of 7.14. It can also be seen that it requires more gas support in winter than the previous participants; winter peaks smear more with the tap water line. Because of the higher initial gas usage and because of the limited increase in electricity usage, the annual financial gain is still decent. Water temperatures are on the high side. There are still gains to be made here.

RHON9wor – This is a **circa 1935 home** with radiators. The gas savings are 67% and the savings performance is on the low side at 4.38. Prior to installing the hybrid, the participant experimented with radiator fans that gave significant gas savings (order 25%). Later, two low-temperature radiators were installed in the living room. This improvement is in his previous energy bill. Presumably, the savings performance is on the low side because there was a significant gain before.

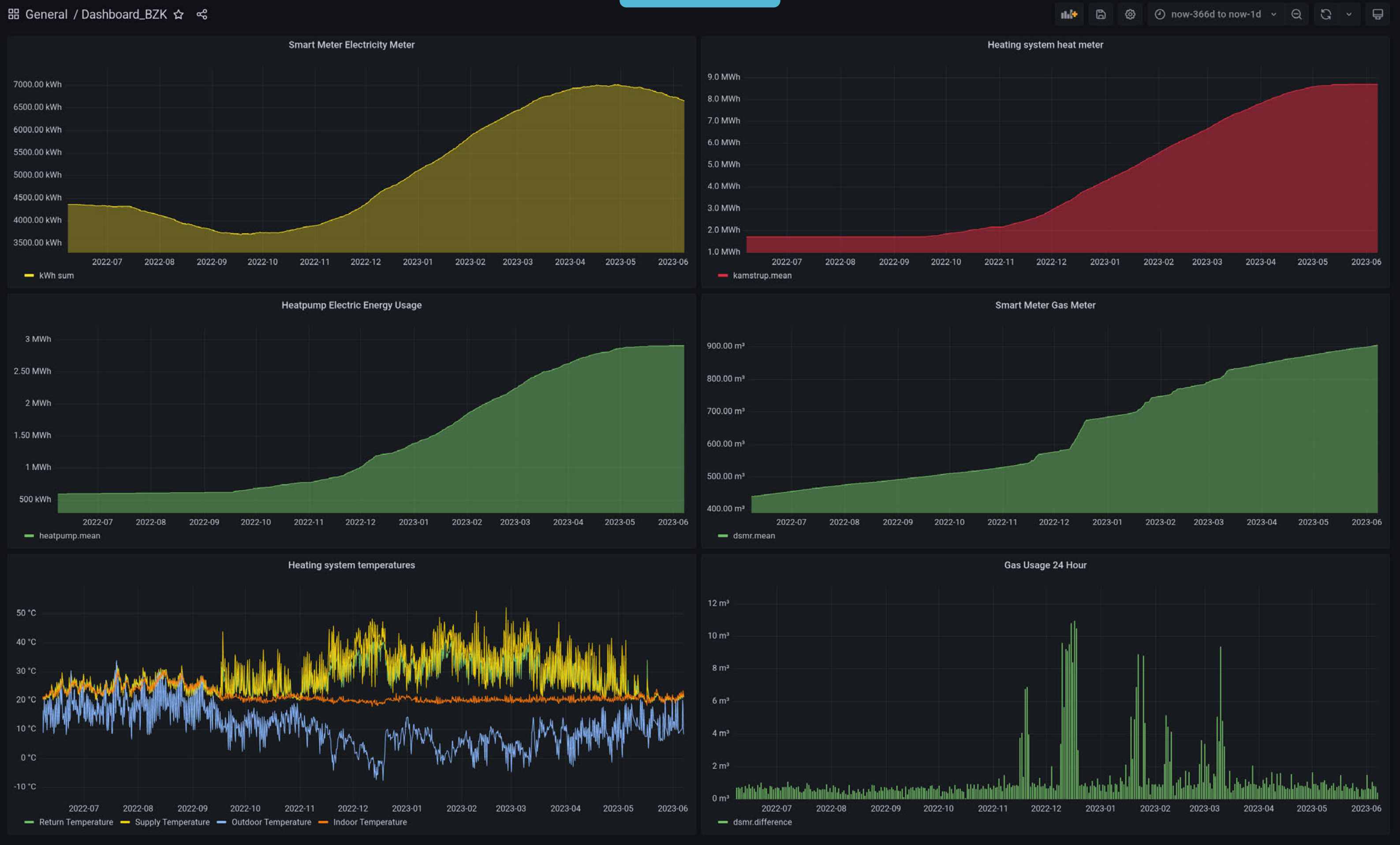
aQ1RbqD6 – This is a **1996 detached house** built with mostly underfloor heating. What stands out is the extremely low tap water usage while the house is occupied by 3 people (0.13 m^3 /day). Upon inquiry, it turned out that a (self-designed) shower-WWT was installed. In addition, the low water temperatures stand out. The savings performance is 5.53. With a little more capacity, greater savings should be achievable. Actually, the hybrid falls a little short at this home. The resident installed a second hybrid as an experiment this past winter (23-24), reducing his gas use heating to zero. Which is clearly visible in the two-year Graphana image of this home.

xSDmm63y – This **housing association row house built around 1965** has water temperatures that are far too high. In addition, the flow through the system is far too low (not visible in the dashboard, but measured). The gas savings are far too low at 38% and the gas usage has a different pattern than the other homes as well. Visits revealed that the radiators were built away behind hole panels (the likely cause). These types of panels for visual concealment of radiators are much more

GdemEVzZ

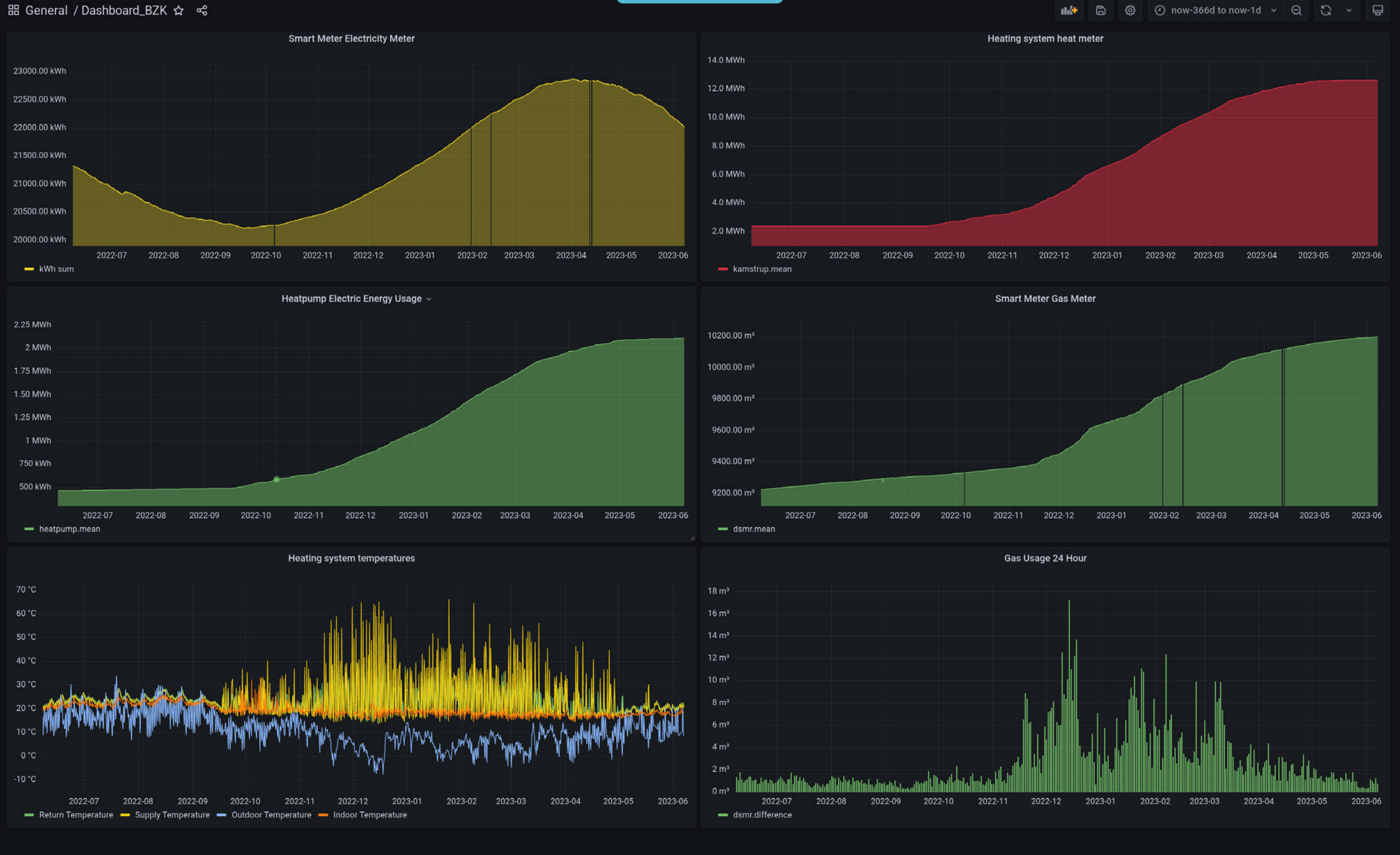

General / Dashboard_BZK
now-366d to now-1d
Smart Meter Electricity Meter
3500.00 kWh
3000.00 kWh
2500.00 kWh
2000.00 kWh
1500.00 kWh
1000.00 kWh
500.00 kWh
kWh sum
Heating system heat meter
10.0 MWh
8.0 MWh
6.0 MWh
4.0 MWh
2.0 MWh
kamstrup.mean
Heatpump Electric Energy Usage
3 MWh
2.50 MWh
2 MWh
1.50 MWh
1 MWh
500 kWh
heatpump.mean
Smart Meter Gas Meter
6300.00 m³
6200.00 m³
6100.00 m³
6000.00 m³
5900.00 m³
dsmr.mean
Heating system temperatures
70 °C
60 °C
50 °C
40 °C
30 °C
20 °C
10 °C
0 °C
-10 °C
Return Temperature
Supply Temperature
Outdoor Temperature
Indoor Temperature
Gas Usage 24 Hour
12 m³
10 m³
8 m³
6 m³
4 m³
2 m³
0 m³
dsmr.difference
2022-07
2022-08
2022-09
2022-10
2022-11
2022-12
2023-01
2023-02
2023-03
2023-04
2023-05
2023-06

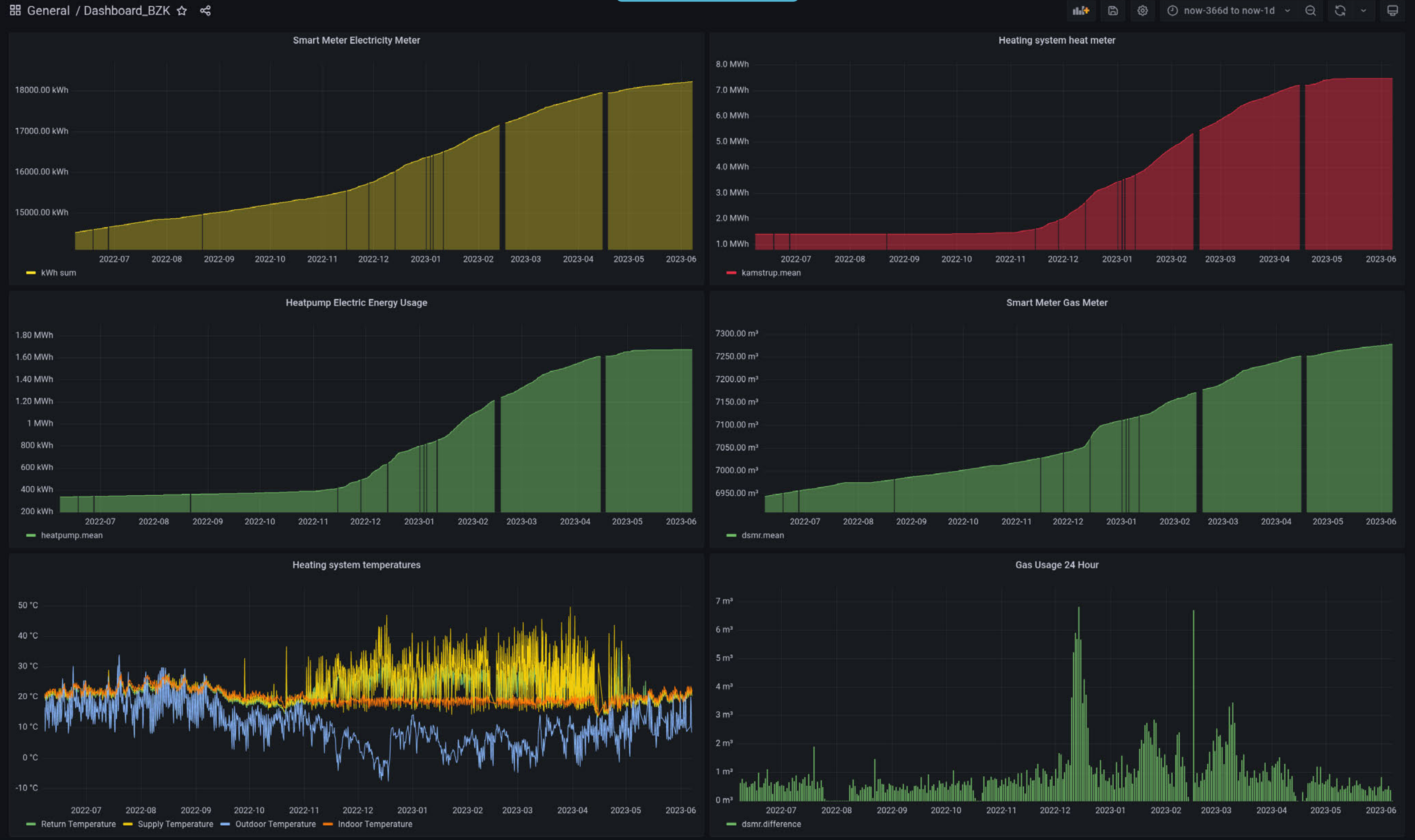
H6PEe0lX

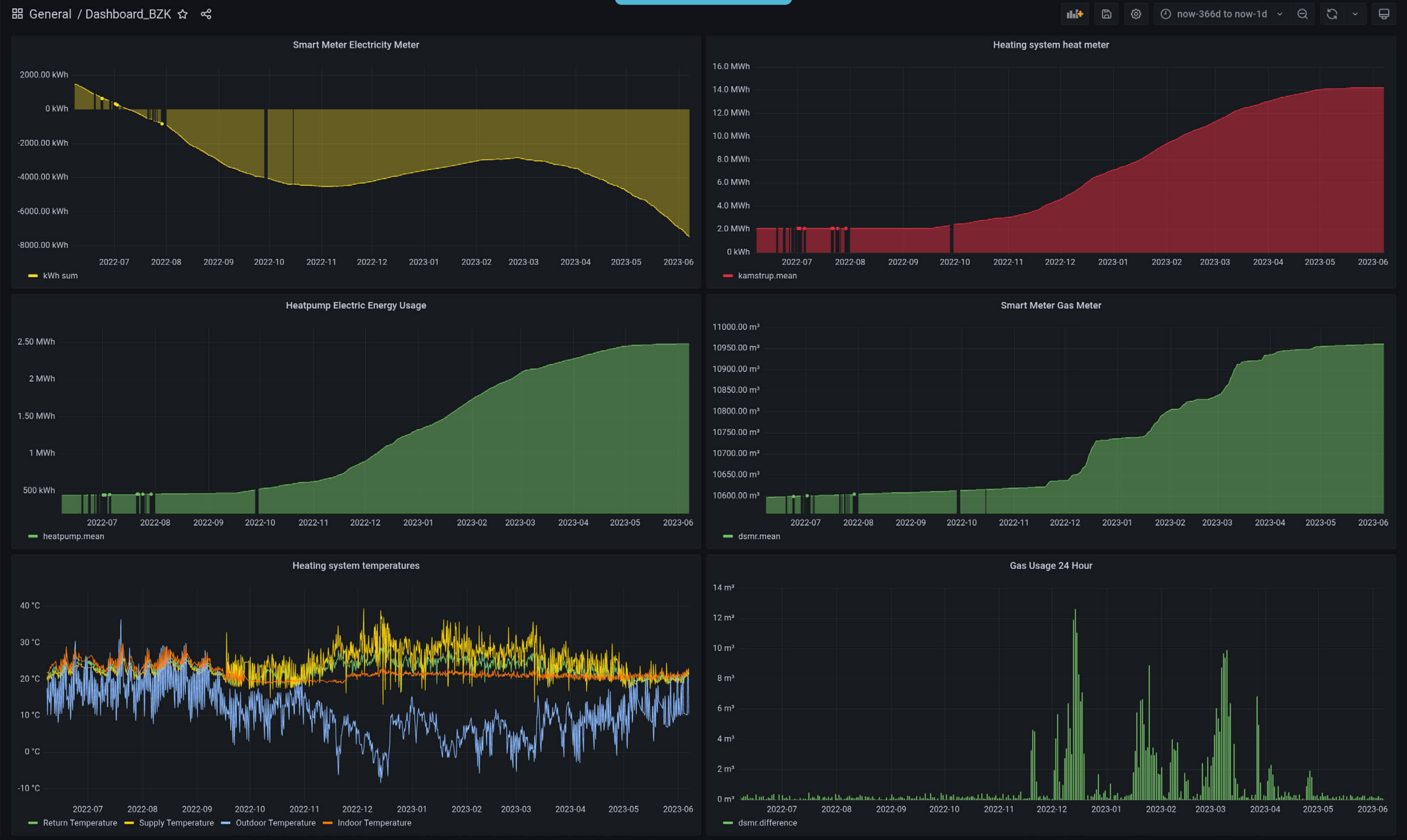


General / Dashboard_BZK
now-366d to now-1d
Smart Meter Electricity Meter
7000.00 kWh
6500.00 kWh
6000.00 kWh
5500.00 kWh
5000.00 kWh
4500.00 kWh
4000.00 kWh
3500.00 kWh
2022-07 2022-08 2022-09 2022-10 2022-11 2022-12 2023-01 2023-02 2023-03 2023-04 2023-05 2023-06
kWh sum
Heating system heat meter
9.0 MWh
8.0 MWh
7.0 MWh
6.0 MWh
5.0 MWh
4.0 MWh
3.0 MWh
2.0 MWh
1.0 MWh
kamstrup.mean
Heatpump Electric Energy Usage
3 MWh
2.50 MWh
2 MWh
1.50 MWh
1 MWh
500 kWh
heatpump.mean
Smart Meter Gas Meter
900.00 m³
800.00 m³
700.00 m³
600.00 m³
500.00 m³
400.00 m³
dsmr.mean
Heating system temperatures
50 °C
40 °C
30 °C
20 °C
10 °C
0 °C
-10 °C
Return Temperature
Supply Temperature
Outdoor Temperature
Indoor Temperature
Gas Usage 24 Hour
12 m³
10 m³
8 m³
6 m³
4 m³
2 m³
0 m³
dsmr.difference

