A heat pump decision tool for homeowners

A advise leading to the benefits of the homeowner and a contribution to the energy transition of the built environment

Master thesis *Building Technology* – Stephan Kolman – TU Delft – October 2022

TU Delft
BK Bouwkunde

Master of Science thesis

Faculty: Architecture and the Built Environment

Master track: Building Technology

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Abstract

The Netherlands is in de midst of an energy transition, 7 million households and 1 million buildings that are currently poorly insulated and heated by natural gas must be transformed into well-insulated buildings and heated with a sustainable heat source. The government encourages homeowners to make their home more sustainable by providing subsidies for insulation and sustainable heating technologies such as heat pumps. Heat pump manufacturers are seizing their opportunity by developing online heat pump decision-making tools that allow homeowners to check whether their home is already suitable for a sustainable heat pump system, said they do this mainly out of their own interest to sell more heat pumps. In addition, there are also independent organizations that develop online heat pump decision making tools, they do this more out of interest for the climate. But it's not clear whether these tools provide all the information and advice a homeowner needs before engaging an installer to install a heat pump system. In addition, it is not clear whether existing tools provide right advice to support the energy transition. Therefore existing online tools are analysed and reflected on through literature and additional research in order to develop a better tool. Therefore the main research question in this thesis is:

How is a heat pump decision tool for homeowners with limited technological knowledge designed, which gives an advice that contributes to the energy transition of the built environment and which provides an advice on which heat pump system and additional measures a homeowner should consider before engaging an installer?

First a literature study is conducted into the energy problems related to space heating in the Dutch built environment. Possible sustainable sources and heat pump systems with a high contribution to the energy transition are defined. These sources and systems are then included in the newly designed heat pump decision making tool.

Existing online heat pump decision making tools are then analysed in order to function as a basis to define all aspects a homeowner should consider before purchasing a heat pump system. A review is made on the basis of the literature study carried out earlier in which areas the advice of the existing tools is lacking. These shortcomings are addressed in the new tool.

Thirdly based on an example home, it is investigated which measures during an energy renovation that a home ultimately uses less energy, emits less CO2, is heated sustainably and has an higher indoor comfort. These findings are included in the new tool.

The new heat pump decision making tool is then developed on the basis of flow diagrams. All decision moments are based on the findings from the various conducted studies. These flowcharts are eventually converted into a digital online heat pump decision making tool. With this new tool, the homeowner is provided with all the necessary research-based information before engaging an installer to purchase a heat pump system. This assures the homeowner of correct advice without the involvement of an installer, which leads to a major contribution to the energy transition, better indoor comfort and lower heating costs.

Overall it can be concluded that: insulating the home first as described in the tool (minimum label B according to the insulation standard) leads to the highest contribution to the energy transition and a higher indoor comfort. And that the choice of the heat pump systems depends on the home-specific aspects, and the wishes of the homeowner.

Acknowledgement

After a long period of hard work on the graduation project, the master thesis: 'A heat pump decision tool for homeowners', is finished. This also leads directly to the completion of the master Architecture, *Urbanism and Building Sciences* with the master track *Building Technology* at the Delft University of Technology.

It all started by contacting my first mentor, Ir. E.R. van den Ham, a great supervisor who has a lot of knowledge about this subject and who could provide me with the right guidance, but still left me enough freedom in the large ''thesis playground''. This freedom was new to me and let me to be very searching in the initial phase of the thesis and to a small change of subject on my initiative. Despite my arduous process, I continuously received valuable guidance and brainstorming sessions. I would like to thank Eric very much for his contribution and confidence in the progress.

Secondly, I would thank André van Deursen who worked at D11 Architects in Delft at the time. I was very kindly received by André and his colleagues at the office. André showed me on a construction site how a building transformation (energy renovation) works, in this case a former hospital building into 20 one bedroom apartments. I was immediately excited to see how paper design was brought into reality. I noticed that the building envelope was insulated according to the Building Degree for renovation, but that the heating system was still provided with a traditional gas boiler. This sparked the love to develop a heat pump decision tool. André van Deursen provided me with valuable insight in the initial phase of the thesis. During the process, the contact from my side got a bit watered down as I didn't seem to need the case study building during the development of the tool. Nevertheless, André made a very valuable addition during the start of the my thesis.

And of course I would like to thank my second mentor Ir. A.C. Bergsma with his down-to-earth view and practical knowledge to support my process with valuable insights. Arie his expertise in construction technique and far-reaching view on decision making helped me a lot during the process. In addition, Arie brings a lot of positivity with him, which promoted work motivation for me.

I would also like to thank Dr. J.L. (John) Heintz for his time and feedback during the official presentations. This gave me independent feedback with which I could continue working.

Lastly, I would like to thank my friends and family for their support and believe during the entire graduation period.

Stephan Kolman

28 October 2022

Contents

1.1 Background

The Netherlands is currently in the middle of an energy transition, the large scale combustion of fossil fuels around the world lead to a CO_2 increase in the atmosphere, which caused temperature increase (global warming) on the planet. Environmental policies aim to phase out the use of fossil fuels entirely (van Leeuwen, De Wit, & Smit, 2017). In 2015 the united nations signed the Paris Agreement. The Paris Agreement had three stated objectives: (1) to grip the increase in global average temperature to “well below” 2° C above pre-industrial levels; (2) to increase the ability to adapt to the negative impacts of climate change; and (3) to make financing flows consistent with both of the above. The goal is to reduce the greenhouse gas emissions as soon as possible and to reach emission neutrality in the second half of this century (Horowitz, 2016). To do so the united nations had to make changes in their national policies and regulations. In the Netherlands this resulted in the Dutch climate agreement (klimaatakkoord) in 2019. This is the Dutch elaboration of the international Paris Agreement. One of the agreements is that 30 ergoregions in the Netherlands investigate where and how sustainable energy can be generated the best. And also which heat sources can be used to disconnect neighbourhoods and buildings from the gas network ("Nationaal Programma,"). The climate agreement states that the Netherlands is at the start of the energy transition of the built environment. 7 million households and 1 million buildings, which are currently poorly insulated and almost all heated with natural gas need to be transformed to well insulated buildings, which are heated with sustainable heat and electricity from renewable sources (*Klimaatakkoord*, 2019).

The Dutch building sector has to contribute to minimize the effect of global warming and climate change. Various measures have been taken in order to ensure this. The building sectors introduces every year lower energy performance coefficients for new buildings by tightening the building standards (Camarasa et al., 2018). Government-supported large scale energy renovations such as ‘stroomversnelling’ and ‘energiesprong’ for existing houses are performed (Camarasa et al., 2018). Subsidy schemes are provided from the government for heat from renewable sources, such as heat pumps and district heating projects based on waste heat streams and renewable sources (van Leeuwen et al., 2017).

1.2 Problem statement

With the measures and incentives as stated in 1.1 background the Dutch government is phasing out the use of natural gas, they encourage homeowners to change the way their homes are being heated and change the homes heating system to a sustainable heating system, for example a heat pump.

Heat pump manufacturers and independent organisation are responding to these government measures and the energy transition by making online heat pump decision tools. These heat pump tools can be used by homeowners to check whether a heat pump system can be used in their home. Heat pump manufacturers often do this out of self-interest in order to sell more heat pumps. Independent organizations are doing this more in interest of the energy transition. The tool being designed in this thesis is an independent heat pump decision tool, with the aim of making a major contribution to the energy transition by any homeowner who uses the tool. On top of that they will also experience a better living comfort in their home.

The difficulty in designing such a tool is that every home is different, every home has different characteristics, different spatial aspects (indoors and outdoors) and a different dimensioned heat emission system. On top of that every home has different energetic quality, since homes can be post-insulated over the years. The purpose of the tool is to be able to map all these aspects of a specific home and then provide a targeted advice in all these areas before a heat pump system can be applied.

Existing heat pump decision tools will be analysed in order to determine how they collect all the necessary information by questioning the homeowner. The shortcomings of existing tools will be improved in the final tool.

In order to be able to provide independent advice to the homeowner who utilizes the tool, the overall energy issue based on space heating must be first mapped out. The possible solutions and sustainable energy systems must be discussed, which will serve as advice in the final tool.

2.1 Main research question

The goal of this thesis is:

Mapping the current energy problems in the Netherlands related to space heating. In addition, discussing solutions for possible other sustainable alternatives for space heating. Then integrate these findings into an independent heat pump decision tool for homeowners. By using this tool, the homeowners receive advice with all the important aspects that come with it before they engage an installer to install a heat pump. The goal is that the advice that the homeowner receives has a major contribution to the energy transition of the built environment and the living comfort of the homeowner himself.

In order to achieve this goal, the following main question has been formulated:

How is a heat pump decision tool for homeowners with limited technological knowledge designed, which gives an advice that contributes to the energy transition of the built environment and which provides an advice on which heat pump system and additional measures a homeowner should consider before engaging an installer?

2.2 Research sub-questions

In order to collect the necessary information to answer the main research questions, the research will be divided into three consecutive parts with each part having its own sub-questions.

Research part 1: 'Theoretical framework'

What are the current energy usages and energy sources of the built environment for in particular space heating of households in the Netherlands, what problems do they cause and what are potential renewable energy sources? (chapter 1)

What policies are already introduced to support the energy transition of the built environment and what are their influences on the built environment and how can these be important in the design of the heat pump decision making tool? (chapter 2)

What heat pump systems are integrated in existing building renovation cases and which envelope improvements are performed and can these techniques be used for the advice in the final heat pump decision tool? (chapter 3)

What heat pump systems and other sustainable heating sources have potential in supporting the energy transition of the built environment and which will be included in the heat pump decision tool? (chapter 4)

Research part 2: 'Empirical research'

What aspects from the analysed existing heat pump decision tools should be combined in the new tool and which aspects remained missing in the existing tools which needs to be included in the new tool? (chapter 5)

What are the boundaries of the selected heat pump systems leading to certain advice formation of the heat pump decision tool? (chapter 6)

In what way can the heat pump decision tool fulfill an educational function for the benefit of the homeowner in terms of insulation, cost and indoor comfort and how can it contribute to the energy transition of the built environment? (chapter 7)

Research part 3: 'Research by design'

How is the heat pump decision tool designed? (chapter 8)

3.1 Scope definition

Because the advice of the tool must contribute to the energy transition, the current problems regarding this energy transition are first mapped out. In addition, measures that offer of possible solution are mapped out, which then serve as an advisory body in the tool. Renewable energy systems and heat pump systems that contribute to the energy transition are also examined and it is determined why they will or will not be used in the tool.

In addition, it is investigated which measures must be taken for the integration of a heat pump system into existing buildings and which complications arise, in order to subsequently find a solution for these complications and draw the homeowners attention to this.

In addition, research is being conducted into existing heat pump decision tools and their shortcomings so that these shortcomings can be tackled, which ultimately leads to a better tool than the ones already exist.

Initially the goals was to make the tool applicable to all housing type, but during the design it turned out that too many parameters would have to be used, which would make this thesis too long. Eventually the tool was limited to owner-occupied homes, in form of ground-level homes, which could be an terraced-house, semi-detached house, or detached house.

The tool must have an educational function for the home owner, every decision moment must offer advice and alternatives, both in the field of energetic quality (insulation), the heat emission system, and the heat pump systems that are applicable based on spatial aspects. The aim is to provide the homeowner with all the necessary information before calling an installer or contractor.

4. Added value of research

4.1 Relevance

Societal relevance

Heat pump systems are a hot topic in the Netherlands. By simple googling ‘warmtepomp’ a ton of a current news articles pop up on Google. A short selection of different articles is provided:

’’Experts see heat pumps as one of the key solution for tackling CO_2 emissions associated with keeping buildings warm’’ (Wit, 2022).

Research by Milieu Centraal shows that one of the biggest challenges in the Netherlands is still the familiarity of the heat pump system. Two in ten homeowners have never heard of a hybrid heat pump. Three in ten have heard of it, but don’t know what it is. A fifth also think that there is no subsidy for it, and half of the people don’t know that there is subsidy (Wit, 2022).

The war in Ukraine has created uncertainty about gas prices and the supply thereof. Installer of heat pumps also notice this. Since the outbreak of the war, they have been getting more questions about heat pumps. This is reported by the sector organization Techniek Nederland ("VRAAG NAAR WARMTEPOMP NEEMT FORS TOE DOOR OORLOG IN OEKRAÏNE," 2022).

Suddenly there is a rise energy costs. What else is all this going to do? And suddenly there is an increase in the subsidy amounts. A heat pump in new buildings is indispensable, but what about existing buildings? Today, everyone already wanted a heat pump yesterday. But installing a heat pump in an existing building is harder (Driel, 2022).

The current chain of home interventions for private individuals falls short providing comprehensive and sensible advice on an individual basis. Digital tools can work, but are either expensive or not very accurate. This has a paralyzing effect on private individuals and hinders a neighbourhood approach. Tenants and owners live together and the image quality in the neighbourhood must be monitored ("Naar betere betaalbaarheid in aardgasvrije wijken: hoe gemeenten beter kunnen profiteren van recente innovaties," 2019).

According to these small selection of new articles there is a big societal relevance in designing a heat pump decision tool, which is understandable home owners who have limited knowledge and still provide an in depth advise.

Scientific relevance

Many previous studies are performed on selecting a heat pump system. The two studies from (Hepbasli & Kalinci, 2009) and (Zhang, Wang, & Wu, 2007) are based on the technological performance of such heat pump systems. (Gustafsson, 2000) proposed a method to calculate the most economical size for hybrid heat pump in a residential building in Sweden. His approach is based on static calculations. Previous studies on the choice of heating systems have focused on household characteristics, income strongly affects investment behaviour for heating system as is conducted in this study by (Nesbakken & Strøm, 1993). According to a study of (Janssen & Jager, 2002) people think about other alternatives when they are not satisfied with their current system. However none of these researches talked about the practical integration of heat pump systems in the existing building stock. The result of this thesis will link to the practical integration combined with the technological performance of the heat pump systems in the existing building stock.

As a result from the research provided by (Decuypere, Robaeyst, Hudders, Baccarne, & Van de Sompel, 2022) who conducted in-depth interviews, with a focus on the installation of heat pump technology, and identified a series of barriers that intermediaries experience when installing heat pumps. Those drivers and barriers resulted in a framework with four concrete propositions that face similar challenges in the transition to climate neutral buildings: (1) *Intermediaries should be aided and* supported *in recommending heat pumps to private homeowners,* (2) *Inform, guide, and sensitize intermediaries about up-to-date heat pump installations,* (3) *Sensitize homeowners by providing non-complex information in a centralized and accessible place,* (4) *Facilitate knowledge transfer between intermediaries who offer their services to the same consumers, transcending time.* The result of this thesis will fill in this gap. The heat pump decision tool will help the intermediaries by supporting in recommending heat pumps to homeowners. The tool will help homeowners by providing non-complex information in a centralized and accessible place (online).

Applicability in practice

The findings of this thesis will be valuable for homeowners in practice. However, it will also be valuable for the Netherlands in general as it will help the energy transition of the existing building stock. It is as well valuable for heat pump installers and suppliers as more systems are getting installed in the existing building stock. This thesis is written in the advantage of the homeowner, but in the end a lot of parties contribute from the findings from this thesis.

Personal motivation

I am working for 6 years in a heating wholesaler, so I am familiar with the practical integration of heating systems in the existing building stock, almost all of the heating systems sold are still traditional gas boilers by the company where I work. I just want to delve more deeply into the integration of more sustainable systems and a way in which the knowledge can be transferred to the 'normal' building owner.

4.2 Research output

Deliverables:

1. A heat pump decision tool for homeowners.

5.1 Outline and methodology + data collection and data analysis

This thesis is structured in three consecutive parts. The theoretical framework, empirical research and research by design. This structure of research is necessary because the information gathered in the section leads to a follow-up step in the next section. In (Figure 1) an overview can be found.

Theoretical framework

Theoretical framework chapter 1

Create an overview of the current energy sources used in the built environment and their size for in particular space heating throughout different scales: European, Dutch, building. And get insights about the need for change of the currently most used energy source. Create an overview of possible renewable energy sources contributing to the energy transition throughout the different scales.

Data collection

Overview of the current energy sources (qualitative data) and the possible renewable sources (qualitative data). The size of the energy usage (quantitative). The need for current energy source change (qualitative data) are all collected through literature research and desk research.

Data analysis

The information obtained gives the researcher and reader an idea of the scientific, practical and social scope of the energy issue in the built environment.

Theoretical framework chapter 2

The second part of the theoretical framework is to get an overview of policies which are made in order to support the energy transition of the built environment introduced both the European Union as well as the Dutch government. This chapter examines how the policies play a role in the design of the heat pump decision making tool.

Data collection

The policies will be collected through government documents due to the absence of scientific literature. The influences of different policies on the built environment (qualitative data) supported by numbers (quantitative data) is collected through literature research.

Data analysis

The information obtained gives the researcher and reader an idea of the scientific, practical and regulatory aspects on the energy transition in the built environment.

Theoretical framework chapter 3

Before the heat pump selection tool can be made, existing situations in which heat pumps are used during the renovation of a space heating system must first be examined, so that all additional matters at building envelope level can be investigated and what problems the integration in existing building entails.

Data collection

The renovation cases are selected based on the usage of a heat pump or other low temperature heat source + they are Zero on the Meter the so called NOM renovations. The data is collected through desk research and observation research.

Data analysis

The information obtained gives the researcher and reader an idea of the practical scope of the current application of heat pump systems in the current built environment. This knowledge is necessary in order to develop the heat pump decision tool.

Theoretical framework chapter 4

An overview of potential heat pump systems and sustainable heating sources which can contribute to the energy transition of the built environment and why they will be included in the tool, or why not.

Data collection
Qualitative data is collected through desk research.

Data analysis
The systems and sources are analysed based on disadvantages, advantages, cost-benefits, carbon/energy gains, strategy for integration in built environment, included in the rest of this thesis (high or low contribution to the energy transition of the built environment).

Empirical research

Empirical research chapter 5
The objective of this chapter is to pick the strong usable elements from the different existing tools and combine those plus elements which are missing in the existing tools, to make the heat pump decision tool for home owners in this thesis.

Data collection
Observation study on existing heat pump decision aid tools

Data analysis
The data is analysed looking at strength and weaknesses of existing online tools concerning. And parts which are lacking in existing tools.

Empirical research chapter 6
Get a more in depth knowledge about the integration of the existing heat pump systems and heat emitters and their boundaries.

Data collection
the data is collected through desk research and technical documents about the heat pump systems.

Data analysis
The chosen systems + the technical findings are displayed after each other

Empirical research chapter 7
Using exploratory research and using example cases to make clear how the heat pump tool fulfils an educational function for the benefit of the home user in terms of insulation, costs, indoor comfort and to contribute to the energy transition of the built environment.

Data collection
The data is collected through exploratory research based on heat pump system application and degree of insulation on an example building. And the opinion of other on the field on the degree of insulation in the built environment of existing buildings is collected on the basis of a parliamentary letter.

Data analysis
Causal relations are analysed between extra insulation and indoor comfort. And causal relations are analysed between degree of insulation, system costs, energy consumption, and CO_2 emissions.

Research by design

Research by design chapter 8

Almost all the knowledge to build the tool is known by now and now it’s time start building the tool with all the information obtained through research. All the lacking knowledge should be filled in with additional research. The purpose of the tool is to educate the user on the importance of insulating an existing home and to give an advice on what amount of insulation, which heat pump system and which emission system is applicable for the home.

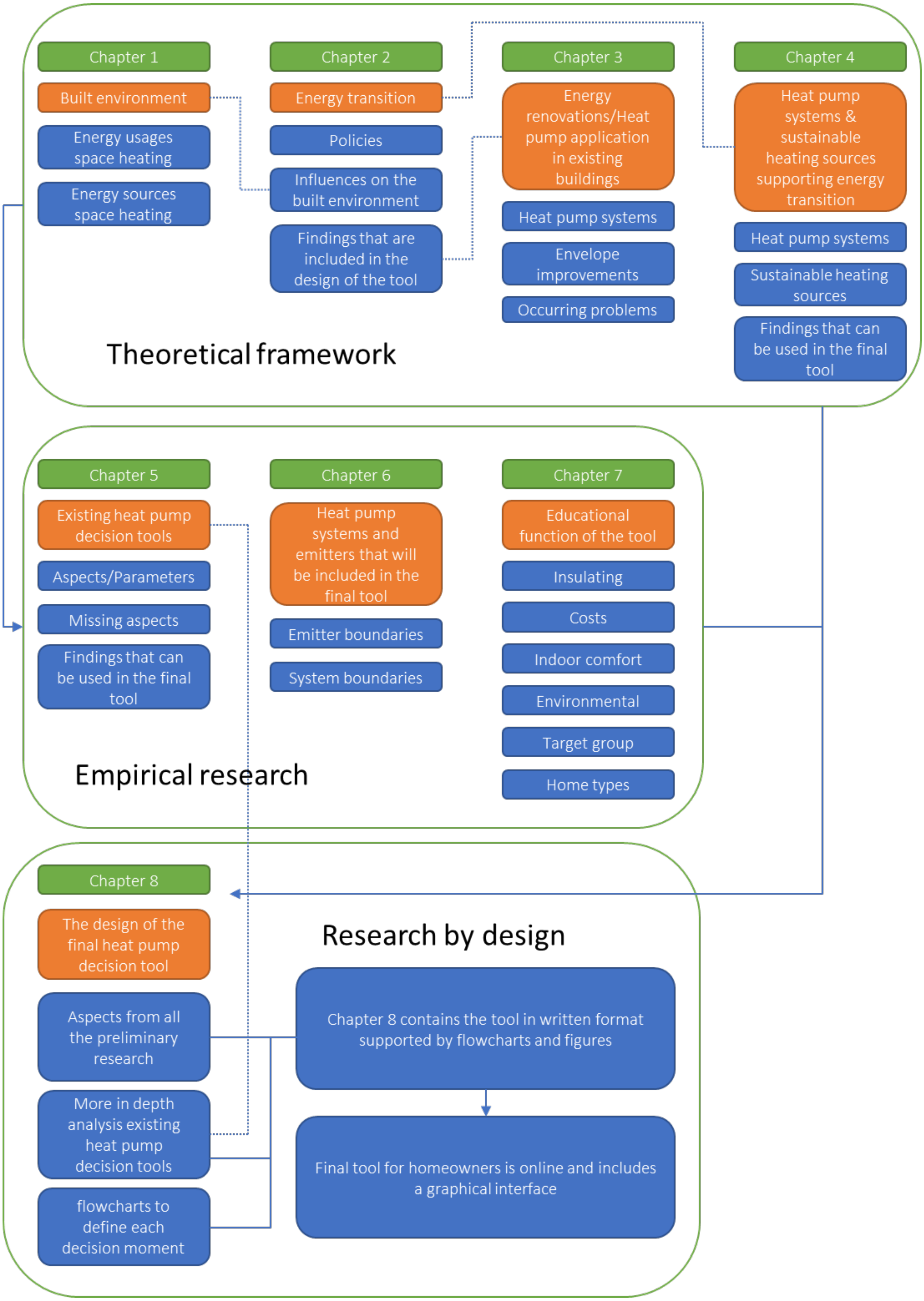


Figure 1. Methodology scheme (Own work)

I-THEORETICAL FRAMWORK

1 An overview of the energy usages and sources in the built environment for in particular space heating

Objective

This chapter contains a preliminary study with insights of the current energy sources used in the built environment and their size for in particular space heating throughout different scales: European, Dutch, building. And this preliminary study gives insights about the need for change of the currently most used energy source gas. In addition, this preliminary study provides possible solutions for renewable energy sources for space heating contributing to the energy transition of the built environment which can be included in the heat pump decision tool.

Sub question

What are the current energy usages and energy sources of the built environment for in particular space heating of households in the Netherlands, what problems do they cause and what are potential renewable energy sources?

1.1 Energy usage and source

European scale

The building sector is one of the most important sectors in terms of generation of wealth and occupation, but it's also one of the main causer of high energy usage and greenhouse gas emissions, at European level the building sector is responsible for 36% of CO2 emissions (Cellura, Guarino, Longo, & Tumminia, 2018). The building sector contains 160 million buildings in Europe which are responsible for 40% of the European energy consumption (Gandiglio, Ferrero, Lanzini, & Santarelli, 2020). The building sector has already exceeded the industry and transport sectors in terms of energy usage (Aldanondo et al., 2014). Population growth, improvement of the building services and comfort levels, together with the rise in time spent inside buildings provoke the upward movement of energy consumption and this will continue in the predictable future (Aldanondo et al., 2014). The reduction of the energy usage in the building sector is therefore one of the highly needed challenges.

Dutch scale

The built environment uses 28% of the total energy consumption in the Netherlands ("Energie in Nederland in 2019," 2020). The total energy used for the Built environment is split in 2 parts: Light & Power 30% and Heat 70% ("Energie in Nederland in 2019," 2020).

Building scale

The heat needed for the building sector, is gathered from different sources. Only 6,3% is from renewable sources 3,7% from biomass, 2,4% from surrounding heat including heat pumps and only 0,2% comes from the sun. The biggest part of the heat comes still from natural gas a total of 85%. This natural gas in combusted in gas boilers to heat up the buildings and provide the domestic hot water (Segers, Niessink, Van Den Oever, & Menkveld, 2019).

The heating energy in de built environment is distributed across different functions on the building scale. The biggest part 46% of the total heat is used for space heating of households with natural gas. 13 % is used for providing domestic hot water for households from natural gas. Only 1% is used for cooking on natural gas. Because the heat pump decision tool designed in this thesis is aimed at space heating from renewable source with heat pumps, it will have a major contribution to reducing energy usage in the built environment.

1.2 Problems current energy source and usage

CO2 emission leading to climate change

The combustion of natural gas led to 50% less CO2 emissions compared to the combustion of coal. The Dutch energy system was relatively environmental friendly compared to countries which rely solely on the combustion of coal. However large scale combustion of fossil fuels around the world lead to a CO2 concentration increase in the atmosphere, which causes temperature increase (global warning) on the planet. Environmental policies aim to phase-out the use of fossil fuels entirely (van Leeuwen et al., 2017). It is not an option to continue using energy in the way as it is done now.

Earthquakes

But the global warning was not the only reason to phase out the use of natural gas. The excessive extraction of natural gas led to earthquakes in the Netherlands (voor Veiligheid, 2015). On October 2017 decided the Cabinet Rutte III that because of the earthquakes related to the gas extraction in Groningen paired with the settlements and the social unrest that measures to decrease the need of natural gas where needed. These measures would lead step by step to a decrease of the natural gas extraction (Rutte, Pechtold, Buma, & Segers, 2017). The cabinet Rutte III wants to built 50.000 gas free houses per year. Also 30.000 to 50.000 existing homes needs to be disconnected from the natural gas network. According to the cabinet is this the first step to scale up to make 200.000 houses per year more sustainable until in 2050 all the 6 million homes in the Netherlands are gas free (Doodeman, 2017).

1.3 Possible renewable energy sources

European scale

The Netherlands has a low amount of renewable energy compared to a lot of other European countries (Figure 2).

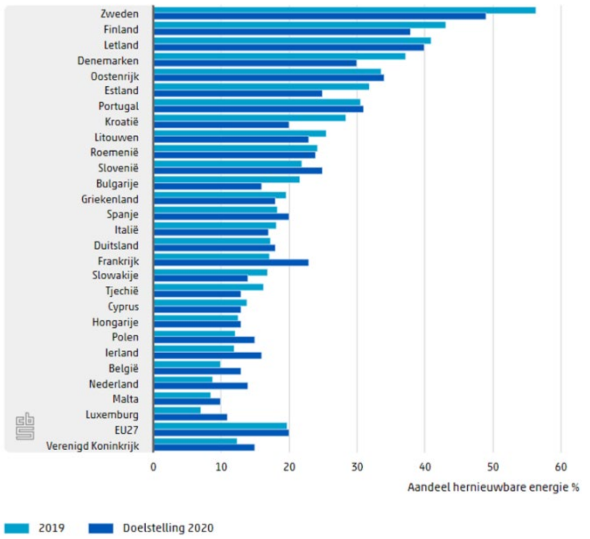


Figure 2. Share of renewable energy 2019 and target 2020 Europe (CBS, 2021)

Looking at renewable energy options on European scale, it comes clear that every country uses options that are available there. In Norway, for example, a lot of energy (electricity) is made of hydropower (Graabak, Jaehnert, Korpås, & Mo, 2017). In the Netherlands there is too little decline in the rivers for this option.

Looking at Austria, the 3 main RES-H technologies in Upper Austria are (1) biomass heating systems (including small-scale wood log, wood chips and pellet boilers but also bigger medium to large scale heating plants and district heating systems), (2) heat pumps (air source and ground source) and (3) solar thermal systems (hot water and combined space heating and DHW) (Kranzl et al., 2013). In the Netherlands wood is too scarce and importing pellet causes a lot of CO_2 emissions due to shipping (voor de Leefomgeving, 2020).

Dutch scale

There are a number of renewable energy options for the built environment when looking at the Netherlands. The alternatives for the energy which comes currently from natural gas could be for example wind energy, solar energy or ground source energy (Ebbers, 2019).

Building scale

In 2020 new techniques on building scale, soil heat (ground source heat pump), solar heat (solar thermal collector), outdoor air source heat are on the rise compared to 1990 (Figure 3).

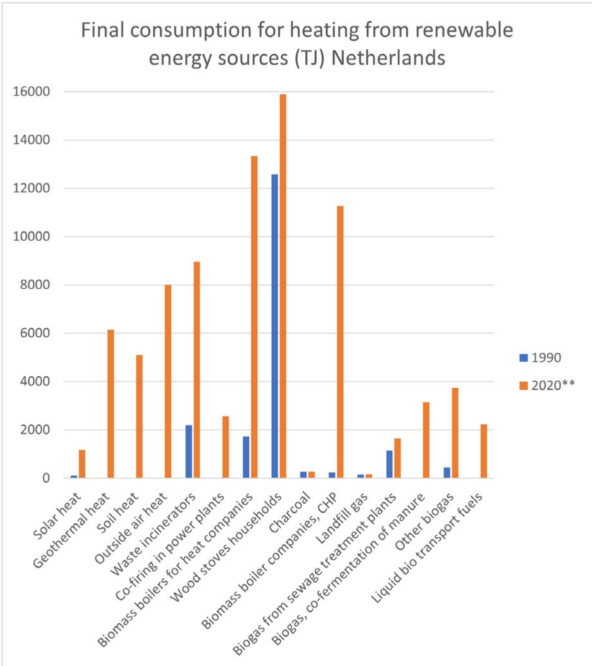


Figure 3. Final consumption for heating from renewable energy sources (TJ) Netherlands (CBS, 2021)

1.4 Problems renewable energy options

Dutch scale

If the total heat demand of the built environment is generated by wind power and the generated electricity is used to heat the current built environment, the total area needed is for all the wind turbines is: 5472km2. The area is calculated with the efficiency from (Bulder, Bot, & Bedon, 2018) and the full load hours from (bijdragers, 2020). As can be seen on (Figure 4) this is a large area and it will be difficult to find this available area. If this same amount of energy is produced by solar panels placed on a field than an area of 901km2 (Figure 5) is needed to produce the heat demand for the built environment purely with electricity ("Uitgebreid PV Systeem Ontwerp,"). The geographical space needed is less than that of windmills, but it is still not easy to find this surface in the densely built-up landscape.

Figure 4. Geographial space total heat demand of the built environment generated by wind power (Own figure)

The Netherlands has 829 km2 roof area available for solar panels (" De potentie van zonnepanelen in Nederland," 2018). But this 829 km2 is not all facing south so in an optimal scenario could all the roof area produce 47% of the total heat demand of the built environment (" De potentie van zonnepanelen in Nederland," 2018). So even if all the available roof surface in the Netherlands is used, there is still to less energy generated to heat the built environment.

1.5 The insights from this preliminary study that are used for the design of the heat pump decision tool

Based on this preliminary study, the advice provided to the homeowners by means of the heat pump decision tool is aimed at reducing the energy needed for space heating throughout the scales. The advice is also aimed at reducing the use of gas as much as possible. The new form of energy that will be used in the future for heating the built environment will be electricity. The needed electricity is generated in a sustainable way by means of wind energy and solar energy. To reduce the geographical space needed for the energy generation, the energy consumption to heat the built environment is reduced through advice of the tool aimed at reducing the energy consumption of the home and using electrical energy as efficiently as possible by means of a heat pump.

Figure 5. Geographical space total heat demand of the built environment generated by solar power (Own figure)

2 An overview of policies supporting the energy transition and how these can contribute to the design of the tool

Objective

The previous (chapter 1) showed that there is a need to change the source and energy usage for heating the built environment. Both European and Dutch regulations have been drawn up for this to support the energy transition. This chapter examines which regulations these are and how they can play a role in the design of the heat pump decision making tool.

Sub question

What policies are already introduced to support the energy transition of the built environment and what are their influences on the built environment and how can these be important in the design of the heat pump decision making tool?

2.1 Policies to phase out the use of fossil fuels

European policies

The Paris Agreement & Paris Proof: In 2015 the united nations signed the Paris Agreement. The Paris agreement had three stated objectives: (1) to grip the increase in global average temperature to "well below" 2° C above pre-industrial levels; (2) to increase the ability to adapt to the negative impacts of climate change; and (3) to make financing flows consistent with both of the above . The goal is to reduce the greenhouse gas emissions as soon as possible and to reach emission neutrality in the second half of this century (Horowitz, 2016).

Dutch policies

The climate agreement:

In 2019 the Dutch cabinet published 'the climate agreement' which is the Dutch elaboration of the international Paris Agreement. The vision of 'the climate agreement' says that we are at the start of the energy transition of the built environment. Transforming the 7 million households and 1 million buildings, which are currently poorly insulated and almost all heated with natural gas to well insulated buildings, which are heated with sustainable heat and electricity from renewable sources (*Klimaatakkoord*, 2019). In order to make the Dutch building stock 'Paris Proof', the energy usage of the built environment needs to be reduced with two third in comparison to the current average ("Paris Proof,").

BENG:

For all new buildings are the BENG regulations obliged. That is actually regulations based on the Trias Energetica in order to reduce the primary energy used by the building ("Met BENG op weg naar energiezuinig wonen," 2021).

Hybrid heat pump obliged:

Home owners are obliged to switch to a hybrid heat pump from 2026 when the gas boiler is replaced (Ministerie van Algemene Zaken, 2022)

Large scale energy renovations:

Supported by the government such as 'stroomversnelling' and 'energiesprong' for existing houses. These old houses are renovated by the large scale energy renovations, by insulating the buildings envelope, adding pv panels and adding an energy efficient installation (Camarasa et al., 2018).

Subsidy schemes for heat from renewable sources:

Subsidy is provided for heat pumps and district heating projects based on waste heat streams and renewable sources. It is an advantage of the renewable heat sources to be supplied with low temperature (30-60 C), this increases the efficiency of solar heating and heat pumps. But this is only possible if the existing buildings are renovated in such a way that low temperature heating is possible (van Leeuwen et al., 2017).

2.2 The effect different introduced policies have on the existing built environment

Large scale energy renovations

The Netherlands started with zero energy housing renovation schemes. The program was supported by the government to support social housing corporations to renovate their building stock to 0-energy buildings. The program is called ‘stroomversnelling’ which means flow acceleration. It all started with 6 housing cooperations and 4 building consortia to start a pilot retrofitting existing houses to 0-enrgy houses. The idea was to upscale this pilot to neighbourhoods with 1000 houses (Rovers et al., 2017).

BENG/Trias energetica

According to (van Leeuwen et al., 2017): The trias energetica is a principle of increasing the energy efficiency by reducing the energy consumption and temperature levels of heating demands. The trias energetica is a three step implementation method of this principle.

The trias energetica is applied in different steps into the built environment.

Step 1: the first step is the reduction of energy consumption (energy-side) and temperature difference reduction (exergy side). The following are examples of this first step in the built environment: increase the buildings insulation, this reduces heat loss but it also reduces the temperature difference between interior wall surfaces and interior air temperature. And/or add recovery ventilation which reduces the heat loss but also decreases the temperature difference between the inlet and outlet air flow temperatures in the room. And/or reduce the surface temperature of the heat emission system. This has two effects, it reduces the reduction of heat loss of the entire building. And second, when renewable heat is used like a heat pump or solar thermal collector an increase of efficiency is achieved. (Leeuwen et al., 2017).

Step 2: the second step of the trias energetica involves the generation of energy from renewable sources (energy-side) and the collection of energy from the environment (exergy side). The collection can be done by wind turbines, pv panels or thermal conversion of bio-based fuels. Or a heat pump can be used: exergy (electrical energy) is used to generate heat at a useful temperature from a lower source (van Leeuwen et al., 2017).

Step 3: the third step of the trias energetica involves using the most efficient conversion ways (energy-side) and on the other hand the reduction of exergy losses from a system (exergy-side) (BSM) (van Leeuwen et al., 2017).

2.3 How these policies and the effects of these introduced policies can be used for the design of the heat pump decision tool

Depending on the policy, it is a given that the energy consumption of the built environment must be reduced. That will also be the starting point of the tool’s advice. The large-scale energy renovations from existing building to zero on the meter building are an example of what is possible in extreme form. It will have to be further investigated whether the techniques used in these renovations can serve as advice to the users of the heat pump decision making tool. The idea of the trias energetica can form a good basis for the decision making of the tool. First reducing the energy demand of the building if necessary, then reducing the temperature of the heat emission system if necessary and then applying an appropriate heat pump. It is also a fact that hybrid heat pumps are becoming mandatory in the Netherlands. The advice of the tool will therefore be based on a minimal application of a hybrid heat pump system. But if possible, an all-electric heat pump system should be strived for is economically feasible in order to contribute to the electrification of domestic energy consumption.

3 Analysis existing renovation cases with a heat pump application for space heating

Objective

As established in the previous chapter (2), further research needs to be done to determine whether techniques such as dose used in large-scale energy renovations can be used in the advisory process for the heat pump decision tool.

Sub question

What heat pump systems are integrated in existing building renovation cases and which envelope improvements are performed and can these techniques be used for the advice in the final heat pump decision tool?

Appendix

The complete analysis can be found in (appendix 1), only a summary is included to shorten the main text.

3.1 Large scale energy renovations

In total, 8 different energy renovation cases were analysed, most of them performed by housing corporations and a single one done at a private home, performed by the following: Pilot nieuw Buinen, Dura vermeer, Wold en Waard, Woonborg, Ballast Nedam, Woonwaard, Alliantie + & DSH architects, Private home Den Bosch.

Now follows a summary of the techniques that have been used and the way in which these techniques can be applied in the advice formation in the final tool. Firstly the building envelope improvements are analysed then the building services applied and the problems which occurred. With the information from these real life test cases a conclusion can be made if the techniques can be useful in the final heat pump decision making tool.

Pilot nieuw Buinen

Building envelope improvements	Building services	Problems
Heat demand has to be brought to a very low level	Air to water heat pump in an extension outside the building	Process was inefficient
		Costs need to reduced
		Building services size needs to be reduced in a way that the total building services can be placed in one compact unit

Table 1. Pilot nieuw Buinen

Wold en waard

Building envelope improvements	Building services	Problems
External added facades	Full electric heat pump (too ambitious)	External added facades were too expensive
Insulating existing facades was a more viable option	Hybrid heat pump	Full electric heat pump was too ambitious for renovation
	Hybrid heat pump system was a better cost effective option in renovation	

Table 2. Wold en waard

Woonborg

Building envelope improvements	Building services	Problems
No envelope improvements	Applying mechanical ventilation and pv panels to reduce the energy label, but this does actually not improve the energetic performance. (Woonborg)	High temperature heat pumps at an affordable price and with an acceptable energy usage need to be developed (Woonborg)

Table 3. Woonborg

Ballast Nedam

Building envelope improvements	Building services	Problems
Façade: prefabricated insulated facade elements are placed against the front and back façade to increase the thermal capacity. The RC-value for the new façade is 5 m2.K/W. The piping for the new installation is placed inside the façade elements.	PV panels are applied on the roof.	The renovation took 3 months instead of the announced 10 days.
Roof: Pre-fabricated roof elements with pv panels and piping incorporated is placed on the house. Total value of the new roof is RC 6 m2.K/W.	An installation unit is placed on the attic. The unit includes a heat pump, heat recovery unit, a boiler, a converter and control technology. It's easy to install this unit at once.	The system blows cold air into the dwellings.
Windows: The prefabricated façade elements contain plastic window frames with triple glazing.	The gas connection is disconnected, the energy needed is generated by the heat pump and solar panels.	When the outside temperature is too cold the house is at an uncomfortable low temperature inside. There is extra heating needed in form of kerosene heaters and electric radiators.
Extra insulation: The crawl space and the loft floor are extra insulated.	The piping is incorporated in the prefabricated roof and façade elements	The total building services system makes a lot of noise.

Table 4. Ballast Nedam

Woonwaard

Building envelope improvements	Building services	Problems
Façade externally improved to Rc 5,0	Mechanical ventilation with heat recovery	Complains about finishing installation parts
Roof externally improved to Rc 5,0	Air source heat pump with boiler	There were some start up problems with the heat pump
Windows improved to triple glazing	Solar panels	Some residence complained about the noise produced by the new building services system
Crawl space insulated to Rc 4,0		

Table 5. Woonwaard

Duravermeer

Building envelope improvements	Building services	Problems
Façade insulation externally upgraded to Rc 7,0	Air to water heat pump outside the building in a so called energy module	Total shell renovations to expensive for home owners
Roof insulation externally upgraded to Rc 7,0	Balanced ventilation system placed in energy module outside the building	
Crawl space extra insulated	PV panels on the roof	
Existing cavity extra insulated with flakes	Power converter in energy module	

Table 6. Duravermeer

Alliantie + & DSH architects

Building envelope improvement	Building services	Problems
Façade insulation improved with prefabricated panels Rc value unknown	Ground source heat pump	Unknown
Roof insulation improved with a unknown Rc value	Solar panels	
Windows improved with a unknown Rc value	Balanced ventilation system	

Table 7. Alliantie + & DSH architects

Private home Den Bosch

Building envelope improvement	Building services	Problems
Facades improved to Rc 9.55	Heated ventilation air + extra electric heating	Initial idea was only heating with ventilation air but a heat loss calculation resulted in additional electric heating
Roof improved to Rc 9.55	Solar panels for electricity	
Floor improved to Rc 8.62	Electric heater for showering	

Table 8. Private home Den Bosch

3.2 What will be included from this analysis in the final heat pump decision tool

Building services

In this chapter a total of 8 renovation cases are analysed. 5 of the 8 renovation cases are executed with an air to water heat pump, this is by far the favourite choice in the analysed renovation cases. Air to water heat pump integration into existing homes is relatively easy. The outdoor part only needs to be supplied with air, so there is no need to drill in the ground, as is required with a ground source heat pump. The indoor part of the heat pump can be placed in many places indoors and if there is no space indoors, it can be placed in a small extension against the home. Because this heat pump system has been proven to work in many existing cases, it will be included in the final tool.

Building envelope

In all of the cases was the envelopes insulation value upgraded so this is a must in case of applying an air to water heat pump. The upgraded insulation value varies between a minimum Rc of 5.0 to a maximum Rc of 7.0 in combination with an air to water heat pump. The analysed cases involved zero on the meter renovations, which is why the insulation value is relatively high. In the thesis must be further investigated whether this high insulation value is indeed needed in combination with a heat pump.

Problems

The most occurring problems with an system with an air to water heat pump were that the system took up too much space and made too much noise for the inhabitants. A ground source heat pump was only applied in 1 renovation case, and a ventilation heating system also only in 1 case, these options are not popular. A lot of these 0-energy renovations were performed by housing corporations, because the total envelope renovations have a high costs and it's not affordable for the private homeowner. Even the housing corporation Wold en Waard mentioned that it was not affordable for them to perform a full zero on the meter renovation and that a smaller renovation with a hybrid heat pump system would be a better option. Some of the zero on the meter renovations turned out not to be economically profitable. That is why the starting point of the final heat pump decision tool is based on the idea that a hybrid heat pump or all electric heat pump can be used with minimal interventions. Noise will also play a major role in the decision-making process of the tool, not only regulations must ensure noise reduction, but also the comfort of the resident has priority.

4 an overview of potential heat pump systems and sustainable heating sources contributing to the energy transition

Objective
Make an overview of potential heat pump systems and sustainable heating sources which can contribute to the energy transition of the built environment and why they will be included in the tool, or why not.

Sub question
What heat pump systems and other sustainable heating sources have potential in supporting the energy transition of the built environment and which will be included in the heat pump decision tool?

4.1 Individual approach & collective approach for renewable energy options

There are different approaches of integrating renewable energy options for the thermal demand of buildings. There are two different approaches the individual approach and de collective approach (Leeuwen et al., 2017). The individual approach is the concept of replacing the existing gas boilers for each building by a heat pump which electrifies the heating demand. The electricity is supplied by a renewable energy source such as solar PV and an increasing number of regional wind turbines approach. For balancing heating energy production and demand, electric and thermal storage are part of the building energy system (Leeuwen et al., 2017). According to (Boersma & Blom, 2018) the individual approach actually consists of more principles: biomass (I), biogas (I) and all-electric (II).

On the other hand there is a collective approach. In a collective approach the heating system is connected to a district heating system. Due to the scale of the district heating systems a wider choice of renewable energy sources is available like waste, biomass, biofuel, solar thermal plants, power to heat, shallow and deep geothermal energy and seasonal storage (Leeuwen et al., 2017).

This master thesis will only be focussed on the individual approach of integrating renewable energy options for the thermal demand of buildings.

4.2 Individual renewable energy options for the thermal demand

The following individual energy options from the City Zen catalog of (Boersma & Blom, 2018) have been analysed to define how the systems work, how they can be integrated in the built environment, and their advantages and disadvantages are mentioned, and assessed whether there is enough contribution to the energy transition, which leads to them being included in the tool: All-electric, Biomass, Biogas, Air source heat pump, Ground source heat pump, Solar thermal collectors, hybrid heat pump.

All-electric
All-electric means that all the energy demand of the building, including the energy for heating, cooling and domestic hot water are supplied by electricity. For this type of approach heating is mostly provided by a heat pump with an air- or ground-source (Boersma & Blom, 2018).

To increase the efficiency of the heat pump the supply temperature for heating should be relatively low and the supply temperature for cooling relatively high. To do so a high energetic performance of the building is required (good envelope insulation). This can be done by increasing the insulation values by adding or changing the insulation of the façade, roof, ground floor, windows and fixing thermal bridges. And most of the time the heat emission system needs to be replaced in order to work with the lower supply temperature. And in most cases even more energy saving measures are achieved by replacing the natural ventilation system for a balanced (mechanical) ventilation system with heat recovery (Boersma & Blom, 2018).

Disadvantage
The disadvantage of the all-electric approach is the increasing peak demands on the electricity grid by the use of the heat pump. These peak demands occur when multiple buildings in a certain area are all using an all-electric heating system. These peak demands determine the capacity of the network and power plants (Boersma & Blom, 2018).

Advantage
Only a connection to the electricity grid is needed to supply the building from all its energy (Boersma & Blom, 2018).

Strategy for integration in built environment
Step 1 is to decrease the energy demand of the building by minimizing the energy losses. The second step is re-use waste energy streams with for example heat recovery integrated in the ventilation system. And the final step is to implement the new installation and the heat emission system

Carbon/Energy gains
All the energy demand of the building is supplied by electricity. The heat demands are provided by a heat pump with an COP of about 4. This way the electricity used from the grid is used very efficient. Since a part of the electricity coming from the grid is still generated using fossil fuels nowadays (Boersma & Blom, 2018).

Included in the rest of this thesis
The individual all electric approach in combination with a heat pump is considered as a good solution to the energy transition of the built environment, as there is only one connection to a electricity grid needed. And minimizing the energy losses and using free exergy energy leading to a decrease of energy usages in the built environment to reach the climate goals.

Biomass
Plants convert solar energy into chemical energy, this process is called photosynthesis. This thermal energy will be released with the combustion of the biomass. This means that the energy is stored in the biomass and can be released when needed by combustion. Examples of biomass sources are: wood, seaweed, energy crops etc (Boersma & Blom, 2018).

The combustion of wood can take place in a wood boiler, stove or a pallet boiler. The energy released because of combustion can be used for space heating and domestic hot water supply. The existing heat emission system can be used (in most cases radiators) due to higher supply temperature of wood/pallet boilers. But a large storage is required for the storage of wood/pallets (Boersma & Blom, 2018).

The sustainability of heating with wood biomass is under discussion. Wood pellets and chips are mostly imported from Scandinavia or Canada. This results in large CO2- emissions during the transportation to the Netherlands (Boersma & Blom, 2018).

Strategy for integration in built environment
To implement the pellet boiler or wood boiler a wood source should be found that can be considered as sustainable. The building should have space for large storage for the facility of the wood/pellets and the installation. But the envelope of the building does not need to change, the pellet boiler can deliver high temperature heat (Boersma & Blom, 2018).

Not included in the rest of this thesis
This potential heat source is rejected for the heat pump decision tool as it is assumed that it will not be the key to the energy transition of the built environment. There is not enough wood in the Netherlands and importing causes a lot of CO2 emissions. Also extra insulation is not needed, which will not reduce the total energy consumption of the built environment and thus will the climate goals not be reached.

Biogas
Biogas is generated with the fermentation of biomass in an anaerobic digester. The source can be food waste, energy crops, seaweed, sludge and animal manure. After the generated biogas is upgraded to the same quality as natural gas by the gas treatment plant it can be transported in the existing gas network towards the buildings. This upgraded biogas is called green gas (Boersma & Blom, 2018).

In the building the biogas will be converted into high temperature heating by use of the existing gas boiler. This means that the installation can remain the same and that there are no other measures are required. Biogas is gradually available over the year, while at the same time the biogas generated outside the heating season can be stored in the existing gas network or in the solid biomass before the conversion (Boersma & Blom, 2018).

Another way of using biogas is to convert biogas into both electricity and heat with a Combined Heat Power (CHP) installation. This principle is also called co-generation and does not only generate energy electricity but also heat. For this process the CHP has a high efficiency up to 90%. A micro-CHP can be used to supply the heat and electricity demands of a single building. A large scale CHP is used to supply heat to district heat network (Boersma & Blom, 2018).

Disadvantage
The disadvantage of biogas is the limited availability. Another way of generate more sustainable gas is by Power-to-Gas installations. However these systems are currently financially not feasible and it is questionable if it will ever become feasible (Boersma & Blom, 2018).

Strategy for integration in built environment
When biogas is upgraded to the same quality as natural gas it can be fed into the current heat network. This will lead to an increase of renewable energy. With the limited potential to replace about 5-10% of the current natural gas supply, this gas should only be used for locations where heat supply by other sustainable sources is not possible. For example to supply high temperature heating for monumental buildings, since they lack the potential for energy renovation since they have a protected status.

Carbon/Energy gains
When using the biogas to generate heat with a boiler or both heat and electricity with a CHP unit CO2-emissions will be released. However the use of biogas is still considered as low carbon, since the biomass has absorbed those CO2 emissions first during its lifespan. (Boersma & Blom, 2018).

Not included in the rest of this thesis
Biogas is too scarce and it is uncertain if it ever will become well available. Therefore its assumed that it will not be the key to the energy transition of the built environment. There is also no need to change the building envelope which doesn’t reduce the energy consumption of the built environment. It will not be included in the heat pump decision tool.

Air source heat pump
The air source heat pump extracts the heat from the outside air by blowing this air across heat exchangers. The heat pump upgrades this heat until the required temperature for space heating is reached. Because the heat pump works the most efficient when the source temperature and heating temperature are close to each other low temperature heating is a must. This technique is mostly used in countries where the outdoor temperature variates between 0 en 30 degrees (Boersma & Blom, 2018).

Disadvantage
Because of the temperature differences between the seasons the air source heat pump has a lower efficiency during the winter, when the outdoor temperature drops. This also results in the fact that the overall efficiency (COP) if this type of heat pump is lower than the efficiency of a ground source heat pump, where the temperature over the year round is 12 degrees (Boersma & Blom, 2018). Another disadvantage is the noise that is generated by the fan and the energy that is needed to keep this fan running (Boersma & Blom, 2018).

Advantage
The main advantage of an air-source heat pump compared to a ground source heat pump is that the cost of this type of heat pump is much lower (Boersma & Blom, 2018).

Strategy for integration in built environment
The heat pump works the most efficient when the temperature difference between the source and the required temperature for heating and cooling is small. Therefore a low temperature heat emission system is desired. This requires high insulation values of the building and floor heating. The heat exchanger needs to be located outside to extract the heat. For this process a fan is installed in the unit, but this fan give noise. Therefore the location of

this unit should be considered well (Boersma & Blom, 2018). Outside air to water heat pump: in 2021 69% of the installed heat pump systems were an outside-air to water heat pump system (DNEResearch, 2021).

Carbon/Energy gains
When the outside temperature is 10 degrees the COP will be about 3,3. Even with a very low outdoor temperature the efficiency of the heat pump will still be much higher than a traditional gas heater. The application of an air source heat pump will give an average of 50% carbon savings (Boersma & Blom, 2018).

Included in the rest of this thesis
Low temperature heat is a must, which leads to an increase of building insulation, which will lower the energy use of the built environment and thus contributes to the energy transition and climate goals. The air source heat pump is considered as one of the keys to the success of the energy transition of the built environment and is therefore included in the rest of this thesis.

Ground source heat pump
A heat pump can use different sources for the heat supply. Currently ground source is the most applied and the most efficient heat source for a heat pump. The heat from the ground is exchanged with the heat pump at the evaporator after which the heat pump increases the temperature of the heat efficiently by electricity (Boersma & Blom, 2018).

When making use of a ground source heat pump a liquid is circulated through pipes of the ground heat exchanger during which it absorbs heat form the ground. This type of heat pump system is more efficient (ground temperature closed to required indoor temperature) than an air source heat pump (Boersma & Blom, 2018).

The ground source heat exchanger can be placed horizontally (trench) or vertically (borehole) in the ground (Boersma & Blom, 2018).

Included in the rest of this thesis
Ground source heat pump has a relatively high COP throughout the year (stable ground temperature), which reduces the primary energy demand and has a high potential in the energy transition and is therefore included in the rest of this thesis.

Solar thermal collectors/PVT heat pump
A solar collector absorbs solar radiation and converts this radiation into heat. The heat is absorbed by a fluid that is running through the pipes of the solar collector. This fluid is most of the time water or a mixture of water and glycerol (which prevents it from freezing). The heated fluid can be used to supply the domestic hot water demands and it can also contribute to space heating. In the spring and autumn it will be more efficient to use the generated heat for the generation of space heating instead of DHW, since the temperature output will be too low to directly use it as hot water supply. The solar collector is used for residential and industrial purposes (Boersma & Blom, 2018).

The solar thermal heating system
Cold water is supplied from the grid and fed into a storage water tank. This storage tank is heated directly or indirectly by the solar collectors. Directly means that the water which is fed to the storage tanks is the same water as what runs through the solar collector. In this case the hot water supply is coming from the top layer of the storage tank (the warmest part). If the storage tank is indirectly heated, this means that the water from the storage tank is different than the fluid running through the solar collector and a heat exchanger. The amount of heat produced won't be sufficient to supply the full hot water demands of a building. Because of that an extra system needs to be integrated to the system such as an heat pump (Boersma & Blom, 2018).

Strategy for integration in built environment A
Storage tank and backup heating system (such as a heat pump) is always needed and needs to be integrated in the system (Boersma & Blom, 2018).

Carbon/Energy gains
The use of the solar collector decreases the amount of hot water needed the generated by a boiler or heat pump for domestic hot water and heating. These energy savings result in CO2 savings (Boersma & Blom, 2018).

Included in the rest of this thesis
Solar thermal collectors don't produce noise and they can work together with a heat pump, they're therefore considered as highly potential to contribute to the energy transition and therefore further included in this thesis.

Hybrid heat pumps
Hybrid heat pumps are in principle a combination of a regular gas boiler and an air-source heat pump. They can provide a supply temperature with a heat of 25 ºC to 80 ºC. With this these temperatures the system can be used with each heat emission system. Thereby the existing piping's and radiators can be used in case of a renovation. Also the building envelope doesn't need to be upgraded very well, since the gas kettle can supply higher temperatures when needed (Boersma & Blom, 2018).

70 to 80% of space heating is provided by the air source heat pump and is therefore renewable. The domestic hot water supplies are therefore provided by the boiler, however pre heating with the heat pump is possible in combination with a storage tank to increase the efficiency (Boersma & Blom, 2018).

Carbon/Energy gains
By using free energy from the outside air carbon emissions are reduced

Strategy for integration in built environment
Implementation strategy: The initial running costs of the hybrid heat pump compared to a standalone heat pump are the lowest for existing buildings. Also the implementation of the hybrid heat pump in existing buildings is an advantage since the existing piping system and heat emission system can be remained the same (Boersma & Blom, 2018).

Included in the rest of this thesis
The hybrid heat pump in combination with a traditional gas boiler still uses some natural gas for the cold periods of the year and for DHW. But together with insulating the building the outdoor temperature can become lower and lower before the gas kettle needs to help. And by insulating the building the supply temperature can become lower and the COP of the heat pump will rise, this will ensure less primary energy demand and can help to reach the climate goals and thus support the energy transition. And the hybrid heat pump is fairly easy to integrate in the existing built environment.

5.3 Summary

System/source/approach	Included in the rest of this thesis (High contribution to the energy transition of the built environment)	Not included in the rest of this thesis (Low contribution to the energy transition of the built environment)
Individual approach of integrating renewable energy options	✓	
Collective approach of integrating renewable energy options		✓
All-electric (heat pump)	✓	
Biomass		✓
Biogas		✓
Air source heat pump	✓	
Ground source heat pump	✓	
Solar thermal collectors (heat pump)	✓	
Hybrid heat pumps	✓	

II-EMPIRICAL RESEARCH

5 analysisis existing heat pump decision tools

Objective

The objective of this analysis is to pick the strong usable elements from the different existing tools and combine those plus elements which are missing in the existing tools, to make the heat pump decision tool for home owners in this thesis.

Sub question

What aspects from the analysed existing heat pump decision tools should be combined in the new tool and which aspects remained missing in the existing tools which needs to be included in the new tool?

Appendix

The complete analysis contains a lot of extra information that can be found in appendix 2

Existing heat pump decision tools

The tools were found via google with search terms that a home owner could use.

List of the analysed heat pump decision tools:

1. https://www.milieucentraal.nl/energie-besparen/duurzaam-verwarmen-en-koelen/volledige-warmtepomp/
2. https://www.samangroep.nl/keuzehulp-warmtepompen/
3. https://www.warmhuis.be/start
4. https://groenpand.nl/warmtepomp/#check
5. https://warmtepompcheck.ithodaalderop.nl/warmtepomp/afa71df8-b136-41cc-a69b-115e88473f30
6. https://www.panasonicproclub.com/NL_nl/tools/aquarea-designer/
7. https://www.vaillant.nl/consument/kennis-en-advies/keuze-advies/ketelkiezer/

(Clymans., et al. 2019) performed an analysis of existing energy decision aid tools. (Clymans., et al. 2019) looking at the strength and weaknesses of existing tools concerning: exact domain and themes, substantive information, usability, context, completeness, management, data policy.

(Clymans., et al. 2019) used five themes to analyse the existing tools. The criteria are:

1: User
2: Owner of the tool
3: Domain technician
4: Data availability
5: Domain and scale level (policy and space)

The method used to analyse existing heat pump decision tools is a method made by (Clymans., et al. 2019), this method was chosen because it analysis the tools in a thoughtful way thinking about things that one would not realize in the first place. This general analysis ensures that you become familiar with existing tools. The strengths and weaknesses of the tools are defined. This is needed in order to design an even better heat pump decision tool. Later in this thesis, specific parts of the tool will be analysed in more detail so that the strengths and weaknesses of the existing tools are used for each specific decision moment. The total analysis can be found in appendix 2. Only a summary will be discussed in this chapter.

