Integrating Installations into a Zero-Energy Renovation

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Abstract

In order to counter climate change many approaches have been taken to make the building sector more sustainable. But for porch houses there aren't many solutions on the market. This research project uses one of the approaches that is does focus on porch houses, 2ndskin. In march 2018 a demonstrator project has been build in Vlaardingen using the 2ndskin approach. The research found a problem with integrating the installations, they took up a lot of space and were so heavy that an extra foundation was needed. This problem is not unique to 2ndskin or the zero-on-the-meter renovations of porch houses, it's a problem in other sustainable projects as well. Therefore this research has looked into the following problem:

The installations needed to renovate a post-war porch house in accordance with the 2ndskin approach are too heavy and take up a lot of valuable space.

Current systems have been analyzed in order to solve this problem. The comparison of these systems unveiled the main causes of the size and weight of these systems: Empty space between the installations, placement of the connections, required space for installation and maintenance, the kind of installations used and the integration between them. In the end three concepts where presented. Prioritizing different aims, the concepts show different ways to integrate the installations according to different priorities.. For the 2ndskin demonstrator project these concepts show that its possible to decrease the by 50% to 70% and the weight by 30% to 60%. The amount of possible decrease depends on the priorities within the project. But, smaller installations spaces are possible when designing from within the installations instead of around it.

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Introduction

Many researches have proven that climate change is real and that measures are needed to counter it. *(2.1.1 Climate change)* But, countering it stays challenging. Different approaches have been set up in order to do this.

This research project has its roots in one approach, the 2ndskin approach. This approach is a collaboration between industry and academic partners. The partners continue to improve on this project. *(Guerra Santin, 2015)* This graduation thesis will research a potential improvement within 2ndskin. The approach itself is looking for a market-ready solution which can be used to renovate post-war houses. After the renovation, the houses should use no energy on a yearly average and be future proof. *(Guerra Santin, 2015)*

Before the start of this thesis 12 porch houses in Vlaardingen have been renovated using the 2ndskin approach. The houses have been built in 1952 and did no longer meet the current housing standards. Instead of renovating the houses to near current standards, they have undergone a deep retrofit. The old windows have been replaced with new window frames with triple glazing. The current roof structure has been covered in insulation panels with solar panels on top. On the outside of the existing facade insulation panels with plaster have been added. Also, new building services have been installed. These installations include a ground heat pump, a boiler and a central heat recovery ventilation unit. *(Boess, S. 2017)*

During this research project these houses will be referred to as the demonstrator project. This demonstrator project will provide the starting point of this thesis. According to the evaluation of this project by the partners, there are a few things that can still be improved. Most of these points concern the installations and the potential to upscale the approach. *(Boess,S. 2017)* The main points of improvement have resulted in the main problem statement of this graduation project.

Background

The 2ndskin demonstrator project

In March 2018 the renovation of the 2ndskin demonstrator project was completed. In order to lower the heat demand of the homes from 300 kWh/m²/yr. to 30 kWh/m²/yr. the outer skin of the houses was improved.*(Climate-KIC, 2018)* Underneath the ground floor an expanding polystyrene insulation has been blown in to prevent heat losses through the ground. Panels of polystyrene have also been added to the façades. The original façade exists out of a constructive wall made from concrete blocks (100 mm), an air layer (70 mm) and a brickwork layer on the outside. (100 mm) The new insulation was added on to the outside wall with an adhesive medium. After placing the insulation, the wall was leveled and plastered. Because the residents wanted brickwork on the outside, stone strips where added to the underside of the wall and the sides of the installation cupboard. Because of these new layers the façades now achieve the values shown in table B1. *(Boess, S. 2017)*

Figure B.1: 2ndskin demonstrator front façade (B.I.K Bouw, 2018)

Element	Specifications
Roof	U 0,14 W/Km2 (Rc 7,0)
Facade elements	U 0,16 W/Km2 Rc 6.0
Ground floor	U 0,28 W/Km2 Rc 3.5
Window	Uw 1 g_g o,8 Rc 0.8
Infiltration	0.3 dm³/s.m²
Ventilation system	Balanced ventilation efficiency 0.95

Table B.2: 2ndskin demonstrator, Facade values after renovation.(Boess,S. 2017, p9)

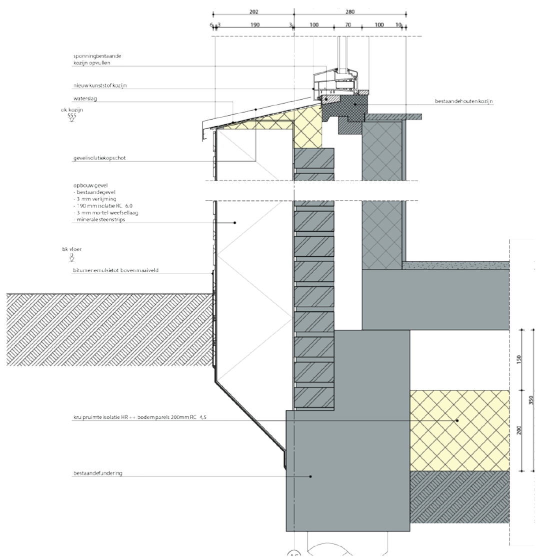


Figure B.2: Fundation detail.(Boess,S. 2017)

For the roof prefabricated insulation panels have been placed on the existing structure. Directly on top of these panels the solar panels were installed. Next to the solar panels other installations have been placed in cupboards in front of the façade behind the houses.

These cupboards are placed on the same construction as the balconies. This construction was needed because the existing façade was not strong enough to carry both the installations and the balcony. For the block of 12 houses there are two columns of stacked cupboards. These columns are 7970m height 1805m wide and 1900m deep and contain 6 cupboards. One cupboard for every house. The outside layers of these cupboards exist out of a wooden frame with insulation. The weight of the ground level cupboard is estimated on 870 kg.

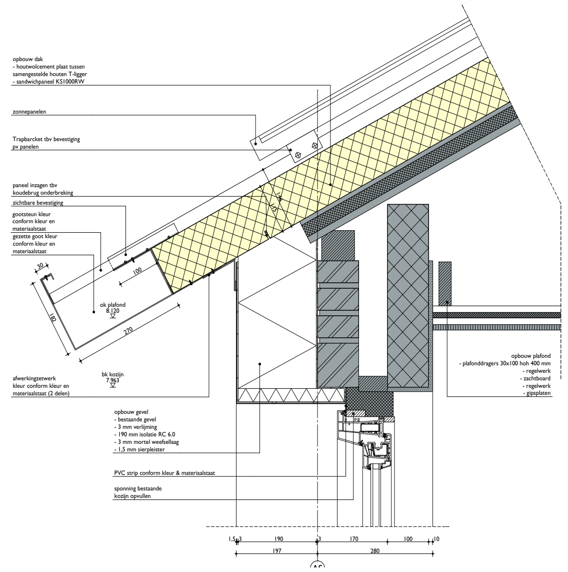


Figure B.3: Roof detail (Boess,S. 2017)

Figure B.4:2ndskin demonstrator rear façade (Boess,S. 2017)

Figure B.5: Roof, installation solar panels (B.I.K Bouw, 2018)

Figure B.6: rear façade, before the renovation (B.I.K Bouw, 2018)

Figure B.7: rear façade, After the renovation (B.I.K Bouw, 2018)

The installations inside the cupboard differ per floor. On the ground floor the cupboard contains: a ground heat pump, a buffer boiler and a heat recovery ventilation unit. On the first floor there is a booster for the heat pump, a buffer boiler and a heat recovery ventilation unit. For the second floor the cupboard only contains a buffer boiler and a heat recovery unit. All the installations where installed on the building site and where placed as close as possible together. However, there is still quite some space between them. *(Boess, S. 2017)*

In order to provide the heat inside there are low temperature radiators placed in every room. Where they are placed and where the pipes are laid to connect them is visualised in the floorplan on the right page. This floorplan also shows the ventilationsystem, the heat demand and the ventilation need.

Figure B.8: rear façade, before the renovation (B.I.K Bouw, 2018)

Figure B.9: 2ndskin cupboard ground floor (Boess,S. 2017)

Figure B.10: 2ndskin cupboard First floor (Boess,S. 2017)

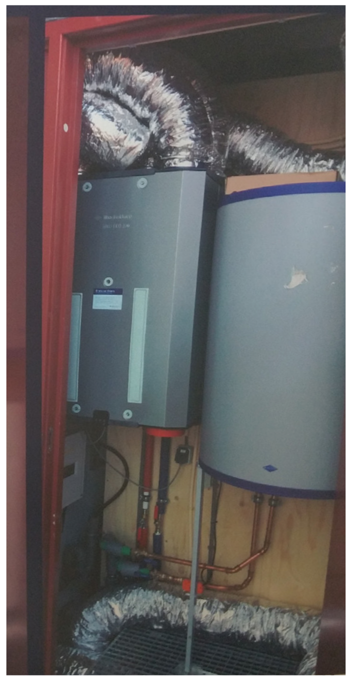


Figure B.11: 2ndskin cupboard second floor (Boess,S. 2017)

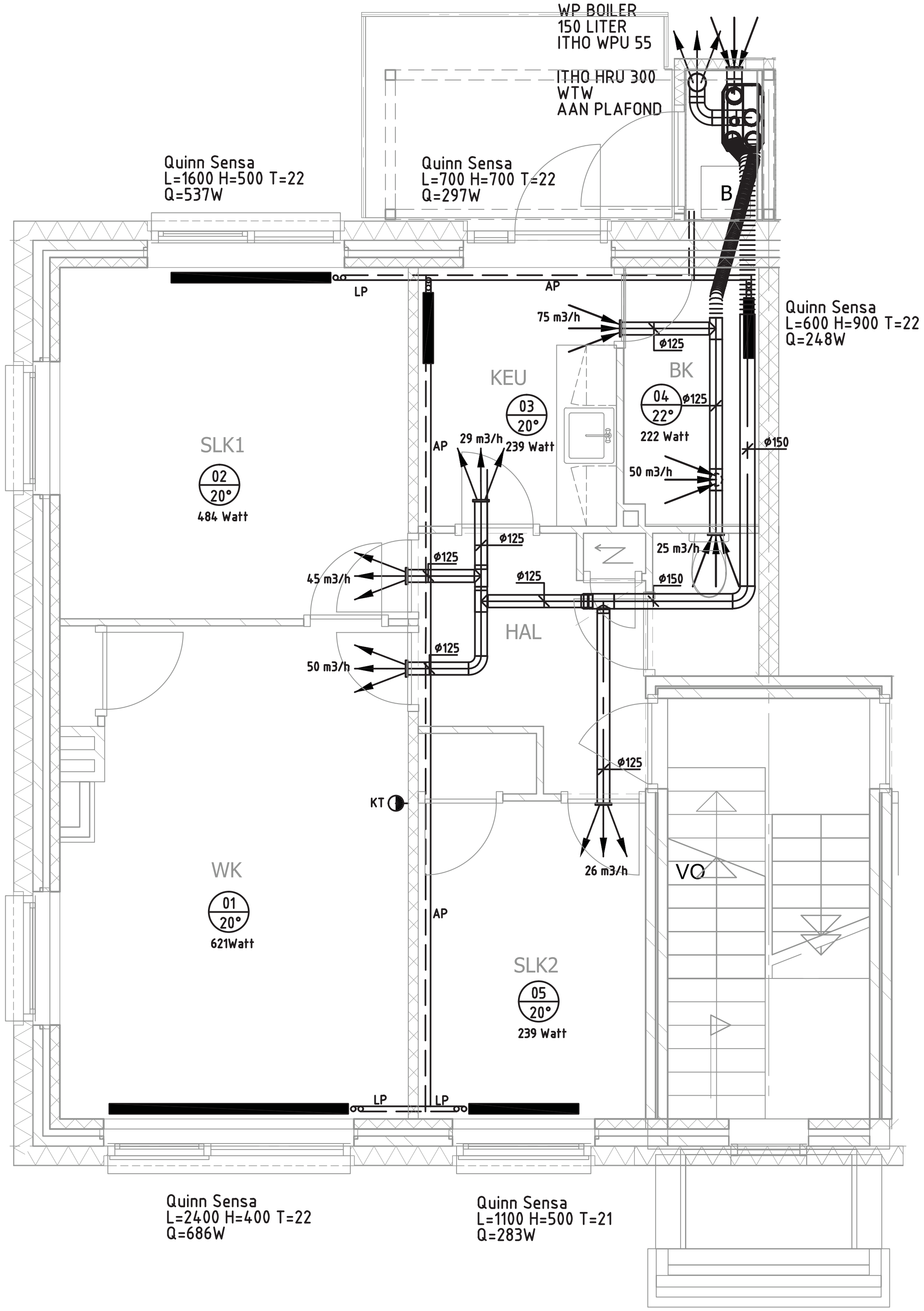


Figure 3.9: 2ndskin demonstrator floor plan installations.(Boess,S. 2017)

1
Methodology

1.1 Problem statement

The installations needed to renovate a post-war porch house in accordance with the 2ndskin approach are too heavy and take up a lot of valuable space.

In the following paragraph, the problem statement will be elaborated on. The paragraph has been broken down in multiple parts. These parts correspond with a specific section of the problem statement. For all these different sections an explanation will be given on why they are important and how they are defined within this research thesis.

The installations...

The evaluation of the demonstrator project state that the installations are to heavy and too big. They take a third of the balcony of a 60 m2 porch house. *(Boess,S. 2017)* Also an extra foundation was needed in order to carry both the installations and the balconies. The size and weight of the installations are not just a problem for this specific project. With the increased focus on sustainability this will be a problem in future projects as well. *(Oettinger, G.H. 2012)*

..to renovate a post-war..

Currently in the Netherlands there are almost 7.7 million dwellings.*(CBS, 2017)* Around 1/3 of these buildings have been built between 1946 and 1970.*(See figure 1.1)* In this research project buildings of this time period are referred to as post-war buildings. Many of these buildings need to be renovated. Currently these renovations are done to bring the buildings to the current building standards. *(Brinksma, H. 2017, p. 35)* This means a decrease in energy use and upgrading to a high energy label. Before the renovation they have a high energy use and a D-label or lower. *(Building-Performance-institute-Europe., 2015)*

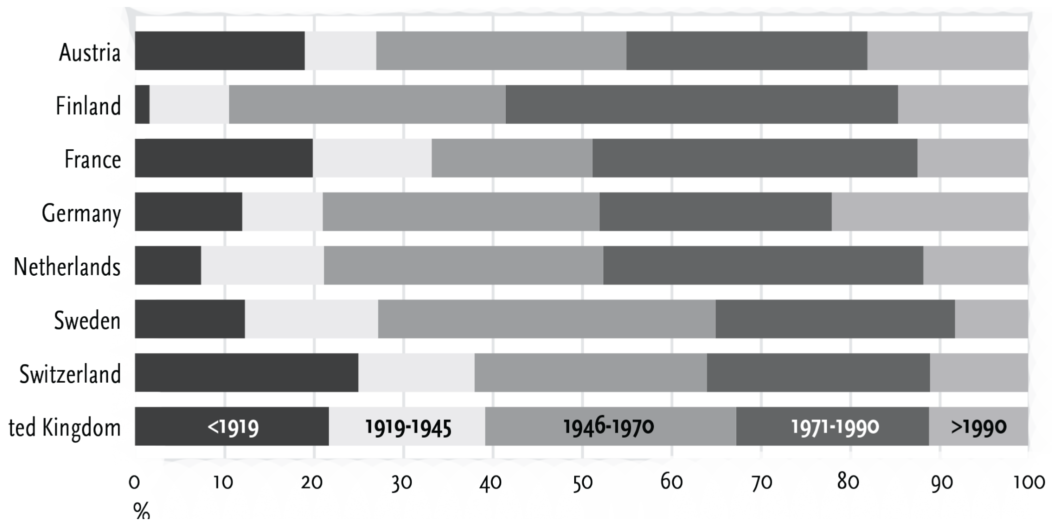


Figure 1.1: Building time of current building stock (Itard,L. 2008)

But there is a growing interest in future proof renovations. The needs of the users change over time and the building standard becomes higher. *(Brinksma, 2017, p. 35) (2.1.1 Climate change)* For this reason the renovation will not just look to ensure the needs of the current users, but also the possible needs and building standards in the coming years.

..porch house..

Often for zero-energy renovations, the new installations are placed in a technical room or a storage space like an attic or garage. For multistory buildings there usually is a technical room in the building, that has enough space for the new installations. For terraced houses and (Semi-)detached houses there is usually a garage or attic. But in porch houses there is very limited storage space to begin with. Sometimes there is no garage or attic available. Or there is an attic but there is no access to it, or it has a very low ceiling height, which is the case in the demonstrator project.

During the post-war time period different houses were built. Table 1.1 gives an overview of how many of the different types of houses were built during this time. Many of those houses where terraced houses. But porch houses are the second most built type. Since porch houses have less space than terraced houses it's more challenging to place the installations in a way that doesn't take up valuable space. Also, a solution that is suited for a porch house can potentially upscaled to bigger houses.

House type	1946-1964	1965-1974	Total
Terraced houses	478000	606000	1084000
Porch houses	267000	112000	379000
Detached houses	225000	119000	344000
Semi-Detached houses	145000	142000	287000
Gallery houses	64000	174000	238000
Apartment Buildings	50000	125000	175000
Maisonette	113000	22000	135000

Table 1.1: Housing types per building year. (Platform31, 2013)

Porch houses or a building containing porch houses is defined as having the following characteristics:

- Its low rise, meaning less than 10 floors. Usually around three floors.*(Kadaster, 2016*)
- The front door of every house is accessible from a common staircase. This staircase is traditionally designed with an open access to the street.
- There is often more than one staircase in a building.
- The spaces within one porch house are all on the same floor.

.. in accordance with the 2ndskin approach..

The 2ndskin approach focuses on the zero-energy renovation of social housing. Out of the post-war buildings almost half of them are in the social housing sector (1.3 million) *(Platform31, 2013)*

Renovating within this sector brings its own set of challenges. One of the challenges is the finance of the renovation. Who is going to pay for it, the owner or the residents of the building? In order to solve this problem, the Dutch government introduced the energy performance fee *(Energy prestatievergoeding, EPV)*. The conditions this fee comes with are explained in 1.3 Boundary conditions. One of these conditions is that at least 70% of the residents must agree to the renovation. *(Rijksoverheid, 2017)*

This condition ties into the 2nskin approach. 2ndskin puts a lot of emphasis on the acceptance from both the residents as well as the owner. One of the main challenges in the way of achieving user acceptance is the nuisance of building. When the building time on site is kept as short as possible and the residents can stay in their houses during the process, user acceptance increases. *(Guerra Santin, 2015, p. 3)*

1.2 Aim, objectives & Reseach questions

The problem statement leads to the overall aim of the project:

To make a design proposal on how the installations can be more efficiently integrated into the 2ndskin renovation of a porch house.

This overall aim is broken down into the following objectives:

- To create an overview of the current and the future state of the Dutch and European regulations and their impact on the design possibilities and the credibility of the available data.
- To understand the different kinds of installations and the possibilities and challenges they bring with them.
- To research installation systems, in order to determine the current state of innovation and future possibilities.
- To research the possibilities to integrate the installations without the need of an extra foundation.
- To make a design proposal as a representation of the possibilities found within the research project.
- The aim of the design proposal is to present an idea of what is possible within the set limits of this thesis in a way that it can be used as a basis for further development
- To make a design proposal to integrate the installations in a way that is smaller and lighter than the reference project.

These objectives lead to the following research questions:

- How to counter climate change within the built environment?
- What are the current and future Dutch and European regulations around sustainable building installations?
- What does the energy label say about the installation and how valid is this information?
- How do heat pumps work and how are they used?
- What are current innovations in sustainable building installations?
- How do these innovations compare?
- What can we learn from these installations?
- How can this be translated into an integrated installation concept for 2ndskin?

All these questions will lead to the answer to the main research question:

How can the installations be more efficiently integrated into an 2ndskin porch house renovation?

1.3 Boundary conditions

In order to make a design proposal as an answer to the research question, this design needs to meet certain requirements. These requirements come from the same basis as the problem statement. One of the aims of the design proposal is to show a possible improvement on the demonstrator project of the 2ndskin approach. This aim directly translates into the first requirement:

- The design proposal needs to show a possible improvement to the demonstrator project.

For all the parts where the design doesn't improve on this means that these need to be on the same level as the demonstrator project. Therefor the minimal requirements for the design proposal are:

- The system needs to be able to deliver a minimal heat demand of 30 kWh/m^2/yr. For future scalability of the project delivering a heat demand of 50 kWh/m^2/yr. should be possible, with the same design principles.
- The facade used in the design proposal has a maximum infiltration of 0,3 dm^3/s.m^2.
- The facade elements have a U-value of 0,16 W/Km^2 and a minimal RC-value of 6
- The roof, the windows and the ground floor used in the reference project will stay the same in the design proposal
- The total size needed by the integrated installations, of the final design proposal should in total be smaller than the installations in the reference project. This includes the empty spaces and outside covering.
- The weight of the design integrated installations including the covering of the final design proposal should be lighter than the installations and covering in the demonstrator project.
- The electricity demand of the installations can increase a little but the solar panels of the 2ndskin project need to still be able to provide the needed electricity. The current energy demand for the installation systems is 840 kWh per house, with a reserve of 466 kWh per house.

In order to keep the renovation financially attractive for the owner of the building the requirements of the energy performance fee (energyprestatievergoeding, EPV) need to be met. With this fee the owner can ask a compensation from the resident for the renovation. The owner can only ask this when at least 70% of the residents agree to the renovation. (Rijksoverheid, 2017) (Rijksoverheid, 2017) The resident can in his turn expect the certain standards from the renovation. These standards translate to the following requirements for the design proposal of this project:

- The building needs to be well insulated
- The maximum heat demand is less the 50 kWh/m^2 per year. The height of the heat demand determines the height of the EPV. A lower heat demand results in a higher fee.
- Next to providing the heat demand, the building should also provide a minimum of 15 kWh/m^2 of tap water.

- The building produces enough energy for the building bound installations. Building bound installations are: ventilation systems, cooling/ heating systems and system for monitoring etc. On top of this the building installations need to provide 26 kWh/m^2 extra for the resident. This term has a minimum of 1800 kWh and a maximum of 2600 kWh
- Every individual house has their own monitoring system *(Rijksoverheid, 2017)*

When looking at an satisfaction survey done for the Ministry of Internal Affairs and Kingdom Relations on how residents look back on a renovation with EPV, a view points come up. One of the main negative points was the amount of sound the installations make. *(Jong, F.d.& Boger, B. 2018)* For this thesis the production of sound and the insulation of sound will be taken into an account. An other point this survey makes is the complained about the noice of having a building site around the house.

Next to for filling the requirements set by the demonstrator project and the EPV the design proposal also needs to take into an account the aims from the 2ndskin project:

- The residents need to be able to stay in their homes during the renovation. They cannot stay without heating or warm water;
- The work on site should be reduced as much as possible.
- The old building installations should still work until the transition to the new building services;
- The living situation during the renovation should be safe for the residents.
- Work inside the houses needs to be limited. In order to do this the and to preserve space inside, the number of added pipes and installations inside the house should be minimized.
- Maintenance to the installations should preferably be possible from the outside;
- 2ndskin has the aim to upscale the project other building types. Where possible, this should be taken into an account.
- Even though circularity is one of the points to in proof on within the 2ndskin project this will not be a priority within this project.

1.4 Structure of the paper

This paper consists of 6 chapters. Each chapter has its own overall theme and looks at specific objectives in order to answer certain sub-research questions.

Chapter 2: The regulations
In order to stimulate sustainability in the building sector, there are a lot of regulations in place by both the European Union as well as the Dutch government. This chapter gives an inside into: how regulations have changed over the years, what regulations are in place now and what they are going to be after 2020. This will be the first part of this chapter. The second part of the chapter will focus on specific requirements that come from these regulations. Further research will be done on how these requirements are measured and how reliable the numbers are.

Objectives of this chapter:
- To create an overview of the current and the future state of the Dutch and European regulations and their impact on the design possibilities and the credibility of the available data.

Questions answered in this chapter:
- How to counter climate change within the build environment?
- What are the current and future Dutch and European regulations around sustainable building installations?
- What does the energy label say about the installation and how valid is this information

Chapter 3: Current state of innovation
Before looking at other innovative systems a basic knowledge is required about how the individual installations work. This chapter will mostly focus on the working of the heat pump.

Objectives of this chapter:
- To understand the different kinds of installations and the possibilities and challenges they bring with them.
- To research installation systems, in order to determine the current state of innovation and future possibilities.
- To research the possibilities to integrate the installations without the need of an extra foundation.

Questions answered in this chapter:
- How do heat pumps work and how are they used?
- What are current innovations in zero-energy building services?

Chapter 4: Analysis of comparable systems
With an understanding of the requirements and the basic designs of the installations as basis, new innovative systems will be analyses. These systems will be compared with the installation system that is currently installed in the 2ndskin project. The focus of this analysis will lay on learning what is possible right now and in the future.

Objectives of this chapter:
- To research installation systems, in order to determine the current state of innovation and future possibilities.
- To research the possibilities to integrate the installations without the need of an extra foundation.

Questions answered in this chapter:
- How do these innovations compare?
- What can we learn from these installations?

Chapter 5: The design proposal
This chapter builds on the answers found in the previous systems and uses these to make a design proposal. First a final system will be chosen based on the previous chapters.

Then the design proposal is presented. An explanation will be given on how the design came together and where the inspiration of the final design came from.

Objectives of this chapter:
- To make a design proposal as a representation of the possibilities found within the research project.
- The aim of the design proposal is to present an idea of what is possible within the set limits of this thesis in a way that it can be used as a basis for further development
- To make a design proposal to integrate the installations in a way that is smaller and lighter than the reference project.

Questions answered in this chapter:
- How can this be translated into an integrated installation concept for 2ndskin?