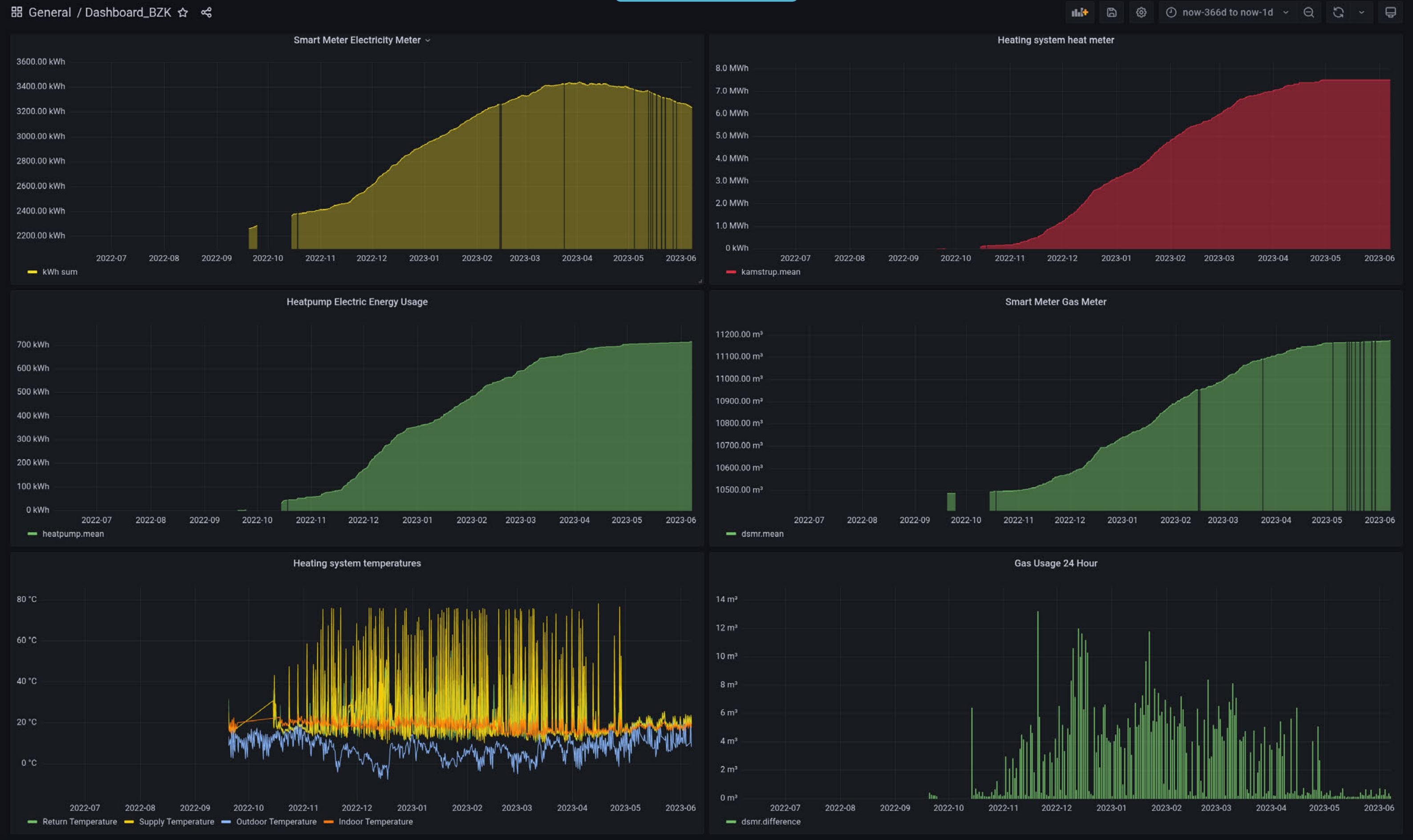
IVK0bORa


General / Dashboard_BZK
now-366d to now-1d
Smart Meter Electricity Meter
23000.00 kWh
22500.00 kWh
22000.00 kWh
21500.00 kWh
21000.00 kWh
20500.00 kWh
20000.00 kWh
2022-07 2022-08 2022-09 2022-10 2022-11 2022-12 2023-01 2023-02 2023-03 2023-04 2023-05 2023-06
kWh sum
Heating system heat meter
14.0 MWh
12.0 MWh
10.0 MWh
8.0 MWh
6.0 MWh
4.0 MWh
2.0 MWh
2022-07 2022-08 2022-09 2022-10 2022-11 2022-12 2023-01 2023-02 2023-03 2023-04 2023-05 2023-06
kamstrup.mean
Heatpump Electric Energy Usage
2.25 MWh
2 MWh
1.75 MWh
1.50 MWh
1.25 MWh
1 MWh
750 kWh
500 kWh
2022-07 2022-08 2022-09 2022-10 2022-11 2022-12 2023-01 2023-02 2023-03 2023-04 2023-05 2023-06
heatpump.mean
Smart Meter Gas Meter
10200.00 m³
10000.00 m³
9800.00 m³
9600.00 m³
9400.00 m³
9200.00 m³
2022-07 2022-08 2022-09 2022-10 2022-11 2022-12 2023-01 2023-02 2023-03 2023-04 2023-05 2023-06
dsmr.mean
Heating system temperatures
70 °C
60 °C
50 °C
40 °C
30 °C
20 °C
10 °C
0 °C
-10 °C
2022-07 2022-08 2022-09 2022-10 2022-11 2022-12 2023-01 2023-02 2023-03 2023-04 2023-05 2023-06
Return Temperature
Supply Temperature
Outdoor Temperature
Indoor Temperature
Gas Usage 24 Hour
18 m³
16 m³
14 m³
12 m³
10 m³
8 m³
6 m³
4 m³
2 m³
0 m³
2022-07 2022-08 2022-09 2022-10 2022-11 2022-12 2023-01 2023-02 2023-03 2023-04 2023-05 2023-06
dsmr.difference

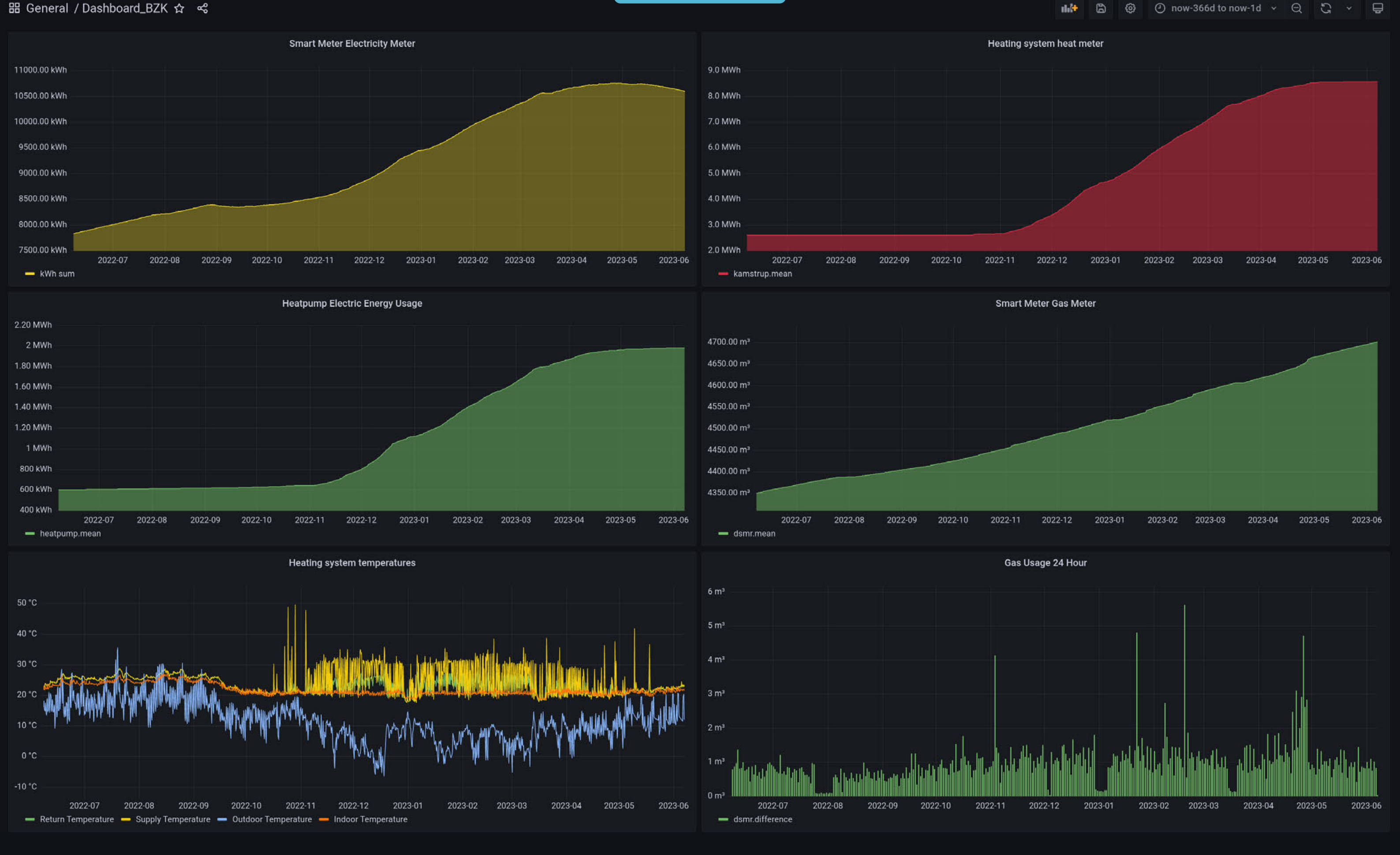

General / Dashboard_BZK
now-366d to now-1d
Smart Meter Electricity Meter
18000.00 kWh
17000.00 kWh
16000.00 kWh
15000.00 kWh
kWh sum
Heating system heat meter
8.0 MWh
7.0 MWh
6.0 MWh
5.0 MWh
4.0 MWh
3.0 MWh
2.0 MWh
1.0 MWh
kamstrup.mean
Heatpump Electric Energy Usage
1.80 MWh
1.60 MWh
1.40 MWh
1.20 MWh
1 MWh
800 kWh
600 kWh
400 kWh
200 kWh
heatpump.mean
Smart Meter Gas Meter
7300.00 m³
7250.00 m³
7200.00 m³
7150.00 m³
7100.00 m³
7050.00 m³
7000.00 m³
6950.00 m³
dsmr.mean
Heating system temperatures
50 °C
40 °C
30 °C
20 °C
10 °C
0 °C
-10 °C
Return Temperature
Supply Temperature
Outdoor Temperature
Indoor Temperature
Gas Usage 24 Hour
7 m³
6 m³
5 m³
4 m³
3 m³
2 m³
1 m³
0 m³
dsmr.difference
2022-07
2022-08
2022-09
2022-10
2022-11
2022-12
2023-01
2023-02
2023-03
2023-04
2023-05
2023-06

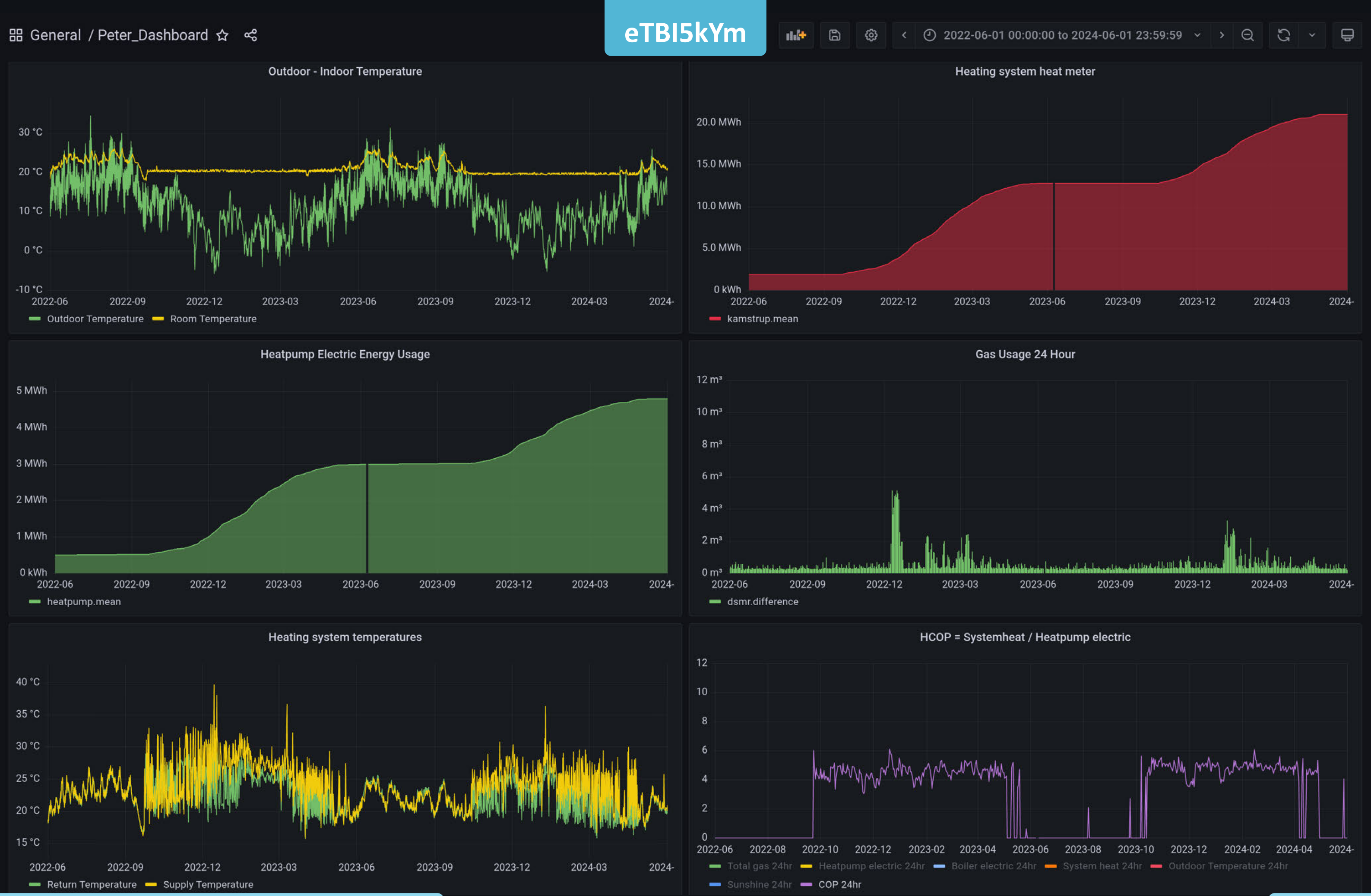

General / Dashboard_BZK
now-366d to now-1d
Smart Meter Electricity Meter
2000.00 kWh
0 kWh
-2000.00 kWh
-4000.00 kWh
-6000.00 kWh
-8000.00 kWh
kWh sum
Heating system heat meter
16.0 MWh
14.0 MWh
12.0 MWh
10.0 MWh
8.0 MWh
6.0 MWh
4.0 MWh
2.0 MWh
0 kWh
kamstrup.mean
Heatpump Electric Energy Usage
2.50 MWh
2 MWh
1.50 MWh
1 MWh
500 kWh
heatpump.mean
Smart Meter Gas Meter
11000.00 m³
10950.00 m³
10900.00 m³
10850.00 m³
10800.00 m³
10750.00 m³
10700.00 m³
10650.00 m³
10600.00 m³
dsmr.mean
Heating system temperatures
40 °C
30 °C
20 °C
10 °C
0 °C
-10 °C
Return Temperature
Supply Temperature
Outdoor Temperature
Indoor Temperature
Gas Usage 24 Hour
14 m³
12 m³
10 m³
8 m³
6 m³
4 m³
2 m³
0 m³
dsmr.difference
2022-07
2022-08
2022-09
2022-10
2022-11
2022-12
2023-01
2023-02
2023-03
2023-04
2023-05
2023-06