Milieucentraal

	Strength	Weaknesses
Theme 1: user		
Characterization	The home owner is the user of the tool and is central to the tool	
Information exchange	The information the tool needs is questioned in a way that people with little knowledge can answer the questions and provide the needed data for the underlaying calculations of the tool.	Because of the simplicity of the questioning the underlaying calculations cannot be very detailed due to the lacking information. For example the energetic performance remains an indication. - no pictures of actual systems
Usability calculations and data	Advice takes into account the rising energy prices and the received grants which supports the investment decision. If the user for example doesn't know the insulation level of his building, the tool will use the standard insulation value for the construction year of the building.	The energetic performance of the building is not expressed in a number. So the user of the tool doesn't actually know how well it's building performs before choosing a sustainable heating system.
Theme 2: Owner tool	Focus on home owners, easy accessible free tool for all home owners	
Theme 3: Domain technician		
Assessment advice	The grants for a specific system are shown in the advice, which encourages the home owner to install the system.	Limited choice of alternative sustainable systems. Heat dissipation systems remains underexposed. The spatial effects of the new heat pump system and buffer remains underexposed. Outdoor noise of heat pump is not addressed.
Availability technologies	Most common systems in the Netherlands are used in the tool. Hybrid heat pump, air to water heat pump, water to water heat pump (ground source)	Other potential techniques are not used in the tool such as solar collector heat pump.
Theme 4: Data availability		
Data policy/accessibility		Adjustment of algorithms or further personalization advice not possible
Data management	Independent foundation no advice preference	no parameterization update to reflect current building state
Theme 5: domain and scale level		

Samangroep

	Strength	Weaknesses
Theme 1: user		
Characterization	Simple understandable input parameters for user of the tool	Simple input parameters led to a not in detail performed energetic assessment of the building
Information exchange	Pictures of the different systems at the result page	No information about system install locations or system sizes
Usability calculations and data		Result personalisation not possible and no underlaying formulas are shown
Theme 2: Owner tool	Also heat pump supplier and installer	The tool can form a less objective conclusion because the installer wants to sell more heat pump systems
Theme 3: Domain technician		
Assessment advise	Existing heat dissipation system is taken into account. - installation costs are shown	- No spatial aspects are asked - no payback time shown
Availability technologies	Easy installable heat pump solutions: air-source heat pump and hybrid air source heat pump.	No ground source heat pump or solar heat pump
Theme 4: Data availability		
Data policy/accessibility		Algorithm adjustments or further personalization results is not possible
Data management		Based on more sales of heat pump products
Theme 5: domain and scale level		No link to national or municipal policy, no different scale levels

The method used by (Clymans., et al. 2019) ultimately turned out to be too complex and contained too much unnecessary data for the purpose of this thesis. Simply doing this analysis for each tool wouldn't contribute to a better research in the end. It has therefore been decided to further explore the existing tools in a different way. This is done by looking at specific components during the design phase later in this thesis. Containing the energetic state of a home, the heat emission system and spatial aspects and how these are addressed in existing tools and on which fronts these components fall short. This will be discussed later in the thesis. At this moment, the advice provided by existing heat pump decision tools has been analysed. In this way, it can already be determined in which the existing tools fall short in de advisory process and what needs to be improved in the final heat pump decision tool.

Milieucentraal advice

Heat pump system type

The tool mentions in the form of text which type of heat pump system is probably possible. The advice may consist of: no heat pump, hybrid heat pump, all electric heat pump.

Heat emission system

The tool mentions that a (hybrid) heat pump system works the most efficient at a as low as possible supply temperature. In order to check if your heat emission system is sufficient for the lower temperature the tool mentions a link to an external heating test which can only take place in winter.

Costs and savings

The costs are based on a reference house.

Figure 6. verwarmingstest (milieucentraal, 2022)

Extra insulation

The tool mentions what building parts need to be insulated first.

What is good and can be used in the final tool, and what can be improved considering what and how the results are displayed?

It is good that the tool mentions what type of heat pump is possible based on the energetic performance. But it does not mention that sound of the outdoor unit needs to be taken into account. The heating test can only be done in winter and users of the tool haven't probably enough time to wait until it is winter, because they want to upgrade their homes as quick as possible, so they want the advice as quick as possible. The good point is that the costs and savings give a nice and simple overview for the user.

Samangroep

The tool only displays what heat pump system could be installed: all electric outside air heat pump, hybrid outside air heat pump and the costs.

What is good and can be used in the final tool, and what can be improved considering what and how the results are displayed?

The only good point is the visual picture of the heat pump, so the user of the tool has an idea what such a system looks like. But in addition, there is a lot of information missing about extra insulating leading up to other heat pump options or changes to the heat emission system aren't mentioned.

Warmhuis

The tool is mainly focused on shell improvement options and cost savings and not on a heat pump integration (Figure 7).

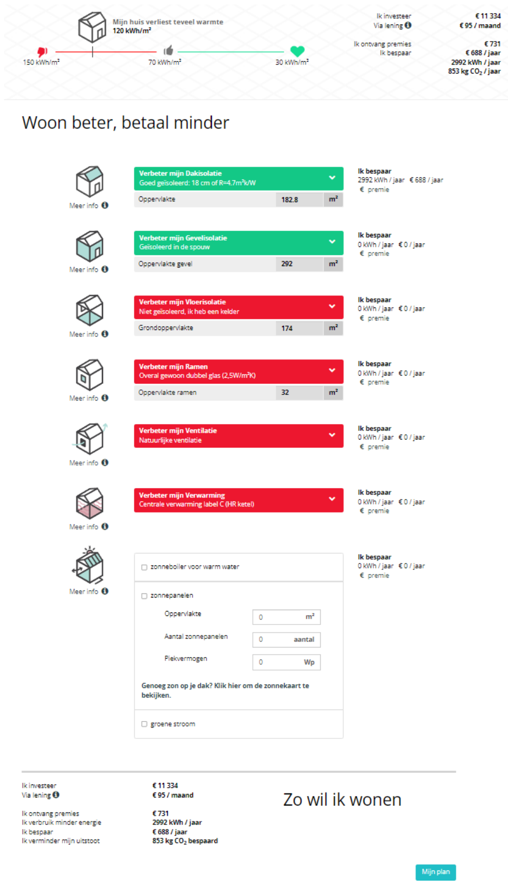


Figure 7. Warmhuis advice (Warmhuis, 2022)

What is good and can be used in the final tool, and what can be improved considering what and how the results are displayed?

The icons used are clear, but there is a lot of information lacking concerning the heat pump itself and the heat emission system.

Groenpand
Advice: HOERA! Your house seems suitable for a real Groenpand heat pump!

What is good and can be used in the final tool, and what can be improved considering what and how the results are displayed?

Advice is actually meaningless, an installer still has to come immediately to provide more information.

Ithodaalderop
Your home seems suitable for a heat pump! And then the tool shows heat pumps that seem suitable for your home.

What is good and can be used in the final tool, and what can be improved considering what and how the results are displayed?

The only good thing is prices and installer costs.

Panasonic pro club
Advice: this tool is actually only used by installers, so it gives a specific heat pump option from the Panasonics database. It shows user costs, maintenance costs, installation costs, fuel costs, co2 savings, hydraulic installation scheme.

What is good and can be used in the final tool, and what can be improved considering what and how the results are displayed?

This tool is designed for an installer and should therefore also only be used by an installer. The only good thing is that it shows the costs for the home owner.

Vaillant
It showed only what heat pump system could be installed, but nowadays it only shows possible gas boilers. They discharged their heat pumps form the advice.

Conclusion:

It is actually striking about all the analysed tools that the user fills in a lot of information about his home and then sees an end page with the given advice about with heat pump system would be possible. Milieucentraal takes this one step further by providing the end page with the heat pump advice plus advice regarding the heat emission system and possible insulation improvements. What actually is missing in all tools is that the homeowner must be guided in choices and possibilities for improvements per subject in form of examples and explanations regarding each subject (energetic state of the home, insulation improvements, heat emission system, spatial aspects). In this way the homeowner can use the tool as an advisory body and see which choices in the tool's trajectory can lead to a different heat pump outcome. The final heat pump decision tool will not have 1 end page with which system could possibly be installed based on the entered data, but it will give the homeowner insights and alternatives at every step so that he can see what is possible in the field of insulation, heat emission system, spatial aspects. With this the homeowner can actually form an idea for himself where he wants to go with his home and what options there are. For example the user can choose to apply a hybrid heat pump with minimal interventions and costs, since this will be mandatory from 2026. But the user is also shown which benefits the alternatives for example insulating more, applying an all-electric heat pump will give over an longer period. The heat pump decision tool will therefore not contain 1 end page, but it is an step by step plan that the homeowner will go through, with each time different options and advice so that the user can form an image for himself. And with that image in mind the homeowner can for example look for a contractor who improves his homes insulation, or find an installer who changes the heat emission system, or find and installer who can install the desired heat pump for the homeowner.

6 Map heat pump systems & emitter boundaries

Objective

Get a more in depth knowledge about the integration of the existing heat pump systems and heat emitters and their boundaries.

Sub question

What are the boundaries of the selected heat pump systems leading to certain advice formation of the heat pump decision tool?

6.1 Heat emitter

To get the building to work with a sustainable heat source such as a heat pump the building has to be heated with a low temperature heat source. The supply temperature of a low temperature heat source is below 55 ºC. Heat emitters can be supplied with the following supply temperatures (ISSO, 80)

			Suitable delivery temperature for use with heat pumps						
					Preferred temperature for heat pumps				
	HTH Θ2>55°C		MTH 45°C<Θ2<55°C		LTH 35°C <Θ2<45°C		VLTH Θ2<35°C		
		TK66	TK55	TK48	TK42	TK36	TK33	TK30	
Design temperatures									
Supply Θ2 [°C]	80	66	55	48	42	36	33	30	
Return Θ3 [°C]	60	50	43	38	34	30	28	26	
Difference Θ2-Θ3 [K]	20	16	12	10	8	6	5	4	
Average (Θ2+ Θ3)/2 [K]	70	58	49	43	38	33	30,5	28	
Scope									
Radiator	○	○	○	○	○				
Convector	○	○	○	○	○				
Floor heating				○	○	○	○		
Wall heating				○	○	○	○		
Air heating	○	○	○	○	○	○			
LT radiator (With Fan)			○	○	○	○	○	○	(VASCO, 2018)

Table 9. Heat emitter supply temperatures (ISSO 80 & Vasco)

Floor heating capacity
The floor heating capacity is limited by the surface temperature of the floor. The surface temperature of the floor in the living zone may not exceed 25-27°C. The floor temperature in edge zones may not exceed 29-31°C. (ISSO 49). This results in a maximum heating capacity of 100W/m^2 in the living zone. And this results in a maximum heating capacity of 170W/m^2 in the edge zones. According to (ISSO 49) floor heating is possible as main heating in case the heat demand of the home does not exceed 90W/m2.

Radiator capacity
The heat output (P) of a radiator is in relation with the heat transfer coefficient (k), the surface area of the radiator (A) and the logarithmic mean temperature difference between the heat emitting surfaces and the ambient air (ΔT_{log}) (Hesaraki, Ploskic, & Holmberg, 2015) & (Østergaard, 2018).

Add-on fan heat output +20% (SpeedComfort, 2022).

6.1 Heat pump boundaries

Hybrid heat pump
A very complete analysis has been done about the complete operation and cooperation of a hybrid heat pump together with a gas boiler in appendix 3, this extensive research was done so that initially product innovations could be made, but this objective was abandoned because otherwise the thesis would become too large. The findings in appendix 3 could be used in a follow-up research study on product innovation in the field of heat pumps. In this chapter only the matters that lead to certain advice formation of the heat pump decision tool are explained.

How the system works
with a hybrid heat pump system (Figure 8), the natural gas boiler and a heat pump work together. The heat pump is linked to the existing natural gas boiler. On peak moments when it's cold during the winter, the natural gas boiler helps the heat pump. The natural gas boiler also produces the domestic hot water. The system is not totally gas free, but reduces the gas usage compared to a system with only a natural gas boiler (Dutch New Energy Research, 2018).

This explanation plus image will be shown to the user of the tool.

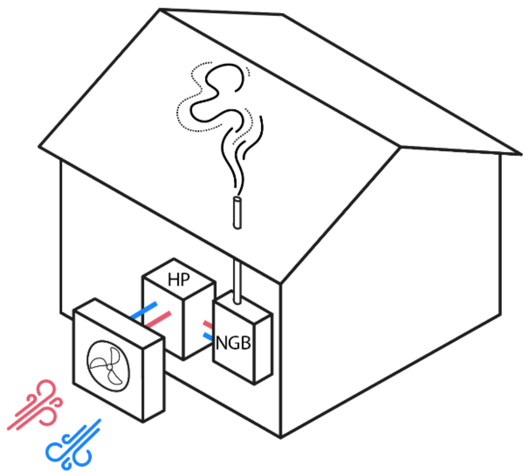


Figure 8. Hybrid air source heat pump (Own figure)

Boundaries supply temperatures
In order to provide people who are using the tool with the right advice, the supply temperature must be determined in each operation mode. Depending on the supply temperature the correct heat emission system can be selected for the home.

Hybrid heat pump mode	Supply temperature °C (max)	source
Heat pump only mode	55	(Remeha, 2021)
Hybrid mode	Varying 50-55	Research appendix 3
Gas boiler only mode	70	(Remeha, 2021)

Table 10. Hybrid air source heat pump supply temperatures

Boundaries outdoor unit and indoor unit placement hybrid heat pump

There are 3 types of hybrid heat pumps (air source):

1. Split heat pump + gas boiler (Figure 9) (Warmteservice, 2022).
2. Monoblock heat pump + gas boiler (Figure 10) (Warmteservice, 2022).
3. add-on heat pump + gas boiler (Groupe Atlantic Nederland BV, 2020) (Figure 11).

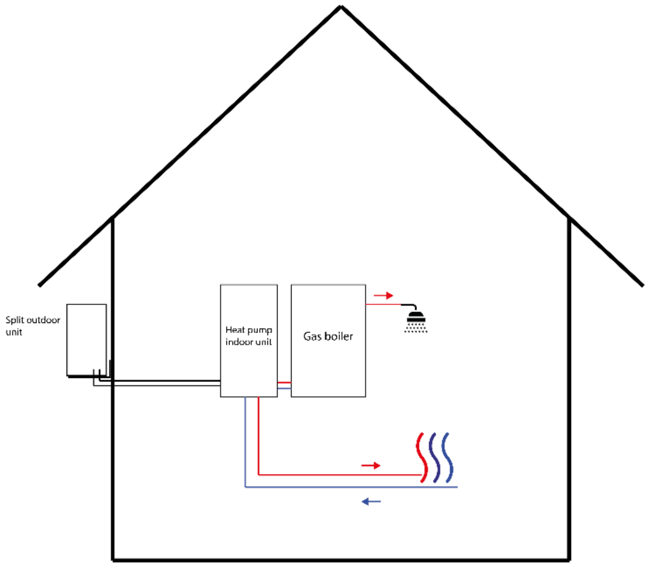


Figure 9. Split heat pump + gas boiler based on principles of (Warmteservice, 2022)

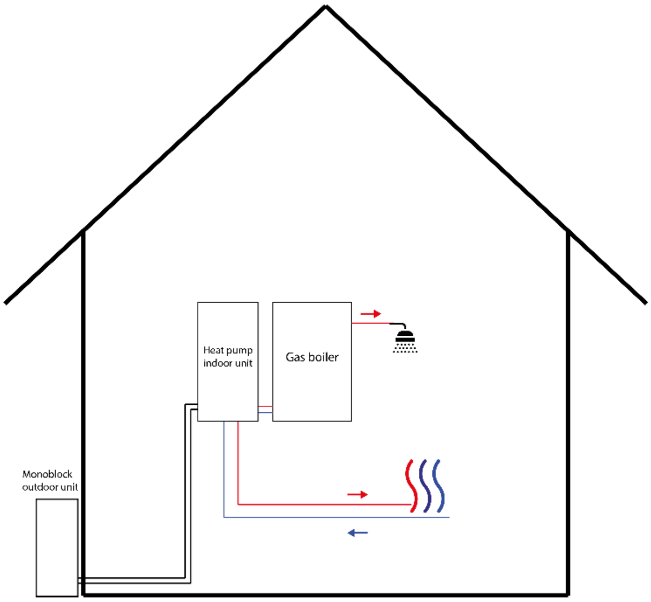


Figure 10. Split heat pump + gas boiler based on principles of (Warmteservice, 2022)

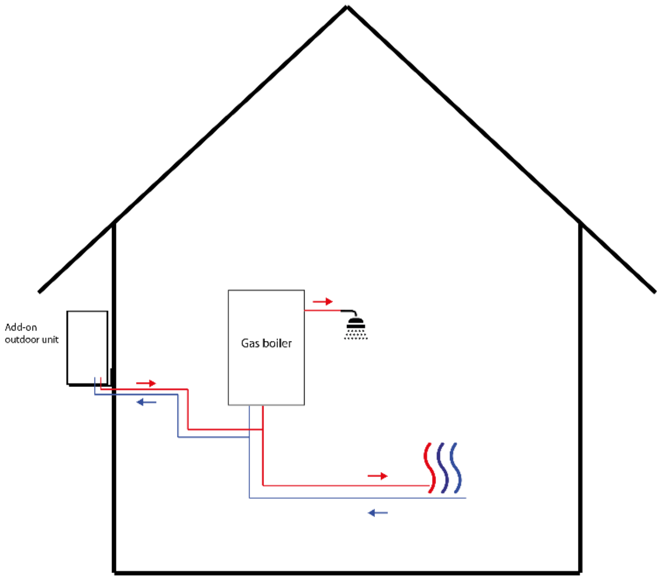


Figure 11. Add on heat pump + gas boiler on principles of (Warmteservice, 2022)

Boundaries outdoor unit

Heat pump type	Outdoor units location	Source
Split unit heat pump + gas boiler	Wall, ground, roof	("Plaatsing warmtepomp," n.d.) & (P. van der Wilt, 2022)
Monoblock heat pump + gas boiler	Ground, roof, Wall (heavy bracket)	("Plaatsing warmtepomp," n.d.) & (P. van der Wilt, 2022)
Add-on heat pump + gas boiler	Wall, ground, roof	("Plaatsing warmtepomp," n.d.) & (P. van der Wilt, 2022)

Table 11. Boundaries placement outdoor unit air source heat pumps

Sound regulations

During the day the maximum noise is allowed to be 45dB and during the night the maximum noise may be 40dB on the property boundary (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2021).

Heat emission system suitable for the hybrid heat pump

Heat pump type	Operating in hybrid both on LT < 55 °C (Figure 13)	Operating in hybrid system LT/HT (< 55 °C/ 70 °C) (Figure 12)
Split or monoblock unit heat pump + gas boiler	< 55 °C : Floor heating, LT-radiators, Over dimensioned normal radiator (+add on fan) (chapter 6.1) & (Table 9).	< 55 °C : Floor heating, LT-radiators, Over dimensioned normal radiator (+add on fan) (chapter 6.1) & (Table 9). (70 °C) : radiators (supplied by gas boiler) (Nefit, 2016).

Table 12. Heat emitter hybrid air source heat pump

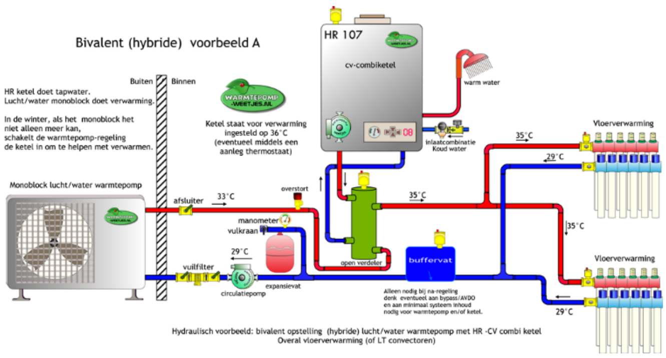


Figure 13. Air source heat pump in hybrid mode both on LT <55°C (warmtepomp-weetjes.nl, n.d.)

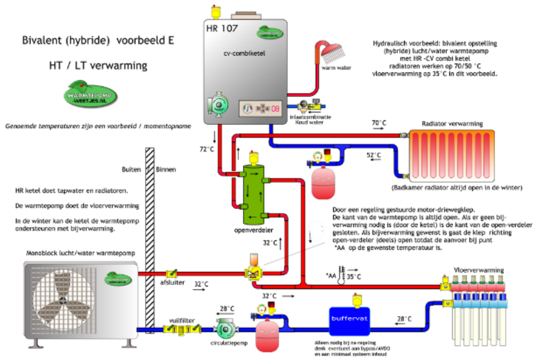


Figure 12. Air source heat pump in hybrid mode LT/HT (<55°C/70°C)(warmtepomp-weetjes.nl, n.d.)

Boundary SCOP

Supply temperature	SCOP
Varying throughout the year 0-70 °C	4,3 (Buiting, 2022)

Table 13. SCOP hybrid air source heat pump

Boundary price

€ 4.500 en € 6.000 including installation costs (kemkens, nd)

Outside air to water heat pump all electric

with this heat pump type (Figure 14), heat is extracted from the outside air and transferred to a refrigerant. This refrigerant then transfers the heat to the heat delivery system of the building and to the domestic hot water boiler (DNEResearch, 2021). An all-electric outside air heat pump is basically the same as the previous shown hybrid systems, but then without the gas boiler and without the hydraulic separator. The system has an electric backup heater for cold winter days.

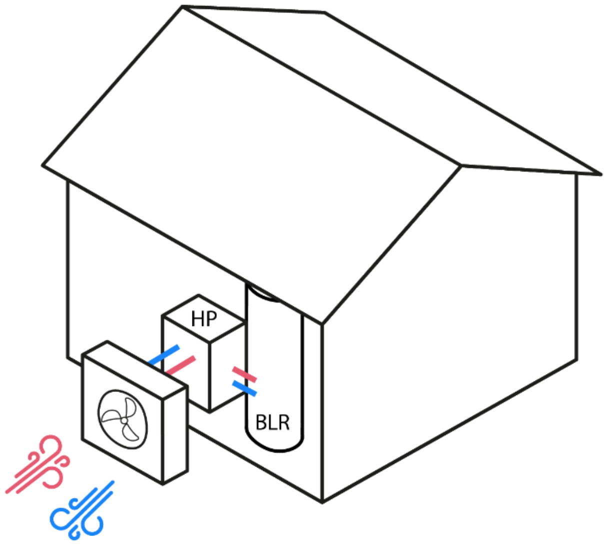


Figure 14. Outside air to water heat pump all electric (Own figure)

Boundaries supply temperatures

All electric	Supply temperature (max)
Heat pump only mode	55 (Warmtepompvergelijker, 2022).

Table 14. All-electric air source heat pump supply temperatures

Boundaries outdoor unit

Heat pump type	Outdoor unit location	Source
All electric split unit heat pump	Wall, ground, roof	("Plaatsing warmtepomp," n.d.) & (P. van der Wilt, 2022)
All electric monoblock heat pump	Ground, roof, Wall (heavy brackets)	("Plaatsing warmtepomp," n.d.) & (P. van der Wilt, 2022)

Table 15. All-electric air source heat pump outdoor location

Sound regulations

During the day the maximum noise is allowed to be 45dB and during the night the maximum noise may be 40dB on the property boundary (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2021).

Heat emission system suitable for the hybrid heat pump

Heat pump type	Operating in hybrid both on LT < 55 °C (Figure 13)
All electric split unit heat pump & monoblock	**< 55 °C** : Floor heating, LT-radiators, Over dimensioned normal radiator (+add on fan) (Table 9) & (Chapter 6.1)

Table 16. All-electric air source heat pump heat emitter

Boundary SCOP

Supply temperature	SCOP
35°C	5 (Warmtepompvergelijker, 2022)
55°C	3 (Warmtepompvergelijker, 2022)

Table 17. SCOP all-electric air source heat pump

Boundary price
€ 7.500- 12.500 including installation costs (verwarminginfo, 2019)

Solar collector/PVT heat pump

A PVT heat pump uses a so-called heat pump solar panel (PVT) (Figure 15). This panel contains a conductive system where water flows through, which extracts solar heat from the PVT panel and is then transported to the heat pump inside the building. The heat pump upgrades the heat from the solar collector to heat up the building and to heat up the boiler for domestic hot water (DNEResearch, 2021).

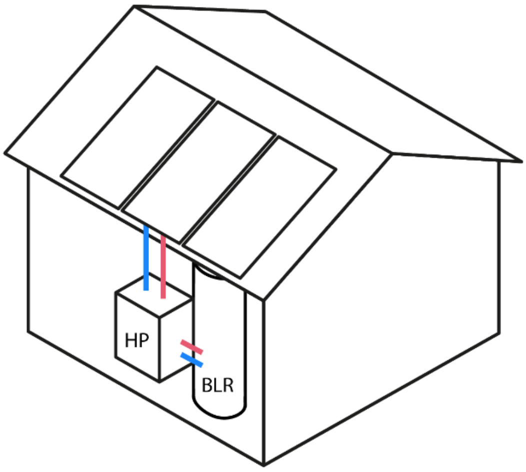


Figure 15. Solar collector/PVT heat pump (Own figure)

Boundaries supply temperatures

PVT heat pump mode	Supply temperature (max)	
All electric PVT heat pump	55°C	(NIBE, n.d.)
Hybrid PVT heat pump + gas boiler	70°C	(Triple Solar BV, 2022)

Table 18. Supply temperature PVT heat pump

Boundaries outdoor unit :
Per kW heat demand, 2 PVT panels with a total roof area of 1,69+1,69=3,38m^2 are needed (Qsilence B.V, n.d.). 4 kW is considered as a hybrid (Remeha, 2021) and therefore 4*3,38= about 14m2

Heat pump type	Needed roof area
All electric PVT heat pump	14+ m2 (depending on heat demand)
Hybrid PVT heat pump + gas boiler	14m2 (Hybrid 4kW)

Table 19. PVT heat pump needed roof area

Heat emission system suitable for the all-electric PVT heat pump

Heat pump type	Heat emitter
All electric PVT heat pump	**< 55 °C** : Floor heating, LT-radiators, Over dimensioned normal radiator (+add on fan) (Table 9) & (Chapter 6.1)
Hybrid PVT heat pump + gas boiler	**< 55 °C :** Floor heating, LT-radiators, Over dimensioned normal radiator (+add on fan) (chapter 6.1) & (Table 9). **(70 °C)** : radiators (supplied by gas boiler) (Nefit, 2016).

Table 20. PVT heat pump heat emitter

Boundary SCOP

Supply temperature	SCOP
35°C	5,13 (Qsilence BV, 2022)
55°C	3,73 (Qsilence BV, 2022)

Table 21. SCOP PVT heat pump system

Boundary price
€ 15.000 - 25.000 (Slimster, 2022b)

Ground source heat pump

Closed loop ground source water to water heat pump: the heat from the soil is transferred to the heat pump. The heat pump upgrades the heat so that it can be used for space heating and domestic hot water. A ground source heat pump system has the capability of free cooling in summer (DNEResearch, 2021).

Boundaries supply temperatures

Ground source heat pump	Supply temperature (max)
All electric ground source heat pump	55 (NIBE, n.d.)

Table 22. All-electric ground source heat pump supply temperature

Boundaries outdoors

The boundaries are related to different outdoors subjects: space, regulations and interference.

Space
reachable by ground drilling rig, specific size is shown later in thesis

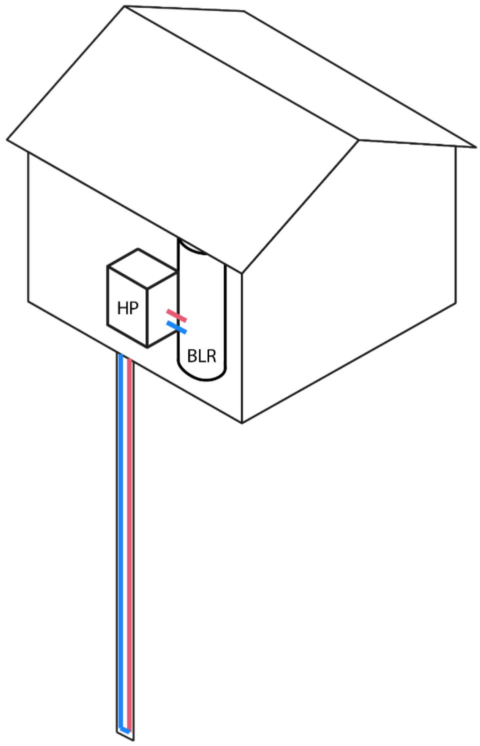


Figure 16. Ground source heat pump (Own figure)

Regulations
In the tool only closed looped systems as shown in (Figure 16) are taken into account. As these systems require the least area for drilling.

If the system is situated in an 'area of inference' or a 'Environmental permit limited environmental test' then a notification is always needed. (Is warmte/koudeopslag een vergunningplichtige activiteit?, n.d.).

Interference
If ground source systems are situated close to each other the risk of interference may occur. Usually the municipality is the competent authority.

The tool will only include the boundary related to outdoor space. The other two boundaries related to regulations and interference are harder to define and not directly necessary in the first place, so they will be defined by the installer who will place the heat pump.

Heat emission system suitable for ground source heat pump

Heat pump type	LT < 55 °C
All electric ground source heat pump	Floor heating, LT-radiators, Over dimensioned normal radiator (+add on fan) (Warmtepomp Installatie Tips, 2021).

Table 23. All electric ground source heat pump heat emitter

Boundary SCOP

Supply temperature	SCOP
35°C	5,3 (Bosch, 2022)
55°C	4 (Ecobouwers, n.d.)

Table 24. All electric ground source heat pump SCOP

Boundary price: €13.500 to €25.000 (Slimster, 2022a)

Boundaries indoor spatial aspects all systems

To ensure that the final heat pump decision tool provides advice regarding what specific heat pump system fits into an existing situation, all the dimensions of each system were investigated in real life scenarios. Later in this thesis the dimensions will be translated to a question in the heat pump decision tool. In the end the homeowner can see based on several questions which specific heat pump system can fit in his home based on the indoor spatial aspects.

All-electric air source heat pump + domestic hot water boiler (Figure 17)

System component	Size (cm)	Source
Air source heat pump indoor module	70x45x30	(intergas-verwarming, n.d.)
DHW boiler 200L or 300L	56x161 or 64x185	(intergas-verwarming, n.d.)

Figure 17. All-electric air source heat pump + DHW boiler (installatieenbouw, 2022)

All-electric air source heat pump + domestic hot water boiler + central heating buffer (Figure 18)

System component	Size (cm)	Source
Air source heat pump indoor module	70x45x30	(intergas-verwarming, n.d.)
DHW boiler 200L or 300L	56x161 or 64x185	(intergas-verwarming, n.d.)
Central heating buffer	50x500 or 50x1000 or 50x1500	(nefit-bosch, n.d.-d)

Figure 18. All-electric air source heat pump + DHW boiler + Central heating buffer (panasonicwarmtepompen, 2019)

Hybrid air source heat pump (split or monoblock) + gas boiler + central heating buffer (Figure 19)

System component	Size (cm)	Source
Hybrid air source heat pump indoor module	70x45x24	(nefit-bosch, n.d.-b)
Gas boiler	70x45x30	(nefit-bosch, n.d.-c)
Central heating buffer	50x500 or 50x1000 or 50x1500	(nefit-bosch, n.d.-d)

Figure 19. Hybrid air source heat pump + gas boiler + central heating buffer (Korbee, n.d.)

Hybrid air source heat pump (split or monoblock) + gas boiler (Figure 20)

System component	Size (cm)	Source
Hybrid air source heat pump indoor module	70x45x24	(nefit-bosch, n.d.-b)
Gas boiler	70x45x30	(nefit-bosch, n.d.-c)

Figure 20. Hybrid air source heat pump + gas boiler (Dorth, n.d.)

Ground source heat pump with integrated 180L domestic hot water boiler + extra central heating buffer (Figure 21)

System component	Size (cm)	Source
Ground source heat pump indoor module + integrated 180L DHW boiler	60x61x1780	(nefit-bosch, n.d.-a)
Central heating buffer	50x500 or 50x1000 or 50x1500	(nefit-bosch, n.d.-d)

Figure 21. Ground source heat pump with integrated 180L DHW boiler + extra central heating buffer (nefit-bosch, n.d.)

Ground source heat pump with integrated 180L domestic hot water boiler no extra central heating buffer (Figure 22)

System component	Size (cm)	Source
Ground source heat pump indoor module + integrated 180L DHW boiler	60x61x1780	(nefit-bosch, n.d.-a)

Figure 22. Ground source heat pump with integrated 180L DHW boiler (nefit-bosch, n.d.)

PVT heat pump indoor unit + domestic hot water boiler + central heating buffer (Figure 23)

System component	Size (cm)	Source
PVT indoor unit	80x50x45	(Qsilence BV, 2022)
Domestic hot water boiler	60x140	(Qsilence BV, 2022)
Central heating buffer	50x50	(nefit-bosch, n.d.-d)

Figure 23. PVT heat pump indoor unit + DHW boiler + central heating buffer (Youtube)

Hybrid heat pump (monoblock only) without indoor unit but with hydraulic separator (Figure 24)

System component	Size (cm)	Source
Gas boiler	70x45x30	(nefit-bosch, n.d.-c)
Hydraulic separator	36x14x7	(pentecbv, n.d.)

Figure 24. Hybrid heat pump (monoblock only) with only a hydraulic seperator indoors (pdebonthbv, n.d.)

7 define how the tool can fulfil a educational function to the homeowner

Objective

Using exploratory research and using example cases to make clear how the heat pump tool fulfils an educational function for the benefit of the homeowner in terms of insulation, costs, indoor comfort. And the advice of the tool should contribute to the energy transition of the built environment.

Question

In what way can the heat pump decision tool fulfil an educational function for the benefit of the homeowner in terms of insulation, cost and indoor comfort and how can it contribute to the energy transition of the built environment?

7.1 Educational function heat pump decision tool

Environmental education

The tool can be used to make homeowners aware of the fact that a change is needed in the field of space heating. Space heating is currently performed for the largest part from natural gas, which causes global warming. The tool can also be used to make homeowners aware of the fact that not only global warming but also earthquakes in Groningen are a result of using natural gas. Therefore an change has to be made switching from using natural gas for space heating to sustainable electricity in combination with a heat pump.

Implementation education

The tool has an advisory function and must educate the homeowner in an understandable manner that insulating is the basis for better living comfort, cost reduction and contribution to the energy transition. It is important to firstly insulate the building to decrease the heat demand before applying a heat pump system.

Comfort education

It must be made clear to the homeowner that insulating and installing a heat pump leads to a better living comfort. This should be educated by means of displaying examples in the final tool.

Education costs

According to the societal relevance there is a sudden rise of energy costs going on. And many people want a heat pump system to reduces their energy costs. The tool must educate that the measures indicated by the tool save money compared to the use of the traditional gas boiler. This should also be educated by the means of examples.

Target group

The heat pump decision tool will be made for homeowners with an owner-occupied home. The tool in this thesis is being developed for ground-level homes, which could be a terraced house, semi-detached house or detached house. Home owners are increasingly faced with high gas prices and are increasingly forced to look for more sustainable alternatives. But these people do often not know where to start, immediately call in an installer to install a heat pump or perhaps first call a contractor who comes to insulate their home. This tool ensures that these people with some technical knowledge are provided with all the information at a level that they understand. By using this heat pump decision tool, they get all the necessary information in the field of energetic performance of their home, the heat emission system and the possible applicable heat pump systems based on spatial aspects, both indoors and outdoors. By using this tool, they can therefore see whether they must first hire a contractor for insulation improvements or can do this themselves. Or they can engage an installer for a heat pump. And based on this tool, they could develop a preference for a particular heat pump system and search for an installer more specifically.

Motive for purchase

(Reichler, 2019) did a research study for his thesis, based on a qualitative approach, emphasises the role of rational and bounded rational decision-making factors in the purchase of renewable heating technologies. According to the study from (Reichler, 2019) core motives for consumers purchasing existing renewable heating technologies are: *figure related aspects, such as economic data,* on whether a purchase will be profitable or not. Or clear and transparent information regarding incentive programs and incentive programs and authorities is required in order to validate these large investments. The alternative would be strong rules and restrictions (Reichler, 2019). (Reichler, 2019) concludes from his research that the necessity of the purchase of renewable heating technologies represents a comprehensive decision-making process, long-term and rather complex. Different aspects like priority over other investments, or the choice to first just observe the development of fuel prices for non-renewable technologies influence the decision in the long-run. The availability of adequate financial resources is very important in the decision-making process. The heat pump decision tool therefore provides a broad picture of matters that play a role when purchasing a heat pump.

Vision

So the vision (Figure 25) of the heat pump selection tool based on the framework by (Reichler, 2019) and the findings from the literature study and past empirical research study will be to show the user of the heat pump decision tool an overview of what they should think about before purchasing a heat pump system. By showing this to the user of the tool they get a lot of useful information before determining which specific heat pump options are available for their own home.

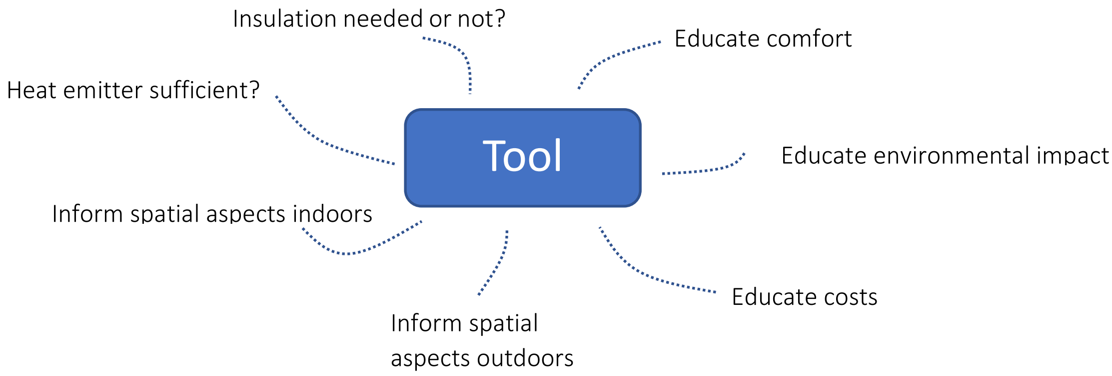


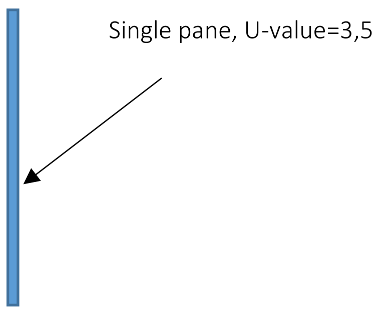
Figure 25. Tool vision (Own figure)

7.2 Example home, the effects on indoor comfort by insulating the home and lowering supply temperature

This research was carried out so that in the final heat pump decision tool, findings from this research can be used to educate the home owner what effects insulating the building envelope and lowering the supply temperature has on the indoor comfort. The insulation values from bad to good and the related comfort level of 3 homes built in 1977, 2002 & 2009 respectively are compared.

Example home 1977 poor insulated

The example home is a German home taken from research by (Rettig ICC). The Dutch construction method associated with the insulation value have been defined. As a result, a link can easily be made between a certain construction method in the Netherlands to indoor comfort.

Construction year		1977	Building construction method in the Netherlands
U-value window or RC value	W/m²K or m²K/W	U=3,5 or Rc=0,29	 Single pane, U-value=3,5 Single pane

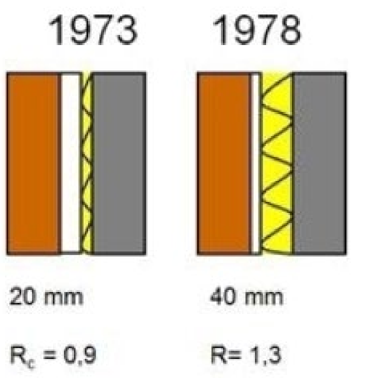
U-value façade or RC value	W/m²K or m²K/W	U=1 or Rc=1	 *Figure 26. Cavity with around 30 mm insulation* (duurzaammbo, n.d.)
Specific heat demand	W/m²	130	
T_{supply}/T_{return}	°C	90/70	

Table 25. Example home 1977 poor insulated

Indoor comfort 1977 single pane and 30mm insulation

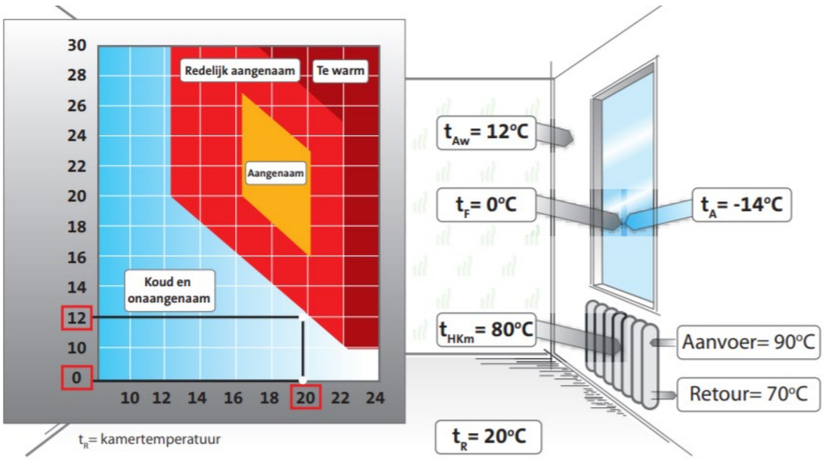


Figure 27. Temperatures in example home pre-1977 (90-70-20C), (Rettig ICC)

Windows with an U-value of 3,5 are single pane glazing. If the outdoor temperature is -14°C (Germany) then the indoor surface temperature of the window becomes 0°C. To get the indoor room temperature to a comfortable level (20°C) the supply temperature of the radiators needed to have an average water temperature of 80°C. But despite this high supply water temperature the surface temperature of the indoor walls became at most 12°C, with big temperature differences and clearly noticeable cold spots as a result. The surface temperatures are displayed at the y-axis (Figure 27). The room temperature is displayed at the x-axis (Figure 27). The intersection between the surface temperature of the window 0°C and the room temperature 20°C and the intersection between the surface temperature of the wall 12°C and the room temperature 20°C show that the indoor comfort at an outdoor temperature of -14°C as a result of temperature differences between indoor surfaces and indoor air is cold and unpleasant (Figure 27)(Rettig ICC).

Example home 2002 well insulated

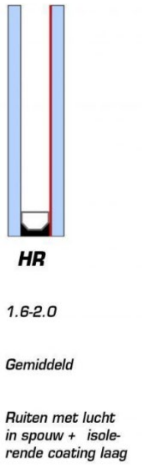
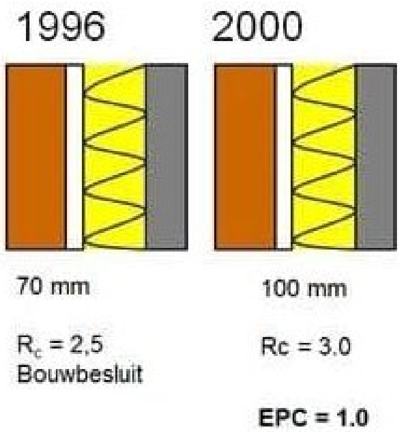
Construction year		2002	Building construction in the Netherlands
U-value window or RC value	W/m²K or m²K/W	U=1,7 or Rc=0,59	 (alhra, 2021)
U-value façade or RC value	W/m²K or m²K/W	U=0,35 or Rc=2,86	 *Figure 28. Cavity with around 90 mm insulation* (duurzaammbo, n.d.) Or single brick wall + retaining wall with 90mm insulation (termical, n.d.)
Specific heat demand	W/m²	50	
T_{supply}/T_{return}	°C	55/45	

Table 26. Example home 2002 well insulated

With these insulation values the ideal room temperature of 20°C could be reached with an average supply temperature of 50°C. The indoor walls had a surface temperature of 17°C. The indoor surface temperature of the in this case double pane HR glazing became 14°C (Figure 29).The 2 intersection points between the surface temperatures and the indoor room temperature are now in the range fairly pleasant to pleasant.

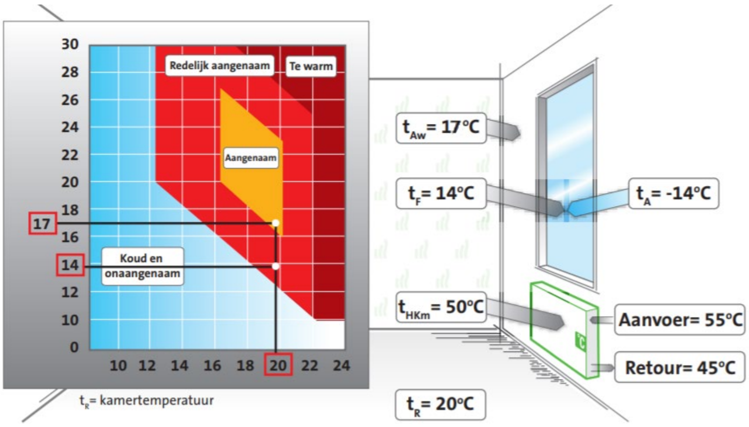
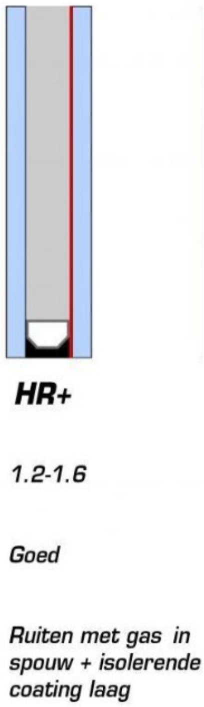


Figure 29. 2002 (55°/45°/20°C), (Rettig ICC)

Example home 2009 excellent insulated

Construction year		2009	Building construction method in the Netherlands
U-value window or RC value	W/m²K or m²K/W	U=1,3 or Rc=0,77	 (alhra, 2021)

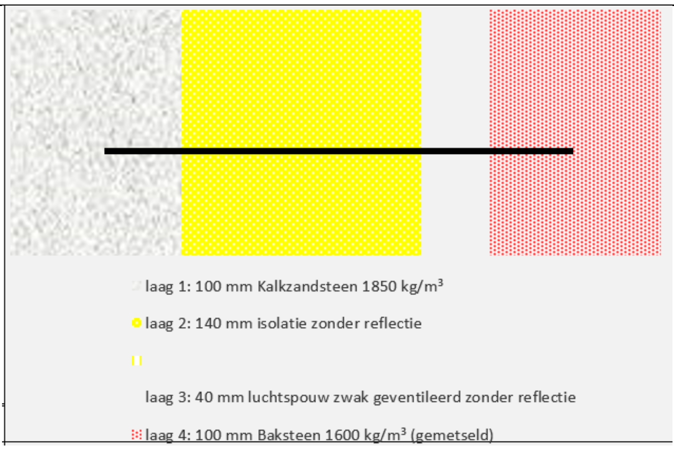
U-value façade or RC value	W/m²K or m²K/W	U=0,24 or Rc=4,17	 *Figure 30. Cavity with around 140mm insulation Rc=4,12* (recticelinsulation, n.d.) Or single brick wall with retaining wall + insulation of 140mm (termical, n.d.)
Specific heat demand	W/m²	35	
T supply/T return	°C	45/35	

Table 27. Example home 2009 excellent insulated

With these insulation values the surface temperature of the walls is almost the same as the indoor air temperature. And despite the freezing cold outside, the windows have an indoor surface temperature of 17°C (Figure 31). This is the ideal situation in terms of indoor comfort, the intersection between the surface temperatures and the indoor room temperature are both pleasant. And its beneficial that this high level of indoor comfort is achieved with a 50% lower supply temperature compared to the same building from 1977.

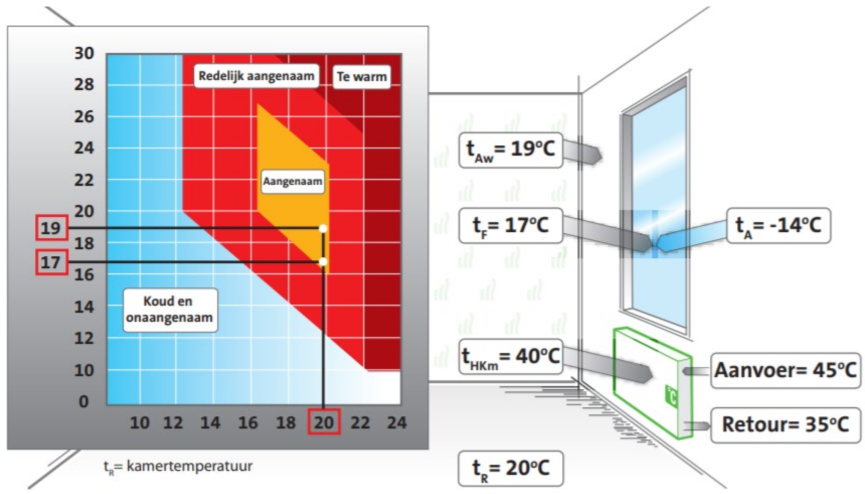


Figure 31. 2009 (45°/35°/20°C), (Rettig ICC)

Conclusion + what to show in the heat pump decision tool

A better insulated building results in less temperature differences between indoor surfaces and indoor air temperature, which results in a perceived temperature closer to the indoor air temperature and thus a higher indoor comfort. But in existing situations it is not always possible to aim for the amount of insulation (14 cm) as in the example home from 2009, because the existing construction or the budget of the homeowner does not allow this. Nevertheless, it is given as an example to the user of the tool, to show the positive effect on insulating on the indoor comfort. The 3 example homes are sketched with insulation values and the associated indoor comfort, these images (Figure 34)(Figure 32)(Figure 33) will fulfil an educational function in the heat pump decision tool related to the indoor comfort.

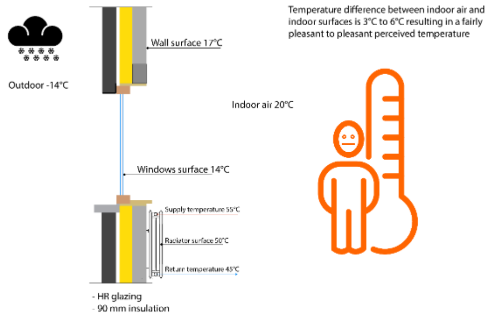


Figure 34. Indoor comfort good insulated building (Own work)

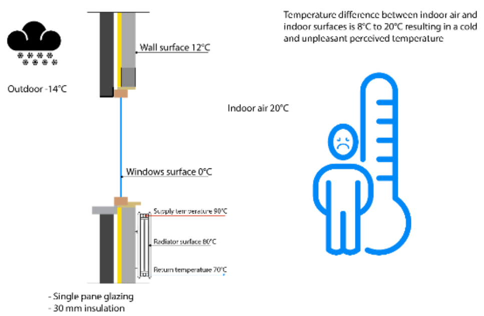


Figure 32. Indoor comfort bad insulated building (Own work)

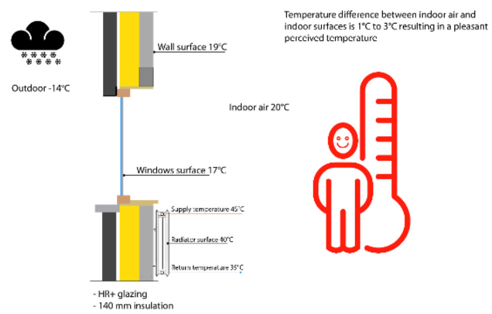


Figure 33. Indoor comfort perfect insulated building (Own work)

7.3 Example home, the effects on costs by insulating the home and applying an heat pump

As an example the comparison of the heat demand related to the 3 different homes and insulation levels as discussed in (chapter 7.2) will be made.

		1977	Dutch construction	ENEV 2002	Dutch construction	ENEV 2009	Dutch construction
U-value window	W/m^2K or RC	3,5 or 0,29	Single pane	1,7 or 0,59	Double pane (HR)	1,3 or 0,77	Double pane (HR+)
U-value façade	W/m^2K or RC	1 or 1	30mm insulation	0,35 or 2,86	90mm insulation	0,24 or 4,17	140mm insulation
Heat demand	W/m^2	130		50		35	
Tsupply/Treturn	°C	90/70		55/45		45/35	

Table 28. Overview 3 example homes

For this comparison is assumed that the 3 homes have a floor area of $100m^2$. Every example home will be equipped with a heat pump. According to the systems as determined in (Chapter 6), the home from 1977 cannot be heated with the systems selected in this thesis. The hybrid systems go up to 70°C supply temperature (Table 10) & (Table 18) and the all-electric systems go up to 55°C (Table 10), (Table 14), (Table 18), (Table 22) while 90°C degrees is needed (Table 28). In order to be able to perform this comparison, an extra system has been included, a high temperature heat pump. This system was initially not included in this thesis because it doesn't contribute to the trias energetica principle, since the building envelope doesn't need to be improved. But by the means of this example the home owner is informed what the results are when using a high temperature heat pump.

Example 1997
heat demand is 130 W/m^2 at a supply temperature of 90°C.

The floor area of the building is 100m^2 resulting in a total heat demand of: 130*100=13kW. This 13kW is the heating capacity needed to get the building to an comfortable indoor temperature at the time it is freezing cold outside, this results in a heat pump size of 13kW.

The supply temperature needed in order to get the building warm with this specific heat emissions system is 90 degrees (Radiator), the only way of achieving such high supply temperatures with a heat pump is with a high temperature heat pump.

For these high heat demands and high supply temperatures are currently not many heat pumps available. Feenstra and Vattenfall are working together developing a high temperature CO_2 heat pump which can heat up supply water to a temperature of 90°C (Brinck, 2021). The COP of this high temperature heat pump installed in the Netherlands is currently unknown. But one of the cooperating companies 'Denso' which is involved in the heat pump developed by Vattenfall and Feenstra already produces high temperature CO_2 heat pumps since 2001 in Japan, with a COP of 3. But this COP of 3 is achieved in Japan, and Japan has a different climate than the Netherlands (E3TNW). But according to an article by (Heurman, 2021), Vattenfall announced that a gas reduction of 1250m^3 results in an increase of electricity usage of 5000 kWh by the high temperature heat pump. A short calculation reveals the SCOP according to Vattenfall: 1250 * 0,95 (gas boiler efficiency) * 9,77 (kWh per 1 m^3 gas)=11601 kWh. Resulting in a SCOP of the Vattenfall high temperature heat pump: 11601/5000= 2,3.

The high temperature heat pump from Vattenfall will cost €15.000 (Vattenfall, 2022).

The lifespan is unknown, but on average a heat pump system lasts 15 to 20 years. But the lifespan depends on the operating hours of the compressor("Economische- en praktijk levensduur ", 2021). And since the high temperature heat pump is installed in less insulated buildings the heat pump has more full load hours compared to a heat pump in a better insulated building, because the heat pump starts heating at a higher outdoor temperature compared to a heat pump in a better insulated building. Therefore we assume in this case that the high temperature heat pump has a lifespan of 15 years.

Example 1997 annual electricity costs
The annual heat demand of a building is made up of space heating and water heating. In this example we are only looking at the heat demand for space heating. The peak heati demand is the highest instantaneous demand in kW. And the annual heat demand is a quantity over time (one year) in kWh (PlanLoCaL, 2021). In order to know the annual heat demand for space heating the annual energy put into the building to heat up the building must be known. This annual energy can be traced in different ways, in case of a gas boiler heater the gas meter can be read minus the amount of gas used for showering and cooking. Or the annual heat demand for space heating can be simulated with different energy simulations such as design builder for example or it can be calculated statically with temperature bins of the outdoor temperature (Dongellini, Naldi, & Morini, 2015). But in order to simulate or calculate the exact characteristics of the buildings need to be known. The characteristics known from this particular example are too marginal to perform an energy simulation. But for this particular example it is not needed to be 100% exact, so the heat demand for space heating which is 130W/m^2 is converted to an annual heat demand for space heating of 270 kWh/m^2 based on key figures ("Warmtepomp indicatietabel ", 2021). The key figures are based on multiple cases of buildings with different insulation values according to their construction year and building type. As shown before this building from 1977 with a RC of 1 has approximately the same characterises as a building in the Netherlands from the 1973-1978 (Table 25). This correspondents with the building class 1965-1974 in the key figure table ("Warmtepomp indicatietabel ", 2021). For building type is in this example case chosen for a corner dwelling. But again this is just an estimation since the 130W/m^2 is calculated at an outdoor temperature in Germany of -14 and the key figure table starts at -10 which is used in the Netherlands.

Again this example case is to show relations between insulation and energy usages and CO2 emissions so the translation from space heat demand to annual net heat demand doesn't need to be 100% correct.

So in this case the annual heat demand for space heating of the example building from 1977 according to the key figures will be: 270*100=27.000kWh.

With a SCOP of 2,3 results this in a yearly electricity usage of: 27.000/2,3=11.739kWh

With the current electricity prices are the operating costs of the heat pump will be: 11.739*0,635(Overstappen.nl, 2022b) = €7.454 yearly

Example 2002

The heat demand is 50 W/m^2 at a supply temperature of 55°C.
Total heat demand of the building: 50*100=5kW (size of heat pump).
The costs of a 5kW heat pump are around: €7500 (chapter 6.1).
The heat pump needs to produce a water temperature of 55°C, according to research performed in (chapter 6.2) the SCOP will then be 3,15.
The lifespan will be a bit longer then the heat pump in the 1977 dwelling due to the lower full load hours a year, a lifetime of 18 years is assumed.
The conversion from power demand for space heating to net annual heat demand is again an educated guess due to the lacking building characteristics. According to key figures a building with a heat demand of 50 W/m^2, will fall in the category of buildings (2010-2015) with an RC of 5, but according to the RC value of 2,86 the building will fall in the category of (1990-1999) but this category has a heat demand for space heating of 80W/m^2. So again key figures do not ensure a correct conversion from W/m^2 to kWh/m^2. But since this an example and the correct numbers do not really matter in this case there is chosen to use the building category (2000-2010) with an annual heat demand for space heating of: 114kWh/m^2 ("Warmtepomp indicatietabel ", 2021).
So in this case the annual heat demand for space heating of the example building from 2002 is estimated ass: 114*100(floor area)=11.400kWh.
With a COP of 3,15 results this in a yearly electricity usage of: 11.400/3,15=3.619kWh
With the current electricity prices the yearly operating costs will be: 3.619*0,635 = € 2298 yearly

Example 2009 at 45°C supply temp

The heat demand is 35 W/m^2 at a supply temperature of 45°C.
Total heat demand of the building: 35*100=3.5kW (size of heat pump).
The costs of a 3.5 kW heat pump are assumed the same as a 5kW heat pump: €7500.
The heat pump needs to produce supply water at a temperature of 45°C, the SCOP will then be 3,3 (klimaatexpert, nd).
The lifespan is assumed to be a bit longer than the heat pump in the 2009 building due to the lower full load hours: therefore the lifespan is assumed to be 20 years.
We assume that this building with a heat demand of 35 W/m^2 and a RC of 4,17 will fall in the category of buildings (2010-2015) resulting in an annual heat demand for space heating of: 70 kWh/m^2 ("Warmtepomp indicatietabel ", 2021).
So in this case the annual heat demand for space heating will be: 70*100=7.000kWh
With a COP of 3,3 this results in a yearly electricity usage of: 7000/3,3= 2.121kWh
With the current electricity prices the yearly operating costs will be: 2.121*0,635= €1.347
Heat pumps have the best COP at an even lower supply temperature namely around a supply temperature of 35°C, this is due to the lower temperature difference between the heat source (outdoor air/ground) and the temperature of the supply water.

Example 2009 at 35°C supply temp

The home from 2009 with a heat demand of 35 W/m^2 could also be heated with a very low temperature source of 35°C if the right heat emission system is used for example underfloor heating or wall heating instead of radiators. (chapter 6.1).
The size of the heat pump will remain the same: 35*100=3.5kW (size of heat pump).
The costs of the heat pump will be the same: €7500.
But the supply water is heated to a temperature of 35°C which results in a SCOP of 4,5 (Daikin, 2022).
The annual heat demand remains the same: 70*100=7000kWh
With a SCOP of 4,5 will this result annual electricity usage of: 7000/4,5=1.556kWh
The yearly operating costs will be: 1.556*0,635=€988

Annual heating costs to compare

		1977	Dutch construction	2002	Dutch construction	2009	Dutch construction
U-value window	W/m^{2}K or RC	3,5 or 0,29	Single pane	1,7 or 0,59	Double pane (HR)	1,3 or 0,77	Double pane (HR+)
U-value façade	W/m^{2}K or RC	1 or 1	30mm insulation	0,35 or 2,86	90mm insulation	0,24 or 4,17	140mm insulation
Heat demand	W/m^2	130		50		35	
Tsupply/Treturn	°C	90/70		55/45		45/35	
Annual heating costs in combination with all electric heat pump	€	7.454		2.298		1.347 at 45°C 988 at 35°C	

Conclusion + what to show in the heat pump selection tool

It is necessary to show the user of the heat pump selection tool the need for insulation in relation to the indoor comfort (as in chapter 7.2) and annual heating costs in a understandable easy manner (Figure 35).