Conclusion
The conclusion will sum up the answer to the research question: *How can the installations be more efficiently integrated into an 2ndskin porch house renovation?*

2
Regulations

2.1 European regulations

2.1.1 Climate change

The problem of climate change has been gaining attention in the recent years. Many scientists study the causes and solutions. One of the main causes of it are the greenhouse gas emissions. These emissions increase the concentration of CO2 in the atmosphere. These higher concentrations increase global warming and cause climate change. *(Grammelis, 2016)*

In order to counter this the European union has set targets for 2020 to: reduce the greenhouse gas emissions, increase the use of renewable energy and improve the efficiency. *(European Environment Agency, 2017)*The goal is to improve all of these by 20% in comparison to 1990. The Member States and the European Environment Agency (EEA) have estimated in 2016 that these targets will be reached by the Member States if the current trend continues. But new goals have been set for 2030 and 2050. For 2030 the targets are:

- 40% reduction of greenhouse gas emissions
- 27% increase of use of renewable energy resources.
- 30% improvement of energy efficiency *(European Environment Agency, 2017)*

All these goals are compared with the levels of 1990. For 2050 are the targets 1,5 to 2 as high as 2030. For example, the greenhouse gas emissions need to be reduced by 80% in comparison to 1990. *(European Environment Agency, 2017)*

In reduction of greenhouse gas, the Netherlands does quiet well but in the other two area the Netherlands was lacking behind in 2015, and although it's on track for 2020 now it needs to step up to meet the 2030 and 2050 goals. In the figure 2.1 the needed reduction in green gas emissions from different industries are plotted against the time. Also, the trend of the current policy is illustrated in this figure. This trend clearly illustrates that in order to meet the targets changes need to be made. One of the industries that needs to make changes is the residential industry. From producing 18% of all the gas emissions they need to go to a maximum of 2% in comparison to the total emissions in 1990. *(European Environment Agency, 2017)*

In order to achieve this the European Commission, suggest that current approaches need to be implemented faster and on a broader range. Both new and existing building need to be made more efficient when it comes to energy use. Preferably both residential as non-residential buildings should produce more energy than they need. *(European Environment Agency, 2017)* In order to achieve this most of the energy used in 2050 needs to be renewable energy. But currently these technologies are still very expensive. Further development needs to make these installations more cost efficient and design with the consumer in mind. *(Oettinger, G.H, 2012)* In order to reach the zero-energy goal the consumer needs to be able to understand and control his energy use. Because when the user understands the installations and energy use, he can further decrease his consumption *(Guerra Santin, 2015)*

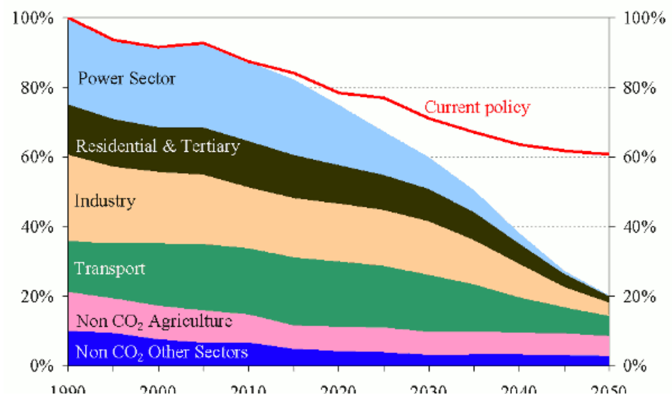


Figure 2.1: Needed Reduction Green house gases (European Environment Agency, 2017)

2.1.2 Regulations by the European Union

As a reaction to climate change many regulations have been made. Not just on a European level but also on a National level. On European level the European Commission put out the: Energy Performance of Building Directive (EPBD) and the Energy Efficiency Directive. The EPBD states that:

- All new buildings from 31 December onward must be nearly zero-energy
- All public buildings need to be zero-energy from 31 December 2018;
- When a building is being sold or rented an Energy Performance certificate (Energy label) must be issued. This certificate must also be included in all advertisements for the sale or rental of the building;
- The heating and air conditioning systems need to be regularly inspected or other measures with equivalent effect need to be taken. The countries are responsible for establishing this themselves;
- The EU countries must set a minimum energy performance requirement for new buildings, major renovations and the replacement of building elements. All these requirements should be set at a cost-optimal level;
- There must be a national list of financial measures for the improvement of the energy efficiency of buildings. *(European-Commission, 2018a)*

In November 2016 and in June 2018 the following updates where added to this directive

- Smart Technologies need to be further promoted.
- The national energy performance requirements need to be expressed in a way that allows for cross-national comparisons
- The health and well-being of the building users will be promoted.
- Countries need to have stronger long-term renovation strategies. These strategies need to aim at decarbonizing the national building stock by 2050. This strategy needs to have a solid financial component
- For the rating of the smart readiness of buildings, a common European scheme will be introduced. *(European Commission, 2018a)*

Besides the EPBD the European Commission also has the Energy Efficiency Directive for the building sector:

- For renovations in EU countries at least 3% of the total floor area of a building owned and occupied by a central government must be energy efficient
- Any building purchased by an EU government should be highly energy efficient
- The EU countries must make long-term plans to renovate national buildings. These plans can be included in their National Energy Efficiency Action Plans. *(European Commission, 2018a)*

2.2 Dutch regulations

Some of the regulations set by the EU were already in place in the Netherlands at the time. But some still needed to be added to the regulations. All the regulations were added to the Dutch regulations in November 2015. *(Ministerie-van-Wonen-en-Rijksdienst, 2015)*

2.2.1 EPN

Before the EPBD was fully formulated the Netherlands already had the Energy Performance Norm (Energieprestatienorm, EPN) *(Agentschap NL Energie en Klimaat, 2010)* This norm has been active from 1995. The norm was separated over two NEN-norms, NEN 5128 and NEN 2916. NEN 5128 was for the Energy Performance Housing *(Energieprestatie Woningbouw, EPW)* and the NEN 2916 for the Energy Performance Utility Buildings (Energieprestatie Utiliteitsbouw, EPU). *(Agentschap NL Energie en Klimaat, 2010)*

This norm provides the first version of the terms, definitions and the EPC method. The Energy Performance Coefficient (EPC) gives an inside into the performance of the building. In December of 1995 an EPC-value of 1.4 was required for all new build buildings by the building regulations. This number was set for the building sector to get used to the EPC. After two years the value was lowered to 1.2 and in 2000 it was 1.0. This number continues to get lower. In 2012 the EPN got replaced by the EPG. At this time the EPC is 0,6. By the time the BENG regulation will be introduced the EPC should be 0,0.

2.2.2. EPG

In 2012 the EPN was replaced by the Energy Performance Buildings. (Energie performance gebouwen, EPG) in this norm both the housing and the utility sectors are represented. The NEN 5128 and NEN 2916 are replaced by the NEN 7120.

2.2.3 BENG

In 2020 the EPC will be replaced by the three BENG requirements. BENG stands for: Almost Energy Neutral.*(Rijksdienst-voor-ondernemend-Nederland, 2018)*

The BENG divides the basis of the EPC in three parts: the BENG 1,2 and 3. The requirements set for these BENGs are different for Residential buildings, Utility buildings, Hospitals and schools.

BENG 1 Is about the building bound energy demand. The building bound energy demand is the energy needed to heat and cool the building. This demand is dependent of the materials used build the building and how the building is orientated. The demand is provided by the heating and cooling systems of the building. For utility buildings the energy use for lighting is also added to this. The maximum energy use for building bound installations for residential building is set on 25 kWh/m^2 per year. for industry buildings this is 50 kWh/m^2.

BENG 2 is about how much primary fossil fuel the building uses in order to produce the required energy. If the building also uses renewable energy this can be subtracted from the primary fossil fuel. The BENG 2 is depended on the building installations. The maximum primary fossil energy use is 25 kWh/m^2 per year.

BENG 3 concerns the percentage of renewable

$$\text{Percentage renewable energy} = \frac{\text{Renewable energy}}{\text{Primary fossel fuel} - \text{renewable energy}} \times 100\%$$

energy. This percentage is calculated the following way:

The renewable energy is not just the energy out of solar panels and wind energy. but also, the energy won by heat pumps or biomass heaters minus their electricity use. The minimum percentage for BENG 3 is 50%. *(Rijksdienst-voor-ondernemend-Nederland, 2018)*

In 2020 the NEN 7120 will expire and be replaced by the NTA 8800. Currently all the calculations needed to calculate the three BENGs are still heavily based on the NEN 7120. But in 2020 there will be a calculation method introduced in the NTA 8800. How much this is like the calculation method in the NEN 7120 is still unknown. *(Rijksdienst voor ondernemend-Nederland, 2018)*

2.2.4 Saldering

Since 2004 the 1998 electricity law makes it possible to deliver renewable energy to the electricity net. The law states that the company in charge of the net in that region is obligated to take that renewable energy. Over the period of a year amount of energy that is delivered to the net is subtracted from the amount of energy used from the net. If there is more energy used, then delivered the user pays the company for the difference. If there is more energy delivered, then used the company gives a compensation to the user. The height of the compensations differs per company. There are no regulations in place that state the height of the compensation.

Initially there was a limit on how much renewable energy could be delivered back. in 2008 this limit was raised from 3000 kWh to 5000 kWh and in 2014 it became limitless. From that point in time the company is required to take all the renewable energy given to them and subtract this from the yearly use. *(Dutch ministery of Economics, 2016)*

In the 2016 evaluation of the saldering regulation by the Dutch ministry of Economics concludes that the regulation has had a positive influence on the growth of the production of renewable energy. But the saldering regulation has turned out to be a costly instrument achieve this growth. For this reason, the government wants to replace this regulation. *(Dutch-ministery-of-Economics, 2016)*

The replacement will come in the form of the subsidy: stimulating sustainable energy production. What this subsidy means for the residential building stock is still unclear. But the government still wants to make it possible to earn back the investment in renewable energy in around 7 years. Without the salderings regulations or any replacement subsidy, the earning back time is between the 13 and 22 years. *(Dutch ministry of Economics, 2016)*

The exact time that the saldering will stop to exists is still under debate. it will probably happen between 2020 and 2023. The consequences of this new subsidy are still a bit uncertain because the regulation isn't clear yet.

2.2.5. Energy label

2.2.5.1 Energy label for housing

In 2008 under the EPN regulations an energy label is required or new buildings, and the selling and renting of houses. The 2010 European Energy Performance of Building Directive (EPBD) also make an Energy Performance Certificate required for buildings. *(European Commission, 2018)* In 2015 the requirements of the EPBD where fully added to the Dutch regulations. *(Eck, H.v., 2016)*

Some buildings are excluded from the Dutch requirement. The kind of buildings that are required to have an energy label according to the government are: Houses and apartments, caravans meant for permanent use, recreational houses that are used more than 4 months out of the year or ones that are expected to have more than 25% of the consumption in permanent use, Buildings with non-individual living spaces. These buildings will be considered one building. *(Rijksoverheid, (n.d.)-b)*

The energy label is based on the following characteristics of the house:

- House type
- House subtype
- Building year
- Living area
- Glazing in living area
- Glazing in bedroom
- Insulation within the facade
- Insulation in the roof
- Heating system
- Hot water system
- Ventilation system
- Solar boiler
- Solar panels

The Energy Label goes from A until G and can only be given out by a certified person. *(Rijksoverheid, (n.d.)-a)* With this certificate an Energy Presentation Advise is given. This document gives a list of possible measurements that can be implemented in order to improve the energy label. *(Rijksoverheid, (n.d.)-a)*

2.2.5.2 Energy label for building installations

Next to energy label for houses also labels are given to installations. These labels are required by the European union under the Energy Performance of Building Directive (EPBD). *(European-Commission, 2018a)* The information these labels display is determined by the European regulations.*(European-Commission, 2018b)* The top part is the same for all labels. The European flag and the blue label show that its and energy label according to the regulations of the European Union. Under this, the name of the company is written, as well as the name of the product.*(European-Commission, (n.d.)*

The required information differs per type of installation. But every product will display the energy efficiency label. Some have a range from A until G. Others also include A+ up to A+++. The energy efficiency label is based on the SEC, the specific energy use class. *(European-Commission, 2013b)*

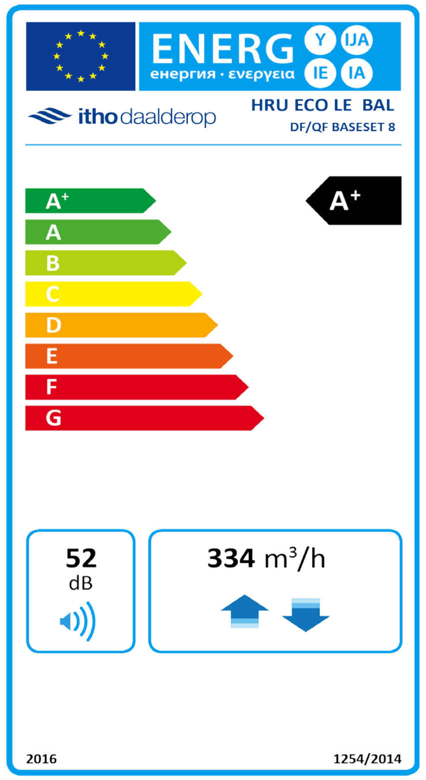


Figure 2.2 Energy label of an heat recovery ventilation unit (Itho daalderop)

Ventilation systems
The labeling of ventilation systems is done under the Energy Labeling Directive 2010/30/EC. Under this regulation the European Commission has published regulation No 1254/2014 for residential ventilation units. The regulation applies to ventilation system with a power input higher than 30 W. *(European Commission, 2014)*

On the energy label of a ventilation system there are two numbers. The left number is the sound level that is produced by the ventilation unit. Since the sound level is usually above 30 dB the installation cannot be placed in a living space. The Dutch building codes describe that the allowed installation noise inside of a living space cannot be higher than 30 db.

The other number is the maximum flow rate from the system in m3/h. Below the flow rate there are one or two arrows. One arrow means that the airflow is only in one direction. Two arrows mean that the air flow goes in two directions. So, both in input air as well as the output air go through the system.

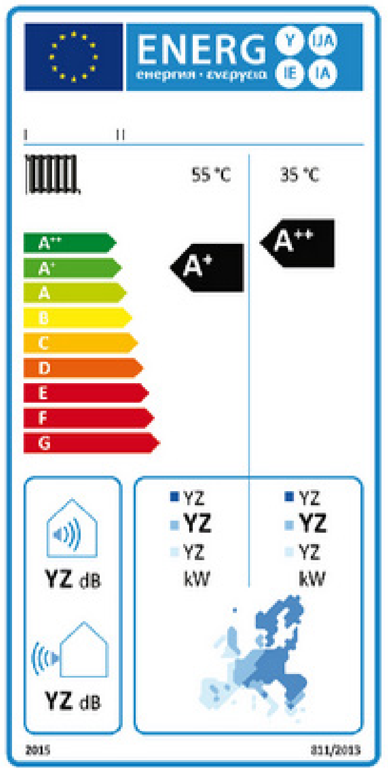


Figure 2.3 Energy label Heat pump (heating) (European commission, retrieved from Energylabel.nl)

Heat pumps
The labeling of space heaters and combination heaters is done under the Energy Labeling Directive 2010/30/EC. Under this regulation the European commission has published regulation No 811/2013. The energy label is mandatory for heaters under the 70 kW. This includes a big part of residential heaters. *(European-Commission, 2013a)*

Under the manufactures name and the product name there will be one or two icons. An icon that look like a tap symbolizes the hot tap water. This symbol is accompanied by a letter, usually an M, L or XL, this letter reverses to the load capacity of the system. The energy efficiency beneath this imply how energy efficient the water is heated.

The icon that looks like a heating element implies that the energy efficiency label below it applies to the heating efficiency of the installations. The heating is usually accompanied by a 350ºC, 550ºC or both. The 350ºC stands for low-temperature heating and 550ºC medium-temperature heating.

In the bottom left there are two sound level indications. The one on top is the sound level from the inside unit of the heat pump. Below that is the sound level of the outside unit. Sometimes one of the levels is not given. Usually this means that the installation doesn't have a separate inside/outside unit.

2.2.5.5 SCOP

In the right bottom corner of the energy label of the heat pump, the Seasonal coefficient of performance (SCOP) values are given. The SCOP is the overall coefficient of a heating installation for a specific heating season calculated with the reference yearly heating demand divided by the yearly energy use. *(European Commission, 2016)*

These values always come with a map of Europe. This map represents the three different seasons in Europe where the SCOP is based on. The climate seasons are divided in:

- Warmer climate conditions;
- Average climate conditions;
- Colder climate conditions. *(Calero-Pastor, M. 2017. P. 8)*

These different climate conditions are based on the temperature and solar radiance conditions that are characteristic for the three cities were the different climates are based on. The warmer climate conditions are based on the characteristics of Athens, for the average climate conditions this is Strasbourg and for the colder climate conditions it's Helsinki. *(Calero-Pastor, M. 2017. P. 8)*

These climate conditions correspond with reference design conditions as can be seen in table 2.1. This table shows the reference design conditions for a system with a heat pump. The first table will give the reference temperature for designing the heat pump in the specific season. The second column show the bivalent temperature. The bivalent temperature is the temperature where the maximum capacity of the heat pump is reached. The bivalent temperature is not allowed to be higher than the given temperature in the table for the climate where this installation is installed in. The last column shows the operational limit temperature. This is the lowest temperature at which the heat pump can still produce. Below this temperature the capacity of the heat pump is 0°C. *(European Commission, 2016)*

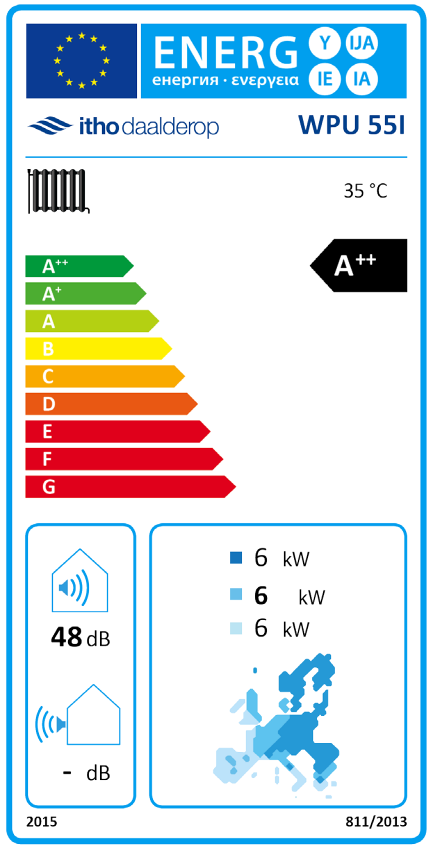


Figure 2.4 Energy label

Climate condition	Reference design temperature	Bivalent temperature	Operation limit temperature
	Tdesignh	T_{biv}	TOL
Average	− 10 (− 11) °C	maximum + 2 °C	maximum − 7 °C
Colder	− 22 (− 23) °C	maximum − 7 °C	maximum − 15 °C
Warmer	+ 2 (+ 1) °C	maximum + 7 °C	maximum + 2 °C

Table 2.1: reference design conditions (European Commission, 2016)

Next to determining the climate conditions and designing according to the reference design conditions. The SCOP is partly calculated based on the calculations of the specific heat loads and the specific efficiency at specific outdoor temperatures. These specific temperatures are set on -7°C, +2°C, +7°C and +12°C for the outside. For all these temperatures the declared capacity and the energy efficiency ratio for the part load need to be calculated with an indoor temperature of 20°C. *(European Commission, 2016)*

Next to this the SCOP is also dependent on:

- The kind of heat pump;
- High or low temperature heating;
- Humidity of the climate;
- Domestic water operational limit temperature;
- Supplementary heater output;
- The kind of energy input of the supplementary heater;
- The amount of energy input of the supplementary heater;
- In case of air heat pumps: the air flow rate outside;
- in case of a ground heat pump: the water flow rate in the outside heat exchanger;
- The kind of coolant used in the heat exchangers;
- The electricity or fuel consumption of the heat pump;
- The efficiency losses in the system.
- The efficiency of the separate elements of the heat pump like the compressor. *(European-Commission, 2016)*

Depending on the focus of the manufacturer the SCOP values will differ. If the heat pump is optimized for one climate the SCOP values for the other climates might be lower. Based on the basic working of a heat pump *(See 3.1.1 Basic working heat pump)* one would expect that especially an air heat pump would have a lower SCOP for colder climates. But because the SCOP takes into an account so many aspects like the secondary heater, kinds of energy use, efficiency etc. The SCOP are in same cases the same or even higher in colder climates. Because of the complexity of the SCOP the values will be used to choose the best installation for the reference project but the different values for the different systems/climates will not be further analyzed.

In order to evaluate if the SCOP of a specific product that comes on the market is correct the member states authorities of the European union shall test a single unit. *(European-Commission, 2013a, p. 182)* The authorities have appointed a notified body to oversee these tests. *(European-Commission, 2018b, p. 42)*
The values declared by the manufacturer must meet the requirements set by annex 2 of the Commission Regulation (EU) No 814/2013. If the tested values measured do not meet the parameters measured by the manufacturer, there will three additional units tested. if all units fail the test the results and all relevant information will be send to the other member states and the European Commission and a decision will be taken on the non-compliance of the model. *(European-Commission, 2013a, p. 182)*

2.3 Conclusion

Regulations in order to reduce greenhouse gas emissions, increase of use of renewable energy resources, improvement of energy efficiency have been made by both the European commission as well as the Dutch government.

These regulations have evolved over the year and are getting stricter. Goals are set for 2020, 2030 and 2050. But the exact requirements from 2020 onward aren't very defined and there are still many discussions about these requirements

The energy label is one of the results of current regulations. The label is required for both houses as well as individual installations. The information on the labels differs per category. Depending on where the label is for certain information is required.

One overall requirement is the energy efficiency label (A (+++) t/m G) this energy efficiency is based on the COP value of the product. The COP shows how efficient the installations uses electricity.

For the heat pump the SCOP indications is required. The SCOP gives the Seasonal COP based on three areas. The SCOP is dependent on many different properties of the heat pump. This explains why the SCOP can differ for every area. In order to ensure the correctness of the SCOP value a single unit is tested. If the units meet the values set by the manufacturer then the test is positive. If the values are off the installations could be taken out of the market.

3
Current state of innovation

3.1 Functioning of the installations

3.1. The Heat pump
Some of the basic challenges and limits of heat pumps come from how the heat pump works. In order to explain these challenges and limits, a basic understanding of the system is needed.

3.1.1 A basic heat pump
The heat pump works with a refrigerant. The temperature from the source will be guided into the heat exchanger. The source can be air or water dependent in the kind of heat pump. Because of the temperature difference of the refrigerant and the source medium, the refrigerant in the heat exchanger will evaporate.
The refrigerant will then be put under pressure by the compressor and let into another heat exchanger. Because of the pressure the temperature of the coolant rises. In the heat exchanger the refrigerant gives of this heat to the heat circulation system of the building. During the process of cooling down, the refrigerant returns to a liquid state. The pressure is taken off this liquid by an expansion valve and then let into the first heat exchanger again.
(Leijendeckers, Fortuin, & Herwijnen, 2000, p. G2/6-7)

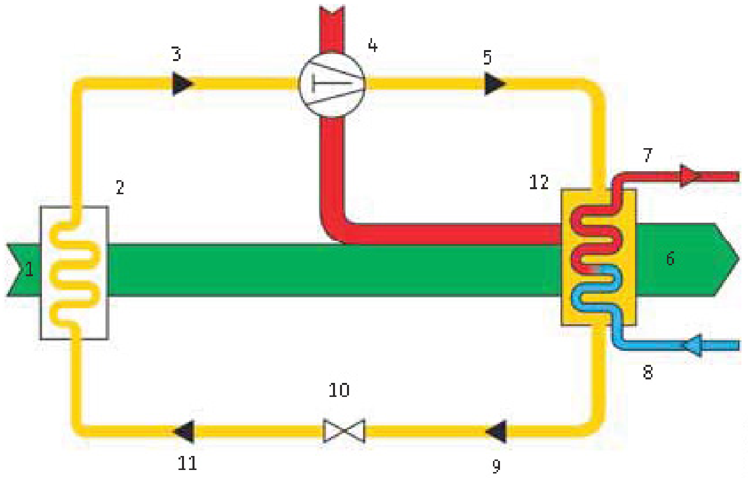


Figure 3.1: Circulation principle heat pump (Stiebel Eltron, p. 8)

3.1.2 Types of heat pumps
There are different kinds of heat pumps, examples are:

1. Air heat pumps;
2. Water heat pump with open source;
3. Water heat pump with closed loops;
4. Water heat pump with geothermal probe.

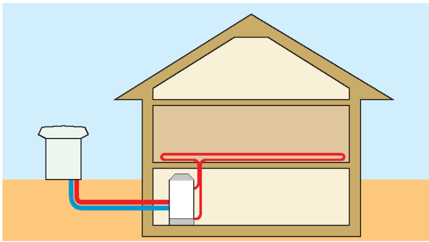


Figure 3.2.1: Air heat pump (Stiebel Eltron, p 8-9)

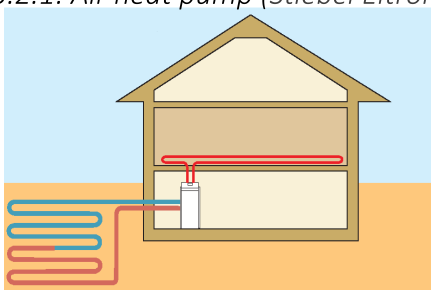


Figure 3.2.3: Heat pump with closed loops(Stiebel Eltron, p 8-9)

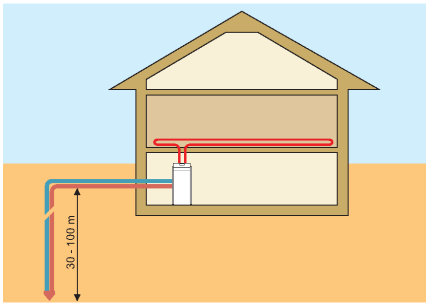


Figure 3.2.4: heat pump with geothermal probe(Stiebel Eltron, p 8-9)

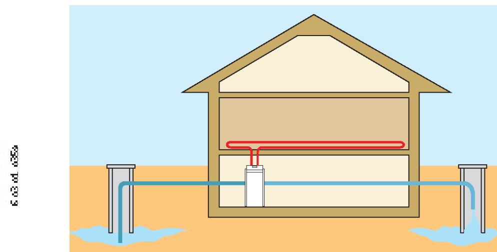


Figure 3.2.2: Heat pump with open source (Stiebel Eltron, p 8-9)

3.1.1.3 The source
The main difference for the different kinds of heat pumps is the heat source. These sources come with different challenges. With an air heat pump there is the risk of frosting. In order to transfer heat in the heat exchanger, there needs to be a temperature difference. The refrigerant always needs to be a few degrees cooler then the outside air. When the air starts to approach 0°C frosting starts to form on the heat exchanger because the refrigerant has a lower temperature than 0 °C. *(Berghmans, 2012, p 284)* In order to keep the system working effectively the frost must be melted away. (Leijendeckers, Fortuin, & Herwijnen, 2000) There are different ways to do this. Examples are: using an electric heater or letting the system run backward. The problem with the last one is that it uses the temperature of the central heating system to defrost the heat pump. In the meantime, there is a heat demand because of the cold outside temperature. The other option deceases the efficiency of the heat pump because this increases the yearly electricity use. *(Stiebel-Eltron, 2012)*

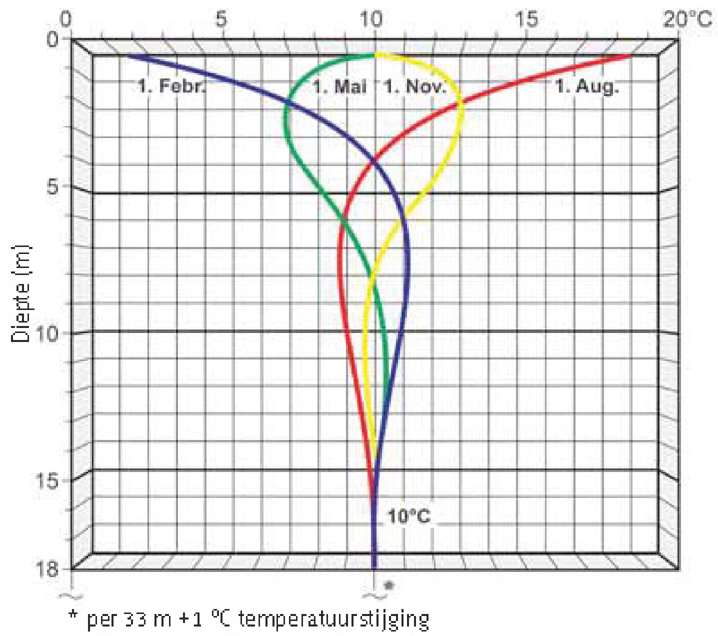


Figure 3.3: Temperature in the ground (Stiebel Eltron, p. 31)

Water heat pumps don't have this problem. The lower in the ground the heat is extracted from the more consistent the temperature becomes. (Figure 3.3) But when it's hot or cold for a time period the temperature of the source gets closer and closer to the temperature of the refrigerant. When the temperature becomes the same as the refrigerant the heat pump doesn't cool or warm anymore, until the heat demand changes. *(Leijendeckers, Fortuin, & Herwijnen, 2000)*

3.1.1.4 Secondary heater
In some situations, the heat pump is the only heat source but sometimes an extra heat source is used in order to ensure that the heat demand is met. When there is no other heat source next to the heat pump, the installation is working monovalent. Monovalent is usually only an option with low temperature heating. It's not always the best option to have only the heat pump or there might be situations where the heat pump falls short by itself. in this case a second heater is used. *(Stiebel-Eltron, 2012)*

There are different ways to use the secondary heater. The secondary heater can work alongside the heat pump. In this situation the secondary heat pump turns on when the bivalent temperature is reached. The bivalent temperature (Tj) is the temperature where the maximal capacity of the heat pump equals the part load. If the temperature gets lower, then this point the secondary heater delivers the rest of the required load. The secondary heater can be different kinds of installations, even a gas heater. if a secondary heater is working with the heat pump this type of installation is called a Bivalent parallel installation. *(Berghmans, 2012)* If the secondary heater is integrated into the heat pump as an electric re-heater then the installation is a mono-energetic installation.