xSDmm63y

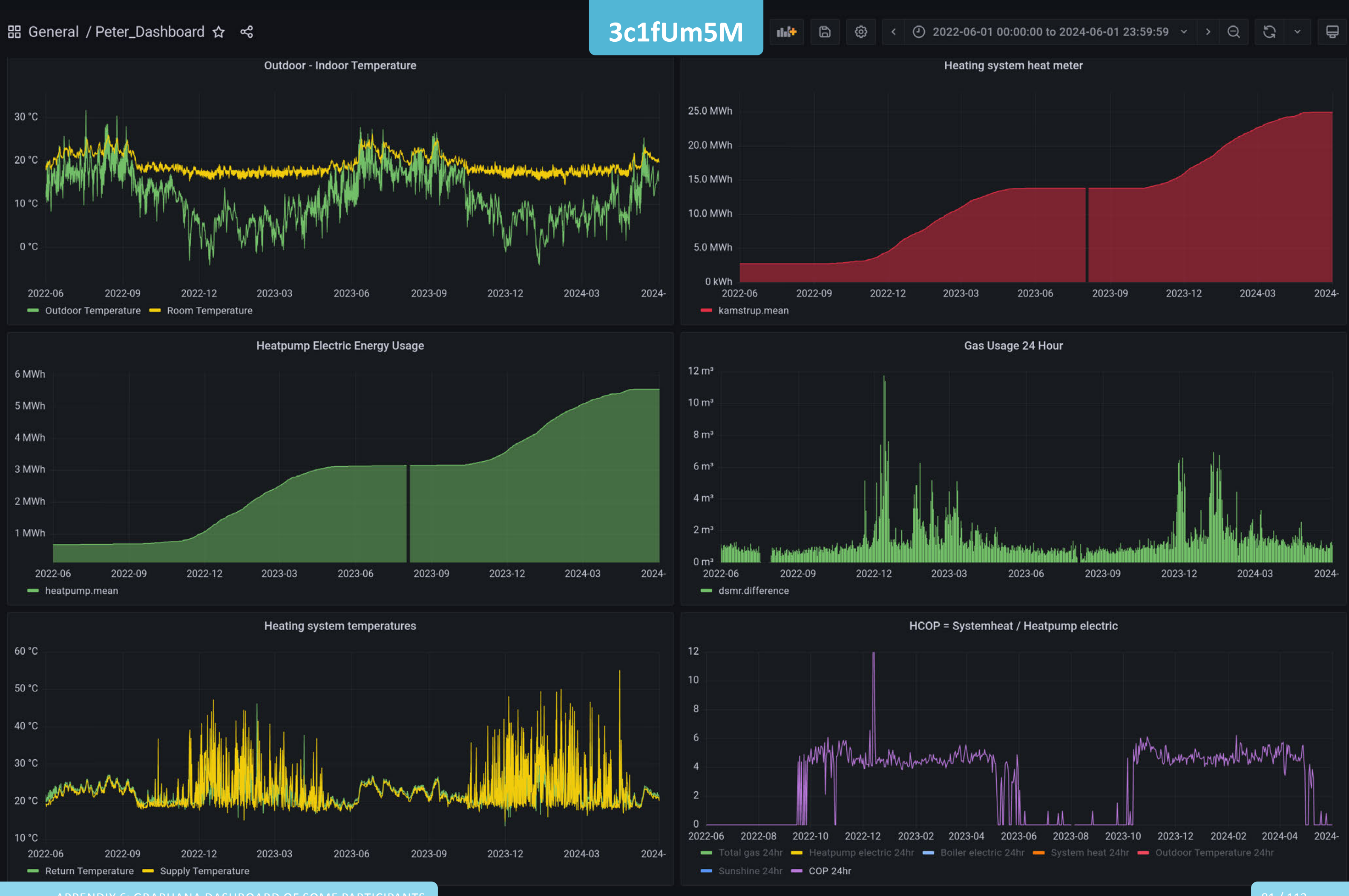

General / Dashboard_BZK
now-366d to now-1d
Smart Meter Electricity Meter
kWh sum
Heating system heat meter
kamstrup.mean
Heatpump Electric Energy Usage
heatpump.mean
Smart Meter Gas Meter
dsmr.mean
Heating system temperatures
Return Temperature
Supply Temperature
Outdoor Temperature
Indoor Temperature
Gas Usage 24 Hour
dsmr.difference

rC_pkM3K

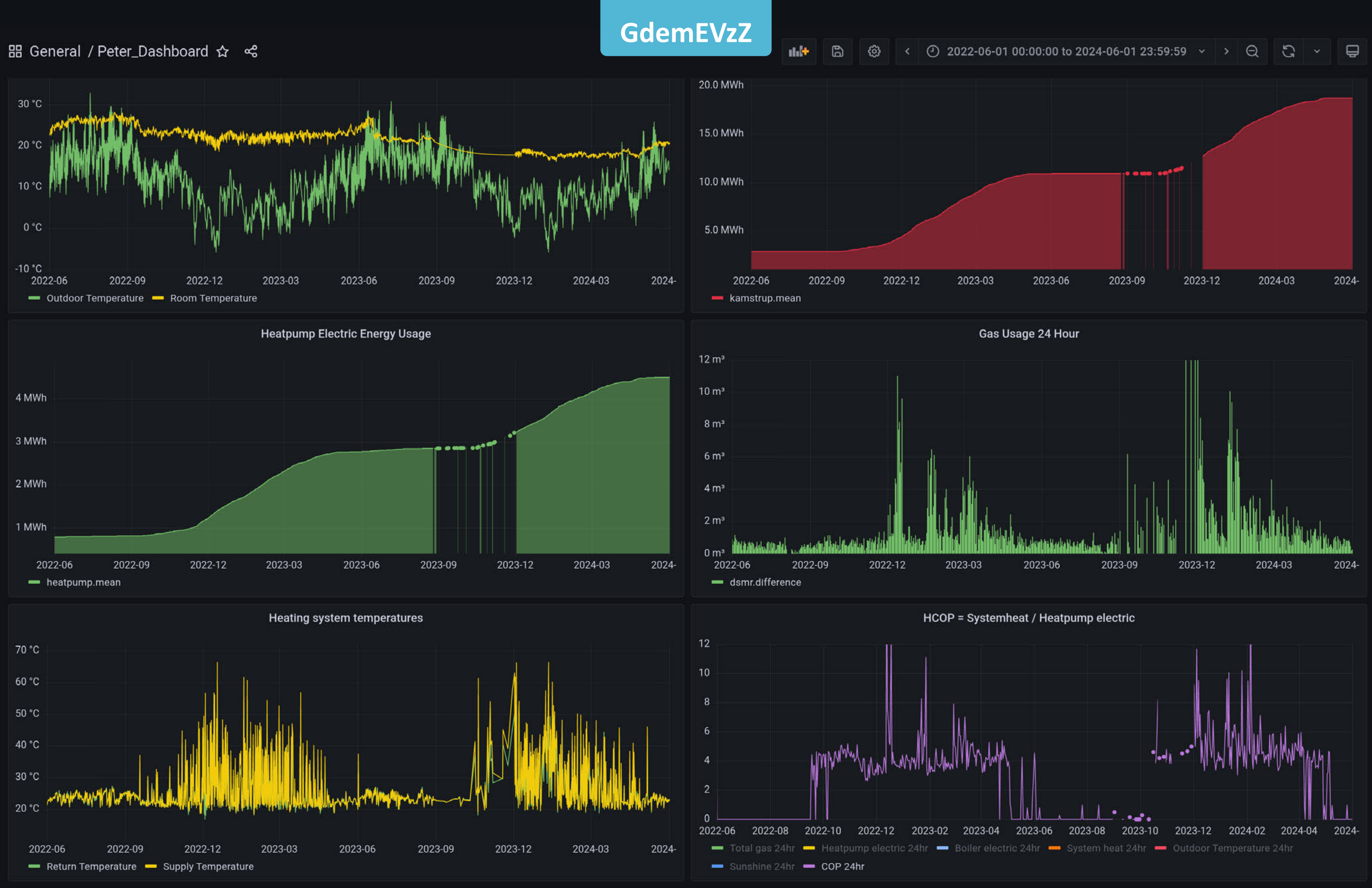

General / Dashboard_BZK
now-366d to now-1d
Smart Meter Electricity Meter
11000.00 kWh
10500.00 kWh
10000.00 kWh
9500.00 kWh
9000.00 kWh
8500.00 kWh
8000.00 kWh
7500.00 kWh
kWh sum
Heating system heat meter
9.0 MWh
8.0 MWh
7.0 MWh
6.0 MWh
5.0 MWh
4.0 MWh
3.0 MWh
2.0 MWh
kamstrup.mean
Heatpump Electric Energy Usage
2.20 MWh
2 MWh
1.80 MWh
1.60 MWh
1.40 MWh
1.20 MWh
1 MWh
800 kWh
600 kWh
400 kWh
heatpump.mean
Smart Meter Gas Meter
4700.00 m³
4650.00 m³
4600.00 m³
4550.00 m³
4500.00 m³
4450.00 m³
4400.00 m³
4350.00 m³
dsmr.mean
Heating system temperatures
50 °C
40 °C
30 °C
20 °C
10 °C
0 °C
-10 °C
Return Temperature
Supply Temperature
Outdoor Temperature
Indoor Temperature
Gas Usage 24 Hour
6 m³
5 m³
4 m³
3 m³
2 m³
1 m³
0 m³
dsmr.difference
2022-07
2022-08
2022-09
2022-10
2022-11
2022-12
2023-01
2023-02
2023-03
2023-04
2023-05
2023-06

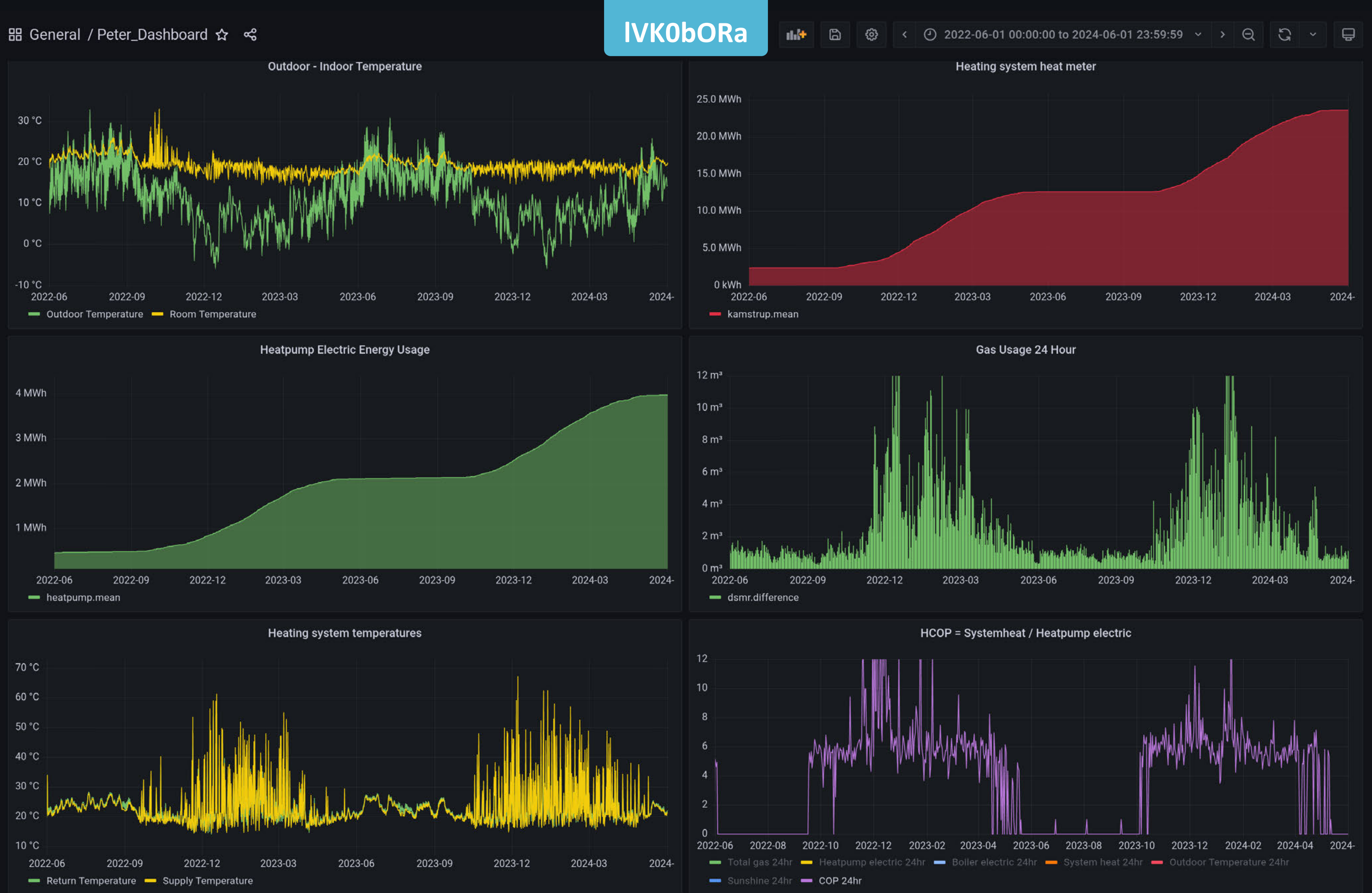

eTBI5kYm
General / Peter_Dashboard
2022-06-01 00:00:00 to 2024-06-01 23:59:59
Outdoor - Indoor Temperature
30 °C
20 °C
10 °C
0 °C
-10 °C
2022-06 2022-09 2022-12 2023-03 2023-06 2023-09 2023-12 2024-03 2024-
Outdoor Temperature
Room Temperature
Heating system heat meter
20.0 MWh
15.0 MWh
10.0 MWh
5.0 MWh
0 kWh
kamstrup.mean
Heatpump Electric Energy Usage
5 MWh
4 MWh
3 MWh
2 MWh
1 MWh
0 kWh
heatpump.mean
Gas Usage 24 Hour
12 m³
10 m³
8 m³
6 m³
4 m³
2 m³
0 m³
dsmr.difference
Heating system temperatures
40 °C
35 °C
30 °C
25 °C
20 °C
15 °C
Return Temperature
Supply Temperature
HCOP = Systemheat / Heatpump electric
12
10
8
6
4
2
0
2022-06 2022-08 2022-10 2022-12 2023-02 2023-04 2023-06 2023-08 2023-10 2023-12 2024-02 2024-04 2024-
Total gas 24hr
Heatpump electric 24hr
Boiler electric 24hr
System heat 24hr
Outdoor Temperature 24hr
Sunshine 24hr
COP 24hr