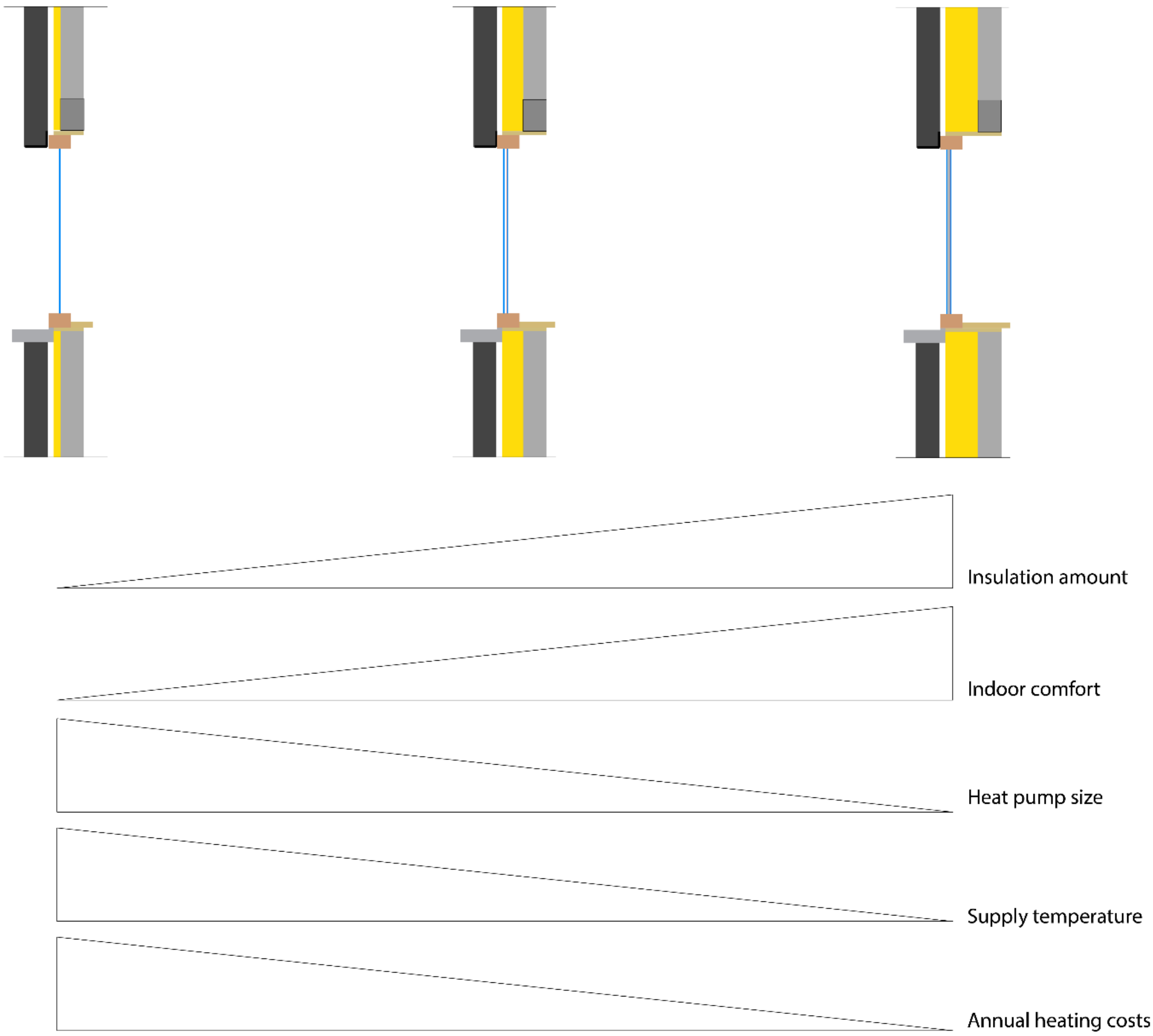


Figure 35. The need for insulation related to the indoor comfort and annual heating costs in understandable overview

It has now become clear that insulation is important when choosing a heat pump system. But the exact amount of insulation and the costs could be a barrier for home owners. But therefore it is necessary to look at the total costs over an longer period up to 2050, because the goal is to phase-out all the fossil fuels by 2050. The cabinet has also noticed that insulating the existing housing stock is a key element in the energy transition of the built environment. Therefore has the minister sent a letter to the Tweede Kamer (House of Representatives) on march 18, 2021 in which she makes a proposal for the amount of insulation needed to make the existing building stock future proof for low temperature heat sources, she calls this the Standard. The Tweede kamer has now discussed this proposal. The elaboration of the Standard and its conversion into regulations will be left to the next cabinet (Hogeweg, 2021).

7.4 parliamentary letter insulation standard

This chapter is a summary of the parliamentary letter about the proposed insulation standard in order to get an insights of the amount of insulation that according to the Dutch government is needed to transform the Dutch building stock to a CO2 neutral building stock by 2050.

Standard for home insulation: future proof

In the climate agreement is agreed that the built environment is gradually made more sustainable and that the CO2 emissions are drastically reduced towards 2050. To reach this goal the heat loss from buildings and the energy consumption of heating systems are limited, natural gas is replaced by sustainable ones and self-generation of energy in buildings increases. To support building owners in this task, it has been agreed in the climate agreement, among other things, to establish a standard for home insulation. This gives building owners a reference for what can be regarded as good and future-proof for home insulation (Ollongren, 2021).

With the insulation standard for existing buildings, homes are prepared for a future in which homes with a lower heating temperatures (50 degrees) can become heated. Due to the wide application of this standard in renovations it can be important to achieving the climate goals and the agreed CO2 reduction in the built environment for 2050. The application of the standard also contributes to lowering the energy bill and the space required for sustainable energy generation. Well insulated homes require less energy. This social considerations have also explicitly played a role in determining the level of the insulation standard (Ollongren, 2021).

Insulation standard mandatory or not?

The insulation standard is aimed at 2050 and is voluntary for owner-occupied homes for the time being. For landlords, however, has been agreed in the climate agreement that the standard will become mandatory in 2050. In addition, the climate agreement states that ‘Landlords are responsible for adapting a home so that it complies with the standard when the homes are renovated via the district-oriented approach and connected to the new low temperature heat infrastructure(Energie, 2021).

Conclusion

The standard is not obligated jet, but it will be used as a guideline the homeowners who will use the heat pump decision tool, to what amount they should insulate in order to be ready for the gas free future.

3.4 The standard & target values

A proposal for the level of the standard is elaborated in in (Figure 36). The standard is expressed in net heat demand [kWh/m2]. This is not easy to calculate in an existing home, so target values (Table 29) of insulation thicknesses are given with which the standard can be achieved in many cases.

Formule Standaard		
Woningtype	**Voorstel Standaard**	
	Compactheid (A_{ls}/A_g)	**Netto warmtevraag [kWh/m^2]**
Eengezinswoningen, voor 1945	< 1,00 ≥ 1,00	= 60 =60 + 105 * (A_{ls}/A_g – 1,0)
Eengezinswoningen, na 1945	< 1,00 ≥ 1,00	= 43 = 43 + 40 * (A_{ls}/A_g - 1,0)
Meergezinswoningen, voor 1945	< 1,00 ≥ 1,00	= 95 =95 + 70 * (A_{ls}/A_g - 1,0)
Meergezinswoningen, na 1945	< 1,00 ≥ 1,00	= 45 = 45 + 45 * (A_{ls}/A_g - 1,0)

Voorstel Standaard

Figure 36. Proposal insulation standard (Ollongren, 2021)

Target values

Realizing the standard can be done in various ways. Better insulate some building parts, to compensate for building parts with low insulation value, or by bringing all building parts to a minimum quality level. In addition, you can opt for a step by step approach or an all-in-one approach. In principle, there are three possible approaches (Energie, 2021):

A. An approach in which the entire home is analysed and a tailor-made advice is made, including the most sensible/cheapest/most cost-efficient way to achieve the standard. The desired insulation values then follow from the chosen plan(Energie, 2021).

B. An approach in which per building component (i.e. step-by-step) is insulated so that that part of the building is certainly at an adequate level and no longer needs to be tackled. This is done per building component, until the standard is reached. The values to strive for are:

Roof	Rc 8 m2K/W (about 35cm insulation)
Floor	Rc 3,5 m2K/W (about 14cm insulation)
Façade	Rc 6 m2K/W (about 26 cm insulation)
Panel	1,4 W/m²K (insulated)
Windows and window frames	1,0 W/m²K (triple glass in new frames)
Front door	1,4 W/m²K (insulated)
Ventilation	Balanced ventilation with heat recovery, control of supply or exhaust through CO2 measurement
Air tightness	qv;10=0,4 dm3/sm2 (improved crack sealing of windows and doors and connection of facade and roof through a professional)

Table 29. Insulation standard, step-by-step approach

Target values, when these values are achieved, the standard is simply achieved (Energie, 2021).

The values pursued in approach B are values in which that specific building component is certainly of a sufficient level and no longer needs to be addressed in the future. Because if a building component is replaced integrally, because of quality, renovation or appearance, a higher insulation value can be achieved at relatively lower costs. For most homes, a building section that is better insulated than this target value hardly results in reduction of the heat requirement. The realization of all building components at target value level leads to a quality level that is amply higher than required by the standard (Energie, 2021).

In other words: when approaching a building element up to the target value, it is usually possible to omit the approach of one or more other parts. A step-by-step approach requires more attention to moisture and mold problems. After tackling one or a few building parts, the Standard is met. This means that the house is prepared to be connected to an alternative of natural gas with regard to space heating (Energie, 2021).

The values pursued in approach B are also intended to stimulate innovation of materials and cost reduction, so that in a number of years the realization of the standard will become easier and cheaper (Energie, 2021).

C. An approach in which every building component is brought to a minimum insulation value. The insulation values used are then the values that add up to the standard. These values are:

Roof	Insulation value Rc=3,5 m2K/W (depending on the insulation material 8 -15 cm insulation)
Floor	Insulation value Rc=3,5 m2K/W (depending on the insulation material and floor type 7 – 14 cm insulation under the floor)
Façade	Insulation value Rc= 1,7 m2K/W (pearls, flakes or foam in the cavity wall)
Panel	If present: insulation value Rc= 1m2K/W (40 mm sandwich panel)
Window and window frames	U-value window = 1,4 W/m²K (HR++ glas) in combination with a insulated door or 1,0 W/m²K (triple glas)
Ventilation	Natural supply and mechanical extraction in toilet, kitchen and bathroom or balanced ventilation with sensor control in living room and master bedroom
Air tightness	qv;10 = 0,7 dm3/sm2 (improved crack sealing of windows and doors and connection of façade and roof)

Table 30. Insulation standard, every building component is brought to a minimum insulation value

Minimum values, when all values are realised, the standard is reached.

The target values from approach B will be used in the tool as a guideline for homeowners, who are planning to insulate certain building parts step-by-step.

7.5 Uninsulated home, road to 2050: The standard & target values combined with a heat pump and emission system

According to the findings about the new insulation Standard for existing buildings, the following matters have been investigated with regard to the choice of a heat pump system leading up to a 'natural gas-free-ready' standard by 2050.

An integral approach with insulation, the heat emission system and a heat pump system leading up to a 'natural gas-free-ready' standard by 2050.

According to the Standard multi-family buildings before 1945 are the hardest to transform, therefore this building is used for the example road to a 'natural gas-free-ready' standard by 2050.

This example case will show the different outcomes with an integral approach combining the buildings insulation, emission system and heat generation system (heat pump) in a road to 2050, regarding the total investments, the annual heating costs, the total cost of ownership, the CO2 emissions and the energy needed for space heating. This is used to investigate what the influences are of insulating or adjusting the heat generator and heat emitter at different moments during the road.

This interim study is twofold, on the one hand the results are examined as described above. On the other hand, in the elaboration of the above, was investigated whether the existing heat emission system in the home can be maintained or whether it needs to be adapted. By figuring this out by the means of an example, it can be found out where the difficulties lie in determining the heat emitter and in what way this can ultimately be baked into the heat pump decision tool in a relatively simple way so that it is useful for the homeowner. Later in this thesis was decided to make the heat pump decision tool applicable to only ground level homes. But nevertheless the outcome of this investigation can still be used to educate homeowners who will use the tool, because the results of insulating will be the same for all building types.

The example home is taken from the report (Cornelisse, Kruithof, & Valk, 2021).

Figure 37. Example home (Cornelisse, Kruithof, & Valkt, 2021)

Meergezinswoning: galerij-/portiekwoning <1945	Dubbele bovenwoning	
General features		
Construction year:	1896	
Surface area:	72	
Compactness ratio:	1,71	
Orientation	North-west / south-east	
Net heat demand	279 kWh/m2.jr	
Power demand for space heating	100W/m2 (calculated in appendix 4)	
Technical systems		**Explanation**
Ventilation system	System A	Natural ventilation
Heat generator	Gas boiler	Assumed 5 years old
Heat emitter system	Traditional radiators	

(Cornelisse et al., 2021)

7.6 Outcome different roads to 2050 uninsulated multi family home <1945

For all the calculations see appendix 4.

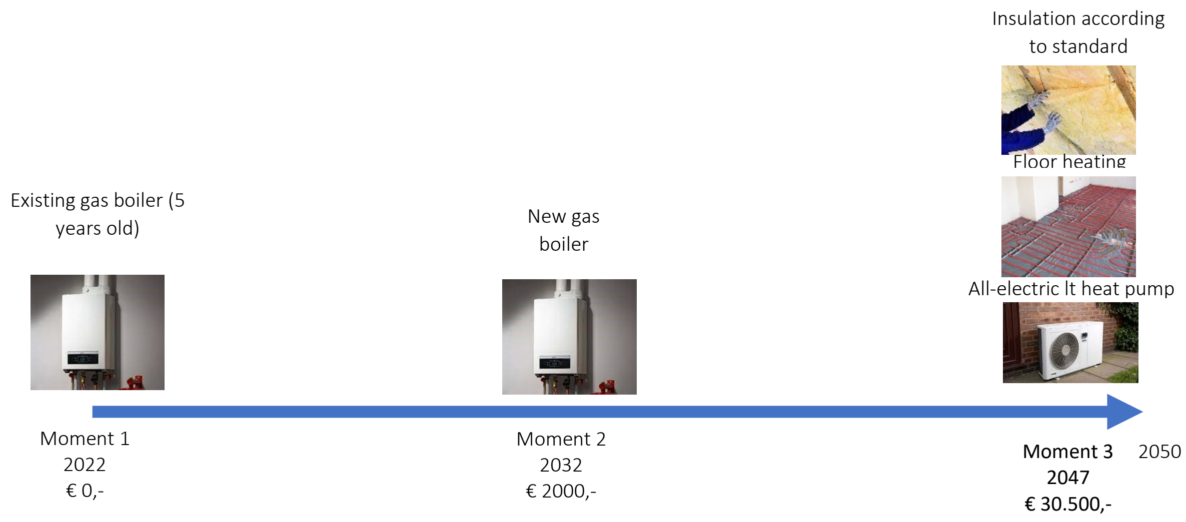
During the different roads, a number of different moments are possible to adjust the insulation level, the heat generator or the heat emission system. The goal is to see the impact on the total cost of ownership, the CO2 emissions and the needed energy by 2050.

Road 1
Moment 1 (2022): For the first road is assumed that the building is not insulated and that the existing gas boiler will last another 10 years.

Moment 2 (2032): The existing gas boiler is replaced by a new gas boiler which will last 15 years, in order to keep the investment costs low.

Moment 3 (2047): In order for the home to be 'natural gas-free' by 2050. The building is insulated according to the new insulation standard as in (chapter 7.4). The heat emitter is changed from radiators to floor heating. And an all-electric heat pump is placed in order to heat the building.

Timeline road 1:

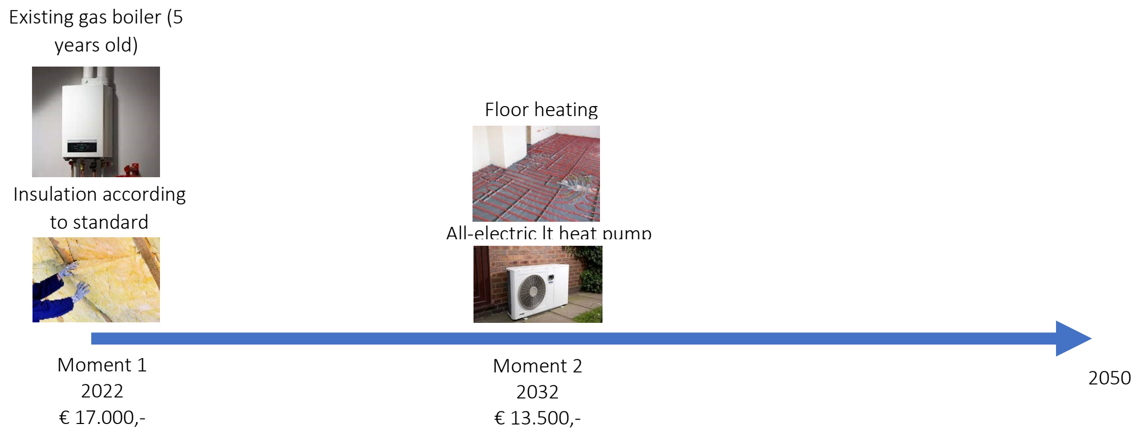


Google images

Road 2
Moment 1 (2022): The existing gas boiler will last another 10 years. But the home is completely insulated according to the standard (chapter 3.4), in order to improve indoor comfort and immediately start saving on heating costs.

Moment 2 (2032): the radiators are replaced by floor heating and the gas boiler is replaced by an all-electric heat pump, in order to be 'natural gas-free' by 2050 as the heat pump will last 20 years.

Timeline road 2.



Google images

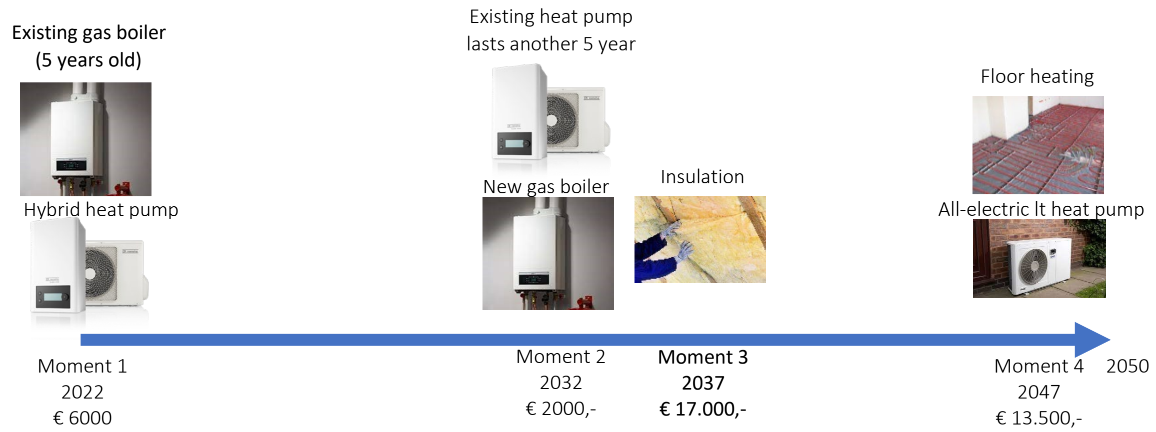
Road 3
Moment 1 (2022): The existing gas boiler will last another 10 years. It has now been decided to place a hybrid heat pump directly next to the existing gas boiler.

Moment 2 (2032): A new gas boiler is placed next to the hybrid heat pump, as the old one needs to be replaced.

Moment 3 (2037): The hybrid heat pump is at its end of life. The gas boiler has still an life expectancy of 5 years so will be remained. The building is now insulated according to the standard.

Moment 4 (2047): The gas boiler is at its end of life. Floor heating in combination with an all-electric low temperature heat pump is placed in order to be 'natural gas-free' by 2050

Timeline road 3.

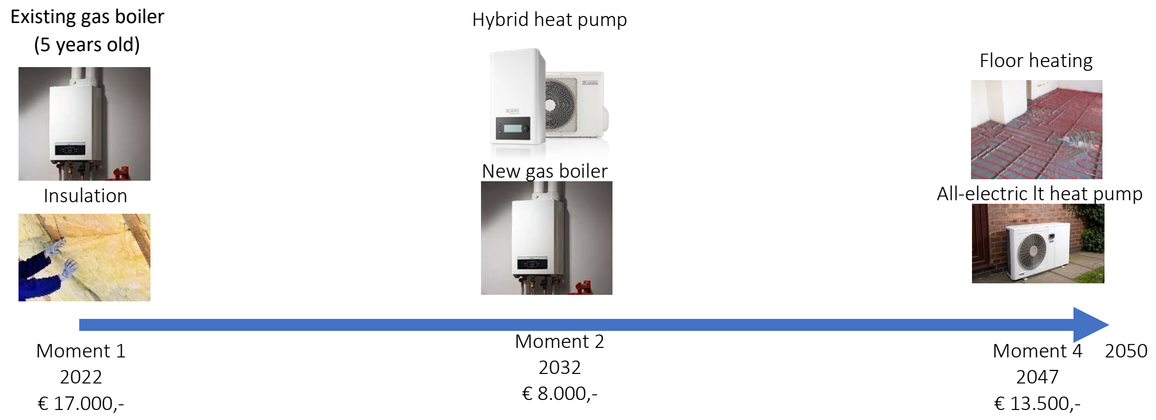


Road 4
Moment 1 (2022): The existing gas boiler will last another 10 years. But the home is completely insulated according to the standard (chapter 3.4), in order to improve indoor comfort and immediately start saving on heating costs.

Moment 2 (2032): The existing gas boiler is replaced by a new one plus a hybrid heat pump.

Moment 3 (2047): in order to be 'natural gas-free' by 2050, floor heating in combination with an all-electric low temperature heat pump is placed.

Timeline road 4.



Road 5

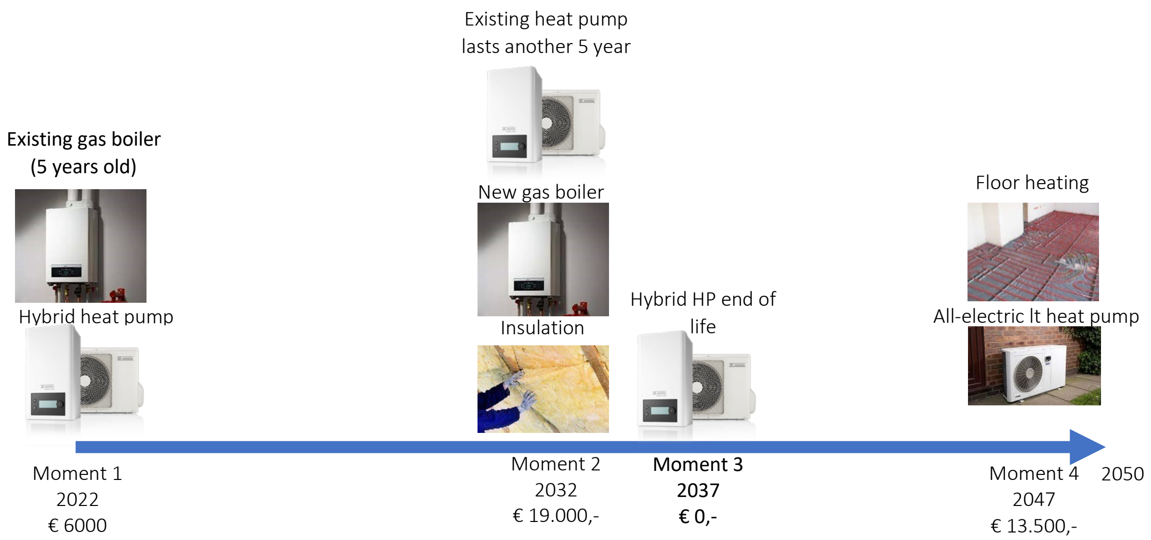
Moment 1 (2022): The existing gas boiler will last another 10 years. It has now been decided to place a hybrid heat pump directly next to the existing gas boiler.

Moment 2 (2032): A new gas boiler is placed and the building is insulated according to the insulation standard.

Moment 3 (2037): hybrid heat pump end of life, but gas boiler will last another 10 years. No action is taken.

Moment 4 (2047): in order to be 'natural gas-free' by 2050, floor heating in combination with an all-electric low temperature heat pump is placed.

Timeline road 5.



Road 6

Moment 1 (2022): the home is immediately fully tackled to make it 'natural-gas-free'. The home is insulated according to the standard, underfloor heating is installed and a low temperature heat pump system is installed.

Moment 2 (2042): the low temperature heat pump is replaced by a new one.

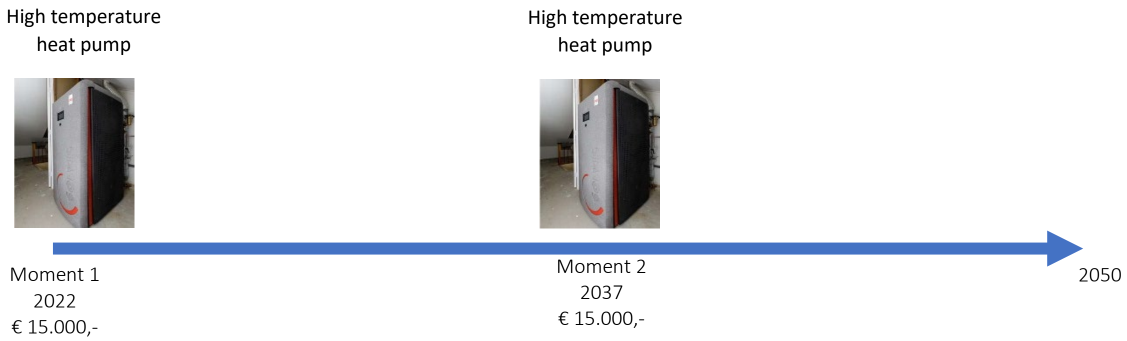
Timeline road 6.

Road 7

Moment 1 (2022): the home is not insulated but directly equipped with a high temperature heat pump because in principle the home is then immediately 'natural-gas-free'.

Moment 2 (2037): the high temperature heat pump is replaced by a new one.

Timeline road 7.



The outcomes of the 7 different roads regarding CO_2 emissions, total cost of ownership and total needed energy are displayed in the table below in the green column.

	2022	2032	2037	2042	2047	2050	2052	2062
Road 1	Existing gas boiler Annual heating costs: €5.735 (gas)	TCO: €57.350 Gas boiler: €2.000 Annual costs: €5.735(gas)			TCO: €145.375 Insulation + floor heating + lt hp: €30.500 Annual costs: €1.483	TCO: €180.324 Natural gas free ready		HP end of life
	96.750 kg CO2				14.840 kg CO2		Total: 111.590 kg CO2 until 2050	
	528.625 kWh				9.340 kWh		Total: 537.965 kWh kWh until 2050	

Road 2	Existing gas boiler + Insulation: €17.000 Annual costs: €2.200 (gas)	TCO: €39.000 Floor heating + LT HP: €13.500 Annual costs: €1.483 (electricity)				TCO: €79.194 Natural gas free ready	HP end of life	
	14.840 kg CO2	15.086 kg CO2					Total: 29.926 kg CO2 until 2050	
	81.090 kWh	44.365 kWh					Total: 125.455 kWh until 2050	
Road 3	Existing gas boiler + hybrid hp: €6.000 Annual costs: €1.780 (electricity) + €2.292 (gas)	TCO: €46.720 Gas boiler: €2000 Annual costs: €1.780 (electricity) + €2.292(gas)	TCO: €69.080 Hybrid heat pump end of life Insulating: €17.000 Annual costs: €2.200 (gas)		TCO: €108.080 Lt hp + floor heating: €13.500 Annual costs: €1.483	TCO: 126.029 Natural gas free ready		HP end of life
	37.515 kg CO2		14.840 kg CO2		3.176 kg CO2		Total: 55.531 kg CO2	
	168.915 kWh		81.090 kWh		9.340 kWh		Total: 259.345 kWh until 2050	
Road 4	Existing gas boiler + Insulation: €17.000 Annual costs: €2.200 (gas)	TCO: €39.000 Gas boiler + hybrid hp: €8.000 Annual costs: €664 (electricity) + 880(gas)			TCO: €70.160 Floor heating + lt hp: €13.500 Annual costs: €1.483 (electricity)	TCO: 88.109 Natural gas free ready		HP end of life
	14.840 kg CO2	14.400 kg CO2			3.176 kg CO2		Total: 32.416 kg CO2	
	81.090 kWh	64.785 kWh			9.340 kWh		Total: 155.215 kWh until 2050	
Road 5	Existing gas boiler + hybrid heat pump €6.000 Annual costs: €1.780 (electricity) + 2.292 (gas)	TCO: 46.720 Gas boiler + insulation: €19.000 Annual costs: €664 (electricity) + €880 (gas)	Hybrid heat pump end of life Annual costs: €2.200(gas)		TCO: 95.440 Floor heating + lt hp: 13.500 Annual costs: €1.483 (electricity)	TCO: 113.389 Natural gas free ready		Hp end of life
	25.010 kg CO2	4.800 kg CO2	14.840 kg CO2		3.176 kg CO2		Total: 47.826 kg CO2 until 2050	
	112.610 kWh	21.595 kWh	81.090 kWh		9.340 kWh		Total: 224.635 kWh until 2050	

Road 6	Insulation + floor heating + lt hp: €30.500 Annual costs: €1.483			TCO: €60.160 Lt heat pump: €7.500 Annual costs: €1.483		TCO: 79.524 Natural gas free ready		HP end of life
	23.026 kg CO2						Total: 23.026 kg CO2 until 2050	
	67.715 kWh						Total: 67.715 kWh until 2050	
Road 7	HT heat pump: €15.000 Annual costs: €5.546(electricity)		TCO: €98.190 Ht hp: €15.000 Annual costs: €5.546(electricity)			TCO: 185.288 Not natural gas free ready Heat emission system + insulation needs to adjust	HT hp end of life	
	86.130 kg CO2						Total: 86.130 kg CO2 until 2050	
	253.286 kWh						Total: 253.286 kWh until 2050	

Table 31. Uninsulated home road to 2050

Conclusion road to 2050 uninsulated home

Total cost of ownership

From (Table 31) can be concluded that road 2 and road 6 followed by road 4 have lowest total cost of ownership, including investment costs and fuel costs up to 2050. What distinguishes these roads from the other 4 is that the home is insulated right away from the start up to the new insulation standard. It can therefore be stated that regardless of the choice of system, properly insulating the home first leads to the lowest total cost of ownership by 2050.

Road 1 and 7 have the worst total cost of ownership: so using the gas boiler as long as possible without insulating the building should be avoided. And a high temperature heat pump should be avoided too.

Spreading investment costs and system choice

It has now become clear that insulating first leads to the greatest cost reduction. Nevertheless, the 3 roads that have been insulated at the beginning are close to each other regarding total cost of ownership, while different systems are applied. So it does not really matter for the costs whether a hybrid system or an all-electric system is installed, given the current energy prices. But as in the future the gas prices rise, the all-electric heat pump will be in favour. The aim is to be totally gas free by 2050. Therefore a hybrid heat pump can be an intermediate step towards 2050 but only beneficial after firstly insulating the building. Next to that, investment costs can be very high if insulation and system are improved in the same year.

CO_2 emissions

Road 6 has the lowest CO2 emissions by 2050. Again on this road the building is insulated in the first year and also supplied with an low temperature all-electric heat pump system in the first years, ensuring the lowest CO2 emissions down the road. So based on CO_2 emissions the building should always be insulated as quickly as possible. And regarding the system choice an all-electric heat pump will reduce the CO_2 emissions the most compared to a hybrid heat pump or gas boiler.

Energy usage for space heating

Road 6 has by far the lowest primary energy usage over an period to 2050. Again insulating as early as possible and adding an all-electric low temperature heat pump for space heating results in the lowest energy needed.

Tailor made insulation approach

This investigation is purely based on the adaption of an existing bad insulated home towards the new insulation standard by applying the tailor made approach A. But the approach A involves high investment costs at once (in the shown example €17.000) because the tailor made approach adjusts the complete home at once towards the new Standard. But there is a big chance that home owners do not have that amount of money available at once or do not want to change their homes insulation that drastically at once.

So the final heat pump decision tool must have an intuitive method with which homeowners can determine which building parts and/or heat emission system at least must be upgraded so that a certain heat pump system can be used in order to get the building warm. Nevertheless, the home owner should be encouraged by the heat pump decision tool to insulate the home up to the standard, because this will result in the lowest cost and the best contribution to the energy transition.

7.7 Insulated home, road to 2050: heat pump and emission system

Road to 2050 if building already meets the new standard

As concluded by the previous road to 2050 (chapter 7.6) it saves costs for the owner to first insulate the building and then choose a heat pump system. But it's not clear if this is also the most cost efficient option in case of an already good insulated building according the standard. Therefore a new small study is done with different roads to 2050 with different heat pump systems in case a building already meets the standard.

For these roads to 2050 the same home as for the previous roads will be analysed the only difference is that the home already meets the insulation Standard in 2022.

For all the calculations see appendix 4

	2022	2032	2037	2042	2047	2050	2052	2057	2062	2067
Road 1	Existing gas boiler Annual: €2.200 (gas)	TCO: €22.000 Gas boiler: €2.000 Annual: €2.200 (gas)			TCO: €57.000 All electric HP: €7.500 Annual: €1.630 (electricity)	TCO: €69.390 Annual: €1.630 (electricity)				HP needs to be replaced
	38.584 kg CO_2				3.492 kg CO_2		Total: 42.076 kg CO_2 until 2050 Amount of trees: 1754			
	210.834 kWh				10.272 kWh		221.106 kWh until 2050			
Road 2	Existing gas boiler Annual: €2.200 (gas)	New gas boiler + hybrid hp: €8.000 Annual: €664 (electricity) + €880 (gas)			TCO: €53.160 All electric HP: €7.500 Annual: €1.630 (electricity)	TCO: €65.550 Annual €1.630 (electricity)				HP needs to be replaced
	14.840 kg CO_2	14.400 kg CO_2			3.492 kg CO_2		Total: 32.732 kg CO_2 until 2050 Amount of trees: 1364			
	81.090 kWh	64.785 kWh			10.272 kWh		Total: 156.147 kWh until 2050			
Road 3	Existing gas boiler	All electric heat				TCO: €58.840	HP needs to be			

	Annual: €2.200 (gas)	pump: €7.500 Annual: €1.630				Annual: €1.630 (electricity)	replaced			
	14.840 kg CO_2	16.587kg CO_2					Total: 31.427 kg CO_2 until 2050 Amount of trees: 1310			
	81.090 kWh	48.792 kWh					Total: 129.882kWh until 2050			
Road 4	New gas boiler + hybrid heat pump: €8.000 Annual: €664 (electricity) €880 (gas)	TCO: €21.440 New gas boiler, hybrid lasts another 5 years: €2000 Annual: €664 (electricity) €880 (gas)	TCO: €31.160 Hybrid end of life, gas boiler lasts another 10 years Annual: €2200 (gas)		€53.160 Gas boiler end of life, new all electric heat pump: €7.500 Annual: €1.630 (electricity)	TCO: €65.550 Annual: €1.630 (electricity)				HP needs to be replaced
	14.400kg CO_2		14.840kg CO_2		3.492kg CO_2		Total: 32.732 kg CO_2 until 2050 Amount of trees: 1364			
	64.785kWh		81.090 kWh		10.272 kWh		Total: 156.147 kWh until 2050			
Road 5	New gas boiler + hybrid heat pump: €8.000 Annual: €664 (electricity) + €880 (gas)		TCO: €31.160 New gas boiler + new hybrid heat pump: €8.000 Annual: €664 (electricity) + €880 (gas)			TCO: €59.232 Annual: €664 (electricity) + €880 (gas) Heating system is not gas free!	Gas boiler + hybrid heat pump needs to be changed to an all-electric heating system			
	27.840kg CO_2						Total: 27.840 kg CO_2 until 2050 Amount of trees: 1160			
	125.251 kWh						Total: 125.251 kWh until 2050			
Road 6	New gas boiler + hybrid heat pump: €8.000 Annual: €664 (electricity) + €880 (gas)		TCO: €31.160 New all electric hp: €7.500 Annual: €1.630 (electricity)			TCO: €59.850 Annual: €1.630 (electricity)		HP needs to be replaced		
	14.400 kg CO_2		12.222 kg CO_2				Total: 26.622 kg CO_2 until 2050 Amount of trees: 1110			
	64.785 kWh		35.952 kWh				Total: 100.737 kWh until 2050			
Road 7	All electric hp: €7.500 Annual: €1.630 (electricity)			TCO: €40.100 New hp: €7.500		TCO: €60.640 Annual: €1.630 (electricity)			HP needs to be replaced	

				Annual: €1.630 (electricity)						
	25.317 CO_2						Total: 25.317 kg CO_2 until 2050 Amount of trees: 1055			
	74.472 kWh						Total: 74.472 kWh			

Conclusion road to 2050 insulated home

Conclusion based on total cost of ownership
If the building is at the start of the road already insulated to a certain degree with which a heat pump system is applicable in this case the degree of the proposed ‘standard’ then the total costs of ownership over all the different roads are much closer together regardless of the choice of the heat pump system.

Conclusion based on CO_2 emissions
Road 7 has the lowest CO2 emissions up to 2050, this road make from the start use of an all-electric heat pump system. So making use of an all-electric heat pump system from the start of the road has the highest contribution to the energy transition of the built environment as it has the lowest CO2 emissions down the road. In case the building is already good insulated.

Conclusion based on energy usage for space heating
Road 7 has also the lowest primary energy usage in total. So again using an all-electric low temperature heat pump from the start of the road results in the best results in terms reduction of primary energy usage down the road and the highest contribution to the energy transition of the built environment. In case the building is already good insulated.

Heat emission system
According to the first heat emitter calculation: ‘uninsulated multi family home <1945’ in (appendix 4). It is not possible if an uninsulated home is insulated to a well-insulated home to keep the existing radiators and supply them with a low temperature supply water by means of a heat pump. But during the first calculation in (appendix 4) it is assumed that the radiators of the uninsulated home are exactly dimensioned according to the heat loss of the home. But in reality, wide margins are used when installing radiators (Harmsen, Van Breevoort, Planje, Bakker, & Wagener, 2009). In the second calculation: ‘insulated multi family home <1945’ in (appendix 4) were the sizes of the radiators estimated according to a rule of thumb with wide margins and then it turned out that there was enough overcapacity available to lower the supply temperature after insulating a home. In addition, according to (Harmsen et al., 2009), there is overcapacity available in case the building envelope has improved over time, but the extent of this overcapacity is unknown. So the first calculation ‘uninsulated multi family home <1945’ applied in the (appendix 4) is too unfavourable. More overcapacity will most likely be available after insulating a building as predicted in the second calculation. But the amount of overcapacity must be estimated in a more precise and better way in the final tool, because guessing the radiator dimensions is too inaccurate. And asking the homeowner to measure all the radiators with a ruler is also too much work and may not be necessary if a smarter way is designed to determine the overcapacity after insulating.

III-RESEARCH BY DESIGN

8 The design of the heat pump decision tool

8.1 Factors related to energetic quality according to the literature study/preliminary study are taken into account for the heat pump decision tool

From the analysis during the theoretical framework (chapter 3.1), about existing renovation cases with a heat pump application was observed that all the renovations were performed by insulating the building to a minimum Rc value of 5.0, before applying a heat pump system. From the study performed in (chapter 3.5) it has become clear that insulating the building according to the insulation standard resulted in an average Rc of 3.5 or individual target values of much higher Rc. It became clear from the example study that good insulating is important in combination with a heat pump. In fact, the more the better, although more than the target vale (chapter 3.5) makes no sense because then no extra reduction in energy, emissions and heating costs are achieved.

However not everyone has the will, ability and budget to insulate their building in one go according to the insulation standard. As a result of the heat pump decision tool, the homeowner can determine what in any case must be insulated, before a certain heat pump system can be used. Although the homeowner is encouraged with examples that better insulation always yields more benefits in terms of comfort, costs and emissions. Most homeowners probably never heard of a Rc-value. Therefore, the Rc-value must be defined in another simpler way wherefore the energetic quality can be tested. Which makes it possible to determine whether a heat pump system could be used.

8.2 More in depth analysis existing heat pump decision tools regarding energetic performance

In appendix 2 the complete analysis can be found.

As concluded in (chapter 5), a more in-depth analysis was needed in addition to the strength and weaknesses of existing heat pump decision tools. Now a more in-depth analysis is performed per existing tool for each specific component that leads to a certain choice. The first component of the in-depth analysis concerns the energetic quality of the home. In this manner it can be determined in which way the existing tools define the energetic quality based on the question to the user of the tool. In addition, it is determined per tool what the good elements of the question and the underlaying goals are and what can be improved in the final heat pump decision tool.

Milieucentraal

Energetic quality is based on the users input, the user has to fill in the home's construction year and the amount of insulation in centimetre for the roof, ground floor, outside walls. In case the user of the tool does not know the amount of insulation in centimetre he can leave out those questions. The user also needs to fill in the glass type in the living room and bed rooms. As well the amount of gas usage a year in case he knows.

The tool of milieucentraal uses the home's construction year for the first indication of the insulation level, then any post-insulation is determined by means of user input based on centimetre insulation. The gas consumption is only used to calculate the gas and cost savings in the final step, but does not contribute to the determination of the energetic quality of the home in the tool.

What is good and can be used in the to be designed tool, and what can be improved considering the determination of the energetic quality of a home:

The home's construction year is a good indicator for the first estimation of the energetic quality, because many homeowners know this and can be easily looked up online. The method used by milieucentraal of determining post-insulation is relatively reliable, however it can be difficult for homeowners. Measuring the amount of insulation in centimetres, holes sometimes must have to be drilled in the wall or roof.

Samangroep

The energetic quality of the home is based on two parameters, the user has to choose the degree of insulation (hardly insulated, moderately insulated, good insulated) and the gas usage in case he knows.

What is good and can be used in the to be designed tool, and what can be improved considering the determination of the energetic quality of a home:

The way of choosing the insulation level is quite subjective. Each person who uses the tool can interpret the insulation level differently, therefore this way of questioning is not accurate. The gas usage is used to determine the size of the heat pump. This tool changes relatively quickly to a solution with a high temperature heat pump. However based on the research of the road to 2050 (chapter 7.6 & 7.7), high temperature heat pumps are not the solution to the energy transition and therefore will not be included in the advice from the to be designed tool.

Warmhuis

This tool uses, like milieucentraal the home's construction year to make a prediction of the energetic state, as each building period has different customs and regulations. This tool uses the same way to determine the amount of post insulation like the tool from milieucentraal, the user has to input the amount of insulation in centimetre for the roof, façade, floor and the glass type.

What is good and can be used in the to be designed tool, and what can be improved considering the determination of the energetic quality of a home:

Same as mileucentraal, determination of post-insulation can be complicated for the user of the tool.

Groenpand

Groenpand also uses the home's construction year or the year of deep renovation to predict the energetic performance of the home. It additionally uses the gas usage, to predict the energy savings.

What is good and can be used in the to be designed tool, and what can be improved considering the determination of the energetic quality of a home:

The home's construction year is a good first indicator, but homes have been insulated a lot throughout the years, therefore a sufficient post insulation check gives a more in depth advise.

Ithodaalderop

The user of the tool is given the choice, standard insulation level or improved throughout the years. The next step is to pick the home's year of construction.

What is good and can be used in the to be designed tool, and what can be improved considering the determination of the energetic quality of a home:

Again the construction year is a good first indicator, but the exact degree of post insulation is not asked in the ithodaalderop tool.

Panasonic pro club

This tool is actually designed for designers, installers and distributors, nevertheless it is included in this analysis in order to see if a tool for this target audience has a more in-depth energetic analysis. This tool is actually only used by professionals after they have determined that the home is energetically suitable for a heat pump. The tool can only determine on the basis of user input or an estimation based on the gas consumption how big (kW) the heat pump should be. However it cannot determine the energetic performance of a home.

What is good and can be used in the to be designed tool, and what can be improved considering the determination of the energetic quality of a home:

This tool does not determine the energetic quality of a home, this is done by the professional himself.

Vaillant

The home's year of construction is used as the first indicator to predict the energetic performance of a home. Then the building elements which have been post-insulated should be ticked. E.g. façade insulation, double glazing, roof insulation, floor insulation.

What is good and can be used in the to be designed tool, and what can be improved considering the determination of the energetic quality of a home:

Again like most of the tools the home's year of construction is used as a first indicator to predict the energetic performance of the home. This is still a solid first indicator. However the way of determine the amount of post insulation is lacking, the tools does not ask how many insulation is present. This was probably done to keep it simpler for consumers, though the reliability of the advice decreases as a result.

Small conclusion
By analysing all the existing heat pump decision tools, an idea has been formed how the energetic quality of a home can be determined on the basis of certain questions.

A recurring question in many of the analysed tools to make a first estimation of the energetic quality of a home is the year of construction. So this question will be used in the to be designed heat pump decision tool.

Only the question to determine the degree of post-insulation still needs to be carefully considered.

8.3 The new heat pump decision tool

The home's year of construction is used to predict the energetic performance of the home, at the time it was built. The energetic quality is derived from the insulation techniques that were applied during a certain construction period. The way in which any post-insulation is analysed will take place in a different way than in the existing tools. The energy label will be used for this. Almost every home has an energy label and this label is easy to request by the homeowner. On the basis of this energy label, a relatively good statement can already be made about the degree of post-insulation.

The energy label class means: the indication of the energetic performance of a home in the form of a letter, G (lowest performance and many improvement opportunities) up to and including A (highest performance and few improvements opportunities). A home with a high energy class is therefore relatively energy efficient (Rijksdienst voor Ondernemend Nederland, 2019).

The determination of the energy label has changed over the years, however in the next (chapter 8.4) is explained why the label can still be used to determine degree of post-insulation.

8.4 Energy label for energetic quality and post-insulation

The energy label was first introduced in 2012 for the categories appliances, cars and homes. After the introduction of the energy labels for homes, the 'tweede kamer' concluded in 2013 that the energy labels for homes became too complicated by 2013. The applicability of the energy labels for homes turned out to be impracticable. A new energy label was developed to comply with European guidelines (Geertsma, 2016).

The new energy label was introduced in 2015. All homes in the Netherlands were assigned a provisional energy label based on the home's construction year and the building type (Goudappel, 2019). The provisional energy label served as an incentive for homeowners to consider possible sustainability measures. In 2021 the determination was changed again and more in line with the Trias Energetica as described in (chapter 2.1) (RVO, 2020).

The differences of determination between the 2015 energy label and the 2021 energy label for existing buildings are shown below.

Determination of old energy label 2015 and new energy label 2021

Energy label 2015	Energy label 2021
Method for existing buildings (owner-occupied home)	Method for existing buildings (owner-occupied home)
Performed by building owner himself (VEL) with an online tool, based on the following parameters (Hans van Eck, 2015): 1. Construction year	Can only be performed by an professional according to BENG NTA8800 basis method for existing buildings. A selection of the main parameters on which the label is based:

2. Glass type livingroom 3. Glass type bedroom 4. Insulation façade 5. Insulation roof 6. Insulation floor 7. Heating system (heat generator) 8. Domestic hot water system 9. Ventilation system 10. Sustainable energy options + geometry	1. Construction year 2. Floor insulation value 3. Roof insulation value 4. Façade insulation value 5. Window glazing type 6. Type heat generator 7. Ventilation system 8. Sustainable heating generation options + geometry
The energy label of a rental home was not allowed to be requested by the VEL method (Woonbewust, 2022). Performed by an professional with an energy index (EI) based on the same 10 parameters + 140 government data parameters (Hans van Eck, 2015). Energy index (EI), what says something about the energy efficiency is converted to a label (Hans van Eck, 2015)	Primary fossil energy consumption is converted to a label (owner-occupied home and rental house)

Table 32. Determination of old energy label 2015 and new energy label 2021

According to research by DGMR Bouw B.V. (2019), there is a difference in outcome between the old and new method. The geometry in the VEL 2015 method had a very limited influence on the final label. The majority if the label class deviations from the new method NTA 8800 are caused by differences in installation-technical and building characteristics principles. The home can differ one on more labels (DGMR Bouw B.V., 2019).

The insulation values included in the label are used to calculate the theoretical energy consumption of the home, which ultimately determines the energy label (van Moorsel, 2013).

There is a difference between the two labels in the determination of the homes insulation value. The 2015 method had three different insulation values for homes built before 1992: 1. No post insulation (Rc/insulation value from construction year), 2. Post insulation (Rc construction year <post insulation< Rc 3), 3. exceptionally well insulated (Rc>3) and HR++ glass. In case the home was built after 1992 there were two insulation values: 1. No post insulation, 2. Exceptionally well insulated (Rijksdienst voor Ondernemend Nederland, 2019), this was probably done because homes after 1992 had standard an insulation value of Rc 2,5. However suppose a home was insulated extra well with an insulation value of far above Rc 3.0, then the performance of the home in the label was actually nullified by the old label.

The new label from 2021 actually looks at the insulation thicknesses and the associated Rc-value for each building part (kennes, 2022), which gives a more realistic translation to the theoretical energy consumption and therefore label.

Both labels are based on the energy efficiency of a home. The amount of fossil energy a home uses depends on the insulation, the building services and the compactness of the home. The use of renewable energy – think of solar panels, solar water heaters and heat pumps – also reduces the fossil energy needed (Energielabelcertificerende instelling b.v., 2021).

As a result the energy label does say something about the insulation values of the home, since these values are used to estimate the energy consumption on which the label is based and not the real energy consumption of the home. However, there is no direct relationship between the energy label and the insulation value because other factors influence the label such geometry and sustainable electricity generation by solar panels.

The energy label is still used for an easy indication of any post-insulation and the current energetic state of the home. A small difference in label classes is not going to make a drastically different advice. The user of the heat pump decision tool must get an idea of what is most likely the possibilities for his home in combination with a heat pump.

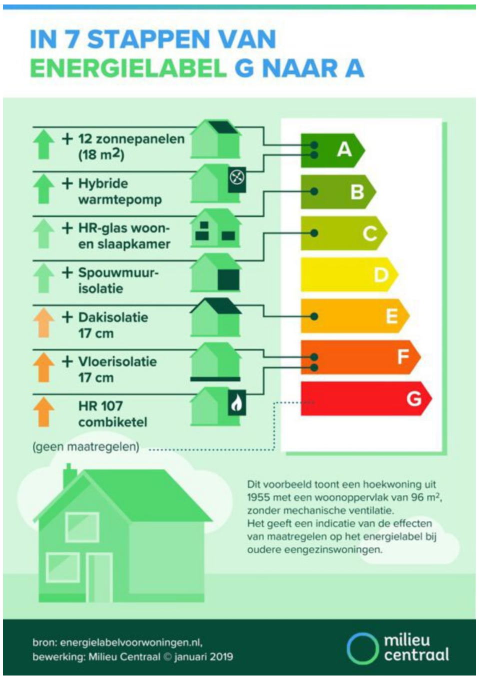


Figure 38. Woningisolatie en energielabel, (Milieucentraal, 2019)

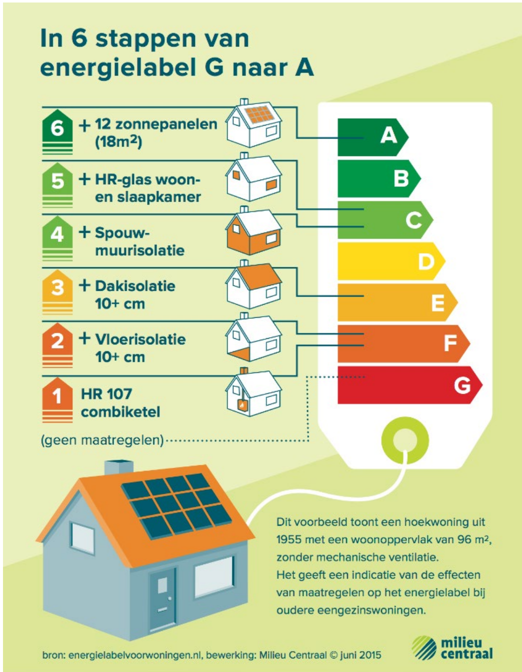


Figure 39. Woningisolatie en energielabel, (Milieucentraal, 2015)

In the tool the label is used to show that a home is post insulated, however the label actually says something about the energy efficiency at a certain moment and nothing about the degree of post insulation. Nevertheless the energy label can be used for this. As the road to 2050 (chapter 7.6 & 7.7) has shown, insulation always results in the greatest reduction in primary energy consumption. Afterwards does the type of heat generator take effect. The only thing that must be ruled out is that a lot of solar panels or a heat pump have been installed on to the house to improve the label, without the house being extra insulated. It is assumed that homeowner who uses the heat pump decision tool owns a gas boiler and not a heat pump, thus it must only be excluded that there is no influence of solar panels on the energy label to determine the insulation level, this way of thinking is also confirmed in the report of (van den Wijngaart & van Polen, 2020). It is therefore plausible that the energetic quality of the home has been significantly improved by means of insulation if the energy label is better than the original label of the home in case no solar panels are installed. As you can see from (Figure 38) (Figure 39), there is a difference in the thickness of the insulation needed to make label jumps throughout the years. Nevertheless, the label can be used as an indication, since the heat emitter system is as well checked by the heat pump decision tool, which must eventually heat up the home. In addition, many homes have a retrievable energy label, which makes it easier for the home owner to use the tool.

7.5 Energy label and expected supply temperature

As stated in chapter 8.4, the old and new energy label can be used to get an indication of the energetic state of the home. However in order to link a heat pump system to a certain label and thus a home, the expected supply temperature per label must be defined, since the supply temperature is a boundary of different heat pump systems as defined in (chapter 6.1). Seven different sources were consulted to link the energy label to a supply temperature. Again this is an indication, in the end an installer will always have to visit the building himself. However the basic principle is that the advice provided by the tool is reliable, hence the building owner does not have to take drastic unexpected measures after the installer has visited.

A total of 7 sources that link energy label and supply temperature

1. The first source links the energy label to the supply temperature of a heat network. The source mentions that existing gas boilers can be replaced by a heat network with the following temperatures related to the energy label (Expertise Centrum Warmte, 2021).

Energy label	Supply water temp
Range E – G	Range 75 – 90
Range B – D	55 – 75
Range B or lower	55 or lower

Table 33. Energy label and supply temperature (Expertise Centrum Warmte, 2021)

2. The second source uses the energy label indirectly for the energetic quality and then displays which heat generator is possible at a certain label (hieropgewekt, n.d.).

   As can be concluded from the flowchart:

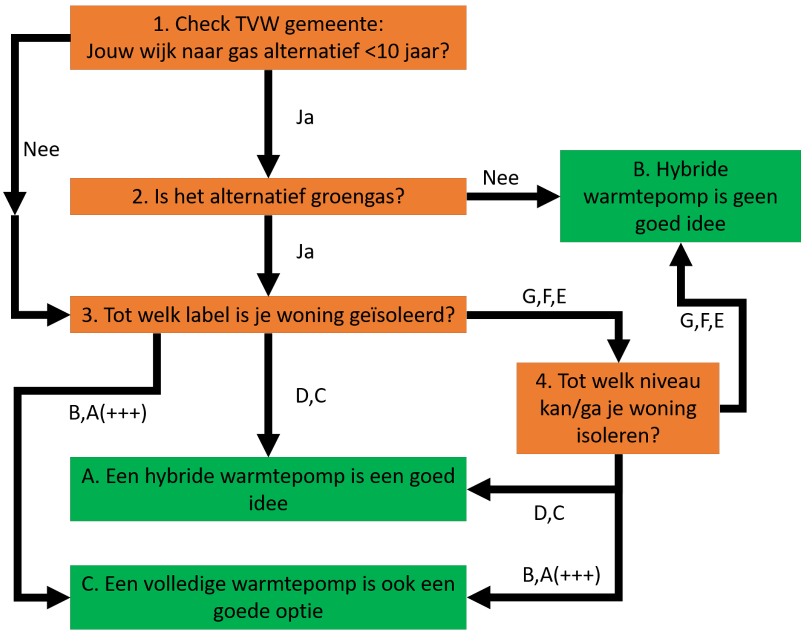


Figure 40. Energy label linked to heat pump system (hieropgewekt, n.d.)

Energy label	Heat generator	And thus supply temperature
E – G	Hybrid heat pump not possible	70 + °C (chapter 6.1)
C – D	Hybrid heat pump good option	0 – 70 °C (chapter 6.1)
B or lower	All electric heat pump is a good option	0 – 55 °C (chapter 6.1)

Table 34. Energy label linked to heat generator linked to supply temperature (hieropgewekt, n.d.)

3. The third source shows that a hybrid heat pump is possible in a home with a minimum label D (de Jonge Baas, 2022). Which leads to a supply temperature of again (0 – 70°C).

4. The fourth source mentions that a label D home is suitable for a supply temperature of 70 degrees (van den Wijngaart & van Polen, 2020).

5. The fifth source mentions that a home with label B should in principle be well insulated enough for an all-electric heat pump (Zuilhof, 2020).

6. The sixth source mentions that according to the expectations of construction and installation companies, consultants and researchers, homes with label B are sufficiently insulated for all-electric heat pumps.

Homes with label B do have an Rc-value of approximately 2.5 (Planbureau voor de Leefomgeving, 2019). Which leads to a supply temperature of (0 – 55 °C).

7. A recent TNO report also shows that home from energy label B onwards can be heated with a heat pump (Tigchelaar, Rovers, Zwamborn, & Cox, 2022).

Based on these sources the heat pump system can be linked to an energy label.

Energy label	Supply water temp	System	Supply water temp	Remarks
Range E – G	Range 75 – 90	No system		
Range B – D	55 – 75	Hybrid heat pump	Range 0 – 70	Always check heat emitter
Range B or lower	55 or lower	Hybrid heat pump & all electric heat pump	Range 0 – 70 and 0 – 55	Always check heat emitter

Table 35. Energy label linked to supply temperature and heat pump system

7.6 Flowcharts used to determine energetic quality of a home

Energy label linked to heat pump system

Based on the findings the first flowchart has been created that establishes the link between energy label and possible applicable heat pump system based on the energetic quality of the home. The final tool has a graphical interface so that the flowcharts does not have to be followed by the user of the tool.

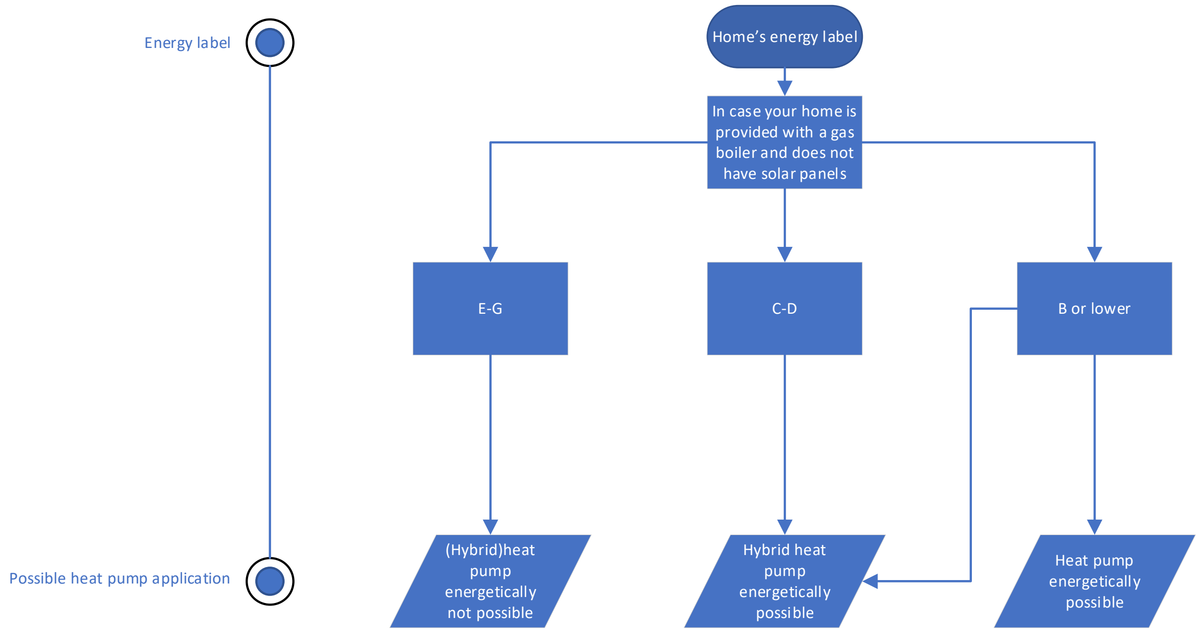


Figure 41. Energy label linked to heat pump system (Own figure)

NL Agentschap has developed thirty example homes that can be used to substantiate policy advice on energy savings (Agentschap NL Energie en Klimaat, 2011). The tool in this thesis is being developed for ground-level homes, which could be a terraced house, a semi-detached house or a detached house. Therefore the construction periods and original energetic level are derived from the report and used in the next flowchart.

Flowchart construction method and energy label derived from construction year

The construction year will be used for the first indication to define construction methods and amount of insulation and an energy label will be linked to the construction year.

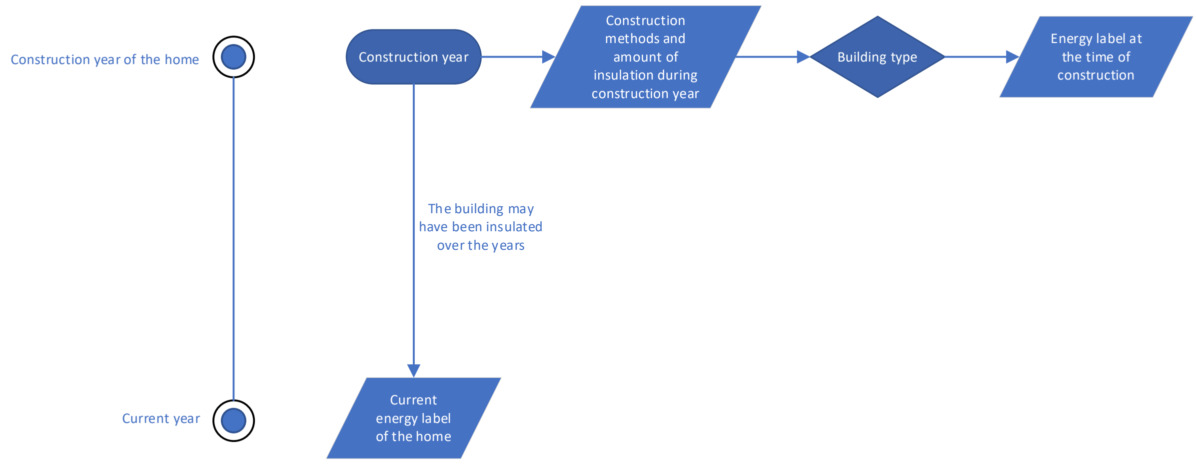


Figure 42. Construction methods and amount of insulation linked to construction year and assigned energy label (Own figure)

Properties of ground-level homes divided into construction year classes as in the report of (Agentschap NL Energie en Klimaat, 2011).