An installation can also be bivalent half-parallel. When the bivalent temperature is reached the secondary heater starts the work parallel to the heat pump. But when the switch point (TU) is reached the heat pump turns off completely and the secondary heater takes over. If the heat pump immediately turns off at the bivalent temperature, it's a bivalent-alternative installation. *(Stiebel-Eltron, 2012)*

How the heat pump works and how the heat load is provided influences the energy use and the efficiency of the system. The secondary system often uses more energy than the heat pump. Because of this the system will get a lower energy label and a lower SCOP rating. But at some temperatures the capacity of the heat pump can become so low that a secondary heater is a more sustainable solution. *(European Commission, 2016)*

Q_n: heating load
T_A: Outside Temperature
T_U: Switch off point
BV: Bivalent Temperature
WP: Heat load by heat pump
ZH: Heat load by secondary heater

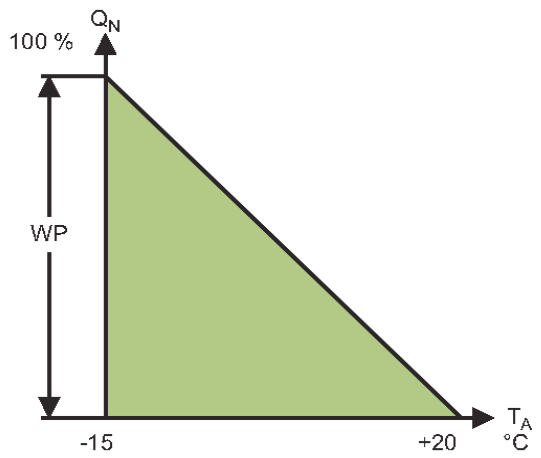


Figure 3.4.1: Monovalent (Stiebel Eltron, 2012, p. 10-11

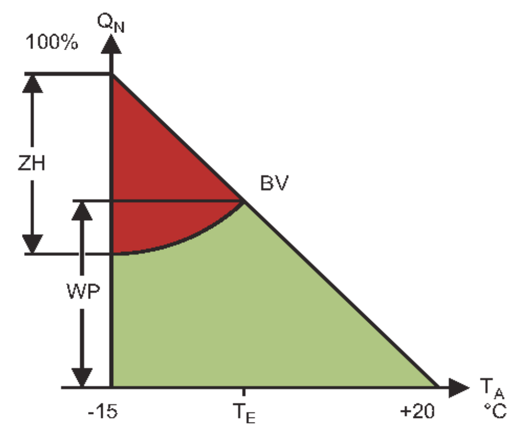


Figure 3.4.2: Mono-energetic/Bivalent-parallel (Stiebel Eltron,2012, p. 10-11

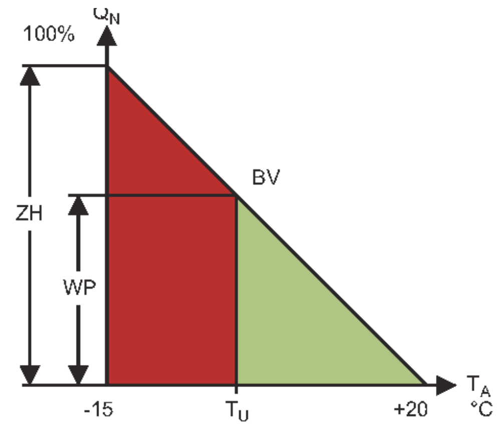


Figure 3.4.3: Bivalent-alternative (Stiebel Eltron, 2012, p. 10-11

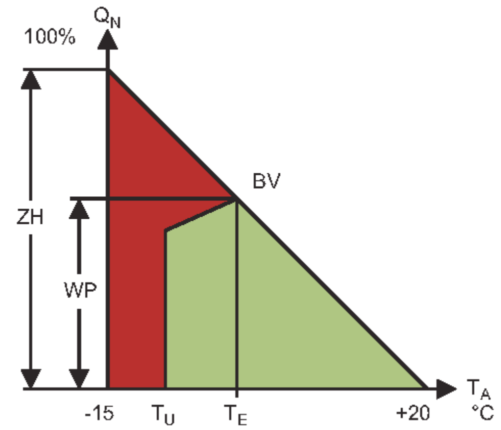


Figure 3.4.4: Bivalent half-parallel. (Stiebel Eltron, 2012, p. 10-11

3.1.1.5 COP

The COP states how much heat the system produces out of 1 kWh. For example, a heat pump with a COP of 6,44 produces 6,44 kWh heat out of 1 kWh electricity. Which basically means that the pump has an efficiency of 644%. The Sankey-diagram shows how this is possible:

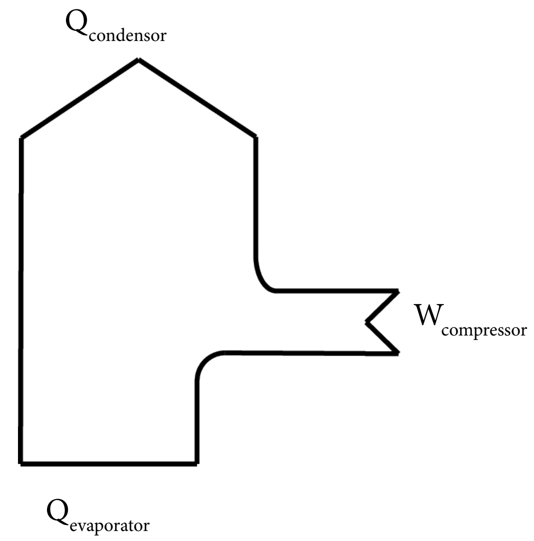


FIgure: 3.5 sankey diagram (Leijendeckers, Fortuin, & Herwijnen, 2000, p. G2/4)

At the evaporator (QV) the outside temperature is adapted into the system fluid. Then the compressor (Pc) brings fluid to a higher temperature. Finally, this heat is released at the condenser into the central heating system.

The Sankey-diagram is based on the first law of thermal dynamics:

Q = U2 - U1 + W

This law is the law of conservation of energy. this law states that no energy is ever lost only transformed. (Wisman, Meijer, & Bart, 1990) Based on this and the Sankey -diagram the COP can be calculated with the following formula:

$$COP = \frac{Q_c}{W}$$

(Leijendeckers, Fortuin, & Herwijnen, 2000, p. G2/5)

In this formula Qc is capacity of the condenser and W is the power compressor these two can be calculated with the following formulas:

$$W = \frac{m(h_4 - h_3)}{\eta_i * \eta_m}$$

Q = V * p *C *ΔT = m * (h4-h1)

V = Volume of the refrigerant
p = density
C = Specific heat
ΔT = Temperature difference in the condenser
m = mass of the fluid
h1, h3, h4 = Different stages of enthalpy
ηi= internal efficiency of the refrigerant
ηm= Mechanical efficiency of the compressor
U = internal energy
(Leijendeckers et al., 2000, p. G2/7)

These last three calculations give an insight into which properties determine the efficiency of the heat pump. The m, C, p, and ηi are all properties of the refrigerant. The mass and volume are dependent on the circulation system of the refrigerant. Also, the amount of refrigerant in the system is restricted by the European union by regulation No 517/2014. Many of the refrigerants used can be damaging for the environment when leaked. Certain refrigerants have been banned or restricted. *(Nederlandse Vereniging van Ondernemingen op het gebied van de Koudetechniek en Luchtbehandeling, 2015)*

The h1, h3, h4are dependent on the kind of refrigerant used and the ΔT. In order to better understand the correlation between these properties the pressure and enthalpy diagram of Mollier can be used. (See figure3.6) *(Leijendeckers, Fortuin, & Herwijnen, 2000, p. G2/2-G2/11)*

In the diagram on the y-axis is the pressure in bar and on the x-axis there is the enthalpy. The parabola symbolizes the saturated vapor line of the liquid. On the left side of this line is the area

where in the fluid is in its liquid state. On the right side of the parabola the fluid is in its gas state. The top point of the parabola is the critical point, above this point the refrigerant is in its gas state and does not become a liquid again.
Also, the temperature of the refrigerant is visualized in this diagram. Underneath the parabola the temperature line runs parallel to the enthalpy. But on the right side the temperature lines bow down. This is because the gas on the right side is overheated.

The entropy lines also change direction on the right side of the parabola. Underneath and on the left side the entropy lines are vertical and on the right side they are diagonal. The entropy value stands for the stability of the refrigerant. If the entropy value is consistent then there is no heat exchange.

The rectangle ABCD is the working area of the heat pump. Line AB represents the refrigerant going through the condenser. In the evaporator the refrigerant is heated an brought to a gas state using the temperature of the source. *(Leijendeckers, Fortuin, & Herwijnen, 2000, p. G2/2-G2/11)*

Between B and C, the gas is put under pressure by the compressor. Because of this the refrigerant will be brought to the desired temperature. The path between C and D represents the condenser. By exchanging the heat with the central heating system, the refrigerant in the system is cooled down and returned to a mostly liquid form. Then between D and A the pressure on the refrigerant is lowered by the expansion valve and then the circle begins again. *(Leijendeckers, Fortuin, & Herwijnen, 2000, p. G2/2-G2/11)*

In order to determine area ABCD the following information is needed:

- Amount of pressure increase by the compressor in bar.
- Amount of pressure decrease by the expansion valve
- Expected temperature difference in the condenser
- Expected temperature difference in the evaporator

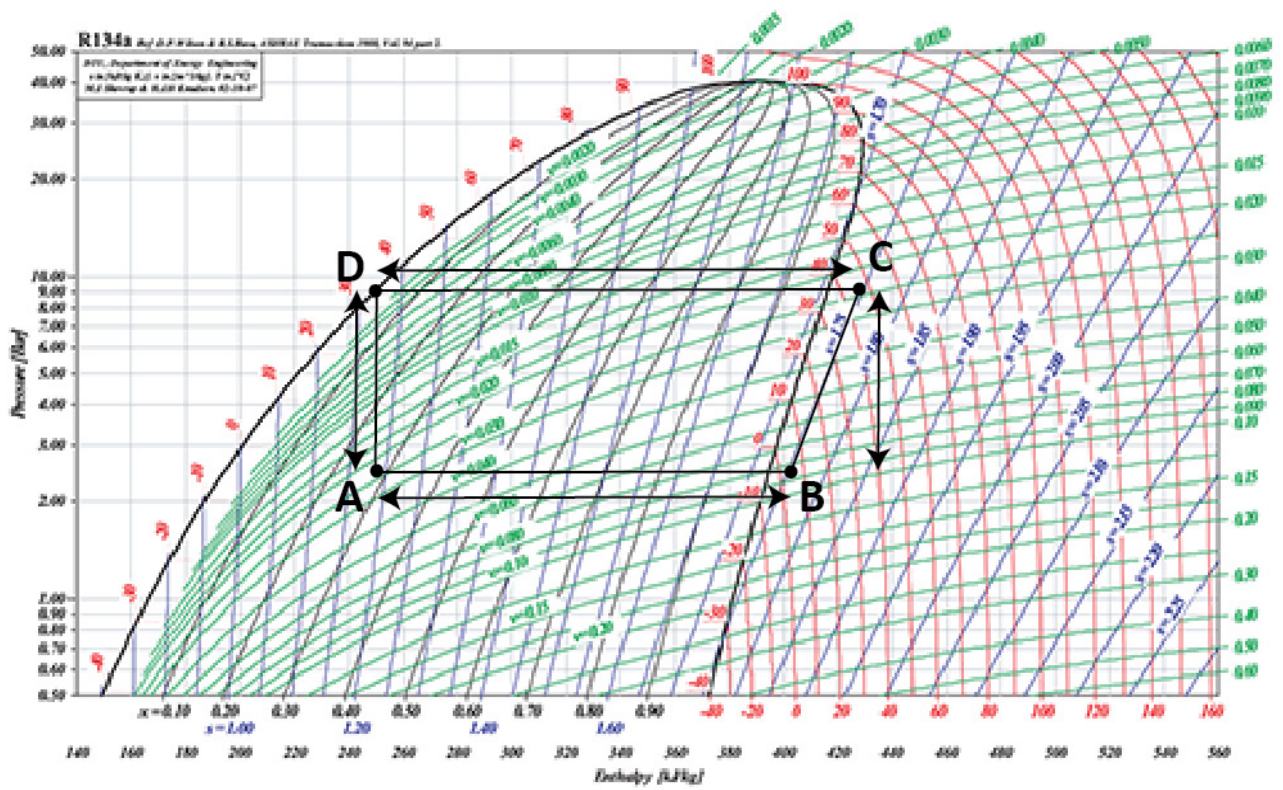


FIgure: 3.6 Pressure, Enthalpy diagram from Mollier (Leijendeckers, Fortuin, & Herwijnen, 2000, p. G2/2-G2/11)

All four of these properties are dependent on the temperature from the source and the temperature needed in the central heating system. If the central heating system works on a high temperature, then refrigerant in the condenser needs to be at even higher temperature. Because only with a temperature difference can heat exchange take place.
In figure 3.6 the refrigerant enters the compressor at a pressure level of 2,5 bar and a temperature of 5oC. In order to bring the refrigerant to a temperature of 450C while maintaining the entropy value the pressure needs to be increased to 9 bar. If the central heating system demands a higher temperature for example 65oC, but the starting temperature stays the same, then the pressure needs to be increased to 14 bar. The same reasoning applies with the temperature and pressure before the compressor. The lower the temperature and pressure are, the more pressure the compressor needs to add in order to deliver the demanded heating temperature.

If the temperature of the source is quite high and the demanded inside relatively low, then the compressor needs to deliver less pressure. This means that the compressor needs to deliver less work. Which results in a higher COP

3.2 Case Studies

In order to get an insight into the current state of innovation in sustainable systems, some different systems have been researched. The research has focused on what can be learned from these case studies and applied to the design proposal. The system that is currently installed in the 2ndskin project will also be taken into an account. The case studies that are looked at in this research are combinations that could possibility be used for the 2ndskin project. Sustainable installation concepts for porch houses are quite uncommon. In order to study cases that use sustainable installations in an innovative way, the research into the projects has not been limited to porch houses.

3.2.1 The companies
There are many companies that deliver sustainable installation systems. In order to find the case studies that are most useful to this research the specific case studies have been chosen by an elimination process.

First a selection has been made of companies that have installed installations in the Netherlands before and are thus familiar with the Dutch regulations. In order to determine this a list of companies that have received funds for sustainable installations in the Netherlands by the government has been used. This list consisted of 113 Companies. The entire list of companies can be found in the appendix of this paper.

In order to make sure that the companies could provide the information needed to determine the case studies that are interesting a second selection has been made. For this selection looked at the information provided by the companies on their website. In order to choose the most interesting cases to study basic information is needed. Therefore, research was done to determine if the website display at least the following information about the installations:

Has installed sustainable installations in the Netherlands before?	113 Companies
Clear product properties om there website	57 Companies
Has an clear zero energy installation concept	4 Companies

Table 3.1. *Choice of companies*

Specific products
Product properties:

- Size
- Weight
- Power
- Noise
- COP

Almost half of the companies did not display this information. Some didn't have any information other than that they sell heat pumps or ventilation systems. These specifications left a list of 57 Companies.

Within these 57 companies research has been done to find clear zero energy installation concepts. The final four concepts where all new sustainable installation concepts that could be used for a porch house and where the companies took care of both delivering the installations as well as placing them. These four are:

- The Energy module of Nathan
- The Energy Bar, Energy Top and the Roof-in from Nefit
- The Energy module of LG Climate Solutions
- The all-in-one LWZ modules of Stiebel Eltron

In order to get more information about these concepts these companies have been contacted for more information. Nathan did not give any response. Since the approaches of Nathan and LG are very similar Nathan has not been included in the case study.

After further research the project of the Brabant houses by Archiservice has been added to this list. This project had initially been dismissed on the basis that the installations are all from different companies. Also, the installation and the maintenance are done by a different company as well. But the project does provide a different approach then the others and still for fills the other criteria.

3.2.2. LG Climate Energy-module
The design of the energy-module exists out of a closet of 2410 x 1500 x 980. The outside of the closet is made of a steel frame with aluminum panels. Inside of the closet are a:
Outside and inside unit air-heat pump;
Buffer tank;
Heat recovery system;
PV converter;
Control panel. *(LG Solutions, n.d.)*

Between the installations there is still space left. LG chose to have this space for multiple reasons. One reason was to keep the possibility to update the individual installations. If the client wants a bigger buffer tank after a view year this is possible. This space also gives the installer space to install the systems inside the closet and have space for the different pipes.

This closet is designed with the idea of plug-and-play in mind. This means that the closet is made in the factory and then transported as one unit to the building site. For transportation the size turned out to be a problem. 2410 m turned out to be too high for transport by truck. So, for a future design LG plans to reduce the height of the module.

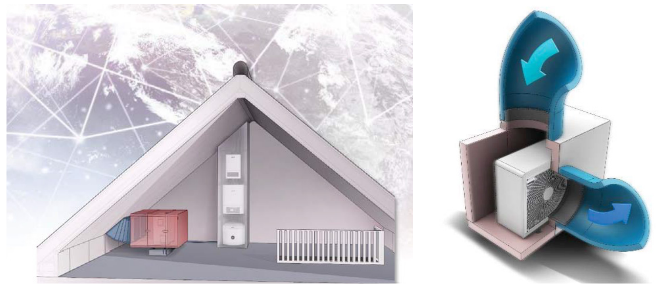
In order to have the unit working as designed they had to go back a few times in order to correct the installation. But this happens very regular with any first-time installation. The other companies have reported to run into the same problem.

Since the module weights 870 kg there is no foundation needed. The closet has been hung on the floor

Unlike the 2ndskin cupboard this module is not installed at the back of the house. Although LG does advertise that this is possible. An advantage of putting the installation at the front door is that the mechanic doesn't need to go into the back garden and since the closet is placed on the ground level no stairs are needed to reach it. But it also gives the installation a bigger footprint. For any kind of maintenance or malfunction where a mechanic must come to the house, the company preferred having the key to the closet instead of giving the key to the user. In their experience many users lack the knowledge and understanding in order to perform any maintenance correctly.
(Based on an Interview with Mauric Rebel (Senior Account Manager) Chris Lam (Marketing Specialist) from LG Electronics, on 3 September 2018)

Figure 3.10: LG Energy Module. (NBD Cobouw, 2017, 8 Juni)

Figures 3.11.1-4: Nefit inroof and Nefit energy Top (Nefit, 2018)



3.2.3 Nefit Energy Bar.
Nefit has 3 different sustainable solutions for terraced houses:
The Nefit Energy Bar;
The Nefit Energy Top;
The Nefit in-Roof. *(Nefit, 2018)*

None of these solutions has been built yet. Currently they are looking for a pilot project. They have made a prototype of the energy bar. The figures 3.11.1-4 show the Energy top and the in-Roof. Both are placed (partly) in the attic of the house. They consist of a unit with the air-heat pump and an in- and outlet. The other installations are placed outside of this unit. These solutions have not been as far developed as the other researched systems. Also, the reference project for this doesn't have an accessible attic and one of the aims of the 2ndskin project is to have less work in the house. For these reasons these solutions have not been further researched within this project.

The Nefit Energy Bar is designed with the idea that there is always a 900 mm blind wall at the front of the house. The unit spans the entire height of the facade of the house. Also, the unit is sunken partly into the facade. The entire Energy Bar is 6000mm x 900mm x 500mm *(MMID, 2017)*
Unlike the other systems the Energy Bar has different cladding options. In figure 3.12 options with steel, aluminum, wood and stone strips.
Inside the unit Nefit has placed the following installations:
Outside unit air heat pump
Inside unit air heat pump with integrated buffer tank and reserve heater
Heat recovery ventilation unit

When it comes to the placement of the installations inside of the unit the Energy Bar there is less air around it in comparison with the LG and 2ndskin installation units. This means there is extra space for a bigger buffer tank. But according to Nefit an update like that would be rare. If it would happen an extra tank can always be placed next to the installation. Also, if they want to update the system, more power doesn't need to mean a bigger installation.

Also, Nefit spent a lot of time planning where the pipes are going to go and minimizing the amount needed. The design is made with the most basic terraced house floor plan in mind. This means that there be connections of the old heat distribution system in the attic, A bathroom on the first floor at the front side of the house and a cupboard with standardized connections down stairs.

For the construction they also made use of the height of the module. The Energy Bar is designed to be connected to all the floors and distribute its weight this way.
(Based on telephone interviews with Tjerk Christenhusz Product Manager and Rob de Bruin Project Manager Nefit)

Figures 3.12: Nefit Energy Bar (MMID, 2017)

Figures 3.13: Designs Nefit Energy Bar (MMID, 2017)

3.2.4. Stiebel Eltron LWZ 304

The compact all-in-one ventilation, heating and hot water unit is a mystery when first encountered. It's only 1885m x 1430m x 725m, which is smaller than all the other systems. Where Nefit already saved space by putting the installations closer together, Stiebel Eltron went a step further and integrated the installations into one unit.

For transportation they split the unit into two halves. When the installation is installed, they connect the two halves and then connect all the systems to the building circulation system.

While the installations of LG Climate, 2ndskin and Nefit are designed to be placed outside, this unit is not. This means that even though the unit is much smaller than the other ones, when comparing them one should take into an account that when placed outside, this unit would need extra insulation. But with that insulation it's very likely that it will still be smaller than the others.

In figures 3.15 and 3.15 show what's in this compact box:

1. Heat recovery ventilation unit
2. Air-Heat pump
3. Solar collector heat exchanger.
4. Buffer tank

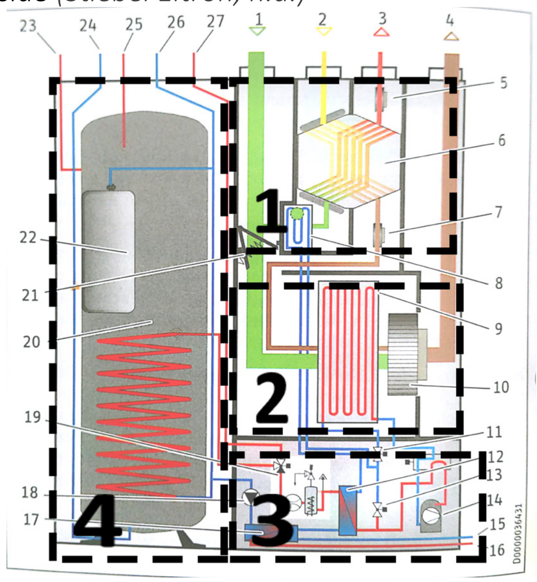
Apart from the option to connect a solar heat exchanger the installations are like Nefit and LG Climate. But Stiebel Eltron has made a connection between the Heat recovery ventilation unit and the air heat pump. Instead of guiding the outlet air from the heat recovery ventilation unit directly outside it is lead into the air heat pump. Because this air is likely warmer then the air from outside (unless its summer) the air heat pump can use this heat for the central heating system.

In the system drawing the numbers 1 until 4 represent the:

1. Air intake for outside;
2. Return air out of the house;
3. Inlet of air into the house;
4. Return of air to the outside
7. Air outlet from the heat ventilation unit into the air heat pump
8. Air inlet for the heat ventilation unit *(Stiebel Eltron, 2016)*

Figures 3.14.: Stiebel Eltron LWZ 304 SOL (Stiebel Eltron, n.d.)

Figures 3.15.: Stiebel Eltron LWZ 304 SOL inside (Stiebel Eltron, n.d.)



Figures 3.16: Stiebel Eltron LWZ 304 SOL inside (Eltron, 2012b)

Not only does this compact design take in less space it's also one of the lightest systems. One explanation for this could be that there is no cladding between the units and no insulation for outside use. Another explanation is that there are less pipes between the installations.

(Based on interview with Marc Emmen Technisch Adviseur, Stiebel Eltron on 4 September 2018)

3.2.5. Brabant houses

The Brabant houses have an installation system that is also designed to be placed inside. In this specific case they have placed the installations inside a closet above the stairs. The dimensions of this closet are bigger then the Stiebel Eltron compact unit. (2500m x 1000m x 1200m)

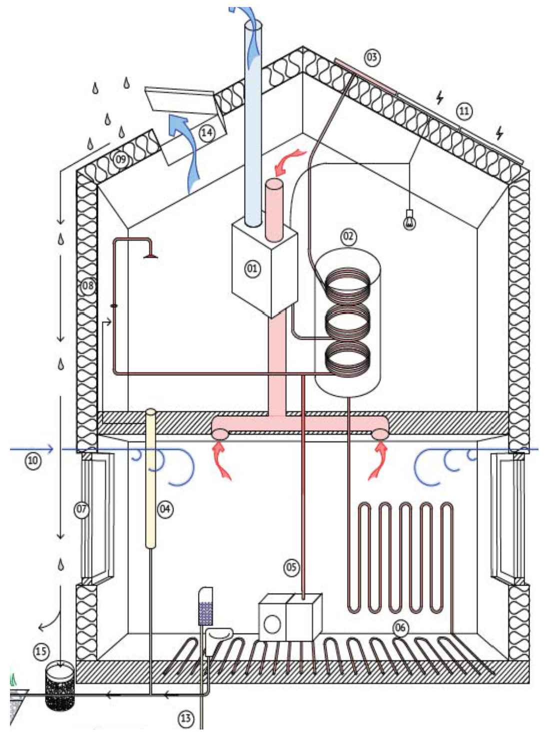
The set-up of the installations can be seen in figure 3.17. On the top left is the air heat pump, behind the air heat pump the solar collector is placed and right from the heat pump the flow heater (doorstromer) is visible

As can be seen on the picture, the installations are still set up with air in between them. But the closet is still smaller than the one of LG and 2ndskin because there is no heat recovery system installed.

