Factory Zero

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Summary

In the neighborhood “Palenstein” in Zoetermeer 120 houses have been renovated by the companies Dura Vermeer and Factory Zero in order to make them energy neutral. By adding better insulation and a unit designed by Factory Zero which includes a heat pump, ventilation, and solar inverter, together with control systems in order to provide the houses with hot water, heating and control the solar panels.

In this report the data collected from the systems in this unit will be analyzed to determine the operational conditions of the heat pump and to determine if it is energy neutral as is guaranteed by the company while also providing with comfortable living conditions.

The data of the different components is checked for errors and possible issues that make it impossible to use for calculations, and from there several results are obtained, the key areas that are focused on are the performance of the heat pump, the ventilation and the total energy balance of the houses.

The heat pumps have an SCOP of about 2,48 on average. With normal performance of heat pumps in practical applications to be around 2.5, these heat pumps perform within the required parameters.

The inside CO2 levels do not exceed the threshold value of 1200 ppm for longer than 10 hours on average during the entire year, and the humidity inside the houses does not exceed 80% for more than 10 hours on average either. This means that both CO2 levels and humidity inside the houses is within the parameters.

The average temperature in the houses is around 22.6 degrees. Which is within the limit but is on the high side. This is because there is no cooling present in the houses, therefore during the summer periods the temperature in the houses reaches around 32 degrees on average, this is above the limit of 24 degrees for a comfortable living experience.

On average the houses have a net positive energy production of 2200 kWh a year, therefore the houses are energy neutral, and might even be considered energy positive. Some of the houses do not meet the energy neutral standard due to these houses having a larger energy use. The houses themselves only use 22% of the total energy produced by the solar panels themselves though, so a battery could be considered in order to up the amount of energy from the solar panels that is used by the houses themselves, and to reduce strain on the power grid.

Content

1 Introduction

Factory Zero is a company that focusses on the manufacturing of climate systems to make both old and new houses energy neutral, in the Netherlands this concept is known as “zero on the meter”. In order to guarantee their proper function, they design and assemble the system in their own factory. Together with Dura Vermeer, one of the largest construction company in the Netherlands and a company that works on sustainable building, they can give both old houses a complete sustainable make-over, as well as equip new projects with sustainable solutions. One of the first large scale projects where this concept was applied is in Zoetermeer, in the neighbourhood of Palenstein. Here 120 houses have been converted in order to become energy neutral.

The installation placed in these houses is the iCEM 3005-e module, this module contains a heatpump, motherboard, heat recovery system, intelligent controls, converter, and a hot water buffer vat. The installation can provide the house with a conditioned living environment as well as hot water and includes a solar inverter to convert the power produced by the solar panels into useable grid power, Factory Zero does not provide the solar panels themselves. The different systems of the module and the solar panels are constantly monitored by the electronics and the data is recorded, with this data the operating parameters of the system can be checked. Since an energy neutral performance of the house after conversion is guaranteed by the company, the system has to monitor all the variables.

Factory Zero looks at the main performances of the houses, this report focusses on getting a better insight on how these houses perform. For this there are three main points that will be looked at throughout this report:

1. The house performance
   performance of the systems inside the house itself, total energy use of the house as well as the use of its subcomponents, energy production, the total energy balance of the house and finally the maximum power going in and out of the house.

2. Heat pump performance
   The operation of the heat pump will be looked at, the SCOP of the entire system will be determined. And the power use of the different modes of the heat pump.

3. Ventilation performance
   There are certain conditions that need to be met inside the house to allow for comfortable living, such as the CO_2 levels inside the house. The energy use of the ventilation must also be determined.

Once these points have been analyzed with the help of the data provided, a conclusion can be drawn regarding the performance of the system in this group of houses, as well as the performance of individual houses among the group.

2 System description

In this chapter we will discuss the climate system that is manufactured by FactoryZero. There will be an in-depth analysis of the components and we will discuss the mutual relations of the climate system.

The climate system is the iCEM 3005e and it is shown in the figure below. The system consists of 7 components that are numbered and is placed in a metal construction that is covered in an isolated plastic casing to minimalize the influence of the weather conditions and protect it against extreme conditions.

Controller

Most of the parts that are inside the climate system are purchased by extern manufacturers. FactoryZero only produces the controller and the motherboard that are inside. This controller is, as the name says, responsible for the control of all the other components and actuators. Besides that, it gathers all the information of sensors that are in the climate system, the house and outside the house. It collects all the data and sends it every 5 minutes to the cloud where it is stored.

Heat pump motherboard

As the name says it, the motherboard is the controller that sends signals to the heat pump inner- and outer part. When the temperature of the buffer tank decreases and comes below 55 degrees Celsius, the heat pump starts running again to increase the temperature towards this threshold.

Heat pump

The heat pump is the key part of the climate system. It consists of 2 parts: an outer part and an inner part. These parts are connected with a set of pipes that are filled with a refrigerant that is better able to transfer the heat from the outside to the inside. The type used in this situation is an air/water heat pump.

The outer part is responsible for the heat recovery outside the house. The refrigerant inside the system is expanded by a throttle valve. The refrigerant is now able to absorb the heat of the outside. After this passes a compressor that compresses the refrigerant. Due to this the temperature rises. The inner part of the heat pump is a heat exchanger that transfers the heat from the refrigerant to the buffer tank or the internal heating. As a result, the refrigerant cools down and flows to the outer part to be used again for the heat. This creates a continuous closed circuit.

Buffer tank

The buffer tank has a capacity of 200 liters that can reach a temperature of 55 degrees Celsius. When there is a demand of tap water is comes from this tank. With a heat exchanger it can heat up the tap water and the water for the radiation system. When the temperature of the water in the tank gets below this temperature the heat pump start working again to increase it to the set temperature.

Heat regeneration

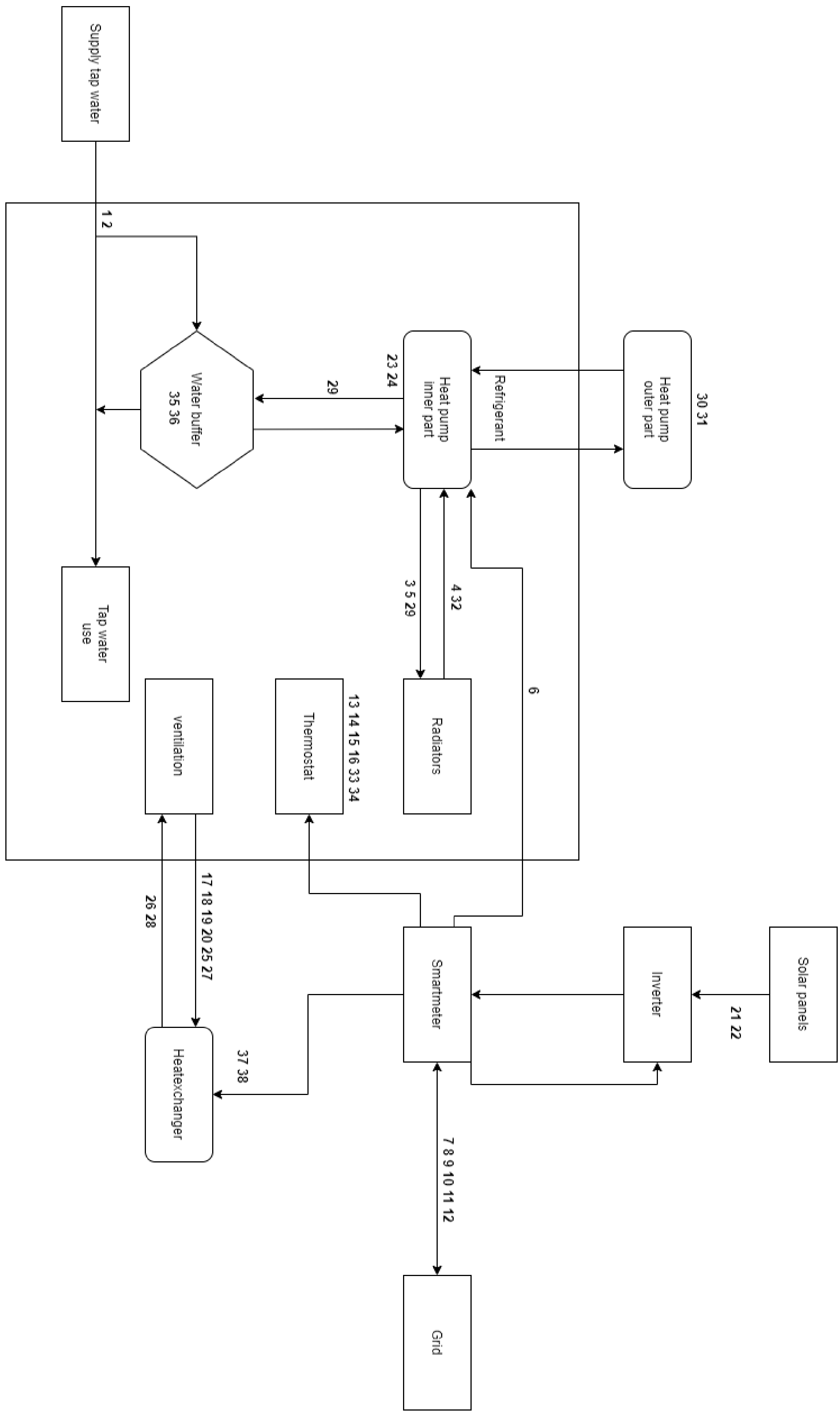
To recover some of the heat (or cold) that enters the exhaust shaft there has been added a heat regenerator. This module can transfer heat (or cold) from the exhaust to the supply shaft to further improve the SCOP of the system. It is also provided with an air filter to improve the quality of the supply air.

Inverter

When the solar panels on the roof of the houses generate electricity, they create a direct current. Since this is different from the alternate current that is used inside the house, the inverter can change this current. It also measures the amount of solar energy that is generated.

2.1 The scheme

The scheme of the house can be found on the next page. Every line that is drawn in this scheme says something about the mutual relationship between the different components that are installed. The numbers represent the different variables that are measures inside (and outside) the house. Their meaning can be found on the page next to the scheme to get a better understanding of the functionality of the system.


Supply tap water
1 2
Water buffer
35 36
Tap water use
29
23 24
Heat pump inner part
Refrigerant
Heat pump outer part
30 31
3 5 29
4 32
6
Radiators
Thermostat
13 14 15 16 33 34
ventilation
17 18 19 20 25 27
26 28
Heatexchanger
37 38
Smartmeter
Inverter
Solar panels
21 22
7 8 9 10 11 12
Grid

List of components

In de following list there is a description of all the sensors which communicate a useful value to the intelligence inside the heat pump. This computer stores all the data in timesteps of ca. 5 minutes. There are over 60 sensors in the whole house, but some of them are not connected or they do not register any useful information for our research. The following numbers describe sensors that are useful to us.

1. Temperature supply tap water [°C]
2. Waterflow supply tap water[m^3]
3. Temperature water to radiators [°C]
4. Temperature water to heat pump [°C]
5. Volume flow water to radiators [m^3]
6. Total use [kWh]
7. Energy at night of the grid (low tariff) [kWh]
8. Energy during the day of the grid (high tariff) [kWh]
9. Nachtstroom (naar net) [kWh]
10. Energy at night to the grid (low tariff) [kWh]
11. Total energy off the grid [kWh]
12. Total energy to the grid [kWh]
13. Temperature living room[°C]
14. Set temperature [°C]
15. Set temperature [°C]
16. Set temperature [°C]
17. CO_2-level measured at exhaust pipe heat regeneration [ppm]
18. Total energy used by heat regeneration [W]
19. Temperature measured at exhaust pipe heat regeneration [°C]
20. VOC-level measured at exhaust pipe heat regeneration [ppm]
21. Power generated by solar panels (negative is production) [W]
22. Energy generated by solar panels [kWh]
23. Power used by booster (legionella) [W]
24. Energy used by booster (legionella) [kWh]
25. Exhaust flow of air [m^3/h]
26. Outside temperature [°C]
27. Inside temperature meassered at exhaust pipe [°C]
28. Supply flow of air [m^3/h]
29. Temperature water from heat pump[°C]
30. Modus heat pump [-]
31. Outside temperature [°C]
32. Return temperature water from radiators [°C]
33. Set room temperature on thermostat [°C]
34. Room temperature [°C]
35. Set temperature tap water [°C]
36. Temperature of boiler [°C]
37. Power air fan heat exchanger [W]
38. Energy use air fan heat exchanger [kWh]

3 Measurement method

3.1 Data quality check

Over the course of the year 2019, the data from 120 houses has been collected in a database, and at the end of the year this is provided in the form of an excel file for every house, including all the data recorded in that house during the time period. There are several errors that could have occurred in this period of time that would compromise the quality of the data and therefore make the end result of calculations done on this data unreliable, or in some cases even impossible.