Construction year

Until 1964

Construction methods and amount of insulation until 1964

until 1964: in the period up to and including 1964, no requirements were set for the energy efficiency of homes. The homes were therefore not insulated. There was natural ventilation (Agentschap NL Energie en Klimaat, 2011).

The insulation values are derived from (woonwijzerwinkel, n.d.).

Building part	Insulation or system
Floor	0 cm insulation
Façade (cavity)	no cavity until 1930, cavity after 1930 (no insulation)
Roof	0 cm insulation
Glass Livingroom	Single pane glazing
Glass bedroom	Single pane glazing
Ventilation	Natural supply and exhaust

Table 36. Home until 1964 insulation values

Expected energy label

Building type	Energy label	Source
Detached house	G	(Agentschap NL Energie en Klimaat, 2011)
Semi-detached house	F	(Agentschap NL Energie en Klimaat, 2011)
Terraced house	F or G	(Agentschap NL Energie en Klimaat, 2011)

Table 37. Home until 1964 energy label

Construction year

1965-1974

Construction methods and amount of insulation until 1965-1974

since 1965, requirements have been set for the energetic quality of homes. Nevertheless, the houses were in comparison to current new construction standards not very well insulated. For the ventilation of these homes was used natural ventilation.

The insulation values are derived from (woonwijzerwinkel, n.d.) & (regionaalenergieloket, n.d.).

Building part	Insulation or system
Floor	0 cm insulation
Façade (cavity)	0 cm insulation
Roof	Poor insulation RC 0,86
Glass Livingroom	Single pane glazing
Glass bedroom	Single pane glazing
Ventilation	Natural supply and exhaust

Table 38. Home 1965-1974 insulation values

Building type and energy label 1965-1974

Building type	Energy label	Source
Detached house	F	(Agentschap NL Energie en Klimaat, 2011)
Semi-detached house	E	(Agentschap NL Energie en Klimaat, 2011)
Terraced house	E	(Agentschap NL Energie en Klimaat, 2011)

Table 39. Home 1965-1974 energy label

Construction year
1975-1991

Construction methods and amount of insulation until 1975-1991
The requirements for the energetic quality of newly built homes were increased in 1975 (Agentschap NL Energie en Klimaat, 2011).

The insulation values are derived from (Agentschap NL Energie en Klimaat, 2011) & (woonwijzerwinkel, n.d.).

Building part	Insulation or system
Floor	RC 1,3
Façade (cavity)	1975 RC 1,3; 1988 RC 2,0
Roof	1975 RC 1,3; 1988 RC 2,0
Glass Livingroom	1979 double glazing
Glass bedroom	single pane glazing
Ventilation	Natural supply and exhaust

Table 40. Home 1975-1991 insulation values

Building type and energy label 1975-1991

Building type	Energy label	Source
Detached house	D	(Agentschap NL Energie en Klimaat, 2011)
Semi-detached house	C	(Agentschap NL Energie en Klimaat, 2011)
Terraced house	D	(Agentschap NL Energie en Klimaat, 2011)

Table 41. Home 1975-1991 energy label

Construction year
1992-2005

Construction methods and amount of insulation 1992-2005
The homes from this period are well insulated. In 1992 the insulation requirements have been increased, so that double glazing and insulation of the façade, floor and roof (Rc 2,5) became standard (Agentschap NL Energie en Klimaat, 2011).

The insulation values are derived from (Agentschap NL Energie en Klimaat, 2011) & (woonwijzerwinkel, n.d.).

Building part	Insulation or system
Floor	8 cm RC 2,5
Façade (cavity)	8 cm RC 2,5
Roof	8 cm RC 2,5
Glass Livingroom	Double glazing
Glass bedroom	Double glazing
Ventilation	natural supply and mechanical exhaust

Table 42. Home 1992-2005 insulation values

Building type and energy label 1992-2005

Building type	Energy label	Source
Detached house	B	(Agentschap NL Energie en Klimaat, 2011)
Semi-detached house	B	(Agentschap NL Energie en Klimaat, 2011)
Terraced house	C	(Agentschap NL Energie en Klimaat, 2011)

Table 43. Home 1992-2005 energy label

Construction year
2006 or younger

Construction methods and amount of insulation 2006 pr younger
The energetic performance became very good.

The insulation values are derived from (duurzaamvecht, 2019)

Building part	Insulation or system
Floor	14 cm RC 3,5
Façade (cavity)	14 cm RC 3,5
Roof	14 cm RC 3,5
Glass Livingroom	HR++ or triple glazing
Glass bedroom	HR++ or triple glazing
Ventilation	balanced ventilation system

Table 44. Home 2006 or younger insulation values

Building type and energy label 2006 or younger

Building type	Energy label	Source
Detached house	A	(Goudappel, 2019)
Semi-detached house	A	(Goudappel, 2019)

Terraced house	A	(Goudappel, 2019)

Table 45. Home 2006 or younger energy label

Based on (Table 42) and (Table 43), it appears that in two of the three cases energy label B correspondents to an Rc-value of 2.5 as indicated in (Planbureau voor de Leefomgeving, 2019). However as we see in (Table 43) a terraced house ends in this case up in label C. After checking the document (Agentschap NL Energie en Klimaat, 2011) turned out that both homes had exactly the same Rc-value of 2.5, the same heat generator, the same mechanical exhaust and no solar panels. The difference in this case is caused by the degree of insulation. Namely, the larger the wall surface, the thicker the degree of insulation (duurzaamvecht, n.d.). The degree of insulation is the percentage of the surface of the relevant building parts of a home that is insulated (Compendium voor de Leefomgeving, n.d.). This degree of insulation of the terraced house from (Table 43) causes the home to ends up in label class C.

It also appears form research from (Delft) that low temperature heating is possible in a label B home in case there is HR++ glass in the warm areas such as the living room, bathroom, kitchen. HR++ glass became mandatory since the year 2000. An extra nuance must therefore be added to label class B based on the year of construction and insulation values. HR++ glass is probably needed in warm areas or you will end up using a hybrid heat pump, this will be given as an extra advice in the tool.

Flowchart heat pump possibility based on energy label at construction year

The flowchart below is embedded in a graphic interface of the tool. The user of the tool only needs to click on the construction period of his ground-level home and based on this the homeowner immediately gets to know whether his home is energetically adequate for a (hybrid)heat pump system. Under the in the final tool is all the extra information provided.

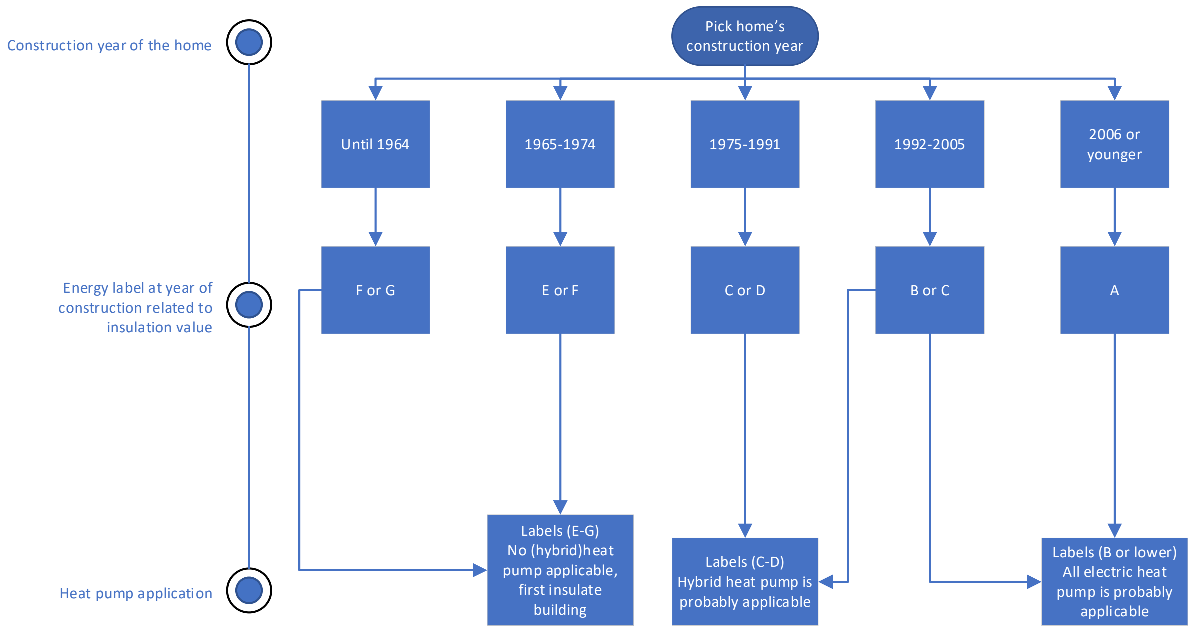


Figure 43. Energy label related to construction year leading to heat pump system (Own figure)

extra information provided in the tool: In case your home has label B but is built before the year 2000 it could be the case that there is standard double glazing in the Livingroom, Kitchen, Bathroom. It is recommended to upgrade this glass to HR++ in order to prevent a cold fall and to heat up the home to a comfortable temperature with a heat pump.

Post insulation

As indicated earlier, it is of course possible that the home has been post-insulated over the years. Based on the current energy label, an estimate can be made whether the home is actually post-insulated and which heat pump application is likely possible at the current energetic state of the home. The degree of post insulation has been included during the record of the current energy label. As a result, the user of the tool does not have to check on which surfaces the house has been insulated at this stage. The only thing that must be ruled out is that solar panels improve the energy label instead of extra home insulation. The current energy label can be requested via the following link: https://www.energielabel.nl/woningen/zoek-je-energielabel/ This link will also be baked into the final tool.

Flowchart heat pump possibility based on current energy label of the home

Because the user of the tool requests his current energy label, he can immediately see, provided the user does not have solar panels, in which label range and thus energetic range his home falls and which (hybrid) heat pump system is currently energetically possible. Suppose the home of the user falls in category (E-G) then he must first insulate his building. Suppose the home of the user falls in category (C-D), then he can be satisfied that the house meets the energetic requirements of a hybrid heat pump. Although the vision of the tool is to be an advisory body on an energetic level, therefore this is also the first moment that additional information is provided to the user to allow him to consider his choice. This information is located under the graphic I in the final tool and it is highly recommended in the tool to always read it.

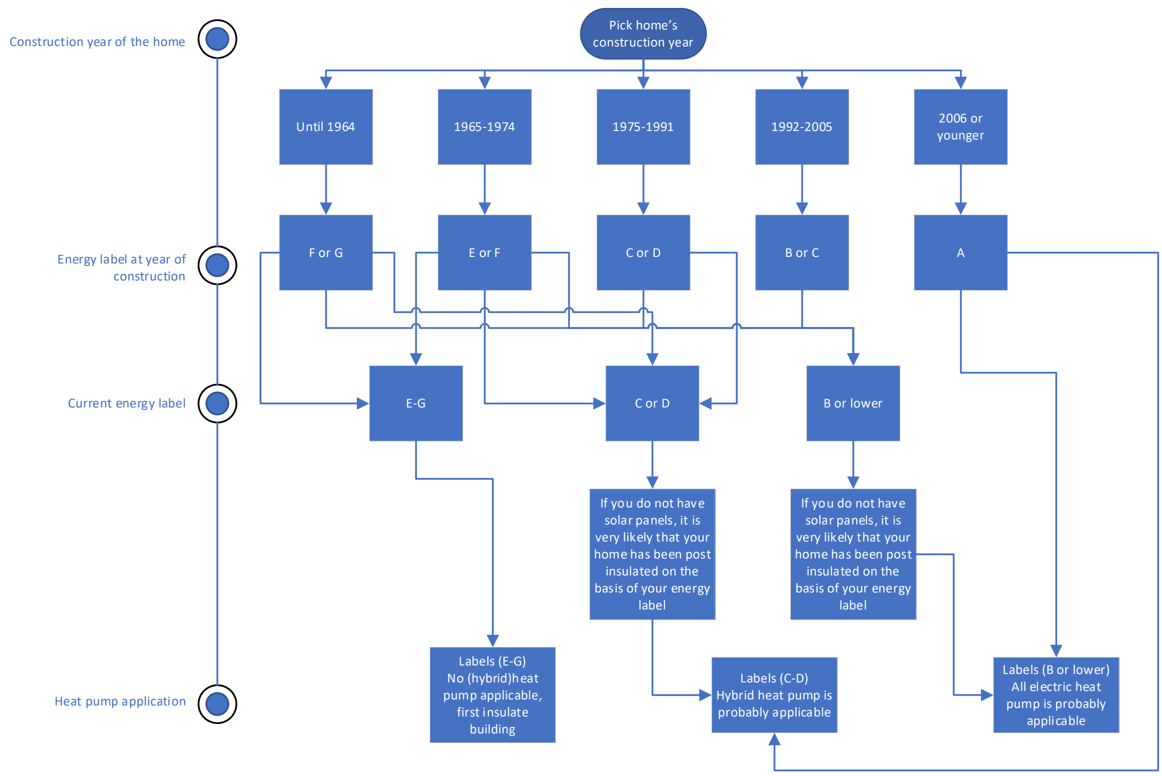


Figure 44. Determine amount of post-insulation based on current energy label

1.  Extra information provided in the tool: Your home falls into category (E-G), your home does not meet the minimum energetic requirements required for a heat pump system. You must at least upgrade your home's insulation to match category (C-D), then you can use a hybrid heat pump system. This is the procedure with the lowest investment. The next step in this tool shows you how to do this. However looking over a longer period up to 2050, it is always wiser to invest more in insulation right now up to at least label B. On the next step you will find how to do this. This ultimately ensures greater comfort, a smaller heat pump and lower total costs in a period up to 2050. And it has the largest contribution to the energy transition and you'll be gas free by 2050.

Your home falls into category (C-D), from an energetic point of view you can choose to immediately apply a hybrid heat pump. Although insulating up to label B first ensures greater comfort, a smaller heat pump and lower total costs up to 2050. The next step will show you how to do this.

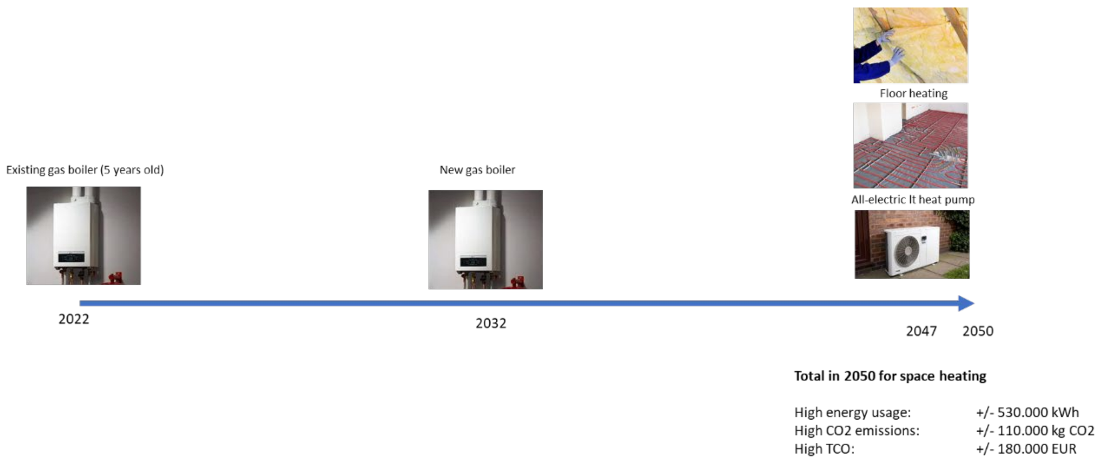
The (Figure 35) will be shown at this stage of the tool in order to give the user an graphical overview.

The figures (Figure 34)(Figure 32)(Figure 33) as presented in (chapter 7.2) that are also shown in the tool to the homeowner, make it clear that more insulation leads to smaller temperature differences, which lead to a higher indoor comfort.

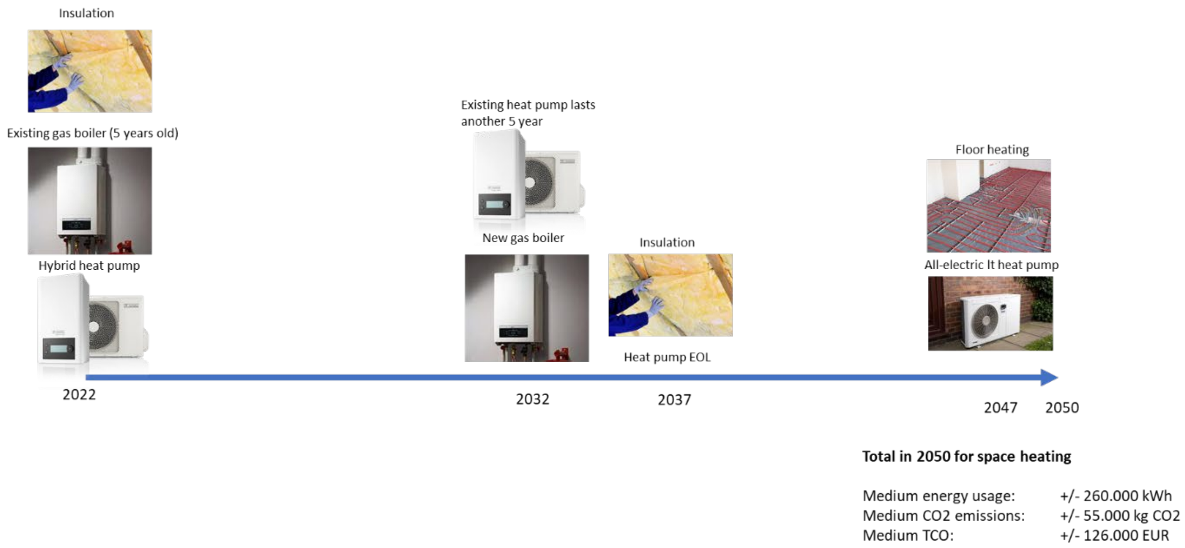
The conclusion of the road to 2050 study is also provided as extra information under the ⓘ in the tool. So that the user of the tool can see that insulating directly to (label B or lower) according to the 'insulation standard/target values' pays off in all respects over a longer period of time. This is purely to make the user of the tool aware that the path with the minimum interventions is certainly not the best in the long term.

The small study stated all buildings must be completely gas free by 2050 in order to comply with the energy transition. The different interventions are shown below. And it turned out that insulating to label B as quick as possible and the application to an all-electric heat pump leads to the lowest total costs. The prices and emissions are of course different for anyone, but this shows the relationship between approaches. The prices and emissions are related to a label (E-G) home with 72m2 floor area.

First road: do nothing stay at label (E-G) and insulate at end of road and apply an all-electric heat pump. This results in high costs, high Co2 emissions and high total cost of ownership.

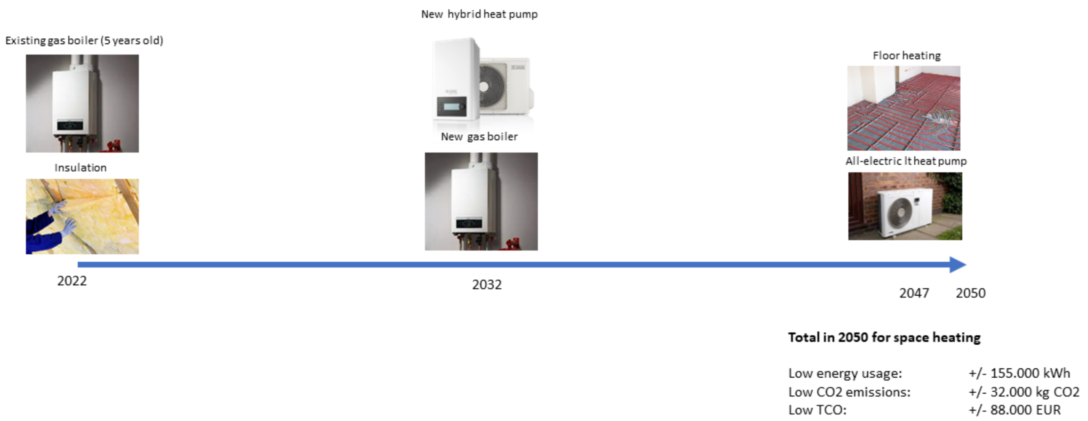


Second road: insulate along the road according 'insulation standard/target values' and apply hybrid heat pump, at the end place all electric heat pump. This results in medium costs, medium Co2 emissions and medium total cost of ownership.



Google images

Third road: insulate immediately to energetic quality (B or lower) according to 'the insulation standard', and replace the heating system on natural moments to a hybrid heat pump system followed by an all-electric heat pump system results in low energy usage, co2 emissions and total cost of ownership.



Fourth road: insulate immediately to energetic quality (B or lower) according to 'insulation standard', and apply immediately an all-electric heat pump results in the lowest energy usage, co2 emissions and total cost of ownership.

As a user of the tool, you can of course also ask yourself why go to all that trouble to insulate when high-temperature heat pumps are also on the way. But firstly, this does not lead to an increase in comfort. And this ultimately leads to high energy consumption, CO_2 emissions and costs. Therefore, a high temperature heat pump is strongly discouraged.

By showing these examples as additional information in the tool, the homeowner is actually being guided on the importance of insulating. Insulating brings the most benefits in all respects. The analysed existing tools did actually mention that insulation is needed, but they didn't teach all the benefits.

Find out post-insulation based on gas consumption.

It is also possible that no current energy label is available for the home. So another easy way to determine the degree of post insulation has been made. The analysed existing tools used the gas usage only for the energy consumption and in order to calculate cost savings. But in this tool the gas usage will actually be used as an second option in case there is no energy label available to make an estimation of the energetic quality of the home. This will be a bit more inaccurate as it depends heavily on the heating behaviour of the residents. Nevertheless, the gas consumption can provide a quick and simple estimation of the energetic quality of a home.

The steps the user of the tool needs to do are as following:

1. First step: determine the amount of gas used for space heating:

Start looking up your gas bill and look at the amount of gas used on yearly basis displayed in m3. If the gas usage of several years is available, take the average of those years.

If you also use gas for cooking or domestic hot water, this must be deducted, so that the actual gas consumption for space heating remains. For cooking deduct 37m2 (Lefevere, n.d.) in total and for DHW deduct 100m3 per person (Remeha, n.d.). The amount of gas that remains is the total annual gas consumption for space heating.

2. Determine the floor area of the home to be heated as accurately as possible.

You can measure the floor area of your home with a tape measure to be as precisely as possible.

Or you can use https://bagviewer.kadaster.nl/lvbag/bag-viewer/index.html#?geometry.x=160000&geometry.y=455000&zoomlevel=0 to determine your floor area.

3. Determine the gas usage per square meter floor area

The total amount of gas for space heating (m3) needs to be divided by the floor area. This gives the amount of gas (m3) needed per square meter floor area (m2).

Gas consumption linked to energy label

The gas consumption can be translated into an energy label. However, it may be the case that initially the energy label for the year of construction is a lot higher than the energy label for gas consumption. This may be because the home is post-insulated, but it can also differ because of the resident's heating behaviour, for example by constantly lowering the thermostat or having the heating turned off in certain rooms. As a result, the real gas consumption is a less accurate way of estimating the energetic quality of a home under standard conditions than the energy label, but it still gives an indication. Research by (Majcen, Itard, & Visscher, 2013) shows that the theoretical gas consumption is for some labels a lot higher than the actual gas consumption (Figure 45) this applies especially to the higher labels. But the research by (Majcen et al., 2013) consists for the most part of social houses (80%), because there was an agreement made between housing associations and government about labelling. While there was no enforcement of labelling for private owners. And the heat pump decision tool is for private owners with ground level homes with different characteristics than social houses, so the differences between actual and theoretical consumption for private owner ground level homes can differ from this research.

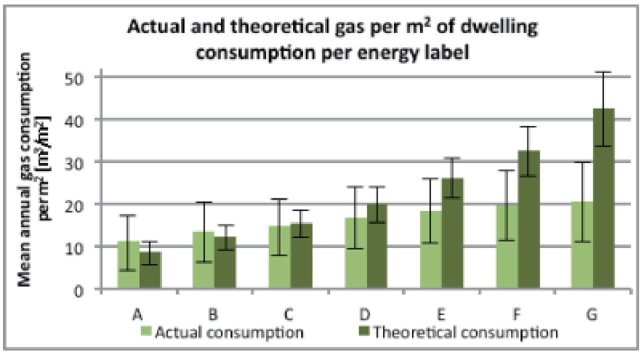


Figure 45. Actual and theoretical average gas consumption m3/m2, (Majcen et al., 2013)

To link the gas consumption purely for space heating to an energy label, the (Figure 46) is used. This results in the following label classification linked to the gas consumption purely for space heating.

Energy label	Gas usage for space heating m3/m2
E -G	26 – 42+
C - D	15 - 26
B or lower	15 or less

Table 46. Energy label linked to gas consumption

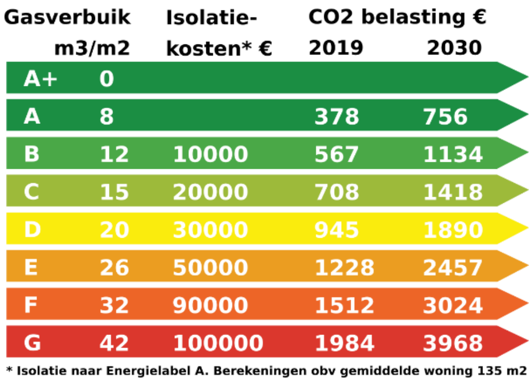


Figure 46. Gas usage for space heating per label, ("Oude woningen stuk minder waard door CO2 tax", 2019)

But to check this classification again with another source, the primary fossil energy consumption per year has been looked at according to the new BENG method linked to an energy label as in (Figure 47).

The following has been calculated to check whether the classification as assumed in (Table 46) is really correct.

Label B or lower: 160 kWh/m2.jr (heating/cooling, DHW, ventilation) (Figure 47).
Average energy for DHW in the Dutch household: 10 GJ (Eneco, 2022).
Average house: 135m2 same as (Figure 46).
Label B or lower: (190kWh*135m2-10GJ)/135=169,4kWh/m2 for space heating
Label B or lower: 169,4/10,55=16m3 gas

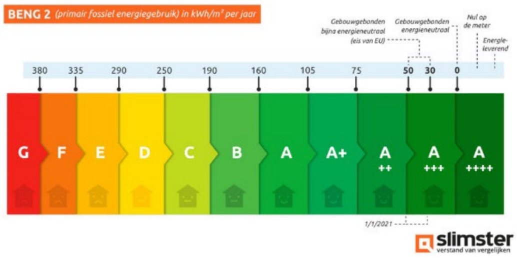


Figure 47. BENG 2 primary energy consumption per label, (Slimster, 2021)

Upper label D: 290 kWh/m2.jr (heating/cooling, DHW, ventilation) (Figure 47).
Average energy for DHW in the Dutch household: 10 GJ (Eneco, 2022).
Average house: 135m2 same as (Figure 46).
Upper label D: (290kWh*135m2-10GJ)/135=269,4kWh/m2 for space heating
Upper label D: 269,4/10,55=25,5m3 gas

On the basis of these two calculations and (Figure 46) it can be stated that the table with the energy labels linked to the gas usage can be used as an indicator for the energy label class if a home does not have an officially assigned energy label. For the classes (B or lower) and (C – D) this will be a relatively good estimation as theoretical and actual gas consumption are close to each other as determined by (Majcen et al., 2013). The homes with a high label (E – G) can, in view of the actual gas consumption, quickly end up in a (C – D) category that is too favourable, while the home energetically does not belong in that category.

If it turns out that a home falls into category (E – G) according to its construction year, but according to its gas consumption it ends up in category (C – D), then the homeowner must check whether his insulation values meet those of a house in class (C – D) respectively a house from 1975-1991, which means it must be provided with some insulation on the roof, facades, floor and have partially double glazing. If so, the category is correct. If one or more fronts of insulation are missing, the category based on the gas consumption is incorrect and it is most likely still in the (E – G) category.

Flowchart current label class based on gas consumption and possible applicable heat pump system

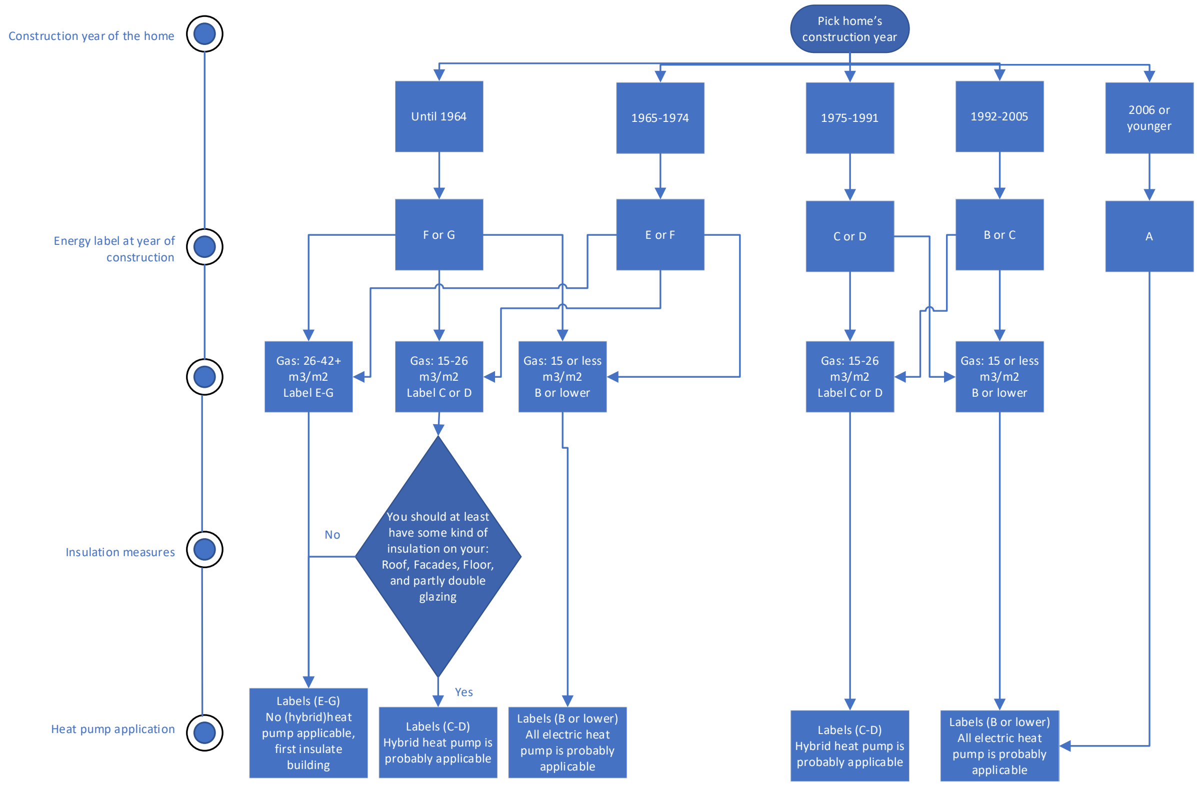


Figure 48. Determine current energylabel/post-insulation based on the gas usage and the possible applicable heat pump system

1.

Under the I, the same information is provided as the I under the heading 'Flowchart heat pump possibility based on current energy label of the home'

Flowchart upgrade current energetic quality by insulating to apply a specific heat pump system

If the heat pump decision tool shows that the home is not sufficiently insulated for a (hybrid)heat pump, the home's insulation value needs to be improved in order for the energetic quality to be sufficient for such a system. The vision of the tool is to be an advisory body for the home owner in a way that they have all the information they need to engage a professional to realize a heat pump system. For insulation improvements the home owner could immediately call in a contractor with the order to better insulate the home so that a heat pump system is energetically possible. But by using this tool to give the home owner an indication of the possible measures, he can search for a contractor in a more targeted way and he will not be faced with surprises, with the amount of insulation measures required. The following flowchart shows and indication if a home has e certain energy label which insulation measures must be taken before a (hybrid)heat pump system can be applied. The gas savings per m^2 can be used as an indication but will of course depend on the Rc-value of the insulation and the insulation degree.

The government wants to help home owners insulate their home in order to accelerate the energy transition of the built environment. The government does this by providing subsidies. Since January 1, 2022 you will be reimbursed 30% of costs if you insulate 2 or more parts of your owner-equipped home (Ministerie van Algemene Zaken, 2021). It has therefore been decided to always tackle two building parts per insulation moment in the flowchart. The insulation measures have been translated into gas savings per year taken from (Milieu Centraal, n.d.) and (EXED, n.d.). It will differ per home type, but this gives an indication of the expected improvement steps in the energy label and also show which (hybrid) heat pump system is most likely energetically possible.

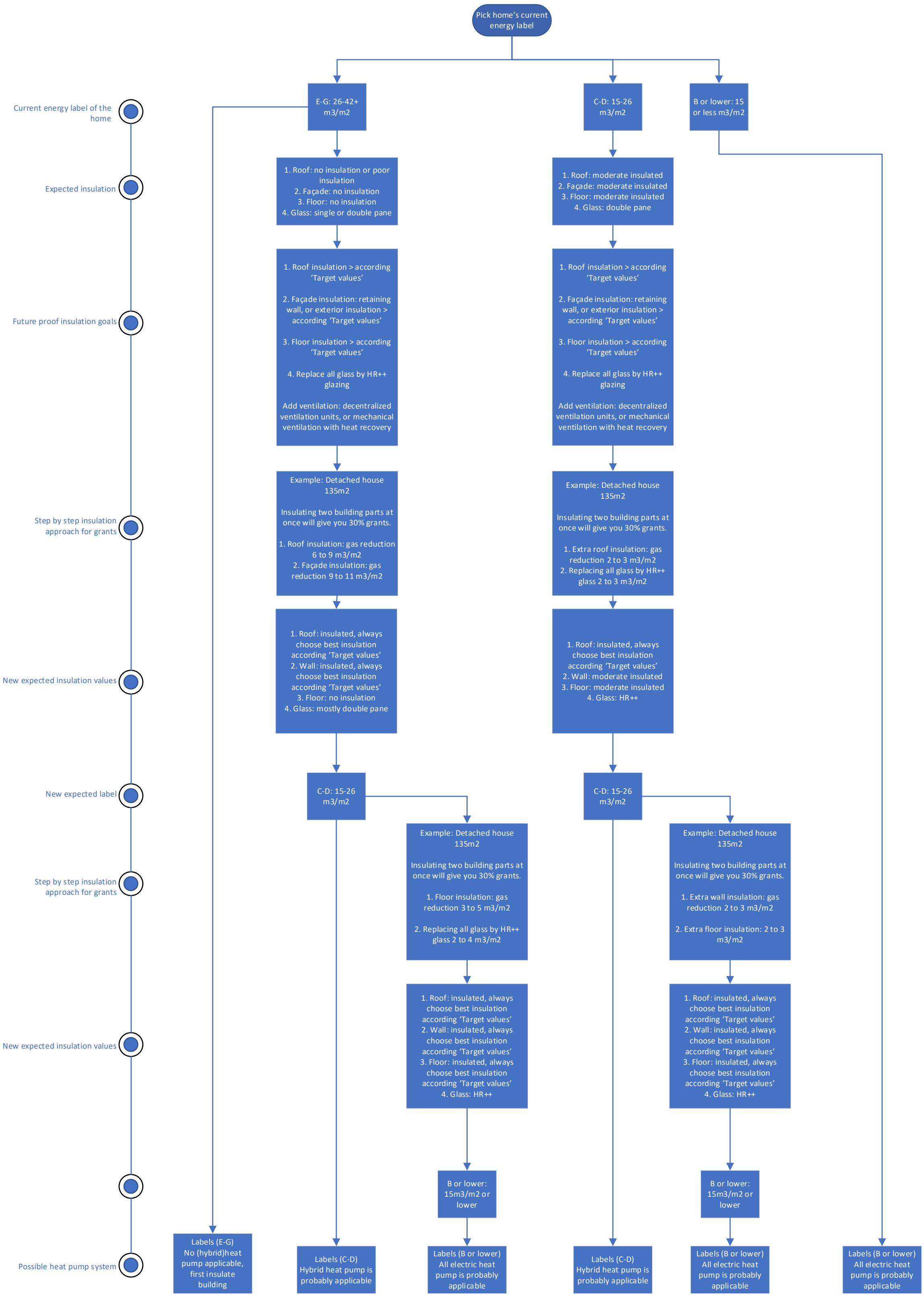


Figure 49. Insulation measures to upgrade the energetic performance and apply a heat pump system

7.7 Capacity heat emitter system

The aspects of the heat emission system that are important in combination with a heat pump system according to the literature study/preliminary study and what is taken into account for the to be designed tool:

According to the findings the current heat emission system of a home has an big impact on the (hybrid) heat pump system choice. In fact, the division into categories is as following. The division is based on the findings in (chapter 6).

Heat pump system	Supply temperature range	Heat emission systems
All-electric heat pump system	0 – 55 °C	• Floor heating • LT-radiators • Over dimensioned normal radiators (+ add on fan).
Hybrid heat pump system	0 – 70 °C	• Floor heating • LT-radiators • Over dimensioned normal radiators (+ add on fan) • Floor heating + radiators

Table 47. Heat pump system linked to heat emitter

Looking at (Table 47) it seems that the heat emission system in both cases have many similarities for the two heat pump systems, this is actually true, it only depends on the way in which the heat emission system is dimensioned which heat pump system could be used. Especially in case radiators are used to heat up a home, because many homes in the Netherlands are still heated by radiators. In many cases radiators are dimensioned at 75 degrees (EN 442, n.d.), but because homes have been better insulated over the years, there is in many cases overcapacity of the heat emission system available, which means that the supply temperature can be lowered. It is therefore important to build a smart skill in the tool that can easily determine the possible overcapacity of radiators in existing homes. This line of thought arose from the preliminary research. Now it is important to first analyse how existing heat pump selection tools have implemented the current heat emission systems in homes for their choices.

7.8 The way the heat emission system is implemented in existing heat pump decision tools and the influence it has on the heat pump system choice:

Milieucentraal

Milieucentraal does not include the heat emission system in the choice for a particular heat pump system. The energetic quality of the home is leading for a specific heat pump advise. The energetic quality can lead to the advice of a hybrid heat pump or an all-electric heat pump. On the final advise page then, it is made clear that both systems work best at low supply temperatures, which is possible with for example under floor heating or large radiators as they mention. If the user wants more information about whether his heat emission system complies, he is referred to another tool from milieucentraal called the heating test https://www.milieucentraal.nl/energie-besparen/aardgasvrij-wonen/verwarmingstest/ . But this heating test is only possible in winter, as a user you can leave your email and you'll receive a message when the time comes to start the test.

What is good and can be used in the final tool, and what can be improved considering the influence that the heat emission system has on the choice of a particular heat pump system.

According to the literature/preliminary study the heat emission system plays a very large role in the choice of a particular heat pump system. This is clearly underemphasized in the tool of Milieucentraal. In addition to possible adjustments to the energetic quality of a home, users must be aware that the heat emission system must immediately taken into account leading up to an heat pump advice and they must be informed if their emission system may need to be adjusted.

Samangroep:
During the selection process of the samangroep it must be checked what heat emission system is present in the home. The user can choose from the following options:

- Underfloor heating
- Radiators
- Underfloorheating and radiators

The tool shows that the choice for a particular emission system always leads to a specific heat pump system choice.

- Underfloor heating > Low temperature heat pump
- Radiators > High temperature heat pump
- Underfloor heating and radiators > Hight temperature heat pump or low temperature heat pump

What is good and can be used in the final tool, and what can be improved considering the influence that the heat emission system has on the choice of a particular heat pump system.

The good part of this tool is that the user has to choose which heat emission system is present in his home. But then the advice provided by the tool is very brief. If the user chooses radiators then the advice always indicates a high temperature heat pump. But according to the preliminary study (chapter 7.3) a high temperature heat pump should be avoided in all cases. It is better to look at whether insulating the home leads to enough over capacity of the radiators to go got an low temperature heat pump.

Warmhuis
The tool only analyses the energetic quality of the home. In case the energetic quality is not sufficient for a heat pump, the tool provides possible options for better insulation. If the energetic quality is good enough according to the tool, a heat pump system can be chosen. The heat emission system is completely disregarded.

What is good and can be used in the final tool, and what can be improved considering the influence that the heat emission system has on the choice of a particular heat pump system.

The heat emission system is not addressed in this tool.

Groenpand
This tool gives a brief explanation of why heat pumps work better when the supply temperature is low. It is then said that the supply temperature can be estimated by means of the heat emission system. The user can choose from:

- Radiators
- Underfloor heating/ Wall heating
- Convector well
- Wood stove/Pallet stove
- Other (infrared panels, gas fireplace, etc.)

And if the user can find out at which temperature the supply water of the existing gas boiler is set, the user must enter this number.

By picking different options it all leads to the same advice:

,,Hoera! Youre house seems suitable for a real groenpand heat pump!'' Fill in your details if you want to receive more information and a quote for a heat pump. You may have to re-enter some of the answers you previously entered with your application.

What is good and can be used in the final tool, and what can be improved considering the influence that the heat emission system has on the choice of a particular heat pump system.

The heat emission system is discussed but otherwise no specific requirements are set, so in fact the user know nothing and first have to request a quote. In the final tool it will have to be clear to the user what influences certain heat emission systems have on the choice of a heat pump system.

Ithodaalderop

While using the tool, you will be asked for the type of heat emitter. The user can choose from:

- Convector well & underfloor heating
- Radiators
- Underfloor heating & radiators
- Underfloor heating

The final advise shows that the energetic quality is leading. The tool stated after filling in: Your home seems suitable for a heat pump! Still, the tools advice is too short-sighted. If, for example, a detached home is chosen with improved insulation after completion with a construction year of <1964 with radiators as heat emitters, the outcome is a hybrid heat pump. If the same home is chosen with improved insulation after completion with a construction year 2000-2009 with radiators, then an all-electric system is also recommended in addition to a hybrid system. Yet this advice is too short-sighted, because the recommended heat pump delivers a maximum of 55 degrees supply temp. And also in homes from 2000-2009, radiators are dimensioned for a 75 degree supply system (EN 442, n.d.). The heat pump will therefore not heat up the house properly because the heat emitter forms a bottleneck.

What is good and can be used in the final tool, and what can be improved considering the influence that the heat emission system has on the choice of a particular heat pump system.

The focus with this tool is too much on the energetic quality of the home. The heat emitter is insufficiently included in the decision making process. The home owner can therefore ultimately still be saddled with high costs if his heat emission system does not meet the requirements and the house does not heat up sufficiently.

Panasonic pro club

The panasonic tool has been developed for professionals, so no choice has to be made in terms of heat emitter, only the supply temperature has to be selected. It is indicated, however, that if the supply temperature is above the operating temperature of the heat pump, it is recommended to adapt the heat emitter system to a different emitter system with a lower supply temperature. According to the tool, the goal is to reduce the water supply temperature to the lowest possible value in order to maximize the efficiency of the heat pump. The supply temperature can be selected between 0 – 55 degrees. With this, the tool actually demarcates that it can only advise an all-electric low temperature heat pump and the heat emitter system must therefore comply with this 55 degrees.

What is good and can be used in the final tool, and what can be improved considering the influence that the heat emission system has on the choice of a particular heat pump system.

This tool can indeed include the advice that the supply temperature should always be as low as possible. But there is a nuance among the home owner in the final heat pump decision tool, because costs play an important role. So in some cases the heat emission system cannot be adapted because this entails too much costs, so that other options such as a hybrid system have to be looked at in order to remain the existing heat emission system.

Vaillant

With the vaillant tool, the first question is which heat emission system the home has. The user can choose from:

- Radiator
- Underfloor heating
- Radiators & underfloor heating

Subsequently, the tool only provides advice for central heating boilers. At the time of the preliminary study, a heat pump advice was provided. But all the heat pumps have been removed from the tool, it is not clear why.

What is good and can be used in the final tool, and what can be improved considering the influence that the heat emission system has on the choice of a particular heat pump system.

The simple way of asking the question and a clear illustration can be used in the final heat pump decision tool.

Short conclusion:

The actual purpose of asking about the type of heat emitter is to estimate the supply temperature at which a particular heat emitter will operate. This is quite simple with a low temperature heating system such as underfloor heating. Which will work with a maximum of 55 degrees in the worst case. And so a low temperature heat pump system can always be used. With radiators this is much more complicated. The degree of overcapacity because the home has been insulated, can be estimated, so that from a hypothetical point of view an estimate can be made with which temperature range the supply temperature can be lowered. However, none of the existing tools show from the above analysis that this hypothesis is taken into account in the decision making. This component will therefore have to be developed for the final heat pump decision tool.

7.9 Heat emitter options in final tool

The home owner is given the following options in the final tool. These are also the options from the Vaillant tool and the most common in existing homes.

- Only floor heating

If the user selects that there is floor heating in the entire home, then no further adjustment of the heat emission system is necessary and a hybrid heat pump or a low temperature all-electric heat pump can always be chosen.

- Radiators + floor heating

If the user selects that there are radiators and underfloor heating in the home, the user will receive a follow-up question about how these emitters are situated:

- ➢ Underfloor heating downstairs and radiators upstairs
    - o Hybrid is always possible
      The ground floor requires a supply temperature of 0 – 55°C. A low temperature heat pump can be used for this. The radiators upstairs require a supply temperature of 0 – 75 °C the existing gas boiler can be used for this. These two together form a hybrid heat pump system.

    - o All electric requires attention
      If the user wants an all-electric system, it must be checked whether the radiators have a possible overcapacity.
- ➢ Underfloor heating and radiators in the same room
    - o Overcapacity of the radiators must be considered.
- Only radiators

Over capacity of the radiators must be considered

7.10 Estimating the possible overcapacity of existing radiators after insulating

The capacity of a radiator depends on the convection area and the supply temperature (Østergaard, 2018). The convection area is fixed, as the radiators are already installed in an existing building.

Radiators are dimensioned at a specific supply temperature. Radiators in old bad insulated buildings are dimensioned at 90 degrees (EN 442, n.d.).

This tool is designed for ground level homes. The sizes of the radiators is also related to the construction year and therefore linked to the original energy label. However, it must be taken into account that the radiators may have been replaced over the years and that they are dimensioned according to the energetic quality at that time.

For example: the building is a ground level built before 1964. Then the original energy label would be an energy label G according to the construction year. Back then the home was heated with local gas heaters. But throughout the years central heating containing radiators and a central gas boiler is installed in these homes. According to (Agentschap NL Energie en Klimaat, 2011) about 70% of all the detached homes built in that period are currently equipped with an HR gas boiler a so called high efficiency gas boiler. The supply temperature of these HR boilers is maximum around 80 degrees (van Beuzekom, van Dam, & Slootweg, 2016).

The old standard for radiators was until 1997: 90/70/20. Which means a supply temperature of 90 degrees a return temperature of 70 degrees at a room temperature of 20 degrees (EN 442, n.d.). In combination with a vr gas boiler which could produce a 90 degrees supply temperature the homes were heated (Visser, 2016). But nowadays almost all the vr boilers are replaced with a hr boiler, with a slightly lower supply temperature maximum 80 degrees.

And from 1997 a new standard for radiators was introduced: 75/65/20 at a room temperature of 20 degrees (EN 442, n.d.).

In order to estimate the design supply temperature of the radiator used in the home of the user of the tool, the question must be asked whether the radiators were installed according to the old standard or to the new standard. But it’s hard for the user to answer this question. That is why an estimate must be made, as indicated by (Expertise Centrum Warmte, 2021) it is plausible that the supply temperature of a labelled (E – G) home between 75-90 degrees is. It is therefore assumed that the radiators of these homes are dimensioned at 90 degrees according to the old standard. If it is the case that those radiators are dimensioned at 75 degrees instead of 90, then it is only advantageous because the overcapacity then turns out to be higher than estimated because temperature does not have to be lowered as much. The homes with label (B – D) have a supply temperature between 55-75 degrees, so it is assumed that these homes are dimensioned according to the new standard at a supply temperature of 75 degrees. So now the supply temperature is estimated for the various labels.

The overcapacity of the existing radiators can be determined by the difference in the heat demand for space heating before and after insulating the building. The heat demand for space heating is not the same within each energy label, nevertheless a range of heat requirements can be determined within each energy label.

During an earlier part of this research (appendix 4) the heat pump indication table as used to convert annual energy consumption into the required heat demand for space heating instead of doing an heat loss calculation which could not be performed because of lacking information about the building characteristics. It was concluded that this method was too imprecise to apply in the final tool, because different building properties and building type had too big an impact on the conversion. If there is no heat loss calculation available for a home, and this can be difficult to do in the final tool, the power for the heating capacity can be estimated by using the concept of full load hours.

Full load hours are the number of hours a heat generator has to work on yearly basis to heat up the home. This depends on the energetic quality (insulation values) of a home, a better insulated home has fewer full load hours because the heat generator only kicks in at a lower outside temperature. The full load hours therefore depend on the energetic quality of the home. The number of full load hours depends on the number of degree days ‘graaddagen’, the outside temperature, the design outdoor temperature (-10 degrees), the heating limit ‘stookgrens’ (depending on the energetic quality of the home), and the desired indoor temperature (20 degrees) (Wijnant, 1987). In this method it is assumed that the gas consumption is directly proportional to the difference between indoor and outdoor temperature. The influences of sun and wind are therefore not taken into account. This method is therefore a worst case scenario but does give a good indication for a dark cold winter day of -10 degrees without sun entry.

According to (Wijnant, 1987) foal load hours can be calculated with the following formula:

$b = 24 * e_z * x * \frac{z*(T_i - T_a)}{\Delta T_{max}}$ full load hours

In which:

z=number of degree days ‘graaddagen’

T_i=indoor temperature(20°C)

T_a=average outdoor temperature (5,4°C)

DT_{max}=maximum temperature difference inside – outside (30°C)

e_z=0,82 voor 6 hours of use

e_z=0,98 voor 20 hours of use , and

x=surcharge factor that is determined by many factors, such as

x_1= the factor that indicates the simultaneity of the heat demand for ventilation air

x_2=the factor for the increased boiler capacity to heat up the building quickly, etc.

Subsequently, according to (Wijnant, 1987) the annual heat demand can be determined depending on the transmission loss and the full load hours.

$Q_{jaar}=b*Q_{totaal}$ kWh/year

In which:

B = full load hours

Q_{totaal} = total heat loss in kW

In the heat pump installer world, these full load hours have already been determined on the basis of key figures and are then classified into homes with different construction years and insulation values. These full load hours are in this thesis linked to an energy label with corresponding construction years and insulation values.

Indicatie table Vollast draaiuren (VL/ uur) & Graad dagen stook (S-GD) voor een doorsnee woning per jaar - bij juist afgestemd transmissie vermogen																	
Gemiddelde jaar temperatuur 10,125°C		D Bouwjaar woning		D Bouwjaar woning		D Bouwjaar woning		D Bouwjaar woning		D Bouwjaar woning		D Bouwjaar woning		D Bouwjaar woning		D Bouwjaar woning	
Gewenst 21,5°C ruimte temp.		1965 t/m 1974		1975 t/m 1995		1995 t/m 1999		2000 t/m 2010		2011 t/m 2015		2016 t/m 2018		2018 t/m 2020		2021	
Buiten temperatuur statistiek NL		A	B	C			E	2000 norm		RC5 (dak)		RC6 (dak)		RC7 (dak)		BENG norm	
Maand	gem.°C in NL F	GD	VL / uur	S-GD 17°C	VL / uur	S-GD 16°C	VL / uur	S-GD 15°C	VL / uur	S-GD 14°C	VL / uur	S-GD 13°C	VL / uur	S-GD 12°C	VL / uur	S-GD 11°C	VL / uur
Januari	3,1	453	284	423	290	392	297	362	304	332	297	301	288	271	260	240	232
Februari	3,3	447	280	417	286	386	292	356	299	325	291	295	282	265	254	234	226
Maart	6,2	359	225	329	225	298	225	268	225	237	212	207	198	176	169	146	141
April	9,2	268	168	237	163	207	156	176	148	146	131	116	111	85	82	55	53
Mei	13,1	149	93	119	81	88	67	58	49	27	25	0	0	0	0	0	0
Juni	15,6	73	46	43	29	12	9	0	0	0	0	0	0	0	0	0	0
Juli	17,9	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Augustus	17,5	15	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	14,5	106	67	76	52	46	35	15	13	0	0	0	0	0	0	0	0
Oktober	10,7	222	139	192	131	161	122	131	110	100	90	70	67	40	38	9	9
November	6,7	344	215	313	215	283	214	252	212	222	199	192	183	161	155	131	126
December	3,7	435	272	405	277	374	283	344	289	313	280	283	271	252	242	222	214
100% vraag BETA 1		2874	1801	2554	1749	2247	1700	1962	1649	1702	1525	1464	1400	1250	1200	1037	1001
Vollast uren per jaar & jaar dekking bij een bivalente inzet / BETA Factor																	
BETA Factor G	Jaar dekking H		VL / uur		VL / uur		VL / uur		VL / uur		VL / uur		VL / uur		VL / uur		VL / uur
0,9	98%		1960		1906		1851		1797		1660		1525		1307		1089
0,8	97%		2182		2122		2061		2000		1849		1698		1455		1213
0,7	95%		2443		2375		2307		2239		2069		1900		1629		1358
0,6	94%		2820		2742		2663		2585		2388		2194		1880		1567
0,5	92%		3312		3220		3128		3036		2805		2576		2208		1841
0,4	91%		4095		3982		3868		3754		3468		3185		2731		2276
0,3	88%		5279		5134		4987		4840		4472		4107		3521		2934
(I) Transmissie indicatie per woning bij 100% inzet & dekking Vermogen in Watt per m² gebruiksoppervlak (Richtgetal)																	
Met WTW					80		70		60		40		35		30		25 !
Mechanische ventilatie			95		90		80		70		50		45		40		25 !
CO² gestuurde ventilatie					85		75		65		45		40		35		25 !
Woning		1965 t/m 1974		1975 t/m 1995		1995 t/m 1999		2000 t/m 2010		2011 t/m 2015		2016 t/m 2018		2018 t/m 2020		2021	
Voorbeeld woning van 100 m² met mechanische ventilatie: benodigde energie en het bijbehorende gasverbruik met HR ketel en kWh verbruik bij een 4,5 SCOP warmtepomp																	
kWh energie nodig per jaar J		17100 kWh		15750 kWh		13600 kWh		11550 kWh		7625 kWh		6300 kWh		4800 kWh		2500 kWh	
M³ gas verbruik per jaar K / L		€ 1.263	1943	€ 1.163	1790	€ 1.004	1545	€ 853	1313	€ 562	866	€ 465	716	€ 354	545	€ 185	284
kWh bij een warmtepomp								€ 513	2566	€ 338	1694	€ 280	1400	€ 213	1066	€ 111	555
Transmissie benadering kW M			9,5		9,0		8,0		7,0		5,0		4,5		4,0		2,5

Figure 50. Full load hour table (Installtek, n.d.)

https://installtek.nl/informatie/indicatietabellen

Subsequently, the gas consumption for each label was converted to kWh.yr and the total heat loss at -10°C is calculated with $Q_{jaar}=b*Q_{totaal}$ in kWh/yr.

Example:

Label D lower limit theoretical gas consumption: 20m3 (Figure 46).

Annual energy consumption for space heating: 20*0,95(boiler efficiyncy)*9,769=185,611 kWh.yr

Q_{totaal}=185,611/1700(full load hours label D)=0,109=109Watt

The results were then compared with the online tool of https://warmtepomp-panel.nl/inzicht_in_gasverbruik.html. Which also calculates the heating capacity based on gas consumption, full load hours, degree days, boiler efficiency, indoor temperature. The results of the hand calculations and the online tool have been compared and the (Table 48) is the result. This will always be less accurate than a heat loss calculation for a specific home, but a reasonable indication of the heating capacity can be given based on theoretical gas consumption and thus linked to an energy label.

Energy label	Vollast uren	Gas usage for space heating m3/m2.yr	Heat demand for space heating W/m2	Design supply temperature for radiators
G	2000	42+	200+	90
F	1750	32 - 42	170 – 220	90
E	1750	26 - 32	140 – 170	90
D	1700	20 - 26	110 – 140	75
C	1700	15 - 20	80 – 110	75
B	1650	12 - 15	65 – 80	75
A	1525	8 - 12	50 – 70	75
A+	1400	0 - 8	< 50	75

Table 48. Energy label linked to full load hours, gas usage, heat demand, and radiator supply temperature

It is immediately noticeable that according to this method, label B has a heat demand of 65-80 W/m2. And if we go back to (chapter 6.1), it was concluded that floor heating is possible as main heat emitter in case the heat demand of the home does not exceed 90W/m2, which is the case with a label B home.

Now the label classes are again divided into the 3 categories as earlier in this thesis:

Energy label	Gas usage for space heating m3/m2.yr	Heat demand for space heating W/m2	Design supply temperature for radiators
E-G	26-42	140 – 220	90
C-D	15-26	80 – 140	75
B or lower	15 or lower	80 or lower	75

Table 49. Energy label class linked to gas usage, heat demand, and radiator supply temperature

Home (E-G) insulated to (B or lower)

Suppose a home with current energy label (E – G) is insulated up to class (B or lower) using the flowchart insulating (Figure 49), as defined earlier. In the most unfavourable situation for the overcapacity the heat demand could have dropped from 140W/m2 to 80W/m2. To check whether the existing radiators can be maintained with a low temperature heat pump, the following formulas are needed:

P=k*A* ΔT_{log} (heat output of radiator) (Østergaard, 2018)

$$\Delta \text{Tlog} = \frac{\text{Tsupply} - \text{Treturn}}{\ln\left(\frac{Tsupply - Tindoor}{Treturn - Tindoor}\right)}$$

$P_{desired}$= $P_{original}$*(ΔTlog desired / ΔTlog original)^n (Østergaard, 2018)
P=heat output radiator
K=heat transfer coefficient

A=surfaced area of the radiator
n=constant describing the type of radiator (1.3 for normal radiator)
(ΔT_{log})= logarithmic mean temperature difference between the heat emitting surfaces and the ambient air

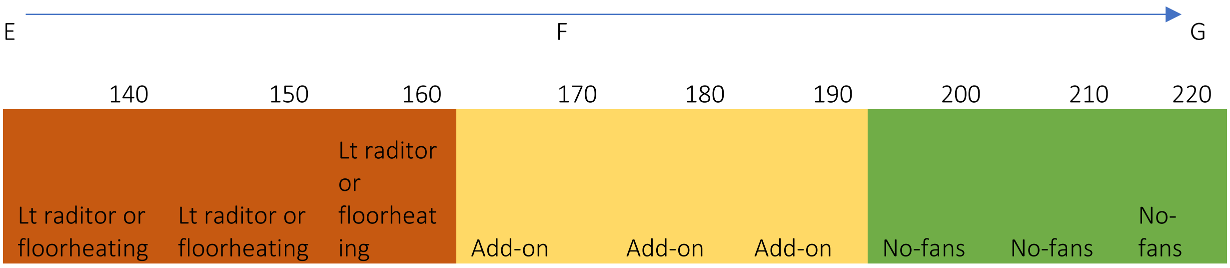
$P_{original}$=140 lower limit class (E – G)

$\Delta \text{Tlog original} = \frac{90-70}{\ln\left(\frac{90-20}{70-20}\right)}$ original supply temp 90/70

$\Delta \text{Tlog desired} = \frac{55-45}{\ln\left(\frac{55-20}{45-20}\right)}$ new supply temp 55/45 (Low temperature heat pump)

By filling in the formula is found that $P_{desired}$=57Watt, which means that by lowering the supply temperature from 90 to 55 results in a power decrease from 140W to 57W where 80W was needed. So the home will not be heated properly. By adding add-on fans this power output is roughly with 21% increased (SpeedComfort, 2022)which results in 69W which is still too low. So in the worst case you will have to replace your radiators with low temperature radiators or underfloor heating if the building is insulated from (E – G) to (B or lower) in combination with low temperature heat pump.

If supposed that a home could also be in the upper limit of class (E – G) then insulating to label (B or lower) results in a decrease from 220W/m2 to 80W/m2. By using the same formula was found that lowering the supply temperature from 90 to 55 was possible, even without add-on fans. The lowering of the supply temperature is calculated for the whole range (E – G) and the outcome is shown below.



As can be concluded by the range above: Can only the existing radiators be kept coming from really high energy labels F en G with or without fan depending on the label. Subsequently, it was calculated in the same way for the other label categories whether the heat emission system must be adapted if the home was insulated to label B for an all-electric heat pump.