Figure 3.18 shows the entire building circulation system. Instead of using a heat recovery unit in order to pre-heat and distribute the air, ventilation grilles above the windows let in fresh air. The inlet is designed to make use of the Coanda effect. This means that the air will be stuck to the ceiling of the room before falling. This also gives the air time to mix with the heated air inside the room so there will be less of a "cold fall." In order to get the used air out of the room, a mechanical ventilation system has been installed. This system will bring the used air into the air-heat pump which then uses it the heat the water for the central heating system. The air heat pump doesn't only function on the return air of the house, there is also an intake of air from outside. The amount of ventilation air will always be kept at the preferred minimum. They heat pump will not take more air if the heat demand is high, because this would be counterproductive.

Figures 3.19: Brabant houses Coanda effect (Archiservice, 2013)

Figures 3.17: Brabant houses (Archiservice, 2013)



Figures 3.18: Brabant houses system (Archiservice, 2013)

Next to the heat pump the central heating system and the hot water system use a solar collector and a flow heater to heat the water. The solar collector uses 5 m2 of solar-collectors on the roofs to pre-heated the water. If the water isn't hot enough to be used then the flow heater will heat the water up to the desired level, using electricity.

(Based on telephone interviews with Renz Pijnenborgh, Architect Archiservice and Hans Crone, Technisch Adviesbureau Crone)

4

System Comparison

4.1 The Preparation

The aim of the analysis is to research the chosen innovations in order to determine what the possibilities for integration are. By analyzing the design of the systems, different possibilities for integration can be determined. Next an analysis will be done in order to find out how if the design of the systems has an influence on the weight, noise and efficiency of the system. This analysis will lead to design strategies for the design proposal and an installation concept.

In order to compare the different case studies, they had to be made equal in order to be able to compare them fairly. But they still had to be representative of the system design, so they cannot be changed to much.

Since the 2ndskin project is designed for porch houses while the others are all designed of terraced houses, the demands on the systems differ. In order to keep the basis of the other systems the same while still being able to compare the 2ndskin project to them, it has been decided to only take the cupboard at the ground floor for the 2ndskin project. This cupboard contains both the heat pump and the installations needed for one house. Even though one porch houses are smaller than a terraced house the same installations are still needed. Comparing the system as installations for a terraced house does mean that, if one installation comes out the best, isn't directly fit for a porch house. But the aim of this analysis is not to find a one-on-one solution, but instead to use the findings of the analysis in order to make a new design proposal.

In order to be able to compare the different installations, research has been done to determine which installations were used in the different installation concepts. This proved to be harder in some cases than in others. The most problems came from the installations that turned out not to be from the company that build the system. The companies where reluctant to admit this and in one case it was never clarified which product of which company was used. The heat recovery ventilation unit of Nefit has stayed undefined during the research After interviews and e-mail contact with Nefit it hasn't gotten clearer then that the unit is from some German company. After doing some research into different kinds of heat ventilation recovery units it turns out that in size, weight, capacity, noise and efficiency there are not many differences between the different units. In the end the ventilation unit of Nefit has been left out of the analysis and where necessary the properties of the LG ventilation unit where used.

Another point that needs to be looked at before the systems can be compared is the heat and ventilation that the systems provide. Where possible, versions of the systems have been used that provided a similar demand as the 2ndskin project. This means for the Nefit energy bar that the updated version with the 5 kW heat pump has been used and the LWZ 304 of Stiebel Eltron. For the Brabant houses a similar update was not possible. Therefor the Brabant houses will be compared as they are now. In the table below the individual system that are used for the system comparison are listed.

Table 4.1 *: Individual installations per system based on email contact with (2ndskin) Onno de Wal, BIK Bouw BV, (LG Energy module) Mauric Rebel (Senior Account Manager) LG Climate, Hans Crone, Technisch Adviesbureau Crone). and Telephone contact with Rob de Bruin Project Manager Nefit)*

	2ndskin	LG Energy module	Nefit Energy Bar	Stiebel Eltron LWZ 304	Brabant houses
Heat pump	Itho WPU 55	AWHP Split HN0914 - HUO51	Nefit Enviline Split 5.0 T-S	LWZ 304 SOL	Inventum Ecolution WP
Heat recovery ventilation unit	Itho 300	Brink Renovent Excellent 400	?	-	-
Buffer Boiler	Itho 150 l. SVV	RTV200E	-	-	Solar Boiler ATAG E325EC ALEC
Reserve heater	-	-	-	-	Doorstomer Stiebel Eltron DHB 11 SLi

4.2 The Analysis

The analysis is set up to compare the systems on: size, weight, connections, sound insulation, sound intensity and efficiency.

The size, placement of installations, connections, covering, sound insulation and weight are based on the information given by the companies through their website or documentation.
For the noise there were different numbers to be found on the website, in the documentation and on the energy label. These differences where mostly due to different location where the sound intensity was measured. There is the sound intensity of:
- The inside unit
- The outside unit
- 1 meter away from the outside unit
- 3 meters away from the outside unit.

The used location of the measurements isn't always stated. So, in order to be able to compare the sound intensity of different systems the sound levels stated on the energy label were used since the numbers of the sound intensity on the energy label should be the ones from the inside and the outside unit.

Next to the sound intensity also the SCOP value from the energy label was initially used. According to the regulations set by the European union the Energy label should provide an accurate number, since an independent company will have tested one unit to verify the numbers or three if the first unit doesn't verify them.

Because some of the SCOP values where unexpectedly high further research was done in order to explain what was happening. In the end in turns out that not only the sound intensity numbers differed, also some other numbers where different between the website, documentation and the energy label. In order to find the current numbers, the quality reports given out by the independent companies of TNO, KIWA and Eurovent where analyzed. These reports are made independent from the manufactures. The reports give an evaluation of the product based on the NEN 7120. The quality report is usually used to calculate the EPC. (Bureau-Controle-en-Registratie-Gelijkwaardigheid) When looking at these reports and the energy label for the same products, different numbers come up:

For the LG Energy module, the heat pump combination of the HU051U42 - HN0914NK2 was used. When looking at the Energy label the SCOP for any climate for low temperature heating is 6. When looking at the quality report by Eurovent, the listed SCOP for low temperature is 4,36. (LG Solutions, n.d: Eurovent, 2017)(Eurovent, 2017; LG-Climate-Solutions, n.d.)
The Nefit Enviline Split 5.0 T-S heat pump has a capacity of 5 kW and a COP of 4,7 according to their website. When opening the quality report made by KIWA for the Split 5.0 T-S. The COP is 4,7 but the reported capacity of the tested product is 7,778 kW instead of 5 kW. When looking at the Nefit Enviline A/W Monoblock 5.0 TS-S which also has a Capacity of 5 but a COP of 4,6 on the website. Unlike the Split, the monoblock does correspond to the numbers in the quality report. (Nefit, 2017: Kiwa, 2016)(Kiwa, 2016; Nefit, 2017a)
Some of the numbers on the quality report for the heat pump from the 2ndskin project are higher than the numbers given by the manufacturer. But the found quality report has been expired since 2015. A newer report could not be found. By the next generation of this heat pump the numbers aren't incorrect but the most positive numbers are taken.
For Stiebel Eltron the quality report couldn't be located. The for numbers of the Inventum heat pump for the Brabant houses no differences were found.

The Dutch authority on food and wares does market inspections in order to ensure that the European and Dutch regulations are followed. They haven't done an inspection report jet on the Energy labels of heat pumps. But they have one on the Energy labels of other installations. In this report lead to a correcting measurement for one of every five manufacturers. Also, around 80% of the companies that were inspected didn't have matters regarding the energy label in order.
(warenautoriteit, 2018)(Nederlandse-Voedsel-en-warenautoriteit, 2018) For heat pumps the same situation seems to be the case.

For this research the quality report is assumed to be correct. The test reports are provided by the website of the companies. But except the quality report for the LG heat pump all the found reports in the database of the office: control and registration equivalence. This office lets a group of independent experts test the product again and tests if the quality reports are valid. Since this means that all the data is checked by two independent companies, it's safe to assume that these numbers are correct and are therefore used in this research

Initially the electricity use of the installations was also included in this analysis but, the companies all present the electricity use in different ways. Some include the energy used to make domestic water while others don't. Some include cooling and others make difference in both climate and type of heating. Most numbers could find only the energy label package, since the energy label turned out to not be accurate the electricity might not be accurate as well. The numbers that where found didn't show big differences also, the COP already gives an idea on how efficient the systems use electricity. Because of this the numbers on electricity use not used in this comparison.

4.2.1 The scoring system

In order to be able to compare the systems on these different areas, a scoring system is used. This scoring system will rate the systems as --,-,o,+ or ++. Within this scoring system – will be considered an undesirable, o is an acceptable situation and ++ would be the desired situation within current standards. The exact criteria of what makes a system – or ++ is set per criteria down below.

Size

--	Total volume of more then 5,0 m^3
-	Total volume of more then 4,0 m^3
0	Total volume of more then 3,0 m^3
+	Total volume of more then 2,0 m^3
++	Total volume of 2,0 m^3 or less

Connections

--	The connections are on more than four sides of the module
-	The connections are on four sides of the module
0	The connections are on three sides of the module
+	The connections are on two sides of the module
++	All connections are on one side of the module

Amount of empty space

--	There are spaces around the installations of more then 0,4 m wide
-	There are spaces around the installations of more then 0,2 m wide
0	There are spaces around the installations of more then 0,1 m wide
+	There are spaces around the installations of more then 0,05 m wide
++	There is less then 0,05 m of space around the installations

Weight

--	More than 1000 kg
-	More than 800 kg
0	More than 600 kg
+	More than 400 kg
++	Less than 400 kg

Sound insulation

--	No insulation in covering, No insulation between installations, Not lifted of the ground
-	No insulation in covering, No insulation between installations, Lifted of the ground
0	Insulation in covering, but hard inner surface, No insulation between installations, Lifted of the ground
+	Insulation in covering, No hard inner surface, No insulation between installations, Lifted of the ground
++	Insulation in covering, No hard inner surface, Insulation between installations, Lifted of the ground

Efficiency

--	3,0 or less
-	3,0 – 4,0
0	4,0 – 5,0
+	5,0 – 6,0
++	6,0 or more

Sound intensity

--	60 dB or more
-	Less than 60 dB
0	Less than 50 dB
+	Less than 40 dB
++	Less than 30 dB

4.2.2 Size

The total sizes of the complete modules vary from 4,5 m3 (2ndskin) to 2 m3 (Stiebel Eltron). For these measurements the covering is also taken into an account. The different modules use different kinds of coverings. Which already show the first size difference. The 2ndskin cupboard is made from a wooden frame with insulation in between. On the inside there are wooden panels and on the outside the cupboard is finished off with plaster and stone strips. This entire package has a thickness of 100 mm. (Boess-S. Konstantinou, 2017)This means that the covering alone ads 0,7 m3 to the total volume of the total volume of the 2ndskin cupboard.

After 2ndskin the covering of the Nefit module adds to most to the volume. This module has a covering with a total thickness of 72 mm. For inside out the covering exists out of a 2mm panel of steel, a 60 mm tick resol rigid foam and a styling panel of 10 mm.(MMID, 2017) This adds 0,8 m3 to the total volume. But even though the Nefit module has more cladding it's still only have the size of the 2ndskin module.
When looking at the total amount of space the biggest installations take in, there is little difference between the systems. Most of them have the same volume. The volume of the 2ndskin installations in a bit bigger than the others. Which is mainly because of the bigger heat recovery ventilation unit. This means that the installations themselves are not the cause of the size difference. (link websites?)
What really makes the difference for the size is the amount of empty space between the installations.

		2ndskin[1]	LG Energy module[2]	Nefit Energy Bar[3]	Stiebel Eltron LWZ 304[4]	Brabant houses[5]
Heat pump	(mm)	1025 x 600 x 480	950 x 843 x 330 850 x 490 x 315	870 x 660 x 320 950 x 830 x 330	1885 x 1430 x 725	1090 x 610 x 471
Heat recovery ventilation unit	(mm)	1036 x 655 x 400	765 x 677 x 564			
Buffer Boiler	(mm)	1266 x 705 x 705	1230 x 580 x 580			1813 x 511 x 395
Reserve heater	(mm)					466 x 225 x 116
Volume Installations	(m^3)	1,1	0,7	0,7		0,7
Total unit size	(mm)	2600 x 1805 x 950	2410 x 1500 x 980	6000 x 900 x 500	1885 x 1430 x 725	2500 x 1000 x1200
Total unit volume	(m^3)	4,5	3,5	2,7	2,0	3,0
Score		-	o	+	++	o

Table 4.2 : Size of the installations
[1] (Daalderop, n.d.)
[2] *LG Solutions, n.d*
[3] *Nefit, 2017*
[4] *(Stiebel Eltron, n.d.)*
[5] *(Invemtum, 2018),(ATAG Verwarming, n.d.)*

4.2.3 The empty spaces

There are a few reasons for why this empty space is there. One of them is that it isn't completely empty around the installations. There are different kinds of valves, an expansion vessel and circulation pumps. But that still leaves a lot of space where there is just air. The reason for this empty space is that it's needed for the installation and the maintenance of the installations. The installation manuals of the different installations show the minimum measurements required for installation and maintenance. However the needed space for the installation and maintenance isn't just different per installation. It also differs per company. For the Stiebel Eltron LWZ unit there is allot of space required around the module. 600 mm in the front, 500 mm on one side, 300 mm on the other side, 200 mm in the back and 670 mm at the top. (link motage doc) Most of the space required for the installation is outside of the unit. Which means that the volume doesn't take most of the required installation space into an account. But the required space does impact the placement of the installation and the usefulness of the space around it. Within the module there very little empty space. There is no space between the installations apart for the space in the bottom right corner. In this corner there are all the small parts of the installations packed together.

For the 2ndskin and the LG Climate modules there is quite some empty space around the individual installations. There is even a corner where possibly another installation could fit. Unlike stiebel Eltron, LG and 2ndskin kept the empty space that's required according to the installation manuals around all the individual installations. This resulted in the empty spaces between the installations. Fitting in the installations as close as possible within a box with the needed installation space has left the extra open space in the bottom left corner (2ndskin) and the top right corner (LG). Some of this space is in order to reach the back side of the installations and the valves and pipes placed in between. But by design this space is bigger than required.

The Nefit module has a lot less space around the installations. According to the installation manual, the inside unit of the heat, which is placed in the bottom, needs am minimum 400 mm of space above it. When looking at the energy module, this is not the case. In the telephone interview with Rob de Bruin, project manager with Nefit, this difference was further explained. By rethinking the placement of the connections, valves and pipes, the needed space could be decreased. When at the Nefit and the Stiebel Eltron modules it becomes clear that the smart placement of the connections can decrease empty space. But is there still enough space for the installation and for maintenance? Nefit and Stiebel Eltron state that this is not the case. Looking at the installation instruction video's of both Nefit and Stiebel Eltron this looks to be correct.

The Brabant houses are not as integrated as the Nefit unit but, the total cupboard still takes in less space then the 2ndskin and the LG modules. The reason for this can be found in the fact that the kind of installations installed are different. Where the installations of the other systems are around the same size the Brabant system exists out of two big installations and one small one. When looking at the final composition of installations it can be seen that this makes a difference. The big buffer boiler is placed in the back and the other installations are place in front of it. Also the flow heater is small enough to be placed next to the heat pump. This has saved up allot of space.

So two conclusions that can be drawn from this are that:

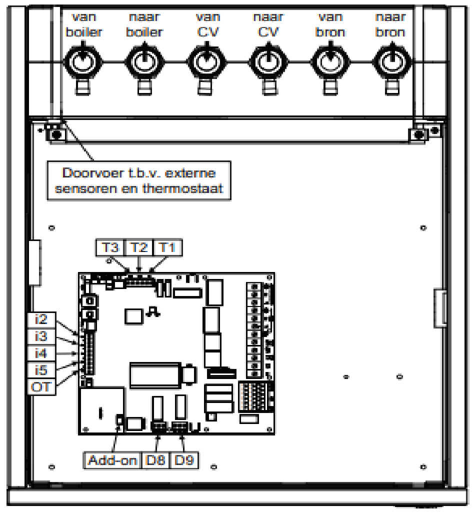
- The placement of the installations can reduce or create space.
- Keeping the installation space outside the module reduces space within the module
- Smart placement of the connections, the pipes and smaller installations can decrease the amount of needed space.

Empty spaces	--	-	+	++	o

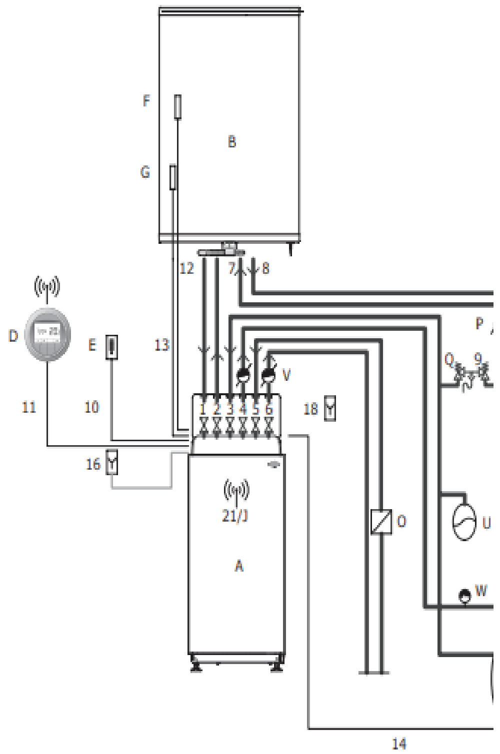
4.2.4. System connections

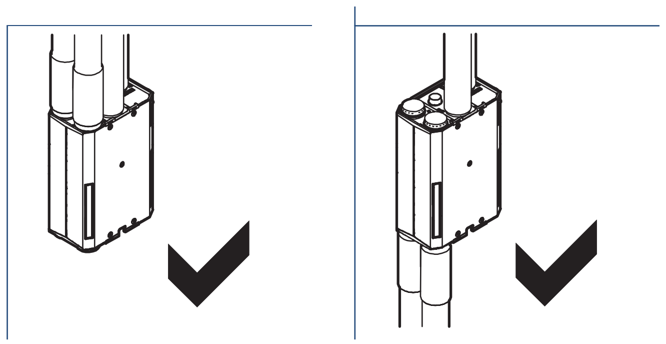
As stated in the previous chapter the placement of the pipes and smaller installations makes a difference in the amount of space that is needed for the system. One of the aspects that impacts the placement of the pipes are the connections on the individual installations.

For 2ndskin the heat pump has all the connections on top of the installation. The buffer boiler is clearly designed to be placed above the heat pump. All the connections are placed on the bottom. And the order of these mirror the ones on the heat pump. On the right side there are the connections to and from the boiler. In the middle there are the connections to the central heating system and on the left side the connections from and towards the source. All the electrical connections are placed more to the front. The other big installation in the cupboard is the ventilation recovery unit. For this unit there are connections at the bottom and the top of the installation. However, its possible to only use the top connections. For flexibility there are extra connection options for connecting the ventilation pipes. Because there are only two connections at the bottom this means that when these are used there will be pipes connected to both the bottom and the top. For 2ndskin the decision was made to only use the connections at the top.



Figures 4.1 2ndskin heat pump top view connections. (Ihto Daaldorp, n.d.-b)

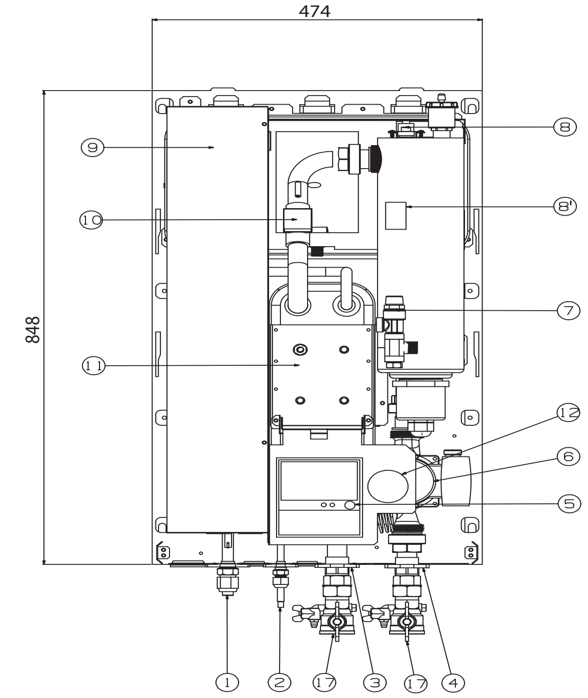




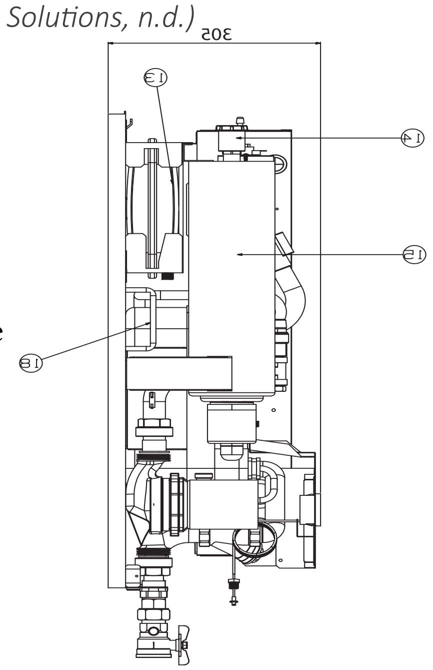
Figures 4.1 2ndskin heat pump top view connections. (Ihto Daaldorp, n.d.-a)

Figures 4.1 2ndskin heat pump top view connections. (Ihto Daaldorp, n.d.-b)

Where the ground heat pump used by 2ndskin has all the connections on top, the inside unit of the heat pump from LG has almost all the connections at the bottom. Only the connection for the room sensor and the thermostat are located at the side. Unlike the 2ndskin heat pump there is no direct connection to the central heating system. There is only a water inlet and a water outlet. Instead of having a separate connection for the buffer boiler and the central heating system there is one connection for both. The installation schemes for this heat pump show that the water outlet from the heat pump is connected to a three-way valve that connects both the buffer boiler as well as the central heating system. It's possible to have a small buffer for the central heating system next to the boiler for the heating system. But this has not been done in this module. For the buffer boiler used in this system all the connections are located at the top and the side of the installation. At the top there is a connection for cold water and tap water. At the side there are the connections for the in- and output from the inside unit of the heat pump and the electrical connections for the heater. LG's outside unit has all the connections at the back-right side of the unit. The heat ventilation recovery unit has all the connections on top of the installation except the condense drain.

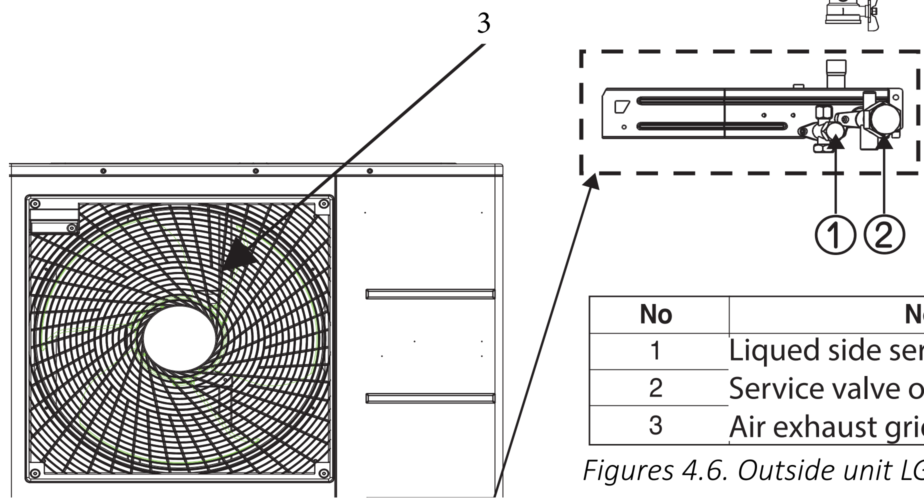


Figures 4.4: Front view inside unit LG LG Climate Solutions, n.d.)



1. koelmiddelpijp
2.koelmiddelpijp
3. water inlet
4. water outlet
5. control panel
6. water pump
7. Safety valve
8. Thermal switch
9. Control unit
10. Flow switch
11Plate heat exchanger
12. Pessure indicator
13. Expansion tank
14. Air ventilation
15. Electric heater
16. Filter
17. Shut-off valve
18. Handle for transport

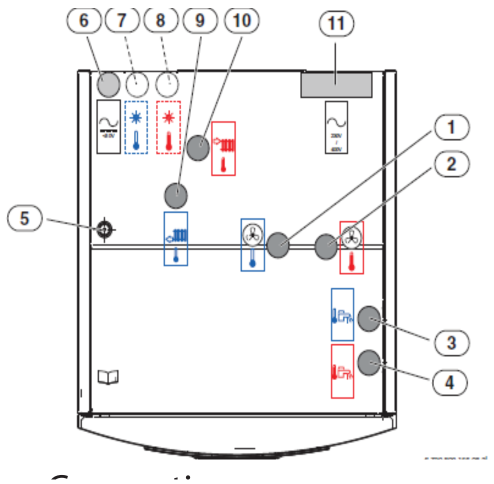
Figures 4.5: Front view inside unit LG (LG Climate Solutions, n.d.)



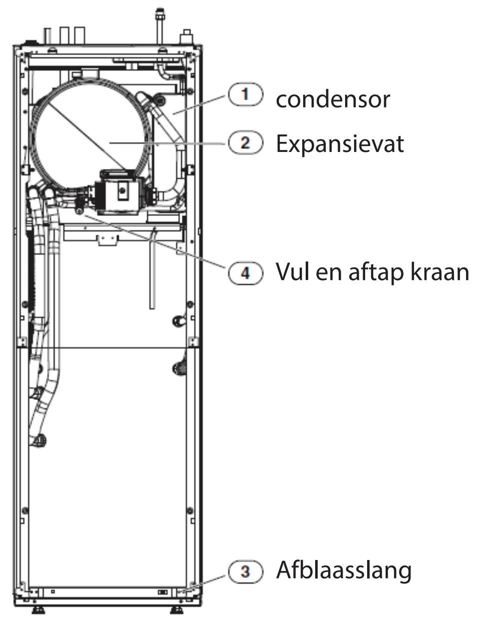
No	Nome
1	Liqued side service valve
2	Service valve on gas side
3	Air exhaust grid

Figures 4.6. Outside unit LG LG Climate Solutions, n.d.)

The inside unit of the Nefit heat pump also has all the connections placed on top of the installation. But unlike the 2ndskin unit the connections are more spread out over the top of the installation. Connections for solar collectors are in the back. The CV connection is more towards the middle. The connections to the outside unit are in the middle and the cold and tap water connections are in the front right side. The scattering of the connections might have had an influence on the limited amount of empty space in the energy bar. However, the research hasn't found proof for this yet. The outside unit of the heat pump has all the connections clustered in one place. They are on the right back side of the unit. Which means that the connecting pipes from the inside unit will have been placed on the back side of the module, towards the outside unit. Because the exact type of ventilation unit is unknown the installation documents cannot be used in order to specifically locate the connections. However, looking at the placement of the unit in the energy bar it' clear that there are connections on top of the unit. There might also be connections at the back of the unit. But this is unclear.