Of the 22 sheets in the excel files there are 11 that contain data which is relevant to the research topics of this report, these eleven tables are:

- waterFlow
- flowHeatSpaceHeating
- energyHeatPump
- smartMeter
- thermostat
- co2sensor
- solar
- energyBooster
- ventilation
- alklimaHeatpump
- energyWtwReg

In order to make sure the values gained from the calculations are reliable, and the program won't get stuck checks have to be written to deal with these errors. There are three kinds of errors that will be looked at before the data of a house can be included in the calculations.

3.2 Empty table check

In some cases, a sheet that is required for a calculation on a house does not contain any data, the table itself is empty. No calculations can be made when there is no data to calculate with, so these tables will be excluded before calculations are performed on the data, these houses will therefore not be included in the final results for this calculation.

When analyzing these 11 tables for all 120 houses, it is found that 10 out of 1320 tables are empty

Figure 1. presence of empty tables

3.3 Timestep check

All systems are supposed to send sets of data after 300 seconds, but sometimes the gap between data is bigger than this, in this case something caused the sensors to not report on the designated time, and a gap in the data occurs, this can affect the quality of the end results.

If the timesteps made in the tables of the houses is analyzed, it is found that the average does not always end up on the 300 seconds as required by the system, in some cases there is a big difference.

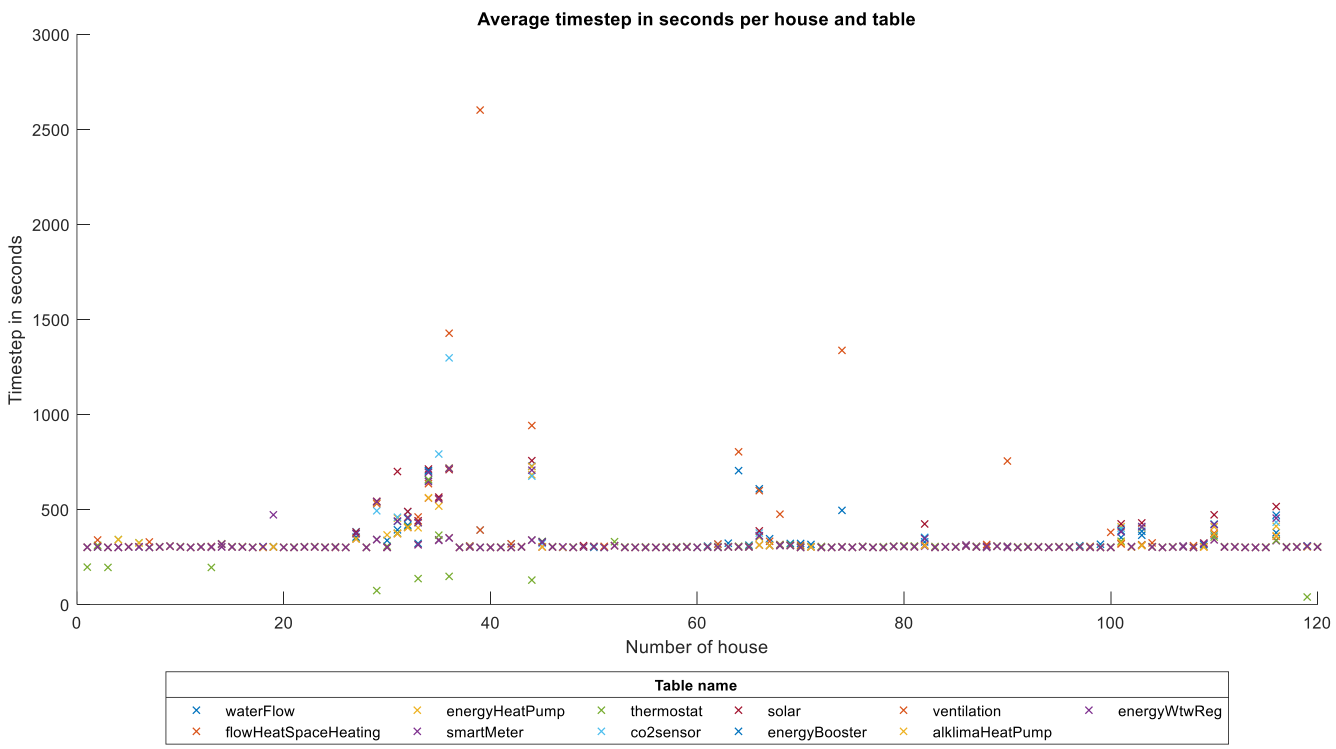


Figure 2. Average timestep per house and table

The timestep can also be analyzed by taking the amount of records that are made for each table, if the system made a record every 300 seconds as it is supposed to, there would be 105120 records in total. If this value is taken as a reference and then compared with the total amount of records in the different tables for all the houses a conclusion regarding the difference in timesteps can be made as well.

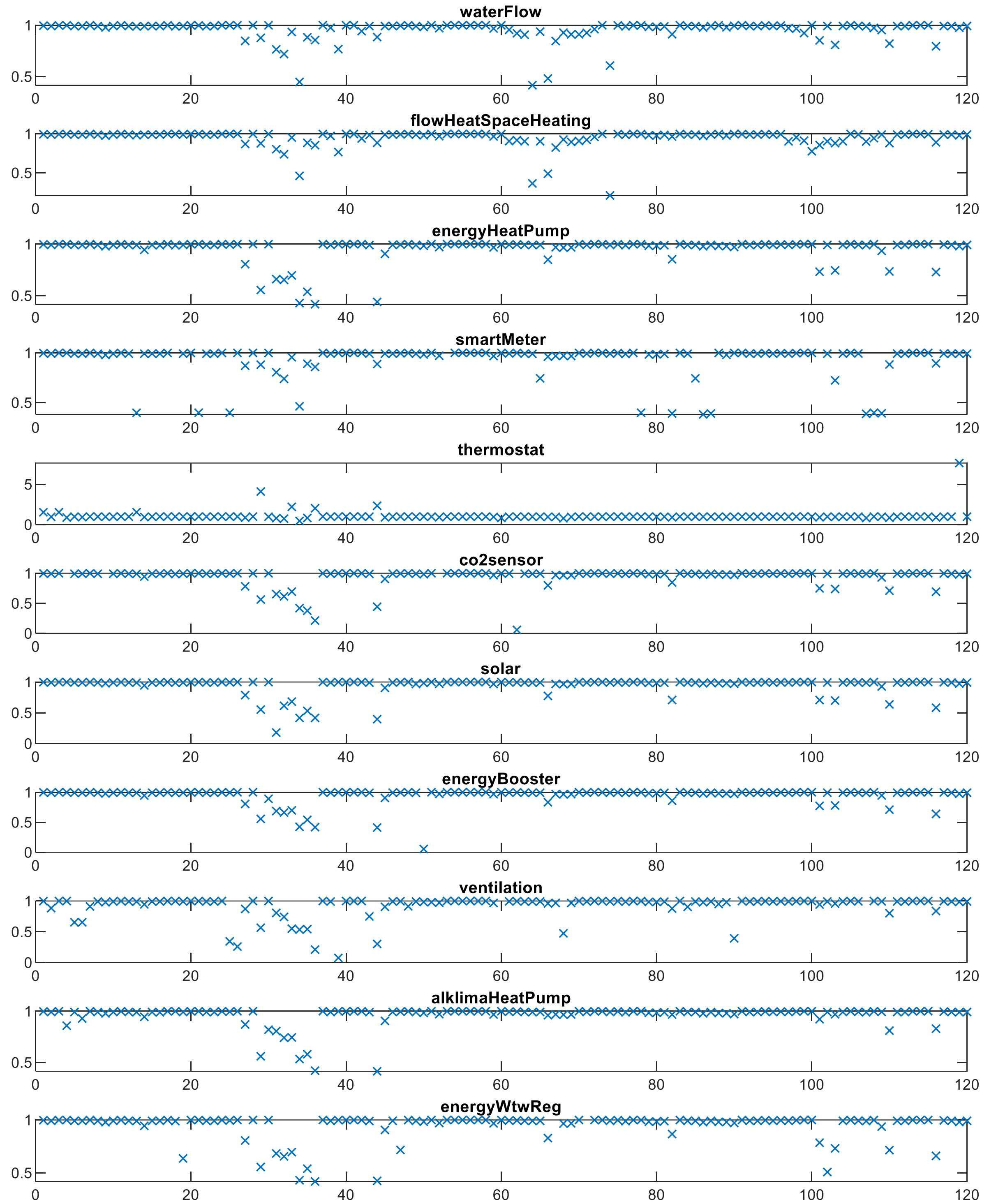


Figure 3. Percentage of records in relation to a record for every 300s.

In these graphs it can be seen that several of the tables have less entries than the expected amount whenever a record is made every 300 seconds, one of the tables, namely thermostat, is showing a far greater amount of entries than is expected for a few of the analyzed houses.

The next thing to look at would be the number of timesteps larger than one day present in the different tables, so how many gaps of one day or more are present in the 1310 tables filled with data. The distribution of these gaps is represented in the following graph:

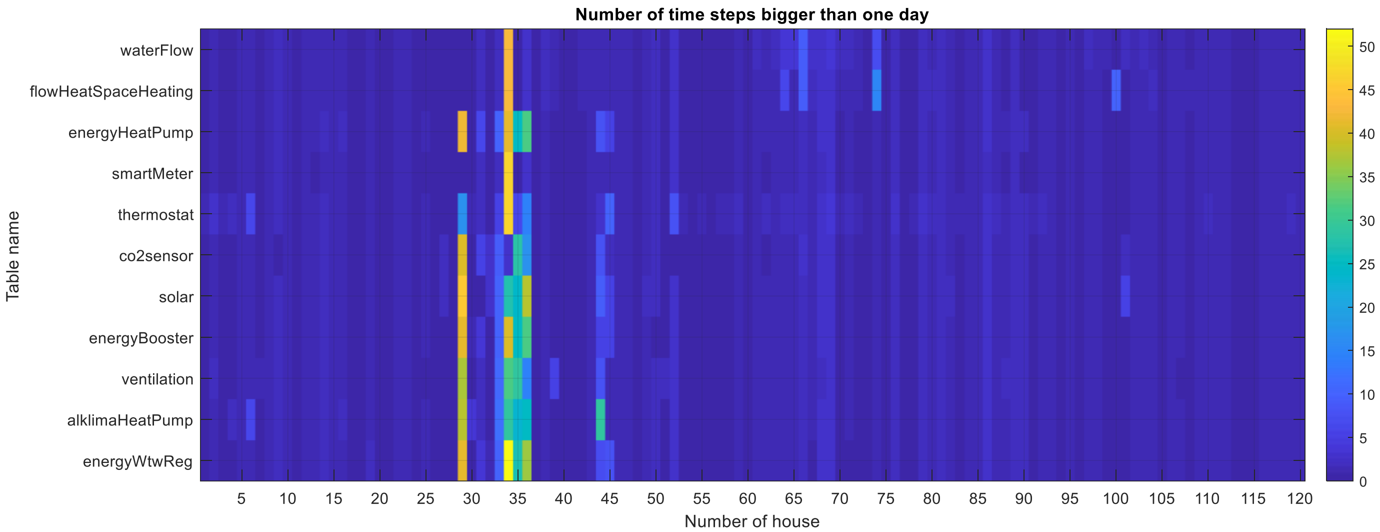


Figure 4. Distribution of data gaps bigger than one day

From this analysis it can be determined that there are a total of 2375 data gaps bigger than one day For a closer look, a single table, AlklimaHeatPump is taken and the number of timesteps bigger than 900 seconds, which is three times more than the expected time of a timestep