3c1fUm5M

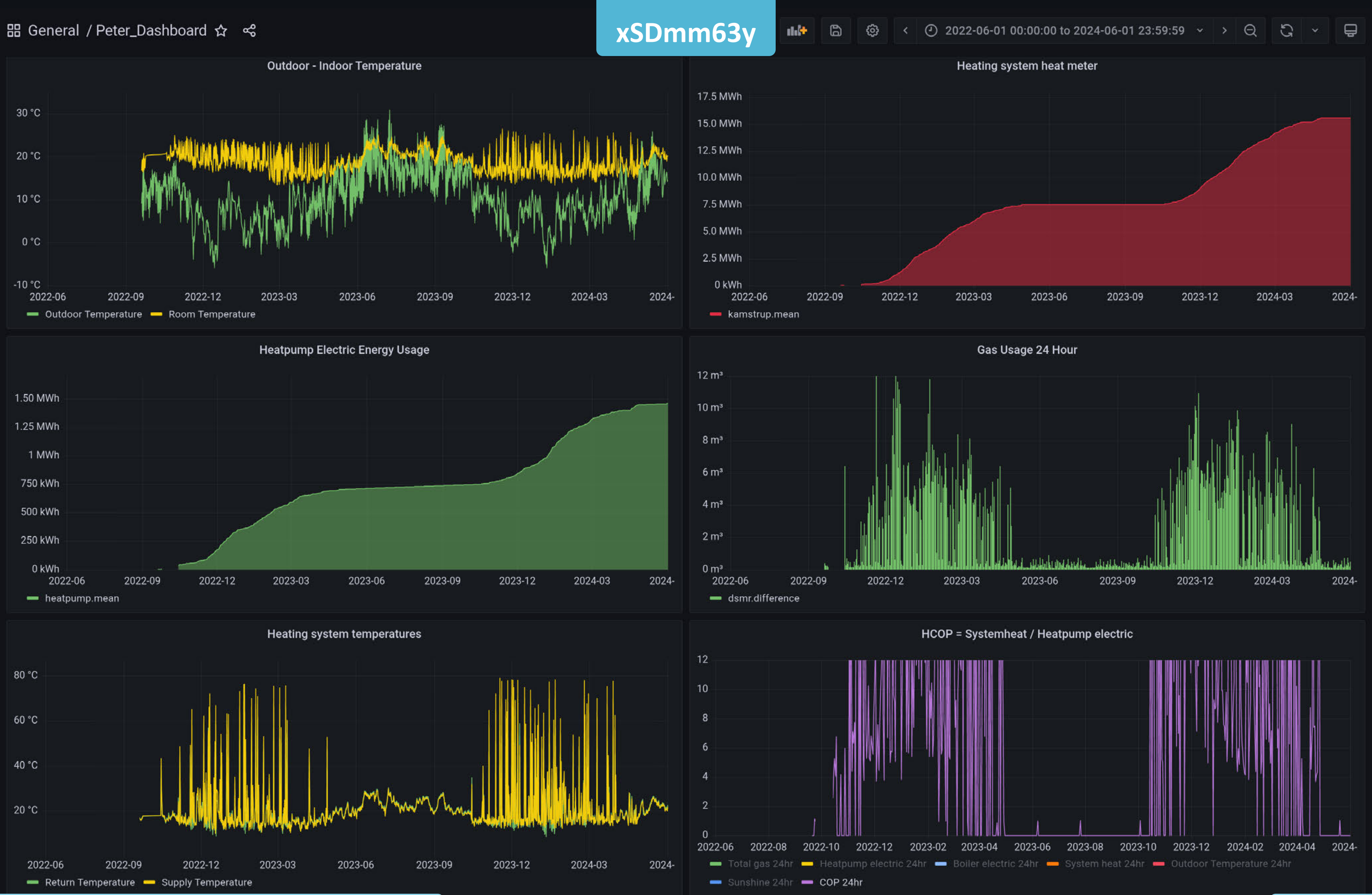


General / Peter_Dashboard
2022-06-01 00:00:00 to 2024-06-01 23:59:59
Outdoor - Indoor Temperature
30 °C
20 °C
10 °C
0 °C
2022-06 2022-09 2022-12 2023-03 2023-06 2023-09 2023-12 2024-03 2024-
Outdoor Temperature
Room Temperature
Heating system heat meter
25.0 MWh
20.0 MWh
15.0 MWh
10.0 MWh
5.0 MWh
0 kWh
2022-06 2022-09 2022-12 2023-03 2023-06 2023-09 2023-12 2024-03 2024-
kamstrup.mean
Heatpump Electric Energy Usage
6 MWh
5 MWh
4 MWh
3 MWh
2 MWh
1 MWh
2022-06 2022-09 2022-12 2023-03 2023-06 2023-09 2023-12 2024-03 2024-
heatpump.mean
Gas Usage 24 Hour
12 m³
10 m³
8 m³
6 m³
4 m³
2 m³
0 m³
2022-06 2022-09 2022-12 2023-03 2023-06 2023-09 2023-12 2024-03 2024-
dsmr.difference
Heating system temperatures
60 °C
50 °C
40 °C
30 °C
20 °C
10 °C
2022-06 2022-09 2022-12 2023-03 2023-06 2023-09 2023-12 2024-03 2024-
Return Temperature
Supply Temperature
HCOP = Systemheat / Heatpump electric
12
10
8
6
4
2
0
2022-06 2022-08 2022-10 2022-12 2023-02 2023-04 2023-06 2023-08 2023-10 2023-12 2024-02 2024-04 2024-
Total gas 24hr
Heatpump electric 24hr
Boiler electric 24hr
System heat 24hr
Outdoor Temperature 24hr
Sunshine 24hr
COP 24hr

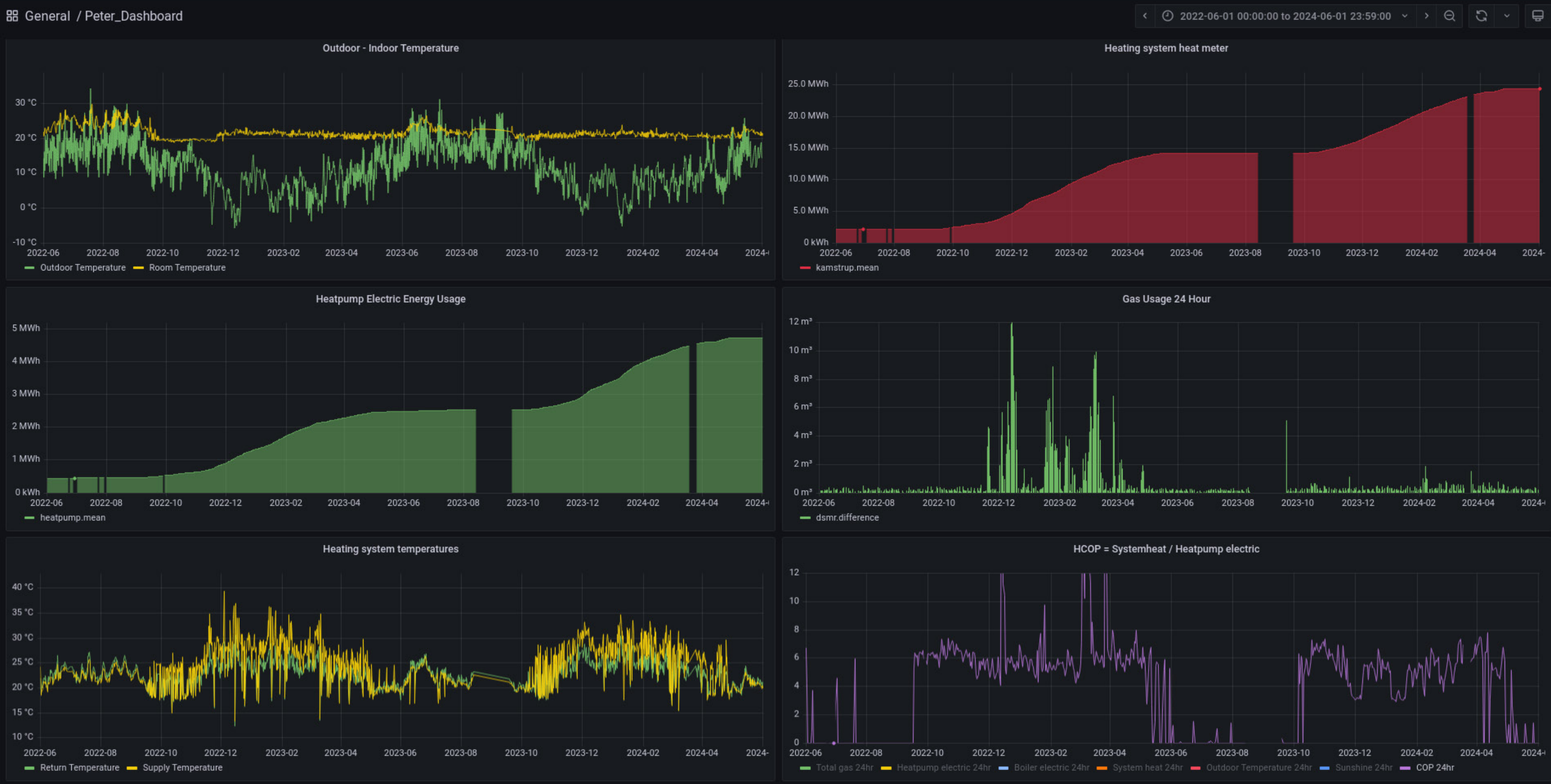

GdemEVzZ
General / Peter_Dashboard
2022-06-01 00:00:00 to 2024-06-01 23:59:59
Outdoor Temperature
Room Temperature
kamstrup.mean
Heatpump Electric Energy Usage
heatpump.mean
Gas Usage 24 Hour
dsmr.difference
Heating system temperatures
Return Temperature
Supply Temperature
HCOP = Systemheat / Heatpump electric
Total gas 24hr
Heatpump electric 24hr
Boiler electric 24hr
System heat 24hr
Outdoor Temperature 24hr
Sunshine 24hr
COP 24hr

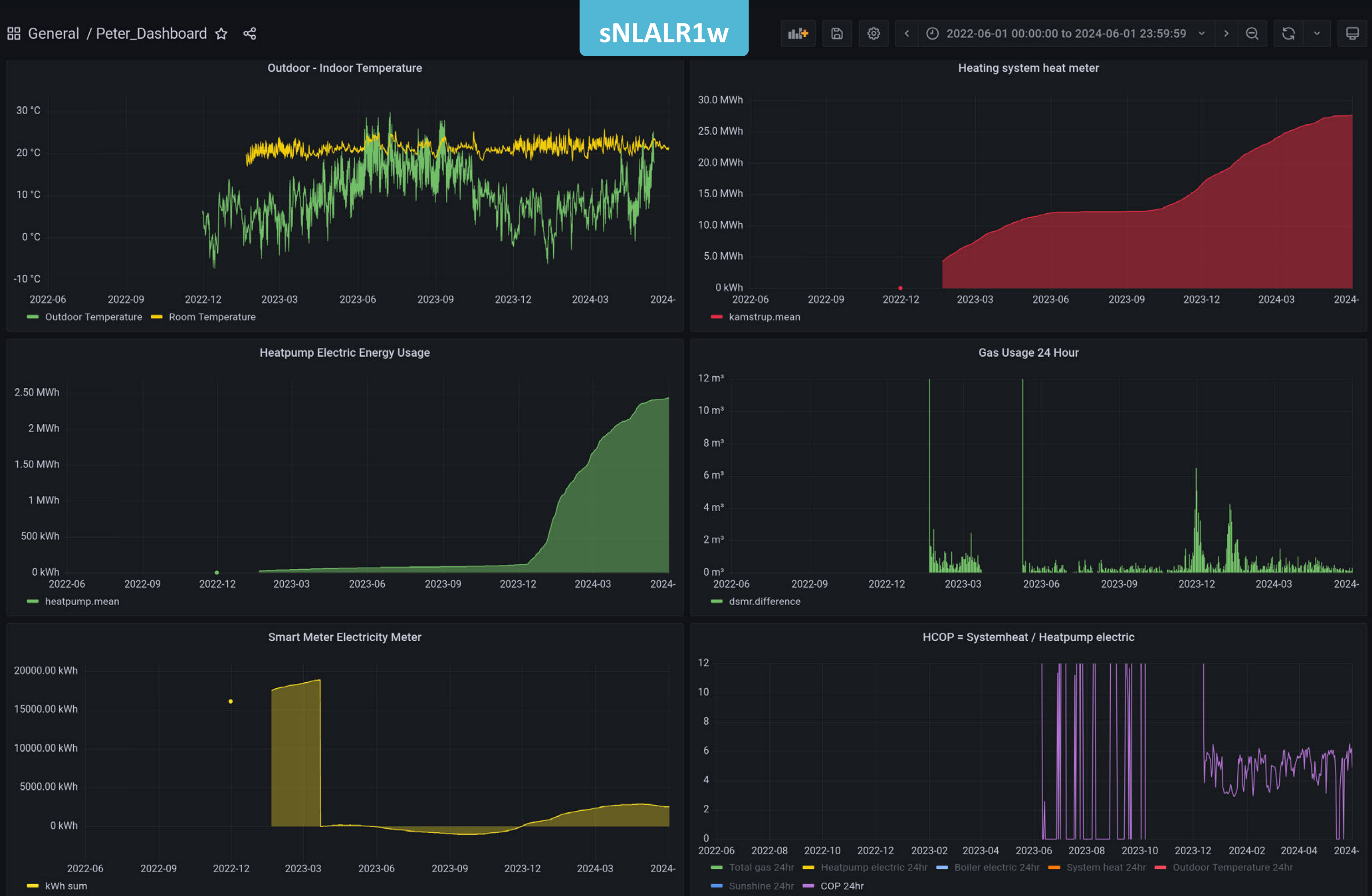

IVK0bORa
General / Peter_Dashboard
2022-06-01 00:00:00 to 2024-06-01 23:59:59
Outdoor - Indoor Temperature
Outdoor Temperature
Room Temperature
Heating system heat meter
kamstrup.mean
Heatpump Electric Energy Usage
heatpump.mean
Gas Usage 24 Hour
dsmr.difference
Heating system temperatures
Return Temperature
Supply Temperature
HCOP = Systemheat / Heatpump electric
Total gas 24hr
Heatpump electric 24hr
Boiler electric 24hr
System heat 24hr
Outdoor Temperature 24hr
Sunshine 24hr
COP 24hr

xSDmm63y


General / Peter_Dashboard
2022-06-01 00:00:00 to 2024-06-01 23:59:59
Outdoor - Indoor Temperature
Outdoor Temperature
Room Temperature
Heating system heat meter
kamstrup.mean
Heatpump Electric Energy Usage
heatpump.mean
Gas Usage 24 Hour
dsmr.difference
Heating system temperatures
Return Temperature
Supply Temperature
HCOP = Systemheat / Heatpump electric
Total gas 24hr
Heatpump electric 24hr
Boiler electric 24hr
System heat 24hr
Outdoor Temperature 24hr
Sunshine 24hr
COP 24hr

aQ1RbqD6


General / Peter_Dashboard
2022-06-01 00:00:00 to 2024-06-01 23:59:00
Outdoor - Indoor Temperature
30 °C
20 °C
10 °C
0 °C
-10 °C
2022-06 2022-08 2022-10 2022-12 2023-02 2023-04 2023-06 2023-08 2023-10 2023-12 2024-02 2024-04 2024-
Outdoor Temperature
Room Temperature
Heating system heat meter
25.0 MWh
20.0 MWh
15.0 MWh
10.0 MWh
5.0 MWh
0 kWh
kamstrup.mean
Heatpump Electric Energy Usage
5 MWh
4 MWh
3 MWh
2 MWh
1 MWh
0 kWh
heatpump.mean
Gas Usage 24 Hour
12 m³
10 m³
8 m³
6 m³
4 m³
2 m³
0 m³
dsmr.difference
Heating system temperatures
40 °C
35 °C
30 °C
25 °C
20 °C
15 °C
10 °C
Return Temperature
Supply Temperature
HCOP = Systemheat / Heatpump electric
12
10
8
6
4
2
0
Total gas 24hr
Heatpump electric 24hr
Boiler electric 24hr
System heat 24hr
Outdoor Temperature 24hr
Sunshine 24hr
COP 24hr


General / Peter_Dashboard
2022-06-01 00:00:00 to 2024-06-01 23:59:59
Outdoor - Indoor Temperature
30 °C
20 °C
10 °C
0 °C
-10 °C
2022-06
2022-09
2022-12
2023-03
2023-06
2023-09
2023-12
2024-03
2024-
Outdoor Temperature
Room Temperature
Heating system heat meter
30.0 MWh
25.0 MWh
20.0 MWh
15.0 MWh
10.0 MWh
5.0 MWh
0 kWh
kamstrup.mean
Heatpump Electric Energy Usage
2.50 MWh
2 MWh
1.50 MWh
1 MWh
500 kWh
0 kWh
heatpump.mean
Gas Usage 24 Hour
12 m³
10 m³
8 m³
6 m³
4 m³
2 m³
0 m³
dsmr.difference
Smart Meter Electricity Meter
20000.00 kWh
15000.00 kWh
10000.00 kWh
5000.00 kWh
0 kWh
kWh sum
HCOP = Systemheat / Heatpump electric
12
10
8
6
4
2
0
2022-06
2022-08
2022-10
2022-12
2023-02
2023-04
2023-06
2023-08
2023-10
2023-12
2024-02
2024-04
2024-
Total gas 24hr
Heatpump electric 24hr
Boiler electric 24hr
System heat 24hr
Outdoor Temperature 24hr
Sunshine 24hr
COP 24hr