Figures 4.7.Top view Nefit heat pump (Nefit,2015)

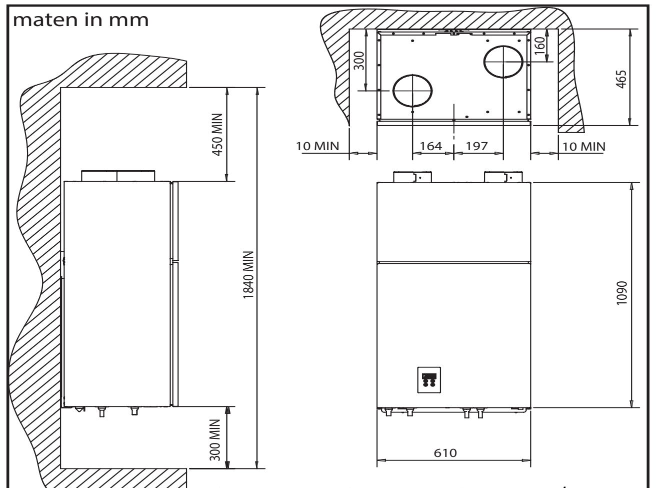


Figures 4.8 front view Nefit heat pump (Nefit,2015)

Figures 4.9: Nefit Energy Bar (MMID, 2017)

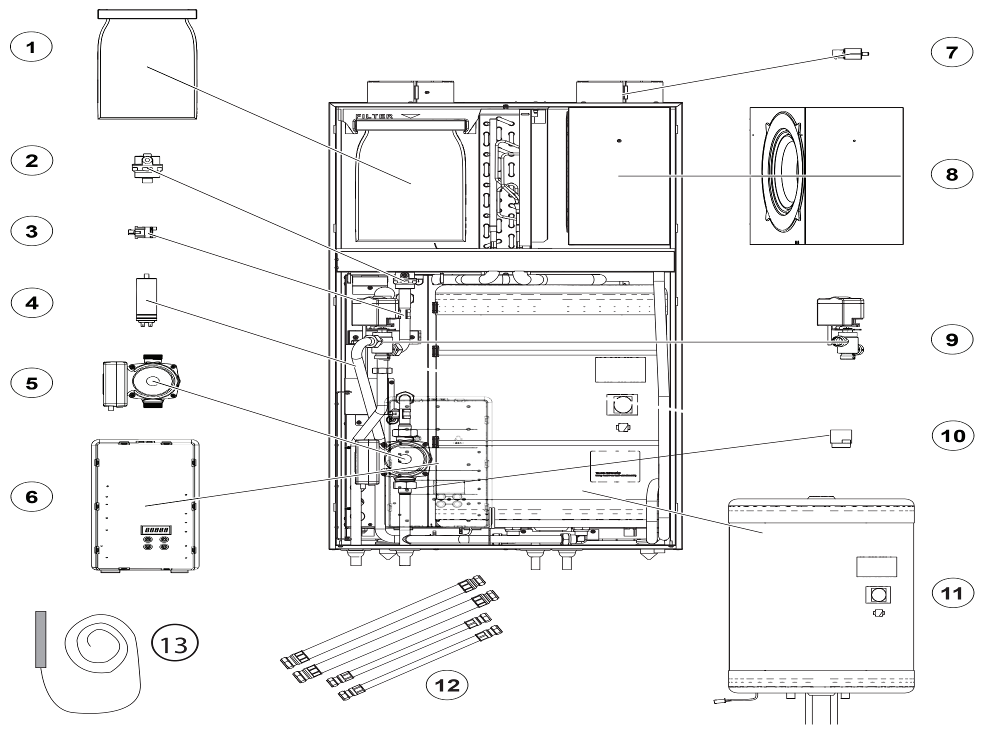
[1] Koudemiddelleiding 3/8" (naar buitenunit)
[2] Koudemiddelleiding 5/8" (naar binnenunit)
[3] Aansluiting koud water
[4] Aansluiting tapwater
[5] Kabeldoorvoer naar IP-module (accessoire)
[6] Kabelkanaal voor CAN-BUS en sensor
[7] Retour naar zonne-energiesysteem (alleen bij ODU Split TS)
[8] Aanvoer van zonne-energiesysteem (alleen bij ODU Split TS)
[9] Retour uit de cv-installatie
[10] Aanvoer naar de cv-installatie
[11] Kabelkanaal voor elektrische aansluiting

The system of the Brabant houses doesn't have a heat recovery ventilation unit. The retour air from the house goes directly to the heat pump. The connection for this is situated at the top of the heat pump. Through this connection also the needed outside air comes in. The air that the installation has used goes out of the installation at the top as well. At the underside of the installation there are connections for central heating on the left side and for both cold and tap water on the right. The heat pump is connected to the buffer of the solar boiler. The solar boiler preheats the water using a solar collector. This warmer water is brought to the heat pump trough the cold-water connection. If need be the heater heats the water before it is used in the house. All the connections of the buffer are situated on the side.



Figures 4.10 Dimentions Brabant heat pump (inventum, n.d.)

Nr.	Artikelcode	Omschrijving
1	S1011771	Luchtfilter Combi 50
2	S1010300	Automatische ontluchter
3	S1011520	Aanvoer/retour sensor cv
4	S1011524	Start/run condensator
5	S1011477	Cv-pomp
6	S1050501	Regelunit Ecolution® Combi 50 en Solo
7	S1011468	Aanvoer/retour sensor lucht
8	S1050500	Ventilatorbox
9	S1011478	Driewegklep
10	S1011559	Keerklep
11	S1050496	Boiler servicepakket
12	S1050760	Flexibele slangenset Combi
13	S15081010	Aanlegsensor

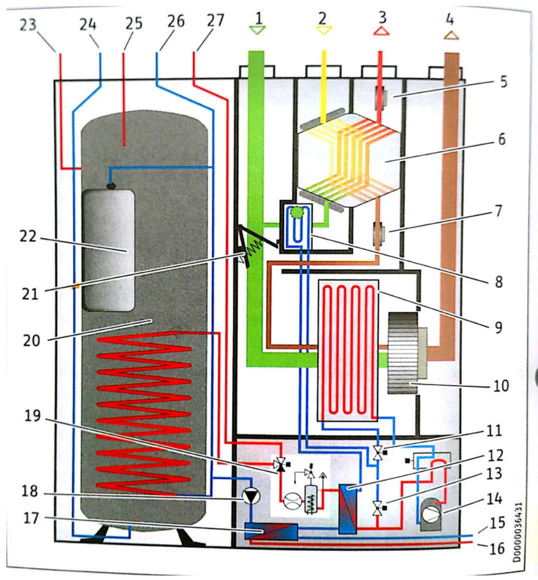


Figures 4.11 connections Brabant heat pump (inventum, n.d.)

The Stiebel Eltron module is the one with the connections on the most sides. There are connections on top of the module, in the back and on one side. On top at the left back side there are the connections for cold water, tap water and the retour and outlet for central heating. On the right side there are the connections for the in- and outlet to the outside air and the in- and outlet of ventilation air. Comparing this to the installations of the other systems there are a lot of similarities. The connections on the left side are similar to the inside unit of Nefit and the 2ndskin heat pump. The connections on the left are similar to the ventilation units of the other projects and the air heat pump of the Brabant project. At the back side there are the electrical connections and a venting drain. On the right side there are the connections for the solar system and the condense drain.

Inside of the module, the connections are kept close together. From the left side downward, there is a pre-heater placed before the inlet of air into the heat recovery ventilation unit. This pre-heater is connected to the condenser at the bottom side. Just below the pre-heater and the ventilation unit there is a connection made between the heat recovery ventilation unit and the heat pump. Before going outside the air out of the ventilation unit is reused in the heat pump. Through the pre-heater and a three way valve the heat pump is connected to the condenser and the compressor at the bottom of the installation. Left from the condenser there is the solar heat exchanger which is connected to the return heating circulation system and the condenser. In the condenser both the heat from the heat pump and the solar collector is used to provide the heat for the heating system and tap water. The connections for this are on the right side next to the buffer boiler. The water for the heating system is directed to the top left of the module. The heating system for tap water is connected directly to the spiral of the buffer. The connection for cold water is at the bottom of this buffer, and the connection for hot water is at the top.

Figure 4.12: Perspective of the LWZ (Stiebel-Eltron, n.d.)



Figures 4.13: Stiebel Eltron LWZ 304 SOL inside (Eltron, 2012b)

Figure 4.14: Top view Buffer (Stiebel-Eltron, 2015)

Figure 4.15: see-trough LWZ model (Stiebel Eltron, 2016b)

Figure 4.16: Open view LWZ (Stiebel-Eltron, 2015)

4.2.5. Weight
Just like with the size of the units there is a difference between the total weight of installations and the total weight of the module. Partly this is because only the installation that contribute the most to the weight and size are taken into consideration.

When looking at total weight the ranking is:
1. Stiebel Eltron LWZ
2. LG Energy Module
3. 2nd skin

Nefit and the Brabant houses aren't in this ranking because for both the total weight is unknown. Nefit estimate that the Energy Bar weights something between the 600 and 1000 kg.

Looking at the installation weight the ranking looks quite different:
1. 2ndskin
2. LG Energy Module
3. Nefit Energy Bar
4. Brabant houses

Even though the 2ndskin module is the biggest in size and the heaviest in total weight, it is the lightest when it comes to installation weight. Without the heat recovery ventilation unit of Nefit, LG and Nefit come relatively close. With a heat ventilation unit, however, Nefit comes close to the Brabant houses. The lighter weight of the 2ndskin module can be partly explained by the difference between a ground heat pump and an air heat pomp. The heat pump of the Brabant houses comes close to the 2ndskin heat pump, but the heat pump of the Brabant houses has a lower capacity. The integrated combination of inside unit and buffer tank of Nefit is heavier than the separate units of LG.





		2ndskin[1]	LG Energy module[2]	Nefit Energy Bar[3]	Stiebel Eltron LWZ 304[4]	Brabant houses[5]
Heat pump	*(Kg)*	125	64 48	60 330	610	145
Heat recovery ventilation unit	*(Kg)*	35	38			
Buffer Boiler	*(Kg)*	181	245			283
Reserve heater	*(Kg)*					3,2
Volume tank	*(L)*	150	198	190	235	200
Total installations	*(Kg)*	341	395	390	-	431
Total unit	*(Kg)*	870	780	600 - 1000	610	-
Score	*(L)*	-	o	x	o	x

Table 4.3 : Weight of the installations
[1] (Daalderop, n.d.)
[2] *LG Solutions, n.d*
[3] *Nefit, 2017*
[4] *(Stiebel Eltron, n.d.)*
[5] *(Invemtum, 2018),(ATAG Verwarming, n.d.)*

4.2.6 Sound intensity

When it come to the noise produced by the installations, all the numbers become very similar. The heat pump of the Brabant houses is the most silent directly followed by the 2ndskin. The LG Energy module and the Stiebel Eltrons modules are the loudest ones. With 64 and 60 db. All these sound intensities are of similar range from light car traffic to the sound of an air-conditioning. But since people complain about the noise it's important to look at it.

LG Advertises that their modules have a silent modus where the sound intensity can drop to 48 db. After looking into this further it turns out that in the silent modus the fan and compressor are turned off. Which means that the entire system is in a standby mode. Since the fan and compressor make the most sound, the system becomes more silent.

The Brabant houses heat pump has a lower capacity but, is still a similar size to the other heat pumps. This means that the installation can work at a lower rate, which means less noise.

These numbers are taken from the energy labels. According to the regulations the numbers can differ 2db in intensity. But since the energy labels already seems to differ in other areas, *(see 4.1 The Preparation)* the actual numbers might differ more than 2 dB from the showed numbers. For this reason, this data isn't taken into an account in the total system comparison. But since it does give some approximation of what overall sound intensity to expect, it's still included in this research.

		2ndskin[1]	LG Energy module[2]	Nefit Energy Bar[3]	Stiebel Eltron 304[4]	Brabant houses[5]
Heat pump inside	*(db)*	48	48	36	59	47
Heat recovery ventilation unit	*(db)*	47	48			
Buffer Boiler						49
Reserve heater	*(db)*					15
Total inside noise	*(db)*	50	51	36	59	51
Heat pump Outside	*(db)*		64	65	59	47

Table 4.4 : Noice of the installations
[1] (Daalderop, n.d.)
[2] *LG Solutions, n.d*
[3] *Nefit, 2017*
[4] *(Stiebel Eltron, n.d.)*
[5] *(Invemtum, 2018),(ATAG Verwarming, n.d.)*

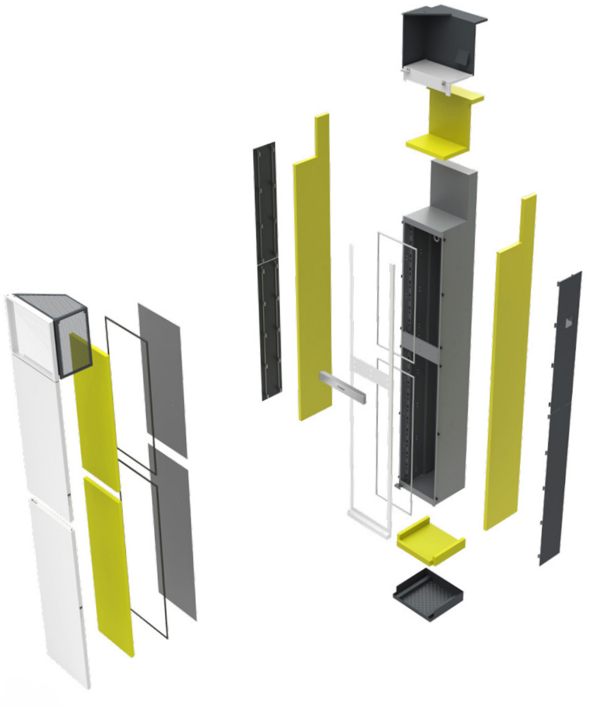
4.2.7 Sound insulation
in order to reduce the amount of sound that the heat pump makes, sound insulation can be used. Heat pumps are installations that make low frequency sounds. These sounds often travel by contact or air. In order to prevent contact sounds, installations can be placed on rubbers. The airborne sounds can be hard to insulate. There are a view ways that the sound can be insulated. One way is to limit the amount of air movement within the module. This is often done with foam block in the spaces between the installations. An other way is to insulate the cladding of the module and prevent hard surfaces on the inside. But these things only work if there are no sound leaks.

Some of the modules have taken some measurements in order to reduce the sound, others have not. One module that has no clear sound insulation is the one from the Brabant houses. There might be some measures taken but, there is no sign of insulation in the cupboard walls. It is possible that the installations themselves are hung in a way to prevent contact sound. But this is not clear. Another module without sound insulation in the cover is the LG climate. However, the module is acoustically disconnected from the floor by blocks to prevent contact sound.

The other modules do have insulation in there covering. The Nefit module has an inner layer of stainless steel. Which means that the sound waves aren't immediately absorbed by the insulation and might actually bounce of the inner layer before it reaches the insulation, which might have a negative effect. The 2ndskin module has the same kind of layering. But, because the inner layer is made of wood it will probably insulate more sound. Also, where the Nefit energy bar has 60 mm insulation layer, the 2ndskin module has 100 mm insulation layer. Which for the lower frequency sound means that more sound is absorbed. Both Nefit as well as 2ndskin are lifted from the ground.

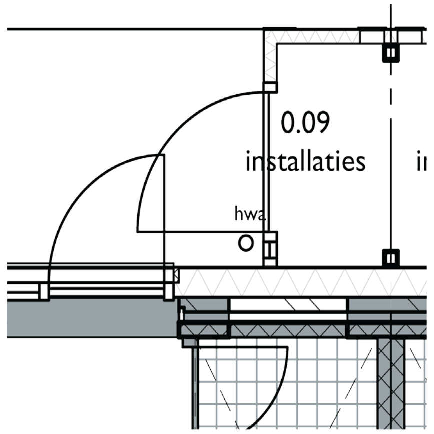
Figures 4.17: Brabant houses (Archiservice, 2013)

Figure 4.18: LG Energy Module. (NBD Cobouw, 2017, 8 Juni)



Figures 4.19: Exploded view Nefit Energy Bar (MMID, 2017)

Of the compared modules the Stiebel Eltron module takes the most measures to insulate the sound. They have lifted the module off the floor. There is insulation in the spaces between the installations. The insulation is placed mainly around the buffer tank and the heat recovery unit. (The white areas in figure 5.21). Also, inside of the cover there are insulation plates used without an extra inner layer. However, it's unclear it there are no sound leaks through the construction of the module.



Figures 4.20: Floor plan installations (Boess,S. 2017)

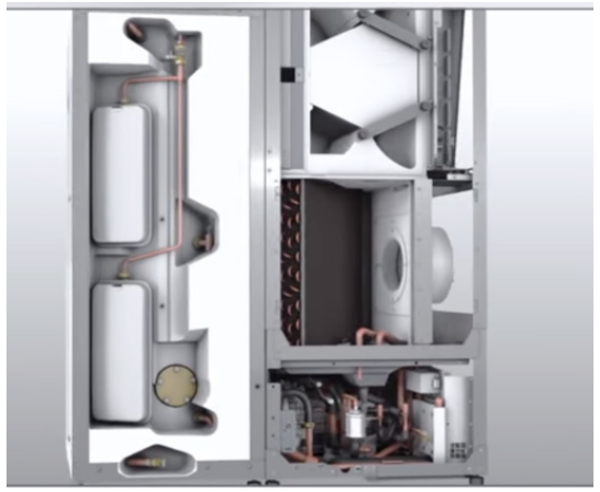


Figure 5.21: Open view LWZ (Stiebel-Eltron, 2015)

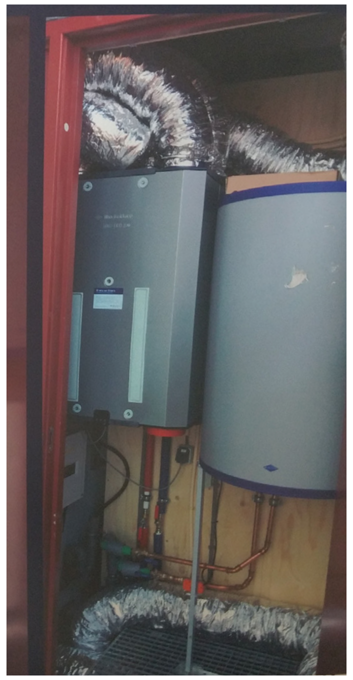


Figure 5.22: 2ndskin cupboard second floor (Boess,S. 2017)

Figure 5.23:open module LWZ model (Stiebel Eltron, 2016b)

	2ndskin	LG Energy module	Nefit Energy Bar	Stiebel Eltron LWZ 304	Brabant houses
Sound insulation	O	-	O	++	--

4.2.8. Efficiency

During the research into the COP, the capacity of the heat pumps turned out to differ between the website and the quality reports. For the other points of comparison this difference in capacity make little to no difference. Because of the lack of quality reports for certain installations at different capacities, the heat pumps are not changed. This means that the capacity between systems differs, but observations can still be made.

First of all, the amount of integration does not seem to affect the COP of the heat pump much. This is probably because the heat pumps themselves are not changed, only the space around them is decreased. This conclusion can be drawn when looking at the numbers from the LG Energy module, Nefit Energy bar and the Stiebel Eltron 304. The more integrated installations from Nefit and Stiebel Eltron show higher COP.

Besides the amount of integration, the type of heat pomp can be compared. In this comparison there is the ground heat pump of 2ndskin, the air-heat pump of LG, Nefit and Stiebel Eltron and the ventilation heat pump of the Brabant houses. The ground heat pump clearly has the highest COP followed by the ventilation heat pump, the air heat pumps come in last. This can difference can partly be explained by the temperature used for the source. Since the ground has a constant temperature of around the 14°C this temperature is used as basis for the ground heat pump. Because the temperature is constant, the heat pump can be optimized for this temperature. Since air heat pumps use the outside air, the temperature is always changing. But for design an average outside temperature of 70°C is used. There is some data of the COP at an outside temperature of -70°C, but since not all companies have provided this information, this is not used. Lastly the ventilation air comes into the heat pump at room temperature. For these measurements this temperature was set at 20°C.

Because of the constant ground temperature, the ground heat pump has the highest COP. Next to that the COP of the air-heat pumps is also lower because at certain temperatures the heat pumps need to be defrosted. Most interesting is the rise in efficiency when ventilation air is used. Because of the higher temperature the efficiency becomes almost as high as the ground heat pump.

	2ndskin[1]	LG Energy module[2]		Nefit Energy Bar[3]	Stiebel Eltron 304[4]	Brabant houses[5]	
Capacity							
Heat pump (kW)	5,4	5,9	7,0	7,8	5,3	1,4	
COP							
Temperature source for COP	14°C	7°C	7°C	7°C	7°C	7°C	20°C
T < 30°C	6,44				4,86	1,44	6,21
30°C < T < 35°C	6,32	4,68	4,39	5,14	4,68	1,44	6,06
35°C < T < 40°C	6,11				4,38	1,43	5,89
40°C < T < 45°C	5,90	3,24	3,17	4,64	4,09	1,42	5,73
45°C < T < 50°C					3,89	1,42	5,58
50°C < T < 55°C		2,54	2,69	3,95	3,65	1,42	5,40
Average	6,19	3,49	3,42	4,58	4.26	1.43	5,81
Refrigerant	R134a	R410A		R410A	R407C	R134a	
Score	++	-		o	o	+	

Table 4.5 : COP of the installations

[1] *(TNO, 2011)*
[2] *(Eurovent, 2017)*
[3] *(kiwa, 2016)*
[4] *(TNO, 2016)*
[5] *(Kiwa, 2013)*

[6] (Daalderop, n.d.)
[7] *LG Solutions, n.d*
[8] *Nefit, 2017*
[9] *(Stiebel Eltron, n.d.)*
[10] *(Invemtum, 2018),(*

4.3 Conclusion

Conclusions per paragraph.
Size and empty spaces
Comparing the installations on size shows that it is possible to design the installations with less empty space between them. The numbers indicate that reducing the amount of empty space can dramatically decrease the size of the installation cupboard. But the installation and the maintenance of the system does needs to be taken into an account. The installation might be integrated well, but it is there to be used.

Connections
The amount sides the connections are on can influences the space needed around the installation. But even having all the connections one side doesn't make the installations more integrated. (2ndskin) However it does give the possibility to integrate them more. (Nefit)

Weight
Since air doesn't add weight. The reduction in weight do to integration is less dramatic then the reduction in size. But the number still indicate that integration reduces the weight. This is mainly because there is less cladding.

Noise
Even though the numbers aren't exact. They do indicate that the integration does not significantly affect the sound intracity. But it also shows that the installations make quite some noise. Therefore, sound insulation would be advisable.

Sound insulation
The amount of sound insulation in the compared modules is very low. Three had some insulation, the Brabant houses have no visible sound insulation and Stiebel Eltron has the most insulation. However sound insulation is the most effective when there are as few leaks as possible.

Efficiency
The efficiency doesn't seem to decrease with integration. However, what this paragraph mostly shows is the dependence of the efficiency on the temperature difference. As suspected the ground heat pump has the highest efficiency. But the ventilation heat pump is very close behind.

The scores
When taking all the different scores together, a conclusion can be drawn on which system scores the best overall. The compared systems are designed for terraced houses while this thesis focuses on porch houses. This means that the design proposal will not include one of these installations as they are in the comparison. However, instead a variation on the original will be used. This is needed because the needs for one porch house are a bit different then for one terraced house.

In the final ranking the module of Stiebel Eltron has come out on top. This is mainly because of the high scores in size, empty spaces and sound insulation. in weight this module still had the highest overall score together with the LG module. In efficiency it scored average compared to the others and on connections it has the lowest score.

The highest score in this category is for 2ndskin. Even though it got a shared third place with the Brabant houses it still got the highest possibly scores on two criteria. Next to those high scores It's not surprising that 2ndskin scored low on size, empty spaces and weight, since the problem statement of this thesis is based on this. But 2ndskin isn't the one with the overall lowest score. The LG module doesn't score well on multiple areas. Compared to the other systems this module often has the second lowest score, except for efficiency where it scores the lowest. Because it scores worse than the reference project the LG module will not be used as reference for the design proposal. The modules from Stiebel Eltron, Nefit and the Brabant houses will be used as reference for the design proposal.

Because the LWZ module of Stiebel Eltron has come out on top it will be used as a basis for the design proposal. But in order to make the unit a good fit for a porch house it will be modified. The needed modifications will be inspired on the good points of the other installations. As mentioned, the Stiebel Eltron module does not score the highest in connections and in efficiency. In these categories other installations will be used as a reference. For the placement of the connection inspiration will be drawn from the Nefit Energy Bar. Because this module has a high score in the area while also scoring high in the empty space and size areas. Which means that it does it in a way that doesn't increase the size of the module.
In order to improve the efficiency of the final design a decision needs to be made on which kind of heat pump to use. Even though the modules of Nefit en Stiebel Eltron have a high score overall, the scores for having an air heat pump are relatively low. Looking at the numbers for efficiency of the ground heat pump and the air heat pump alone, it would make sense to go for a ground heat pump. However, there is only a difference of 0,3 between the two. Which means that for the decision on which one is the best choice for the design proposal might be decided on other attributes of these installations.

When looking past the scores into the designs of the different systems one more design possibility can be found. The Brabant houses show that a zero-energy design is possible without a heat recovery system. Although the effects of not having this system isn't reflected in the scores, it does show a possibility for the design proposal. Having one less system can decrease the weight and size even more.

	2ndskin	LG Energy module	Nefit Energy Bar	Stiebel Eltron LWZ 304	Brabant houses
Size	-	o	+	++	o
Empty spaces	--	-	+	++	o
Connections pipes	++	+	++	o	+
Sound insulation	o	-	o	++	--
Weight	-	o	x	o	x
Efficiency	++	-	o	o	+
Average	o	-/o	o/+	+	o
Ranking	3	4	2	1	3

Table 4.6: Final scores

5

The Design Proposal

5.1 The system

This chapter presents the final design proposal. The drawings for this can be found in appendix A.2. This design proposal is based on the initial research, the system comparison and objectives and boundary conditions of this thesis. This chapter will explain where the design decisions are based on.

5.1.1 The heat pump
As mentioned in the system comparison chapter the installation system will be based on the module of Stiebel Eltron, the LWZ 304 Sol. But in order to implement the system in the reference project some changes need to be made. First of all, the type of heat pump. Out of the system comparison the ground heat pump and the ventilation air heat pump had the best scores on efficiency. Because the difference between the two was so small the decision between the two will be made on other criteria.

There is a clear difference between the heat pumps when looking at what is needed to install them on site. The ventilation heat pump needs to be connected to the pipes of the retour air out of the house, a pipe bringing in outside air, the electricity supply and the heating and (tap) water systems. For the placement of a ground heat pump a well needs to be drilled to use as a source and then the heat pump needs to be connected to the source and, the electricity supply and the heating and (tap)water systems.

One of the aims for 2ndskin is to reduce the amount of work on site.*(Boess, S. 2017)* Next to that a satisfaction survey done for the Ministry of Internal affairs and kingdom relations on how residents look back on a renovation with EPV, has stated that one of the complaints was the length of the building time and the noise during the during this time. *(Jong, F.d.& Boger, B. 2018) (1.3. Boundary conditions)* These points have also been taken up in the boundary conditions of this research. Based on this the conclusion can be drawn that for this project a ventilation air heat pump is the best choice between the two.