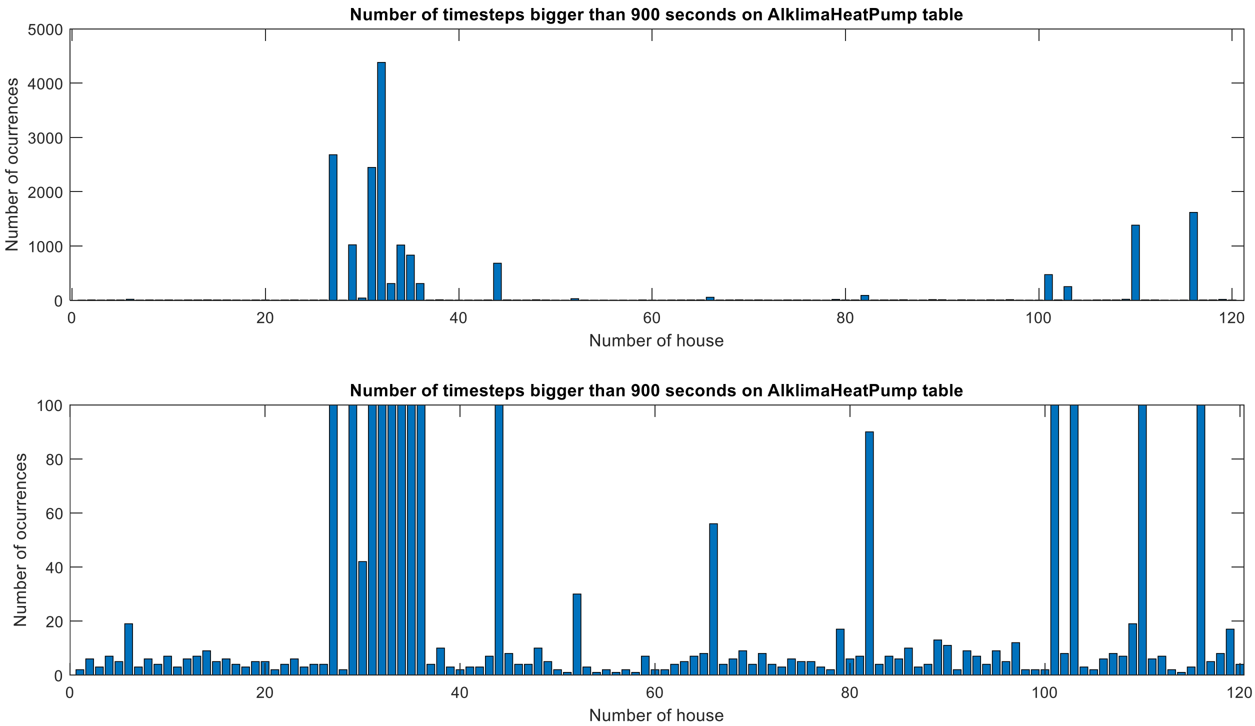


Figure 5. Number of gaps bigger than 900 seconds for the alklimaHeatPump table

There is at least one gap bigger than 900 seconds present in the data for each of the 120 houses, but taking into account the number of occurrences does not say anything about the actual size of the gap in the timestamp beyond the 900 seconds set as a requirement, in the following graph not only the number of timesteps that exceed 900 seconds is noted, but also the size of the gap of these timesteps.

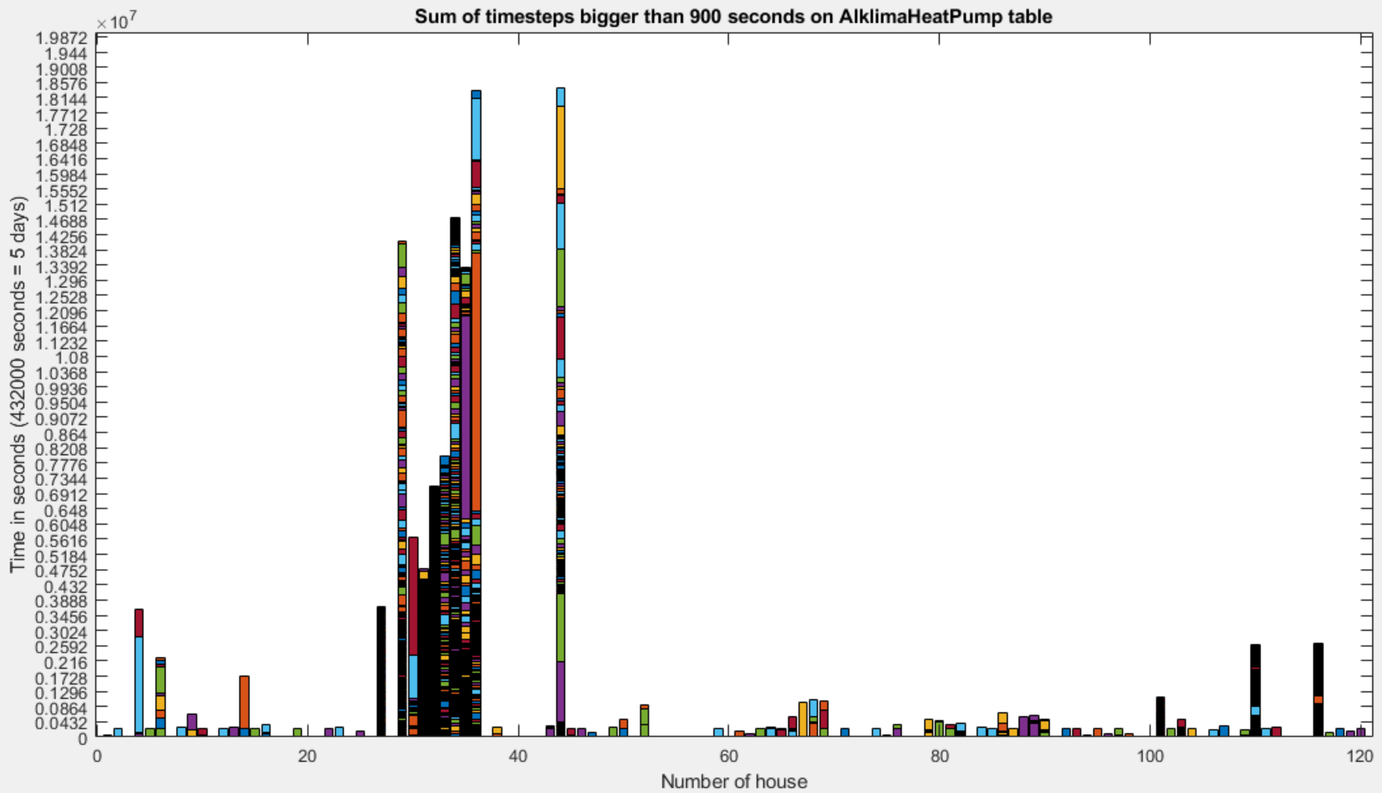


Figure 6. Sum of timesteps bigger than 900 seconds on alklimaHeatPump table

From this graph it can be seen that the gaps present in some of the tables are several days in size, as an example, multiple of the houses that have only 4 gaps that are larger than 900 seconds have either one or two gaps which exceed a time of 2 or more days.

3.4 Meter reset check

The last error that could affect the end result is a reset of the meter. Sometimes during a timestep the meter resets its value and continues counting from zero, when calculations are made using the first and last value of the tables to determine the total amount that has been used, having a reset in the graph could make the values turn out to be far lower than they actually are, or end up giving a negative value.

There are two ways of dealing with an error like this, the first option is to determine when a step between two values has a negative value, and discard the tables that have such resets in them, this is a relatively crude way of dealing with this issue, and is only useful if the amount of tables lost due to the reset isn't that much, so this works for smaller calculations where few different tables are used. In general this method won't be used often.

The second option is by calculating the difference between each step in the table, and then adding up all the differences, excluding the steps that have a negative value, this will end up excluding a value in the data but overall it will not have a significant impact on the end result. This way tables that include a reset can still be included in the calculations, keeping more houses in the sample and therefore better conclusions can be drawn from the results found.

3.5 Data freeze check

A last issue that might occur is a freeze of the meter, it will still continue to update the timestamp of the measurement, but it does not update any of the other values send, when the meter unfreezes it will update all the data that has not been provided in the previous timestamps to the first timestamp afterwards. This will create a datapoint with an unrealistic large value, the size of this depending on the length of the freeze.

This generally does not cause any issues for calculations that add up the total difference of the entire table, since there is no actual change in energy lost in such a freeze. But when looking for specific information such as the maximum amount of power or current that is drawn in or out of the house during the year, it will create an unrealistically high peak value. In order to compensate for this all values that have a set of values which are equal above them can be ignored. This will skip over the datapoints which come directly after a system freeze.

4 Results

4.1 House performance

4.1.1 Total energy use

In this chapter we will discuss the background of our research. In this way we can validate the formulas we use and be sure that there will be no discussion later in the paper when we will talk about the results. Most of the formulas we use can be found in the book 'Toegepaste Energieleer' by A.C. Taal. If there are other books, journals etc. used then there will be referred to in the paragraphs itself.

Table 1. Characteristics of the evaluation of the Total solar production

Tables	smartMeter, solar
Variables	smartMeter.total_energy_out, smartMeter.total_energy_out, solar.total_energy_in, solar.total_energy_out

Formula	diffSmartMeterOut = diff(smartMeter.total_energy_out);
	diffSmartMeterIn = diff(smartMeter.total_energy_In);
	diffSolarOut = diff(solar.total_energy_out);
	diffSolarIn = diff(solar.total_energy_In);
	totalEnergyIn(i)=sum(diffSmartMeterIn(diffSmartMeterIn>=0));
	totalEnergyOut(i)=sum(diffSmartMeterOut(diffSmartMeterOut>=0));
	totalSolarOut(i)=sum(diffSolarOut(diffSolarOut>=0));
	totalSolarIn(i)=sum(diffSolarIn(diffSolarIn>=0));
	totalSolar(i)=totalSolarOut(i)-totalSolarIn(i);
	totalUse(i)=totalEnergyIn(i)+totalSolar(i)-totalEnergyOut(i);

Houses used	101 of 120
Empty check	3 [18, 53, 101]
Incomplete check	16 [13, 21, 25, 31, 36, 59, 65, 78, 82, 85, 86, 87, 103, 107, 108, 109]

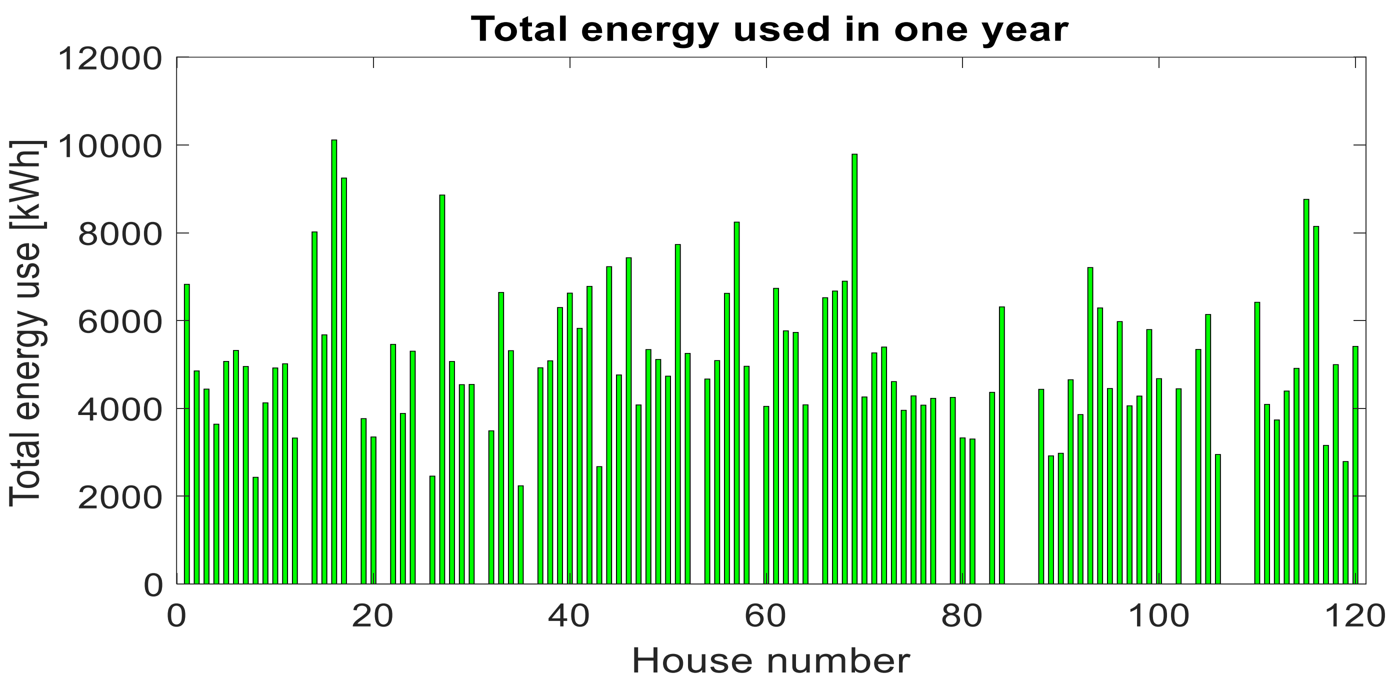


Figure 7. total energy used per house in one year

table 2. maximum, minimum and average energy use of the group of houses

Average energy use	5183 kWh
Maximum energy use	10115 kWh
Minimum energy use	2237 kWh