This resulted in the following flowchart (Figure 51):

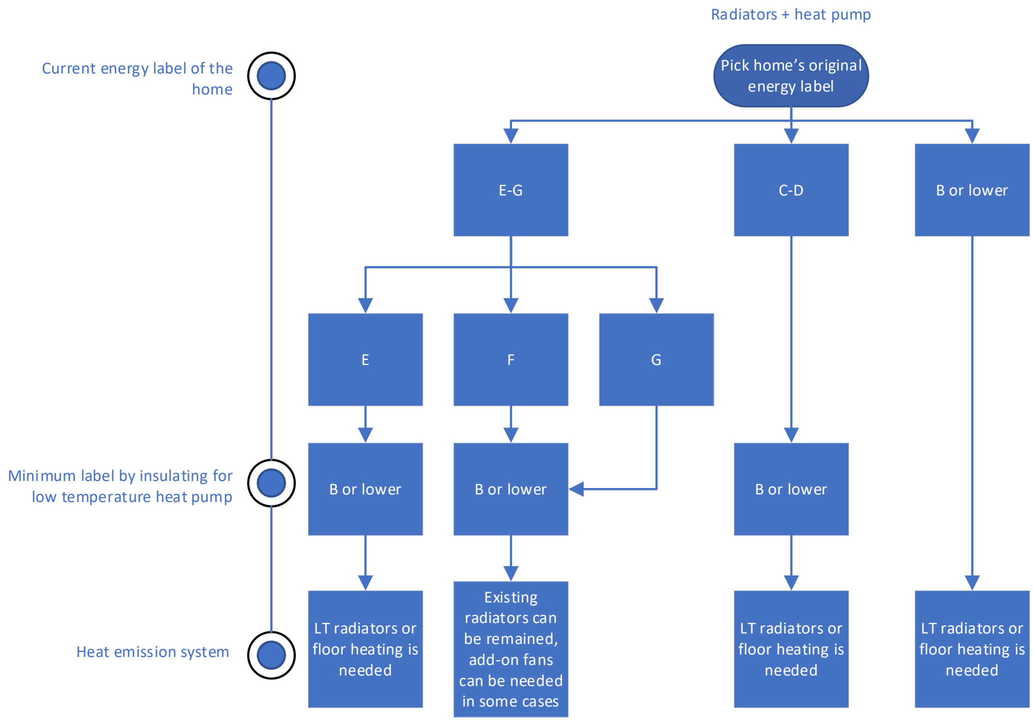


Figure 51. Radiator adjustment after insulating in combination with all electric heat pump

It was then determined in the same way what insulating to label (C – D) does and whether a temperature reduction to 70 degrees is possible with the existing heat emitter. In this way the home owner can see whether he needs to adjust the heat emitter in combination with a hybrid heat pump.

Home (C-D) in combination with radiator and hybrid heat pump

Example label D=140W/m2 (Table 48) at -10 °C. By using the formula: $P_{desired}$= $P_{original}$*(ΔTlog desired / ΔTlog original)^n (Østergaard, 2018) was found that a temperature reduction from 75°C to 70°C let to a power output reduction to 122W/m2. Which means that at -10°C the power output of the radiator is too low, assumed that the radiator is not over dimensioned. An add-on fan increases the power output with 21% which increases the power output to 148W/m2 which ensures that the home is heated well at -10°C.

By using the formula:

$P_h(i) = P_{des} * [\frac{T_{bal}-T_{oa}(i)}{T_{bal}-T_{des}}]$ (Mouzeviris & Papakostas, 2020)

T_{oa} is the corresponding outdoor dry bulb air temperature [°C] at the i-th bin
T_{des} is the design outdoor temperature [°C] of the building location
T_{bal} is the balance-point temperature [°C] is the temperature at which the buildings heating demand becomes zero

was found that 122W/m2 is the heat loss of the building at -6,7°C outdoor temperature. Which means that reducing the supply temperature from 75 to 70 resulting in enough power until an outdoor temperature of -6,7°C. This results in the advice as shown in (Figure 52) existing radiators can be remained and that add-on fans could be needed in harsh winters.

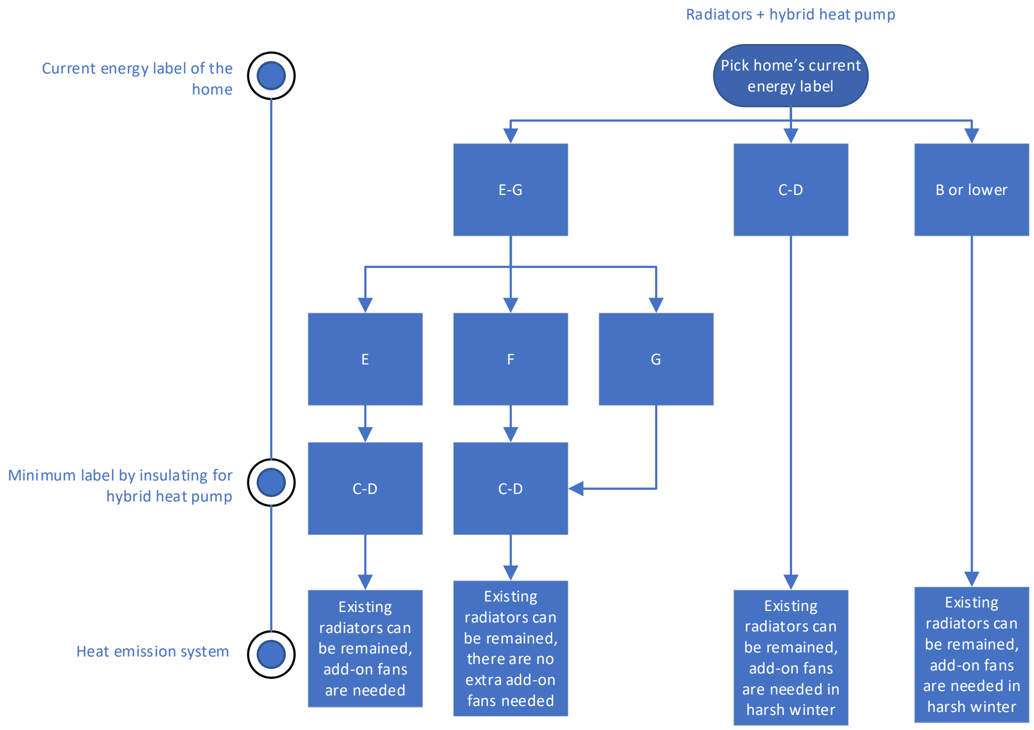


Figure 52. Radiator adjustment after insulating in combination with hybrid heat pump

Flowcharts floor heating ground floor and radiators second floor as defined in (chapter 8.9).

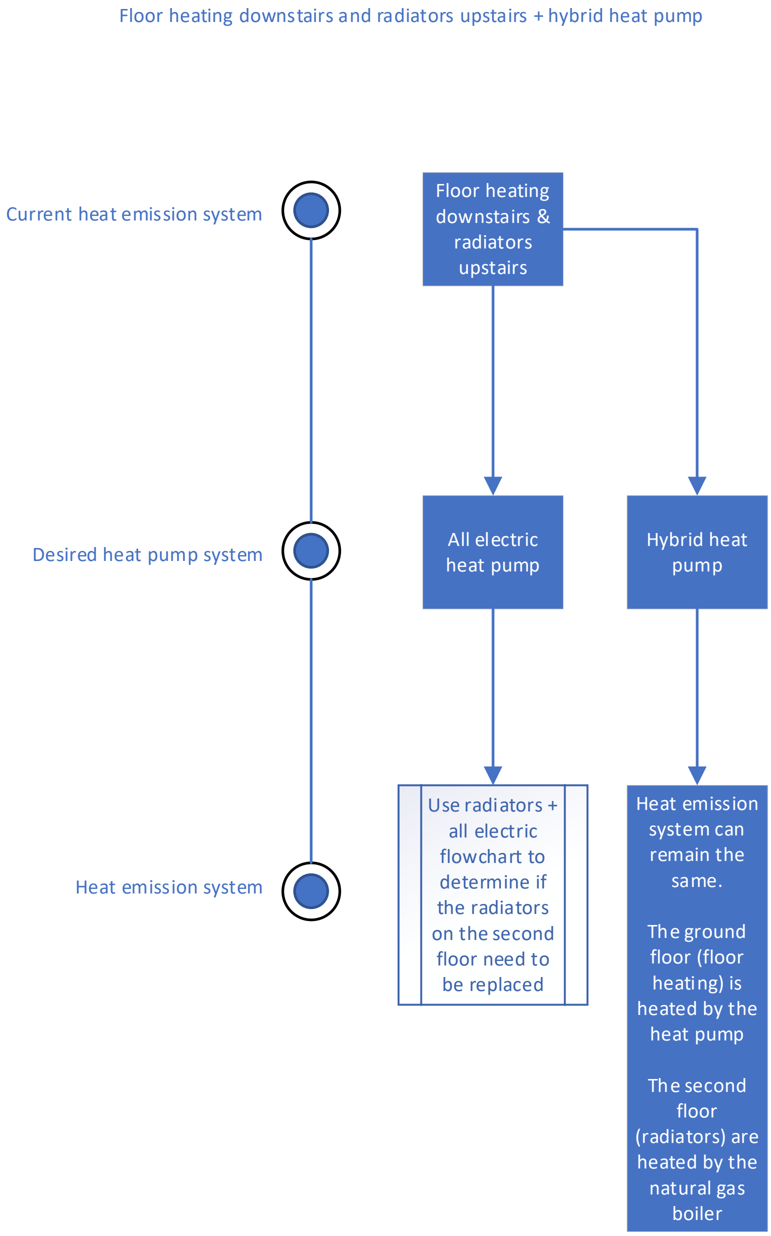


Figure 53. Floor heating downstairs and radiators upstairs in combination with hybrid or all electric heat pump

Flowcharts floor heating and radiators in same room as defined in (chapter 8.9).

In this case, the floor underheating is configures as additional heating. The underfloor heating ensures a constant ‘low’ temperature in the room, of for example, 14°C and the radiators in the room then heat up the room to the requested 20°C. To check whether the radiators should be fitted with add-on fans or be replaced by low temperature radiators, the flowchart: radiator should be checked.

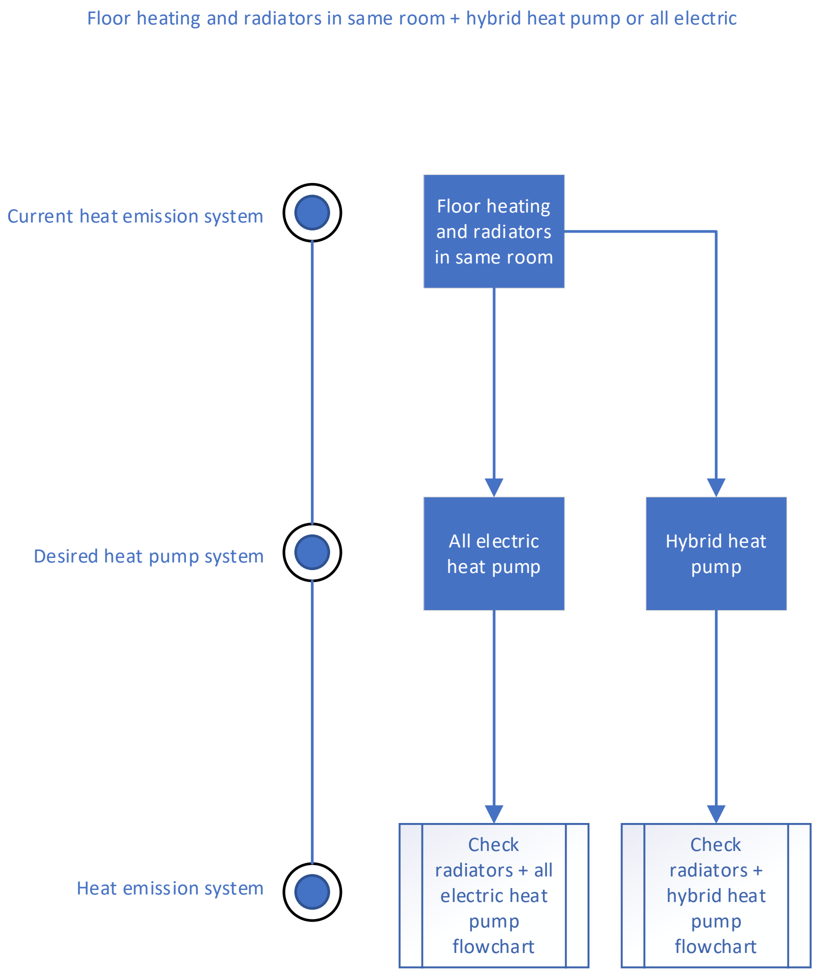


Figure 54. Floor heating and radiators in same room with hybrid or all electric heat pump

7.11 Spatial aspects indoors and outdoors existing heat pump decision tools

First the existing tools are analysed.

Milieucentraal

Figure 56. Spatial aspects indoors (Mileucentraal, 2022)

Figure 55. Spatial aspects outdoors (Milieucentraal, 2022)

What is good and can be used in the final tool, and what can be improved considering the spatial aspects.

It is positive that this tool asks for spatial aspects, which are lacking in most of the tools. But it would be better for the building owner to show reference photos, so that he can get a better idea of the size and properties of the heat pump system that he could possible install into his home.

Samangroep
No spatial aspects indoors or outdoors are asked

Warmhuis
Only spatial aspects concerning a ground source are asked, the tool mentions: those wo have a front yard or a yard that is accessible to a drill (the size of a truck) may consider this option.

What is good and can be used in the final tool, and what can be improved considering the spatial aspects.

This tool is already a bit more specific considering the spatial aspects needed for a ground source heat pump in comparison than milieucentraal, because this tool does not state that a large garden is needed, but that a front garden accessible by an truck is also sufficient. Again, images would make it easier for the homeowner to estimate size of machines and the possibility for soil drilling.

Groenpand
No location aspects indoors or outdoors are asked

Ithodaalderop

Figure 57. Spatial aspects (ithodaalderop)

What is good and can be used in the final tool, and what can be improved considering the spatial aspects.

Spatial aspects is requested in a fairly brief way for both indoors and outdoors. Sound is not addressed.

Panasonic pro club
No spatial aspects indoors or outdoors are asked

Vaillant
No spatial aspects are asked

Conclusion

The spatial aspects needed for different heat pump systems are far too little discussed in existing tools. System location for outdoor unit is based on space but noise is also an important factor. And since in existing buildings the breakdown of a certain system can depend strongly on the small space available, this is an important aspect that must be worked out in much more detail in the heat pump decision tool designed in this thesis.

7.12 Spatial aspects indoors and outdoors in the final tool

Outdoor spatial aspects
The heat pump systems which are included in the tool are already defined in chapter 6.

Air source heat pump	Outdoor spatial aspects
Ground source heat pump	Drilling rig size
Solar thermal collectors (PVT heat pump)	Free available roof area
Hybrid air source heat pumps	Locations for outdoor unit + sound

Table 50. Heat pump systems outdoor spatial aspects final tool

Ground source heat pump
According to (boringenverheyden, n.d.) the site must be easily accessible for a drilling rig with the following characteristics: 2,5m width, 8,5m length and 3m height. And when in operation mode the drilling rig needs an area of 4m width, 8,5m length and 9,5m height. To ensure that the user of the tool gets a sense of the size of the machine, two reference images are shown in the tool plus a sketch with the dimensions of the machine. With these references and the sketch the user should be able to estimate whether his home has enough outdoor space to realize a soil drilling for a ground source heat pump.

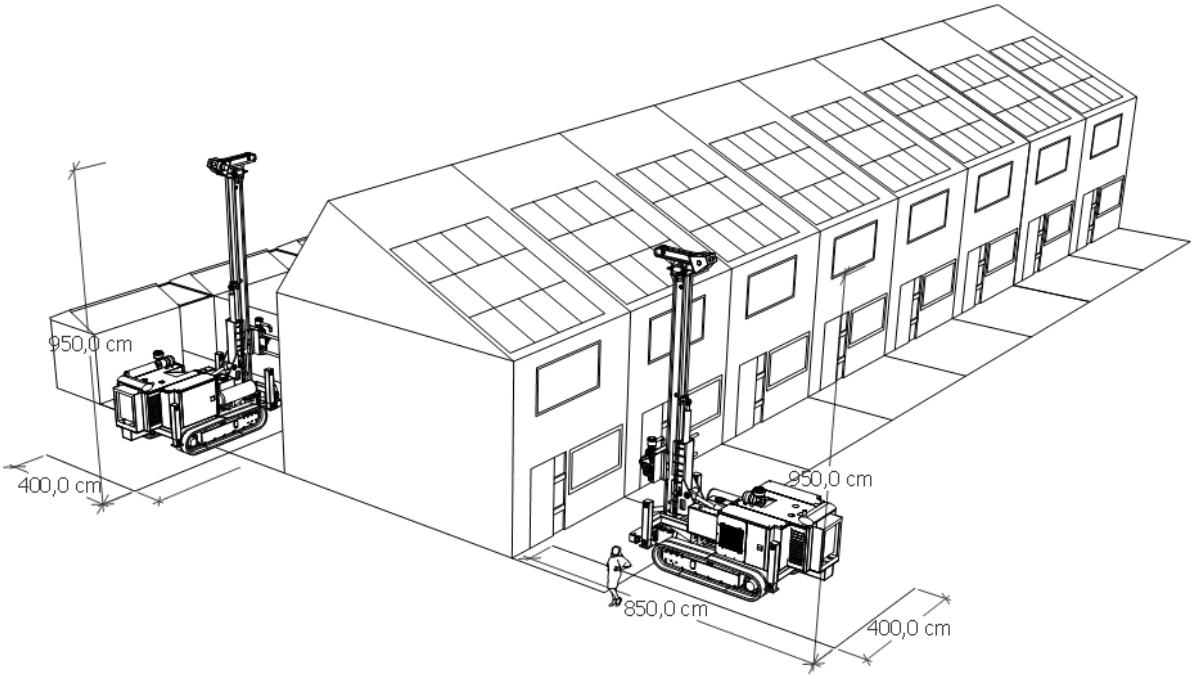


Figure 58. Drilling rig in operation needed work space

This sketch (Figure 58) is composed from an existing cad file of a drilling rig and an existing terraced house from the google SketchUp warehouse. By showing the dimensions taken from (boringenverheyden, n.d.) of the machine and the needed working area, the homeowner can check at his own home by stepping (1m=1step) whether there is enough space available at the front or back garden to do a soil drilling. It can be the case that for example a fence temporarily has to be removed. The homeowner can take these measures in advance, so that the drilling company carrying out the soil drilling can get to work immediately.

Figure 59. Front garden ground source drilling

The final heat pump decision tool also shows references of actual in soil drillings, to get a sense of the machines size and ability to drill, even in a small front yard.

Figure 60. Back garden ground source drilling

PVT heat pump

The amount of PVT panels needed depend on the needed power of the heat pump and thus the heat loss of the home, 2 PVT panels are needed per kW heating power. 1 panel is 1,0 by 1,7 meters. If you want to use the PVT system in a hybrid setup next to your existing gas boiler, a minimum power of 4kW (Remeha, 2021) is assumed reasonable, for which 8 PVT panels are required with a total surface area of around 14m2.

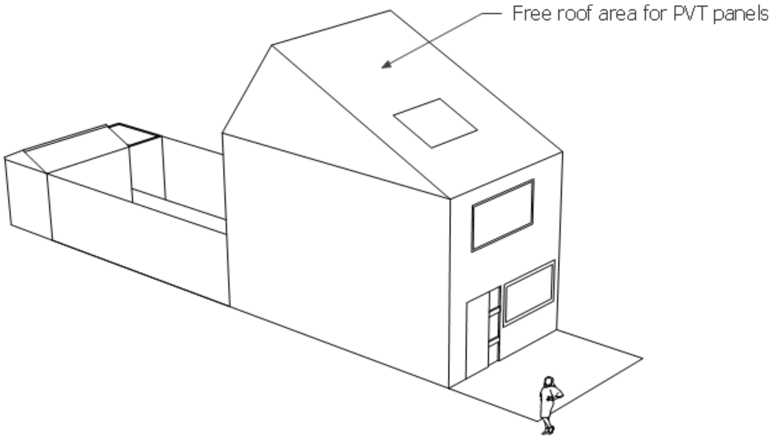


Figure 61. Free roof area for PVT panels

If you want an all-electric system, this means in many cases more than 4kW of heating power is required, which results in more needed roof area. In both cases (hybrid & all-electric) it is necessary to calculate how much m2 of free roof area is available.

One way to estimate the free area available on the roof is by using the free online tool from http://comparemysolar.com/nl/calculator/. This online calculator will also be mention as an external help for the homeowner.

In the heat pump decision tool will the homeowner be asked if there is at least 14m2 roof area is available for PVT panels. If this is the case then there is enough space available for a hybrid heat pump system. In case the user wants an all-electric system then there should be more roof area available for the needed capacity. This capacity will be determined by the heat pump installer with a heat loss calculation.

But to give the homeowner an idea of the possible required roof surface, the following reasoning has been applied: as has been shown from this thesis, an all-electric heat pump is only possible with a well-insulated home, which is translated into a minimum label B home. As concluded in (chapter 8), this will be a home with in the worst case a heat requirement of 80W/m2. The required roof surface for a PVT heat pump depends on the total heat demand of the home and this can therefore be estimated by multiplying the floor are of the home by 80W/m2. The required roof area can then be calculated with: 1kW=3,4m2 roof area. So amount of roof area needed for an all-electric PVT system: floor area (m2)*0,08*3,4=needed roof area m2)

Example home 120m2 label B all-electric PVT: 120*0,08*3,4=33m2 roof area

This example + formula are shown in the tool, so that the homeowner can estimate if he has enough free roof area for whether an hybrid PVT heat pump system or an all-electric PVT heat pump system.

Air source heat pump outdoor unit

The homeowner is first provided with general information regarding the outdoor unit of an air source heat pump by means of the heat pump decision tool:

Due to the new regulations, the placement of the outdoor unit is highly dependent on the noise produced by the unit on the property boundary. During the day the maximum noise which is allowed to be produced on the property boundary is 45dB and during the night the maximum noise which is allowed to be produced on the property boundary is 40dB (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2021). This sound level compares to the average home noise in a home, made by the refrigerator, or computer hum (Figure 62). These regulations are drawn up so that neighbours are not disturbed by the noise from the heat pump.

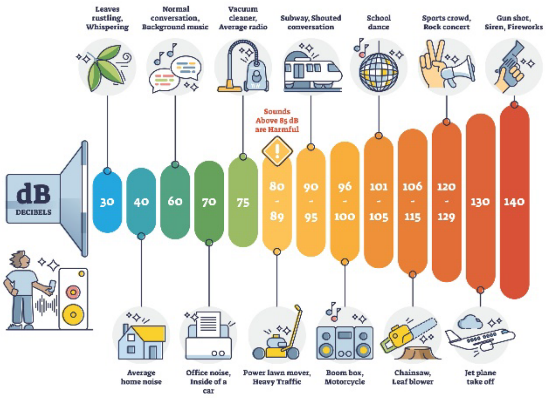


Figure 62. Decibel scale comparison

The most air source heat pump outdoor units, produce more than 45dB noise. There is a trend going on developing more quit units, but it is technically still not possible to make units which deliver enough power to heat up a home and be as quit as 45dB (Energieplein, 2020). Smart tricks are applied, for example by using a night setting so that the unit produces less noise in the evening by reducing the fan speed. Unfortunately, there is not yet a database available with all the noise levels that the different heat pumps of different brands produce. The only thing the installer can do is ask the manufacturer for the maximum sound level that the outdoor unit can produce.

'De Consumentenbond' recently carried out a test of the maximum noise level of various outdoor units of air source (hybrid) heat pumps of both split units and monoblocks. The test results were as following:

Brand & Power	Monoblock	Split-unit	Silent night modus
Atlantic 5 kW	61dB(A)		Yes
Ferolli 4kW	67dB(A)		Yes
Vaillant 5kW		55dB(A)	Yes
Itho 6kW		66 dB(A)	Yes
Atag 4kW	59dB(A)		Yes
Daikin Intergas 5kW		60dB(A)	Yes
Bosch 5kW	53dB(A)		Yes
Remeha 4 kW		57dB(A)	Yes

The test shows that there are currently no heat pumps on the market that comply with the noise regulations. As we know the sound level decreases the further away from the sound source. The installer of the heat pump will therefore have to look for a place on or around the house far enough from the property boundary to ensure that the noise level does not exceed the limit there. On the one hand this new sound regulation ensures a trend among heat pump manufacturers who now have to design quieter units. And neighbours will no longer be bothered by heat pump noise. But the homeowner's comfort is now somewhat forgotten, this was also concluded in (chapter 4), which showed that in existing renovations cases with heat pump application residents themselves complained about the noise of an air source heat pump. It is therefore always advisable to provide the heat pump with a sound absorbing housing. Such a sound-absorbing housing dampens the sound by approximately 9-15 dB(A) and the efficiency of the heat pump remains unchanged (merford, n.d.) & (golantec, n.d.). This corresponds approximately to a noise reduction of 90% (Peter van der Wilt, 2020). Such sound-absorbing housing gives the installer greater freedom of installing a heat pump with regard to the noise regulations, the residents also experience much less noise nuisance, and on top of that the housing provides a different appearance. The outdoor units of air source heat pumps are often experienced as ugly (Smorenburg, 2021). Sound proofing housing come in all sizes and types so that heat pumps can always be integrated into the context (Figure 63), (Figure 64), (Figure 65) and remains no longer an unsightly appendage. It is therefore strongly recommended to always make this extra investment when purchasing an air source heat pump.

Figure 64. sound-absorbing heat pump housing (Merford, 2022)

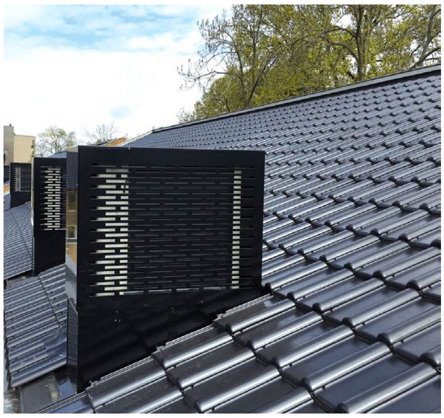


Figure 63. sound-absorbing heat pump housing (HydroCap, 2022)

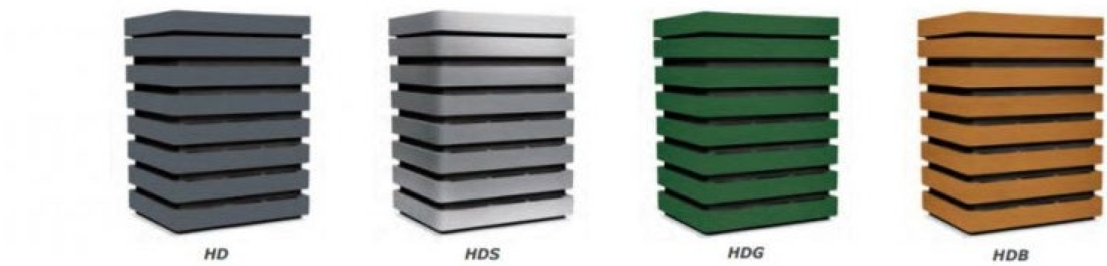


Figure 65. sound-absorbing heat pump housing (golantec, 2022)

Air source heat pump spatial aspects

The tool then shows a number of examples (Figure 66) of ground-based homes with an air source heat pump outdoor unit at various locations. These example images are used from the PBL sight tool. Based on these examples, the building owner must now indicate whether he thinks there is a suitable place on or around the house for an outdoor unit of an air source heat pump. Ultimately, the final location will be determined in agreement with an installer, but the homeowner can already gain an insight into the possible building services location. If the homeowner thinks that there is room for an outdoor unit based on the examples, then he must indicate this in the tool.

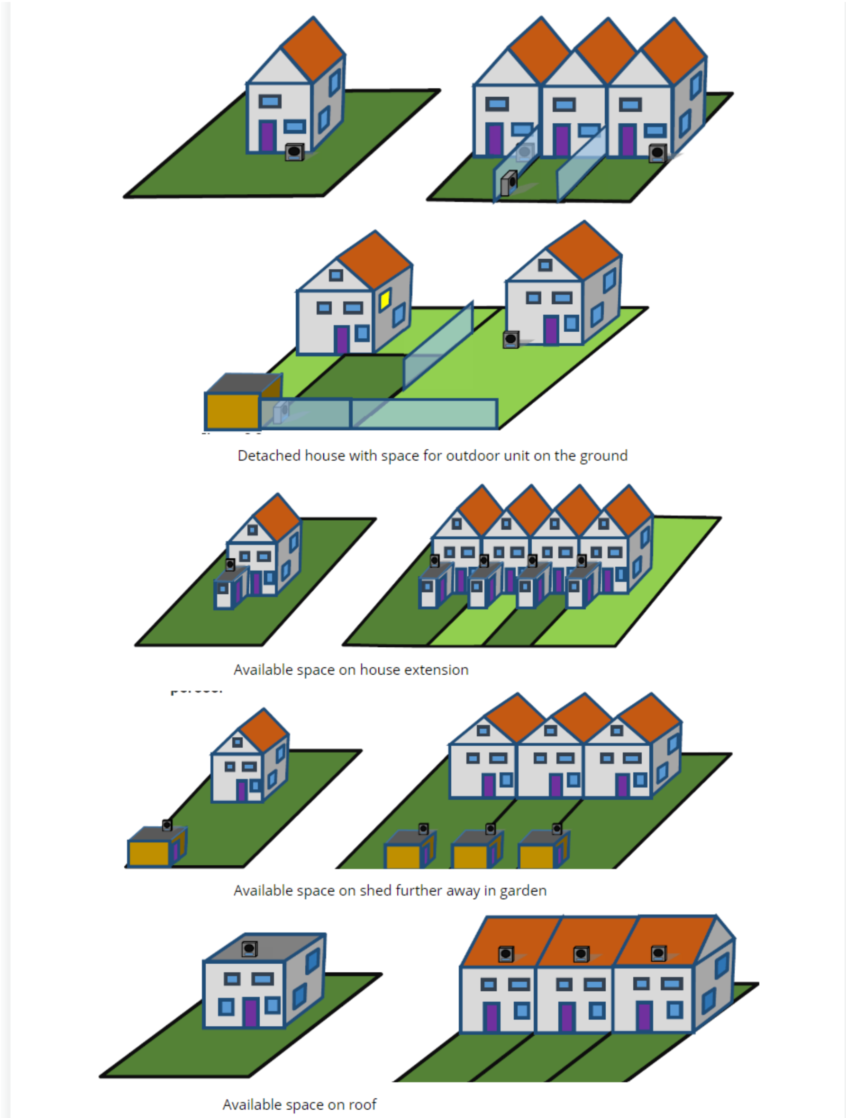


Figure 66. Air source heat pump outdoor unit possible locations (Pictures from PBL tool)

Flowchart outdoor spatial aspects

Following from the above 3 outdoor spatial aspects, the tool uses the flowchart below to determine which heat pump system(s) is/are possible in the home. As a result, the applicable systems are sketched together with a small description how they work. In addition, the systems are also provided with a price indication & grants.

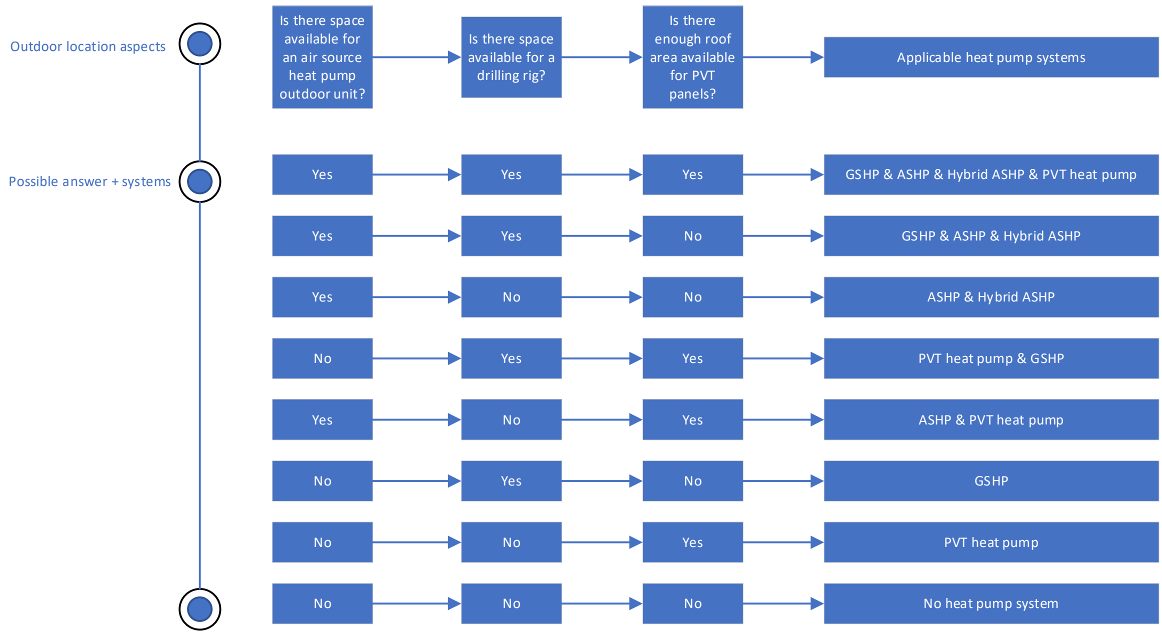


Figure 67. Flowchart outdoor spatial aspects

4. 

Since the air source heat pump has been installed in many existing buildings as found in the preliminary research, additional information has been provided at this stage in the tool. There are two types of air source heat pumps that can be installed by different technicians. A monoblock can be installed by any central heating installer. A split unit can only be installed by an installer with an F-Gas certification.

Monoblock: A monoblock air source heat pump system contains an outdoor unit and in many cases an indoor unit connected by the means of two thin pipes. And through these pipes flow normal water. Because water flows through these pipes, this heat pump type can be installed by any heat pump installer and there is no special qualification needed to install this type of heat pump. A disadvantage of a monoblock system is that there is a risk that the system can freeze in winter.

Split unit: A split-unit system contains of an outdoor unit and an indoor connected by means of two thin pipes. And through these pipes flows refrigerant. Because refrigerant flows through these pipes, this heat pump type must be installed by an installer with a special F-gas qualification. But by no means all heat pump installers have this qualification, so it can be more difficult to find an installer who can install a split-unit system for you. A major advantage of this system is that the refrigerant cannot freeze in winter.

1.5 Spatial aspects indoors final heat pump decision tool

Indoor area needed

For all the systems references (chapter 6.1) are researched in order to determine the indoor size for each different heat pump system. From all these references there are sketches made and with those there is a variants study which is included in the flowchart spatial aspects indoors (Figure 74) performed on 6 different indoor scale levels from big to small. The user of the tool is first shown a sketch of the largest scale (level 1) with the largest heat pump system with its dimensions. The user must indicate whether he thinks that the displayed system will fit in his home near the existing gas boiler. If he answers yes to the first scale level, then all the heat pump systems are possible in his home. If he answers no, then the second scale level will be displayed to the user, again he has to answer if he thinks that system will fit. And so the scale levels are reduced and more and more systems are excluded if the user answers no.

The following six scale levels and their heat pump systems are included in the tool:

Applicable heat pump systems based on scale level 1 (Figure 68)

1. PVT heat pump + DHW boiler + central heating buffer (Figure 23)
2. PVT heat pump + DHW boiler
3. GSHP with integrated DHW boiler + central heating buffer (Figure 21)
4. GSHP with integrated DHW boiler (Figure 22)
5. ASHP + DHW boiler + central heating buffer (Figure 18)
6. ASHP + DHW boiler (Figure 17)
7. Hybrid air source heat pump + central heating buffer (Figure 19)
8. Hybrid air source heat pump (Figure 20)
9. Hybrid air source no indoor unit (hydraulic separator) (Figure 24)

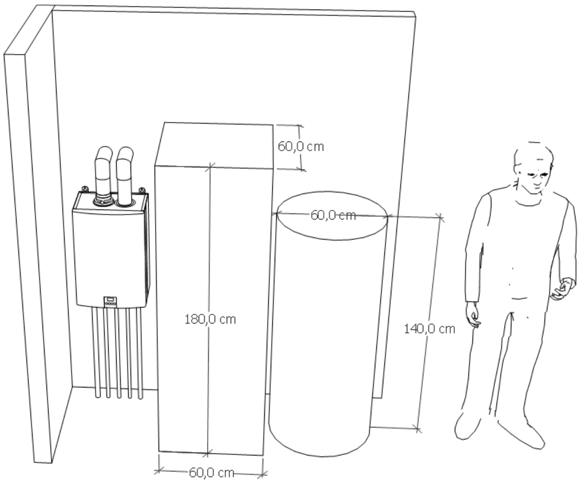


Figure 68. Indoor spatial aspects, scale 1

Applicable heat pump systems based on scale level 2 (Figure 69Figure 68)

1. PVT heat pump + DHW boiler
2. GSHP with integrated DHW boiler + central heating buffer (Figure 21)
3. GSHP with integrated DHW boiler (Figure 22)
4. ASHP + DHW boiler + central heating buffer (Figure 18)
5. ASHP + DHW boiler (Figure 17)
6. Hybrid air source heat pump + central heating buffer (Figure 19)
7. Hybrid air source heat pump (Figure 20)
8. Hybrid air source no indoor unit (hydraulic separator) (Figure 24)

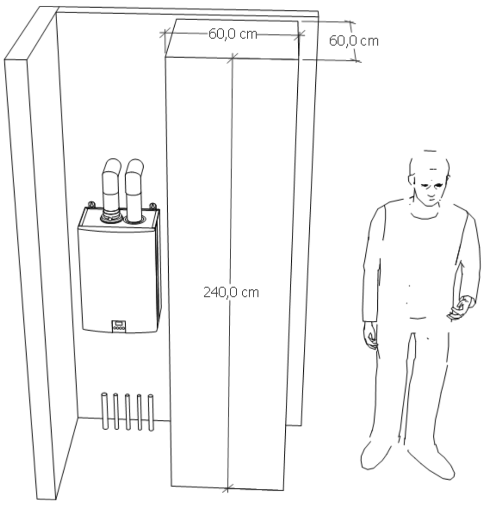


Figure 69. Indoor spatial aspects, scale 2

Applicable heat pump systems based on scale level 3 (Figure 70)

1. PVT heat pump + DHW boiler
2. GSHP with integrated DHW boiler + central heating buffer (Figure 21)
3. GSHP with integrated DHW boiler (Figure 22)
4. ASHP + DHW boiler (Figure 17)
5. Hybrid air source heat pump + central heating buffer (Figure 19)
6. Hybrid air source heat pump (Figure 20)
7. Hybrid air source no indoor unit (hydraulic separator) (Figure 24)

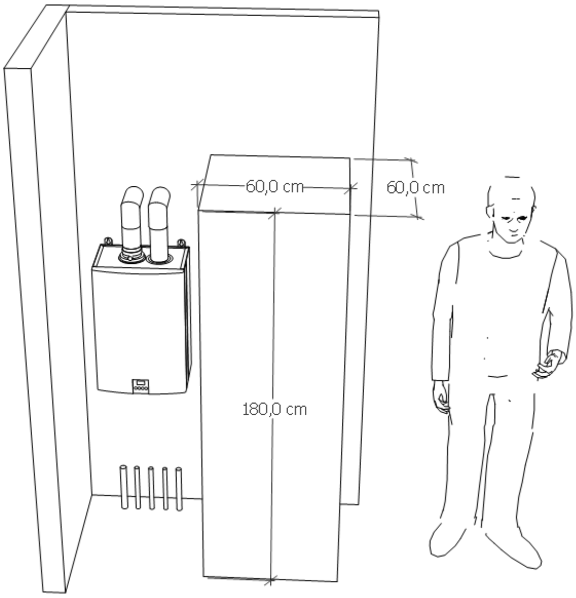


Figure 70. Indoor spatial aspects, scale 3

Applicable heat pump systems based on scale level 4 (Figure 71)

1. Hybrid air source heat pump + central heating buffer (Figure 19)
2. Hybrid air source heat pump (Figure 20)
3. Hybrid air source no indoor unit (hydraulic separator) (Figure 24)

Applicable heat pump systems based on scale level 5 (Figure 72)

1. Hybrid air source heat pump (Figure 20)
2. Hybrid air source no indoor unit (hydraulic separator) (Figure 24)

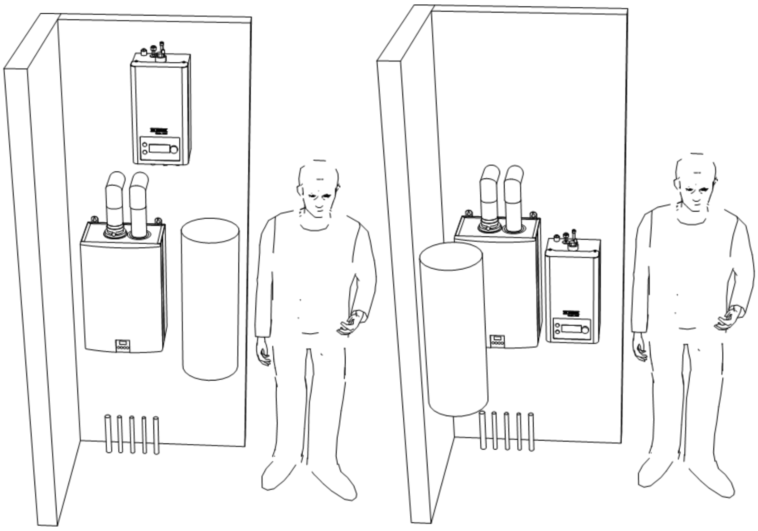


Figure 71. Indoor spatial aspects, scale 4

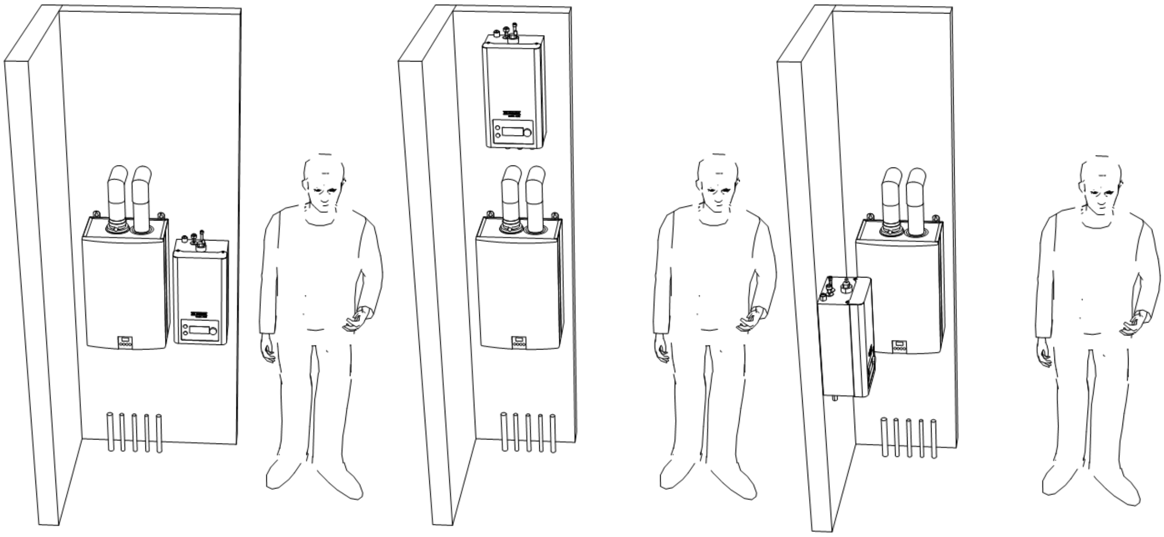


Figure 72. Indoor spatial aspects, scale 5

Applicable heat pump systems based on scale level 6 (Figure 73)

1. Hybrid air source no indoor unit (hydraulic separator) (Figure 24)

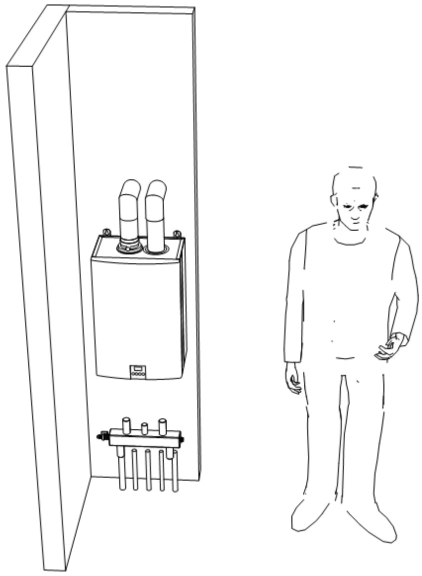


Figure 73. Indoor spatial aspects, scale 6

After the homeowner has gone through all scale levels, the heat pump systems remain that can be used in the home based on the space next to the existing gas boiler. A reference image is displayed for each system in the tool, so that the homeowner can get an idea of what such systems look like in real life and what its approximate size is.

Flowchart that is embedded in final tool + variants study (Figure 74)

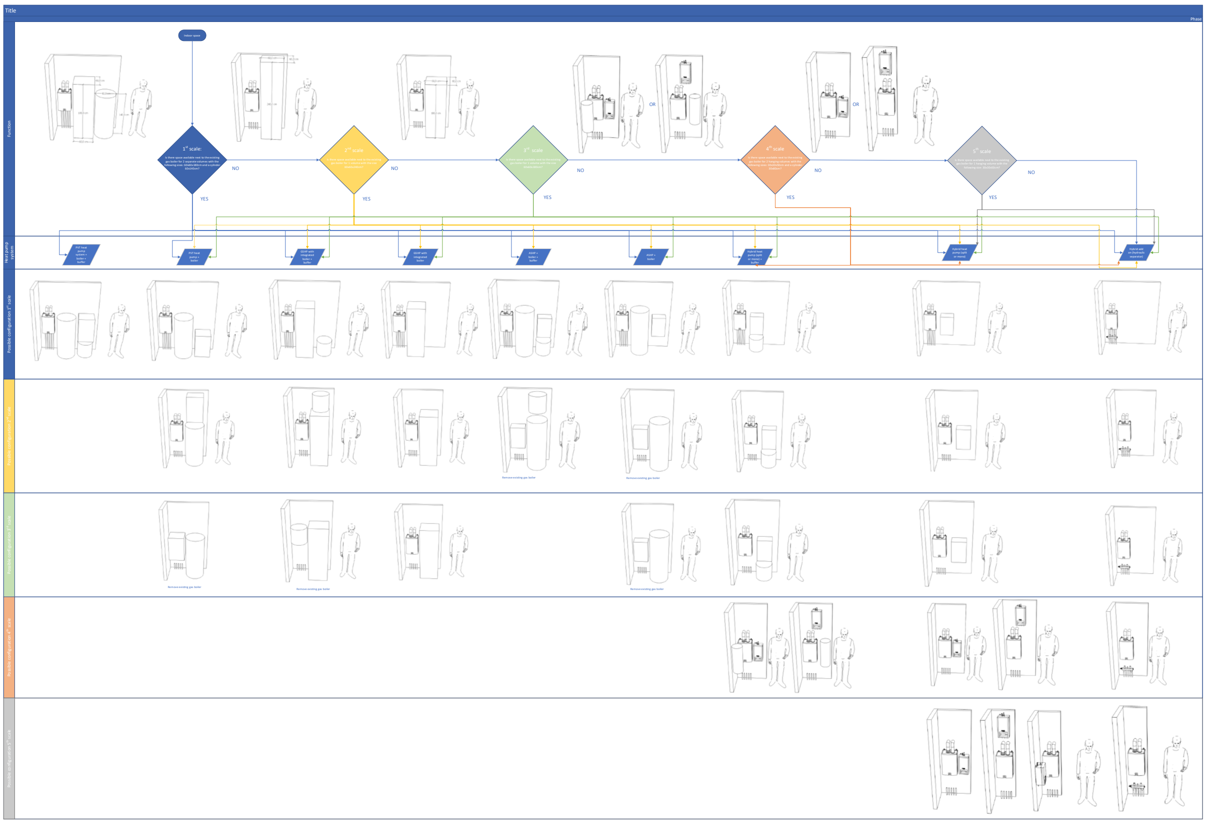


Figure 74. Flowchart indoor spatial aspects + variants study

5.

It may be the case that more heat pump systems are possible on the basis of indoor space than of the basis outdoor spatial aspects. The homeowner can choose the systems that are applicable to both indoor and outdoor spatial aspects according to the tool. But the outdoor spatial aspects are decisive. If it is the case that a certain heat pump system is applicable on the basis of outdoor spatial aspects, but this system is not shown in the spatial aspects indoors, then it can always be checked with the installer whether another place in the home can be found where the system does fit, this will probably lead to a lot of pipework having to be changed. This entails more costs, but can be achieved. The other way round is not possible, since the spatial aspects outside the home cannot be adjusted because the context is virtually fixed.

Online tool

After P4, the determination of the energetic state of the home has been tightened up slightly. The determination can be seen in the following flowchart (Figure 75).

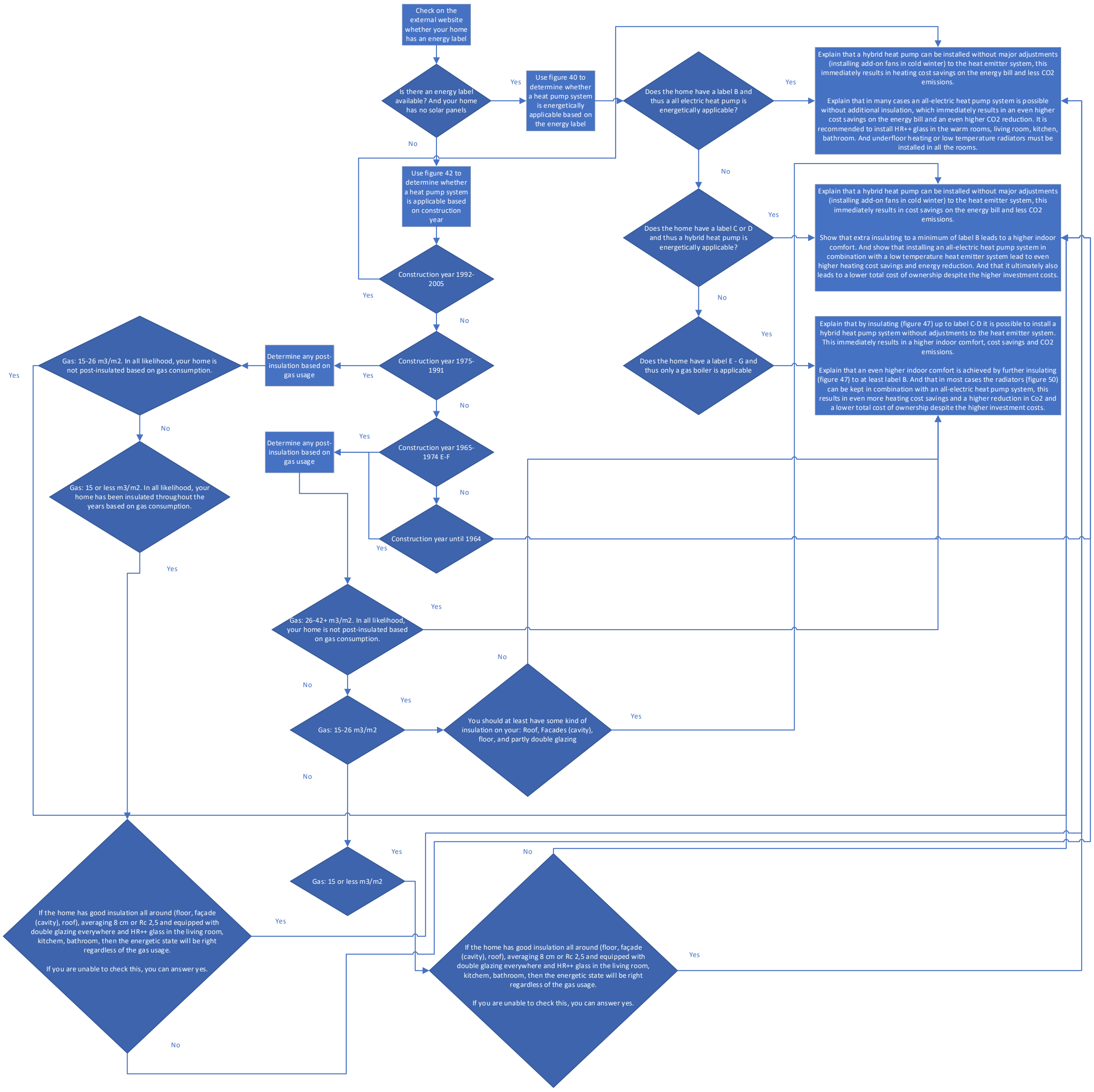


Figure 75. Determination energetic state of the home

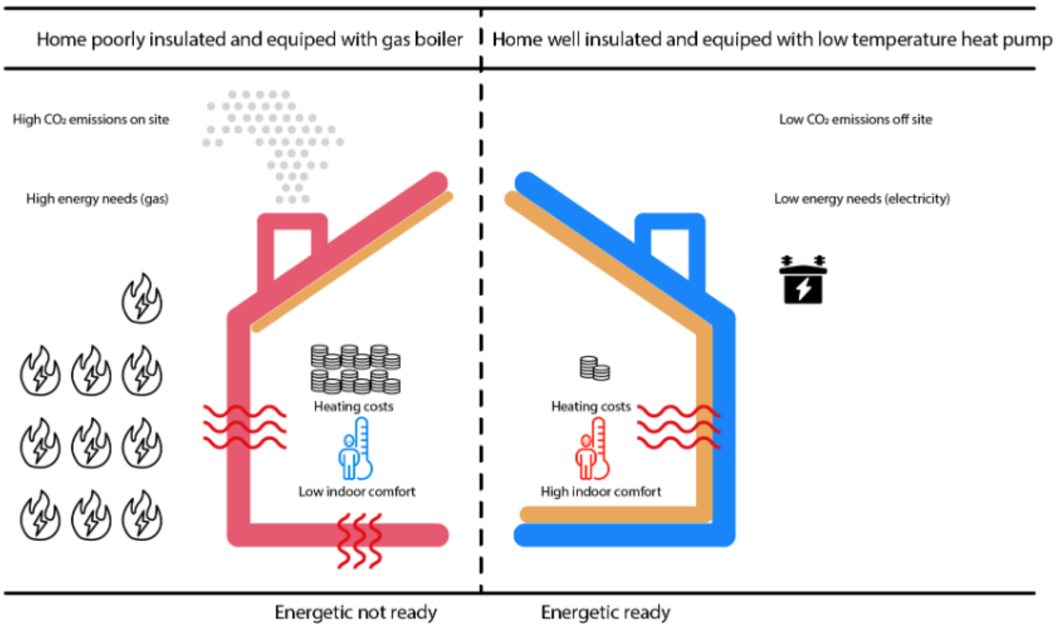
The first page of the tool looks like (Figure 76) and the tool can be used by the following link:

https://ztree.ai/684865704

Heat pump decision tool

Heat pump decision tool for ground-level homes: terraced-house, semi-detached house, or detached house

This tool determines on the basis of a number of questions whether your home is well insulated (energetic ready) for a low temperature heat pump and or hybrid heat pump and if not what building envelope upgrades are needed. Whether your heat emission system is ready for a low temperature heat pump and if not what heat emission upgrades are needed. And what specific heat pump system fits your home based on spatial aspects (outdoors & indoors).



Start determining what heat pump system is suitable for your home

The energy label is used to determine the energetic quality of your home in order to determine whether a (hybrid)heat pump system is applicable.

Determine the energy label of my house

Back Restart

Figure 76. First page heat pump decision tool

Conclusion:

How is a heat pump decision tool for homeowners with limited technological knowledge designed, which gives an advice that contributes to the energy transition of the built environment and which provides an advice on which heat pump system and additional measures a home owner should consider before engaging an installer?

Research part 1: 'Theoretical framework'

In order to answer the main research question firstly the sub-questions are answered:

What are the current energy usages and energy sources of the built environment for in particular space heating of households in the Netherlands, what problems do they cause and what are potential renewable energy sources?

The built environment uses 28% of the total energy consumption in the Netherlands. 30% of that energy is used for lighting and 70% for heating. The biggest part 85% of the heat comes from natural gas. 46% of the total heat is used for space heating of households with natural gas, which is almost half of the total heating energy of the built environment and therefore a large share. The combustioning of natural gas leads to CO2 emissions which caused climate change. The excessive extraction of natural gas also led to earthquakes in the Netherlands. Potential renewable energy sources in the Netherlands are: wind energy, solar energy or ground energy. The generation of these renewable energy sources requires large geographical space. In order to reduce the CO2 emissions the advice of the tool leads to a reduction of energy needed for space heating, which also leads to less needed geographical space in order to generate the needed energy. In order to even further reduce the needed geographical space for energy (electricity), the advice of the tool is aimed at using the electrical energy as efficiently as possible by the means of a heat pump.

What policies are already introduced to support the energy transition of the built environment and what are their influences on the built environment and how can these be important in the design of the heat pump decision making tool?

On European scale the Paris Agreement is introduced in order to grip climate change by reducing greenhouse gas emissions and reach emission neutrality by 2050. The Dutch elaboration of this agreement is the climate agreement 'klimaatakkoord', states that the currently 7 million households and 1 million buildings, which are currently poor insulated and almost all heated with natural gas need to be transformed to well insulated buildings, which are heated with sustainable heat and electricity from renewable sources. In order to speed up this energy transition the Dutch government provides subsidy schemes for heat from renewable energy sources, such as heat pumps and it also provides subsidy schemes for building insulation. Next to that, homeowners are obliged to switch to a hybrid heat pump from 2026 when the central gas heating boiler needs to be replaced. It follows from the policies that the energy consumption of the built environment must be reduced, which is also one of the reasons behind te tool by giving advice on the importance of insulating the home. In addition, the tool provides advice on the minimum energetic quality that a home must have for the mandatory hybrid heat pump from 2026, but the tool also advices that, if possible, an even better insulated home with an all-electric heat pump should be strived for, to further reduce the energy consumption.

What heat pump systems are integrated in existing building renovation cases and which envelope improvements are performed and can these techniques be used for the advice in the final heat pump decision tool?

By analysing existing building renovation cases was found that the buildings envelope firstly needed to be insulated to a very good level by insulating the roof, facades, floor and windows before applying a heat pump. The air to water heat pump and ground source heat pump were mainly used in existing situations. Most occurring problems for inhabitants were system noise and the space the systems took up. Both the air and ground source heat pump are included in the advice of the tool, because the cases show that this technique work in existing buildings. To make building owners aware of the size of such systems, the tool clearly includes examples of the space required for such systems, so that home owners are not surprised when they call an installer. The home owner is also prepared by the advice of the tool for the noise such systems make and how this can be limited.

What heat pump systems and other sustainable heating sources have potential in supporting the energy transition of the built environment and which will be included in the heat pump decision tool?

The tool is focussed on the individual approach of integrating renewable energy options. De following options are included in the tool: air source heat pump, ground source heat pump, solar thermal heat pump (PVT heat pump) and hybrid heat pumps.

Research part 2: 'Empirical research'

What aspects from the analysed existing heat pump decision tools should be combined in the new tool and which aspects remained missing in the existing tools which needs to be included in the new tool?

A simple way to determine energetic quality and possible post-insulation of the home is missing in existing tools. And certainty whether a certain existing heat emission system can be maintained while using a heat pump system is missing in existing tools. And spatial aspects both indoors and outdoors that lead to a specific heat pump system are very marginal in existing tools.

What are the boundaries of the selected heat pump systems leading to certain advice formation of the heat pump decision tool?

Different heat pump systems have a different maximum supply temperature, leading to advice of different heat emission systems and energetic building qualities. Boundaries concerning the placement of an air source heat pump outdoor unit, results in context specific advice. Boundaries concerning space needed for ground source drilling results in context specific advice, just as the roof area which is needed for a PVT heat pump. System sizes results in context specific advice, indoors and outdoors.

In what way can the heat pump decision tool fulfill an educational function for the benefit of the homeowner in terms of insulation, cost and indoor comfort and how can it contribute to the energy transition of the built environment?

Different roads to 2050 are given as an example with different interventions regarding insulation and heat pump system choices, so that the building owner can form an image for himself which total costs of ownership different interventions entail over an longer period.

The research showed that insulating first if energetically necessary and only then applying a heat pump leads to the highest cost reduction over a long period of time, this is made clear to the homeowner through the tool.

The homeowner is also informed by means of examples that insulating leads to a higher indoor comfort because surface temperature differences reduce.

Insulating also leads to the greatest reduction in primary energy required for heating, which has the greatest positive impact on the energy transition and leads to the greatest reduction in CO_2 emissions. Only when the insulation is in order does the heat pump system provide an additional reduction in primary energy and CO_2 emissions. This is passed on to the building owner through the advice of the tool.

Research part 3: 'Research by design'

How is the heat pump decision tool designed?