5.1.2.Ventilation
Another boundary condition is: The number of added pipes and installations inside should be minimized. One way to do this in the design proposal is to not have a heat recovery unit. The system of the Brabant houses has shown that a heat recovery ventilation unit is not needed in order to make a house zero on the meter. Not having this unit means that the air that is needed for ventilation can be brought into the houses by grills and opening windows, instead of using pipes. Research has shown that there is some people open the window when they want to bring in fresh air. *(Dorer & Breer, 1998)*. When not heat recovery system is used the residents can continue to open up their windows. As mentioned in the conclusion of the previous chapter, having one unit less can decrease the space needed by the system.

5.1.3. Solar collectors
Next to the heat pump, solar collectors will be used in order decrease the demand on the heat pump. The Stiebel Eltron unit has to possibility to integrate this without increasing in size. Also the project already uses solar panels for electricity and the combination with solar collectors is proven to not decrease the electricity by much. (Zakharchenko et al., 2004)

For the water storage two different options where considered. Option one is to have one tank for 3 houses, the other one is to have an individual tank per house. Having one tank would reduce the overall weight and size. But the problem with having one tank is that there is a big difference between households on how much water they use. *(Guerra Santin, 2015) (Guerra Santin, 2015)* Also the EPV requires individual monitoring of the use of water, heating and electricity, which is easier with separate buffer tanks. But the main problem that this research is addressing is reducing the size and weight of the installations. Based on these different points there will be three different design proposals made in this thesis:

1. All-individual: everyone has their own installations, nothing is shared;

2. Hybrid: In the hybrid option three houses share one heat pump, but all have their own water tank, solar panels / solar collectors;

3. All-in-one: All installations are shared by the three houses.

5.1.4. Facade integration
The Nefit Energy bar has presented the possibility to integrate the installation cupboard into the facade. But this does create more challenges then it solves. The facade still has to meet the required RC-values and air-tightness even behind the installations. This means extra care needs to be taken with designing and building this part, which will result in extra cost and a possible increase in heat demand if these requirements aren't met. Therefore, the choice was made to not integrate the installation deep into the facade. In order to retain the required RC-Values and the airtightness, the facade of the reference project is maintained. *(Boess, S. 2017) (Boess-S. Konstantinou, 2017)*

The modular concept of the Nefit energy bar was taken as inspiration for the design of the cupboard. The final cupboard is designed in a way that the installations can be assembled in the cupboard in the factory and thus only have to be connected to the building installations on site.

For the design of the different concepts the following installations are used as basis, the installations are integrated in a way that based on existing products is possible:

Heat pump: The LWZ 340 SOl from Stiebel Eltron

PVT panels: combination of: Nefit solarwatt Solar panel 60P BLUE 270 WP *(Nefit, 2017b)*
and Stiebel Eltron's the Solar Keymark SOL 27 basic *(Stiebel-Eltron, 2018a)*

PV converter: Nefit Sunny Boy *(Nefit, 2017b)*

Water storage: KS 150 Sol double coil from Stiebel Eltron. *(Stiebel-Eltron, 2018a)*

Space heater: Quin Sensa, LT-Radiator. (same as reference project) *(Boess, S. 2017)*

5.1.5 Cables and installations

The installation diagram gives an inside on what installations are placed on the ground floor and which on the other floors. Also, the needed cables are indicated. *(Figure 5.0)*

All-individual

Ground, First and second floor

Air heat pump
Expansion vessel
Safety valve
Fill and drain valve for heat pump
Control unit

Circulation pump heating system
Circulation solar system
3-way valve
Outside temperature sensor
Double coil water boiler
Cold water safety assembly to DIN 1988
fill and drain valve for boiler
Solar module
Control unit
PV- converter.

All-in-one Concepts

Ground Floor

Air heat pump
Expansion vessel
Safety valve
Fill and drain valve for heat pump
Control unit

Circulation pump heating system
Circulation solar system
3-way valve
Outside temperature sensor
Double coil water boiler
Cold water safety assembly to DIN 1988
fill and drain valve for boiler
Solar module
Control unit
PV- converter.

Shaft

Return ventilation air
Warm water from heat pump
Cold water towards heat pump
Warm water from solar collector
Cold water from solar collector
Electricity from P-panels

Hybride Concept

Ground floor

Air heat pump
Expansion vessel
Safety valve
Fill and drain valve for heat pump
Control unit

Circulation pump heating system
Circulation solar system
3-way valve
Outside temperature sensor
Double coil water boiler
Cold water safety assembly to DIN 1988
fill and drain valve for boiler
Solar module
Control unit
PV- converter.

Shaft

Return ventilation air
Warm water from heat pump
Cold water towards heat pump
Warm water from solar collector
Cold water from solar collector
Electricity from P-panels

First and second floor

Circulation pomp heating system
Circulation solar system
3-way valve
Outside temperature sensor
Double coil water boiler
Cold water safety assembly to DIN 1988
Fill and drain valve for boiler
Solar module
Control unit
PV- converter.

Between house and cupboard
Electricity cable
Input and return heating system
Input domestic water system
Cold water supply
Return ventilation

Roof

Solar collectors with PV

For all these installations, cables and appliances space is reserved in the design proposal.

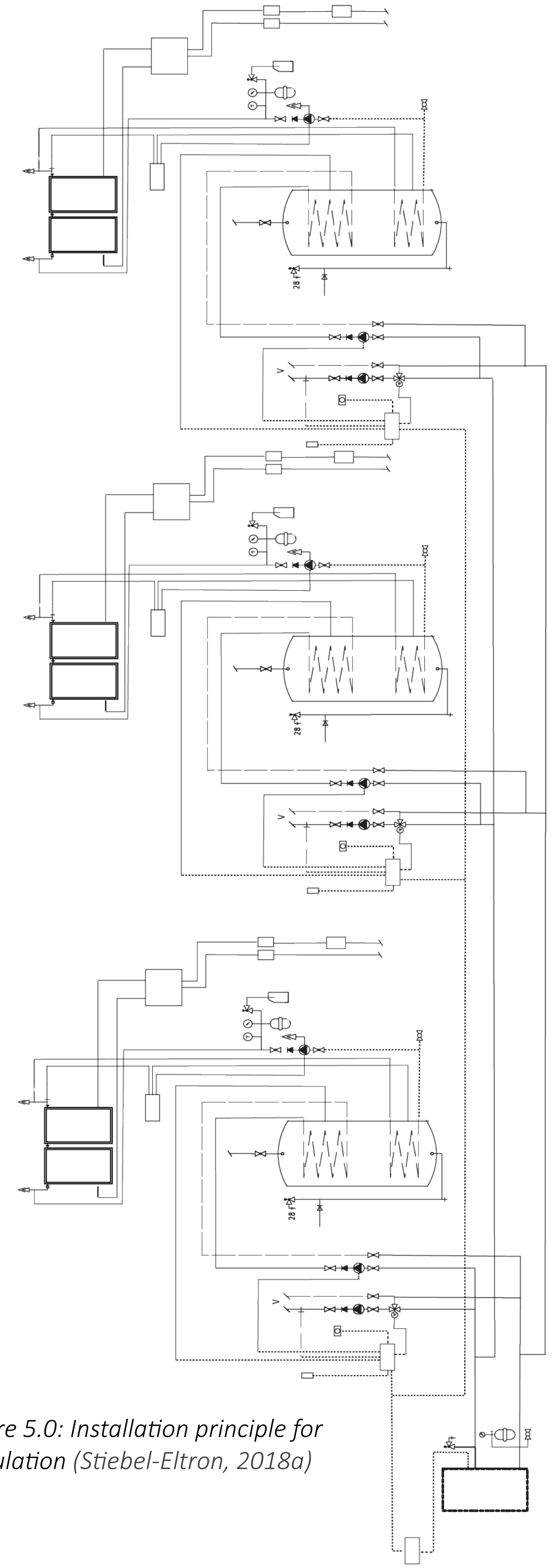


Figure 5.0: Installation principle for calculation (Stiebel-Eltron, 2018a)

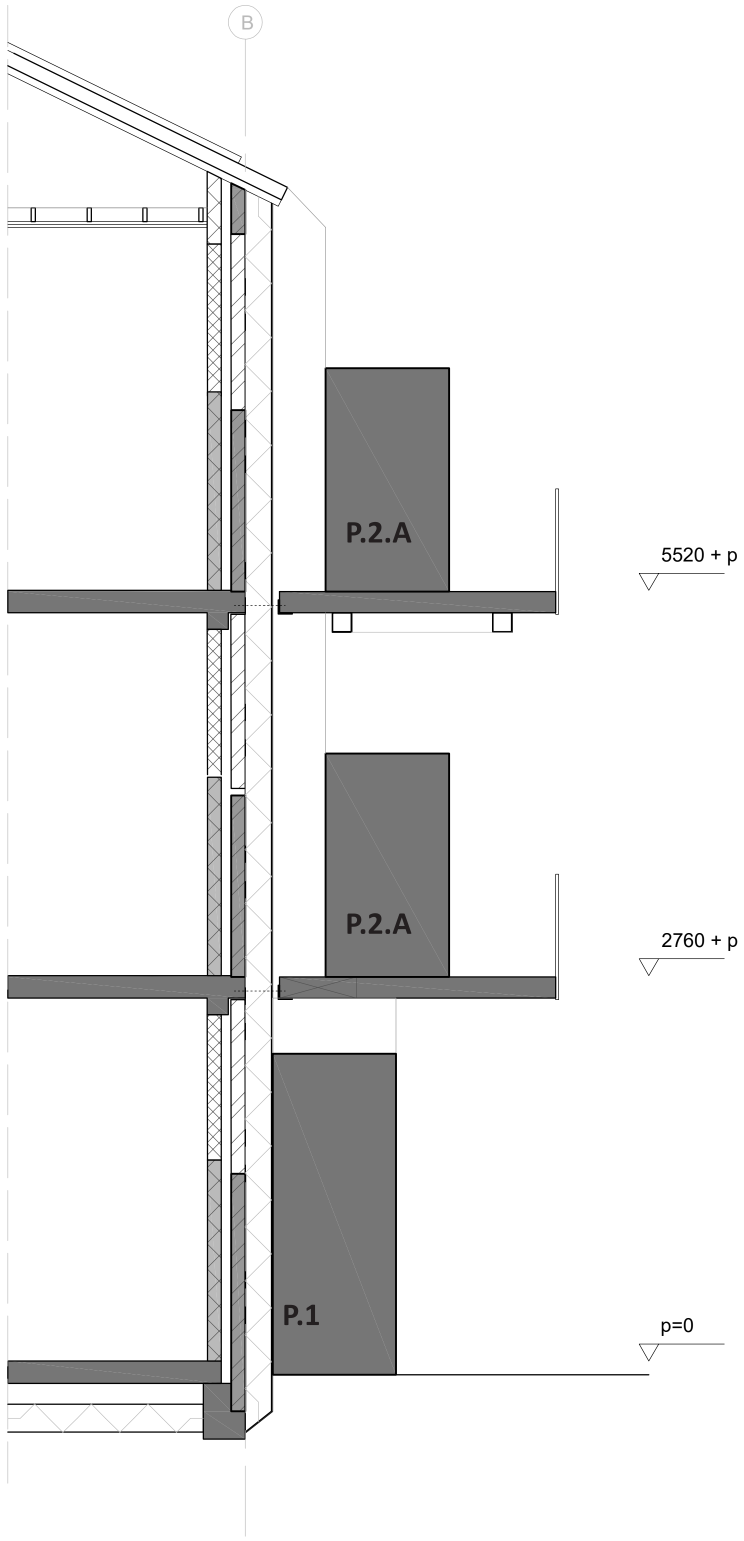
5.1.6 The Concepts

The three concepts are build out of three different floor plans.

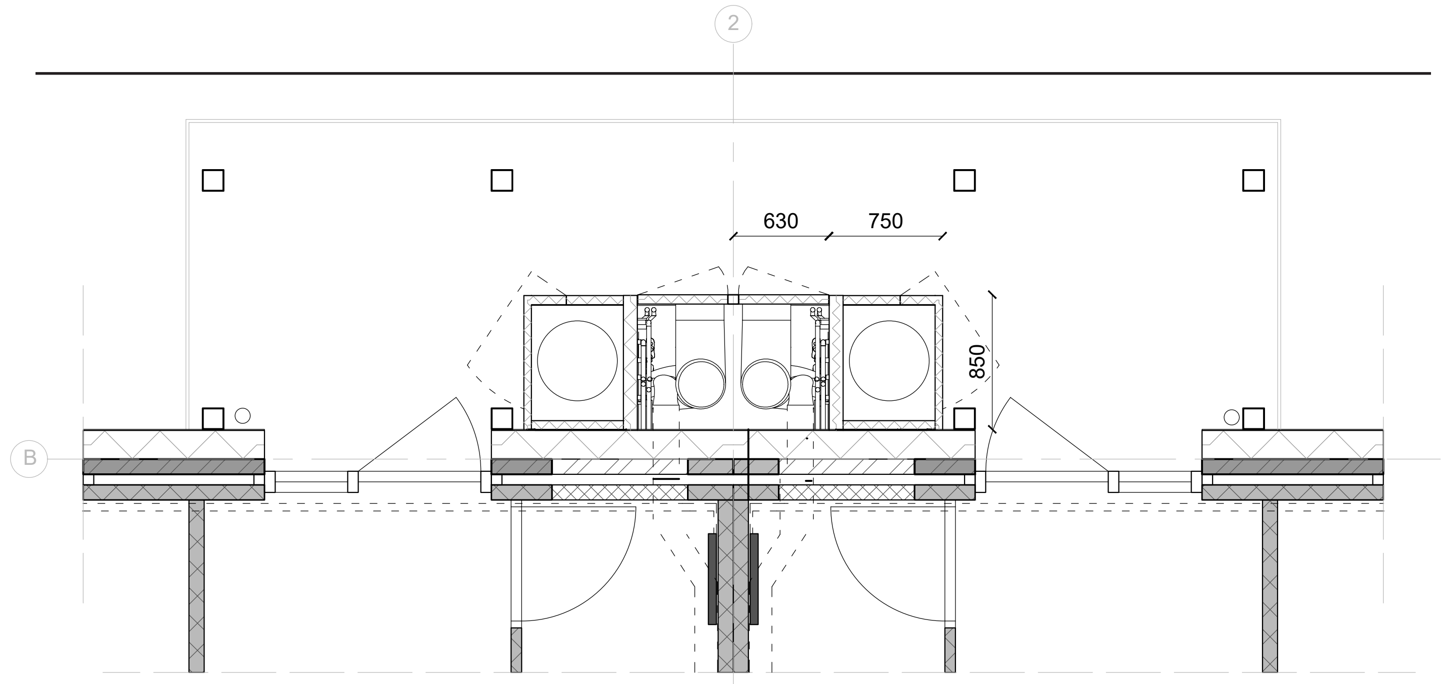
In floor plan P.1 is the shaft placed between the two modules. The two modules on the side contain a heat pump, an buffer tank and the smaller parts needed for the system. The size shaft in the middle has been modeled to fit the air pipe needed for the heat pump. Within the pipe next to the heat pump the ventilation and the outside air are mixed before entering the heat pump.

In floor P.2 the shaft is placed behind the installation. There two versions of this floor plan P2.A and P2.B. P2.A is the version with a buffer tank and the smaller part steaded in the previous paragraph. P2.B has next to the buffer tank an air heat pump. For this version the ventilation is directly connected to the air heat pump. The outside air is brought in through the grill in the door on the side.

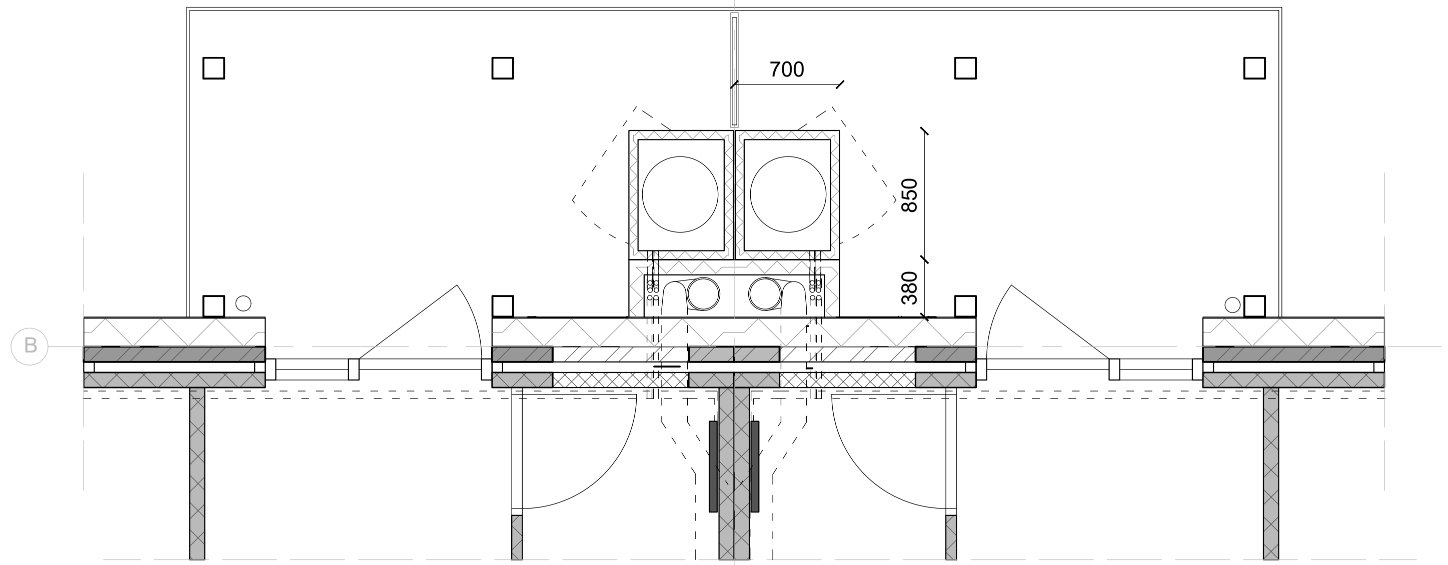
Floor plan P.3. Contains the installations needed for three houses. Because the bigger buffer tank takes in more space the installation has been made bigger.



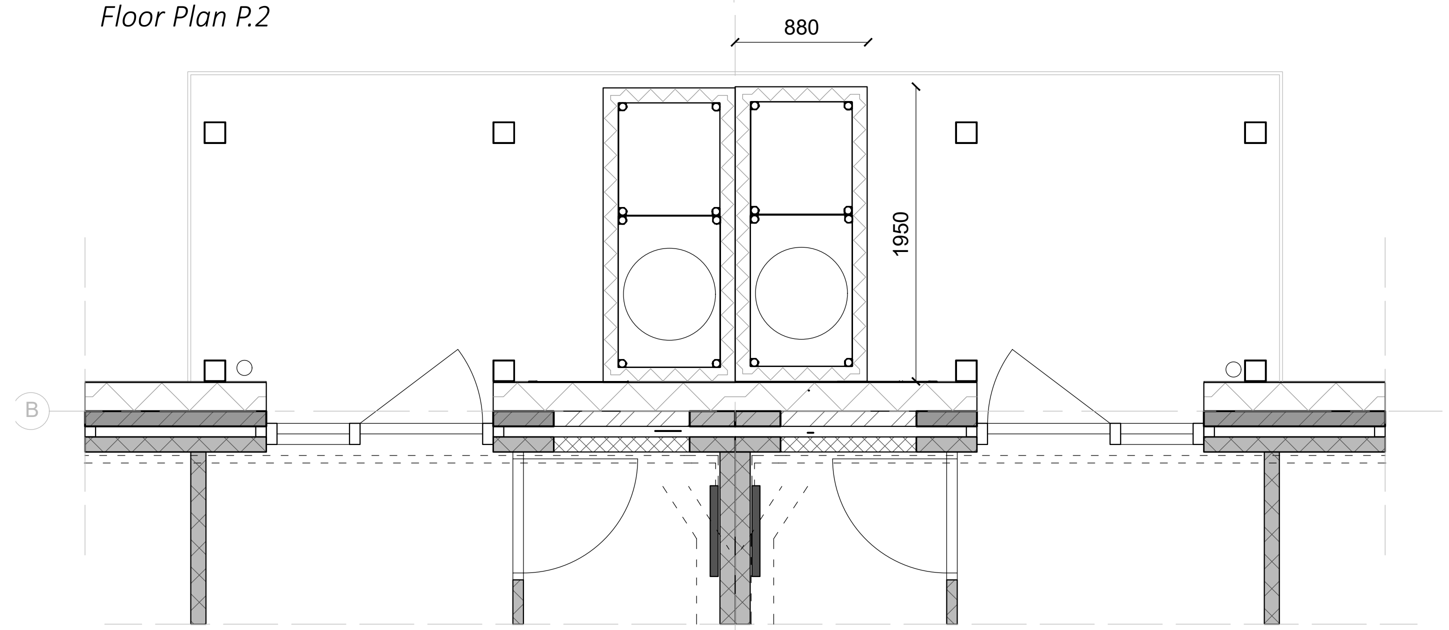
Section Hybride Concept



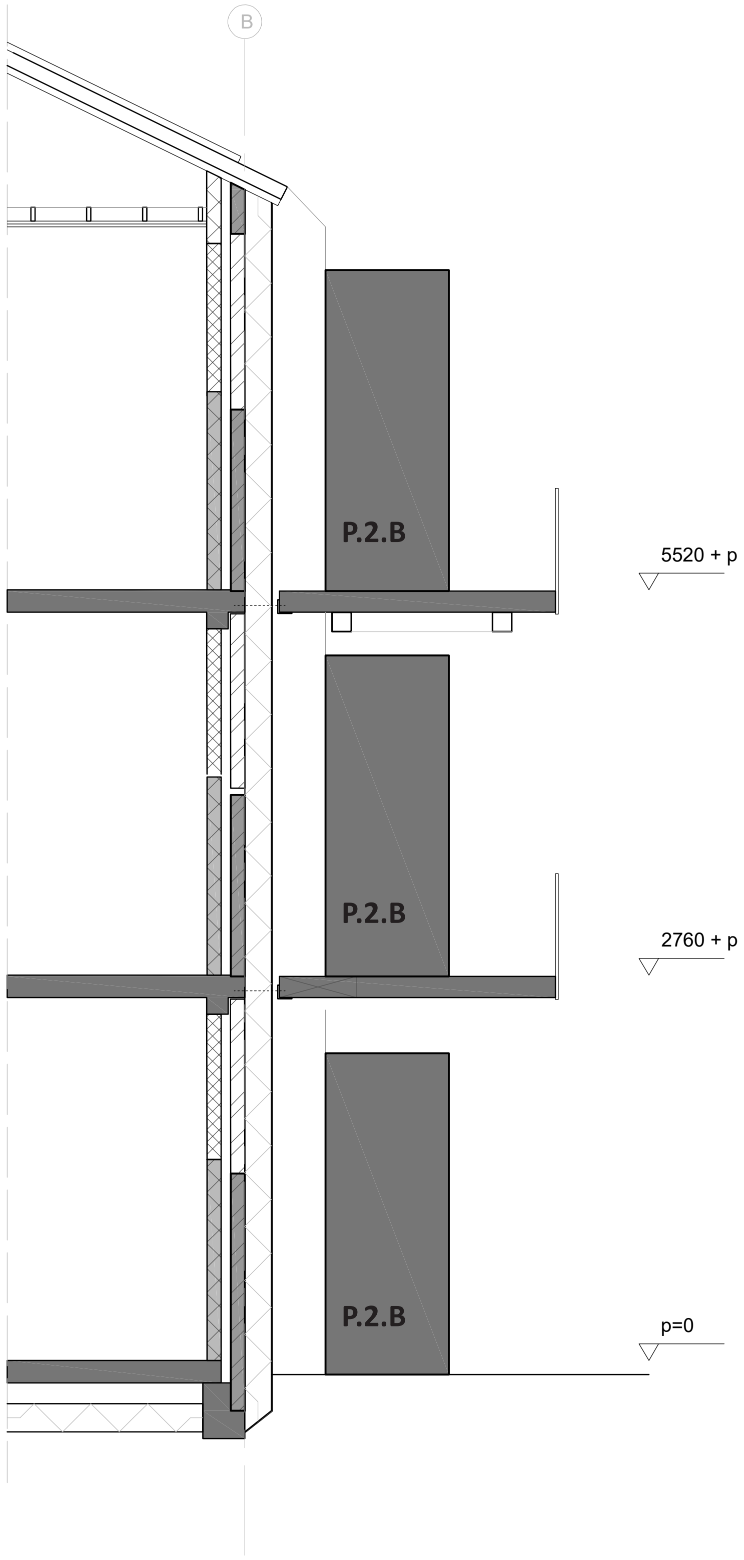
Floor plan P.1



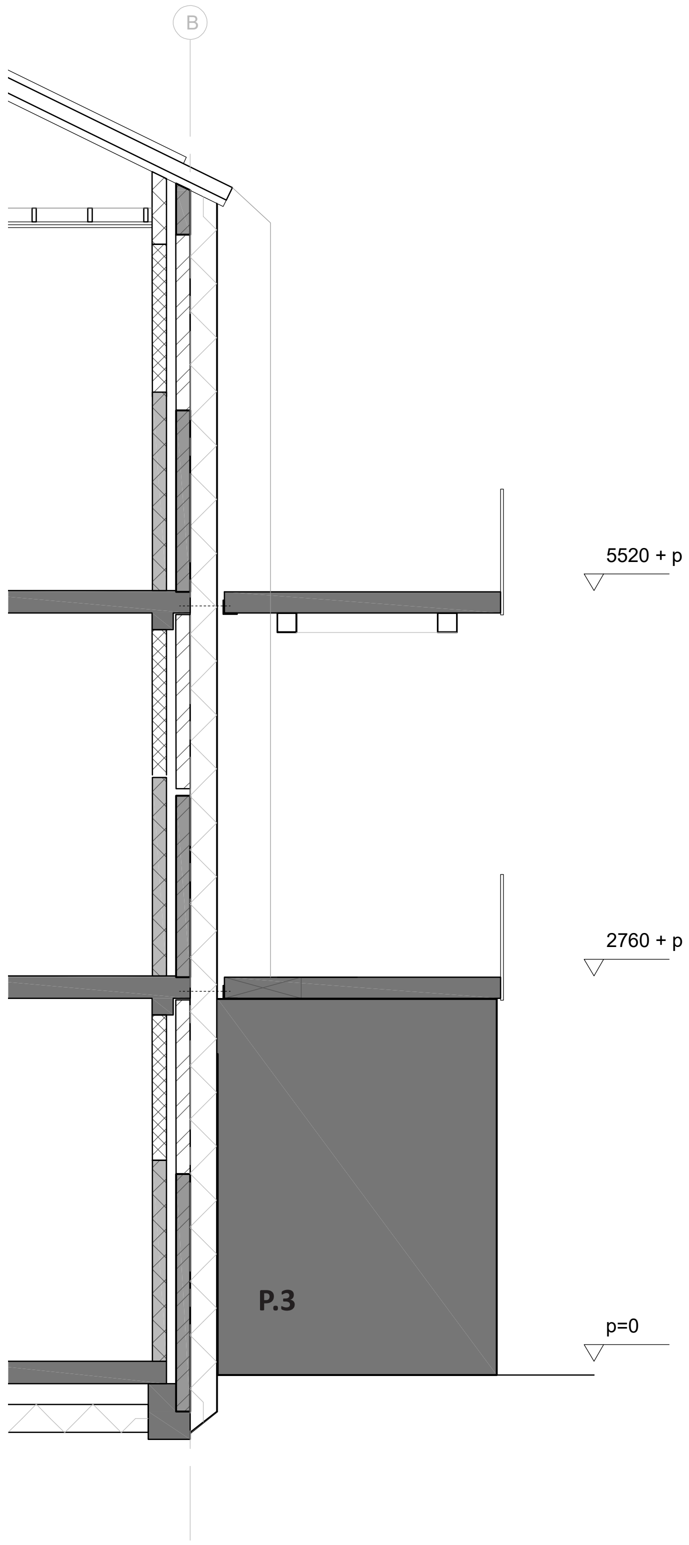
Floor Plan P.2



Floor Plan P.3



Section All- individual Concept



Section All-in-one Concept

5.2 The Demand

Data used in this paragraph:

A_{Closed}	Area	40	m²	*(Boess-S.)*
A_{Floor}	Area	52	m²	*(Boess-S.)*
a_{Sol}	Absorption coefficient of the back of the collector	0,9	-	*(Stiebel-Eltron, 2011)*
A_{Window}	Area	11,7	m²	*(Boess, S.)*
C_{Air}	Specific heat	1.000	J/kgK	*(Janssen & Warmoeskerken, 2006)*
C_{water}	Specific heat	4180	J/kgK	*(Janssen & Warmoeskerken, 2006)*
h_{sol}	Height	0,0093	m	*(Stiebel Eltron, 2011)*
l_{sol}	Length	2,168	m	*(Stiebel Eltron, 2011)*
M_{water}	Weigth water in buffer	150	kg	*(Boess, S.)*
$q_{airflow;\ heat\ pump}$	Air flow needed	1000	m³/h	*(Stiebel Eltron, 2011)*
Q_{inf}	Heatflow by infiltration	0,3 63,7	dm³/sm² m³/h	*(Boess, S.)*
q_{sun}	Solar radiation	569	W/m²	*(Linden, A.C.vd, 2005)*
$q_{ventilation;\ one\ house}$	Ventilation flow	150	m³/h	*(Boess, S.)*
U_e	Heat transfer coefficient	3,42	W/m²K	*(Stiebel Eltron, 2011)*
U_i	Heat transfer coefficient	0,0142	W/m²K	*(Stiebel Eltron, 2011)*
T_{Inside}	Temperature	20	°C	*(Boess-S.)*
T_{water}	Temperature	10	°C	*(Vitens N.V., 2015)*
$T_{Outside}$	Temperature	-7	°C	*(European Commission, 2016)*
ΔT	Temperature increase (60-10)	50	°C	
t_{Sol}	Transmission of the cover	0,8	-	*(Stiebel Eltron, 2011)*
U_{Closed}	Heat transfer coefficient	0,16	W/m²K	*(Boess-S.)*
U_e	Heat transfer coefficient cover solar collector	3,42	W/m²K	*(Stiebel Eltron, 2011)*
U_i	Heat transfer coefficient insulation solar collector	0,0142	W/m²K	*(Stiebel Eltron, 2011)*
U_{Window}	Heat transfer coefficient	1,0	W/m²K	*(Boess-S.)*
v_{sol}	Volume flow	50	l/h	*(Stiebel Eltron, 2011)*
w_{sol}	Width solar collector	1,168	m	*(Stiebel Eltron, 2011)*
ρ_{Air}	Density	1,2	kg/m³	*(Janssen & Warmoeskerken, 2006)*
ρ_{Water}	Density	1000	kg/m³	*(Janssen & Warmoeskerken, 2006)*

Table 5.1: Data for calculations

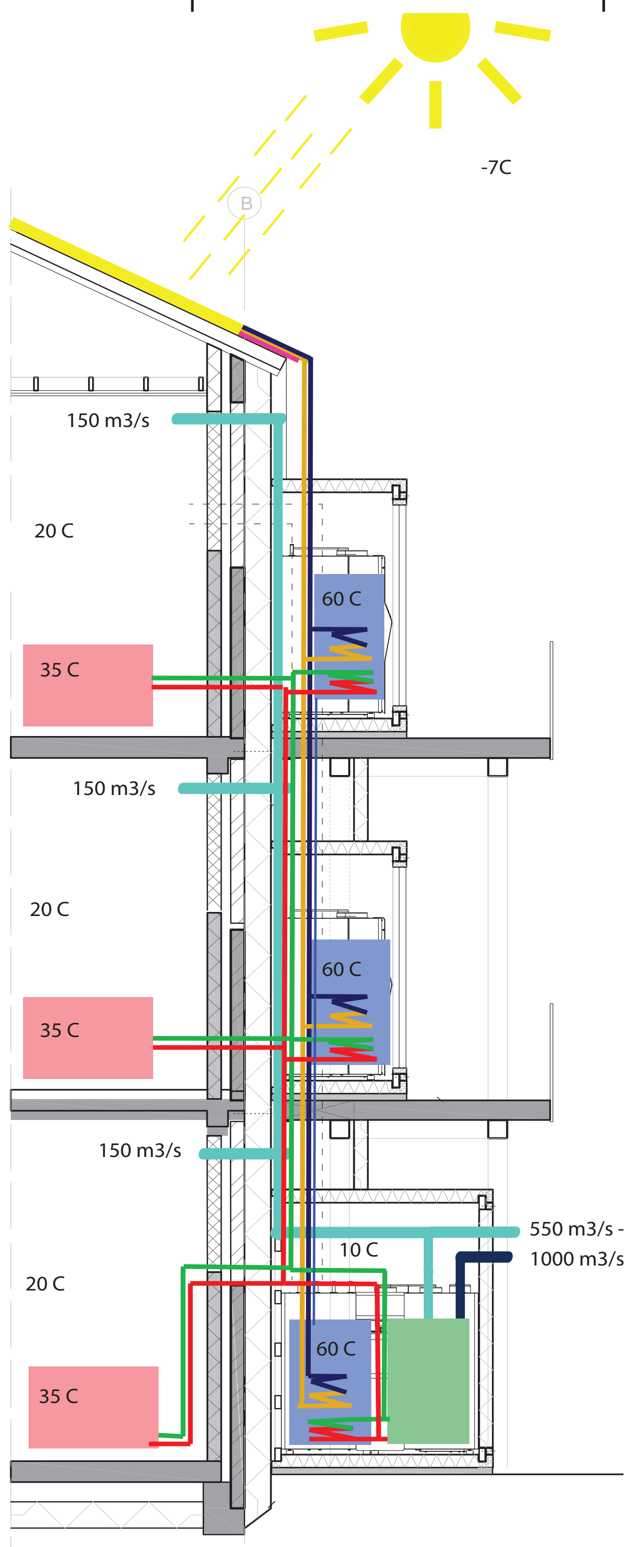


Figure 5.1: Installation principle for calculation

The consc‌epts still needs to be able to provide the required heating, ventilation and warm water. Within this paragraph an estimation of the demand will be calculated on the basis of the requirements of the 2ndskin demonstrator project. This estimation exists out of multiple parts:

- Heat loss inside the houses
- Heat needed form the heat pump
- Temperature increase provided by ventilation
- Heat provided by the solar collector
- Heat needed by the buffer.

Heat demand inside
In order to give an estimation of the heat demand of the houses, the heat losses are used. The heat losses in the house are mainly by ventilation and transmission. Besides the heat losses there are some heat gains by solar radiation and internal energy. But in order to provide the heat demand no matter the situation the heat losses are used in order to have an system that can provided the demand.
In order to calculate the ventilation losses the next calculation was used:

$$Q_{ventilation} = (q_{ventilation} * (1 - \eta_{wtw}) + Q_{inf}) * \rho * c * (T_{inside} - T_{outside})$$

Formula 5.1: Heat-loss by ventilation (Bokel-R, 2015)

When the adding in the numbers from the reference project the $Q_{ventilation}$ ads up to 926 W which is around 18 W/m^2.
Next to the ventilation losses there are the transmission losses. These are calculated with the next calculation:

$$Q_{transmission} = A_{closed} * U_{closed} + A_{window} * U_{window} * (T_{inside} - T_{outside})$$

Formula 5.2: Heat-loss by transmission (Bokel-R, 2015)

$$Q_{heat\ loss} = Q_{transmission} + Q_{ventilation}$$

Formula 5.3: Total heat-loss (Bokel-R, 2015)

The $Q_{transmission}$ ads up to 273 W which is around 5 W/m^2. This means that the total heat loss is 1199 W or 1,2 kW per house. The heat pump thus needs to be able to deliver 1,2 kW per house or at least 3,6 kW per 3 houses.

The $Q_{transmission}$ ads up to 273 W which is around 5 W/m2. This means that the that the total heat loss is 1199 W or 1,2 kW per house. The heat pump thus needs to be able to deliver 1,2 kW per house or at least 3,6 kW per 3 houses. However, there is also a heat gain to take into consider-ation, solar radiation. *(See table 5.2 solar radi-ation in Watt)* Looking at the orientation of the house, starting with the one on the east side, the solar radiation is displayed on the right page. The highest heat gain in summer is 2324,2 W. The highest heat gain in winter is 1791,6. This means that there is a cooling need in summer of 1,1 kW. In the winter there is more solar radiation then heat loss on the middle of the day, if it's a sunny day. Because it's winter, this will not result in a cooling need. But it's also not a heat demand. There is however a heating demand on the other moments of the day. With a radiation of 387,4 W there is still a need for 0,8 kW or 14W/m^2 per house.

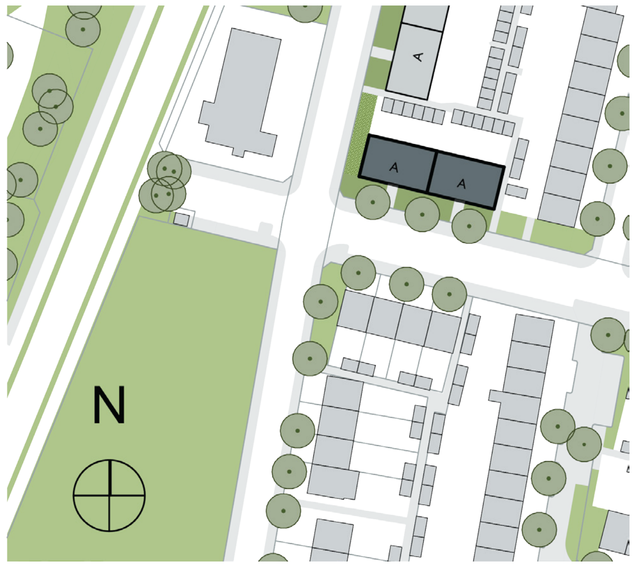


Figure 5.2: Situation (Boess,S. 2017)

Solar radiation
Widows west/east: 3,024 m^2
Windows south: 4,842 m^2
ZTA value: 0,8 W/m^2

West side house: 21 June

	9:00	12:00	15:00
South	300	600	300
South solar intensity	1162,1	2324,2	1162,1
West	-	-	500
West solar intensity			1209,7
Total	1162,1	2324,2	2371,7

Middle house: 21 June

	9:00	12:00	15:00
South	300	600	300
South solar intensity	1162,1	2324,2	1162,1
Total	1162,1	2324,2	1162,1

West side house: 22 December

	9:00	12:00	15:00
South	100	400	100
South solar intensity	387,4	1549,4	387,4
West		100	
West solar intensity		241,9	
Total	387,4	1791,6	387,4

Middle house: 22 December

	9:00	12:00	15:00
South	100	400	100
South solar intensity	387,4	1549,4	387,4
Total	387,4	1549,4	387,4

Table 5.2: Solar radiation in Watt
(Linden-A-C-vd, 2005)

East side house: 21 June

	9:00	12:00	15:00
South	300	600	300
South solar intensity	1162,1	2324,2	1162,1
East	-	-	500
East solar intensity			1209,7
Total	1162,1	2324,2	2371,7

East side house: 22 December

	9:00	12:00	15:00
South	100	400	100
South solar intensity	387,4	1549,4	387,4
East		100	
East solar intensity		241,9	
Total	387,4	1791,6	387,4

Temperature solar collector

The solar collector will deliver some of the heat for tap-water. The amount of tap water is set at 150 L per house. Most of the households in the demonstrator projects consist of two people. Some of them consist of only one person. Looking at table 5.3 the total water use per person is 120 L. Of the 120L, 77,9L is hot tap water. This would mean a total of 155,8 L per day for two persons. But not activities are done at the same time and the buffer will continue the heat during use. Therefor the use is set on 150L per house.

This volume will be partly heated by the solar collector. The temperature that comes out of the solar collector can be calculated using formula 5.4. But, before the temperature can be calculated, a couple of alterations need to be made in order to be able make the calculation with the known information. *(formula 5.5)*

Bath	2,8
Shower	48,6
Sink	5,0
Toilet	33,7
Washing by hand	1,1
Washing machine	14,3
Food preparation	1,4
Dish-washing by hand	3,1
Dishwasher	3,0
Koffie/thee	3,0
Drinking water	0,6
Other	5,3
Total hot water	78,2
Total water	120,1

Table 5.3: Average water use Netherlands *(Vewin, 2011)*

When calculated with the numbers from table 5.1 a temperature of 102 °C comes out. This temperature will be used to heat up the buffer water for tap water. In order to bring the tap water to the desired temperature of 60°C a certain amount of energy is needed. This energy needs to be provided by the solar collector. With a temperature of 102 °C the solar collector can provide enough energy to heat the water. But, how long does this take? This can be calculated by dividing the energy needed to heat the water by the energy delivered by the solar collector. This results in a heating time of 45 minutes. *(formulas 5.7-5.11)*

However, when there is no sun the solar collector does not deliver the energy needed to heat the water. In this case the heat pump can be used to pre-heat the water to around 35°C and a secondary heater will heat the water up to 60°C. Using a formula 5.9 shows that it will then take 3 hours to heat up the entire boiler with an 5 kW boiler and a 2 kW secondary heater. With an 3 kW heat pump and the same heater it will take 3,5 hours

$$T_{Sol;out} = \left(T_{Water} + \frac{a_{Sol} * t_{Sol} - \frac{(T_{Water} - T_{Outside})}{R_e^*} - \frac{(T_{Water} - T_{Outside}}{R_i^*}}{\frac{1}{R_e^*} + \frac{1}{R_i^*}} \right) * e^{-\left(\frac{\frac{1}{R_e^*}+\frac{1}{R_i^*}}{v*h*p*c}\right)} + \frac{a_{Sol} * t_{Sol} - \frac{(T_{Water} - T_{Outside})}{R_e^*} - \frac{(T_{Water} - T_{Outside}}{R_i^*}}{\frac{1}{R_e^*} + \frac{1}{R_i^*}}$$

Formula 5.4 Temperature solar collector (Bokel-R, 2015)

$$T_{Sol:out} = \left(T_{Water} + \frac{a_{Sol} * t_{Sol} - \frac{(T_{Water} - T_{Outside})}{\frac{1}{U_e}} - \frac{(T_{Water} - T_{Outside}}{\frac{1}{U_i}}}{\frac{1}{\frac{1}{U_e}} + \frac{1}{\frac{1}{U_i}}} \right) * e^{-\left(\frac{\frac{1}{\frac{1}{U_e}}+\frac{1}{\frac{1}{U_i}}}{v*h*p*c}\right)} + \frac{a_{Sol} * t_{Sol} - \frac{(T_{Water} - T_{Outside})}{\frac{1}{U_e}} - \frac{(T_{Water} - T_{Outside})}{\frac{1}{U_i}}}{\frac{1}{\frac{1}{U_e}} + \frac{1}{\frac{1}{U_i}}}$$

Formula 5.5 Temperature solar collector (Bokel-R, 2015)

$$102 = \left(10 + \frac{0{,}9 * 0{,}8 - \frac{(10 - -7)}{\frac{1}{3{,}42}} - \frac{(10 - -7)}{\frac{1}{0{,}0142}}}{\frac{1}{\frac{1}{3{,}42}} + \frac{1}{\frac{1}{0{,}0142}}} \right) * e^{-\left(\frac{\frac{1}{\frac{1}{3{,}42}}+\frac{1}{\frac{1}{0{,}0142}}}{\frac{50}{1000*3600}*0{,}0093*1*4180}\right)} + \frac{0{,}9 * 0{,}8 - \frac{(10 - -7)}{\frac{1}{3{,}42}} - \frac{(10 - -7)}{\frac{1}{0{,}0142}}}{\frac{1}{\frac{1}{3{,}42}} + \frac{1}{\frac{1}{0{,}0142}}}$$

Formula 5.6 Temperature solar collector (Bokel-R, 2015)

$$Q_{buffer} = M_{water} * c_{water} * \Delta T_{buffer}$$

Formula 5.7 Energy Buffer (Akker & Mudde, 2008)

$$Q_{sol} = M_{sol} * c_{water} * \Delta T_{sol}$$

Formula 5.8 Energy Solar collector (Akker & Mudde, 2008)

$$Q_{sol} = l_{sol} * w_{sol} * h_{sol} * c_{water} * \Delta T_{sol}$$

Formula 5.9 Energy Solar collecto (Akker & Mudde, 2008)

$$t = \frac{M_{water} * c_{water} * \Delta T_{buffer}}{l_{sol} * w_{sol} * h_{sol} * c_{water} * \Delta T_{sol}}$$

Formula 5.10 Heating time (Akker & Mudde, 2008)

$$t = \frac{150 * 4180 * 50}{1{,}5 * 2{,}168 * 0{,}0093 * 4180 * (101{,}8 - 10)} = 2701\,\text{sec} = 45\ min$$

Formula 5.11 Heating time (Akker & Mudde, 2008)

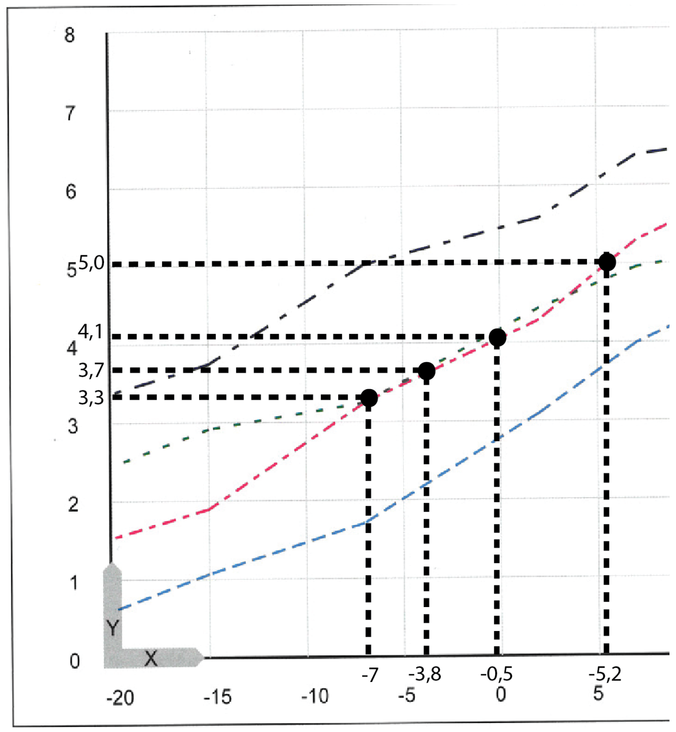
Source temperature heat pump

In order to provide the heat demand inside and warm tap-water when there is no sun, there is a certain capacity needed. The heat demand from the houses is 0,8 kW per house and 2,4 kW per three houses. The heat pumps on the market come with a certain capacity. On the low end there are the 1,5 kW, 3 kW and 5 kW heat pumps. in order to ensure that the demand is met, there will be either a 1,5 kW heat pump per house or a 3 kW pump per 3 houses.

The proposed system uses both ventilation air and outside air as a source for the heat pump. Because of this the source temperature will be slightly higher then the outside temperature. In order to calculate that formula 5.12 is used:

Putting in the temperatures and airflows the average source temperature would be 5,2°C. This temperature is calculated using a $q_{Ventilation;total}$ that is used for the design of the system. In practice this number can be lower during some parts of the day. This means that the average source temperature as well. If the total ventilation would only be the required ventilation flow per person per house (20 dm³/s) then the source temperature would be -0,5°C if all houses where two person households and -3,8°C if all the houses would be one person house hold.

Looking at the heat flow of the heat pump the capacity increases when the temperature is higher. Even then absolute minimum air flow already raises the heat capacity with 0,5 kW. The capacity with the design air flow of 150 m³/h per house is actually enough to still meet the heat demand at -7°C, without using the secondary heater.



X Outside Temperature

Y Capacity heat pump

4 Central heating temperature 35°C no heat recovery system

3 Central heating temperature 35°C with heat recovery system

2 Central heating temperature 55°C no heat recovery system

1 Central heating temperature 55°C with heat recovery system

Figure 5.2: Heat pump capacity and outside temperature (Stiebel Eltron, 2016)

$$T_{Average} = \frac{(T_{Inside} * q_{Ventilation;3\ houses}) + (T_{outside} * (q_{Airflow\ heat\ pump} - q_{Ventilation;3\ houses}))}{(q_{Airflow\ heat\ pump})}$$

Formula 5.12 Heating time (Akker & Mudde, 2008)

$q_{ventilation;\ total}$	$q_{Airflow\ heat\ pump}$	$q_{Airflow\ from\ outside}$	T_{Inside}	$T_{Outside}$	$T_{Average}$
450	1000	550	20	-7	5,2
240	1000	730	20	-7	-0,5
120	1000	880	20	-7	-3,8

Table 5.4: Source Temperature heat pump

Next to the increase in capacity, the higher source temperature also means that the heater will freeze over less. But, if it does the ventilation air can be used in order to defrost it. Which together with the higher capacity decreases the amount of electricity needed by the system. Which increases the efficiency of the system.

Conclusion

Heat demand per house	0,8 kW
Cooling demand	1,1 kW
Heat demand per 3 houses	3,6 kW
Temperature from solar collector	102°C
Heating time 150L buffer boiler with solar collector	45 min
Heating time buffer boiler no sun	3 to 3,5 hours
Capacity heat pump, per 1 house	1,5 kW
Capacity heat pump, per 3 houses	3 kW

Table 5.5: Conclusion calculations

5.3 Design proposal

5.3.1 Accessibility

The system comparison has shown that the empty spaces around the installations are there for maintenance and the placing of the installations. However, it also shows that it's possible to have an installation that can be maintained and installed without this extra space.

For the design proposal the LWZ 304 SOL is used as basis. Even though this system has no empty space between the installations, the installation guide still requires allot of space around the module. One way to decrease the space around the installation can be learned from the Nefit energy bar: decreasing the amount of sides with connections. In order to this, a closer look has been taken at the LWZ module.

Currently the connections are mainly paced on the top, the right side and the back of the module. Because most connections are placed on top near the back. It would make sense to bring either all connections to the top, or the back. First a look is taken at the connections at the right side. These are the connections towards and from the solar collector and two condense drains. *(Stiebel Eltron, 2016a, 2018a)* Looking into the module it's clear that the connections can be brought to the back by adding an extra bend before the pipes leave the unit. If the connections need to go to the top, they cannot go through the inside of the module. Above the current placement of the connections there is the heat pump. So, the connection will have to be guided up from the outside up, which is not ideal for condense drains. However, the exact other end of these is unclear. So, the condensation pipes can be redirected to the back. But not to the top.

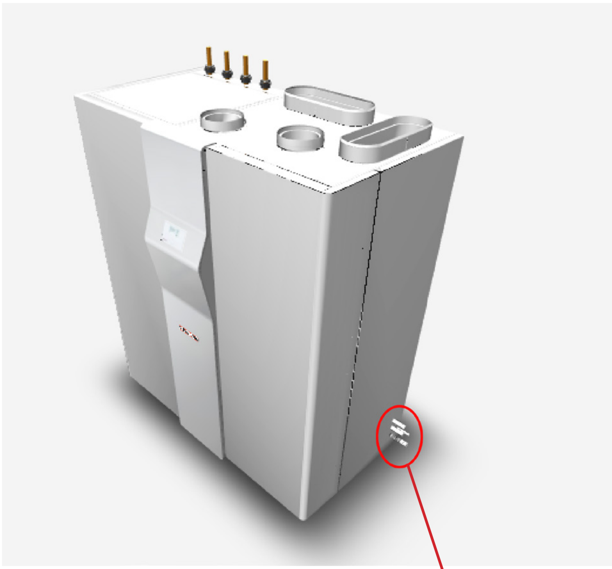


Figure 5.3: Perspective of the LWZ (Stiebel-Eltron, n.d.)

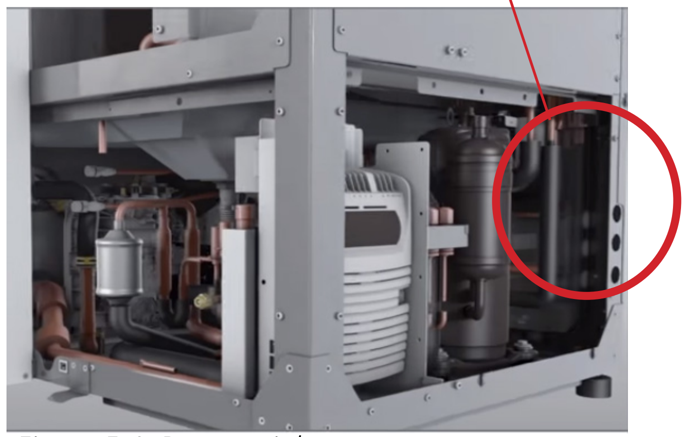


Figure 5.4: Bottom right corner of the LWZ

On the top right there are four connections:

1. Air supply heat pump
2. Air used by the heat pump
3. Air supply heat recovery ventilation unit.
4. Air used by the heat recovery ventilation unit

Because no heat recovery ventilation unit will be used connections 3 and 4 will not be needed for the design proposal. Looking at the air supply to the heat pump from where it comes in to where it needs to end up, the location of the pipe between those points becomes clear. The only place where it can be is behind the heat recovery unit. This means that its already placed at the back of the installation. So, it would be possible the make the connection towards the back as well.

At the back there is another condensation pipe and the connection to the electrical panel which is placed at the right side. The electrical supply can be easily redirected from the top to the bottom. Due to the problem of the condensation pipes it is possible to either have all the connections at the back or all the connection except for the condensation pipes at the top.

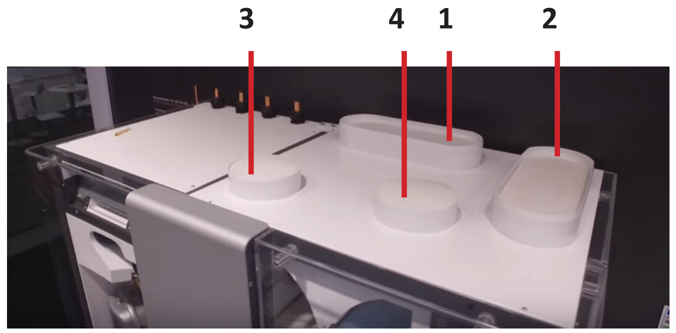


Figure 5.5: see-trough LWZ model (Stiebel Eltron, 2016b)

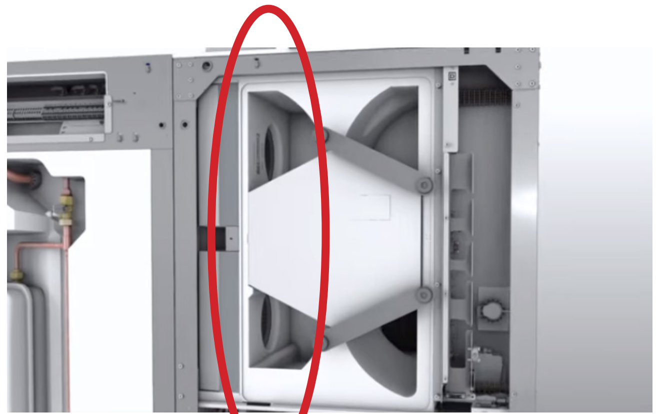


Figure 5.6: see-trough LWZ model (Stiebel Eltron, 2016b)

Figure 5.7: see-trough LWZ model (Stiebel Eltron, 2016b)

The four connections at the top left come with a mystery, when looking at the schematic representation of the module from the installation guide there are five connections instead of four. The installation guide has stated that this is the “zirkulation” pipe. The pipe is connected to the hot water outlet and helps to improve the circulation of hot water. The second pipe from the left is for the cold-water supply, this one is first directed downwards and then connects to the buffer at the front of the module. The third pipe is the tap water supply and is connected to the front of the buffer. The two pipes on the left are the connections for the central heating. These are connected in the front towards the bottom right. (see red circle figure 5.11)

Figure 5.8: see-trough Perspective of the LWZ (Stiebel-Eltron, n.d.)