As the energy going into the house by the smart meter does not include the part of the power needed that is compensated by the solar panels at that time. The power production coming from the solar panels and the part of this which is send to the grid by the house need to be considered in order to determine the total energy used by the house. The average energy use per household in the year 2020 is 2832 kWh (Nibud, 2020), this is roughly 2300 kWh more than the average energy use of the group of houses, almost double the amount. The highest average energy use for a family of 5 people, the largest quantity recorded by Nibud, is 4180 kWh (Nibud, 2020), which is still below the average use of our group of houses, and less than half that of the maximum energy use of the group. This is because the average household in the Netherlands uses gas for heating and cooking, this means that the energy used for heating, hot tap water and cooking is not represented in the energy use of a house.

In order to determine the power use of the houses without taking the energy used for heating the house into account, the used power has to be divided into its sub components, therefore a new calculation is made taking into account the power used by the Heat pump, the ventilation, and finally the other appliances present in the house.

Table 3. Characteristics of the evaluation of the Total solar production

Tables	smartMeter, solar, energyHeatpump, energyBooster, energyWtwReg
Variables	smartMeter.total_energy_out, smartMeter.total_energy_out, solar.total_energy_in, solar.total_energy_out, energyHeatpump.total_energy_in, energyBooster.total_energy_in, energyWtwReg.total_energy_in

Formula	diffSmartMeterOut = diff(smartMeter.total_energy_out);
	diffSmartMeterIn = diff(smartMeter.total_energy_in);
	diffSolarOut = diff(solar.total_energy_out);
	diffSolarIn = diff(solar.total_energy_in);
	totalEnergyIn(i) = sum(diffSmartMeterIn(diffSmartMeterIn>=0));
	totalEnergyOut(i) = sum(diffSmartMeterOut(diffSmartMeterOut>=0));
	totalSolarOut(i) = sum(diffSolarOut(diffSolarOut>=0));
	totalSolarIn(i) = sum(diffSolarIn(diffSolarIn>=0));
	totalSolar(i) = totalSolarOut(i)-totalSolarIn(i);
	totalUse(i) = totalEnergyIn(i)+totalSolar(i)-totalEnergyOut(i);
	diffEnergyHp = diff(energyHeatpump.total_energy_in);
	diffEnergyBooster = diff(energyBooster.total_energy_in);
	diffEnergyWtw = diff(energyWtwReg.total_energy_in);
	totalEnergyHp(i) = sum(diffEnergyHp(diffEnergyHp>=0)) + sum(diffEnergyBooster(diffEnergyBooster>=0));
	totalEnergyWtw(i) = sum(diffEnergyWtw(diffEnergyWtw>=0));
	totalEnergyAppliances(i)=totalUse(i)-totalEnergyHp(i)-totalEnergyWtw(i);

Houses used	95 of 120
Empty check	5 [18, 53, 67, 71, 101]
Incomplete check	20 [13, 21, 25, 31, 36, 45, 47, 50, 59, 65, 78, 82, 85, 86, 87, 102, 103, 107, 108, 109]

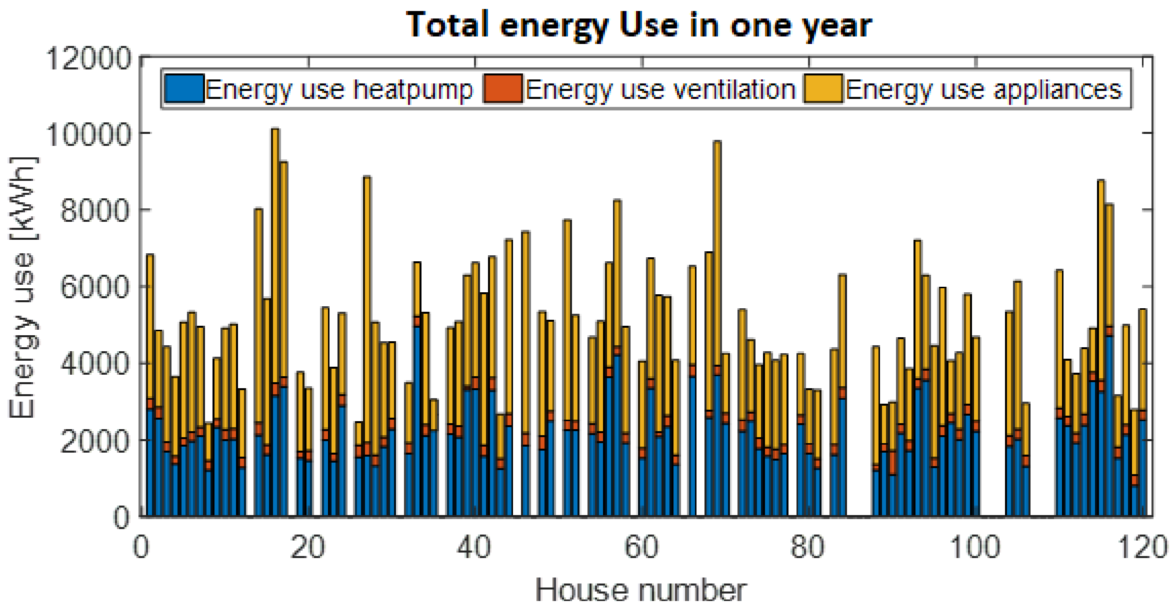


Figure 8. total energy used per house divided into systems in one year

Table 4. average energy use per system for the group of houses

Average energy use Heat pump	2225 kWh
Average energy use Wtw	263 kWh
Average energy use appliances	2745 kWh

Table x. average percentage of total energy used per system

Percentage of total energy used	
Heat pump	43%
Wtw	5%
appliances	52%

After analysing the distribution of the power used, it can be seen that the heat pump is responsible for close to half the energy use of the group of houses, when subtracting the average energy use of the heat pump from the total average energy use, we are left with 2958 kWh as the average energy use of the group of houses. This still includes cooking using electricity instead of gas, as no separate measurement is made of the energy use of the stove, this cannot be separated from the appliance's category.

The heat pump itself uses on average 2225 kWh to provide for heating and hot tap water for the house. An average household in the Netherlands uses around 1300 m^3 of gas, which is equivalent to 12480 kWh of energy, roughly 5,6 times as much as the power use of the heat pump. This brings the total energy use of the average household to 15300 kWh in a year, which is 3 times as large as the energy use of the converted energy neutral houses. This difference is mainly in the energy use of heating and hot tap water. This can be explained by the generally high efficiency of the Heat pump, but is also because the houses themselves have been properly insulated in the conversion, therefore retaining more of their heat than the average household in the Netherlands.

4.1.2 Energy Production

Table 5. Characteristics of the evaluation of the Total solar production

Tables	solar
Variables	solar.total_energy_out
Formula	**totalEnergyOut=solar.total_energy_out(end)-solar.total_energy_out(1)**
Houses used	116 of 120
Empty check	0
Incomplete check	3 [31, 36, 59]
Reset check	1 [35]

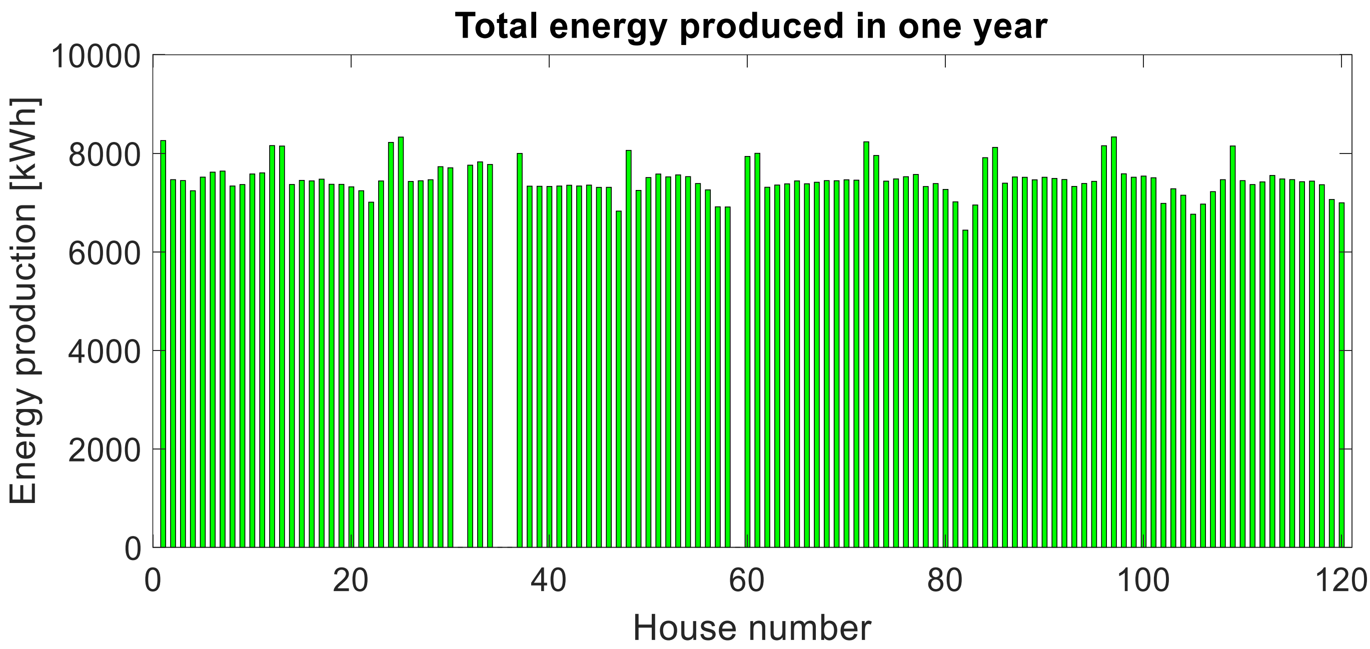


Figure 9. total solar energy production per house in one year

table 6. average, maximum and minimum solar energy production of the group of houses

Average solar energy production	7487 kWh
Maximum solar energy production	8332 kWh
Minimum solar energy production	6440 kWh

The solar energy production is relatively stable apart from a few houses, there are 10 sets of peaks present in the graph of the solar production and there are two houses in each peak. It can be determined that these houses are the houses that stand on the corners of each row, in determining the amount of energy that would be required to make a house energy neutral, one of the factors that has to be taken into account is the surface area from which heat can leak from the house, the areas of the house exposed to the outside. The houses in the middle of the rows are exposed to the outside from the front and the back, while the sides are covered by the other houses in the row. The houses on the corners however are exposed to the outside on the front, the back and the corner of the row, therefore more surface area is exposed to the outside on the houses on the corners, and more heat will be lost. To compensate for this additional solar panels have been added to the houses on the corner to compensate for the additional power needed for heating and to keep the houses energy neutral.

Some of the houses on the corners are not as pronounced as the others, and some are missing, this can be accounted for by the checks performed by the code, at least one of the corner houses has been filtered out by the data checks. Some houses are lower than others, there seems to be no issue with the data provided on these houses, therefore the differences can be attributed to environmental factors that cannot be known.