Step 1: The energetic quality of the home must be determined, to verify whether the home is energetically ready for a heat pump system or whether it needs to be insulated first. This first indication is done on the basis of the construction year of the home, certain construction methods and insulation values are associated with the construction year and therefore an estimated energy label can be linked to that.

Step 2: any post-insulation is determined by means of the current energy label of the building, which in many cases can be requested from an external online database. The energy label can be used to estimate the energetic state because the label includes all insulation values of the building envelope. This is a relatively easy way for homeowners to quickly find out the current energetic state of their home. It could be the case that there is no energy label included in the online database for the relevant home. A second possibility is to estimate the energy label linked to the energetic state of the home based on the gas consumption of the home. However, because the theoretical gas consumption of a certain energy label can differ from the real gas consumption, it is in some cases necessary to verify the assigned energy label based on gas consumption by checking whether certain building envelope parts are indeed insulated belonging to the assigned energy label based on gas consumption.

Then the home can energetically fall into the following label categories: '(E-G)': no (hybrid) heat pump applicable, first insulate building, or '(C-D)': hybrid heat pump is probably applicable, or '(B or lower)': all electric heat pump is probably applicable.

The homeowner is at this stage in the process of the tool provided with extra information about the facts that extra insulating his home towards the best label category '(B or lower)' results in the most benefits in terms of costs over an longer period of time, comfort, and the biggest contribution to the energy transition of the built environment. But in case the homeowner's home falls in category '(E-G)' he can also choose for the lowest investment costs and only insulate to label category '(C-D)' in order to be energetically ready for a hybrid heat pump.

Step 3: If necessary, the homeowner can now find out which specific insulation measures he must apply: roof, walls, windows, floors in order to end up in a certain label category to be able to apply a certain heat pump.

Step 4: The homeowner must then indicate which emission system is present in the home: underfloor heating, underfloor heating + radiators, radiators. The homeowner also receives advice on whether insulating the building resulting in energy label jumps or without insulating the building and remain at the same energy label requires to adjust the heat emission system. The advice can vary from: keep original radiators, install add-on fans, install low temperature radiators, install underfloor heating.

Step 5: The homeowner is shown various images of the outdoor spatial aspects required for different heat pump systems. On the basis of yes/no questions is determined which (hybrid) heat pump systems are applicable based on these outdoor spatial aspects.

Step 6: at his final step the homeowner is shown various images of the indoor spatial aspects required for different heat pump systems. Based on questions about whether the space is available, the tool determines which specific heat pump systems are applicable based on the indoor spatial aspects.

How is an heat pump decision tool for home-owners with limited technological knowledge designed, which gives an advice that contributes to the energy transition of the built environment, and which provides an advice on which heat pump system and additional measures a home owner should consider before engaging an installer?

A generic design for a heat pump decision tool for home-owners is challenging as each building has its own characteristics/energetic quality, its own heat emission system, and different spatial aspects. By researching different renewable energy options was found that renewable electricity in combination with a heat pump system leads to the biggest contribution to the energy transition of the built environment. The tools advice is based on these findings. Next to that was found that insulating the home according to the new insulation standard will contribute to the biggest reduction in CO2 emissions and electricity needed before applying a heat pump system and next to that it boosts the homes indoor comfort. All these findings are built into the final tool in form of an educational feature with all the measures a homeowner needs to consider before installing a heat pump system.

In addition, the analysis of existing tools showed that the energetic quality of a home is relatively difficult to determine for a home owner with limited technological knowledge. Insulation thicknesses often had had to be entered manually, which is not always easy to figure out for the homeowner. So it was decided to base the final tool on energy labels and/or gas consumption in order to find out the energetic state of the home in a simple way. In addition, improvement measures are shown in the field of insulation if it appears that the energetic quality is not sufficient for a heat pump. This way the homeowner gets an idea of the building parts that he still needs to insulated and he can search for a contractor to do this in a more targeted way. Subsequently, the heat emission system and spatial aspects are tested in a relatively simple manner, using flow diagrams and images, both indoors and outdoors so that the homeowner knows what to expect and he can specifically search for an installer who will then adjust the emission system if necessary or select and install a heat pump selected based on the spatial aspects. The tool is based on literature, information from various websites and own findings. However, the ultimate usability would have to be tested with building owners and installers to verify or improve the operation of the tool.

Discussion

Limitations of the research:

Advice

The tool provides the building owner with all the necessary information with the best choice regarding a heat pump system based on insulation, living comfort, cost savings and contribution to the climate. The tool tries to convince the home owner with examples to follow these advices. Ultimately the homeowner has to find an installer himself who will install the insulation and/or heat emitter and/or heat pump system indicated by the tool. It may of course be the case that that the installer has other ideas, for example, in case he is not familiar with the system, or he finds for example the insulation values excessive. Then the problem can arise that the home has to be tackled again in the future, because the advice of the tool was not followed. A possible solution for the limitation could be to have this tool reviewed by some of the leading major installer companies known by the homeowners. And by advertising with this, the confidence of the homeowner in this tool can be won so that they actually follow the advice of the tool.

Comfort

Comfort is in this research only mentioned in the sense of temperature differences between surfaces. But there are many more aspects that can be counted under comfort and added to the heat pump decision making tool. In the part of the tool where the heat emission system is tested, it is also assumed that the home owner wants to maintain the same indoor temperature and thus comfort. But research could also be done on whether people are satisfied with a slightly lower indoor temperature for a small part of the year, so that the heat emission system does not have te be adjusted at all.

Building type

The first idea was to make the tool applicable to all building types. Ultimately, this was reduced to only ground-level homes because each type of home entail additional parameters. Flat and apartment buildings benefit more from a collective approach (chapter 4.1) in combination with a district heating system, but this thesis focussed only on the individual approach. In the future the tool could be extended with more housing types. To do so, it would have to be investigated whether individual systems can offer a solution in apartment buildings or flats. The noise of an air source heat pump will probably cause many problems. On top of that there are no individual gardens available for a ground source heat pump, and it is wiser to make 1 large collective ground source. That way small multiple sources do not interfere with each other. In addition individual PVT systems will also be a burden because not every induvial can claim a piece of roof on an apartment building or flat.

Heat pump systems

The research focuses mainly on existing and proven applied heat pump techniques. Other new innovative systems could also be added to the tool. The new heat pump techniques may only be added to the tool if the supply temperature is 55 °C or lower, in order to promote further insulation of the built environment. In addition, new heat pump techniques may only be added to the tool if the SCOP is better than the systems already included in the tool. If the SCOP were significantly worse, they should not be added to the tool because then the goal of the tool (having a major contribution to the energy transition) will be neglected by adding less performing heat pump systems. Initially, the idea was also to make recommendations in the field of heat pump product innovations. It was ultimately decided to delete this part from the thesis because otherwise it would be too large a study. A part of the functioning of existing (hybrid) heat pump systems has been investigated as in appendix 3. These findings and information could be used for another research in the field of heat pump product innovation.

Excel/Energy label

Initially the idea was to make an excel file for the heat loss calculation in order to define the energetic quality of the home, this excel tool was completed at the previous P4. This excel file was actually a heat loss calculation, the user had to fill in all the heat loss areas including each Rc-values. In addition the user needed to select the infiltration rate and the ventilation system. Next to that the user had to fill in the areas of the radiators. Whit all this information the excel file could calculate for each outdoor temperature with which temperature the supply water of the radiators could be lowered. And whether a hybrid heat pump or all-electric heat pump could be installed with the existing radiators. In addition the excel tool calculated the expected energy costs of various heat pump systems based on the energy usage related to the supply water temperature and the source temperature and the COP. But this tool turned out te be far too complicated for the purpose I wanted to achieve.

So in order to make it more user friendly for the homeowners was decided to make use of the energy label in order to define the energetic quality of the home. Ultimately, the detailed heat loss calculation will be made by the heat pump installer, in order to dimension the right size heat pump.

The part in the excel tool in which the total energy and usage costs were exactly calculated were eventually built into the final tool in a different more abstract but clearer way as described in (chapter 7). It is made clear to the homeowner which steps he must take in order to get to the lowest costs. It is also made clear that that interventions with the lowest investment can ultimately lead to higher costs. But the final tool compared to the excel tool at the previous P4 no longer talks about exact costs, but only what actions lead to certain costs higher or lower.

However in the final tool the energetic quality within the same label can differ per housing type. The difference in the final tool remained limited because it concerned only ground level homes. But if other building types will be added to the tool in the future it must be investigated whether the energy label can continue to be used in the same way to test the energetic quality of the home, in order to assign a specific heat emission and heat pump system. After all an installer will perform an detailed heat loss calculation in order to apply the right heat pump size. The tool only makes an informed estimate based on the energy label of the home.

The tool can actually be used in the future for different home types as long as the homes comply with the insulation standard as described in the tool. In fact, a simple way should be added to the tool that can be used to check whether a particular home meets the insulation standard. For example, it could be investigated whether the energy label meets the insulation standard for each type of the home. Or it could be investigated in another way how the tool can easily check whether a home meets the insulation standard.

Recommendations for further research:

Survey homeowners

The tool could be tested by different homeowners. A survey could be continued about the tool, which could further improve the tool from the homeowners point of view.

Heat pump installer

The tool is based on existing information gathered and interpreted by me from many different sources. Still, it would be of added value to have various heat pump installers with a lot of expertise in the field to have a look at the tool. Their expertise could be of valuable addition to improve the tool in various areas.

Generating electricity

It is assumed from preliminary research that the electrical energy will be generated sustainably in the future. But a plugin could also be added to the tool that indicates how to make the home zero-energy. So that homeowners do not have to wait for national changes in the field of electricity generation, but can immediately realize a self-sufficient house related to space heating.

Heat emitter

The research mainly focuses on the capacity of the heat emitter at certain supply temperatures to heat the home to an comfortable indoor temperature. But research could also be done onto different comfort properties per heat emission system. For example even heat release or rapid temperature release.

Product innovation

As indicated in the discussion, a lot of extra information is included in the appendix about the operation and boundaries of existing heat pump systems. This information could be used to conduct a study into product innovation in the field of heat pumps.

Reflection

How is your graduation topic positioned in the studio?

The topic of this master thesis is the design of a heat pump decision tool for homeowners that contributes to the energy transition of the built environment and the benefits of the homeowner in terms of cost and living comfort. The master studio Building Technology encompasses a broad spectrum of engineering and architectural skills that lead to one of the dominant professions of the future. The topic is mostly related to the climate design of the studio. The outcome of this thesis can lead to a built environment with buildings which are sustainable, comfortable and environmentally intelligent.

How did the research approach work out (and why or why not)? And did it lead to the results you aimed for? (SWOT of the method)

Looking back on the progress of this thesis so far, I found out that in the beginning I actually didn't know at all what drafting a research entails and what a thesis actually entails. Fortunately, I chose a topic that I find interesting in every way from start to finish, which gave me the motivation to keep working on it and to put in the hours that made me little progress every time. Only in the beginning I had a lot of trouble defining the research, I had researched many things in different word documents without a clear plan. I started very late to put everything together into one clear story, which made me doubt about the things I had researched, which caused the stress level to increase and increase, in a way that I lost overview. Eventually my research gradually started to gain more structure, so that I regained confidence which also ensured that the stress decreased so that I regained overview and positively influenced working on it.

The linear approach of the research led to new insights every time, which meant that the approach was continuously adapted. At the time of my first p4 is was satisfied with the research in terms of depth on the subject, but I was not completely satisfied with the story of the report. I would preferred to have worked out the tool by the previous p4 but unfortunately that didn't work out.

After I was told that I had to do a retake because the tool was not there, I immediately started building a tool. After all, I had almost all the information available due to all the research performed. But again I went a little too hard with developing a working online tool. At a certain point the tool was finished and working, then I started writing the thesis again to substantiate all the steps in the tool. This made me realize that certain decision moments had to be shaped differently. As a result, the tool is now fully available on paper as written in this thesis, but the graphical online variant has to be adapted again according to the written variant. There is still time up to P5 to also make the online tool corresponded to the written variant so that both the research report and the product are completely finished.

I now understand why a study program is finalised with a thesis. It is the ultimate learning experience about the field in which I certainly want to work after finishing. I learned a lot about the intricacies of the subject and writing the thesis itself just by doing and putting in the work. In addition, it has also learned a lot about myself, so far I have encountered myself a few times because of the uncertainties, but lately I have been able to work on it more clearly without stress. It certainly prepares me for the next step in the future.

How are research and design related?

The design of the heat pump tool is based on literature study, and looking into actual systems and applications of heat pump systems and already existing tools. By gaining more and more knowledge during the project more and more building blocks for the tool are collected, with which the final tool can be built. Every design decision moment in the tool is based on research.

To what extent are the results applicable in practice?

Heat pumps are a hot topic in daily news. This tool provides the building owner insights into the choices regarding such system.

To what extent has the projected innovation been achieved?

The analysed weaknesses of the existing tools are tackled in the final tool. This new tool is in many areas much more in-depth than the existing tools in the field of energetic quality, heat emitter system and spatial aspects. By using this tool, the homeowner gets all the necessary information that he certainly does not when using the existing tools on the market.

Does the project contribute to sustainable development?
This tool does definitely contribute to sustainable development, I saw today a news message that heat pumps are mandatory from 2026. The message states that more installers are being trained to install heat pumps. But this project makes it clear to the home user that an integrated approach with insulation has many advantages, before contacting a heat pump installer.

What is the relation between the project and the wider social context?
A wider social context related to this project is the social sustainability it measures the humans welfare. And in contributes to the humans welfare by improving the living comfort and reducing the living costs.

How does the project affects architecture / the built environment?
This project helps to turn the built environment into a sustainable built environment in terms of space heating

Appendix 1

Heat pump application in existing building renovations

Stroomversnelling:

The Netherlands started with 0-energy housing renovation schemes. The program was supported by the government to support social housing corporations to renovate their building stock to 0-energy buildings. The program is called 'stroomversnelling' which means flow acceleration. It all started with 6 housing cooperations and 4 building consortia to start a pilot retrofitting existing houses to 0-enrgy houses. The idea was to upscale this pilot to neighborhoods with 1000 houses (Rovers et al., 2017).

The program set high ambitions, aiming at what is now called NOM houses (NulOpdeMeter) or (zero On the Meter). The energy generated includes also the production of electricity for household use and not only building related energy. This makes the roof surface a critical parameter, since the area should produce all the household energy on a yearly basis and the electricity needed for the building related energy. Therefore the heat demand has to be brought to a very low level, so that the roof space for PV panels can be used to power the household appliances. The main equipment for heating is a heatpump, air to air or air to water. After the first pilots of 'Stroomversnelling' it became almost a standard to have a heating and ventilation installation brought together in a building extension placed outside the dwelling (Figure 77). This has a positive effect on the size used inside the houses and no need to enter the houses to install the installation. But there are still some problems, the process needs to be more efficient, the costs need to reduce and there needs to be developments of new installation devices, in a way that the whole installation can be placed in one compact unit (Rovers et al., 2017).

Figure 77. Heating and ventilation installations brought together in a building extension placed outside the dwelling.

Pilot nieuw Buinen

Building envelope improvements	Building services	Problems
Heat demand has to be brought to a very low level	Air to water heat pump in an extension outside the building	Process was inefficient
		Costs need to reduced
		Building services size needs to be reduced in a way that the total

		building services can be placed in one compact unit

Wold en Waard

There was an expectation that due to upscaling of NOM projects the cost would reduce. But the due to the price increase in the building sector the prices for the renovations went up too. Therefore a lot of corporations decided to stop with 0-energy renovations, because they are not viable. 'Wold en Waard' has stopped after their pilot with NOM-renovations, but continuous to build new NOM-houses. New buildings are just viable, renovations are not. For renovations they take on step back, that results in no external added facades, but insulation in the existing façade. On top of that are less pv panels placed and is there chosen for a hybrid heat pump system instead of a full all electric heat pump (van der Schoor, 2020).

Building envelope improvements	Building services	Problems
External added facades	Full electric heat pump (too ambitious)	External added facades were too expensive
Insulating existing facades was a more viable option	Hybrid heat pump	Full electric heat pump was too ambitious for renovation
	Hybrid heat pump system was a better cost effective option in renovation	

Woonborg

Woonborg a different corporations has also stopped renovating buildings to NOM. Woonborg uses an easier way of renovating till energy label B nen7720. By applying mechanical ventilation and pv panels the energy labels can be reduced to level A. According to Woonborg we need to wait for affordable heat pumps which run on a higher temperature (80 degrees) at an acceptable energy usage (van der Schoor, 2020).

Building envelope improvements	Building services	Problems
No envelope improvements	Applying mechanical ventilation and pv panels to reduce the energy label, but this does actually not improve the energetic performance. (Woonborg)	High temperature heat pumps at an affordable price and with an acceptable energy usage need to be developed (Woonborg)

'Stroomversnelling' Ballast Nedam Nul op de Meter (NOM)

The construction company Ballast Nedam also performed a Zero on the Meter renovation. (Brinksma, 2017) did research on the measures that were taken by the construction company to make the building Zero on the Meter (Figure 78). But (Brinksma, 2017) did not talk about the problems which occurred after the building was up and running for a while. The problems became clear after reading a article from a trade journal called FluxEnergie for the energy sector (Redactie, 2016). All the findings are enumerated below (Figure 2).

Figure 78. Ballast Nedam Zero on the Meter renovation

Building envelope improvements	Building services	Problems
Façade: prefabricated insulated facade elements are placed against the front and back façade to increase the thermal capacity. The RC-value for the new façade is 5 m2.K/W. The piping for the new installation is placed inside the façade elements.	PV panels are applied on the roof.	The renovation took 3 months instead of the announced 10 days.
Roof: Pre-fabricated roof elements with pv panels and piping incorporated is placed on the house. Total value of the new roof is RC 6 m2.K/W.	An installation unit is placed on the attic. The unit includes a heat pump, heat recovery unit, a	The system blows cold air into the dwellings.

	boiler, a converter and control technology. It's easy to install this unit at once.	
Windows: The prefabricated façade elements contain plastic window frames with triple glazing.	The gas connection is disconnected, the energy needed is generated by the heat pump and solar panels.	When the outside temperature is too cold the house is at an uncomfortable low temperature inside. There is extra heating needed in form of kerosene heaters and electric radiators.
Extra insulation: The crawl space and the loft floor are extra insulated.	The piping is incorporated in the prefabricated roof and façade elements	The total building services system makes a lot of noise.

Housing corporation 'Woonwaard' in combination with construction company BAM participating in Stroomversnelling

The housing corporation Woonwaard had 200 70's homes transferred to zero on the meter homes (NOM renovation). This was all part of the project 'Stroomversnelling' ("Project stroomversnelling Heerhugowaard Interduct," 2020). The following figures:(Figure 79), (Figure 80), (Figure 81), (Figure 82) illustrate how the transformation was performed.

Figure 79. Woonwaard NOM renovation, Building services in extension

Figure 80. Woonwaard NOM renovation, envelope renovation

Figure 81. Woonwaard NOM renovation, new ventilation piping + old connections natural gas boiler still visible

Figure 82. Woonwaard NOM renovation, piping

The façade and roof insulation was performed with prefab elements from the outside with both a insulation value of Rc 5,0. The glazing was changed into triple glazing, and the crawl space was insulated with chips to an insulation value of Rc 4,0. (Borsboom, Leidelmeijer, de Jong, & Kerkhof, 2016).

The building services containing a mechanical ventilation with heat recovery an air-to water heat pump with boiler were placed in an extension outside the building (Figure 79), this was done for space saving and maintenance.

The piping was mostly hidden in already existing shafts. And solar panels were added to cover the electricity usage (Borsboom et al., 2016).

But according to the document 'residents experiences and measurement results from zero on the meter houses in Heerhugowaard' there were positive findings but also some problems after a while, the problems according to the document are listed below. The positive things mentioned by the residence are: comfortable indoor temperature, no draught, less noise from outside (Borsboom et al., 2016).

Building envelope improvements	Building services	Problems
Façade externally improved to Rc 5,0	Mechanical ventilation with heat recovery	Complains about finishing installation parts
Roof externally improved to Rc 5,0	Air source heat pump with boiler	There were some start up problems with the heat pump
Windows improved to triple glazing	Solar panels	Some residence complained about the noise produced by the new building services system
Crawl space insulated to Rc 4,0		

Duravermeer NOM renovations 'Stroomversnelling'

Duravermeer was the first construction company who transformed dwellings to zero on the meter as part of the 'stroomversnelling' agreement. These first dwellings were located in Presikhaaf a district in Arnhem ("De Arnhemse wijk Presikhaaf,"). The following figures illustrate the renovation: (Figure 83), (Figure 84), (Figure 85), (Figure 86).

Figure 83. Presikhaaf NOM, left after and right before renovation

Figure 84. Presikhaaf NOM, before and after renovation

Figure 85. Presikhaaf NOM, prefabricated facade panel with incorporated piping

Figure 86. Presikhaaf NOM energymodule

The construction year of the buildings are from the 50's, 60's & 70's. The façade was improved with a pre fabricated vapor open Unidek SIPS element to an of Rc 7,0 with integrated ventilation canals and finished with gypsum ore stonestrips, bolted with a steel support to the existing concrete foundation. The roof was also insulated to a to an Rc of 7,0 with pre fabricated wooden roof panels applied on the existing roof decking. And the crawl space was insulated with Neopixels. Also the existing cavity wall is insulated with Knauf Supafill glass wool flakes to prevent cold traps. The building services are placed in an so called energymodule outside the building containing a air to water heat pump which provides domestic hot water and space heating. The balanced ventilation system and the power converter are also placed in the energy module (Verwoolde, 2017).

According to the document ‘experiences in presikhaaf and malburgen, Arnhem’ there were some problems with the zero on the meter transformation. Renovations with a completely new shell are very expensive and not whether hardly afforded by homeowners. And on a small scale these renovations also bring few cost benefits. But on the other hand if zero on the meter renovations are carried out on a large scale, it remains still a significant investment for the home owner ("ERVARINGEN IN PRESIKHAAF EN MALBURGEN, ARNHEM,").

Building envelope improvements	Building services	Problems
Façade insulation externally upgraded to Rc 7,0	Air to water heat pump outside the building in a so called energy module	Total shell renovations to expensive for home owners
Roof insulation externally upgraded to Rc 7,0	Balanced ventilation system placed in energy module outside the building	
Crawl space extra insulated	PV panels on the roof	
Existing cavity extra insulated with flakes	Power converter in energy module	

Alliantie + & DSH architects 10 private homes zero on the meter renovation

A group of 10 residents in corporation of a architectural firm and a construction company transformed 10 dwellings from the 60’s to zero on the meter dwellings (Figure 87), (Figure 88). The label of the building changed from G to A++ after renovation. The facades insulated was improved with pre-fabricated panels, and with personalized window frames chosen by the residents. The building got a new roof with extra insulation and also the crawl space was insulated. The building services costed 1/3 of the total renovation costs including a ground source heat pump with solar panels and a balanced ventilation system with heat recovery (Alliantie, 2017).

Figure 87. 10 private homes before renovation

Figure 88. 10 private homes almost finished renovating

Building envelope improvement	Building services	Problems
Façade insulation improved with prefabricated panels Rc value unknown	Ground source heat pump	Unknown
Roof insulation improved with a unknown Rc value	Solar panels	
Windows improved with a unknown Rc value	Balanced ventilation system	

Private home Den Bosch zero on the meter renovation

The client already had some ideas to improve the buildings insulation value. They wanted to place exterior wall insulation. The client already filled the cavity with insulation. But the renovation team told that it's probably not a good idea because there is a change of a false air cavity which is a space between the insulation and the inner cavity leaf which could cause convection streams, with leads to energy losses (Diersen, 2018).

The renovation team mapped the energy distribution of the building with a thermal camera (Figure 89). The cavity insulation fall towards the neighbours, which leads to thermal losses. Normally a secretion made within the cavity prevents the insulation from falling towards the neighbours, but in this case it didn't (Diersen, 2018).

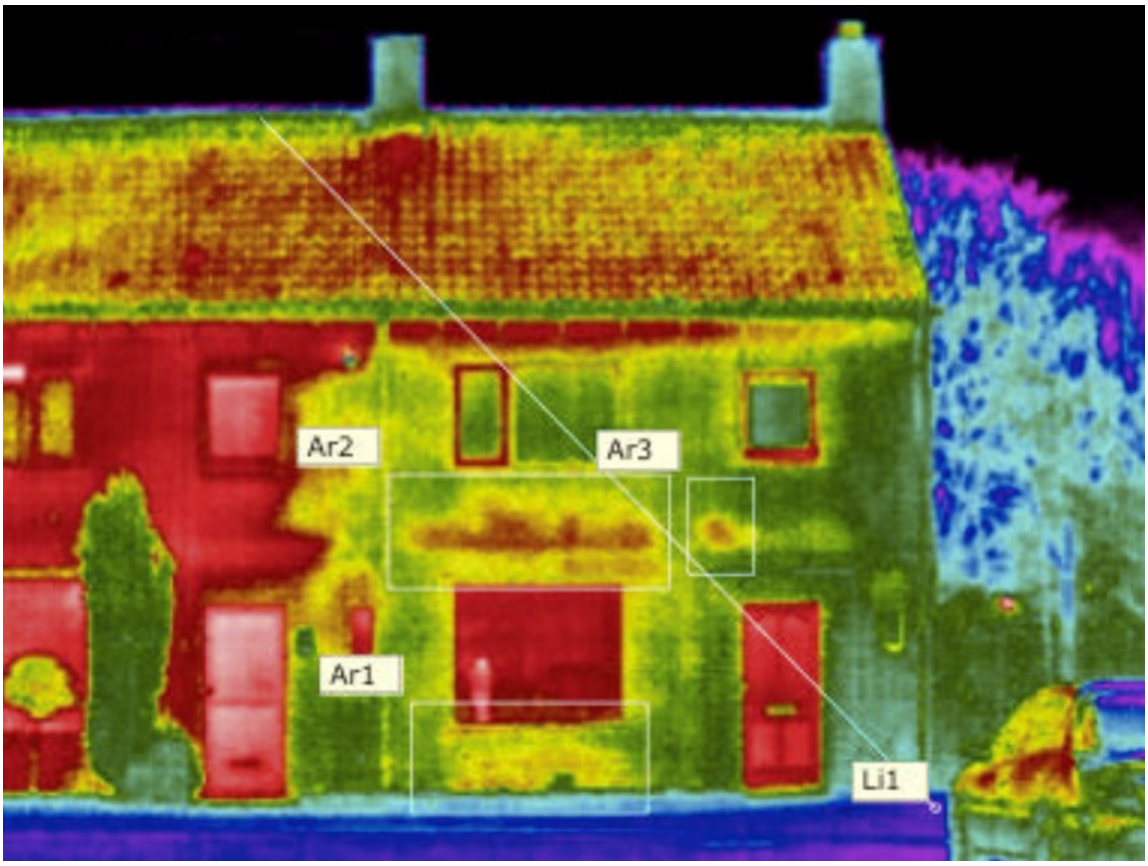


Figure 89. Private home Den Bosch NOM thermal camera

The renovation team came up with the idea to demolish the outer leaf (Figure 90) and replace it with 310 mm EPS insulation with graphite layer. This insulation is on the front façade finished with stone strips and on the side façade with gypsum. The new Rc value of the façade became 9,55 (Diersen, 2018).

Figure 90. Private home Den Bosch NOM outter leaf demolished

The floor was planned to be insulated with 70 cm Argex granules. But the Argex was not registered in EPA, and because of that the clients would miss out on the insulation grants. In the end there is chosen to fill the crawl space with soil (from the excavation of the extension), than add XPS insulation and then poor a concrete floor. Around the existing foundation edge insulation (30cm xps) is placed to prevent cold bridges with the new concrete floor, this way the Rc value of the floor became 8.62. The building got a new roof with a Rc value of 9.55 (Diersen, 2018).

Heated ventilation air was the initial idea. Balanced ventilation system with heat recovery and electric reheating (Figure 91). DHW is provided by a solar water heater with buffer, with 4 solar panels. For the electricity needed: 16 solar panels are placed, facing south and east (Diersen, 2018).

Figure 91. Private home Den Bosch NOM balanced ventilation system

Heating with only ventilation air is possible if the heat demand does not exceed 10 Watt per m2 on the coldest day of the year. But the calculations gave a demand of 15 Watt per m2 this resulted in extra electric heating, which would exceed the energy generated with solar panels. So this option was turned down. A better solution was to change the 4 solar collectors by normal pv panels and use an electric heater for showering (Figure 92). This resulted in enough electricity to be zero on the meter (Diersen, 2018).

Figure 92. Private home Den Bosch NOM electric heater for showering

Building envelope improvement	Building services	Problems
Facades improved to Rc 9.55	Heated ventilation air + extra electric heating	Initial idea was only heating with ventilation air but a heat loss calculation resulted in additional electric heating
Roof improved to Rc 9.55	Solar panels for electricity	
Floor improved to Rc 8.62	Electric heater for showering	

Summary:

In this chapter are a total of 8 renovation cases analysed. 5 of the 8 renovation cases are executed with a air to water heat pump, this is by far the favourite choice in the analysed renovation cases. In all of the cases was the envelopes insulation value upgraded so this is a must in case of applying a air to water heat pump. The upgraded insulation value varies between a minimum Rc of 5.0 to a maximum Rc of 7.0 in combination with an air to water heat pump. The most occurring problems with an system with an air to water heat pump were that the system took up too much space and made too much noise for the inhabitants. A ground source heat pump was only applied in 1 renovation case, and a ventilation heating system also only in 1 case these options are not popular. A lot of these NOM renovations were performed by housing corporations, because the total envelope renovations have a high costs and it’s not affordable for the private owner. Even the housing corporation Wold en Waard mentioned that it was not affordable for them to perform a full zero on the meter renovation and that a smaller renovation with a hybrid heat pump system would be a better option.

Appendix 2

First tool analysed:

https://www.milieucentraal.nl/energie-besparen/duurzaam-verwarmen-en-koelen/volledige-warmtepomp/

General analysis

Description	'milieucentraal warmtepomp check' indicates whether a owned house or a rented house is already suitable for a heat pump. The tool also advices which heat pump type suits the best to the house. The tool shows which costs this new heat pump system saves. And the tool will also tell you what changes you need to make to your home to make it suitable for a heat pump.
Supporter	Milieucentraal
Type	Online clickable tool
Link	https://www.milieucentraal.nl/energie-besparen/duurzaam-verwarmen-en-koelen/volledige-warmtepomp/
Purpose	Informing home owners on a well understandable manner what heat pump options are available for their home or what changes need to be made in order to make their home suitable for a heat pump system
Vision	Vision mileucentraal cited from their website: , Milieu Centraal is an information organization with the mission of 'helping consumers make sustainable choices'. There are many websites and online forums for consumers with information about sustainable living. The Milieu Centraal information organization distinguishes itself with independent, reliable and practical information'
Function	Informing home owners to accelerate the energy transition
Date online	?
responsible person	?

Theme 1: User

Characterization

Who is the user of the tool?	
Individual	Home owners & tenants
For which building type does the tool function?	
Residential homes (distinction in type?)	Terraced house, corner house, detached house, semidetached house, ground floor apartment (without roof), upstairs apartment (no ground floor), apartment in a building with 3 or more residential units
Non-residential homes (distinction in type?)	No, choice
No distinction in building type	
Does the tool provide calculations and services?	The tool uses user input for calculations
How does the tool know what type of user it is dealing with?	The user of the tool has to choose whether he is a home owner or a tenant

Information exchange

What does the user get from the tool?	
Info	- Results of your home: insulation level, available space for heat pump. - explanation about a low temperature delivery system and a link to the 50 degree supply temperature check. (https://www.milieucentraal.nl/energie-besparen/energiezuinig-huis/wonen-zonder-aardgas/50-gradentest/) - Prices for a low temperature radiator system - Total investment costs - Annual savings - explanation about the expected energy costs in 2030 for the calculations - link to more information about the operation of a heat pump system (https://www.milieucentraal.nl/energie-besparen/energiezuinig-huis/energiezuinig-verwarmen-en-warm-water/volledige-warmtepomp/) - link to heating test (https://www.milieucentraal.nl/energie-besparen/aardgasvrij-wonen/verwarmingstest/)
Advice	- Not enough room in the garden, therefore air source heat pump. - Heat pump type - costs

	- grants - gas savings - extra electricity usage - savings CO_2 emissions - savings energy costs - keep in mind the plans of the municipality, they need to have a heat plan - alternative system in case the municipality plans to make a heat network - the alternative system is a hybrid heat pump system - upgrade advices for the glass types - upgrade advices for insulation level
At what level does this advice come?	
Personalized	personalized advice for heat pump selection and building envelope and glass upgrades based on user input
Generic	- municipality plans - different links to more information - explanation of low temperature delivery system
On which theme does the advice succeed?	
Energy-saving measures	- gas savings - energy cost savings
Renewable energy sources	- heat pump systems
How much interaction time (with tool) is needed to receive advice?	5 minutes
The tool provides information that:	
Can be obtained by querying the internet	- heat pump system costs - grants
Complementary to information on the internet	
Unique compared to information on the internet	Underlying calculations determine the energetic quality of the house
What makes the tool unique in terms of making information available?	The tool is made by an independent foundation which ensures honest advice
With every update	Calculations take into account the expected energy prices – support investment decision
Ambiguities in the tool	Some questions are asked in a way that the user might answer them wrong. - the question asked what is the level of the insulation of the outside walls, a answer could be: not applicable because I have neighbours left and right, but then still you have 2 outside walls in the front and back. - The glass type of the living room is asked, but the answer could be different in case of a

	conservatory or extension next to the living room. - Exterior space for the air source heat pump may be available, but could not be allowed because of the VVE (association of owners).

Usability calculations and data

What is the accuracy of the advice provided by the tool?	
Exactly	Heat pump system, costs based on one-off investment costs, savings on energy bill with expected energy prices in 2030
Building approach	Energetic performance is based on user input, and insulation changes advices are based on calculations performed by the tool
Higher spatial level approach	User needs to take into account the municipality plans
The key figures and parameters used that apply to the type of building, family, and district are:	
Personalized	- buildings insulation value (user input) - gas usage (user input) - insulation value (user input)
Averaged for specific user types (based on input data)	Energetic performance is based on underlaying tables and formulas dependent on insulation and building types
Average without distinguishing user types	Heat pump prices are based on type (air-source, ground-source) and not based on size so just average pricing
What type of data is provided by the user?	
Energy performance: consumption and production	Amount of showers and baths taken
Socio-economic key figures	Amount of residences
Building related information	-Construction year - insulation values for roof, walls, windows, floors
Spatial information	- heat pump installation location

Theme 2: Owner tool

Objective of the owner of the tool:	
Providing information to the private individual/consumer/user	Provide information to homeowners on which sustainable heating system is available to accelerate the energy transition in the Netherlands
Investment interest in specific renewable energy sources	Heat pump system
Investment interest for specific energy saving measures	Improving insulation and glazing
Existing policy for evaluation	Aim for gas free building stock
What the tool advises on (triad):	
Limit energy demand	Improve insulation and glazing
Use sustainable energy sources	Use sustainable heat source (heat pump)

Theme 3: Domain technician (Clymans., et al. 2019)

assessment advice

Which technologies are covered?	Air source heat pump, ground source heat pump, hybrid heat pump
Following criteria are used in the assessment of technologies?	
quantitative	
Energy/heat production	kWh annual for electricity (heating), gas (heating)
Investment cost	In euro's
Payback period	In Years
Costs avoided	Annual savings in euros on energy bill
Avoided environmental impact	CO_2 reduction
Avoided emissions (x less CO2 emissions)	Total kg per year

Clymans., et al. 2019 didn't use any qualitative data in the analysis. But for my thesis the qualitative criteria is important, that's precisely what makes a specific tool outstanding compared to the rest. Therefore the following qualitative elements are added to the domain technician criteria:

Spatial aspects	
Indoor spatial aspects for building services	Available space next to existing gas boiler,
Outdoor spatial aspects building services	- Available space for outdoor unit with examples: the unit looks like an airco and the available spaces are for example: on a flat roof, on a balcony, against the rear façade close to the ground, or in the garden/ garden shed. - Available space for ground source: big garden reachable for trucks

The following elements are made by Clymans., et al. 2019:

Technologies are assessed/advised via cost-benefit as	Mixed solution

Availability technologies

Including technologies that exceed investment capacity home owner	no
Availability of technologies is determined by	Not addressed

Theme 4: Data availability (Clymans., et al. 2019)

Data Policy/Accessibility

The tool uses the following data types (including owner and spatial level):	
Databases: Declarations, certificates, permits, registrations	Construction year: BAG viewer (https://bagviewer.kadaster.nl/lvbag/bag-viewer/#?geometry.x=160000&geometry.y=455000&zoomlevel=0)
Spatial data layers	
Research results: Key figures, parameterization	Algorithms are used to convert personalized input data to a specific heat pump advise

Measurements: Energy production and consumption data,…	Gas consumption (user input), gas consumption based on averages for housing type if no user input
Static	Parameters stay the same as programmed in the tool, unless the tool gets updated
Dynamic	Different expected energy prices
The tool includes a disclaimer for:	
Accuracy data	Energy prices
Source data	Privacy
Not	No information about underlaying formulas or key figures
Text warning	If you have answered 'I don't know' for one or more insulation questions, we will calculate with the minimum insulation that your home type should have had during construction.

data management

The tool is:	
Independent (stands alone)	yes
Dependent on other tools	no
Depending on other models	no

Theme 5: Domain and scale level (Clymans., et al. 2019)

At what scale level does the tool function	
Building	Only building
At a higher scale level, the tool makes use of	Municipality plans
There is a direct link with the following policy areas:	
Climate	Connection with energy transition in nl

After the analysis the strength and weaknesses of all the tools will be explained. The strength and weaknesses will be explained according to the five themes in the same way as performed by Clymans., et al. 2019.

	Strength	Weaknesses
Theme 1: user		
Characterization	The home owner is the user of the tool and is central to the tool	Office owners and thus office buildings are left out
Information exchange	The information the tool needs is questioned in a way that people with little knowledge can answer the questions and provide the needed data for the underlaying calculations of the tool.	Because of the simplicity of the questioning the underlaying calculations cannot be very detailed due to the lacking information. For example the energetic performance remains an indication. - no pictures of actual systems
Usability calculations and data	Advice takes into account the rising energy prices and the received grants which supports the investment decision. If the user for example doesn't know the insulation level of his building, the tool will use the standard insulation value for the construction year of the building.	The energetic performance of the building is not expressed in a number. So the user of the tool doesn't actually know how well it's building performs before choosing a sustainable heating system.

Theme 2: Owner tool	Focus op home owners, easy accessible free tool for all home owners	
Theme 3: Domain technician		
Assessment advice	The grants for a specific system are shown in the advice, which encourages the home owner to install the system.	Limited choice of alternative sustainable systems. Heat delivery systems remains underexposed. The spatial effects of the new heat pump system and buffer remains underexposed. Outdoor noise of heat pump is not addressed.
Availability technologies	Most common systems in the Netherlands are used in the tool. Hybrid heat pump, air to water heat pump, water to water heat pump (ground source)	Other potential techniques are not used in the tool such as solar collector heat pump or surface water heat pump.
Theme 4: Data availability		
Data policy/accessibility		Adjustment of algorithms or further personalization advice not possible
Data management	Independent foundation no advice preference	no parameterization update to reflect current building state
Theme 5: domain and scale level		

https://www.samangroep.nl/keuzehulp-warmtepompen/

Description	Based on the user input, a product recommendation is generated from all the heat pumps supplied by the installation company
Supporter	Saman group (InstallQ recognized installer)
Type	Online clickable tool
Link	https://www.samangroep.nl/keuzehulp-warmtepompen/
Purpose	Provide costumers an overview of which heat pump systems installed by samangroep are applicable for their specific building
Vision	Convince home owners that samangroup always has a heat pump solution for their home
Function	Informing and convincing home owners to sell more products

Theme 1: User (Clymans., et al. 2019)

Characterization

Who is the user of the tool?	
Individual	Home owners, tenants
For which building type does the tool function?	
Residential homes (distinction in type?)	Apartment, terraced house, corner house, semi-detached house, detached house
Non-residential homes (distinction in type?)	No, choice

Does the tool provide calculations and services?	The tool uses user input for calculations
How does the tool know what type of user it is dealing with?	It doesn't it only asks the amount of residence in the household

Information exchange

What does the user get from the tool?	
Info	The user doesn't get any specific information from the tool. The tool only mentions at the end that based on the input data the tool recommends the products as shown. There is some general info about the products on the same page as the results of the tool, but this info is not personalized according to the input of the tool.
Advice	According to the input data the tool advices what heat pump systems are applicable. The advice varies from hybrid and all-electric heat pump solutions
At what level does this advice come?	
Personalized	Specific heat pump systems installed by samangroep displayed with their power output, installation costs and purchase costs.
Generic	Information about the different heat pump systems is for all results the same
On which theme does the advice succeed?	
Renewable energy sources	Heat pump
How much interaction time (with tool) is needed to receive advice?	2 minutes
The tool provides information that:	
Can be obtained by querying the internet	General information about different heat pump systems
Complementary to information on the internet	
Unique compared to information on the internet	It advices specific heat pump systems including capacity based on user input
What makes the tool unique in terms of making information available?	Directly as a result from the tool, the heat pump including a picture and price and installation cost is shown. The user can immediately click further to plan a installing appointment.
Rewards are…of nature:	
One-time	It is not clear how often calculation algorithms are updated.
With every update	Heat pump system prices are updated because they are linked to their own database including actual pricing and installation costs
Ambiguities in the tool	- Changings the insulation and keeping the other parameters the same doesn't change the heat

	pump advise. Probably the advice is stronger linked to the gas usage. - Gas usage higher than 2000m3 + radiators and floor heating always results in a high temperature heat pump. - Gas usage higher than 2000m3 + floor heating results in LT heat pump.

<u>Usability calculations and data</u>

What is the accuracy of the advice provided by the tool?	
Exactly	Heat pump system costs and installation costs. Heat pump system power output.
Building approach	no
Higher spatial level approach	no
Personalized	- existing building or newly built building - heat delivery system - insulation level (simple) - amount of residence - gas usage - heat pump system buying or renting
Averaged for specific user types (based on input data)	Energetic performance is based on underlaying formulas combining insulation level and gas usage
Average without distinguishing user types	Heat pump system prices are automatically calculated based on the cost prices and installing prices of samangroep.
What type of data is provided by the user?	
Energy performance: consumption and production	-gas usage
Socio-economic key figures	
Building related information	- amount of residence - heat delivery system - building type - insulation value
Spatial information	no
Others	no

Theme 2: Owner tool (Clymans., et al. 2019)

Objective of the owner of the tool:	
Providing information to the private individual/consumer/user	Providing information to the home owner that the samangroep always has a heat pump solution for every home
Investment interest in specific renewable energy sources	Hybrid heat pump, all electric heat pump, high temperature heat pump
Investment interest for specific energy saving measures	Gas usage reduction
What the tool advises on (triad):	
Use sustainable energy sources	Heat pump system

Theme 3: Domain technician (Clymans., et al. 2019)

<u>assessment advice</u>

Which technologies are covered?	- air source heat pump

	- high temperature heat pump - hybrid heat pump
Following criteria are used in the assessment of technologies?	
quantitative	
Energy/heat production	Heat output of system in kWh
Investment cost	One-time purchase costs and installation costs in euros

Clymans., et al. 2019 didn't use any qualitative data in the analysis. But for my thesis the qualitative criteria is important, that's precisely what makes a specific tool outstanding compared to the rest. Therefore the following qualitative elements are added to the domain technician criteria:

Existing building services	
Currently existing heat delivery system	Choose from: floor heating, radiators or combination floor heating and radiators
Currently existing heating system	A gas boiler is assumed, as the gas usage of the building needs to be filled in

The following elements are made by Clymans., et al. 2019:

Technologies are assessed/advised via cost-benefit as	Individual solution

Availability technologies

Including technologies that exceed investment capacity home owner	no
Availability of technologies is determined by	The heat pump systems that can be supplied and installed by the samangroep

Theme 4: Data availability (Clymans., et al. 2019)

Data Policy/Accessibility

The tool uses the following data types (including owner and spatial level):	
Databases: Declarations, certificates, permits, registrations	
Research results: Key figures, parameterization	User input combined with standard values are converted with underlaying algorithms to a specific user advice.
Measurements: Energy production and consumption data,...	Consumption is not addressed amount of showers is not asked, probably a standard value is used in the underlaying formula based on the amount of residence.
Models: Energy production and consumption data,...	Energy consumption based on DHW usage is based on existing models
The tool uses the following types of algorithms:	
Static	The result of the tool remains static, the parameters in the tool are fixed

Dynamic	The pricing of the results vary as the product prices are linked to their website

<u>data management</u>

Update of the source data in the tool is done:	The owner of the tool
Update of the calculation algorithms in the tool happens:	Not clear
The tool is:	
Independent (stands alone)	yes

Theme 5: Domain and scale level (Clymans., et al. 2019)

At what scale level does the tool function	
Building	Only building scale
The tool differentiates between scale levels:	No different scale levels
There is a direct link with the following policy areas:	
Climate	Less gas usage

After the analysis the strength and weaknesses of all the tools will be explained. The strength and weaknesses will be explained according to the five themes in the same way as performed by Clymans., et al. 2019.

	Strength	Weaknesses
Theme 1: user		
Characterization	Simple understandable input parameters for user of the tool	Simple input parameters led to a not in detail performed energetic assessment of the building
Information exchange	Pictures of the different systems at the result page	No information about system install locations or system sizes
Usability calculations and data		Result personalisation not possible and no underlaying formulas are shown
Theme 2: Owner tool	Also heat pump supplier and installer	The tool can form a less objective conclusion because the installer wants to sell more heat pump systems
Theme 3: Domain technician		
Assessment advise	Existing heat delivery system is taken into account. - installation costs are shown	- No spatial aspects are asked - no payback time shown
Availability technologies	Easy installable heat pump solutions: air-source heat pump and hybrid air source heat pump.	No ground source heat pump or solar heat pump
Theme 4: Data availability		
Data policy/accessibility		Algorithm adjustments or further personalization results is not possible
Data management		Based on more sales of heat pump products
Theme 5: domain and scale level		No link to national or municipal policy, no different scale levels

https://www.warmhuis.be/start

Description	The tool tells you how energy efficient your home is. It tells you how it can be better. It tells you what it costs to be more energy efficient and it tells you what it brings. It tells which grants are available. It shows the possibilities to make your home more energy efficient, you can download a step-by-step plan and calculated your profit. Renovate smartly, live energy efficiently, energy efficient living doesn't have to be complicated. With a few interventions you can seriously limit the energy consumption of your home. More comfort, less costs. This ensures a higher living comfort and saves money. With the amount of money you save annually, you can enjoy a lot more, or buy things you like.
Supporter	Interleuven
Type	Online tool, with clickable options or exact data input fields
Link	https://www.warmhuis.be/start
Purpose	The application aims to provide residents with insights into the energetic situation of their home and the measures that can be taken to improve it. The privacy of the user is important. That is why a conscious decision was made to keep the application low-threshold and not to ask for personal data in order to use the application.
Vision	-Renovate smartly and live energy efficiently - More comfort, less costs
Function	Informative: insight into energy efficiency building and options to improve it
Date online	?
responsible person	informatieveiligheid@interleuven.be

Theme 1: User (Clymans., et al. 2019)

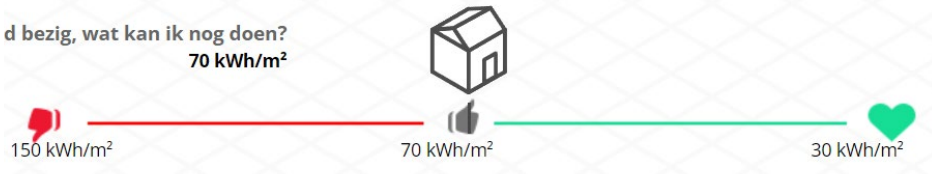
Characterization

Who is the user of the tool?	
Individual	Home owner
Policy makers	Data can be used for statistics and research on characteristics of the housing stock in a specific municipality and potential renovation rate
For which building type does the tool function?	
Residential homes (distinction in type?)	Detached house, semi-detached house, terraced house
Non-residential homes (distinction in type?)	no
Does the tool provide calculations and services?	The tool provides the energetic performance of the building and the possible measures to improve the energetic performance of the building

How does the tool know what type of user it is dealing with?	The user of the tool has to choose whether he is a home owner or a tenant

Information exchange

What does the user get from the tool?	
Info	- annual energetic performance in kWh/m² on a scale from 30 to 70 kWh/m² which is displayed as green (good) and a scale from 70 to 150 kWh/m² which is displayed as red (bad). - improvement options for insulation: floor, roof, facades, glass including the investment costs and the energy savings annual - improvement options for heating system: HR gas boiler, air-water heat pump, ground source water-water heat pump - on-time investment costs - loan for investment - grants received - annual energy savings in kWh - annual savings in kg CO_2
Advice	If the user picks a heat pump system and the energetic performance of the building is to low then the tool gives a warning: , your house does not meet the conditions for selecting a heat pump. The selection has been deselected. The roof and windows must be perfectly insulated.' The investment costs shown is only an indication based on average cost for the various systems. For each improvement option is a button with , more advice' available with a detailed explanation of all the improvements and systems.
At what level does this advice come?	
Personalized	Building upgrades specific for inputted building
Generic	The investment costs shown is only an indication based on average cost for the various systems. - upgrade options where to choose from are generic options
On which theme does the advice succeed?	
Energy-saving measures	Savings in kWh
Renewable energy sources	Annual CO_2 reduction and heat pump choice
How much interaction time (with tool) is needed to receive advice?	5 minutes
The tool provides information that:	

Can be obtained by querying the internet	Information about different insulation measures and heat pump systems
Complementary to information on the internet	
Unique compared to information on the internet	The tool provides detailed specific upgrade measures according to the users input
What makes the tool unique in terms of making information available?	The tool show the energetic performance of the building on a visual scale: 
With the exception of advice, do the following rewards involve an incentive for participation/use?	
Access databases	No database accessed
One-time	Parameters are fixed during the design of the tool
With every update	Parameters can be updated manually by the owner
Ambiguities in the tool	Gas usage is asked, but it is not clear if this is only the gas usage for heating or also for domestic hot water use and cooking. The gas usage incl. showering and cooking results in a higher heat loss calculation.

Usability calculations and data

What is the accuracy of the advice provided by the tool?	
Exactly	- Annual savings in kWh - Annual savings in euros - improvement energetic performance in kWh/m^2 - savings kg CO_2
Building approach	-The insulation improvements are explained in detail when clicking the I icon next to the improvement.
Higher spatial level approach	no
The key figures and parameters used that apply to the type of building, family, and district are:	
Personalized	- Building type - construction year - roof shape: flat, sloped, mixed - building size: big, medium, small or exact floor area - insulation: roof, façade, floor - glass type - ventilation type

	- current heat supply system - currently installed renewable systems: solar collector, solar panels, green electricity
Averaged for specific user types (based on input data)	Energetic performance is based on underlaying tables and formulas dependent on insulation and building types and gas and electricity usage
What type of data is provided by the user?	
Energy performance: consumption and production	Geometric (dimensions), building physics (insulation value), technical installation characteristics
Socio-economic key figures	Amount of residence
Building related information	Already applied sustainable systems
Spatial information	City or municipality has to be chosen

Theme 2: Owner tool (Clymans., et al. 2019)

Objective of the owner of the tool:	
Providing information to the private individual/consumer/user	Home owner
Build a database of interest (specific) energy-saving measures	Anonymous data can be used for statistics and research in the characteristics of the housing stock in a specific municipality and potential renovation rate. This tool is used the context of the European See2Do! Project.
What the tool advises on (triad):	
Limit energy demand	Improve insulation and limit energy demand
Use sustainable energy sources	Use heat pump system if energetic applicable
Use fossil energy sources as efficiently as possible	Reduce the use of fossil fuels by improving insulation

Theme 3: Domain technician (Clymans., et al. 2019)

assessment advice

Which technologies are covered?	
Following criteria are used in the assessment of technologies?	
quantitative	
Investment cost	In euros
Costs avoided	Annual savings
Avoided emissions (x less CO2 emissions)	CO_2 savings in kg per year

The following elements are made by Clymans., et al. 2019:

Technologies are assessed/advised via cost-benefit as	Individual solution

Availability technologies

Including technologies that exceed investment capacity home owner	no

Availability of technologies is determined by	Technologies are baked into the tool and selectable through a dropdown menu. The availability on the actual market is not addressed.

The analysis below is performed in a different way from the claymans method

https://groenpand.nl/warmtepomp/#check

What advice follows from the tool?

- ‘groenpand’ heat pump applicable or not

What characteristics are asked?

- Construction year

Which spatial aspects are requested in the tool?

- No spatial aspects

Which heat pumps system are used in the tool?

- ‘groenpand’ heat pump

What is the target audience of the tool?

- Home owners

Who made the tool?

- ‘groenpand’ installer and advisor

Which other aspects are addressed in the tool?

- Amount of residence
- How often the heating is turned on and on which temperature
- Heat delivery system: radiators, floor heating, convector, infrared panel, wall heating
- The supply temperature of the gas boiler
- Do you have moving or renovation plans that might hinder the purchase and installation of a heat pump?
- What is the homeowner budget:

How are the questions asked?

- With text

Ambiguities in the tool:

- It doesn’t become clear according to the tool how ‘groenpand’ heat pump functions, whether it's a ground or air-source or different.

Advise:

- It only gives a advise that a ‘groenpand’ heat pump is probably applicable or not
- You need to request a quote for more information

Which aspects are missing in the tool?

- Insulation level is not asked, the result is related to the construction year and gas usage

Pro's

- Heat delivery systems are well addressed

Con's

- Advise based on less input parameters: only gas usage and construction year
- You need to request a quote for more information

https://www.wildkamp.nl/kenniscentrum/verwarming/warmtepomp-check

What advice follows from the tool?

- No advise, email and telephone number should be applied and then the company will contact the user of the tool with the advise

What characteristics are asked?

- Building type
- Newly built or renovated
- Construction year
- Insulation: facades, roof, floor
- Glass type
- Energy label
- Area
- Roof height
- Amount of residence
- Current heating system
- Current heat delivery system: radiators, convector, floor heating, floor heating combined with radiator
- Current ventilation system

Which spatial aspects are requested in the tool?

- No spatial aspects

Which heat pumps system are used in the tool?

- Doesn't come clear, advise isn't given at the end

What is the target audience of the tool?

- Home owners

Who made the tool?

- Wildkamp, technical wholesale

Which other aspects are addressed in the tool?

How are the questions asked?

- Text, no pictures

Ambiguities in the tool:

Advise:

- No advise given, email and telephone number should be entered

Pro's

- Relative short form and easy to fill in

Con's

- Advise is not directly given

https://warmtepompcheck.ithodaalderop.nl/warmtepomp/afa71df8-b136-41cc-a69b-115e88473f30

What advice follows from the tool?

- Whether the building is suitable for a heat pump and which heat pump type could be used

What characteristics are asked?

- Building type
- Insulation standard or improved according to construction year: facades, floor, roof
- Construction year
- Floor area
- Amount of residence
- Ventilation type
- Gas usage
- Shower and or bath
- Cooking on gas or not
- Heat delivery system: convector & floor heating or radiator, radiator's, floor heating & radiators, floor heating

Which spatial aspects are requested in the tool?

- How much room is available next to the gas boiler: no, <0,5m^2, +/-1m^2, >1m^2
- How much room is available outdoors for a air source heat pump: no, 1m^2

Which heat pumps system are used in the tool?

- All electric
- Hybrid
- Ventilation heat pump

What is the target audience of the tool?

- Home owners

Who made the tool?

- Heat pump manufacturer

Which other aspects are addressed in the tool?

How are the questions asked?

- Text and small icons

Advise:

- Different types of heat pumps: ventilation heat pump, hybrid heat pump or all electric

Pro's

- Gas usage is split into cooking, showering and heating

Con's

- It gives no advise to which insulation value the building needs to be upgraded to use a all electric system

https://www.panasonicproclub.com/NL_nl/tools/aquarea-designer/

What advice follows from the tool?

The software allows designers, installers and distributors to identify the right heat pump for a particular application from the Panasonic aquarium range or calculate the savings compared to, among other things, other heat sources (bron Panasonic)

What characteristics are asked?

- Country
- Components: space heating, domestic hot water, cooling

Which spatial aspects are requested in the tool?

- Country
- City (climate location
- Design outdoor temperature
- Water supply temperature
- Water return temperature
- Minimum outdoor temperature without heating (heating setpoint)
- Indoor temperature
- Domestic hot water supply: same heat pump as space heating, by alternative heat source, electric heated, no DHW
- Amount of residence
- Heating capacity calculation based on: gas usage, oil usage, pellet usage, energy usage, or specific value in kW
- Internal heat gains
- Solar gains
- Full load hours

Which heat pumps system are used in the tool?

- All in one: split heat pump system with indoor unit with integrated hot water tank. (bron Panasonic)
- Bi-block: split heat pump system. A boiler can be configured individually for hot water preparation (bron Panasonic).
- Monoblock (bron Panasonic). heat pump system with integrated hydronic module in the outdoor unit. A boiler can be configured individually for hot water preparation.

What is the target audience of the tool?

- Heat pump installers, designers, distributors

Who made the tool?

- Panasonic heat pump manufacturer

Which other aspects are addressed in the tool?

- Heat pump mode: mono-energetic, monovalent, bivalent
- Bivalent temperature setpoint
- Heat pump cascade mode
- Heat fraction of the heat pump
- Heat pump voltage
- Capacity of heating element
- Boiler size

How are the questions asked?

- Text, some small pictures of the different heat pump systems

Advise:

- Simulation of the COP
- Heat pump choice (air source)
- User costs
- Maintenance costs
- Co2 reduction
- Hydraulic scheme
- Label calculation

Pro's

Many details

Con's

Can only be filled in by a professional

No system sizes

No spatial aspects

https://www.vaillant.nl/consument/kennis-en-advies/keuze-advies/ketelkiezer/

What advice follows from the tool?

What characteristics are asked?

- How is the building currently heated: gas, heat pump, no idea
- How do you want to heat the building: gas, heat pump
- Heat delivery system: radiator, floor heating, radiator + floor heating
- Building type
- Construction year
- After insulation
- Floor area
- Energy source: air, ground

Which spatial aspects are requested in the tool?

- no

Which heat pumps system are used in the tool?

- Air source heat pump
- Ground source heat pump

What is the target audience of the tool?

- Home owners

Who made the tool?

- Vaillant heat pump manufacturer

Which other aspects are addressed in the tool?

How are the questions asked?

- Text with icons

Advise:

- Advise is not given without email registration
- ‘We are happy to find a suitable installation partner for you. Provide your contact details so that we or one of our affiliated installation partners can contact you to provide advice or a quote’

Pro’s

- Well formulated understandable questions

Con’s

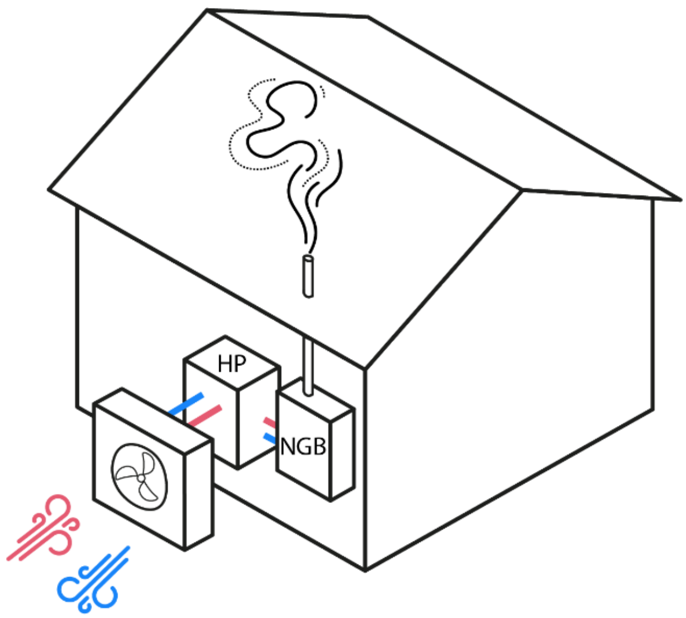
- No direct advise

Appendix 3

Hybrid heat pump extensive heat pump, initially the idea was to come up with design improvements for existing (hybrid)heat pump systems. This idea was in the end scrapped because otherwise the thesis would become much too long. The findings could be used in a follow-up research study on product innovation in the field of heat pumps.

Hybrid heat pumps

with a hybrid heat pump system, the natural gas boiler and a heat pump work together. The heat pump is linked to the existing natural gas boiler. On peak moments when it's cold during the winter, the natural gas boiler helps the heat pump. The natural gas boiler also produces the domestic hot water. The system is not totally gas free, but reduces the gas usage compared to a system with only a natural gas boiler.



Boundaries heat pump working together with gas boiler (hybrid mode) water flows and temperatures:

When thinking about installation options of a hybrid heat pump combined with gas boiler or thinking about a design improvement the working of the system combined with the existing gas boiler needs to be analysed in depth. Now an existing heating system (gas boiler) is analysed and step by step a heat pump is added to the system which makes it a hybrid heat pump system. The step by step approach is explained by the means of sketches based on the explanation of the following YouTube video (Heat Geek, 2017).