Appendix 7: Jupyter table of all participants

Participant_id	Year built [years]	House Type	Gas_for_2 [m³]	Gas_for_1 [m³]	Gas_after [m³]	Gasbsp [–]	Elek_hyb [kWh]	Deck_degree [–]	Gas loss [–]	SCOP_below [–]	SCOP [–]	SCOP_sys [–]	Bsp_pres [–]	Netto bsp [euro]
* OMa7vZ0x	[1920-1939]	freestanding	1190	450	325	0,6	4375	0,79	2,99	3,88	3,3	3,23	1,11	-697,7
bB9dwLYE	[1960-1979]	freestanding	1294	1200	616	0,51	3533	0,63	1,48	3,07	2,59	2,03	1,75	-255,54
GMbBE51s	[1900-1919]	freestanding	2124	1813	228	0,88	6013	0,94	1,33	3,82	3,76	3,38	2,83	451,07
cggNkr7C	2000=>	freestanding	2849	412	684	0,58		0,7	1,28					
ib2L3SnU	[1980-1999]	semi-detached	1512	887	288	0,76		0,92	1,19					
5GCcwjbF	[1980-1999]	freestanding	1334	823	34	0,97	2953	1	1,18	4,08	4,08	4,03	3,45	473,21
-uFUg8jU	[1900-1919]	freestanding	1468	2584	920	0,55	3126	0,8	1,13	4,03	3,91	2,6	3,46	502,35
3QryrLjd	[1960-1979]	freestanding	4543	3122	979	0,74		0,79	1,1					
e6Pc72sP	[1980-1999]	freestanding	1999	1644	195	0,89		0,96	1,08					
xURf3a0o	[1960-1979]	freestanding	1503	1554	158	0,9	3744	0,92	1,08	3,9	3,87	3,24	3,58	662,42
pv_IsvbE	2000=>	freestanding	1925	2247	363	0,83	4283	0,98	1,06	4,16	4,16	3,93	3,93	963,64
eS3U7RoL	[1920-1939]	freestanding	1800	1881	442	0,76	3848	0,89	1,05	3,76	3,73	2,91	3,55	667,69
QytoLUAL	[1900-1919]	freestanding	1541	1695	364	0,77		0,89	1,02					
di1C3DT-	<1900	freestanding	1946	1645	528	0,71		0,78	1,01					
nPZwu5CK	[1920-1939]	freestanding	1387	1387	533	0,62	2390	0,73	1	3,48	3,48	2,07	3,49	394,6
0RQyG6WX	[1960-1979]	freestanding	1411	1475	573	0,6	2436	0,62	0,99	3,44	3,46	1,79	3,49	401,65
kKi5OIGx	[1960-1979]	semi-detached	2189	1834	294	0,85	5264	0,92	0,99	3,15	3,15	2,69	3,19	652,37
ywCyyxQF	[1980-1999]	semi-detached	1599	1649	645	0,6		0,64	0,99					
A0JoUuz-	[1980-1999]	freestanding	1129	1107	349	0,69	1925	0,74	0,96	3,68	3,74	2,11	3,9	425,49
P1IrM5bq	[1980-1999]	semi-detached	2175	2175	389	0,82		0,94	0,94					
bW_iJrKG	2000=>	semi-detached	1867	1759	390	0,79	3753	0,96	0,94	3,47	3,48	3,14	3,71	729,56
0rE1EXuT	[1980-1999]	semi-detached	1680	1558	150	0,91	2804	1	0,93	4,75	4,75	4,75	5,12	1084,89
5n48RmBE	[1920-1939]	freestanding		1300	295	0,77	2116	0,82	0,93	4,23	4,3	2,62	4,64	680,25
cfs3OE3j	[1920-1939]	freestanding	3605	1176	1253	0,48		0,57	0,92					
gfhTqPfk	[1980-1999]	semi-detached	1279	1453	647	0,53	1788	0,6	0,92	3,42	3,63	1,66	3,93	402,38
3jcFOgZ5	[1980-1999]	freestanding	2834	2581	917	0,66		0,7	0,91					
Lo8oUUaQ	2000=>	freestanding	2376	2203	312	0,86		0,97	0,91					
XmrgAM1Q	[1960-1979]	freestanding	1500	1500	520	0,65	2251	0,81	0,91	3,79	3,88	2,39	4,25	605,87
wv6qC56z	[1980-1999]	semi-detached	1321	1208	338	0,73	2314	0,78	0,91	3,47	3,57	2,18	3,91	514,46
6U_ZxCz7	[1980-1999]	corner house	1743	1943	284	0,85		0,91	0,9					
Dduwcofx	2000=>	freestanding	2337	2133	783	0,65	2948	0,77	0,9	4,17	4,31	2,3	4,81	1016,84
ZzY3cd3h	[1980-1999]	freestanding	3000	550	533	0,7	3429	0,73	0,9	3,04	3,17	1,89	3,54	588,6
SDIPnuVt	[1980-1999]	freestanding	1675	1521	861	0,46	1801	0,51	0,89	3,16	3,57	1,44	4	422,07
RHON9wor	[1920-1939]	semi-detached	1316	954	373	0,67	1698	0,81	0,87	3,68	3,81	2,3	4,38	487,08
zK4WxULP	2000=>	semi-detached	1406	1211	454	0,65	1766	0,75	0,87	3,89	4,1	2,13	4,73	589,39
3WCTOMF1	[1900-1919]	freestanding	1589	1461	275	0,82	3145	0,87	0,86	3,25	3,33	2,44	3,88	688,03
EyZIyLSP	2000=>	semi-detached	1500	1500	51	0,97	3724	1	0,85	3,21	3,21	3,21	3,8	772,21
fEQuZI6P	[1960-1979]	semi-detached	1275	1506	300	0,78	3137	0,89	0,85	2,82	2,88	2,28	3,39	477,27
1WyeUbFg	[1940-1959]	terraced house	2114	1501	274	0,85		0,96	0,83					

Participant_id	Year built [years]	House Type	Gas_for_2 [m³]	Gas_for_1 [m³]	Gas_after [m³]	Gasbsp [–]	Elek_hyb [kWh]	Deck_degree [–]	Gas loss [–]	SCOP_below [–]	SCOP [–]	SCOP_sys [–]	Bsp_pres [–]	Netto bsp [euro]
MBelxm3z	2000=>	terraced house	707	696	262	0,63		0,72	0,83					
hRPmkwLs	[1960-1979]	semi-detached	1075	1071	216	0,8	1895	0,88	0,83	3,54	3,65	2,56	4,42	551,94
CbPETsjw	2000=>	corner house	941	1062	110	0,89	1961	1	0,82	3,66	3,66	3,66	4,44	578,23
Mz219wDb	2000=>	semi-detached	837	902	333	0,62	1553	0,82	0,82	2,63	2,76	1,95	3,38	232,84
VF54k5wO	[1920-1939]	freestanding	2910	2898	916	0,68	4310	0,74	0,82	3,39	3,68	1,92	4,51	1307,94
SZphemL4	[1980-1999]	freestanding	1433	1469	261	0,82	2254	0,86	0,81	4,01	4,17	2,67	5,16	883,82
aQ1RbqD6	[1980-1999]	freestanding	1280	1443	79	0,94	2265	0,98	0,81	4,44	4,47	4,04	5,53	1003,51
-B51sQOp	[1980-1999]	freestanding	2400	2200	323	0,86		0,96	0,8					
3voUJ8cb	[1920-1939]	semi-detached	2746	2855	1236	0,56	3624	0,62	0,8	2,87	3,38	1,52	4,22	957,67
GDO9C-2s	[1980-1999]	freestanding	1413	1410	159	0,89		0,94	0,8					
Y6E5x8IP	2000=>	freestanding	2400	2317	93	0,96		0,98	0,8					
g6cwpA70	[1980-1999]	freestanding	2310	2602	322	0,87	4190	1	0,8	3,99	3,99	3,94	4,98	1539,34
1uGr4CK2	[1980-1999]	freestanding	1786	1900	533	0,71	2697	0,76	0,78	3,36	3,69	1,95	4,75	906,38
3c1fUm5M	[1980-1999]	freestanding	1650	1824	507	0,71	2450	0,83	0,78	3,59	3,81	2,3	4,91	876,7
b_eXywsq	[1980-1999]	freestanding	2293	2293	417	0,82		0,96	0,78					
ccN0cg3e	[1980-1999]	semi-detached	1260	1284	259	0,8	1725	0,8	0,78	4,15	4,47	2,28	5,74	812,5
d7dbrO23	2000=>	semi-detached	1106	1146	128	0,89	2221	0,91	0,78	3,32	3,42	2,59	4,39	638,43
diDdCX6N	[1960-1979]	terraced house	2204	2204	183	0,92		0,98	0,78					
2aE7xTqC	[1920-1939]	freestanding	2153	1746	257	0,87		0,91	0,77					
3V2aOh4L	[1980-1999]	freestanding	1843	1444	483	0,71	2189	0,73	0,76	3,44	3,92	1,83	5,18	865,27
RirVqJd3	2000=>	semi-detached	1539	1626	263	0,83		0,94	0,76					
W3lmQOBD	[1920-1939]	freestanding	3723	3126	983	0,71	4894	0,75	0,76	3,28	3,69	1,86	4,87	1730,68
b0-a0MJb	[1980-1999]	semi-detached	1304	1198	329	0,74	1725	0,85	0,76	3,74	3,96	2,44	5,22	691,07
wEqq3ifR	<1900	freestanding	4317	4012	2883	0,31	5360	0,33	0,76	0,64	1,79	0,94	2,34	43,19
TkMyAOp1	[1980-1999]	freestanding	1850	1790	302	0,83	3264	0,92	0,75	3,32	3,42	2,67	4,54	1006,8
GdemEVzZ	2000=>	semi-detached	1265	1302	524	0,59	1736	0,7	0,74	2,71	3,18	1,61	4,27	471,68
JyqlksBN	[1980-1999]	terraced house	2315	2136	569	0,74		0,93	0,74					
e-V7pn_P	[1940-1959]	freestanding	2171	2307	1112	0,5	1650	0,54	0,74	3,37	4,91	1,35	6,67	987,58
aGIM-uhc	2000=>	freestanding	1680	1580	160	0,9	2685	0,92	0,73	3,8	3,93	2,91	5,35	1122,49
btF7zwOl	2000=>	corner house	1551	1723	328	0,8	2581	0,88	0,73	3,45	3,64	2,44	4,95	940,41
ez7d4xNY	[1940-1959]	corner house	1717	1742	167	0,9	2536	0,98	0,73	4,37	4,4	3,97	6,02	1291,77
vtBLsHpC	2000=>	freestanding	1751	1741	213	0,88		0,93	0,73					
yjpSQKFb	[1980-1999]	freestanding	1593	1510	308	0,8	2602	0,86	0,73	3,22	3,42	2,25	4,67	846,77
-ORiFQC6	2000=>	semi-detached	1271	1304	144	0,89	2258	0,97	0,72	3,52	3,57	3,14	4,95	821,13
2L97t6LT	[1940-1959]	freestanding	2213	2305	212	0,91		0,93	0,72					
4OnYOkIn	[1900-1919]	freestanding	2035	2519	745	0,67	2701	0,74	0,72	3,42	3,98	1,81	5,54	1200,45
DsPYyuTY	[1960-1979]	freestanding	2420	2363	516	0,78	2585	0,81	0,72	4,66	5,12	2,39	7,09	1692,69
OnRTARXf	[1920-1939]	freestanding	1505	1570	608	0,6	1500	0,68	0,72	3,59	4,37	1,68	6,05	771,14
cXHtdNjQ	[1980-1999]	freestanding	1863	2037	94	0,95	4519	0,98	0,72	2,85	2,87	2,73	4,01	1067,35
U-vtaXTk	[1980-1999]	freestanding	2109	1757	677	0,65	1995	0,68	0,71	3,54	4,37	1,65	6,15	1051,65
W5J0QUUq	2000=>	semi-detached	1235	1316	467	0,63	1701	0,79	0,71	2,93	3,29	1,87	4,64	547,84
WUAgbEil	[1980-1999]	freestanding	2150	2494	359	0,85	4185	0,95	0,71	3,16	3,24	2,71	4,58	1313
on1VMMTO	[1960-1979]	freestanding	4031	3097	2229	0,37	2476	0,38	0,71	1,19	3,72	1,02	5,27	1007,99
w2fLs42F	2000=>	freestanding	1753	1992	608	0,68	1586	0,79	0,71	4,9	5,5	2,28	7,79	1189,6
D8ZSj9yG	[1960-1979]	freestanding	3750	3656	955	0,74	4608	0,76	0,7	3,5	4,06	1,88	5,83	2226,36
Di0nyhC7	[1980-1999]	freestanding	1850	1920	415	0,78	2922	0,83	0,7	3,16	3,45	2,1	4,91	1048,91
FFOpKdF2	[1980-1999]	freestanding	2319	2224	178	0,92	4819	0,97	0,7	2,95	2,99	2,74	4,24	1290,51

Participant_id	Year built [years]	House Type	Gas_for_2 [m³]	Gas_for_1 [m³]	Gas_after [m³]	Gasbsp [–]	Elek_hyb [kWh]	Deck_degree [–]	Gas loss [–]	SCOP_below [–]	SCOP [–]	SCOP_sys [–]	Bsp_pres [–]	Netto bsp [euro]
I3v9SmRO	[1980-1999]	semi-detached	1209	1022	197	0,82		0,95	0,7					
JEZzJ1_-	[1980-1999]	freestanding	2138	2160	108	0,95	4218	0,95	0,7	3,23	3,3	2,81	4,73	1407,23
Lm4kAwHz	2000=>	semi-detached	1282	1402	306	0,77	1765	0,89	0,7	3,78	3,99	2,64	5,73	830,55
Z5tUk-4t	[1960-1979]	semi-detached	1585	1536	195	0,88		0,92	0,7					
uTJqSvxx	2000=>	freestanding	1778	1554	462	0,72	2237	0,76	0,7	3,2	3,7	1,82	5,26	907,98
xSDmm63y	[1960-1979]	terraced house	1199	1391	799	0,38	745	0,42	0,7	1,79	4,53	1,08	6,49	427,99
uUFhBQzs	[1940-1959]	terraced house	1657	1731	361	0,79		0,9	0,69					
5NNgThim	[1920-1939]	freestanding	3727	3718	811	0,78	4218	0,81	0,68	4,05	4,56	2,2	6,74	2565,16
96H2Z6-Y	[1980-1999]	freestanding	2225	2129	168	0,92		1	0,68					
MNbpwIxe	[1980-1999]	freestanding	2301	1611	290	0,85	4326	0,93	0,68	2,45	2,55	2,11	3,76	874,83
yNmVF4oy	[1980-1999]	freestanding	1917	1615	281	0,84	2288	0,89	0,68	4,07	4,31	2,74	6,34	1265,35
qAVHYp3J	[1920-1939]	semi-detached	2361	2235	943	0,59		0,71	0,67					
4iyux5_5	[1980-1999]	freestanding	1567	1798	474	0,72	1717	0,77	0,66	3,87	4,57	1,93	6,88	1075,55
BdMf5w-N	[1960-1979]	semi-detached	3042	3135	1063	0,66	3471	0,8	0,66	3,25	3,74	1,93	5,7	1617,91
h57Wozww	[1920-1939]	terraced house	2089	1886	200	0,9	2540	0,95	0,66	4,39	4,52	3,46	6,88	1590,1
0_6TUlP4	[1960-1979]	corner house	1842	2103	878	0,55	1504	0,58	0,65	2,79	4,62	1,29	7,11	989,32
tZSnEgva	[1940-1959]	semi-detached	2137	2252	893	0,59	2284	0,67	0,65	2,66	3,63	1,44	5,57	1022,57
vAibnS26	[1960-1979]	semi-detached	2489	2458	375	0,85	3234	0,89	0,65	3,85	4,12	2,62	6,34	1788,69
6-gOUJps	[1960-1979]	semi-detached	1809	2135	470	0,76	2590	0,84	0,64	3,22	3,63	2,05	5,67	1194,45
0z5clxou	[1940-1959]	freestanding	743	4947	839	0,71	3253	0,74	0,63	2,96	3,77	1,62	6,03	1660,2
UkhY0kLf	[1980-1999]	freestanding	1922	2163	148	0,93		0,98	0,63					
QtE_uvEX	[1960-1979]	terraced house	1098	1022	114	0,89	1491	0,9	0,62	3,6	3,86	2,53	6,2	795,93
MT_lo4kd	[1980-1999]	terraced house	959	1077	118	0,88		0,95	0,61					
eTBI5kYm	[1980-1999]	semi-detached	1589	1425	173	0,89	1831	0,96	0,61	4,22	4,35	3,43	7,12	1206,6
kaTMcjBU	[1900-1919]	freestanding	2765	2207	635	0,74	2570	0,81	0,61	3,65	4,28	2,02	7,03	1664,4
9-agjI3L	[1920-1939]	freestanding	2689	3846	916	0,72	2696	0,77	0,6	4,12	5,12	1,89	8,52	2292,13
ooQJGe15	[1920-1939]	semi-detached	2849	2589	856	0,69		0,75	0,6					
rC_pkM3K	2000=>	terraced house	1312	1275	349	0,73	1416	0,9	0,6	3,61	3,89	2,52	6,52	816,98
6sdsV762	[1960-1979]	freestanding	3091	3821	865	0,75	3863	0,81	0,59	3,21	3,85	1,86	6,55	2248,18
qdC1C7Lx	2000=>	semi-detached	1538	1491	127	0,92	1779	0,98	0,59	4,47	4,53	4	7,62	1294,43
B4oZ6JEm	[1980-1999]	freestanding		4000	550	0,86	5317	0,91	0,58	3,42	3,69	2,46	6,34	2940,48
hlOONbvk	[1980-1999]	freestanding	1458	1518	175	0,88	1780	0,97	0,58	4,13	4,21	3,64	7,21	1194,82
lVK0bORa	[1960-1979]	freestanding	2198	2377	921	0,6	1870	0,71	0,58	2,95	4,17	1,49	7,14	1238,3
7JgOwuUh	[1980-1999]	freestanding	1568	1416	450	0,7	1670	0,79	0,57	2,74	3,45	1,66	6,1	868,16
LyD1Zpmn	[1920-1939]	freestanding	2801	3136	691	0,77	2602	0,8	0,57	3,92	4,84	1,93	8,55	2223
Q_CTMAg9	2000=>	freestanding	1002	1206	99	0,91	1640	1	0,57	3,41	3,41	3,41	5,99	828,25
e9WTomef	[1980-1999]	freestanding	2237	2000	462	0,78	2388	0,82	0,57	3,22	3,85	1,91	6,78	1462,73
tJM9KqTt	[1940-1959]	terraced house	1080	1146	552	0,5	869	0,7	0,57	2,4	3,58	1,37	6,31	476,56
yxOWx66O	[1980-1999]	freestanding	1560	1466	140	0,91	1465	0,92	0,57	4,86	5,21	3,13	9,16	1372,21
6oWZr5LM	[1980-1999]	freestanding	2558	2235	1256	0,48	1395	0,52	0,56	1,27	4,47	1,03	7,99	1084,45
9SiQCg0b	2000=>	semi-detached	1585	1305	284	0,8	1601	0,85	0,56	3,42	3,95	2,1	7,09	1048,19
y5TEbHnC	2000=>	freestanding	1661	1883	426	0,76	1784	0,8	0,56	3,36	4,15	1,84	7,37	1236,43
5QvgGmut	2000=>	terraced house	1184	1195	493	0,59	1156	0,68	0,55	1,98	3,21	1,26	5,89	568,2
9LFZHK7q	[1980-1999]	terraced house	1680	1786	246	0,86	1576	0,88	0,55	4,45	5,04	2,5	9,22	1489,31
Kwb9DHh8	2000=>	freestanding	1500	1548	314	0,79		0,89	0,55					
frZKRmLD	2000=>	freestanding	3011	2864	966	0,67	2957	0,82	0,55	2,9	3,55	1,78	6,51	1705,43
tf9oJob7	[1980-1999]	corner house	1806	1261	644	0,58	1026	0,66	0,55	2,62	4,64	1,3	8,47	864,85