4.1.3 Energy Balance

Table 7. Characteristics of the evaluation of the energy balance

Tables	smartMeter
Variables	smartMeter.total_energy_in, smartMeter.total_energy_out

Formula	diffSmartMeterOut = diff(smartMeter.total_energy_out);
	diffSmartMeterIn = diff(smartMeter.total_energy_in);
	balanceEnergyIn = sum(diffSmartMeterIn(diffSmartMeterIn>=0));
	balanceEnergyOut = sum(diffSmartMeterOut(diffSmartMeterOut>=0));
	totalBalance(i) = balanceEnergyOut - balanceEnergyIn;

Houses used	103 of 120
Empty check	3 [18, 53, 101]
Incomplete check	14 [13, 21, 25, 59, 65, 78, 82, 85, 86, 87, 103, 107, 108, 109]

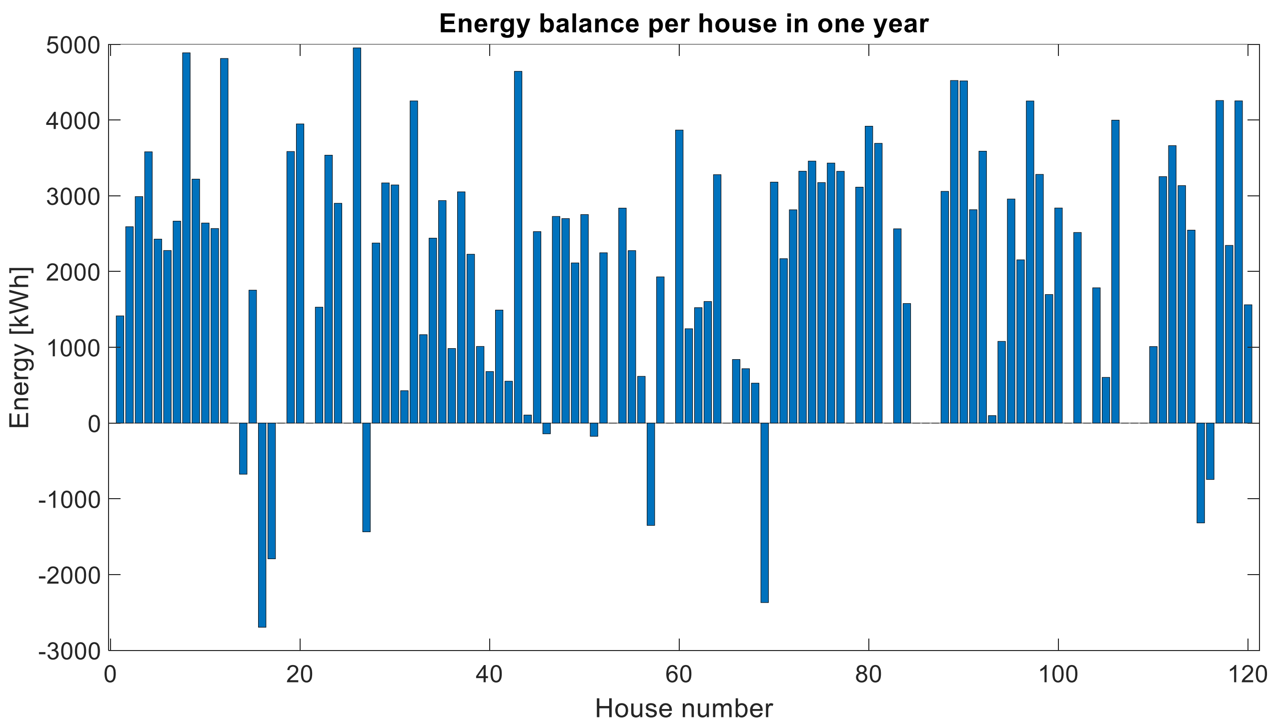


Figure 10. Energy balance of the group of houses, positive values means power supplied to the grid, negative values means power taken from the grid

table 8. maximum, minimum and average energy balance of the group of houses in one year, positive values means power supplied to the grid, negative values means power taken from the grid

Average energy balance	2215 kWh
Maximum energy balance	4952 kWh
Minimum energy balance	-2694 kWh

Most of the houses supply energy back to the grid over the course of a year, there are a few houses which use more energy than they produce over the course of a year. Since the production of the solar panels across all houses is relatively stable, an explanation can be found in the energy use of those houses. The houses that end up using more than their production are the houses with the highest energy use of the group. By comparing the energy production and energy use graphs one can find correlations that match the energy balance graph. There are various reasons for a higher energy use of the houses; more use of tap water, the amount of inhabitants etc.

4.1.4 Maximum current

Table 9. Characteristics of the evaluation of the maximum power

Tables	smartMeter
Variables	smartMeter.total_energy_out, smartMeter.total_energy_in, smartMeter.Timestamp, smartMeter.power

Formula	`diffTime=diff(smartMeter(:,1));`
	`diffPower=diff(smartMeter(:,6));`
	`diffIn=diff(smartMeter(:,7));`
	`diffOut=diff(smartMeter(:,8));`
	
	`% delete values after non updating time period`
	`diffPowerZeros=diffPower==0`
	`sequence=[1 1 1 1 0];`
	`position=findstr(diffPowerZeros',sequence)+4;`
	`diffIn(position)=[];%deletes the possible outliers`
	`diffOut(position)=[];`
	`diffTime(position)=[];`
	
	`%calculates the maximum current`
	`currentIn= (diffIn*3600*1000)./(diffTime*230);`
	`currentOut= (diffOut*3600*1000)./(diffTime*230);`
	`maxCurrentIn(i)=max(currentIn);`
	`maxCurrentOut(i)=max(currentOut);`

Houses used	117 of 120
Empty check	3 [18, 53, 101]

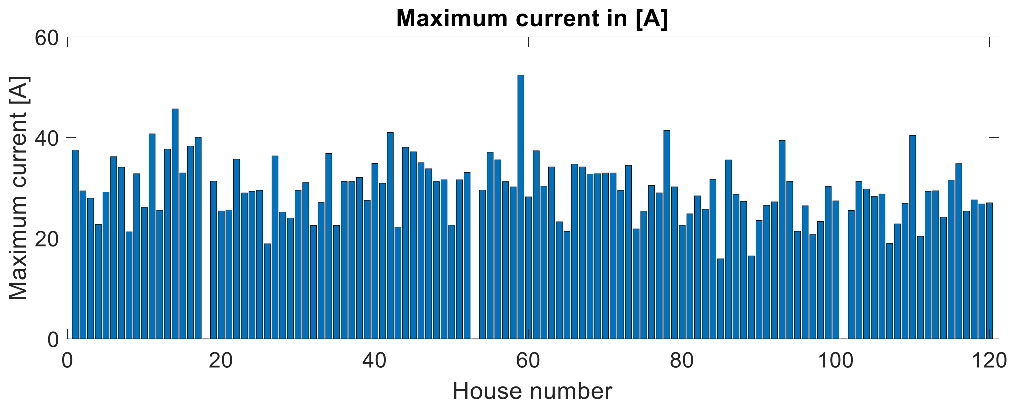


Figure 11. maximum current in per house

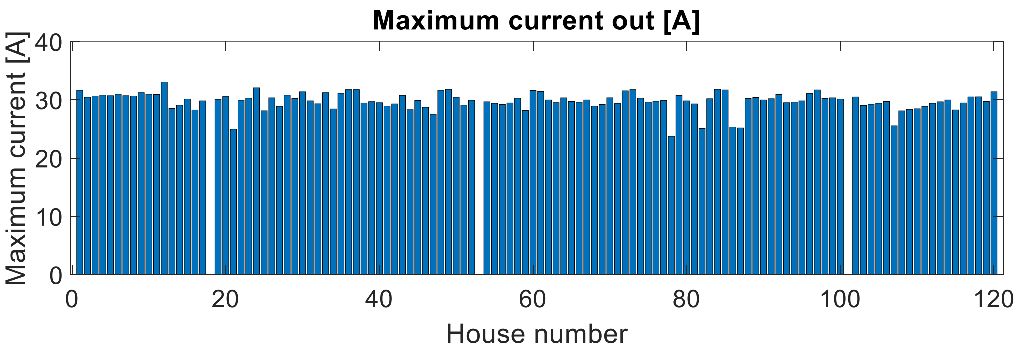


Figure 12. maximum current out per house

table 10. maximum and average current in and out for the group of houses

Maximum of maximum current in	52,43 A
Average of the maximum current in	29,43 A
Maximum of maximum current out	33,07 A
Average of the maximum current out	29,82 A

For these graphs, the incomplete tables have also been included. Only the empty tables are left blank in the graph are the ones without data. Since a single maximum value has to be determined, it is still possible to get the highest value from the remaining datapoints available in the dataset. There were some outliers we manually removed from the graphs.

In some cases, the smart meter would record a new timestamp but not update the data in the other tables, this leaves several consecutive lines within these tables with the same values. Once these tables then properly update again, all the records that have been skipped in the lines before it get updated in that one timestamp, causing a large peak value which greatly exceeds the current that can be supplied to a house before the fuses will trigger. These values are not correct and therefore code is used that will ignore the record whenever there are at least 4 equal power values above it.

The average and maximum current going out of the house is relatively stable, the maximum and average are 3 Amperes apart, which is relatively close to each other, this difference can be explained the same way as the outliers in the energy production, the houses that have a higher peak production are probably the ones that are on the corners, which have more solar panels installed to compensate for the higher energy need for heating. When carefully looking at the graphs the same peaks can be seen in the maximum current out graph as the ones found in the power production graph.

The maximum current in varies among the different houses, there are a few peaks, but these could be explained by the amount of people present in the house, possibly a special occasion in which the house in question used more power than usual, or something like a short circuit causing a power spike in the house. All of these things are environmental factors and cannot be explained by looking at the data of the house alone.

4.2 Heat pump performance

4.2.1 heat pump SCOP

Table 11. Characteristics of the evaluation of the heat pump SCOP

Tables	waterFlow, flowHeatSpaceHeating, energyHeatpump, energyBooster
Variables	waterFlow.volume_out flowHeatSpaceHeating.total_energyGJ energyHeatpump.total_energy_in energyBooster.total_energy_in
Formula	cp=4180 TGround=12 setpointHotWater=55 volumeWater=(waterFlow.volume_out(end)- waterFlow.volume_out(1)) heatSpaceHeating= (flowHeatSpaceHeating.total_energyGJ(end)-flowHeatSpaceHeating.total_energyGJ(1))*1e+9 energyHp= (energyHeatpump.total_energy_in(end)-energyHeatpump.total_energy_in(1))*3600000 energyBt= (energyBooster.total_energy_in(end)-energyBooster.total_energy_in(1))*3600000 hotWaterEnergy=volumeWater*1000*cp*(setpointHotWater-TGround) **scopHeatPump=(heatSpaceHeating+hotWaterEnergy)/(energyHp+energyBt)**
Houses used	92 of 120
Empty check	0
Incomplete	27 [34, 45, 50, 59, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 74, 97, 98, 99, 100, 101, 102, 103, 104, 107, 108]
Reset + Gap	1 [35]

On the records of the variable flowHeatSpaceHeating.total_energyGJ two type of anomalies have been detected. A sudden jump on the value of the recorded values and single outlier records. Because of these anomalies the SCOP values of these houses with the used calculation code was not correct. That is why on houses [19,28,42] the heating energy delivered has been calculated as the difference between the first and the last recorded value.