The gas boiler on this sketch (Figure 93)with a pump speed of 20 litres per minute modulates at a delta T of 20°C, a supply temperature of 60°C results therefore in a return of 40°C. The temperature in the heat emission system is 50°C.

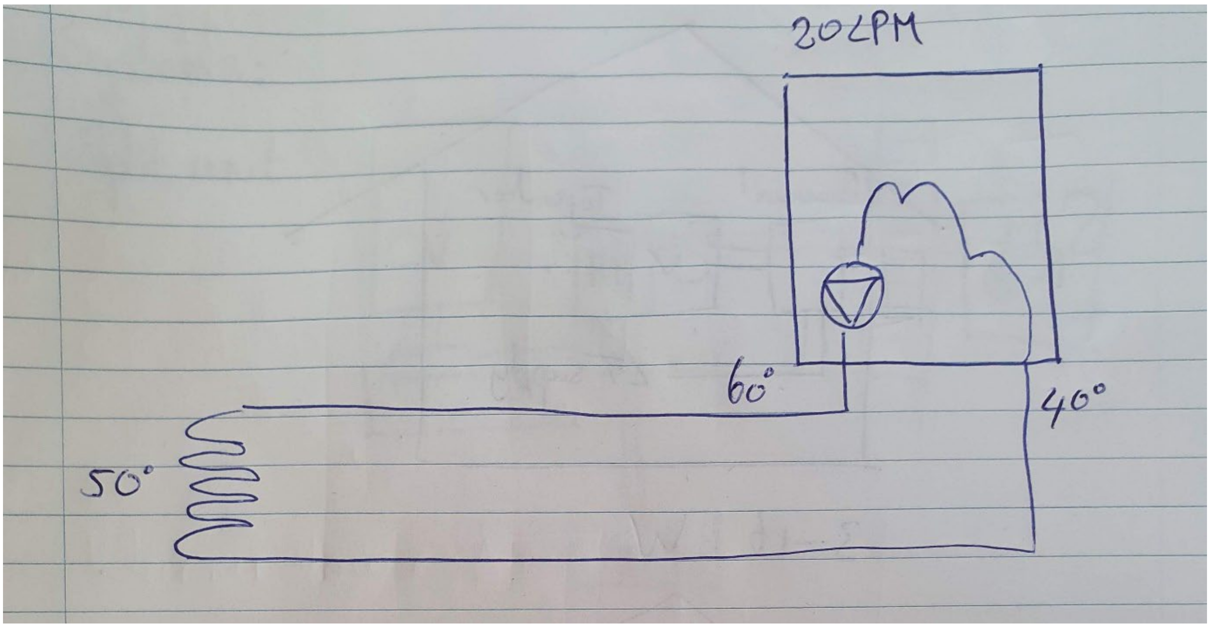


Figure 93. Gas boiler only (Own figure)

By adding a hydraulic separator which is actually a big empty tube a second pump can be installed in the system without interfering the original pump (Figure 94). If the second pomp is turned off the supply water from the gas boiler will flow straight back through the hydraulic separator to the return of the boiler because there is the least resistance.

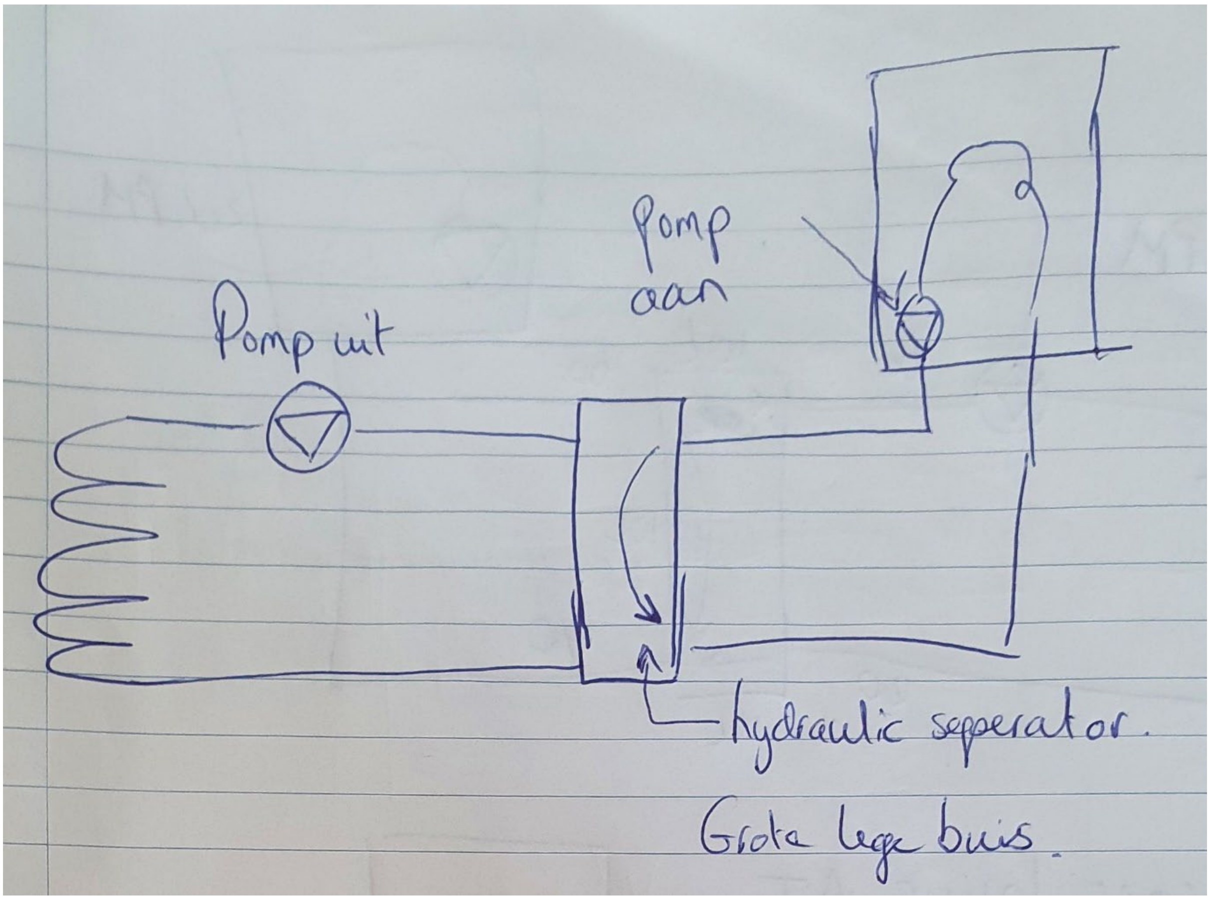


Figure 94. Gas boiler + hyrdraulic seperator + second pump (own figure)

If only the second pump is turned on the pump from the gas boiler is turned off, then the water will only flow on the left side in the picture (the heat emission side) (Figure 95).

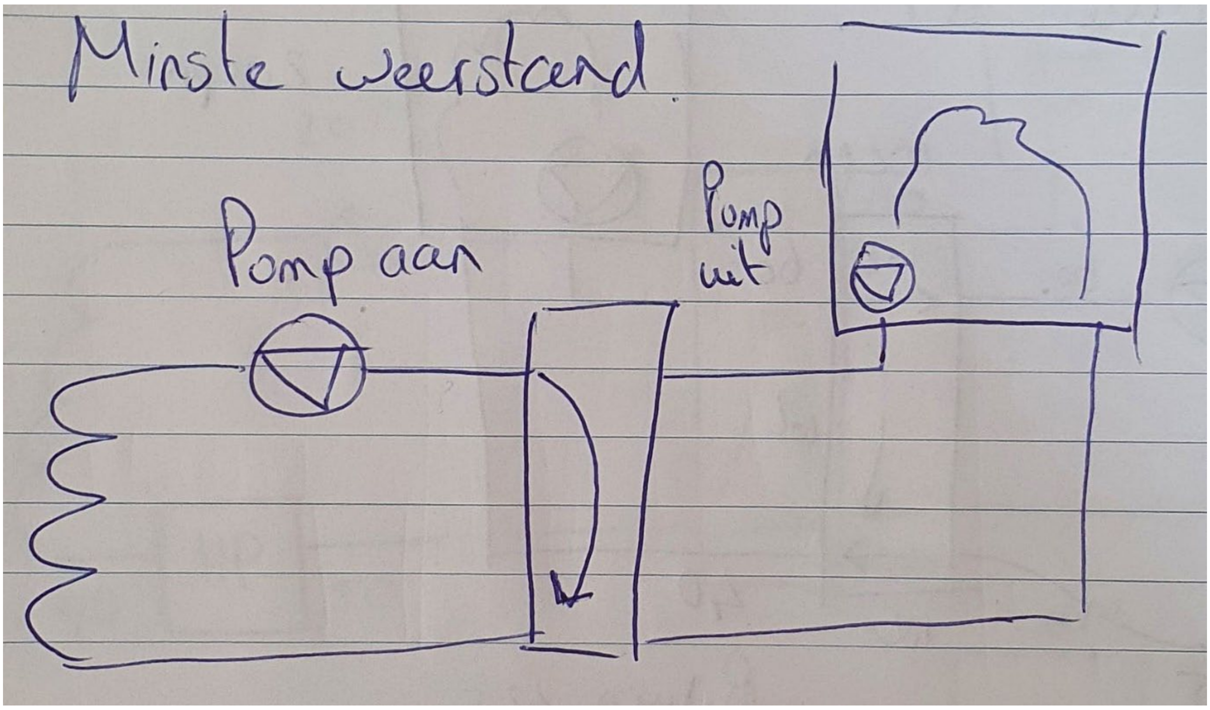


Figure 95. Gas boiler + hydraulic seperator, gas boiler pump turned off (Own figure)

If the pump on the emission side is running at 20 litres per minute and the pump of the gas boiler is running at 10 litres per minutes the following flows occur (Figure 96). The gas boiler is still modulating at a delta T of 20°C, resulting in a supply temp of 60°C and a return temp of 40°C. The pump on the emission side asks for 20 litres of water per minute, it gets 10 litres of water with a temperature of 60°C because the boiler runs at 10 litres per minute, the other 10 litres come from the return of the emission system through the hydraulic separator with a temperature of 40°C. 10 litres of 60°C + 10 litres of 40°C result in a supply temperature from the heat emission system of 50°C. A supply temperature of 50°C and a return of 40°C result in a temperature of 45°C in the heat emission system. So adding a hydraulic separator and a second pump drops the temperature in the heat emission system with 5°C compared to the original situation (Figure 94).

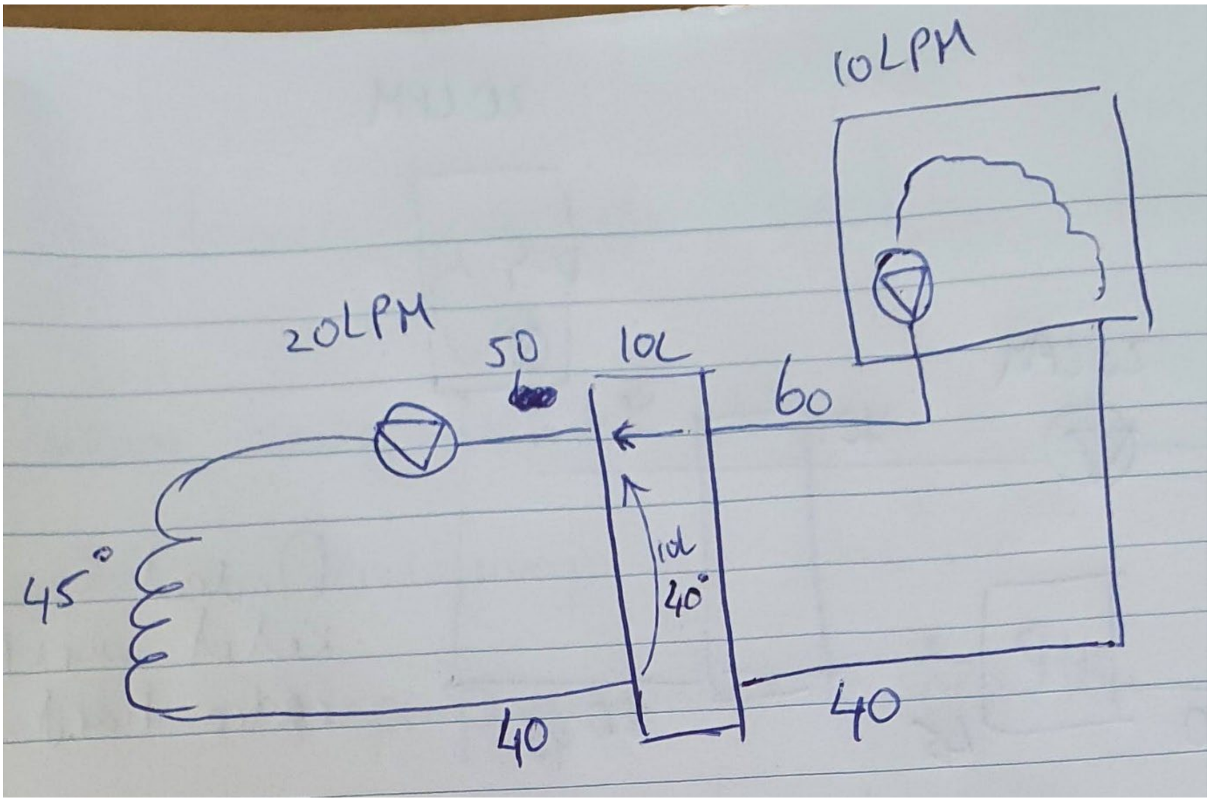


Figure 96. Emission side pump flow higher than boiler side (Own figure)

By adding a heat pump on the return on the emission side the return temperature is for example upgraded from 40°C to 50°C by the heat pump (Figure 97). The upgraded return temperature results in a lower delta T (10°C instead of 20 °C) for the gas boiler which results in less gas usage compared to (Figure 93) and the flow of 10 lpm in (Figure 97) is lower than (Figure 93) so less water is heated by the gas boiler resulting in less gas usage. Because of the upgraded return by the heat pump the supply of the heat emission system becomes (10*50+10*60)/20= 55°C. Resulting in a temperature of 47,5°C in the heat emission system, this is only slightly lower than the original system but with much less energy usage.

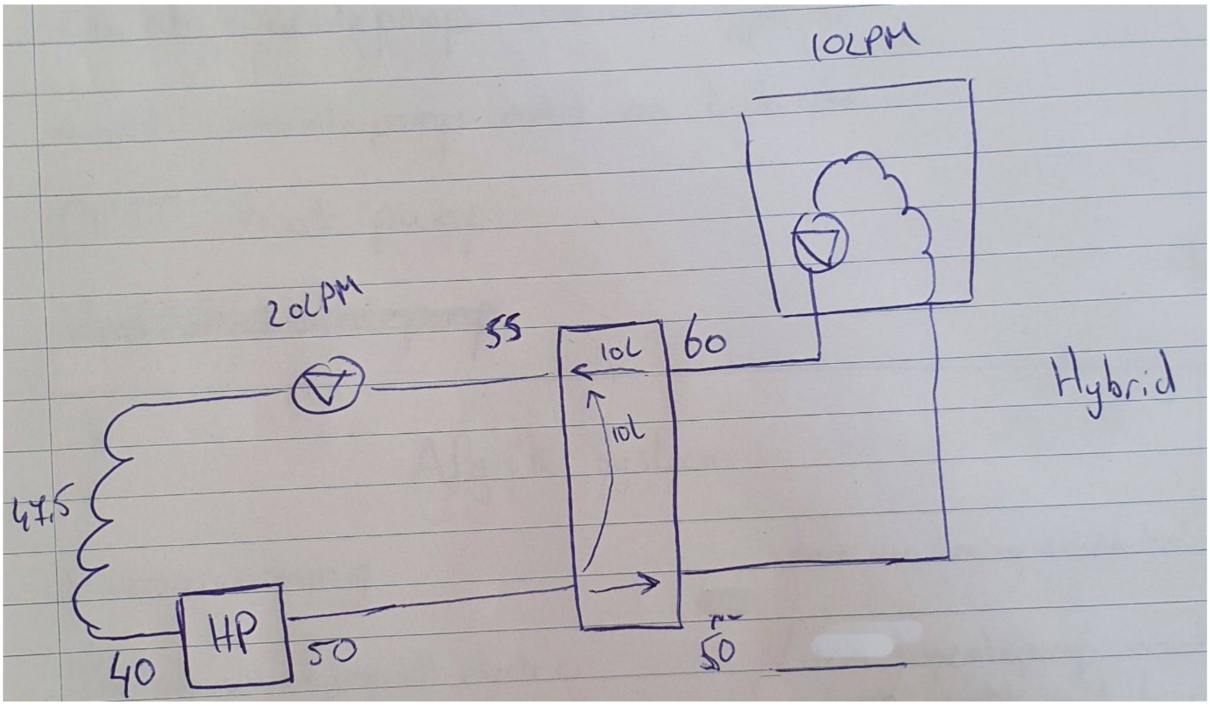


Figure 97. Gas boiler + hydraulic seperator + heat pump in hybrid mode (Own figure)

The same system can also work in full heat pump mode, the pump speed of the gas boiler is then set to 0 (Figure 98). The heat pump is performing all the work by itself. The supply temperature is 50°C the return temperature is 40°C which results in a temperature of 45°C in the heat emission system.

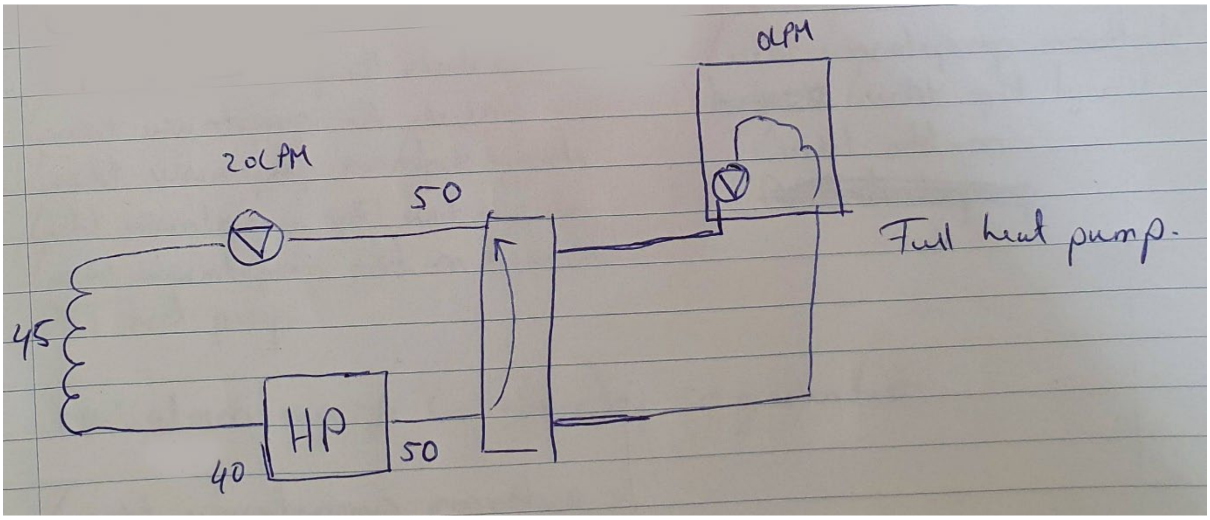


Figure 98. Gas boiler + hydraulic seperator + heat pump in full heat pump mode (Own figure)

The system can also work in gas boiler mode only, the circulation pump on the emission side and the circulation pump in the gas boiler are then running on the same speed, the return water is flowing through the heat pump, which is switched off (Figure 99). But there is a limit the return of the emission flowing through the heat pump may not have a too high temperature, or else it could damage the heat pump.

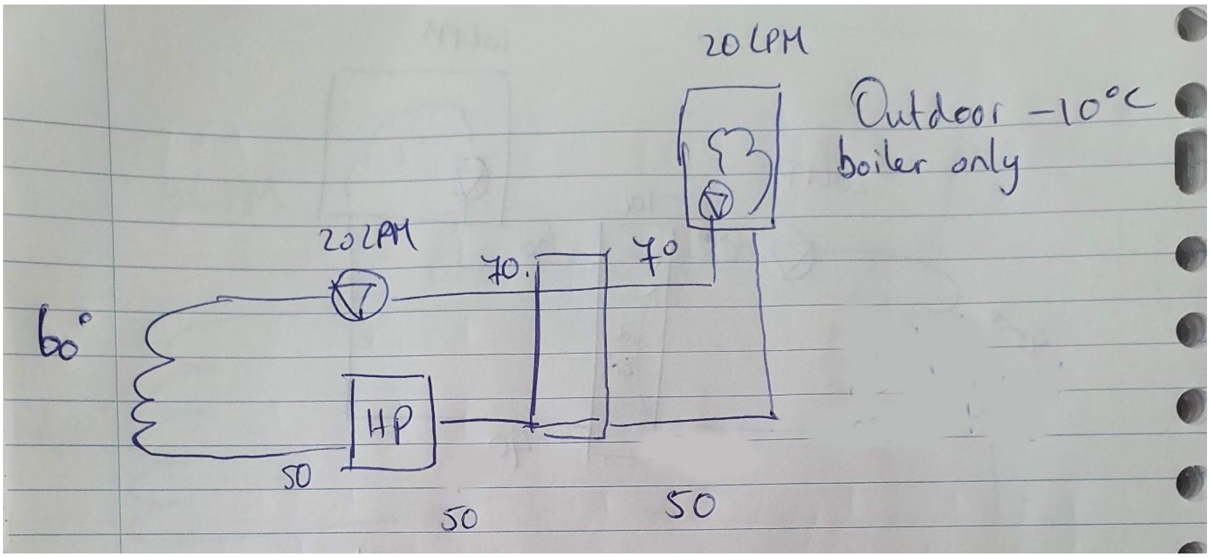


Figure 99. Gas boiler + hydraulic seperator + heat pump in full gas boiler mode (Own figure)

Boundaries hybrid heat pump types

Hybrid air heat pump types: Split heat pump + gas boiler (Warmteservice, 2022), monoblock heat pump + gas boiler (Warmteservice, 2022), add-on heat pump + gas boiler (Groupe Atlantic Nederland BV, 2020).

Integration in existing building:

Configuration hybrid air heat pump types:

(Figure 100):

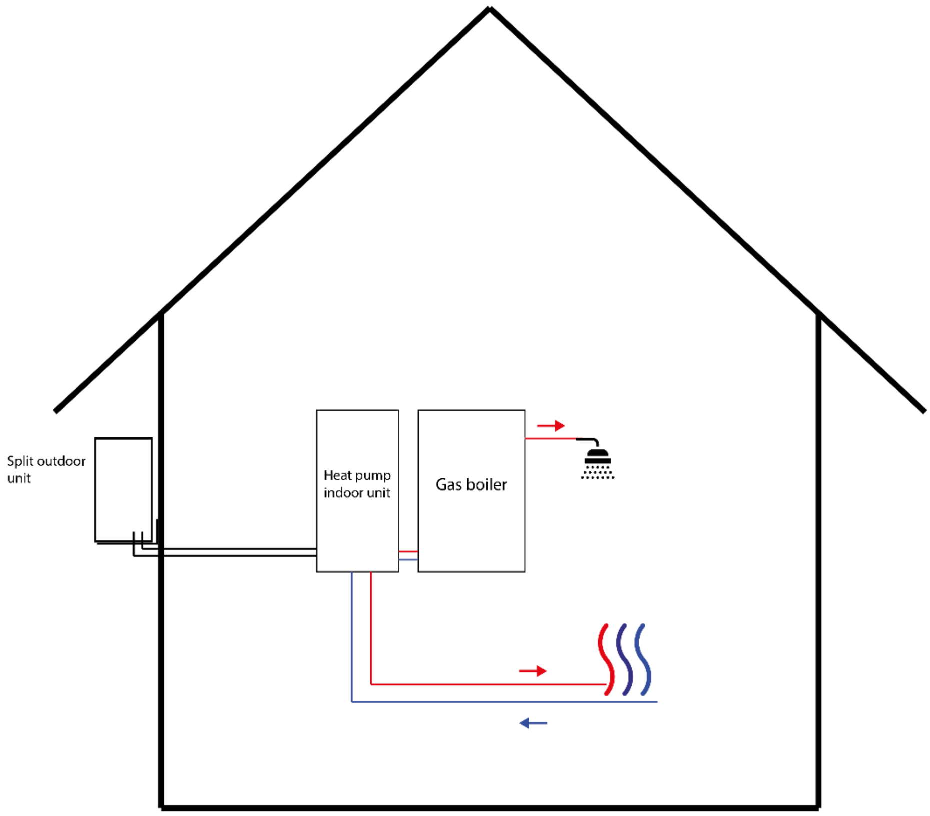


Figure 100. Split heat pump + gas boiler based on principles of (Warmteservice, 2022)

Split heat pump boundaries and shortcomings integration in building

Distance between indoor and outdoor unit: Through the piping doesn't flow water but refrigerant. It is not usual to run these piping underground. The piping needs to be insulated and then placed in a bigger pvc pipe to prevent degradation of ground water and it's necessary for leak detection. The maximum piping length is 25m (Mooi, 2021).

Tubing size between indoor and outdoor unit:

The diameter of piping regarding a split unit is smaller than a monobloc, the sizing varies between 10 to 16mm (Mooi, 2021).

Boundaries performance: SCOP 4.3 (Buiting, 2022)

Boundaries outdoor temperature and heating mode split hybrid:

A split unit functions according to (Remeha, 2021) in hybrid mode within an outdoor temperature range of 4°C - 15°C. A indoor unit from the heat pump contains a circulation pump and an open divider and a condenser which exchanges the heat extracted from the air by the outdoor unit to the water of the heating system (Figure 101). The temperatures in (Figure 101) are based on the temperatures of (Figure 97). But these setpoint temperatures can be changed depending on the heat demand of the building.

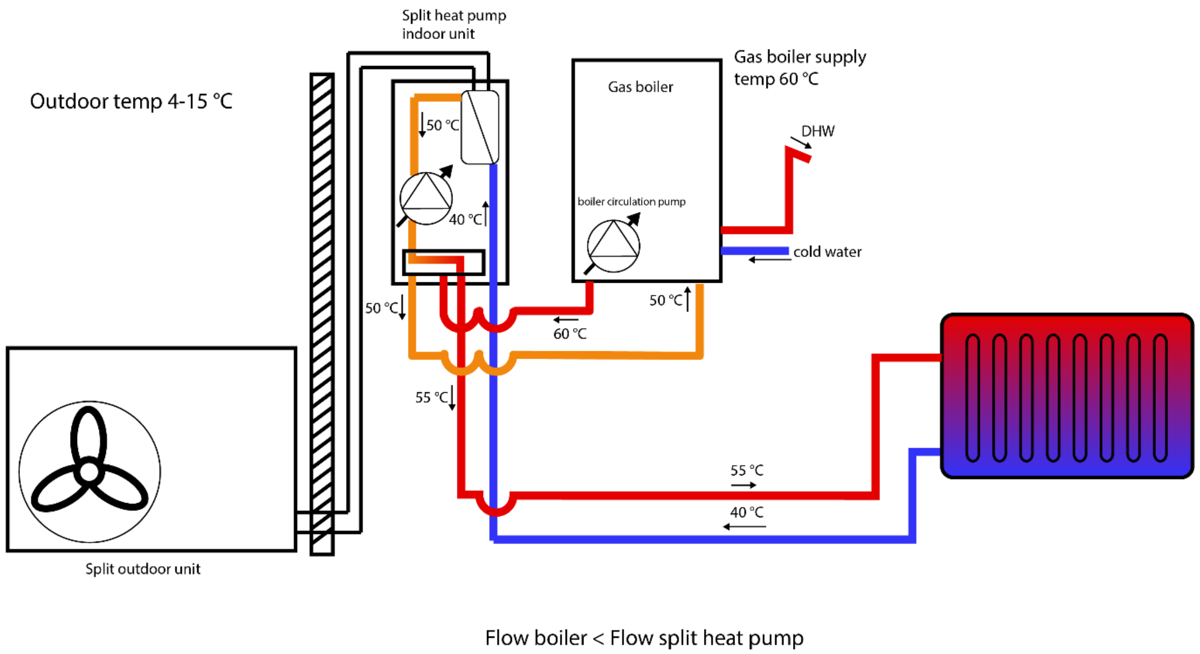


Figure 101. Split unit hybrid heat pump in hybrid mode (Own figure)

The same split unit hybrid system functions according to (Remeha, 2021) in full heat pump with an outdoor temperature of 15+ °C (Figure 102), but again this setpoint temperature can be changed.

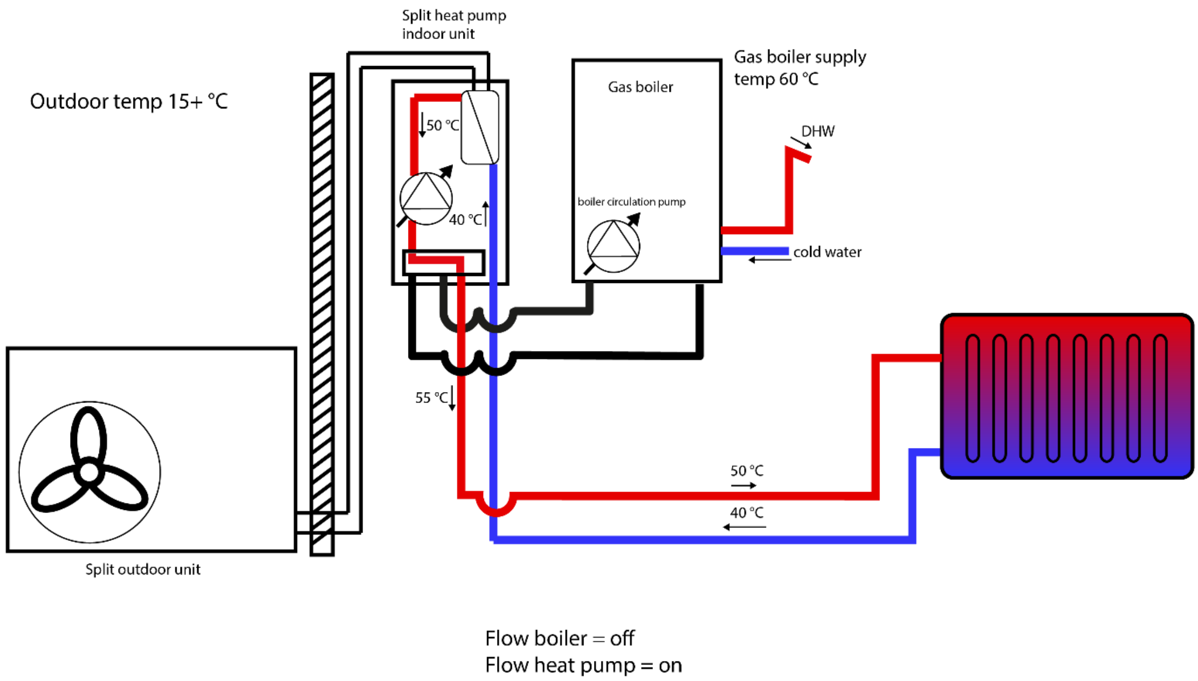


Figure 102. Split unit hybrid heat pump in full heat pump mode (Own figure)

According to (Remeha, 2021) the maximum supply temperature of a heat pump system in gas boiler only mode is 70°C (Figure 103).

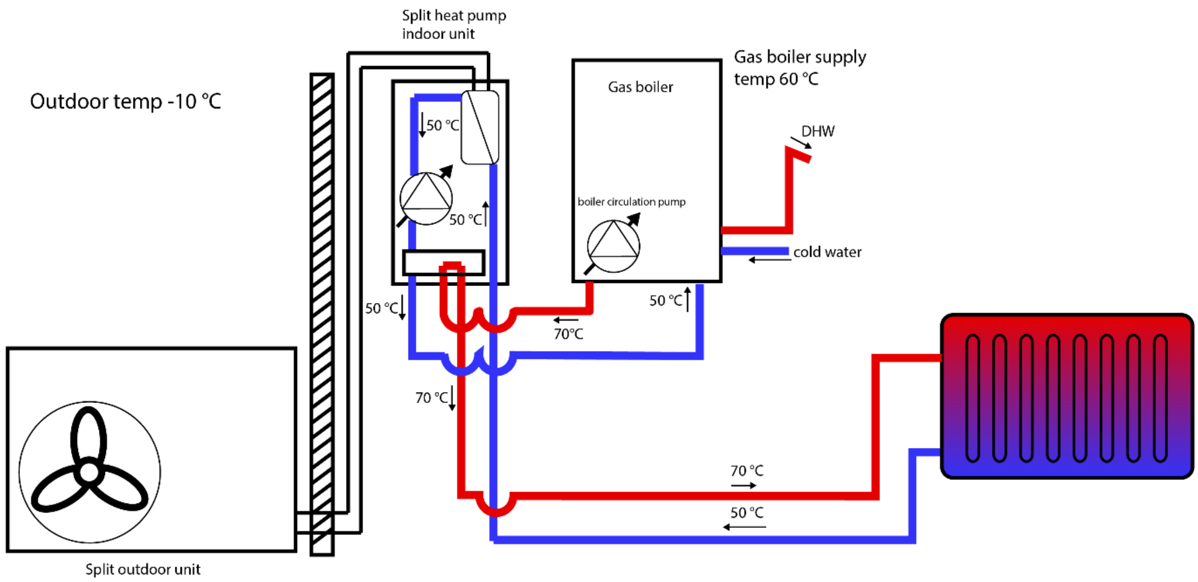


Figure 103. Split unit hybrid heat pump in full gas boiler mode (Own figure)

Shortcomings:

- The indoor unit takes op space next to the existing gas boiler.
- A split unit needs 2 circulation pumps which require energy, 1 pump which pumps the central heating water through the indoor unit and 1 pump which pumps the refrigerant between the outdoor unit to through the condenser of the indoor unit.
- The fan of the outdoor unit makes noise.
- The heat pump doesn't function when the outdoor temperature drops too low.

Monoblock heat pump + gas boiler (Figure 104):

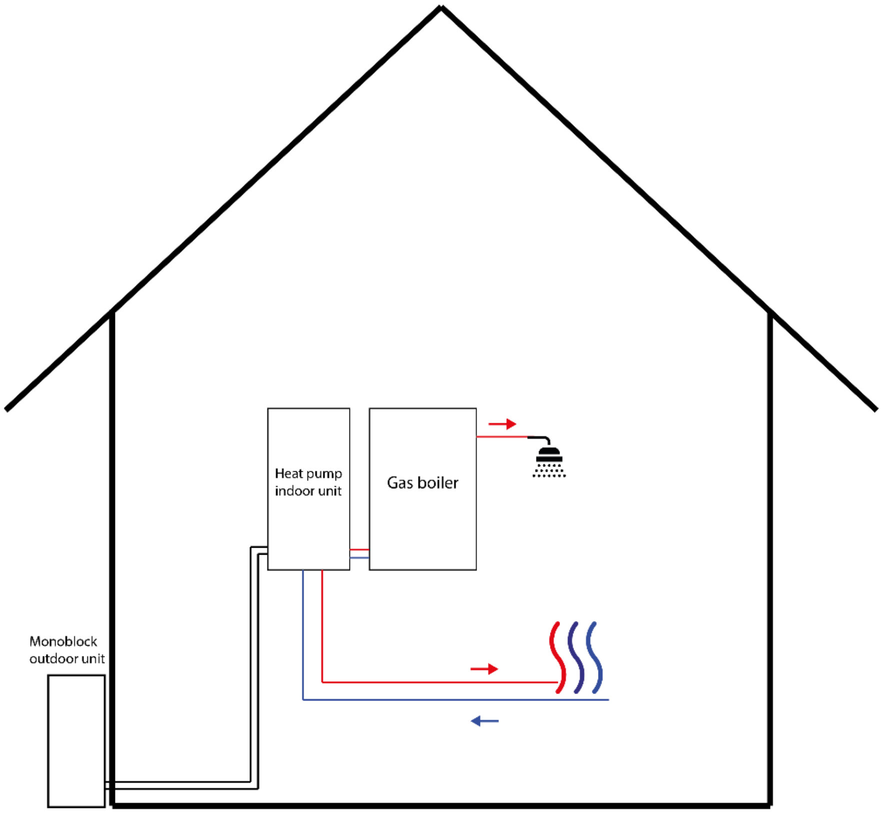


Figure 104. Monoblock heat pump + gas boiler based on principles of (Warmteservice, 2022)

Monoblock boundaries and shortcomings integration in building

Boundary refrigerant:

Refrigerant is situated in the outdoor unit. The refrigerant is added in the factory and forms a close circuit in the outdoor unit of the heat pump. Between the outdoor unit and indoor unit circulates normal central heating water. The installation does not require someone with F Gas qualifications to get involved in use of refrigerants, the monobloc systems are an excellent additional string to the bow of most professional heating installers who, after attending a relevant training course, will be well placed to join the growing band of installers that will be required to fit these heat pump systems in our home markets (Detailing the Differences between Split and Monobloc Heat Pumps, 2020).

Shortcoming:

This leads to the shortcoming that the system could potentially freeze during the winter as the medium between inside the house and the unit is water.

Boundary distance between indoor and outdoor unit:

It is a fact that the central heating pipes between the outdoor and indoor unit are a critical part of the installation. The central heating pipes running outside the building to the outdoor unit cause heat losses. The most heat pump suppliers maintain a maximum length of 30 metres between the outdoor unit and the indoor unit (Mooi, 2021).

Shortcoming: heat loss through pipe length between indoor and outdoor unit

Boundary tubing size between indoor and outdoor unit:

Monobloc with lower capacity 5 or 6 kW require a tubing size of 25 to 28 mm between the indoor and outdoor unit. A capacity if 10 or 12 kW requires piping from 28 or 32 mm (Mooi, 2021).

Boundary tubing outside the building:

If the outdoor unit is placed close to the façade then tubing with insulation is sufficient. If the outdoor unit is placed further away from the façade then the tubing needs to be insulated and placed underground to prevent it from freezing and heat losses (Mooi, 2021). Longer piping always causes more risks of heat losses. Underground piping with a length of 30 metres in a moist soil can cause heat losses of 0,5kW. It is therefore recommended to keep the underground pipes as short as possible (Mooi, 2021). It is advisable to situate the piping below the frost depth. A minimum depth of 60cm below ground level is needed. Vaillant advises to place the piping at least 80cm below ground level (Mooi, 2021).

Shortcoming: placing the unit far away from the façade causes a lot of extra costs and potential for energy loss. Therefore it's recommended to keep distance between indoor and outdoor unit as short as possible.

Boundary maintenance:

For the installation of a monobloc heat pump is not an installer with a F Gas qualification needed. However, if there is a leak or a broken component in the refrigerant circuit, it is mandatory to call in an F Gas certified technician (Mooi, 2021).

Boundary frost protection: the heat pump will certainly run for a long time during periods of frost, because of the higher heat demand of the building. If there is no heat demand for hours, the heat pump is equipped with a frost protection. The heat pump switches on briefly to warm itself and the piping. That should be enough to prevent freezing of the system (Mooi, 2021).

Shortcoming: the heat pump will not function when its freezing outside and the defrost will cause extra energy usage in winter.

Boundary condensation water: condensation water forms on the back of the outdoor unit, this water sinks down into the condensation tray. This water is heated by means of a thermo ribbon so that it does not freeze. The condensation water is discharged through the drain at the rear. A thermo ribbon must also be installed in that drain pipe (Stokman, 2021).

Shortcoming: condensation water can possible freeze if thermo ribbon is broken which causes problems for the heat pump

Boundary placement outdoor unit: stable flat surface. Enough space at the back to suck air in and enough space at the front to blow air out. Placed at least 30cm from the wall (Stokman, 2021). The outdoor unit of a monobloc is bigger than the outdoor unit of a split system and therefore harder to mount on the façade, and sometimes not possible to mount to a façade (P. van der Wilt, 2022).

Shortcoming: not mounting on the façade is in many cases in the built environment not possible. As a lot of buildings do not have a garden or a flat roof surface for mounting the outdoor unit.

Boundary control: weather-dependent control on the outside of the house on the north side. A sensor is placed there.

Boundaries outdoor temperature and heating mode monoblock hybrid:

A monoblock heat pump in hybrid configuration only contain a circulation pump and a hydraulic separator in the indoor unit in (Figure 105) the circulation pump and hydraulic separator are drawn separately but some brands provide them in one indoor unit like in (Figure 104). The temperatures are based on (Figure 97).

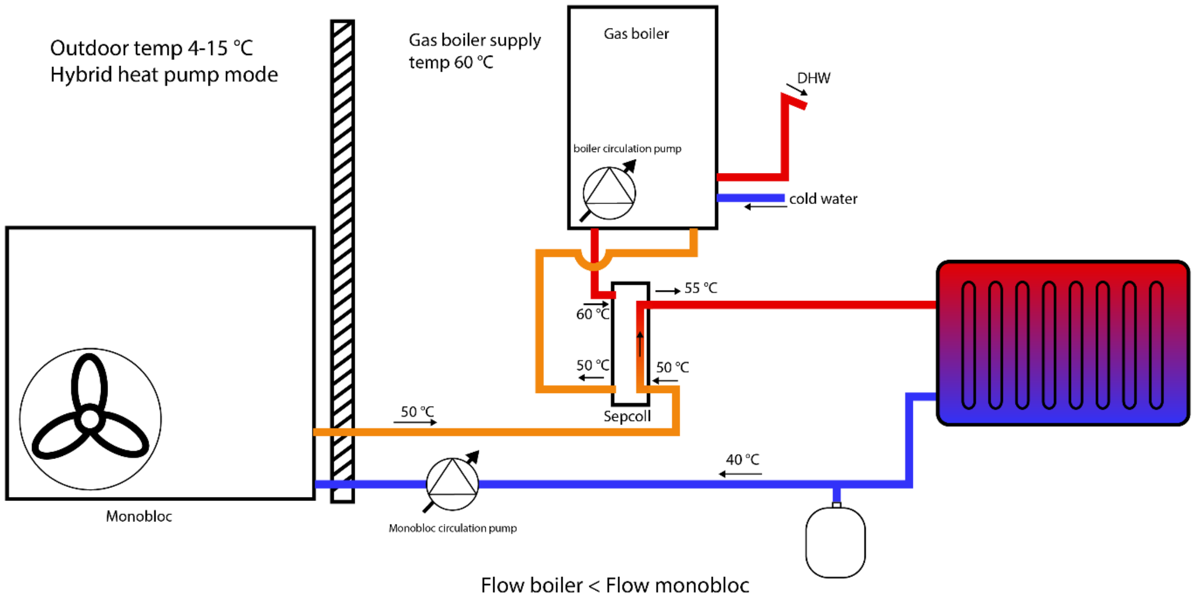


Figure 105. Monoblock hybrid heat pump in hybrid mode (Own figure)

A monoblock heat pump in full heat pump mode functions the same way as a split unit in full heat pump mode (Figure 106).

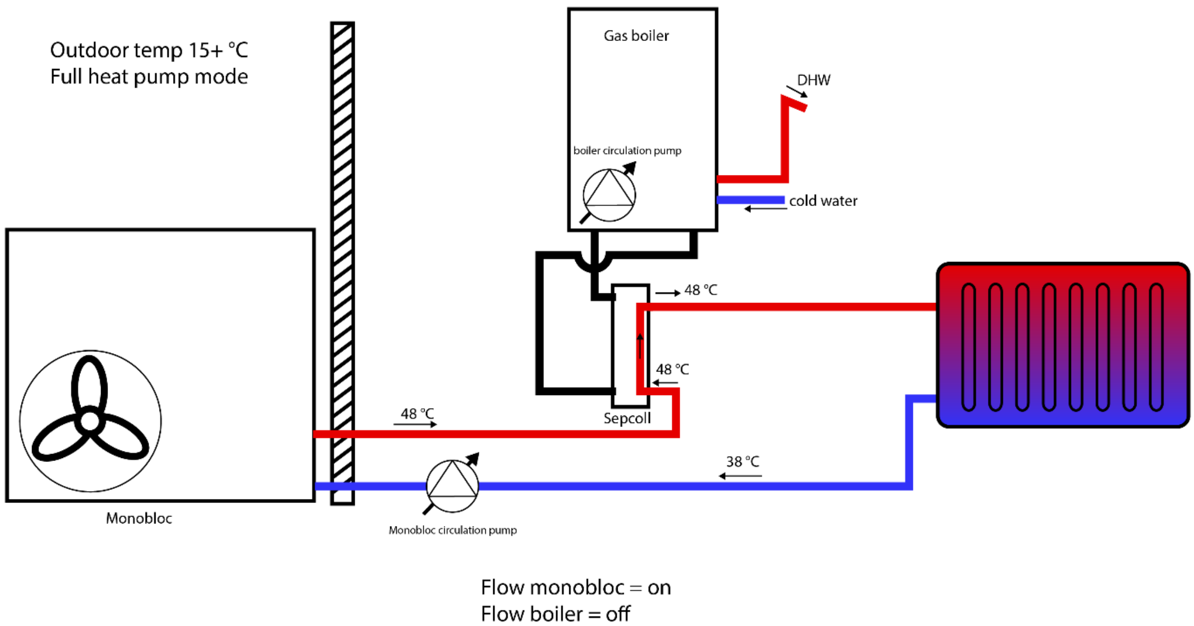


Figure 106. Monoblock hybrid heat pump in full heat pump mode (Own figure)

A monoblock in full gas boiler mode brings some problems (Figure 107), the return water flows through the monoblock which is situated outdoors and turned off. This cools down the return water even more, so during the winter when the buildings heating load is the highest the monoblock causes extra energy losses on top of that so the gas boiler has to work extra hard.

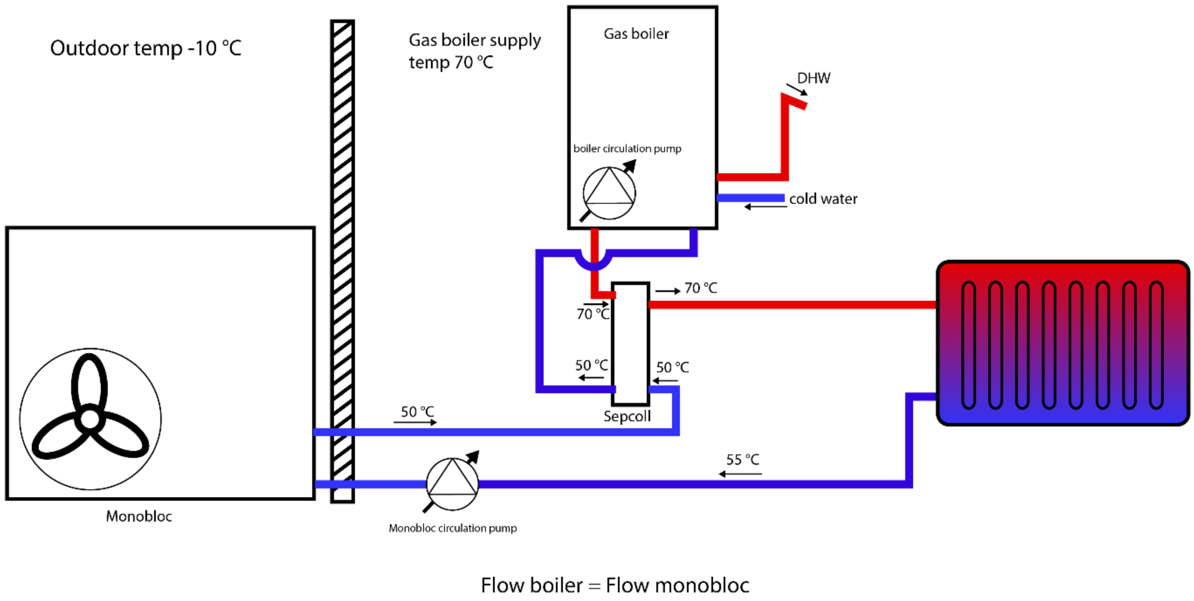


Figure 107. Monoblock hybrid heat pump in full gas boiler mode (Own figure)

Split heat pump & monoblock heat pump with indoor unit system installation space

Boundary system installation space

Hybrid heat pump split unit or monoblock indoor unit + small buffer for space heating (Figure 108):

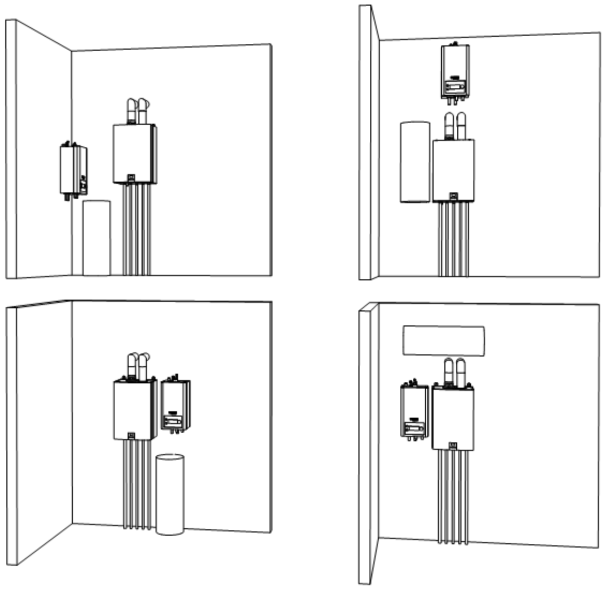


Figure 108. Split heat pump/monoblock indoor unit + small buffer for space heating configuration options (Own figure)

Indoor unit size split and monoblock: about 30cm width, bij 25cm depth, bij 50cm height (Remeha, 2021)

Small buffer size: diameter 29cm and length 79cm (Remeha, 2021)

If there is no place for a small buffer for space heating next to the indoor unit, then it's still possible to install a heat pump, but the lifespan of the system can be shortened due to commuting without buffer.

Hybrid heat pump split unit or monoblock indoor unit without small buffer for space heating (Figure 109**)**

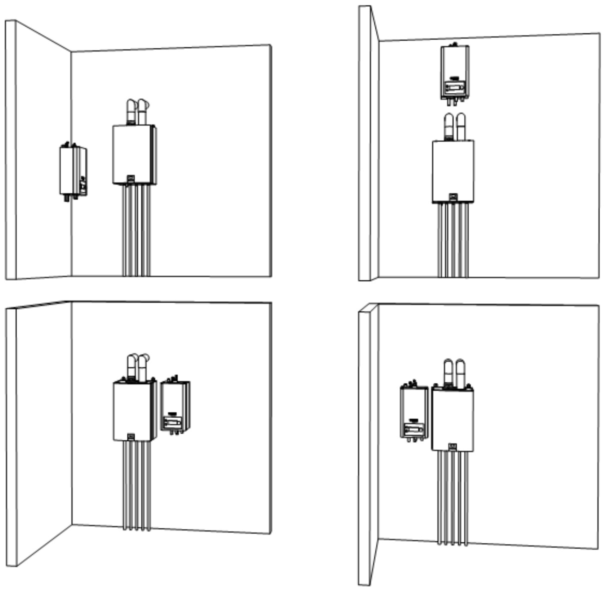


Figure 109. Split heat pump/monoblock indoor unit without buffer for space heating configuration options (Own figure)

If there is not enough space next to the existing gas boiler for a indoor unit + small buffer. The heat pump can still work without a buffer.

Hybrid heat pump split unit or monoblock indoor unit in other room than gas boiler (Figure 110**)**

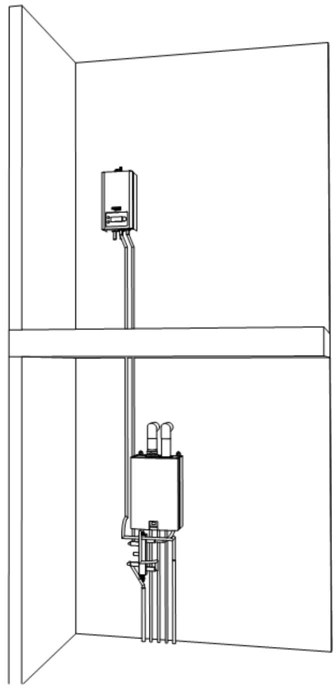


Figure 110. Hybrid heat pump split unit or monoblock indoor unit in other room than gas boiler (Own figure)

There is no place to install a small buffer (diameter 29cm and length 79cm) nor a hybrid split heat pump indoor unit (30cm width, bij 25cm depth, bij 50cm height) close to the existing gas boiler. But there is place somewhere else in the building. Keep in mind that 2 pipes with a thickness of 22mm (excluding insulation) need to be connected between the existing gas boiler and the indoor split unit of the hybrid heat pump with the use of an extra hydraulic separator as the hydraulic separator in the indoor unit isn't used anymore. It is therefore needed to drill holes through walls or floors. The pipes can be concealed by means of a cove. If the wall construction allows it, the pipes could also be feared.

Monoblock heat pump with circulation pump integrated in outdoor unit

The system that takes up the least amount of space comparing a hybrid heat pump split vs monoblock is a monoblock unit with a circulation pump integrated in the outdoor unit. The only part that needs to fit next to the existing gas boiler is a small hydraulic separator (Figure 111).

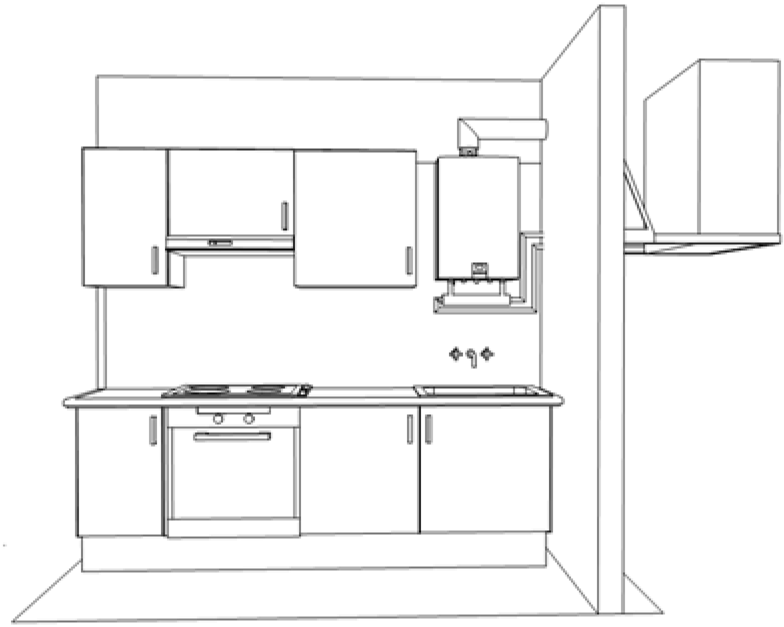


Figure 111. Monoblock with integrated circulation pump + hydraulic seperator next to gas boiler (Own figure)

Add-on heat pump + gas boiler (Figure 112):

A ad-on heat pump is basically a monoblock heat pump with a circulation pump integrated connected to the existing heat emission system without an hydraulic separator. But without a hydraulic separator the setpoint temperatures cannot be changed resulting in the switching temperature, or bivalent temperature in order for the Hybrid add-on to function is +4°C. This value is not adjustable. This guarantees a high efficiency of the heat pump. At temperatures below 4°C or heat demand above 55°C, the gas boiler takes over, guaranteeing comfort. The central heating boiler also provides hot tap water so that you can bathe and shower carefree (Atlanticclimate, 2022).

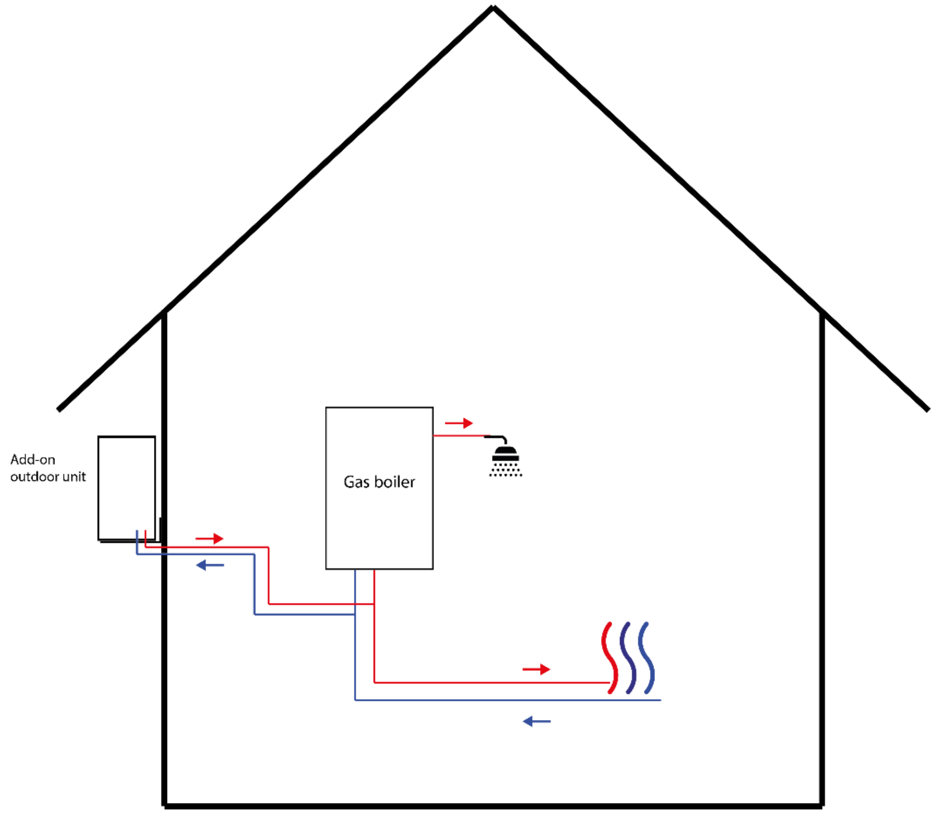


Figure 112. Add-on heat pump + gas boiler based on the principles of (Groupe Atlantic Nederland BV, 2020)

Appendix 4

Calculations used for the table different roads to 2050 uninsulated multi family home <1945

The example building is taken from the report (Cornelisse et al., 2021).

Meergezinswoning: galerij-/portiekwoning <1945	Dubbele bovenwoning	
General features		
Construction year:	1896	
Surface area:	72	
Compactness ratio:	1,71	
Orientation	North-west / south-east	
Net heat demand	279 kWh/m2.jr	
Power demand for space heating	100W/m2 (calculation see below)	
Technical systems		**Explanation**
Ventilation system	System A	Natural ventilation
Heat generator	Gas boiler	Assumed 5 years old
Heat delivery system	Traditional radiators	
Building characteristics	**Thermal quality**	
Floor	Rc=0,33 m2K/W	uninsulated floor
Façade	RC=0,19 m2K/W	uninsulated stone wall (no cavity)
Panel	Rc=0,23 m2K/W	uninsulated panel
Flat roof construction	Rc=0,22 m2K/W	uninsulated panel
Pitched roof construction	Rc=0,22 m2K/W	uninsulated roof
Windows	Uw = 5,10 W/m2K	(36% single pane)
	Uw = 2,90 W/m2K	(64% double pane)
Doors	Ud= 3,4 W/m2K	Uninsulated door
Infiltration	Construction year 1896	

(Cornelisse et al., 2021)

Calculation power demand for space heating

According to the research (Cornelisse et al., 2021) is next to the net heat demand (kWh/m2.jr) which plays a central role in their research to the new insulation standard, the power demand for space heating (W/m^2) an important factor. This is the capacity of the heat output needed to keep the house warm at a comfortable indoor temperature, even in extreme situations (a severe winter). The heating power in (in Watt (W) or kiloWatt (kW)) therefore differs from the heat requirement (in kWh/m2.yr). The heating capacity is determined by the capacity of the heat supply (the 'alternative to natural gas', such as a heat pump, connection to a heat network or other alternative to the central heating boiler) and the facilities for heat release (radiators, convectors or underfloor heating). In their research the capacity of the supply is assumed to be sufficient, in practice this is a matter of correct dimensioning when switching to the alternative to natural gas. The capacity of heat emission system facility does require further consideration. The question is whether the available capacity (designed for a high delivery temperature) is also sufficient at a lower supply temperature. Reducing the net heat demand of the home leads to a lower required heating capacity of the heat emission system. On the other hand, when replacing the heat supply, a lower temperature range for space heating is often used, for example because this is better suited to a sustainable individual heat generator (heat pump) or because there is a low/medium temperature heat network. The required heating power is determined in accordance with ISSO 51. But in their research they selected from each of the 16 housing types 1 reference home from practice to calculate the required heating power. Contrary to the calculation of the net heat demand, one home per category has therefore been assessed and not the complete set of homes form the WOON 2018 database. The reason for this is that, in order to determine the required heating capacity, data of the house at room level must be known, the data from the WOON 2018 database is insufficiently detailed for this. In their report however is the for this example selected building:

Multi-family home	
Construction year:	1896
Surface area:	72
Compactness ratio:	1,71

(Cornelisse et al., 2021).

not worked out using the ISSO 51 calculation.