Participant_id	Year built [years]	House Type	Gas_for_2 [m³]	Gas_for_1 [m³]	Gas_after [m³]	Gasbsp [–]	Elek_hyb [kWh]	Deck_degree [–]	Gas loss [–]	SCOP_below [–]	SCOP [–]	SCOP_sys [–]	Bsp_pres [–]	Netto bsp [euro]
df79ygat	[1960-1979]	terraced house	1403	1376	588	0,58	2359	0,79	0,54	1,4	1,8	1,21	3,32	333,97
oqb_lZc9	[1960-1979]	corner house	942	838	132	0,85	1537	0,95	0,54	2,47	2,6	2,16	4,82	531,35
uennkFAE	2000=>	freestanding	1091	1108	570	0,48	1163	0,71	0,54	1,59	2,42	1,21	4,45	343,68
bep7sbGN	[1920-1939]	terraced house	2016	2016	490	0,76		0,79	0,53					
MPjpuY8a	[1960-1979]	terraced house	1300	1049	310	0,74	1001	0,78	0,52	3,32	4,42	1,7	8,44	839,31
7iTwZNm7	[1920-1939]	semi-detached	2050	1655	355	0,81	1430	0,86	0,5	4,33	5,16	2,24	10,23	1548,6
UigJRsPF	[1980-1999]	freestanding	2372	2195	659	0,71	2360	0,76	0,5	2,32	3,39	1,42	6,73	1428,98
l7_BBT0u	[1980-1999]	freestanding	4226	3945	1390	0,66	2728	0,75	0,5	3,16	4,81	1,5	9,65	2739,13
141Q2Shj	[1980-1999]	semi-detached	1444	1349	700	0,5	2370	0,55	0,49	0,22	1,4	0,76	2,87	191,64
sNLALR1w	[1920-1939]	freestanding	3658	3201	177	0,95	3881	0,97	0,49	3,88	4,02	3,27	8,19	3122,48
1Y5XKgSd	2000=>	freestanding	1282	1400	52	0,96	1432	0,96	0,48	4,09	4,26	3,32	8,8	1270,37
GjGxfcOD	[1920-1939]	freestanding	1973	1790	216	0,89	2230	0,89	0,48	3,01	3,47	2,08	7,3	1523,99
H6PEe0lX	[1960-1979]	-	1951	1814	409	0,78	2534	0,91	0,48	2,4	2,71	1,88	5,68	1173,62
zPZ3d57M	[1920-1939]	freestanding	2000	2199	480	0,77	2094	0,82	0,46	2,63	3,5	1,63	7,56	1505,09
Q7c7Wak6	2000=>	freestanding	1412	1538	439	0,7	966	0,8	0,45	3,26	4,69	1,63	10,48	1078,73
c_pkxwxm	[1920-1939]	freestanding	1939	1604	641	0,64	942	0,74	0,41	2,34	4,8	1,26	11,73	1212
J1bBIrb_	[1960-1979]	freestanding	1912	1561	431	0,75	949	0,86	0,35	3,35	4,74	1,75	13,44	1442,29
HedOCi6L	[1940-1959]	semi-detached	558	346	183	0,59	215	0,83	0,2	0,36	2,42	0,82	12,23	291,03
HuOvEokt	[1960-1979]	terraced house	2421	2411	721	0,7		0,9	0,17					
0XvCtU3v	[1940-1959]	semi-detached	1469	1386	320		1510							
46no-WLf	[1940-1959]	terraced house			109		1406			3,84		2,95		
66lZ2dKl	2000=>	freestanding	4900	4650	624		464							
6pd9A10u	[1960-1979]	freestanding	1746	1414	186	0,88								
9H8W2b5Q	[1960-1979]	semi-detached	2040	1959	332	0,83								
DlCdUGP1	[1920-1939]	terraced house	203	1501	167		123							
IF9c6c-H	[1960-1979]	freestanding	1628	1587			1969							
JqpjoDDU	[1960-1979]	-	3261	2271	730	0,74	4797						4,15	1220,89
Jr9PJjgK	[1980-1999]	freestanding	2179	2380			2790							
KR2H1ovj	[1940-1959]	terraced house	1185	1287	161	0,87								
LzZTAYkZ	2000=>	freestanding	2336	1804	610		2610							
Nkw-o7MK	2000=>	freestanding	2150	1110	679	0,58	2194						4,24	584,98
PL238TVN	[1920-1939]	freestanding			1005		3368			5,79		3,08		
Z5GVYH20	[1980-1999]	terraced house			678		2209			2,73		1,46		
gmtO-Zla	[1920-1939]	appartement	2000	1890			2901							
nkMckb09	[1980-1999]	corner house	972	884	31									
qBr4JQ_w	<1900	semi-detached	3215	2887										
u3RHJ15y	[1980-1999]	semi-detached	1469	1333	593	0,58	2145						3,68	409,74
uQLTOCT9	-	semi-detached												
ueGJf9d5	2000=>	freestanding	2000	1732			3758							
yV4lUIbS	[1980-1999]	semi-detached	825	615	184									
zskLB4tU	[1960-1979]	semi-detached	810	87	1360		1508							
Average			**1914**	**1835**	**483**	**0,748**	**2514**	**0,83**	**0,75**	**3,34**	**3,82**	**2,27**	**5,67**	**1017,88**
Quantity			168	170	168	158	132	152	152	120	117	120	120	120

**) This participant's gas usage (Gas_for_1) already covered a year in which the hybrid was operational. In addition, this home was remodeled so the statement (Gas_for_1) can no longer be used for comparison. Because this only became apparent when this document was issued, removal of this line was not implemented. This explains the significantly different values of this case.*

Appendix 8: Measurement set description and specifications

The Hybrid Demo Project uses various measuring instruments placed in residents' homes to monitor the performance of the hybrid boiler. Great care was taken to ensure the accuracy of the measuring instruments used to obtain reliable data.

An important measuring instrument deployed is the **Kamstrup Multical 403 heat meter.** This heat meter has MID Class B accuracy, which means it complies with strict European directives for measuring instruments. This guarantees reliable measurement of the heat output of the hybrid boiler.

In addition, the power consumption of the heat pump and the boiler are measured separately using two separate **meters of type SDM120M.** These electrical power meters also have MID Class B accuracy. This means that they can provide very precise measurements and meet the same high standards.

Room temperature and humidity are measured using a **Sonoff WiFi meter.** Although the accuracy of the Sonoff WiFi temperature and humidity meter is not very high, it is important to note that the placement of this sensor in the room is of greater importance to the measurements. The focus is more on the trend in room temperature and heating usage, rather than the exact readings themselves.

The electricity and gas consumption of the entire household is measured by reading the existing **smart meter** in the meter box.

All the measurement data from these sensors are collected and sent to the third-party cloud server called Inversible© every 10 seconds. By aggregating and analyzing the data, we can get a good understanding of the performance of the hybrid boiler. Despite the slightly less accurate room temperature measurement, the accurate heat, gas and electricity measurements from the measuring instruments used provide enough reliable data to make a solid statement about the performance of the hybrid boiler in the Hybrid Demo Project.

The Kamstrup MULTICAL® 403 is an advanced energy meter used for measuring and recording thermal energy consumption in heating and cooling systems. The device uses various sensors and technologies to make accurate measurements and determine the total thermal power delivered.

The MULTICAL® 403 measures various physical values to determine thermal energy consumption. It uses ultrasonic sensors to measure the flow of the heating or cooling medium. These sensors measure the velocity of the medium and record volume flows.

In addition, the MULTICAL® 403 uses temperature sensors to measure the inlet and outlet temperatures of the medium. These sensors are placed on the inlet and outlet lines of the system. By measuring the difference in temperature, the meter can perform the thermal energy calculation.

Using the measured flow rate and temperature difference, the MULTICAL® 403 can determine the thermal power. The device uses the thermal power formula **($Q = m \times Cp \times \Delta T$)**, where **Q** is the thermal power, **m** is the mass flow rate, **Cp** is the specific heat capacity of the medium and **ΔT** is the temperature difference between the inlet and outlet temperatures.

By integrating thermal power over a given period, the MULTICAL® 403 can calculate the total amount of thermal energy delivered. This enables users to monitor energy consumption, analyze consumption patterns and manage costs.

MID (Measurement Instruments Directive) Class B refers to a specific classification for measuring instruments used in accordance with the European Measuring Instruments Directive.

Class B measuring instruments are intended for measurements in the fields of electricity, gas, water and thermal energy. They must meet strict accuracy requirements and are often used for billing and trading purposes. Class B instruments are suitable for measuring large amounts of energy and are often used by utility companies.

TS TS27.02+DK268 refers to technical specifications related to electricity measurement. TS27.02 represents a technical specification related to active energy and power measurement in electrical installations. It defines the requirements and specifications that measuring instruments must meet to ensure accurate measurements.

SDM120M Class B power meters are highly accurate measuring instruments used to measure the power of electrical devices or systems. They meet the strict accuracy requirements of Class B according to the European Measuring Instruments Directive (MID). Class B meters are suitable for applications where high precision and reliability are essential, such as billing, trading and critical energy monitoring.

Class B power meters offer an exceptionally high degree of accuracy and reliability in their measurements. They are designed to have very small deviations from the actual power values being measured. This ensures very precise and reliable power measurements.

The accuracy of Class B power meters is usually expressed as a percentage of the measured value, plus a certain number of units of the smallest measured value. For example, a class B meter may have an accuracy of ±0.5% of the measured value plus 0.1 units. This means that, for example, a measurement of 100 watts can have a maximum deviation of ±0.5 watts plus 0.1 watts.

It is important to note that Class B power meters often incorporate advanced features and technologies to ensure accuracy. For example, they may use digital signal processing, calibration techniques and compensation methods to optimize measurements.

In short, Class B power meters offer exceptionally high precision and reliability in their measurements. They are suitable for applications where accurate power measurement is required and offer the assurance of highly accurate results for critical energy-related processes.

For measuring temperature and humidity, the Sonoff WiFi temperature and humidity sensor was used. The reading value of the measurement is highly dependent on the location of the sensor in the room, and therefore the precision of this sensor is not the most important criterion.

When placing the Sonoff sensor in a room, it is essential to consider its position in relation to possible heat or humidity sources, such as radiators, direct sunlight, air currents or other electronic devices. These factors can affect the sensor's measurements and can lead to deviations in the displayed temperature and humidity values.

In summary, when using a Sonoff WiFi temperature and humidity sensor, the location of the sensor in the room is critical to the accuracy of the measurement. It is important to consider positioning relative to heat and humidity sources and to calibrate the sensor if necessary. The precision of the sensor is not the most crucial aspect, but its careful placement and adjustment can ensure more reliable measurements of temperature and humidity in the room (in this I am sure will not always have happened in the practice of the project).

The Hybrid demo project also uses a **P1 gate meter** to measure electricity and gas consumption. When using a P1-gate meter, one is largely dependent on the accuracy of the smart meter because the P1-gate meter reads the data directly from the smart meter.

Smart meters, installed in many households, generally offer good accuracy in measuring electricity and gas consumption. They are designed and manufactured to strict technical standards to provide reliable measurement results. The accuracy of a typical smart meter complies with applicable laws and regulations, such as the MID (Measuring Instruments Directive) in Europe.

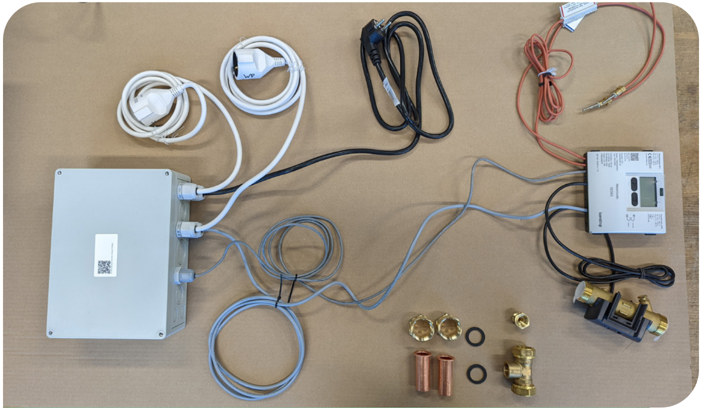
The accuracy of a smart meter is often expressed as a percentage of the measured value, plus a certain number of units of the smallest measured value. For example, a smart meter may have an accuracy of ±1% of the measured value plus 0.2 units. This means that, for example, a reading of 1000 kWh has a maximum deviation of ±10 kWh plus 0.2 kWh may have.

It is important to note that the accuracy of smart meters can vary depending on the model. In general, however, smart meters are designed to provide reliable and accurate readings. In addition, smart meters undergo regular calibrations and checks to ensure they remain accurate. In the Hybrid Demo Project, we rely on the accuracy of the smart meter to measure power and gas consumption. Given the reliability and accuracy of typical smart meters in people's homes, we can reasonably rely on the metering data obtained from the P1 gate meter. This allows us to perform detailed analysis and understand the energy consumption and performance of the hybrid system in the project.

Following pages contain images of the measurement set with the previous measurement units and the data communications added to them. The measurement units are connected to the Mifi router through a resident-protected Wifi channel through which the units transmit data to the router. This was accomplished with off-the-shelf Raspberry PI hardware. The rough setup of the data processing is explained in the main text.