Table 12. Anomalies on flowHeatSpaceHeating.total_energyGJ records

House Number	Anomaly
19	Records value jump. On timestamp 1577712001, from 17,68 GJ to 1332,50 GJ
28	Outlier. On timestamp 1562679004 recorded value 0.1134 GJ in place of 7.8937GJ
42	Outlier. On timestamp 1577712001 recorded value -284751.256 GJ

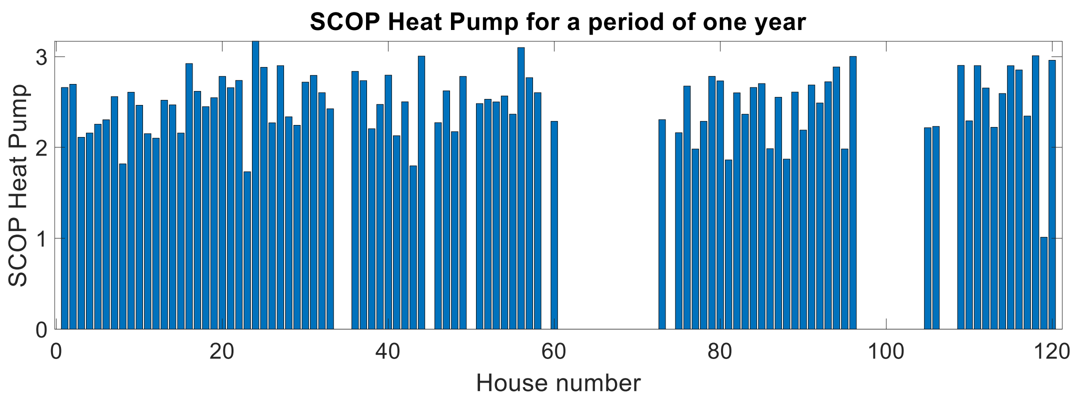


Figure 13. Heat pump SCOP

table 13. average, minimum and maximum SCOP of the group of houses

Average SCOP	2,48
Maximum SCOP	3,17
Minimum SCOP	1,02

The value found for the average SCOP at 2,48 matches that found in other already active and installed heat pumps and sits somewhere around 2,5. In that case the performance of these heat pumps is relatively average and fits the norm. There are a few small exceptions in the group, notably the house which has an SCOP of 1. This is a low value, but the house itself did not seem to be using a large amount of energy for the heat pump. Possible later analysis of the data of the house in question has to be done in order to figure out why this house in particular stands out in between the other houses. We can also look at the energy use of the different modes to see where the power the heat pump consumes is used for

table 14. Characteristics of the evaluation of the heat pump energy use per mode

<table>
<tr><td>Tables</td><td>alklimaHeatPump, energyHeatpump, energyBooster</td></tr>
<tr><td>Variables</td><td>waterFlow.volume_out
flowHeatSpaceHeating.total_energyGJ
energyHeatpump.total_energy_in
energyBooster.total_energy_in</td></tr>
<tr><td>Formula</td><td><pre>
%create row vector with dates, convert from posixtime
rowTimeAlklimaHeatPump=datetime(alklimaHeatPump(:,1),'ConvertFrom','posixtime','TimeZone','Europe/
Zurich');
rowTimeEnergyHeatPump=datetime(energyHeatpump(:,1),'ConvertFrom','posixtime','TimeZone','Europe/Zu
rich');

%create timetables, with the needed data the time row vector

timetableAlklima=array2timetable(alklimaHeatPump(:,10),'RowTimes',rowTimeAlklimaHeat
Pump);

timetableEnergyHP=array2timetable(energyHeatpump(:,3),'RowTimes',rowTimeEnergyHeatPu
mp);

%Syncronize each table to a regular time table, each table uses a different method
    synchronizedAlklima=retime(timetableAlklima,'regular','nearest','Timestep',dt);
    synchronizedEnergyHP=retime(timetableEnergyHP,'regular','linear','Timestep',dt);

 %extract the energy and modus rows from the timetable
    modusHP=timetable2table(synchronizedAlklima);
    modusHParray=table2array(modusHP(:,2));
    modusHParray(1)=[];
    energyHP=timetable2table(synchronizedEnergyHP);
    energyHParray=table2array(energyHP(:,2));
    diffEnergyHP=diff(energyHParray);

%extract the if checks if the two arrays have the same lenght

if length(diffEnergyHP)==length(modusHParray)
    totalEnergyHpNoBooster(i)=sum(diffEnergyHP);
    energyModusStandby(i)=sum(diffEnergyHP(modusHParray==0));
    energyModusHotTapWater(i)=sum(diffEnergyHP(modusHParray==1));
    energyModusHeating(i)=sum(diffEnergyHP(modusHParray==2));
    energyModusDefrost(i)=sum(diffEnergyHP(modusHParray==5));

%The energy of booster modus is on another table
    diffEnergyBooster=diff(energyBooster(:,3));%column e is
energyBooster.total_energy_in
    energymModusBooster(i)=sum(diffEnergyBooster(diffEnergyBooster>=0)); ;%kWh
</pre></td></tr>
<tr><td>Houses used</td><td>103 of 120</td></tr>
<tr><td>Empty check</td><td>0</td></tr>
<tr><td>Incomplete</td><td>4 [4,45,50,59]</td></tr>
<tr><td>Reset + Gap</td><td>1 [35]</td></tr>
<tr><td>Different length</td><td>11 [29, 30, 32, 33, 34, 44, 69, 95, 101, 110, 116]</td></tr>
<tr><td>Other</td><td>House 104 has only modus booster registered</td></tr>
</table>

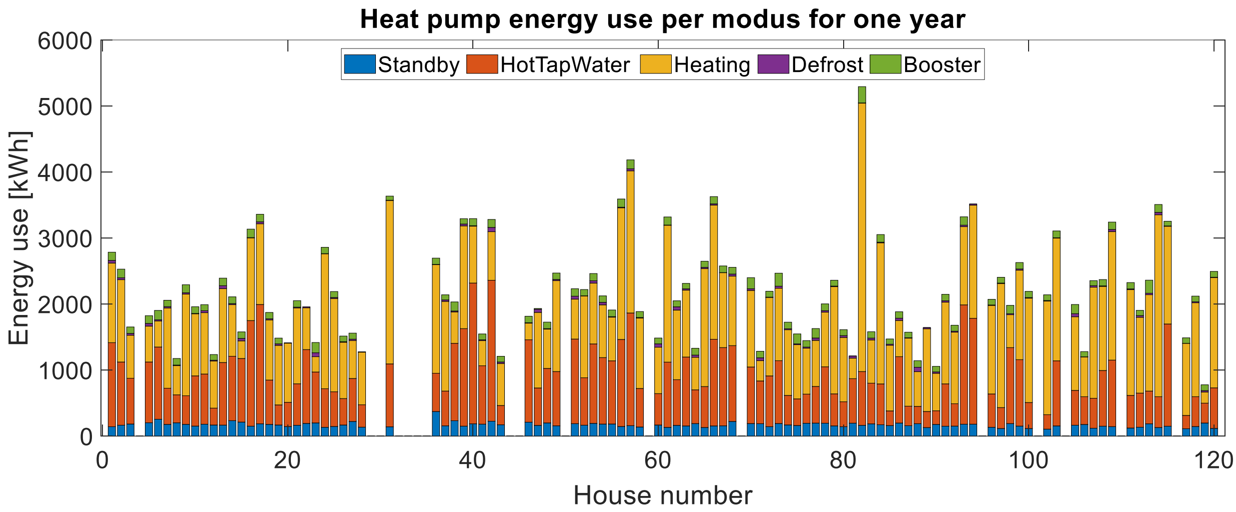


Figure 14. Heat pump SCOP

table 15. energy used per mode, as well as percentage of total use per mode

Standby modus	169,94 kWh	7,71%
Hot tap water modus	778,66 kWh	35,34%
Heating modus	1131,07 kWh	51,33%
Defrost modus	20,29 kWh	0,92%
Booster modus	103,57 kWh	4,70%
Total Energy HP	2203,53 kWh	

4.3 Ventilation performance

4.3.1 Temperature

Table 16. Characteristics of the evaluation of the inside temperature

Tables	alklimaHeatPump
Variables	alklimaHeatPump. room_target_temp alklimaHeatPump. room_temp

Formula	`roomTargetTemp=alklimaHeatPump(:,13)`
	`roomTemp=alklimaHeatPump(:,14)`
	`averageTargetTemp=mean(roomTargetTemp(roomTargetTemp<40 & roomTargetTemp~=0))`
	`maxTargetTemp= max(roomTargetTemp(roomTargetTemp<40 & roomTargetTemp~=0))`
	`minTargetTemp= min(roomTargetTemp(roomTargetTemp<40 & roomTargetTemp~=0))`
	`averageRoomTemp=mean(roomTemp(roomTemp~=0))`
	`maxRoomTemp= max(roomTemp(roomTemp~=0))`
	`minRoomTemp(i)= min(roomTemp(roomTemp~=0))`
	`secondsUnderTargetTemp(i)=sum(roomTemp<roomTargetTemp & roomTemp~=0)*300`
	`secondsOver26(i)=sum(roomTemp>26)*300`
	`secondsUnder19(i)=sum(roomTemp<19 & roomTemp~=0 )*300`

Houses used	120 of 120

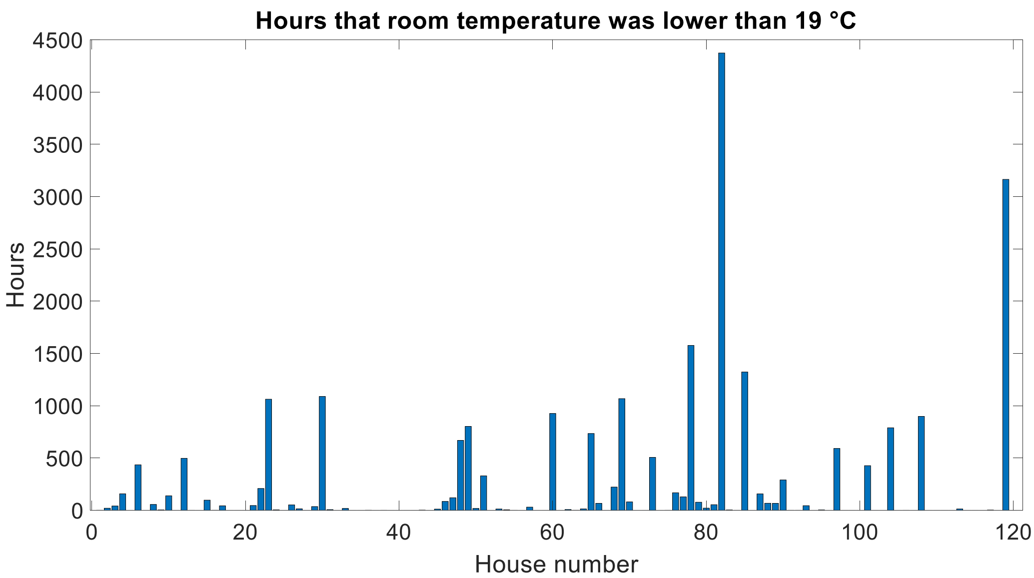


Figure 15. internal temperature lower than 19 degrees

Average amount of hours with room temperature lower than 19 °C 199.75 hours.

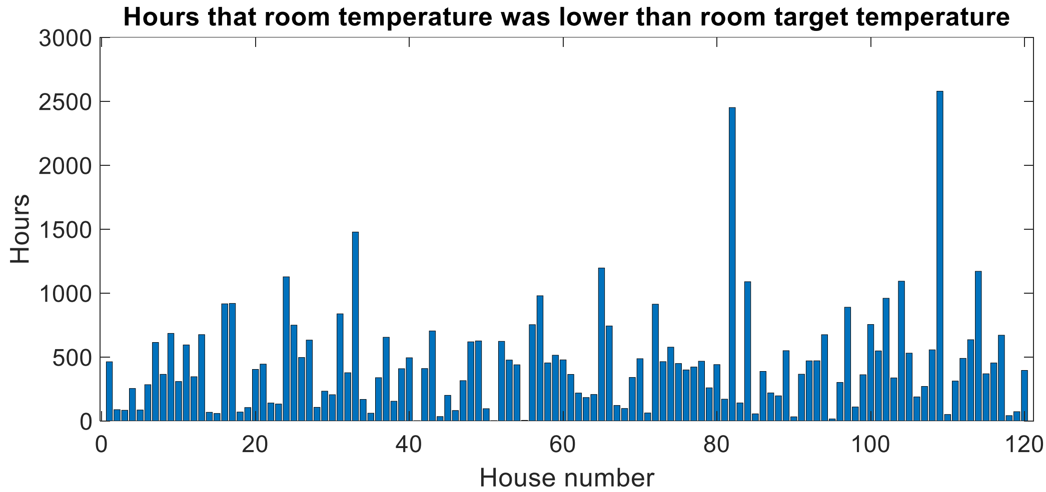


Figure 16. internal temperature lower than set target temperature

Average amount of hours when room temperature was lower than room target temperature 451.47 hours.