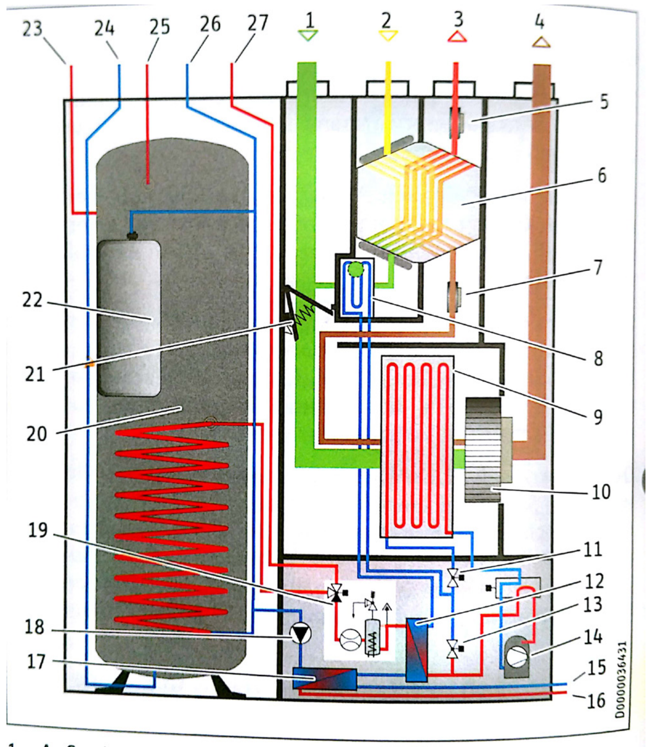


Figure 5.9: see-trough the schematic representation of the LWZ (Stiebel-Eltron, n.d.)

Figure 5.10: Top view Buffer (Stiebel-Eltron, 2015)

Figure 5.11: Open view LWZ (Stiebel-Eltron, 2015)

In order to decide the placement of the connections a look needs to be taken at the placement of the module. In the current demonstrator project, the cupboards are placed back to back perpendicular to the façade. If the new modules would be placed this way there would need to be some space in between the modules for the condensation pipes. According to the installation manual there needs to be 200 mm of space behind the installation. In terms of empty space this would mean that there would be very little. However, the ventilation pipes on top still take in quite some space and in case of the hybrid option they need to be able to come from the top floor and go down to the heat pump at the ground floor. This means that space must be made to place these pipes in order to bring in enough air for the heat pump to work with, without making extra noise by turbulence. For this reason, the pipe has an inner diameter of 300 mm. The other diameter is a bit bigger because of the insulation places around it, in order to prevent heat loss.

Also, what still needs to be taken into an account is the fire safety. The pipes that go between installations need to designed in a way that prevents fire from traveling through the pipes to a different house. The Dutch building code states that a pipe or shaft that goes through multiple houses needs to be a level A2 according to the NEN-EN 13501-1. This means that the materials used should not add to the fire during a fully developed fire. This means that the materials used around the pipes should be practically inflammable.

Figure 5.12 2ndskin demonstrator rear façade (Boess,S. 2017)

In order to adhere these regulations the decision was made to place the pipes in a shaft between the modules. In order to prevent fire from traveling in to the shaft by the ventilation pipes, non-return valves are installed in the transitional area between the house and the shaft. Because adding a shaft also added a lot of pace between the models. The decision was made to place all the connection at the back of the modules. Doing this has let to another opportunity, to decrease the floor space taken in by the installation.

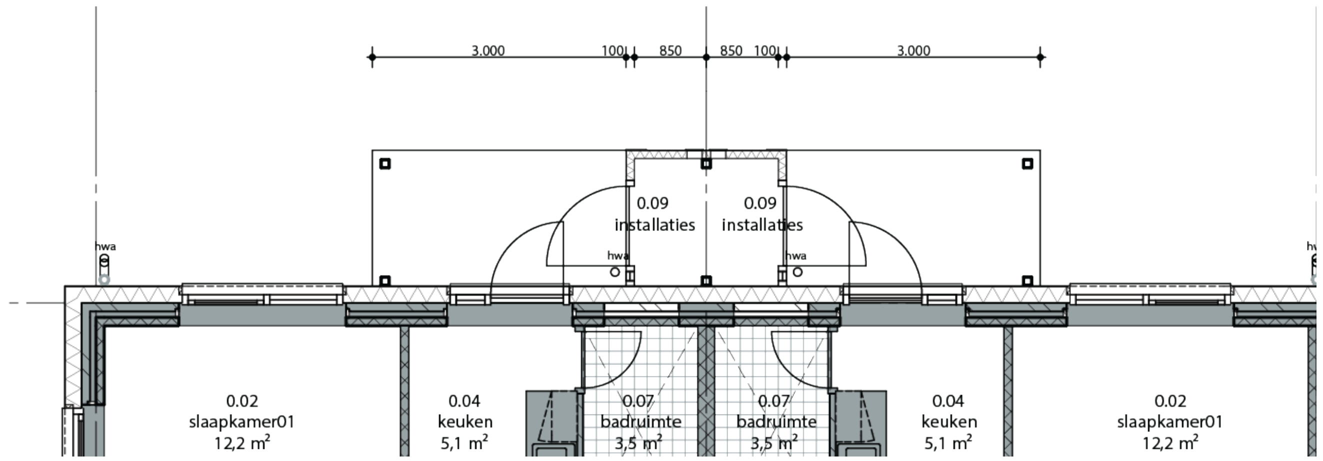


Figure 5.13 2ndskin demonstrator floor plan installations (Boess,S. 2017)

The LWZ 304 SOL unit of Stiebel Eltron has a heat recovery unit and a buffer tank of 235 L. Because the design proposal doesn't use a heat recovery unit and only uses a tank of 150 L the installation can be made smaller. Without the ventilation unit the right part of the unit can be reduced to a height of 1100 mm. Looking at other buffers from Stiebel Eltron, like the KS SOL 150. The left part can also be reduced to this is height. Because the height can be decreased this much it's also possible to steak the parts on top of each other. The height will be 2200 mm without the covering. With the covering it will be around 2400 mm. This means that the module will be slightly too big to be transported by truck. The maximum height for being transported is 2400 mm, but this includes the transport pallet. With would make the unit with covering around 2500 mm. Therefore the unit still needs to be transported in two parts.

This stacked version of the unit will be used for the all-individual concept and the hybrid option. For the all-in-one option the right part will be 1100 mm, but the right part still needs to be 1885 mm in order to store the water for three houses. The height will not be increased when going from 235 l to 450 l. The reason for this is transport. Because of this the left part will have a bigger width and depth.

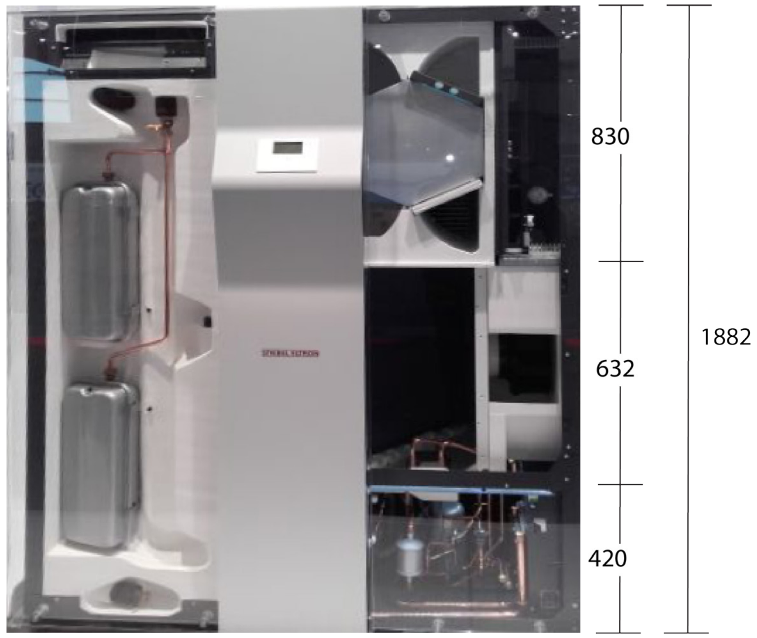


Figure 5.14: S6ee-trough LWZ model (Stiebel Eltron, 2016b)

Figure 5.15: Open view LWZ (Stiebel-Eltron, 2015)

5.3.2 Construction and covering.

The basic construction of the module stays the same, however, because of the choice to stack the modules the construction pipes have been made thicker in order to be still able to carry the installation and the new covering. As for the covering, a difference can be made between the shaft and the covering for the installation. The shaft will be treated as a small fire compartment, while this is not required of the installation covering. The installation covering however, needs to provide some sound insulation.

For the shaft the covering will exists out of a of a 12 mm plaster board on the inside, with PE-foil, 100 mm of insulation, and the desired outside cladding. This outside layer can be customized by project. For the design proposal focused for the demonstrator project a stucco layer is suggested. The shaft also has a door, this door needs to be 30 min fire resistant. For the detailing its important to ensure that the door always fully closes. The construction of the shaft will be made of wood like the original construction of the demonstrator cupboards. *(Figure 5.16)*

For the covering of the installations the most important attribute is sound insulation. As seen in the system comparison the Stiebel Eltron unit has already integrated many measures to reduce the sound. For the covering however, there are still some possible improvements to be made. On order to limit contact sounds the covering will be connected using the principle draw in figure 5.17. The area drawn in black is made of rubber in order to insulated the contact sounds. The placement of the sound insulation is inspired on the Meford heat pump cast. *(Merford, n.d.)(Figure 5.18)*

Figure 5.16: Building the cupboard (B.I.K Bouw, 2018)

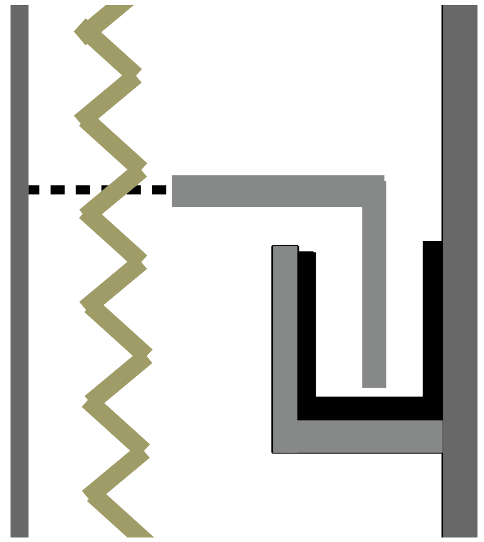


Figure 5.17: principle acoustic detail

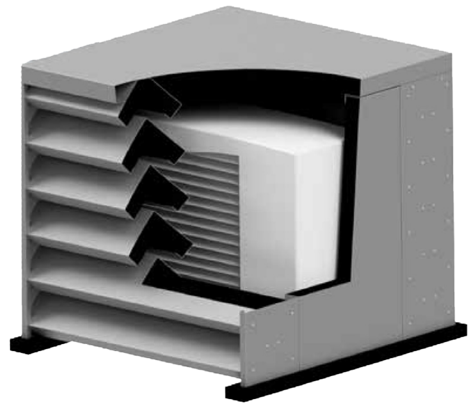
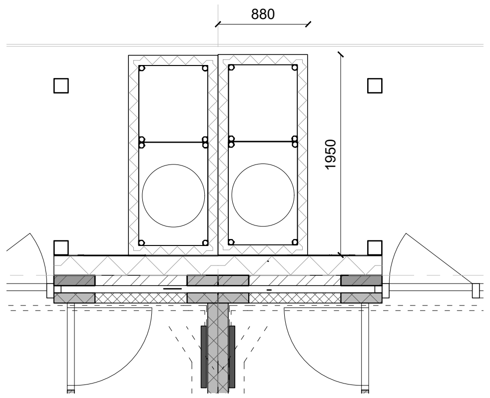


Figure 5.18: Meford cast

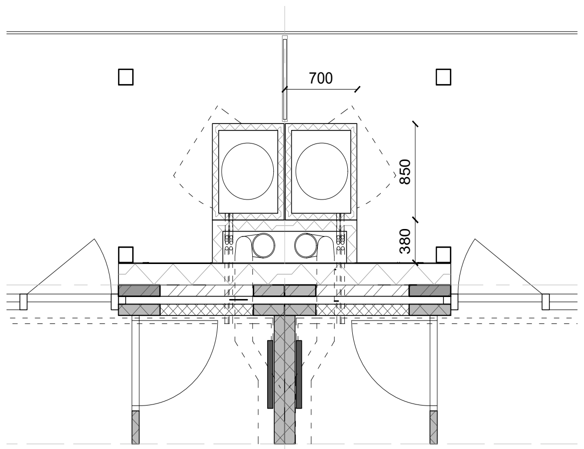
They claim to be able to bring down the sound intensity by 15 dB. Whether this is true or not, the cast uses design tools that have been proven to increase sound insulation: (Leijendeckers et al., 2000; US Office of Planning, 2017)

- There is no inner layer between the insulation which means the sound can be directly absorbed by the insulation
- Angling down the an out/inlet lined by insulation.

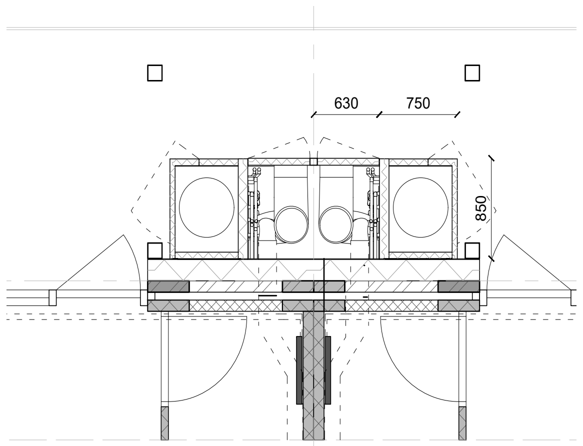
These design tools will also be used to increase sound insulation. The inside of the covering of the installation will be lined with 60 mm polyester wool insulation and the rooster of the outlet and inlet of the air will be angled down and lined with polyester wool as well
Just like the LWZ module the front panel will be able to swing open like a door for installation and maintenance purposes.



Floor Plan P.3



Floor Plan P.2



Floor Plan P.1

The construction of the balcony
With the installation, construction and covering a rough estimation can be made about the possible weight of the modules and shafts on the balconies. This estimation comes out on around 400 kg. One of the aims of this thesis is to decrease the weight of the installations so there would be less construction needed. Because of the mess and the time it takes to remove the balconies, the possibility of being able to place the installations on the existing balconies would create possibilities, not only for porch houses but also for upscaling to apartment buildings. However, the Eurocode: NEN-EN 1991-1-1 National annex states that dependent on the state of the building an existing balcony can carry around 200 to 300 kg per m^2. For balconies build post-war this number will most likely closer to 200 then 300. It's clear that the existing balcony cannot carry the installation. It will also be doubtful if the new balcony can carry the installations without the extra foundation. This will depend on the condition of the existing floor and walls. But according to the estimation by the Eurocode it will be unlikely that it can carry 400 kg with 1 m^2.

5.3 Conclusion

The installation module is almost half the size of the LWZ module. But, when the shaft is taken into account. The total size is much bigger. Also in the bottom of shaft there is still an empty space of 0,78m x 0,6m 1,0m . This empty space was created by the need for space for the ventilation pipes. These pipes need to be this size at the bottom for the need of the heat pump and to decrease turbulence. This space could possible be used for storage by the users.

Looking at the total volume of the design proposal it is slightly bigger then the LWZ module from Stiebel Eltron. However, this is including the shaft that is needed for the installations.

Size
Floor plan P.1

	Length	Depth	heigth	Volume
Installation	0,75 m	0,85 m	2,2 m	1,40 m^3
Shaft	0,63 m	0,85 m	2,4 m	1,28 m^3
Total				2,69 m^3

Floor plan P.2A

	Length	Depth	height	Volume
Installation	0,70 m	0,85 m	1,4 m	0,72 m^3
Shaft	0,70 m	0,38 m	2,4 m	0,46 m^3
Total				1,47 m^3

Floor plan P2.B

	Length	Depth	height	Volume
Installation	0,70 m	0,85 m	2,2 m	1,31 m^3
Shaft	0,70 m	0,38 m	2,4 m	0,64 m^3
Total				1,95 m^3

Weight:
Floor plan P.1 600 kg +/-
Floor plan P.2A 400 kg +/-
Floor plan P.2B 600 kg +/-
Floor plan P.3 800 kg +/-

The ground pump module and shaft are approximately the same weight as the LWZ unit. The units of the higher floors are around 400 kg. Because the balconies can only carry between 200 and 300 kg an extra construction is needed to carry the installations.

Floor plan P.3

	Length	Depth	height	Volume
Installation	0,88 m	2,0 m	2,4 m	5,0 m^3
Total				5,0 m^3

Properties:

Heat demand per house	14 W/m^2
Heat demand per house	0,8 kW
Cooling demand	1,1 kW
Heat demand per 3 houses	3,6 kW
Temperature from solar collector	102^{o}C
Heating time buffer boiler with solar collector	45 min
Heating time buffer boiler no sun	3 to 3,5 hours
Capacity heat pump, per 1 house	1,5 kW
Capacity heat pump, per 3 houses	3 kW

6. Conclusion and Discussion

How can the building services be more efficiently integrated into an 2ndskin porch house renovation?

The building services can be more efficiently integrated by:

- Decreasing the empty space around the installations
- Decrease the amount of sides with connections
- Not using a heat ventilation recovery unit.
- Decrease the sound intensity by using insulation according to the following design principles
    - Preventing contact sounds
    - Place insulation directly around the installations in open spaces.
    - Place insulation on the inside of the covering
    - Angle the air outlet and inlet from the heat pump downward.

The final design proposal shows a possibility to decrease the size of the building services by implementing these points. This design shows that the size can be decreased around 50% and the weight can be decreased between the 250 kg and the 450 kg. However, this is not enough to completely leave out the extra foundation for the balcony, when these installations are placed on it. The only solution where it is possible is the all-in-one unit. By placing all the installations on the ground floor, there is limited weight on the balconies.

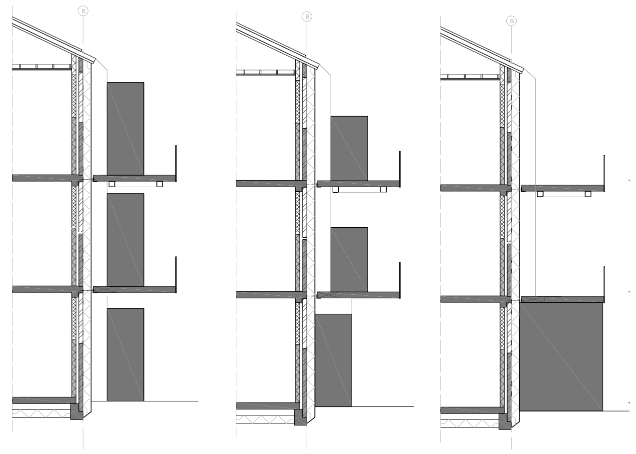
The most improvement has been made by decreasing empty spaces and redirecting the connections to one side. This has been done while still making it possible the install and maintain all the installations. Together with the elimination of the heat recovery ventilation unit this made it possible to make the module smaller and decrease the foot print of it. This was only possible because of the small buffer.

As the system comparison show, a lot of installations on the market are around a certain size. This is because that is usually the most optimal size for that installation. However, the sizes do make it harder tot integrated the installations. This reason in combination with the placement of the connections and the need to be able to access these connections for maintenance and installation, leads to empty spaces. If not inside the module, then around the module. The design proposal has limited the space needed. But there is an empty space in the shaft thats the result of this and the size of the ventilation pipes. Even placing the shaft on top of he installations, as is done by the all-in-one unit still results in some empty spaces.

For this thesis there where three concepts made. All three of these concepts had different aims. For the all-individual the most important aim was the have individual monitoring and a individual buffer. The hybrid option is similar to the demonstrator system the residents had there own buffer. But they share the heat pump. Lastly in the all-in-one concept they share both the buffer as well as the rest of the installation.

The results are state in table 6.1. Looking at the individual units the individual concept comes out the best looking at the properties that have been the main focus of this thesis. All of the concept are smaller as a total concept in comparison to the 2ndskin cupboard.

However, even these three concept still contain empty space. even though it was the focus to decrease it. These empty spaces are all in the shafts, an area that not so dominant in the compared systems. But even with this space this research has shown that it is possible to decrease the space and weight of the installations when designing from within the installations instead of around it.



	Individual	Hybrid	All-in-one
Size biggest unit	1,95 m^3	2,69 m^3	5,0 m^3
	++	+	--
Empty spaces	-	--	-
Connections pipes	++	++	+
Weight	600 kg	600 kg	800 kg
Individual monitoring	++	+	-

Table 6.1

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Appendices

A.1 Company list

nr.	bedrijven	subsidie op 1 of meerdere producten	strooomversnelling	Duidelijke productenwebsite	Nederlands	Vindtbaar duurzaamheids project	Niet de levancier	top 5	Back up opties
61	itho Daalderop	1	1	1	1	1		1	
65	LG climate solutions	1	0	1	1	1		1	
73	Nefit	1	0	1	1	1		1	
95	Stiebel- Eltron	1	0	1	1	1		1	
60	inventum	1	1	1	1				1
40	Enerso	1	0	1	1				1
62	Keyter	1	0	1	1				1
67	Mastertherm	1	0	1	1				1
68	MDV	1	0	1	1				1
76	NIBE	1	0	1	1				1
96	Techneco	1	0	1	1				1
98	TechniQ-Energy	1	0	1	1				1
28	Dimplex	1	0	1	1				0,5
1	ADG Dynamics	1	0	1	0				
2	Aerfor	1	0	1	0				
3	Aermec	1	0	1	0,5				
4	Air Trade Centre	1	0	1	1				
5	Airwell	1	0	1	1				
6	Alpha innotec	1	0	1	1	1	0,5		
7	Alto refrigeration	1	0	0	0				
8	ACR	1	0	1	1		0		
9	Ariston	1	0	0	0				
10	Artel	1	0	1	1				
11	Atlantic	1	0	1	0				
13	Austria Email	1	0	0	0				
14	AWB	1	0	1	1				
15	Buderus	1	0	1	1				
16	Bulex	1	0	1	0				
17	Carrier	1	0	1	1		1		
18	Ciat	1	0	1	1		1		
19	Clage	1	0	0	0,5				
20	Climaveneta	1	0	0	0		0		
21	Climer	1	0	1	1		0,5		
22	Clint	1	0	1	1		0		
23	Clivet	1	0	1	1		0		
24	Copper&Hunter	1	0	0,5	1		1		
25	CTC	1	0	0	0				
26	Daikin	1	0	1	1				
27	Danfoss	1	0	0	1				

nr.	bedrijven	subsidie op 1 of meerdere producten	stroomversnelling	Duidelijke productenwebsite	Nederlands	Vindtbaar duurzaamheids project	Niet de levancier	top 5	Back up opties
29	Domusa Teknik	1	0	1	0				
30	Duco	1	0	1	1				
31	Ecoforest	1	0	0	0				
32	Ecopomp	1	0	1	0				
33	Ecoteq	1	0	1	1				
34	Elco	1	0	0	1				
35	Eldom	1	0	0	0,5				
36	Emmeti	1	0	0,8	0				
37	Eneco	1	1	0	1				
38	Energie EST	1	0	0	0				
39	EnergyPanel	1	0	0,5	1				
41	ES	1	0	1	0				
42	Ferroli	1	0	0	1				
43	Fujitsu	1	0	0,8	1				
44	Galletti	1	0	0	0				
45	Galmet	1	0	0	0				
46	General	1	0	1	0				
47	Gree	1	0	1	1				
48	Haier	1	0	0	0				
49	Hautec	1	0	0,5	0				
50	Heliotherm	1	0	0	1				
51	Herz	1	0	0	0				
52	Hewalex	1	0	0	0				
53	Hidros	1	0	1	0				
54	Hiseer	1	0	0	0				
55	Hitachi	1	0	0	0				
56	Hitecsa	1	0	1	0				
57	Hotjet	1	0	0	0				
58	IDM	1	0	0	0				
59	InterClima-MTA	1	0	1	1				
63	Kodi	1	0	0	1				
64	Lennox	1	0	0	0				
66	Magic Thermodynamic box	1	0	0	0				
69	Meeting	1	0	0	0				
70	Metri Therm	1	0	0	0				
71	Micoe	1	0	0,8	0				
72	Mitsubishi Electric/heavy indus	1	0	0	0				
74	nextterm	1	0	0	0				
75	NRGteq	1	0	0	1				
77	Oilon	1	0	1	0				
78	NILAN	1	0	1	0				
79	Oschner	1	0	0	0				
80	Panasonic	1	0	0,8	0				
81	Phnix	1	0	1	0				
82	Pico Energy	1	0	0	0				
83	Power kombi mdule	1	0	0	0				
84	Radson	1	0	1	0				

nr.	bedrijven	subsidie op 1 of meerdere producten	stroomversnelling	Duidelijke productenwebsite	Nederlands	Vindtbaar duurzaamheids project	Niet de levancier	top 5	Back up opties
85	Remeha	1	0	1	1				
86	Remko	1	0	0	0				
87	Robur	1	0	0	0				
88	Samsung	1	0	1	0				
89	Sanden	1	0	0	0				
90	Sinclair	1	0	0	0				
91	Sirac	1	0	0	0				
92	Solarfocus	1	0	0	0				
93	smartheat	1	0	0	0				
94	SPRSUn	1	0	0	0				
97	Technibel	1	0	0	0				
99	Tesy	1	0	1	0				
100	Thercon	1	0	0	0				
101	Thermia	1	0	1	0,5				
102	Thermics Energie	1	0	0	0				
103	Thoshiba	1	0	1	0				
104	Vaillant	1	0	1	0,5				
105	Venco	1	0	0	0				
106	Viessmann	1	0	1	1				
107	Weishaupt/Monarch	1	0	0	1				
108	Werstern Airconditioning	1	0	1	1				
109	Wolf	1	0	1	1				
110	waterkotte	1	0	1	0				
111	waterfurnace	1	0	1	0				
112	Brink	0	1	0	1				
113	Climarad	0	0	1	1				