P1 port reading smart meter

Mifi router

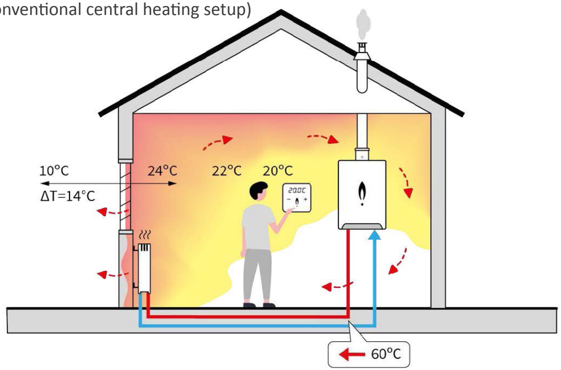


Measurement unit for the power absorbed by the boiler and hybrid, and the amount of heat delivered to the system via flow and delta-T, supply and return temperature, measurement

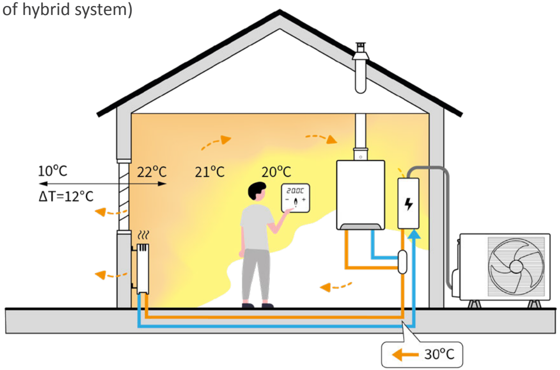
Measuring unit for temperature and humidity in living room

Appendix 9: Water temperature, delta T and warm air distribution

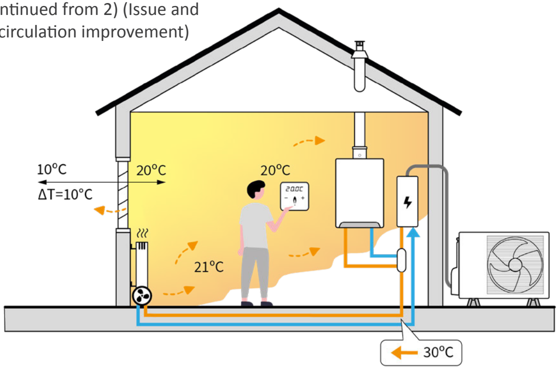
1 High flow temperature
(Conventional central heating setup)



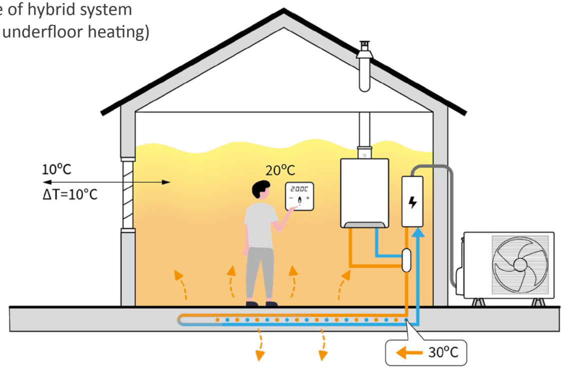
2 Low flow temperature
(Use of hybrid system)



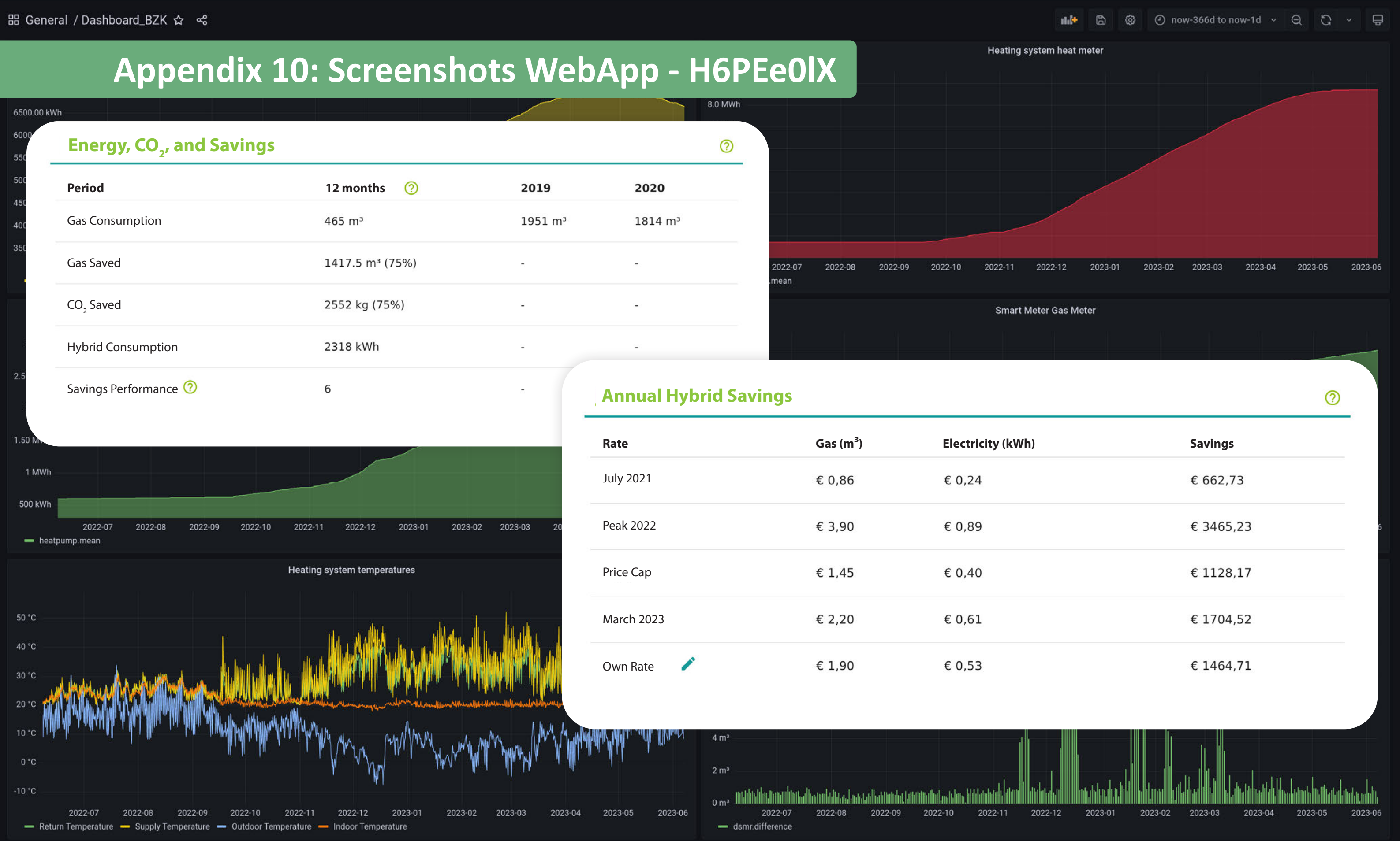
3 Low flow temperature
(Continued from 2) (Issue and
air circulation improvement)



4 Low flow temperature
(Use of hybrid system
and underfloor heating)



Appendix 10: Screenshots WebApp - H6PEe0lX



Energy, CO_2, and Savings

Period	12 months	2019	2020
Gas Consumption	465 m³	1951 m³	1814 m³
Gas Saved	1417.5 m³ (75%)	-	-
CO_2 Saved	2552 kg (75%)	-	-
Hybrid Consumption	2318 kWh	-	-
Savings Performance	6	-	

Annual Hybrid Savings

Rate	Gas (m³)	Electricity (kWh)	Savings
July 2021	€ 0,86	€ 0,24	€ 662,73
Peak 2022	€ 3,90	€ 0,89	€ 3465,23
Price Cap	€ 1,45	€ 0,40	€ 1128,17
March 2023	€ 2,20	€ 0,61	€ 1704,52
Own Rate	€ 1,90	€ 0,53	€ 1464,71

Appendix 11: Participant survey

ID	How did the installation process go?	How satisfied are you with the performance of the hybrid heat pump?	Have there been any problems / malfunctions with the operation of the hybrid heat pump?	If there are (or have been) problems/malfunctions, can you describe them?	How do you experience heating with a hybrid installation? (compared to a traditional central heating boiler)?	How do you experience the noise of the outdoor unit of the heat pump?	What do you think the outdoor unit looks like?	Has your heating behaviour changed?	If your heating behaviour has changed, what is the reason for this?	Has your hot water usage changed?	Has the number of family members in your household changed since joining the project?
2	It took a lot of time	Satisfied	No		It takes longer to heat the house	Not audible / not annoying	Not pretty	Heating more economically (e.g. lower room temperature / thermostat rather lower)	Trying to achieve the lowest possible gas consumption	Use less hot water / shower less	Not changed
3	Seamlessly	Very satisfied	No		Pleasant, now that the heating is on 20 degrees 24/7. Otherwise, it will take too much energy to heat up the floor again	Not audible / not annoying	Not pretty	Constant temperature below of 20 degrees	A lot of energy is needed to heat up the underfloor heating.	No change in hot water usage	Not changed
4	Seamlessly; A lot of extra work was needed	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	Heating more / warmer (higher room temperature / thermostat higher)	More constant, room thermostat must be set higher to match the comform of central heating temperature.	No change in hot water usage	Fewer family members
5	Seamlessly	Very satisfied	No		Stayed the same, it gets warm in the house just as quickly	Not audible / not annoying	Pretty	No change in heating behaviour		No change in hot water usage	Not changed
6	Seamlessly	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	Not pretty	Set the thermostat lower by default		Use less hot water / shower less	Not changed
7	Seamlessly	Satisfied	Yes	Escaped refrigerant	It takes longer to heat the house	Not audible / not annoying	Not pretty	No change in heating behaviour		Use more hot water / shower more	Not changed
8	Seamlessly	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	Set the thermostat lower by default		No change in hot water usage	Not changed
9	Seamlessly	Very satisfied	No		Below 5° temperature remains between 18° and 19°	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
10	Seamlessly	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Fewer family members
11	A lot of extra work was needed	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Fewer family members
12	Seamlessly	Satisfied	Yes	Something was connected incorrectly. However, it was later fixed for free	It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	Set the thermostat lower by default	More economical and temperature constant day and night.	No change in hot water usage	Not changed

ID	How did the installation process go?	How satisfied are you with the performance of the hybrid heat pump?	Have there been any problems / malfunctions with the operation of the hybrid heat pump?	If there are (or have been) problems/malfunctions, can you describe them?	How do you experience heating with a hybrid installation? (compared to a traditional central heating boiler)?	How do you experience the noise of the outdoor unit of the heat pump?	What do you think the outdoor unit looks like?	Has your heating behaviour changed?	If your heating behaviour has changed, what is the reason for this?	Has your hot water usage changed?	Has the number of family members in your household changed since joining the project?
13	Seamlessly	Satisfied	No		It takes longer to heat the house	Annoying	No opinion / Neutral	Heating more / warmer (higher room temperature / thermostat higher)	Turned up the night temperature because otherwise it takes too long to reach the day temperature.	Use less hot water / shower less	Not changed
14	Seamlessly	Neutral	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
15	A lot of extra work was needed	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
16	Seamlessly	Dissatisfied	Yes	After a power failure, the entire pump was disrupted.	Stayed the same, it gets warm in the house just as quickly	Outdoor unit no noise pollution. But the indoor unit is in our attic and makes a lot of noise.	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
17	Seamlessly	Very satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		Use less hot water / shower less	Not changed
18	Seamlessly	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
19	Seamlessly, however, little explanation;	Very satisfied	Yes	The company that was supposed to take care of the installation and maintenance went bankrupt last October. No maintenance, so maintenance contract canceled and had to call in another company.	Stayed the same, it gets warm in the house just as quickly	Not audible / not annoying	No opinion / Neutral	Thermostat 24/7 at 21.5 degrees due to underfloor heating		Use less hot water / shower less	Not changed
20	Seamlessly	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
21	Seamlessly	Very satisfied	No		It takes longer to heat the house	Annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
22	Seamlessly	Satisfied	No		Stayed the same but a little more noise due to the outdoor unit	Audible, but not annoying	Not pretty	Underfloor heating so as little as possible temporarily lowering the thermostat		No change in hot water usage	Not changed
23	Seamlessly	Very satisfied	No	Hybrid heat pump is not a problem in itself, only the control from Honeywell EvoHome to be able to heat per room is a drama. Half an hour on, off, on, off, on, off... instead of nice long runs for the heat pump. I have made a post-regulation for this myself.	It takes longer to heat the house	Not audible / not annoying	No opinion / Neutral	Heating more / warmer (higher room temperature / thermostat higher)	In the past, the thermostat was set to 20.5 degrees and was only heated downstairs. Now at 22 degrees and heating can be done per (study/children's/bedroom/work) room. We used to do that with an electric heater. We hardly use the soapstone stove anymore, previously up to 3m² of wood per year.	No change in hot water usage	Not changed

ID	How did the installation process go?	How satisfied are you with the performance of the hybrid heat pump?	Have there been any problems / malfunctions with the operation of the hybrid heat pump?	If there are (or have been) problems/malfunctions, can you describe them?	How do you experience heating with a hybrid installation? (compared to a traditional central heating boiler)?	How do you experience the noise of the outdoor unit of the heat pump?	What do you think the outdoor unit looks like?	Has your heating behaviour changed?	If your heating behaviour has changed, what is the reason for this?	Has your hot water usage changed?	Has the number of family members in your household changed since joining the project?
24	Seamlessly	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
25	Seamlessly	Very satisfied	No		Stayed the same, it gets warm in the house just as quickly	Annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
26	Seamlessly	Very satisfied	No	Only the sound is a problem. I bought an SUS cabinet for that which was quite pricey (approx. € 2,000)	Stayed the same, it gets warm in the house just as quickly	Annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
27	Seamlessly	Very satisfied	Yes	Interaction between boiler and WP to find a balance between comfort and savings	Stayed the same, it gets warm in the house just as quickly	Not audible / not annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
28	It took a lot of time	Neutral	Yes	Main fuse Enexis unfolded 3 times	It takes longer to heat the house	Annoying	No opinion / Neutral	Heating more economically (e.g. lower room temperature / thermostat rather lower)	Consume less power	No change in hot water usage	Fewer family members
29	Seamlessly	Very satisfied	Yes	Sometimes the heat pump does not start up while the thermostat indicates a temp that is too low. Could also be the thermostat.	It takes longer to heat the house	Annoying	No opinion / Neutral	No change in heating behaviour		Use more hot water / shower more	Not changed
30	Seamlessly	Satisfied	Yes	The installation failed at a few moments because the installation cannot get rid of the heat. The underfloor heating is limited in temperature and in other places the temperature has been reached/pinched. To solve that myself, I have set up a number of locations (kitchen, office and bathroom for heat as a buffer.	It takes longer to heat the house	Audible but not annoying. We had a problem with an ice plug in the outflow, which created a loud noise. After two days this was solved by removing the ice with a hair dryer.	Not pretty	Thermostat is set to 19 degrees all times. Temperature is standard 19.5 degrees in the living room		No change in hot water usage	Not changed
31	Seamlessly	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Not audible / not annoying	Is not visible	No change in heating behaviour		No change in hot water usage	Not changed
32	Seamlessly	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
33	It took a lot of time	Neutral	No		Fewer gradations keep the house warm	Audible, but not annoying	No opinion / Neutral	There is 20 degrees at night and 21 degrees during the day	The night temperature is higher because the installer indicated that it costs less energy if there are greater differences between the night and day temperature.	No change in hot water usage	Not changed
34	A lot of extra work was needed	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed

ID	How did the installation process go?	How satisfied are you with the performance of the hybrid heat pump?	Have there been any problems / malfunctions with the operation of the hybrid heat pump?	If there are (or have been) problems/malfunctions, can you describe them?	How do you experience heating with a hybrid installation? (compared to a traditional central heating boiler)?	How do you experience the noise of the outdoor unit of the heat pump?	What do you think the outdoor unit looks like?	Has your heating behaviour changed?	If your heating behaviour has changed, what is the reason for this?	Has your hot water usage changed?	Has the number of family members in your household changed since joining the project?
35	Seamlessly	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
36	A lot of extra work was needed	Neutral	Yes	Combination of heat pump and central heating did not work properly, the software has been replaced	It takes longer to heat the house	Audible, but not annoying	Pretty	Set the thermostat lower by default	You get used to turning down the heating, good for the environment.	No change in hot water usage	Not changed
37	Seamlessly	Very satisfied	No		It takes longer, but the heat is constant.	Audible, but not annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
38	Seamlessly	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
39	Was not properly adjusted	Neutral	No		Ground floor good, upstairs moisture problems	Audible, but not annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
40	Seamlessly	Very satisfied	No		With the underfloor heating, the temperature remains the same day and night	Not audible / not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
41	Seamlessly	Very satisfied	No	However, the e-Twist thermostat did not wake up properly in January 2024 during the frost period.	It takes longer to heat the house	Audible, but not annoying	I have now put a black case around it.	No change in heating behaviour		No change in hot water usage	Not changed
42	There was uncertainty about the possibilities and the method of heating. Remeha has visited 4 times	Satisfied	Yes	There was uncertainty about the supply of heat that the heat pump should be able to supply at a Delta of 5°. Also by Remeha technicians themselves. Replace the circuit board, replace heat agent and replace flow sensor. Last mechanic indicated that he worked as expected and that they could not do anything else.	I started heating something else, always constant temperature. As a result, I can't say anything about the warm-up time. In freezing cold let the central heating help and then it works like for the heat pump	Not audible / not annoying	Not pretty	Set the thermostat lower by default		No change in hot water usage	Not changed
43	Seamlessly	Satisfied	No		It heats up faster in the house	Audible, but not annoying	Pretty	Heating more / warmer (higher room temperature / thermostat higher)	Constant day and night at 20 degrees, instead of lower at night.	No change in hot water usage	Not changed
44	Seamlessly	Neutral	No		It takes longer to heat the house	Audible, but not annoying	Not pretty	Heating more economically (e.g. lower room temperature / thermostat rather lower)	We are now heating at 19 degrees	No change in hot water usage	Not changed
45	Seamlessly	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Not audible / not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed

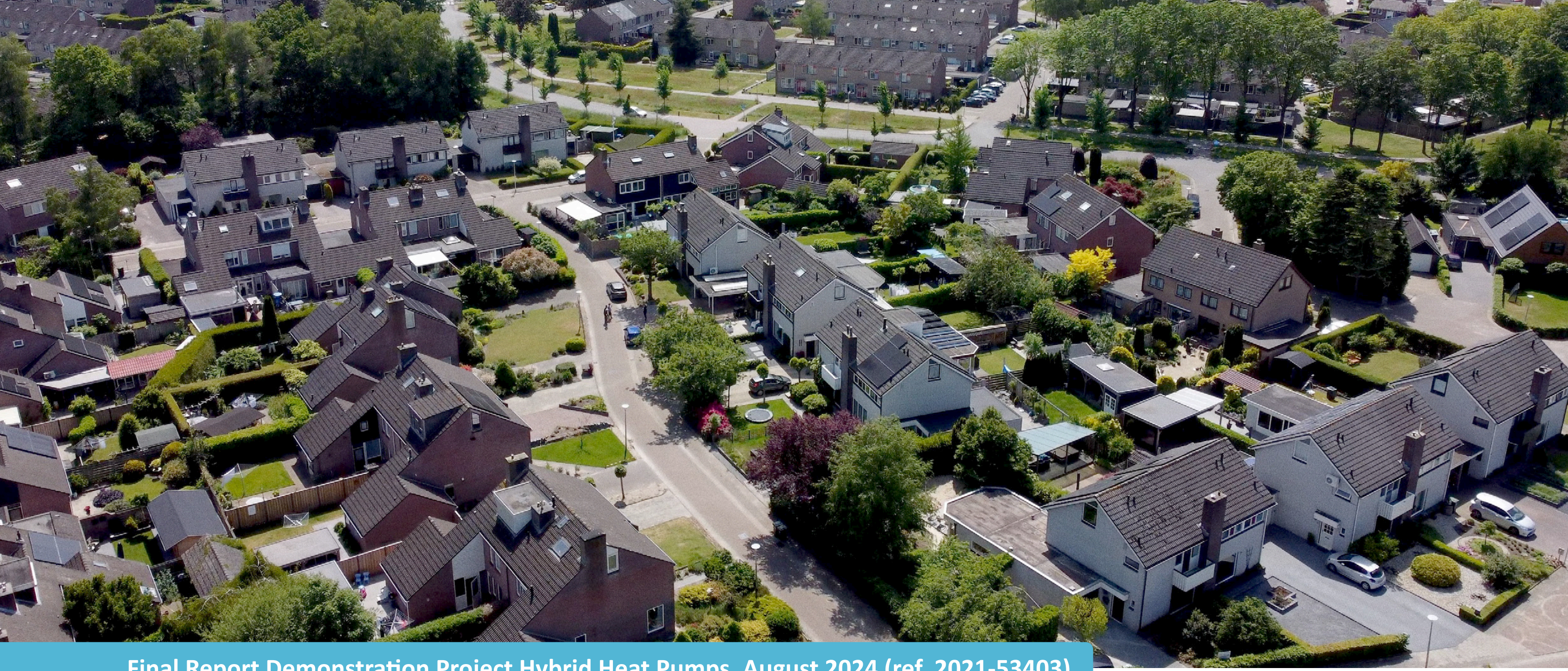
ID	How did the installation process go?	How satisfied are you with the performance of the hybrid heat pump?	Have there been any problems / malfunctions with the operation of the hybrid heat pump?	If there are (or have been) problems/malfunctions, can you describe them?	How do you experience heating with a hybrid installation? (compared to a traditional central heating boiler)?	How do you experience the noise of the outdoor unit of the heat pump?	What do you think the outdoor unit looks like?	Has your heating behaviour changed?	If your heating behaviour has changed, what is the reason for this?	Has your hot water usage changed?	Has the number of family members in your household changed since joining the project?
46	Seamlessly	Satisfied	Yes	It turned out that something had gone wrong with the installation. According to the mechanic who handled a malfunction, something is still not connected properly. There is also no buffer tank installed according to the maintenance technician of the central heating system.	Stayed the same, it gets warm in the house just as quickly	Not audible / not annoying	No opinion / Neutral	Set the thermostat lower by default	We often have the wood stove on in the evenings.	No change in hot water usage	Not changed
47	A lot of extra work was needed	Very satisfied	Yes	Outdoor unit froze too often	Stayed the same, it gets warm in the house just as quickly	Not audible / not annoying	Pretty	No change in heating behaviour		Use less hot water / shower less	Not changed
48	Seamlessly	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
49	Setup to get that right was a puzzle	Very satisfied	Yes	To get the settings right to my liking	Bathroom stayed too cold	Audible, but not annoying	No opinion / Neutral	No night reduction applied	It took too long to heat up in the morning	No change in hot water usage	Not changed
50	Seamlessly	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
51	Seamlessly	Satisfied	No		It heats up faster in the house	Audible, but not annoying	Could be nicer...	Heating more economically (e.g. lower room temperature / thermostat rather lower)	We have a wood stove and partly because of this we also have to set the central heating system / thermostat higher.	No change in hot water usage	Not changed
52	Seamlessly	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
53	Seamlessly	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
54	It took a lot of time	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Annoying	No opinion / Neutral	No change in heating behaviour	Heating more with air conditioners	No change in hot water usage	Not changed
55	A lot of extra work was needed;It took a lot of time;Het was voor de installateur de eerste....;	Satisfied	No	Upper floor cold (radiators) Ground floor fine (underfloor heating)	Cold upstairs, warm downstairs	Annoying	No opinion / Neutral	Now weather-dependent arrangement, to make comfort upstairs somewhat acceptable	Comfort too low (cold on 1st floor)	No change in hot water usage	Not changed
56	It took more time than planned	Satisfied	No		You should try to keep the temperature setting constant as much as possible. Then it stays warm in the house.	Audible, but not annoying	No opinion / Neutral	Heating more economically (e.g. lower room temperature / thermostat rather lower)	Insulating the ground floor, but also due to the slightly milder winter.	No change in hot water usage	Not changed
57	Seamlessly	Satisfied	No		The temperature stays the same because you don't turn the thermostat back.	Annoying for the neighbors and that is quite difficult	Not pretty	Stay off the thermostat.	On the advice of the installer, keep the thermostat at the same temperature.	No change in hot water usage	Not changed

ID	How did the installation process go?	How satisfied are you with the performance of the hybrid heat pump?	Have there been any problems / malfunctions with the operation of the hybrid heat pump?	If there are (or have been) problems/malfunctions, can you describe them?	How do you experience heating with a hybrid installation? (compared to a traditional central heating boiler)?	How do you experience the noise of the outdoor unit of the heat pump?	What do you think the outdoor unit looks like?	Has your heating behaviour changed?	If your heating behaviour has changed, what is the reason for this?	Has your hot water usage changed?	Has the number of family members in your household changed since joining the project?
58	Seamlessly	Very satisfied	Yes	First no buffer tank, then problems with defrosting	Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	Constant temperature	Constant temperature, I have underfloor heating.	No change in hot water usage	Not changed
59	Seamlessly	Very satisfied	No		Much more even heating.	Audible, but not annoying	No opinion / Neutral	Set the thermostat lower by default	Due to the even heating, the temperature setting of the thermostat can be lowered by 1 degree	No change in hot water usage	Not changed
60	Seamlessly	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	Heating more economically (e.g. lower room temperature / thermostat rather lower)	One degree lower, see how this goes. So far: good.	No change in hot water usage	Not changed
61	Seamlessly	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	Not pretty	Air conditioning installation added to add extra heat in the living room in the evening. Room thermostat is set to 19 degrees 24 hours a day, is just not warm enough for the evening.	see question 12	No change in hot water usage	Not changed
62	Seamlessly	Very satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	Weather dependent	Due to the weather-dependent heating curve, no night reduction has been set	No change in hot water usage	Not changed
63	Seamlessly	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
64	Seamlessly	Very satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
65	Recoil turned out to be wrongly placed. Installation company repaired this 6 months after installation	Satisfied	No	As indicated earlier, the non-return valve was placed incorrectly.	In places where underfloor heating is present, there is no difference with the old installation. In places where radiators are present, it does not heat up properly.	Audible, but not annoying	No opinion / Neutral	Constant temperature. In the past, especially at night, lower temperatures.	It takes a long time if lower temperature is set at night	No change in hot water usage	Not changed
66	Seamlessly	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
67	It took a lot of time	Neutral	No		It doesn't get warm enough in the house	Annoying	Not pretty	Set the thermostat lower by default	Because the heat pump cannot heat the house to 20 degrees or with great difficulty	No change in hot water usage	Not changed
68	Seamlessly	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	Heating more / warmer (higher room temperature / thermostat higher)	Heat pump works better at even temperature. So at night the heating is higher.	No change in hot water usage	Not changed

ID	How did the installation process go?	How satisfied are you with the performance of the hybrid heat pump?	Have there been any problems / malfunctions with the operation of the hybrid heat pump?	If there are (or have been) problems/malfunctions, can you describe them?	How do you experience heating with a hybrid installation? (compared to a traditional central heating boiler)?	How do you experience the noise of the outdoor unit of the heat pump?	What do you think the outdoor unit looks like?	Has your heating behaviour changed?	If your heating behaviour has changed, what is the reason for this?	Has your hot water usage changed?	Has the number of family members in your household changed since joining the project?
69	Installation went well. Commissioning took a little longer. Pump unit was soon broken, but has been neatly replaced. Overall satisfied;	Satisfied	Yes	1 continued to run on a gas boiler for a few days in the first winter while the temperature had already risen again. Recovered fairly quickly. 2 pump units did not work and it has been replaced	It takes longer to heat the house	Only audible at full power when you are outside. No problems inside. We only hear the switching on/off.	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
70	Seamlessly	Satisfied	No	Difficult to get the settings/parameter right	Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	Set the thermostat lower by default		Use more hot water / shower more	Not changed
71	Seamlessly	Very satisfied	No		It takes longer to heat the house	Audible and annoying, I myself think it is an issue especially deep in the winter. Then you will hear flow noise in the installation and hum sound from the outdoor unit.	Pretty	Set the thermostat lower by default	Ukraine war	No change in hot water usage	Not changed
72	Seamlessly	Very satisfied	No	I do think that optimal efficiency of the heat pump requires that you as a user can configure it properly. An installer configures too standard.	It doesn't get warm enough in the house	Not annoying because we have no close neighbors.	Not pretty	Set the thermostat lower by default		No change in hot water usage	Not changed
73	A lot of extra work was needed; It took a lot of time	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	Heating more economically (e.g. lower room temperature / thermostat rather lower)	Energy costs	No change in hot water usage	Not changed
74	Seamlessly	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	Heating more / warmer (higher room temperature / thermostat higher)	The temperature is now constantly at 20 degrees. Previously, this was varying between 17 and 20 degrees during the day	No change in hot water usage	Not changed
75	Seamlessly	Very satisfied	Yes	Choosing the right settings is very complicated and different for each individual situation. A wizard or manual is necessary. Especially in cold periods, consumption increases too much and the COP decreases.	It takes longer to heat the house	Not audible / not annoying	Not pretty	Heating more / warmer (higher room temperature / thermostat higher)	I have continuously turned on 20 degrees and at times 21. Night reduction no longer used.	No change in hot water usage	Not changed

ID	How did the installation process go?	How satisfied are you with the performance of the hybrid heat pump?	Have there been any problems / malfunctions with the operation of the hybrid heat pump?	If there are (or have been) problems/malfunctions, can you describe them?	How do you experience heating with a hybrid installation? (compared to a traditional central heating boiler)?	How do you experience the noise of the outdoor unit of the heat pump?	What do you think the outdoor unit looks like?	Has your heating behaviour changed?	If your heating behaviour has changed, what is the reason for this?	Has your hot water usage changed?	Has the number of family members in your household changed since joining the project?
76	Seamlessly	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	Set the thermostat lower by default	Reduce the difference between the day and night temperature..... day=19.5 degrees and night=18 degrees	Use less hot water / shower less	Not changed
77	Seamlessly	Very satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
78	A lot of extra work was needed	Very dissatisfied	Yes	Too many things to mention now. No hot water, parts broken, with a few degrees of frost temperature only achievable by noon, 18.5 degrees. And many other things.	It takes longer to heat the house	Annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
79	Seamlessly	Very satisfied	No		It takes longer to heat the house	Audible, but not annoying	Pretty	No change in heating behaviour		No change in hot water usage	Not changed
80	Seamlessly	Very satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	Heating more economically (e.g. lower room temperature / thermostat rather lower)	Aware of potential savings	No change in hot water usage	Not changed
81	Seamlessly	Satisfied	No		It takes longer to heat the house	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
82	Seamlessly	Very satisfied	No		It takes longer to heat the house	Not audible / not annoying	Pretty	No change in heating behaviour		No change in hot water usage	Not changed
83	Seamlessly	Satisfied	Yes	After the first summer, the pump no longer functioned. The cause was the liquid in the pipe between the indoor and outdoor unit. This was remedied after notification by the installation company.	Stayed the same, it gets warm in the house just as quickly	Not audible / not annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
84	Seamlessly	Satisfied	No		It heats up faster in the house	Audible, but not annoying	Bad. Didn't think about it. Cover cap grey, housing white, cover cap at the bottom black, grid cover black, fan cover beige. All in all wrong color combination.	Heating more economically (e.g. lower room temperature / thermostat rather lower)	It was too hot in the house.	No change in hot water usage	More family members
85	Aftercare deserves attention.	Satisfied	Yes	Thermostat is malfunctioning.	Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	Heating more economically (e.g. lower room temperature / thermostat rather lower)	Have a new thermostat installed that is controlled per room.	No change in hot water usage	Not changed

ID	How did the installation process go?	How satisfied are you with the performance of the hybrid heat pump?	Have there been any problems / malfunctions with the operation of the hybrid heat pump?	If there are (or have been) problems/malfunctions, can you describe them?	How do you experience heating with a hybrid installation? (compared to a traditional central heating boiler)?	How do you experience the noise of the outdoor unit of the heat pump?	What do you think the outdoor unit looks like?	Has your heating behaviour changed?	If your heating behaviour has changed, what is the reason for this?	Has your hot water usage changed?	Has the number of family members in your household changed since joining the project?
86	Condensation collection/ drainage did not function properly. Hopefully it will be fixed now	Satisfied	Yes	See question 3	Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
87	Seamlessly	Satisfied	No		Stayed the same, it gets warm in the house just as quickly	Not audible / not annoying	No opinion / Neutral	Heating more / warmer (higher room temperature / thermostat higher)	Comfort	No change in hot water usage	Not changed
88	Seamlessly	Very dissatisfied	Yes	The heat pump uses too much electricity.	Office remains far too cold	Not very annoying, but the sound does become more annoying (louder)	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed
89	Seamlessly	Very satisfied	No		Stayed the same, it gets warm in the house just as quickly	Audible, but not annoying	Not pretty	Heating more economically (e.g. lower room temperature / thermostat rather lower)		Use less hot water / shower less	Not changed
90	It didn't go quite according to plan. Intergas has been many times to solve the problems.	Neutral	Yes	Error message on heat pump. After telephone contact, the heat pump was reset. Thermostat that didn't work.	It takes longer to heat the house	Annoying	Not pretty	No change in heating behaviour		No change in hot water usage	Not changed
91	Seamlessly	Very satisfied	No		Heat in the house good, bathroom stays too cold when it is cold outside too.	Annoying	Not pretty	Particularly longer, to shorten the warm-up time.	The heating time is longer, so it is on longer. Also adjusted to later in the morning, because the neighbor is bothered by the outdoor unit.	No change in hot water usage	Not changed
92	Seamlessly; Some problems here and there, for example the coolant escaped during installation.	Very satisfied	No		It takes longer to heat the house	Not audible / not annoying	No opinion / Neutral	No change in heating behaviour		No change in hot water usage	Not changed



Final Report Demonstration Project Hybrid Heat Pumps, August 2024 (ref. 2021-53403)

This project resulted from a collaboration between the central government, Techniek Nederland and Vereniging voor Duurzame Warmte and was carried out by the Smart Energy Foundation. The results have been verified by the University of Twente.

Members of Vereniging voor Duurzame Warmte (Association for Sustainable Heat):

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