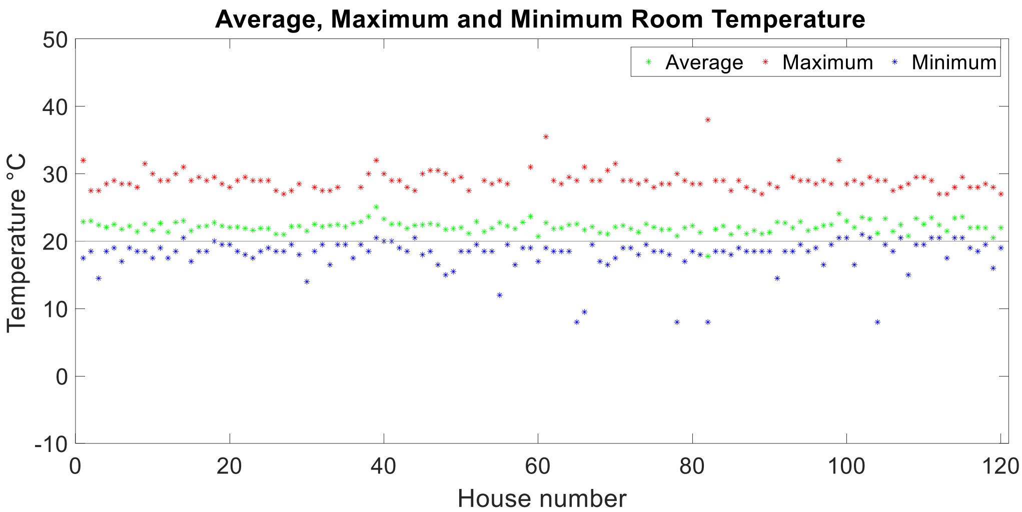


Figure 17. average, minimum and maximum temperature

table 17. average, minimum and maximum inside temperature

Average of maximum room temperatures	32.97°C
Average of average room temperature	22.6°C
Average of minimum room temperatures	18°C

4.3.2 CO2 levels

Table 18. Characteristics of the evaluation of CO2 levels and humidity

Tables	`co2sensor`
Variables	`co2sensor.co2` `co2sensor.humidity`

Formula	`co2=co2sensor(co2sensor.co2)`
	`humidity=co2sensor(:,3)`
	`averageCo2(i)=mean(co2(co2~=0))`
	`maxCo2(i)= max(co2(co2~=0))`
	`minCo2(i)= min(co2(co2~=0))`
	`averageHumidity(i)=mean(humidity(humidity~=0))`
	`maxHumidity(i)= max(humidity(humidity~=0))`
	`minHumidity(i)= min(humidity(humidity~=0))`
	`co2above1000(i)=sum(co2>1000)*300`
	`co2above1200(i)=sum(co2>1200)*300`
	`humidityBelow30(i)=sum(humidity<30 & humidity~=0 )*300`
	`humidityBelow40(i)=sum(humidity<40 & humidity~=0 )*300`
	`humidityAbove60(i)=sum(humidity>60 )*300`
	`humidityAbove70(i)=sum(humidity>70 )*300`
	`humidityAbove80(i)=sum(humidity>80 )*300`

Houses used	`117 of 120`
Empty check	`3, [4,9,52]`

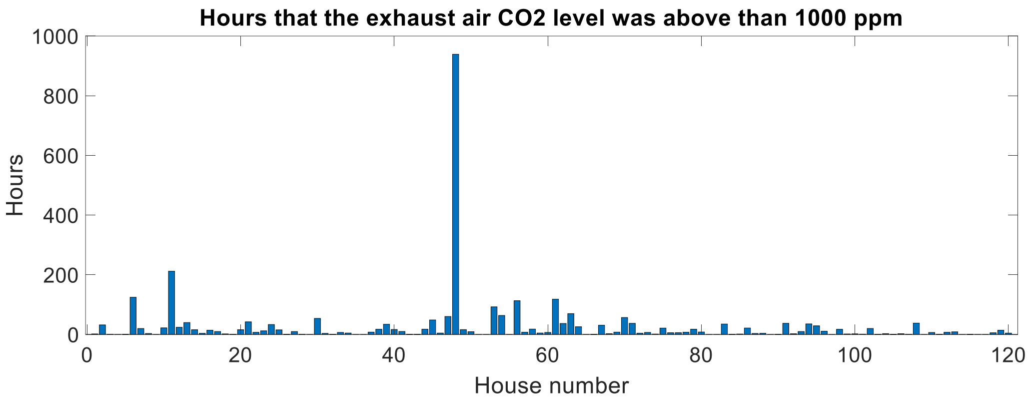


Figure 18. CO2 levels above 1000 ppm

Average hours above 1000 ppm = 25,04 hours.

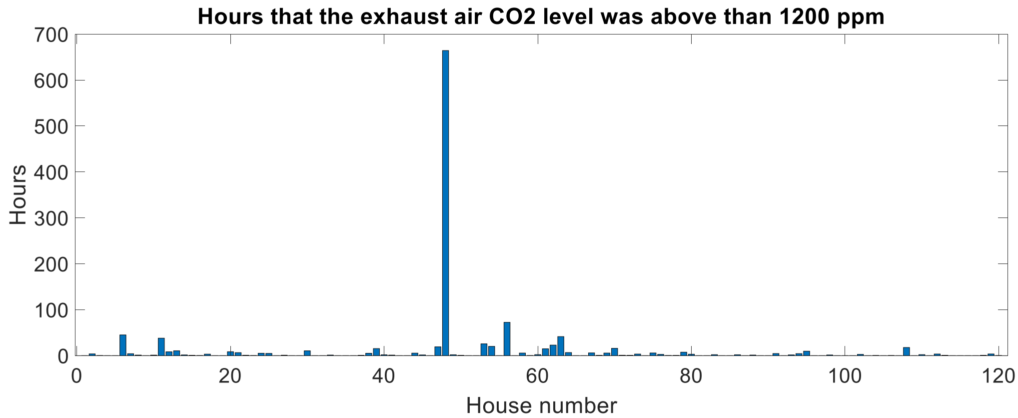


Figure 19. CO2 levels above 1200 ppm

Average hours above 1200 ppm = 10,00 hours.

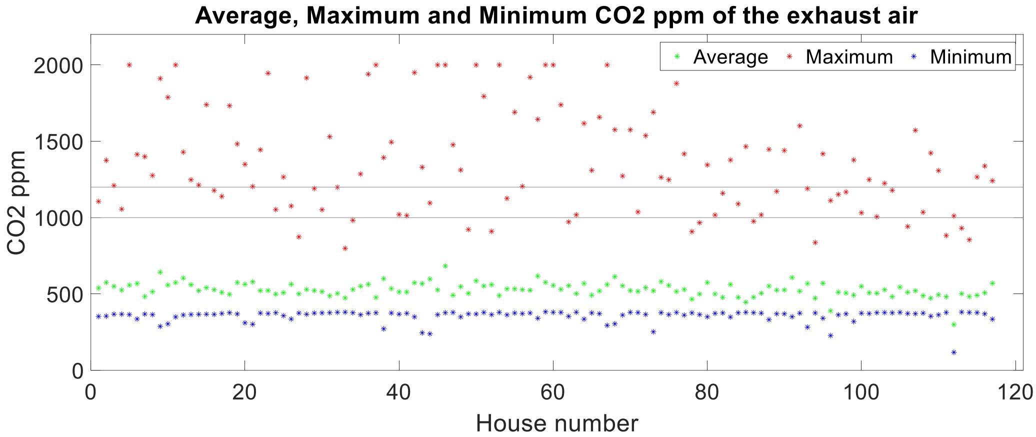


Figure 20. average, minimum and maximum CO2 levels

table 19. average, minimum and maximum CO2 levels

Average of maximum CO2 level	1373.11 ppm
Average of average CO2 level	529.2 ppm
Average of minimum CO2 level	356.4 ppm

4.3.3 Humidity

Table 20. Characteristics of the evaluation of CO2 levels and humidity

Tables	`co2sensor`
Variables	`co2sensor.co2` `co2sensor.humidity`

Formula	`co2=co2sensor(co2sensor.co2)`
	`humidity=co2sensor(:,3)`
	`averageCo2(i)=mean(co2(co2~=0))`
	`maxCo2(i)= max(co2(co2~=0))`
	`minCo2(i)= min(co2(co2~=0))`
	`averageHumidity(i)=mean(humidity(humidity~=0))`
	`maxHumidity(i)= max(humidity(humidity~=0))`
	`minHumidity(i)= min(humidity(humidity~=0))`
	`co2above1000(i)=sum(co2>1000)*300`
	`co2above1200(i)=sum(co2>1200)*300`
	`humidityBelow30(i)=sum(humidity<30 & humidity~=0 )*300`
	`humidityBelow40(i)=sum(humidity<40 & humidity~=0 )*300`
	`humidityAbove60(i)=sum(humidity>60 )*300`
	`humidityAbove70(i)=sum(humidity>70 )*300`
	`humidityAbove80(i)=sum(humidity>80 )*300`

Houses used	`117 of 120`
Empty check	`3, [4,9,52]`

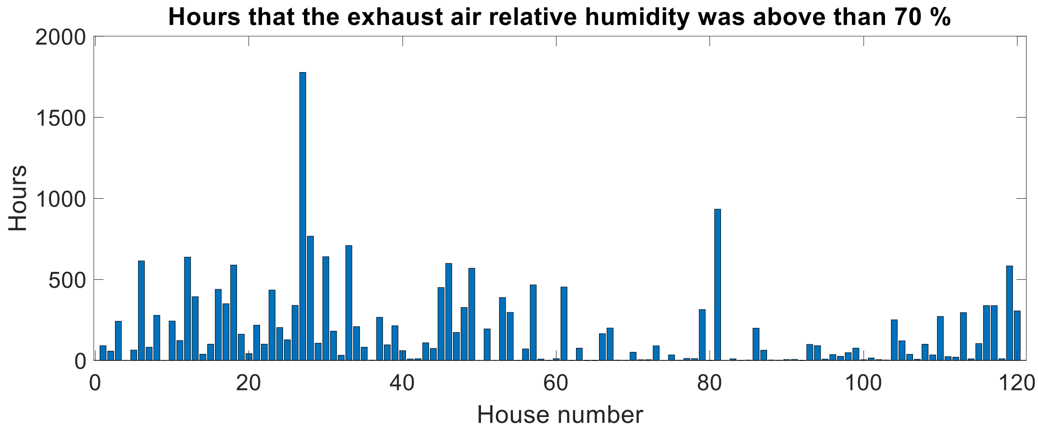


Figure 21. time in which humidity was above 70%

Average hours above 70% relative humidity = 172,96 hours.

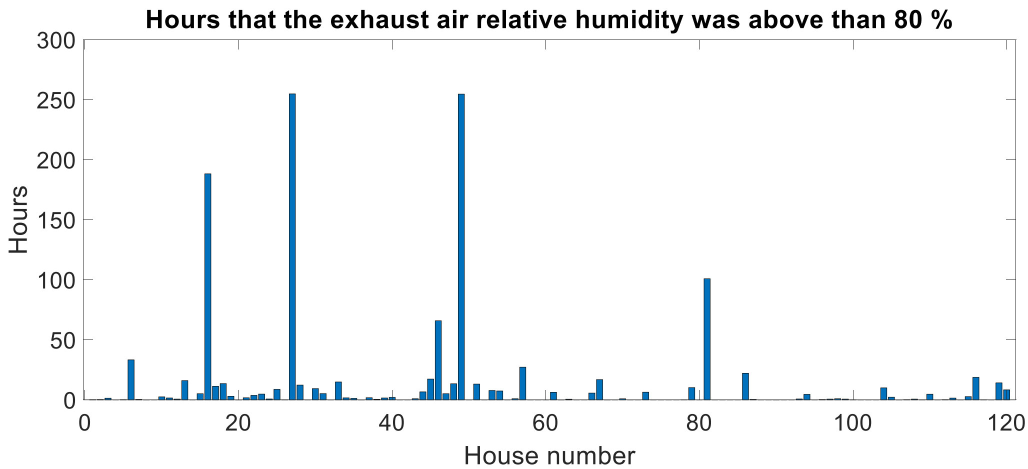


Figure 22. time in which humidity was above 80%

Average hours above 80% relative humidity = 10.56 hours.

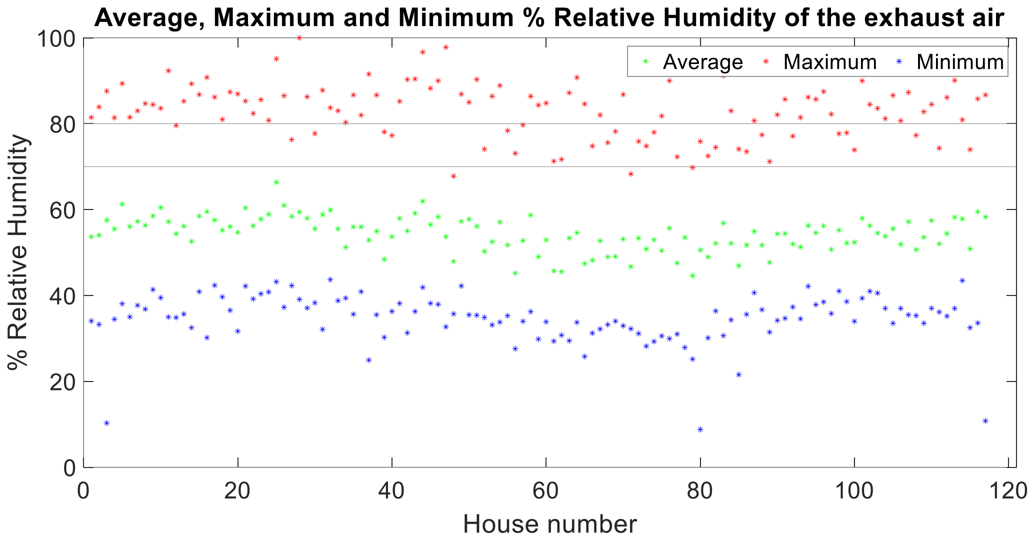


Figure 23. average, minimum and maximum relative humidity

table 21. average, minimum and maximum relative humidity

Average of maximum relative humidity	82.91 %
Average of average relative humidity	54.38 %
Average of minimum relative humidity	34.64 %

5 Discussion

Is this paper there where many different components that where analyzed. As pointed out in the introduction there are 3 main points that will be looked at in this report. Based on the performances of the installation and the results provided by the controller that is inside we will discuss in this paragraph.

5.1 The house performance

The performance of the houses is house is measures based on the energy used and generated by the houses. We could call this the NZEB part of the discussion, since FactoryZero claims that the houses are with the current heat pump that is installed.

First, we have a look at the total energy usage of the houses and how this is divided between the components. According to NIBUD, the National Institute for Budgetary Information, an average household of 2 persons yearly consumes 2860 kWh and 1290 m^3 of gas. In our analysis the houses use on average 2745 kWh for appliances. This is almost the same, and it would be strange if there had been a difference in this part.

Where average household uses gas to heat up the water for the tap water and the radiators, the renovated houses in this case use a heat pump for that part. When we convert 1290 m^3 gas to the amount of kWh it contains we reach a total usage of 1290 [m^3] * 31,65 (undervalue) [MJ/m^3] * 1,07 (HR-boiler) [%] / 3,6 [MJ to kWh] = 12135 kWh a year for the heating of an average house. When we compare this value to the total energy usage of the heat pump and the heat regeneration, 2225 kWh + 263 kWh = 2488 kWh, we see a reduction in the energy usage of 79,5% on a yearly base.

The yearly solar production of the houses is 7487 kWh. The distribution of the houses is pretty equal, and the corner houses produce just a bit more since they need a little more for the heating. When this is compared to the average energy usage of the houses, 5183 kWh a year, there is way more energy produced on average then there is consumed.

When we have a look at the energy balance, where the production minus the consumption is plotted, we see that there are 10 houses that use more than they produce. In the other 93 houses, the production is higher than the usage.

5.2 Heat pump performance

The performance of a heat pump can be described by the SCOP. This stand for the Seasonal Coefficient of Performance. This is commonly used for heat pumps, refrigerators, and air conditioning systems. Another value that can be used is the Coefficient of Performance, but then you calculate the value based on a single moment. In this paper we took the performance over the course of year.

The average SCOP that we calculated over 92 houses is 2,48. This is conform the scores that can be found in a research done in Italy over the course of a year. When the score is compared to values that can be reached under “perfect conditions” inside a lab, it is almost halve of it.

There are some important notes that have to be made concerning this performance rating. In the houses we analyzed there is no air conditioning available. Since these usually decrease the performance it might not be completely similar to the Italian scores. But there are also some built-in measures that have a negative influence on the score. Every now and then the heat pump heats up the water to 70 degrees to prevent the growth of Legionella in the buffer tank. There is also a defrost mode that heats up the installation in the winter to prevent it from freezing.

5.3 Ventilation performance

The last main point that we will discuss is the performance of the ventilation. Since the house performance and the heat pump performance cannot describe the quality of living indoor, we discuss that is this paragraph.

There are 3 major variables that tell us something about the living comfort. The first one is the relative humidity indoors. There are 2 thresholds for this one, is should be at least 30% in the winter and at most 60% in the summer to have a perfect indoor climate. As we can see in the graph and the table the average minimum is around 35%, which is great. The maximum value that is reached during the year lays on average around 82%. Since this is the single highest value that can be found for every house it does not say that much. But when there are multiple days that the value is above this, it can cause fungi to grow on various places. The average value during the year is 54%, which is good.

The second parameter is the indoor temperature. For a perfect indoor climate, the temperature has to vary between 21 degrees and 24 degrees. As we can see in the table, the average indoor temperature is 22,6 degrees during the year. There is one important side note in this case, and that is that there is no air conditioning system inside the houses. So, in the summer the indoor temperature can reach temperatures around 33 degrees. This is way to high, but not further relevant for our analysis.

The last parameter are the indoor CO_2-levels. For this one there are also 2 thresholds, 1000 ppm and 1200 ppm. When the levels are below 1000 degrees, the living condition are, according to the Bouwbesluit good. When the value rises above the 1200 ppm the living condition are considered undesirable because it can cause a variety of health issues. Since the average level is 529 ppm during the year the living condition for the CO_2-levels are perfect. There are some peaks that can reach values of 2000 ppm in different houses, which might seem dangerous. But when there is a visit of some friend it can peak very fast, but when this is for short periods of time it does not really matter.

6 Conclusion

In this report we have analyzed the data over the year of 2019. Based on all the data we have been provided with, we gained a lot of results and spoke about these in the discussion. In this chapter we have made a conclusion for the 3 main points we spoke of in the introduction.

The first point is the performance of the heat pump. For this point we were able to use the data of 92 of the 120 houses to get a better insight of the SCOP of a set of houses. We found that the average SCOP of the houses is equal to 2,48. We compared this to a research that has been done in different cities in Italy and they came up with a similar value (Vocale & Morini, 2014). This is a value that is acceptable for heat pumps and we can say that their performance is as expected.

The second point the performance of the ventilation that is inside the houses. For this point we have had a look at the indoor relative humidity, the temperature, and the CO_2-levels that we found over the course of a year. The results show that the average relative humidity is around the 55%, which is acceptable for houses. There can be found some peaks during the year, but since there are peaks for short amounts of time, there are not harmful for the inhabitants. The temperature is barely below the set temperature of the 21 degrees Celsius in the coldest periods in the winter. So, the heat pump is working properly. The last part of this point is the CO_2-level in the house. There has been set a threshold at 1200 ppm. The average value is 583 ppm, so this is good. There are some peaks that reach the point of 2000 ppm, but since there are for short periods of time, they are not hazardous for the inhabitants. We can say that the performance of the ventilation according to the expectations.

The last point is the performance of the houses. The total energy usage of the houses for appliances is conform the averages that can be found on the site of NIBUD. When we add the energy usage of the heat pump and compare this to traditional boilers, we see a decline in use of energy of nearly 80%. The solar panels produce more than enough energy for the average house. So, we could say that, as FactoryZero claimed, the installations create Net Zero Emission Buildings when they have an average usage of the energy. Since it is not true for every house that we analyzed (93 out of 103), we cannot say it is true for the houses, but it is true for the neighborhood

7 Recommendations

Based on the results we found, the comparison we made in the discussion to different set values and different researches done, and a 2 discussion we had after presenting our results to research groups, we have made a list of recommendations for further research.

1. Holiday mode on the heat pump

After analyzing the SCOP of the heat pumps we found minor differences in the results. At first, we thought it could be explained due to some holiday mode that is installed on the heat pumps. After we made a plot of this result, we found out that no-one ever used this mode. So to further improve the SCOP and to reduce the energy usage we would like to recommend an explanation on how to use this setting,

2. Adding a cooling system to the houses

The average temperature we found in the houses is 22,6 degrees. After we plotted a single house over the course of a year, we saw that the temperatures can reach temperatures of 35 degrees in the summer period since there is no active cooling possible. To improve the quality of living we would strongly recommend adding this feature to new heat pumps.

3. Making a questionnaire for the inhabitants

At the start of our project we were told that there would be a questionnaire to analyze the behavior, the amount of people that live there etc. At first, we did not really know how to use this data, but since we analyzed a lot of data and got a better insight in the differences between the houses it could clarify a lot of the data. In the future this could lead to a better understanding of the data.

4. Adding a battery to the system

The last recommendation is to install a battery with a certain, to be determined in the future, capacity that could increase the amount of self-used energy. Since the houses use on average 22% of the electricity they produce, it becomes a certain problem for the grid to keep the balance. With a battery this could increase a lot and makes the houses more (self)sustainable.

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Appendix

Appendix 1; criteria

	Onderdeel	Wat meten	Periode	Eenheid	Prioriteit
Machines	COP	Warmtepomp	Dag	#	1
			Maand	#	1
			Jaar	#	1
	Rendement	Boiler	Dag	%	1
			Maand	%	1
			Jaar	%	1
		Warmtewisselaar	Dag	%	1
			Maand	%	1
			Jaar	%	1
		Omvormer	Dag	%	1
			Maand	%	1
			Jaar	%	1
	Warmtepomp	Vakantie (1/0)	Jaar	Hours on/off	1
		Modus (0-6)	Maand	Hours mode 0-6	1
			Jaar	Hours mode 0-6	1
Elektra	Opwekking	Maximaal	Jaar	A	2
		Verbruik omvormer	Jaar	kWh	2
		Totaal	Dag	kWh	2
			Maand	kWh	2
			Jaar	kWh	2
	Energieverbruik	Maximaal	Jaar	A	2
		Totaal	Dag	kWh	2
			Maand	kWh	2
			Jaar	kWh	2
		Excl. warmtepomp	Dag	kWh	2
			Maand	kWh	2
			Jaar	kWh	2
		Warmtepomp	Dag	kWh	2
			Maand	kWh	2
			Jaar	kWh	2
	Netstroom		Dag	kWh	2
			Maand	kWh	2
			Jaar	kWh	2
	Energiebalans	Totaal	Dag	kWh	2
			Maand	kWh	2
			Jaar	kWh	2
Warmte	Temperatuur	Buiten	Jaar	C	2
		Binnen	Jaar	C	2

		Verschil	Dag	C	2
			Maand	C	2
			Jaar	C	2
		Verwarming in	Jaar	C	2
		Verwarming uit	Jaar	C	2
		Gem. verwarming	Jaar	C	3
Water	Waterverbruik	Boiler	Jaar	m3	3
		Rest van huishouden	Jaar	m3	3
Lucht	Ventilatie	Woonruimtes in	Dag	m3	3
			Maand	m3	3
			Jaar	m3	3
		Woonruimtes uit	Jaar	m3	3
	CO2	Onder 1000 ppm (uren)	Dag	Hours	3
			Maand	Hours	3
			Jaar	Hours	3
		Boven 1200 ppm (uren)	Dag	Hours	3
			Maand	Hours	3
			Jaar	Hours	3
	Vochtigheid	Tussen 40%-60%	Jaar	Hours	3
		Onder 40%	Jaar	Hours	3
		Boven 60%	Jaar	Hours	3
	VOC	<200 ug / m3	Dag	Hours	3
			Jaar	Hours	3
		>200 ug / m3	Jaar	Hours	3