So for this research the power demand for space heating for the specific home must be determined as it is not done in the research by (Cornelisse et al., 2021). Since we do not know the floor plan and specific building characteristics needed to perform a heat loss calculation according to ISSO 51 this needs to be done differently. The building characteristics which are needed to perform a ISSO 51 calculation were already investigated in the 'Emperical Research' phase, but these characteristics cannot be found in the report from (Cornelisse et al., 2021). Another finding during the 'Emperical Research' phase was that the annual heat demand (net heat demand) in combination with the full load hours of the heating system lead to the heat capacity. A table with the different pre-fixes is (Figure 113)

Indicatietabel monovalent warmtepomp verwarming vollast-uren per jaar (voorbeeld woning met Gebruiks-Oppervlak van 150 m²)																			v2019
Gemiddeld NL klimaat			< 18°C		< 17°C		< 16°C		< 15°C		< 14°C		< 13°C		< 12°C		< 11°C		
buiten temp	gemiddeld		1965 - 1974		1975-1980		1981-1989		1990-1999		2000-2010		Rc 5 (2010-2015)		Rc 6		Rc 7		*BENG*
A	B		C	D	E		F			G	H	EPC 0,8	i	EPC 0,6	J	EPC 0,4	K	EPC 0.2	L
°C	uur		kW	kWh som	kW	kWh som	kW	kWh som	kW	kW som	kW	kWh som	kW	kWh som	kW	kWh som	kW	kWh som	kWh som
-10	8		15,00	120	13,50	108	13,00	104	12,00	96	10,50	84	7,50	60	6,75	54	6,00	48	42
-9	11		15,00	165	13,50	149	12,50	138	11,29	124	9,47	104	6,47	71	5,56	61	4,71	52	49
-8	14		15,00	210	13,24	185	12,00	168	10,82	152	9,06	127	6,18	86	5,29	74	4,47	63	59
-7	21		14,71	309	12,71	267	11,50	242	10,35	217	8,65	182	5,88	124	5,03	106	4,24	89	84
-6	27		14,12	381	12,18	329	11,00	297	9,88	267	8,24	222	5,59	151	4,76	129	4,00	108	102
-5	32		13,53	433	11,65	373	10,50	336	9,41	301	7,82	250	5,29	169	4,50	144	3,76	120	113
-4	44		12,94	569	11,12	489	10,00	440	8,94	393	7,41	326	5,00	220	4,24	186	3,53	155	145
-3	68		12,35	840	10,59	720	9,50	646	8,47	576	7,00	476	4,71	320	3,97	270	3,29	224	208
-2	91		11,76	1071	10,06	915	9,00	819	8,00	728	6,59	600	4,41	401	3,71	337	3,06	278	257
-1	117		11,18	1308	9,53	1115	8,50	995	7,53	881	6,18	723	4,12	482	3,44	403	2,82	330	303
0	164		10,59	1736	9,00	1476	8,00	1312	7,06	1158	5,76	945	3,82	627	3,18	521	2,59	424	386
1	218		10,00	2180	8,47	1847	7,50	1635	6,59	1436	5,35	1167	3,53	769	2,91	635	2,35	513	462
2	242		9,41	2278	7,94	1922	7,00	1694	6,12	1480	4,94	1196	3,24	783	2,65	641	2,12	512	456
3	279		8,82	2462	7,41	2068	6,50	1814	5,65	1576	4,53	1264	2,94	821	2,38	665	1,88	525	460
4	315		8,24	2594	6,88	2168	6,00	1890	5,18	1631	4,12	1297	2,65	834	2,12	667	1,65	519	445
5	373		7,65	2852	6,35	2370	5,50	2052	4,71	1755	3,71	1382	2,35	878	1,85	691	1,41	527	439
6	440		7,06	3106	5,82	2562	5,00	2200	4,24	1864	3,29	1449	2,06	906	1,59	699	1,18	518	414
7	470		6,47	3041	5,29	2488	4,50	2115	3,76	1769	2,88	1355	1,76	829	1,32	622	0,94	442	332
8	469		5,88	2759	4,76	2235	4,00	1876	3,29	1545	2,47	1159	1,47	690	1,06	497	0,71	331	221
9	477		5,29	2525	4,24	2020	3,50	1670	2,82	1347	2,06	982	1,18	561	0,79	379	0,47	224	112
10	488		4,71	2296	3,71	1808	3,00	1464	2,35	1148	1,65	804	0,88	431	0,53	258	0,24	115	0
11	472		4,12	1944	3,18	1499	2,50	1180	1,88	888	1,24	583	0,59	278	0,26	125	0,00	0	
12	460		3,53	1624	2,65	1218	2,00	920	1,41	649	0,82	379	0,29	135	0,00	0			
13	461		2,94	1356	2,12	976	1,50	692	0,94	434	0,41	190	0,00	0					
14	451		2,35	1061	1,59	716	1,00	451	0,47	212	0,00	0							
15	446		1,76	787	1,06	472	0,50	223	0,00	0									
16	399		1,18	469	0,53	211	0,00	0	U kunt										
17	355		0,59	209	0,00	0			geen rechten										
18	308		0,00	0					ontlenen										
19	248								aan deze										
20	184								indicatie tabel										
boven 20 °C	608								!!!										
totaal kWh voorbeeld hoekwoning			M	40685		32706,26		27369,5		22532,24		17161,12		10565,88		8108,471		6070,59	5044,71
totaal uren(jaar)	8760		VL-uur:	2855	N	2423		2147		1878		1634		1409		1201		1012	961
Ventilatie in woning									1990-1999		2000-2010		Rc 5		Rc 6		Rc 7		BENG**
hoekwoning richtgetal met WTW :					80 W/m2		75 W/m2		70 W/m²		60 W/m²		40 W/m²		35 W/m²		30 W/m²		25 W/m²
hoekwoning richtgetal CO2 gestuurd :			x		85 W/m2		O 80 W/m2		75 W/m²		65 W/m²		45 W/m²		40 W/m²		35 W/m²		30 W/m²
hoekwoning richtgetal mechanisch :			= of >100 W/m²		90 W/m²		85 W/m²		80 W/m²		70 W/m²		50 W/m²		45 W/m²		40 W/m²		35 W/m²
warmteverlies berekening :			15 kW		P 13,5		12,75 kW		12 kW		10,5 kW		7,5 Kw		6,75 kW		6 kW		5,25
Bovenstaande richtgetallen zijn gebaseerd op een hoekwoning, u kunt het aantal Watt per m² aanpassen met onderstaand																			
Aanpassing richtgetal tussenwoning			Q -10 W/m²		-8 W/m²		-7 W/m²		-6 W/m²		-6 W/m²		-6 W/m²		-5 W/m²		-4 W/m²		-2 W/m²
Aanpassing richtgetal vrijstaand			+10 W/m²		R +6 W/m²		+5 W/m²		+4 W/m²		+4 W/m²		+4 W/m²		+3 W/m²		+2 W/m²		+1 W/m²
Voorbeeld verbruik op basis van richtgetal hoekwoning met 150 m² Gebruiks Oppervlak met mechanische ventilatie :																			
Equvalent gasverbruik HR ketel m³:			S 4623		3717		3110		2560		1950		1201		921		690		573
Warmtepomp verbruik bij SPF 4,5 in kWh:											T 3814		2348		1802		1349		1121
warmtepomp-weetjes		BENG 1 uitkomst verwarmen (met mechanische ventilatie type C zonder CO2 sturing en zonder gebouw koeling) in dit voorbeeld 5044 kWh : 150 m² = kWh/m² per jaar:																U	33,6

Figure 113. De indicatie tabel warmtepomp vollast draaiuren per jaar -N- (warmtepomp-weetjes, nd)

In this table (Figure 113) the house 1965-1974 has a net heat demand of 40.685 kWh and has a usable area of 150m^2. So the net heat demand is: 40.685/150=271 kWh/m2.jr. This is almost the same as the analysed multi-family house from 1896 which had a net heat demand of **279** kWh/m2.jr. These results cannot be compared 1 to 1 due to the different construction year resulting in a different wall type no cavity in 1896 and cavity in 1965, and also the we don't the orientation of the building the window to wall ratio and many parameters, but this comparison will give a good example. According to the table a terraced-house with a net heat demand of 271 kWh/m2.jr will lead to a space heating capacity of 90 W/m^2. But since our building is a bit older for this research the space heat demand of a corner house is taken which is 100 W/m^2.

Based on this table is assumed that the power demand for space heating will be: 100 W/m^2.

Resulting in a total heat demand for the building of: 100*72=7.2 kW

The goal is to see the impact of the total cost of ownership by 2050, CO2 emissions and energy needed.

1. For the first road is assumed that the building is not insulated and that the existing gas boiler will last 10 years and is then replaced by a new gas boiler. This will show the effects by 2050. The maintenance costs are not taken into account, only the investment costs are included in the calculation. The current gas prices are taken into account for the calculation.

The buildings net heat demand: **279 kWh/m2.jr**

According to (Cornelisse et al., 2021) the net heat demand is determined in accordance with the NTA 8800 (2020+A1:2020). Because at the time of the research performed there was no (validated) software for the NTA 8800, is the by INNAX developed calculation tool used. The calculation tool of 15-06-2020 was used for the calculation of the net heat demand.

Which results in the annual energy for space heating: 279*72=20.088kWh

The natural gas boilers efficiency is 95% (Energymatters, 2014)

1 m^3 gas is equal to 35,17 MJ. 1 kWh has a heat content of 3,6MJ. 1 m^3 of gas is therefore equal to 35,17/3,6=9,77 kWh ("Omrekening MMBTU naar kubieke meter aardgas," 2019)

The annual gas usage in original state is: 20.088/9,77 (kWh to gas) /0,95 (boiler efficiency) = 2164m^3 gas.

Current gas prices is € 2,65 per 1 m^3 gas (Overstappen.nl, 2022a)

So the annual heating costs are: 2164 * 2,65 = € 5735,-

- Start 2022 road 1

Insulation: no (original building as shown above)

System: Existing gas boiler (assumed 5 years old), a gas boiler has an average life expectancy of 15 years (Energymatters, 2014).

Heating costs: annual gas costs: 2164 * 2,65 = € 5735,-

The power demand for space heating: 100 W/m^2

- 2032 road 1

2032 is the first year that there is an investment needed, the gas boiler is at this stage 15 years old and need to be replaced. A new gas boiler will cost € 2000,-, the replacement is easy since only the boiler needs to be swapped ("Verwarmingsketel kopen? Beste ketels + prijzen 2022," 2022).

The total cost of ownership until 2032 only result from the annual gas costs: 5735*10=€57.350

The total investment costs: only the new gas boiler €2000,-

- 2047 road 1

The gas boiler is now again 15 years old and needs to be replaced.

2050 is approaching fast, only 3 years is left. To adapt this building to the new Standard a lot of investments have to performed in the year 2047.

To apply the building to the new Standard (Cornelisse et al., 2021) performed 3 different options with different measures to apply to the new standard these different measures are according to approach A, a tailor-made advice.

	Meergezinswoning, bouwperiode <1945 (1708406104)		Niveau 3		
Bouwkundig					
	huidige thermische kwaliteit (in WOON 2018 database)		**Mogelijke invulling rekenwaarde**	**Rekenwaarde**	**Herkomst rekenwaarde**
Vloer boven kruipruimte (2,8m²)	R_c = 0,33 m²K/W	(ongeïsoleerde vloer)	**140 mm isolatie onder vloer**	**R_c = 3,50 m²K/W**	**huidige nieuwbouweis**
Gevel	R_c = 0,19 m²K/W	(ongeïsoleerde steensmuur)	geen verbetermaatregelen	R_c = 0,19 m²K/W	ISSO 82.1
Paneel	R_c = 0,23 m²K/W	(ongeïsoleerd paneel)	geen verbetermaatregelen	R_c = 0,23 m²K/W	ISSO 82.1
Hellend dakconstructie	R_c = 0,22 m²K/W	(ongeïsoleerd dak)	**150 mm isolatie tussen spanten/gordingen**	**R_c = 3,50 m²K/W**	**berekend volgens ISSO 82.1**
Plat dakconstructie	R_c = 0,22 m²K/W	(ongeïsoleerd dak)	**150 mm isolatie tussen spanten/gordingen**	**R_c = 3,50 m²K/W**	**berekend volgens ISSO 82.1**
Ramen	U_w = 5,10 W/m²K	(36% enkel glas)	**HR++-glas, houten/kunststof kozijn**	**U_w = 1,40 W/m²K**	**kwaliteitsverklaring**
	U_w = 2,90 W/m²K	(64% dubbel glas)	**HR++-glas, houten/kunststof kozijn**	**U_w = 1,40 W/m²K**	**kwaliteitsverklaring**
Deuren	U_d = 3,4 W/m²K	(ongeïsoleerde deur)	ongeïsoleerde deur	U_d = 3,40 W/m²K	ISSO 82.1
Infiltratie	bouwjaar 1896		**verbeterde kierdichting**	$q_{v-10;kar}$ = 1,80 dm³/s·m²	forfaitaire rekenwaarde, geen renovatiejaar
Installatietechnisch					
Ventilatiesysteem	systeem A		**C2. natuurlijke toevoer - mechanische afvoer (luchtdrukgestuurde roosters)**		
Algemene kenmerken					
Bouwjaar	1896				
Gebruiksoppervlakte	72 m²				
Compactheid	1,71				
Oriëntatie	Noord-west / zuid-oost				
Warmtevraag	**279 kWh/m²**		**107 kWh/m²**		

Niveau 3 - maatwerk variant 1			Niveau 3 - maatwerk variant 2		
Mogelijke invulling rekenwaarde	**Rekenwaarde**	**Herkomst rekenwaarde**	**Mogelijke invulling rekenwaarde**	**Rekenwaarde**	**Herkomst rekenwaarde**
geen verbetermaatregelen	R_c = 0,33 m²K/W	(ongeïsoleerde vloer)	geen verbetermaatregelen	R_c = 0,33 m²K/W	(ongeïsoleerde vloer)
140 mm isolatie in voorzetwand	**R_c = 3,47 m²K/W**	**kwaliteitsverklaring**	**140 mm isolatie in voorzetwand**	**R_c = 3,47 m²K/W**	**kwaliteitsverklaring**
geen verbetermaatregelen	R_c = 0,23 m²K/W	(ongeïsoleerd paneel)	geen verbetermaatregelen	R_c = 0,23 m²K/W	(ongeïsoleerd paneel)
150 mm isolatie tussen spanten/gordingen	**R_c = 3,50 m²K/W**	**berekend volgens ISSO 82.1**	**150 mm isolatie tussen spanten/gordingen**	**R_c = 3,50 m²K/W**	**berekend volgens ISSO 82.1**
150 mm isolatie tussen spanten/gordingen	**R_c = 3,50 m²K/W**	**berekend volgens ISSO 82.1**	**150 mm isolatie tussen spanten/gordingen**	**R_c = 3,50 m²K/W**	**berekend volgens ISSO 82.1**
geen verbetermaatregelen	U_w = 5,10 W/m²K	(36% enkel glas)	**monumentenglas (dubbel glas)**	**U_w = 2,90 W/m²K**	**Forfaitaire rekenwaarde dubbel glas**
HR++-glas, houten/kunststof kozijn	**U_w = 1,40 W/m²K**	**kwaliteitsverklaring**	geen verbetermaatregelen	U_w = 2,90 W/m²K	(dubbel glas)
geen verbetermaatregelen	U_d = 3,40 W/m²K	(ongeïsoleerde deur)	geen verbetermaatregelen	U_d = 3,40 W/m²K	(ongeïsoleerde deur)
geen verbetermaatregelen	forfaitaire rekenwaarde	bouwjaar 1896	**verbeterde kierdichting**	$q_{v-10;kar}$ = 1,80 dm³/s·m²	forfaitaire rekenwaarde, geen renovatiejaar
C1. natuurlijke toevoer - mechanische afvoer			**C1. natuurlijke toevoer - mechanische afvoer**		
106 kWh/m²			**107 kWh/m²**		

In the report TNO 2020 P11608 was analysed what these measures would cost (Menkveld, Rovers, en Arjan, & van Binnenlandse Zaken, 2020).

The cost of the 3 tailor made advices are as following (Figure 114):

Tabel 6-17 Kosten varianten meergezinswoning 2

	Niveau 3		Variant 1		Variant 2	
Warmtevraag	**107 kWh/m²**		**106 kWh/m²**		**107 kWh/m²**	
Vloer	Isolatie 140 mm	€ 121				
Gevel			Isolatie voorzetwand 140 mm	€ 1.753	Isolatie voorzetwand 140 mm	€ 1.753
Dak	Isolatie 150 mm	€ 6.067	Isolatie 150 mm	€ 6.067	Isolatie 150 mm	€ 6.067
Glas	HR++ glas i.p.v. enkel/dubbel glas	€ 854	HR++ glas i.p.v. dubbel glas	€ 510	Monumentenglas i.p.v. enkel glas	€ 446
Infiltratie	Kierdichting	€ 447			Kierdichting	€ 1.143
Ventilatie	Ventilatiesysteem C4a i.p.v. A	€ 3.672	Ventilatiesysteem C1	€ 3.565	Ventilatiesysteem C1	€ 3.565
Meerkosten op natuurlijk moment		***€ 11.160***		***€ 11.895***		***€ 12.975***
Totale kosten op zelfstandig moment		*€ 17.066*		*€ 17.107*		*€ 17.979*

Figure 114. Costs meeting the Standard multi-family home <1945

So the investment costs to make this house meet the new standard are around €17.000,-

The new net heat demand after insulating and changing the ventilation system is: 107 kWh/m2.jr

Again the power demand for space heating must be re-established. Looking at (Figure 113) the new net heat demand after meeting de Standard is 107 kWh/m2.jr which corresponds with a corner dwelling from 2000-2010 which has a net heat demand of 114 kWh/m2.jr. The corresponding heat demand will be 70W/m². Again this may be incorrect since the heat demand since the heat demand for space heating should actually be determined according to the ISSO51 maar but this table gives a guideline.

Effect on the heat emission system:

Heat emission system: the original heat emission system was designed to heat up the building with a supply temperature of 90°C to 100W/m². Now it has to be checked whether lowering the supply temperature of the original radiators still can deliver enough heat namely 70W/m².

For convenience we take a room of 10m².

The original heat demand would be: 10*100=1000Watt for that room

According to (warmtepomp-paneel, nd) a radiator with the size: T22 H300 W800 could deliver a 1000Watt with a supply of 90°C and return of 70°C at a room temperature of 20°C. So in case the radiator would be designed perfectly according the heat demand this would be the size. But in practice radiators are almost always over dimensioned, in order to guarantee indoor comfort or a higher preferred room temperature by the occupant.

Radiatorgegevens:	Waarde:
Type:	22
Hoogte:	300 mm.
Breedte :	800 mm.
Aanvoertemp.:	90 °C.
Retourtemp.:	70 °C.
Gewenste kamertemp.:	20 °C.

Bereken warmteafgifte

Resultaat:

Warmteafgifte radiator bij:	Watt
75/65/20 (EN-442):	791
Uw situatie bij 90/70/20:	1001
Met boosterventilatoren bij 90/70/20:	1390

https://warmtepomp-panel.nl/dbe2.html

After meeting the Standard the heat demand of the room will be: 10*70(W/m^2)=700Watt.

Lowering the supply temperature of the radiator to the maximum supply temp of a heat pump with a reasonable COP will be supply of 55°C. The same radiator T22 H300 W800 could deliver 378Watt at a supply and return temp of 55°C and 43°C. The 55°C and 43°C are from (table: Suitable delivery temperature for use with heat pumps, empirical research). This would be too low. Installing booster fans would increase this power to 560Watt but this is still not enough and it would decrease the indoor comfort in terms of noise.

Radiatorgegevens:	Waarde:
Type:	22
Hoogte:	300 mm.
Breedte :	800 mm.
Aanvoertemp.:	55 °C.
Retourtemp.:	43 °C.
Gewenste kamertemp.:	20 °C.

Bereken warmteafgifte

Resultaat:

Warmteafgifte radiator bij:	Watt
75/65/20 (EN-442):	791
Uw situatie bij 55/43/20:	378
Met boosterventilatoren bij 55/43/20:	560

https://warmtepomp-panel.nl/dbe2.html

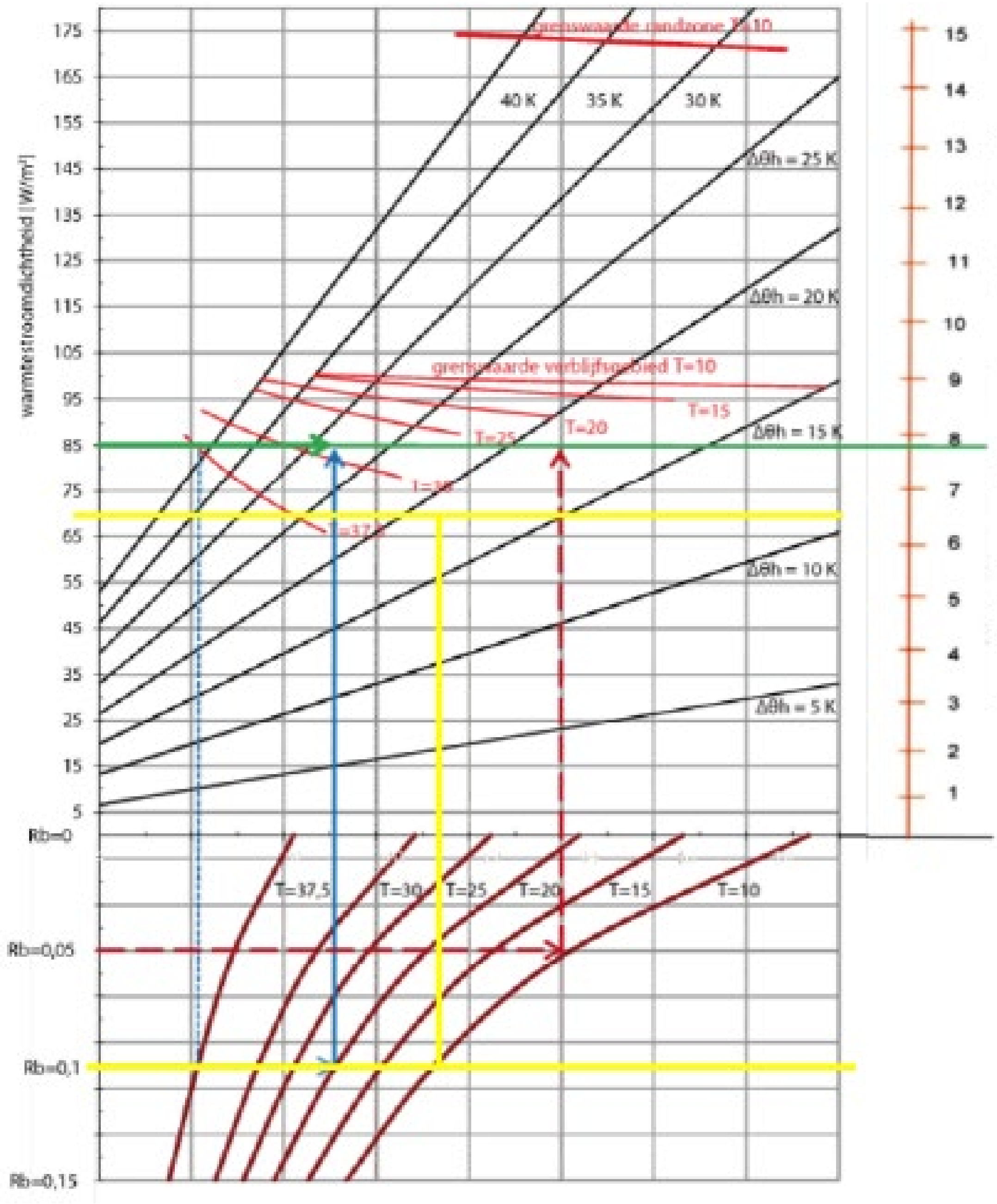
So even after insulating and meeting the Standard the heat delivery system needs to be upgraded, to get the building warm at a lower supply temperature.

The two options are: add more additional radiators, or replace radiators with low temperature radiators, or replace the radiators with floor heating.

This example will be replacing existing radiators with floor heating: This can ensure an even lower supply temp and thus a higher COP of the heat pump and no fan noise of low temperature radiators. And if it's chosen to meet the Standard by placing retaining walls, the existing radiators would then have to be removed anyway.

The maximum heat emission is limited by the floor temperature as discovered during the 'empirical research' which is a maximum heating capacity of 100W/m^2 in the living zone, and a maximum heating capacity of 170W/m^2 in the edge zones. So the needed 70W/m^2 can be reached with floor heating. And in case of meeting the standard the newly insulated windows will prevent cold trap. A little cold trap can be prevented by increasing the floor heat emission power by placing the floor heating pipes closer together close to the façade in case of windows.

The goal when applying floor heating is to bring the supply temperature down as low as possible in order to increase the COP of the heat pump, which will result in lower electricity demand. Therefore the distance of the pipes will be chosen as dense as possible, without exceeding limit values.



The determination is according to ISSO 49

From the specific heat demand (70 W/m^2) is a horizontal line drawn (yellow).

From the heat resistance of the finishing layer Rb=0,1 which is a relatively bad layer in terms of heat transport (5mm thick carpet) is a horizontal line drawn (yellow).

Than a vertical line is drawn between the two horizontal lines starting from T=10, which is a centre to centre distance of 10 cm. The vertical line cuts the horizontal specific heat demand line below the 'grenswaarde verblijfsgebied T=10' which means that the 70 W/m2 will can be reached without exceeding the maximum floor surface temperature.

Now is determined that the specific heat demand can be reached without exceeding the maximum floor surface temperature and therefore will not affect the indoor comfort in a bad way.

The next step is to determine the supply water temperature:

the difference between s between supply and return temperatures is approximately 5K. With a smaller s-value, a lot of liquid has to be pumped which costs a lot of pumping energy. Larger differences easily lead to big differences in heat emission across the floor area, which leads to discomfort. (ISSO 49).

The supply water temperature θw,I is calculated with the following formula: $\theta_{w,i} = \Delta\theta_h + \theta_i + \sigma/2$ (ISSO 49).

Δθ h = mean overtemperature (following from design diagrams) [K]

θ i = design indoor temperature [ºC]

σ = difference between supply and return water temperature [K]

Δθ h is the intersection between the horizontal specific heat demand line and the vertical line, the intersection lays between Δθ h = 15K and Δθ h = 20K more towards Δθ h = 20K and is in this case Δθ h = 18 K

The indoor design temperature is chosen as θ i = 20 degrees

σ = 5K

The supply water temperature is in this case: $\theta_{w,i} = \Delta\theta_h + \theta_i + \sigma/2 = 18+20+5/2=40{,}5$°C

The costs for floor heating 72m^2 are around €6000 (Verbouwkosten B.V., 2022)..

So the analysed multi-family home from 1896 which falls in the category of the Standard: 'Multi family home < 1945 with compactness > 1' which complies after the tailor made approach to the meet the standard as shown in (**Error! Reference source not found.**) as performed by (Cornelisse et al., 2021), still needs a heat emission system adjustment to be comfortable heated with a low temperature source.

This confirms the concerns suggested by 'Techniek Nederland' in the report 'Standaard en Streefwaarden: uitkomst traject begeleidingscommissie' (Energie, 2021) who said that the standard primarily focuses on reducing the net heat demand, but that it's essential that we need to continue a approach for a comfortable and energy-efficient home from an integral point of view and that this lead to heat emission adjustment in homes. According to 'Techniek Nederland' there is a urgent appeal to ensure the necessary adjustments to the heat emission system when communicating the Standard and target values (Energie, 2021).

From the analysed home can be concluded that: 'Multi family home < 1945 with compactness > 1' in this example case do need an adjustment to the heat delivery system whilst compiling to the Standard. The original radiators could be changed to floor heating with a pipe distance of 10 cm. There is extra research needed if for example low temperature radiators or convectors can heat up the home to a comfortable temperature. As long as the power of the heat emitter at a low temperature (< 55 degrees) is higher than the specific heat demand of the home, the building can be kept warm.

The heat generator: in this example low temperature heat pump

While designing the heat emission system the supply temperature is designed as low as possible depending on the energetic qualities of the home, this resulted in a supply temp of 40,5 °C.

A supply temp of 40,5 results in a SCOP of about: 3,3

The price of a in this example low temperature air to water heat pump is about €7.500 ("Kosten warmtepomp [2022]: prijzen + info," 2021)

The size of the heat pump will be the specific heat demand times the floor are 70*72=5.04 kW, as discovered during the 'emperical research' the size is always related to the heat demand as the domestic hot water needs are lower.

Annual heat demand of the home after insulating is 107*72=7.704kWh

This will result of an yearly electricity usage for space heating of: 7.704/3,3=2335kWh

This will result in yearly electricity costs for space heating: 2335*0,635=€1.483

Cost overview in 2047 road 1

Total costs made until now:57.350(TCO 2032)+2000(investment 2032)+5735(yearly heating costs)*15= €145.375

Total investment costs in 2047: Tailor made insulation to reach the Standard €17.000 + Floor heating €6000 + Heat pump €7.500 = €30.500

Annual heating costs from 2047 on: €1.483

2050 road 1

Total costs made until no (TCO): 145.375 (TCO 2047)+30.500(investment 2047)+1.483(yearly heating costs)=€180.324

And the home is 'natural gas-free-ready'

Conclusion 1st road

This 1st road let to a home which is insulated according to the proposed Standard (Energie, 2021). The buildings heat emission system is changed during the road and is now capable of keeping the building comfortably warm at a low supply temp (<55). The home is currently heated with a sustainable heat source (heat pump) which still has a life expectancy of 17 years left. So there are no further investments needed until 2067.

The second road

For the second road to 2050 there will be a slightly different approach. First the building will be insulated according to the new Standard with the same tailor made approach as done by (Cornelisse et al., 2021), this will reduce the heating costs from moment 1. The gas boiler will be replaced with a low temperature heat pump and floor heating as soon as it's at the end of its life.

2022 road 2

Costs meeting the Standard: €17.000 (Figure 114).

The net heat demand after meeting the Standard is the same as in road 1: 107 kWh/m2.jr

The power demand for space heating after meeting the standard is the same as in road 1: 70W/m^2

The annual heating costs will be: 107 (net heat demand) * 72 (floor area) = 7704 kWh.jr

7704/0,95 (boiler efficiency) = 8109 kWh

8109/9,77(gas to kwh)=830 m^3 gas a year

Annual heating costs: 830 * 2,65 (current gas price per m3) = €2200,-

2032 road 2

The gas boiler is now 15 years old and needs to be replaced.

TCO 2023: 17.000(investment 2022)+2200(annual heating costs)*10=€39.000

As investigated in road 1 the heat emission system needs to be replaced in order to keep the home warm at a low supply temperature.

The investment costs for floor heating are again €6000,- (Verbouwkosten B.V., 2022).

The investment costs for the heat pump are again €7500,- ("Kosten warmtepomp [2022]: prijzen + info," 2021)

The new annual heating costs will be again: 107*72/3,3*0,635=1.483,-

The total investment costs in 2032 will be: 6000 (floor heating) + 7500 (hp) = €13.500

2050 road 2

TCO 2050: 39.000 (TCO 2023) + 13.500 (investment 2032) + 1.483*18=€79.194

The home is insulated according to the Standard (Energie, 2021)

The home and its heat emission system are ‘natural gas-free-ready’.

The heat pump needs to be replaced in 2 years 2052

Then the heat pump can be replaced for a new one, or the home can be directly connected to a low temperature heat network

Conclusion road 2

The investment costs are more spread out compared to road 1 and the TCO in 2050 is much lower compared to road 1.

Road 3 is a approach with a trend we currently see with more people buying a hybrid heat pump. But then along the road to 2050 the building needs to be insulated sometime to be ‘natural gas-free-ready’ by 2050.

2022 road 3

A hybrid air to water heat pump costs around €6000,- (kemkens, nd).

The original net heat demand of the building is: 279*72=20.088 kWh.jr

A hybrid heat pump covers around 60% of the total heat demand as found out in part 3 of the empirical research.

Total net heat demand covered by the heat pump: 20.088/100*60=12.053 kWh

SCOP 4,3 (Buiting, 2022) the SCOP is higher than the air to water heat pump because as found out during the ‘emperical research’ a hybrid heat pump starts heating at an outdoor temperature of +4 degrees. The SCOP could in this case be lower than the 4,3 as stated by (Buiting, 2022) due to the original high supply temperature of the building. In this example, the hybrid system will perform in real life slightly worse, because the SCOP will be lower than 4,3 because the home is not insulated first and so the supply temperature must be higher a longer period of the year.

Annual electricity used by HP: 12.053/4,3=2803kWh

Annual electricity costs HP: 2803*0,635=€1780,-

The other 40% of the net heat demand is covered by the existing gas boiler: 20.088/100*40=8035kWh

The annual amount of gas used: 8035/0,95(boiler efficiency)/9,77(kWh to m^3 gas)=865m^3

Yearly gas costs: 865*2,65=€2292,-

2032 road 3

TCO: 6000 (investment 2022) + 1780*10+2292*10=€46.720

The existing gas boiler is at this stage 15 years old and needs to be replaced. The hybrid heat pump will still last another 5 years, so only the gas boiler will be swapped.

A new gas boiler costs: €2000,-

2037 road 3

TCO: 46.720(TCO 2032) + 2000 (investment 2037) + 1780*5+2292*5=€69.080

At this stage the hybrid heat pump needs to be replaced but the in 2023 replaced gas boiler will still last another 10 years. Instead of replacing the hybrid heat pump in this road the option of insulating according the Standard is chosen.

Insulating the building according the Standard will cost the same as shown before: €17.000

The net heat demand will be lowered to: 107 kWh/m2.jr

The gas boiler from 2032 will be used for space heating the upcoming 10 years.

The annual costs from space heating will be: 107*72/0,95/9,77*2,65=€2200,-

2047 road 3

TCO: 69.080 (TCO 2037) + 17.000 (investment 2037) + 2200 (annual heating costs) * 10 = € 108.080

At this stage the gas boiler is 15 years old and needs to be replaced. As the building needs to be gas free ready by 2050 the heat emission system must be replaced. The costs for floor heating: €6.000. In this example again there is chosen for a low temperature heat pump, since it is unclear if there will be a low temperature heat network available in the upcoming 3 years.

The costs for the low temperature heat pump again are: €7.500

This will result in the total investment costs of: € 13.500

The annual electricity costs for space heating become: the same as in road 1 (2047)= € 1.483

2050 road 3

TCO: 108.080 (TCO 2047) + 13.500 (investment 2047) + 1.483*3=€126.029

The home is now completely natural gas free and ready for a low temperature heat network.

The existing heat pump will last until 2067

Road 4 has a slightly different approach than road 3. Firstly the building is insulated according the Standard and then when the existing heat pump needs to be replaced the gas boiler will be swapped with a new gas boiler + hybrid heat pump.

2022 Road 4

To bring the home up to the Standard according to the tailor made advice by (Cornelisse et al., 2021) again an investment of €17.000 is needed.

The annual heating costs will be: 107*72/0,95/9,77*2,65=€2200,-

2032 road 4

TCO 17.000 (investment 2022) + 2200(annual heating costs)*10=€39.000

The existing gas boiler is in the meanwhile 15 years old and needs to be replaced.

In this case there is chosen for a new gas boiler €2000 in combination with a hybrid heat pump €6000

The total investment costs become: 2000+6000=€8000,-

The heating costs are calculated as following: 107*72=7704kWh.jr

60% is covered by the hybrid heat pump: 7704/100*60=4622kWh

SCOP hybrid heat pump is 4,3 resulting in electricity demand of: 4622/4,3=1045kWh

This efficiency is probably correct since the hybris is used after insulating, and the supply temperature can therefore be lower a longer period during the year.

Annual electricity costs for heating: 1045*0,635=€664,-

40% of net heat demand covered by gas boiler: 7704/100*40=3082kWh

Annual gas costs for heating: 3082/0,95(boiler efficiency)/9,77*2,65(gas price per m^3)=€880,-

2047 road 4

TCO: 39.000 (TCO 2032) + 8000 (investment 2032) + 664*15+880*15=€70.160

The gas boiler and hybrid heat pump are both 15 years old and need to be replaced. To make the home gas free ready up to 2050 the heat emission system needs to be changed. Floor heating will cost again €6000 for this home. As it is unclear if there will be a heat network available by 2050 the gas boiler and hybrid heat pump are now changed to an all-electric heat pump. The costs of this all electric system are again €7500.

The total investment costs in 2047 are: 6000+7500=€13.500

The new annual heating costs will be again: 107*72/3,3*0,635=1.483,-

2050 road 4

TCO: 70.160 (TCO 2047) + 13.500 (investment 2047) + 1483*3=€88.109

The home is natural gas free ready and the heat pump lasts until 2067

Road 5 starts again with a hybrid heat pump, but during the road different choices are made compared to road 3 which also started with a hybrid heat pump next to the existing gas boiler.

2022 road 5

The hybrid heat pump costs: €6000 (same as start road 3)

Annual electricity costs HP: 2803*0,635=€1780,- (same as start road 3)

Yearly gas costs: 865*2,65=€2292,- (same as start road 3)

2032 road 5

TCO: 6000 (investment 2022) + 1780*10 + 2292*10=€46.720

The existing gas boiler is now 15 years old and needs to be replaced.

The hybrid heat pump still lasts another 5 years.

A new gas boiler costs: €2000

There is also chosen to insulate the building to reduce the annual heating costs.

Insulating: €17.000

Annual electricity costs for heating: 1045*0,635=€664,-

Annual gas costs for heating: 3082/0,95(boiler efficiency)/9,77*2,65(gas price per m^3)=€880,-

2037 road 5

TCO: 46.720 (TCO 2032) + 19000 (investment 2032) + 664*5 + 880*5= € 73.440

The hybrid heat pump is now 15 years old and needs to be replaced, the gas boiler can still last another 10 year. Because the ages of the boiler and the heat pump are not the same, there is now chosen to not replace the heat pump but let the gas boiler work till the end of its life.

The annual heating costs will be: 107*72/0,95/9,77*2,65=€2200,-

2047 road 5

TCO: 73.440 (TCO 2037) + 2200*10 = €95.440

The gas boiler is now 15 years old and needs to be replaced.

In order to make the home natural gas free ready the heat emission system needs to be replaced by floor heating which costs: €6000,-

The Low temperature heat pump costs: €7500

The new annual heating costs will be: 107*72/3,3*0,635=1.483,-

2050 road 5

TCO: 95.440 (TCO 2047) + 13.500 (investment 2047) + 1.483*3=€113.389

The building is natural gas free ready and insulated according the Standard.

The installed heat pump will last until 2067

Road 6 is the approach with the highest investment costs in 2022. The whole house is insulated to the Standard. The heat emission system is adjusted for a low temperature source and a low temperature heat pump is installed.

2022 road 6

Home insulating according to the Standard: €17.000

Floor heating system: €6000

Low temperature heat pump: €7500

The new annual heating costs will be: 107*72/3,3*0,635=1.483,-

2042 road 6

TCO: 30.500 (investment 2022) + 1483*20= 60.160

The heat pump is 20 years old and needs to be replaced

New heat pump costs: €7.500

Annual heating costs: €1.483

2050 road 6

TCO: 60.160 (TCO 2042) + 7500 (investment 2042) + 1483*8=€79.524

The home is natural gas free ready and the heat pump lasts until 2062

Route 7 takes a completely different approach, there is currently innovation on the heat pump market ongoing in making heat pumps with higher output temperatures. Vattenfal says that this is a better option for consumers if they want to avoid high insulation costs (Vattenfall, 2022). In this route will be checked wat the outcome will be in terms of a high temperature system.

Start 2022 road 7

The building is not getting insulated since the heat pump can deliver the supply temperature at a high enough temperature.

The price of the high temperature heat pump is: €15.000

SCOP: 2,3 as found out in empirical research

The annual net heat demand without additional insulation is: 279*72=20.088kWh

The annual electricity used: 20.088/2,3=8734kWh

The annual operating costs are: 8.734*0.635=€5.546

The life expectancy of a high temperature heat pump is 15 years (as determined during empirical research)

2037 road 7

TCO: 15.000(investment 2022) + 5.546(annual heating costs)*15=€98.190

The heat pump is now 15 years old and needs to be replaced.

In this example is chosen for replacing the high temperature heat pump with a new one.

The new high temperature heat pump costs: €15.000

2050 road 7

TCO: 98.190 (TCO 2037) + 15.000 (investment 2037) + 5.546*13= € 185.288

The building is not natural gas free ready, the buildings insulation value and heat emission system are not ready for a low temperature heat network and the high temperature heat pump must be replaced in 2 years.

CO_2 and energy usage different roads

NTA 8800 0,183 kg CO2 per kWh Gas

NTA 8800 0,340 kg CO2 / kWh Electricity

(Insulated) Gas boiler annual CO2 emissions: 7704/0,95(boiler efficiency)*0,183(kg CO2 per kWh according to NTA 8800)=1.484 kg CO2/year

(Insulated) Gas boiler + hybrid hp CO2 emissions: (7704/100*40/0,95*0,183)+(7704/100*60/4,3*0,34)=960kg CO2/year

(Insulated) All electric heat pump: 7704/3,3*0,34=794kg CO2/year

(Uninsulated) Gas boiler CO_2 emissions: 20.088/0,95*0,183=3.870 kg CO2/year

(Uninsulated) Gas boiler + hybrid hp CO2 emissions: (20088/100*40/0,95*0,183)+(20088/100*60/4,3*0,34)=2501 kg CO2/year

(Uninsulated) High temperature heat pump: 20088/2,3*0,34=2970 kg CO2/year

Energy usage

(Insulated) Gas boiler annual energy: 7704/0,95=8.109 kWh

(Insulated) Gas boiler + hybrid hp energy annual: 3244+1075=4.319 kWh

(Insulated) All electric heat pump annual energy: 2335 kWh

(Uninsulated) Gas boiler CO_2 emissions: 20.088/0,95=21.145 kWh

(Uninsulated) Gas boiler + hybrid hp CO2 emissions: (20088/100*40/0,95)+(20088/100*60/4,3)=11.261 kWh

(Uninsulated) High temperature heat pump: 20088/2,3=8.734 kWh

Road 1

CO_2

2022 to 2047, 25 years * 3.870 = 96.750 kg CO_2

2047 till 2050, 4 years * 794 =14.840 kg CO_2

Total: 96.750+14.840=111.590 kg CO_2

Primary energy usage

2022 to 2047, 25 years * 21.145 = 528.625 kWh

2047 till 2050, 4 years * 2335 = 9.340 kWh

Total: 317.175 + 9.340 = 537.965 kWh

Road 2

CO_2

2022 to 2032, 10 years * 1.484 kg = 14.840 kg CO_2

2032 till 2050, 19 years * 794 = 15.086 kg CO_2

Total: 14.840 + 15.086 = 29.926 kg CO_2

Primary energy usage

2022 to 2032, 10 years * 8.109 = 81.090 kWh

2032 till 2050, 19 years * 2335 = 44.365 kWh

Total: 81.090 + 44.365 = 125.455 kWh

Road 3

CO_2

2022 to 2037, 15 years * 2501 kg = 37.515 kg CO_2

2037 to 2047, 10 years * 1.484 = 14.840 kg CO_2

2047 till 2050, 4 years * 794 = 3.176 kg CO_2

Total: 37.515 + 14.840 + 3.176 = 55.531 kg CO_2

Primary energy usage

2022 to 2037, 15 years * 11.261 = 168.915 kWh

2037 to 2047, 10 years * 8.109 = 81.090 kWh

2047 till 2050, 4 years * 2335 = 9.340 kWh

Total: 168.915 + 81.090 + 9.340 = 259.345 kWh

Road 4

CO_2

2022 to 2032, 10 years * 1.484 kg = 14.840 kg CO_2

2032 to 2047, 15 years * 960 = 14.400 kg CO_2

2047 till 2050, 4 years * 794 = 3.176 kg CO_2

Total: 14.840 + 14.400 + 3.176 = 32.416 kg CO_2

Primary energy usage

2022 to 2032, 10 years * 8.109 = 81.090 kWh

2032 to 2047, 15 years * 4.319 = 64.785 kWh

2047 till 2050, 4 years * 2335 = 9.340 kWh

Total: 81.090 + 64.785 + 9.340 = 155.215 kWh

Road 5

CO_2

2022 to 2032, 10 years * 2501 kg = 25.010 kg CO_2

2032 to 2037, 5 years * 960 = 4.800 kg CO_2

2037 to 2047, 10 years * 1.484 = 14.840 kg CO_2

2047 till 2050, 4 years * 794 = 3.176 kg CO_2

Total: 25.010 + 4.800 + 14.840 + 3.176 = 47.826 kg CO_2

Primary energy usage

2022 to 2032, 10 years * 11.261 = 112.610 kWh

2032 to 2037, 5 years * 4.319 = 21.595 kWh

2037 to 2047, 10 years * 8.109 = 81.090 kWh

2037 to 2047, 4 years * 2335 = 9.340 kWh

Total: 112.610 + 21.595 + 81.090 + 9.340 = 224.635 kWh

Road 6

CO_2

2022 to 2050, 29 years * 794 kg = 23.026 kg CO_2

Total: = 23.026 kg CO_2

Primary energy usage

2022 to 2050, 29 years * 2335 = 67.715 kWh

Total: 67.715 kWh

Road 7

CO_2

2022 to 2050, 29 years * 2970 kg = 86.130 kg CO_2

Total: = 86.130 kg CO_2

Primary energy usage

2022 to 2050, 29 years * 8.734 = 253.286 kWh

Total: 253.286 kWh

Calculations used for the table different roads to 2050 insulated multi family home <1945

Meergezinswoning: galerij-/portiekwoning <1945	Dubbele bovenwoning	
General features		
Construction year:	1896	
Surface area:	72	
Compactness ratio:	1,71	
Orientation	North-west / south-east	
Net heat demand	107 kWh/m2.jr	
Power demand for space heating	70W/m2 (calculation see below)	
Technical systems		**Explanation**
Ventilation system	System C1	Natural ventilation
Heat generator	Gas boiler	Assumed 5 years old
Heat delivery system	Traditional radiators	
Building characteristics	**Thermal quality**	

Meergezinswoningen, voor 1945	< 1,00	= 95
	≥ 1,00	=95 + 70 * (A_{ls}/A_g - 1,0)

Infiltration	Construction year 1896

This multi family home <1945 with a compactness factor of 1,71 has a net heat demand of 107 kWh/m2.jr. To verify if the building already meats the Standard a small calculation has to be made.

According to the standard the net heat demand may be at max: 95+70*(Als/Ag -1,0)

By filling in the formula we find the maximum allowed net heat demand: 95+70*(1,71-1,0)=144,7 kWh/m2.jr, so this dwelling meets the requirements of the standard.

The next step is to check whether the heat emission system is capable of heating the building at a lower supply temperature.

Therefore the power demand for space heating is needed, as calculated in the earlier in the empirical research this is 70W/m^2.

As checked before in the empirical research the assumed dimensions of the existing radiators are not capable of keeping the home warm at a lower supply temperature. Earlier in the empirical research was chosen for a floor heating system as the retaining walls ensured that the original radiators had to be removed anyway.

In this example there is chosen for a different way of insulating but still meeting the standard the tailor made approach is again defined by (Cornelisse et al., 2021). As in (Figure 114) can be seen for this road to 2050 is assumed that the building is insulated with: Floor insulation, roof insulation, glass, air tightness and ventilation system. There is assumed that the residents have chosen for this approach since the home was inhabited and they didn't want to place retaining walls so the radiators had to be moved.

And because the home is still inhabited for this road to 2050 is chosen of a heat emission system replacement with low temperature radiators.

In order to do this the amount of existing radiators must be known and the dimensions. The dimensions of the existing radiators can be mentioned with a ruler and then the amount of low temperature radiators and the size can be determined.

This multifamily house 1896 is taken from the WOON 2018 database by (Cornelisse et al., 2021). But the floor plans and existing radiators cannot be get from the WOON 2018 database nor the report of (Cornelisse et al., 2021). So for this example a there is made a estimation of the amount of radiators. From the report becomes clear that the home is a 'dubbele bovenwoning' with a floor area of 72m^2.

Now an estimation is needed for the amount of radiators in the home and their size. It is estimated that the ground floor is 36m^2 with a combined kitchen and living room and that second floor has two bedrooms of around 15m^2 and a small bathroom. The radiators in the existing home are probably dimensioned with a standard easy radiator formula, these simple formula ensures that the home gets heated well but the radiators are probably oversized. The estimation is made that the existing gas boiler will deliver the supply temperature at 80 degrees.

Estimation of the existing radiators an power output according to (badkamerxxl, nd)

Livingroom + kitchen: 36m^2 * 2,7 (estimated height) * 77 watt (rule of thumb radiator)=7484Watt

Bedroom: 15*2,7*60=2430Watt, results in: 500H x 1600H T22 2644 Watt (warmtepomp-paneel, nd)

Bedroom: 15*2,7*60=2430Watt, results in: 500H x 1600H T22 2644 Watt at 80 degrees (warmtepomp-paneel, nd)

Bathroom: 4*2,7*85=1022Watt, result design radiator (towel) 600B*1495H (radik bron)

1 radiator living room side: 600H 2000B T22 3834 Watt at 80 degrees (warmtepomp-paneel, nd)

1 radiator kitchen side: 900H 800B T22 2168 Watt at 80 degrees (warmtepomp-paneel, nd)

1 radiator in between kitchen and living room: 600H 1100B T21 1747 Watt (warmtepomp-paneel, nd)

The above radiators give summed up a total power output of: 2638+2638+1022+3814+2106+1609=13.827 Watt at 80 degrees supply temperature

This is far above the by key figures determined power demand for space heating of 100W/m^2 resulting in 72*100=7.200Watt

But most of the radiators in existing buildings are dimensioned with these rule of thumb by plumbers. They are provided by hot supply temperature around 80 degrees by an over dimensioned gas boiler, as over dimensioned gas boilers hardly bring any extra costs (Linssen, 1993).

Power demand for space heating

As determined before the power demand for space heating after insulating based on key figures will be: 70W/m^2.

So the total power demand for space heating will be: 70*72=5040Watt

Now that the dimensions of the existing radiators have been determined, is the next step to check if the heat emission system can deliver the needed power demand for space heating after renovation at a lower supply temperature.

The 70W/m^2 is for the whole home but the demands on room level can differ a little bit.

The temperature in the bedrooms is in general lower compared to the other rooms (Maeyaert).

The temperature in the living room can be higher due to higher temperature needs of the residents, because in that room the most of the time is spend.

And the 70W/m^2 is for the complete floor area of the home, but there are always unheated places where there is no radiator for example the landing upstairs or the toilet or a possible existing walk-in closet. So the radiators should fulfil the power demand for space heating on room level, but in total the power demand of all the radiators combined should be the total power demand for space heating of the building since radiators will also heat unheated spaces next to the room.

Therefore it is necessary that the power demand for space heating is reached in the living room and that is also the most critical departure. Because the 70W/m^2 is based on key figures and not on a ISSO 51 calculation there is a security factor estimated for the living room of + 20W/m^2, but again this is still based on a estimation for fear that the residents are out in the cold. So further research later in this thesis is needed to investigate whether an ISSO 51 calculation deviates a lot from this key number on living room level.

The room temperature has been chosen for all the rooms at 20 degrees for the output power of the radiators

Room	Area	W/m^2	W needed	Radiator size	Amount of radiators	Original output at 80/70	Output at 55/43	Output 55/43 + Booster fan	Output 42/34	Output 42/34 + Booster fan
Livingroom + Kitchen	36	90	3240	600H 2000B T22	1	3834	1611	2386	852	1317
				900H 800B T22	1	2168	911	1349	482	745

				600H 1100B T21	1	1747	734	1087	388	600
Combined						7749	3256	4822	1722	2662
Bedroom	15	70	1050	500H 1600B T22	1	2644	1111	1645	588	909
Bedroom	15	70	1050	500H 1600B T22	1	2644	1111	1645	588	909
Bathroom	4	70	280	600B 1500H	1	1022	449	-	245	-
Total rooms			5620							
Total floor area of the home	72	70	5040							

As can be seen in the table the original assumed radiator sizes in this example will deliver enough output power at a supply temperature of 55 degrees, as the output power is higher than the needed power. According to the Standard, a home with a construction year of <1945 with a delivery temperature lower than 70 degrees, a limited adjustment of the heat emission system is probably necessary in some of the homes to ensure that the home can be heat up (Energie, 2021). But in this example as we can conclude from the table above the home from 1896 can be heated at a supply temperature of 55 degrees without changing the heat emission system. But this small part of the research contains too many uncertainties to make the conclusion that all the homes from 1896 and other homes can be heated without changing the heat emission system after meeting the Standard in terms of insulation, as the radiators could always be dimensioned different.

The following uncertainties need to be tackled to verify the need for change of the heat emission system:

First uncertainty: Power demand for space heating on room level (ISSO 51)

Second uncertainty: The sizes and amounts of existing radiators (USER INPUT)

But for now is assumed that this example home can be heated with the existing heat emission system at a supply temperature of 55 degrees.

CO2 reduction till 2050

NTA 8800 0,183 kg CO2 per kWh Gas

NTA 8800 0,340 kg CO2 / kWh Electricity

Gas boiler annual CO2 emissions: 7704/0,95*0,183=1.484kg CO2/year

Gas boiler + hybrid hp CO2 emissions: (7704/100*40/0,95*0,183)+(7704/100*60/4,3*0,34)=960kg CO2/year

All electric heat pump: 7704/3*0,34=873kg CO2/year

Road 1:

Primary gas consumption: 7704/0,95(boiler efficiency)=8109kWh primary gas consumption per year

CO2 gas emissions delivered at home NTA 8800: 0,183 kg CO2/kWh

Annual CO2 emissions: 8109*0,183=1.484 Kg CO2

These emissions apply for the years 2022 to 2047 in total 26 years

26*1.484=38.584kg

Primary electricity consumption: 7704/3(SCOP heat pump)=2568kWh primary electricity consumption.

CO_2 emissions electricity delivered at home NTA8800: 0,3400 kg CO_2/kWh

Annual CO_2 emissions: 2568*0,3400=873kg

These emissions apply for the years 2047 till 2050 in total 4 years

4*873=3.492

Total CO_2 emissions road 1: 38.584+3.492=42.076kg

Primary energy usage

2022 to 2047: 26*8109=210.834kWh

2047 till 2050: 4*2568=10.272kWh

Total: 210.834+10.272=221.106kWh primary energy

Road 2:

2022 to 2032, 10*1.484=14.840 kg CO_2

2032 to 2047, gas boiler + hybrid hp:

40% by gas boiler 7704/100*40=3082kWh

Primary gas consumption: 3082/0,95(boiler efficiency)=3244kWh

Annual CO_2 emissions gas: 3244*0,183=594kg

60% by heat pump 7704/100*60=4622kWh

Primary electricity consumption: 4622/4,3 (SCOP likely to meet since supply 55degrees)=1075kWh

Annual CO_2 emissions electricity: 1075*0,3400=366kg

Total annual CO_2 emissions: 594+366=960kg

2032 to 2047 is 15 years * 960=14.400kg

2047 till 2050, all electric for 4 years: 4*873=3.492kg

Total CO_2 emissions road 2: 14.840+14.400+3.492=32.732kg

Primary energy usage

2022 to 2032: 10*8109=81.090kWh

2032 to 2047: 15*(3244+1075)=64.785kWh

2047 till 2050: 4*2568=10.272kWh

Total: 81.090+64.785+10.272=156.147kWh

Road 3:

2022 to 2032, 10 years existing gas boiler: 10*1.484=14.840kg CO2

2032 till 2050, 19 years all electric hp: 19*873=16.587kg CO2

Total CO2 emissions road 3: 14.840+16.587=31.427kg CO2

Primary energy usage

2022 to 2032: 10*8109=81.090kWh

2032 to 2050: 19*2568=48.792kWh

Total: 81.090+48.792=129.882kWh

Road 4:

2022 to 2037, 15 years * 960=14.400kg CO_2

2037 to 2047, 10 years * 1.484=14.840kg CO_2

2047 till 2050, 4 years * 873=3.492kg CO_2

Primary energy usage

2022 to 2037: 15*(3244+1075)=64.785 kWh

2037 to 2047: 10*8109=81.090 kWh

2047 till 2050: 4*2568=10.272 kWh

Total: 64.785+81.090+10.272=156.147 kWh

Road 5:

2022 till 2050, 29 years * 960=27.840kg CO_2

Primary energy usage

2022 to 2050: 29*(3244+1075)=125.251 kWh

Road 6:

2022 to 2037, 15 years * 960=14.400 kg CO_2

2037 till 2050, 14 years * 873=12.222 kg CO_2

Primary energy usage

2022 to 2037: 15*(3244+1075)=64.785 kWh

2037 till 2050: 14*2568=35.952 kWh

Total: 64.785+35.952=100.737 kWh

Road 7:

2022 till 2050, 29 years * 873 = 25.317 CO_2

Primary energy usage

2022 to 2037: 29*2568=74.472 kWh

Literature

Agentschap NL Energie en Klimaat. (2011). *Voorbeeldwoningen 2011 Bestaande bouw*. sittard Retrieved from https://energiecoach.energieverbonden.nl/wp-content/uploads/2021/05/Brochure-Voorbeeldwoningen-2011-bestaande-bouw_compressed-1.pdf

Aldanondo, M., Barco-Santa, A., Vareilles, E., Falcon, M., Gaborit, P., & Zhang, L. (2014). *Towards a bim approach for a high performance renovation of apartment buildings*. Paper presented at the IFIP International Conference on Product Lifecycle Management.

alhra. (2021). Isolatiewaarde glas | Alhra Glas Rotterdam. Retrieved from https://www.alhra.nl/glas/blog/wat-is-de-isolatiewaarden-van-glas/

Alliantie. (2017). Eerste Gevels Nul-Op-De-Meter Woningen Geplaatst. Retrieved from http://www.alliantieplus.com/index.php/blog/item/55-eerste-gevels-kluswoningen-geplaatst

Atlanticclimate. (2022). FAQ – Atlantic. Retrieved from https://atlanticclimate.nl/FAQ/

badkamerxxl. (nd). Bereken eenvoudig het vermogen voor jouw radiator. Retrieved from https://www.badkamerxxl.nl/verwarming/radiator-vermogen-berekenen

bijdragers, W. (2020). Vollastuur. Retrieved from https://nl.wikipedia.org/wiki/Vollastuur

Boersma, S., & Blom, T. (2018). *City Zen Catalogue of Measures*. Retrieved from http://www.cityzen-smartcity.eu/wp-content/uploads/2018/12/city-zen_d4-5_catalogue-of-measures-v1-1_181102.pdf

boringenverheyden. (n.d.). Veelgestelde vragen over putboringen voor warmtepompen. Retrieved from https://www.boringenverheyden.be/geothermie-boringen-warmtepomp/veelgestelde-vragen/

Borsboom, W., Leidelmeijer, K. V., M, de Jong, P., & Kerkhof, H. (2016). BEWONERSERVARINGEN EN

MEETRESULTATEN UIT NUL

OP DE METER WONINGEN IN

HEERHUGOWAARD (BAM). *Energiesprong*.

Bosch, N. (2022). Compress 7800i LW(M)F bodemwarmtepomp. Retrieved from https://www.nefit-bosch.nl/producten/warmtepompen/bodemwarmtepompen/compress-7800i-lwmf

Brinck, T. T. (2021). Plug and play-warmtepomp voor 'moeilijke' huizen productierijp. Retrieved from https://www.wattisduurzaam.nl/28295/energie-besparen/warmte-koude/plug-and-play-warmtepomp-van-vattenfall-voor-moeilijke-huizen/

Brinksma, H. (2017). Toekomstbestendig renoveren. *A+ BE| Architecture and the Built Environment*(13), 1-286.

BSM, T. E. C. U. Age distribution of the Dutch building stock, differentiating between single-dwelling

buildings (SDB), includding row houses, and multi-dwelling buildings (MDB) In.

Buiting, E. (2022). Hybride warmtepomp scoort SCOP van 4,3. Retrieved from https://www.installatie.nl/nieuws/hybride-warmtepomp-scoort-scop-van-43/

Bulder, B., Bot, E., & Bedon, G. (2018). *Optimal wind farm power density analysis for future offshore wind farms*: Petten: ECN.

Camarasa, C., Catenazzi, G., Goatman, D., Jakob, M., Meijer, A., Nägeli, C., . . . Saraf, S. (2018). Building Market Brief The Netherlands.

Cellura, M., Guarino, F., Longo, S., & Tumminia, G. (2018). Climate change and the building sector: Modelling and energy implications to an office building in southern Europe. *Energy for Sustainable Development, 45*, 46-65. Retrieved from https://www.sciencedirect.com/science/article/pii/S097308261731431X?casa_token=QcptWzq2JuAAAAAA:g7NOCfUkYZ7gB89SIZXbV2IDE_xD8_j3kP-lVcV8tYTjyU8FPrjTGj4nq_Y7hgqX6QRGjyo

Compendium voor de Leefomgeving. (n.d.). Isolatiemaatregelen woningen, 1982-2018. Retrieved from https://www.clo.nl/indicatoren/nl0383-isolatiemaatregelen-woningen

Cornelisse, M., Kruithof, A. F., & Valk, J. J. (2021). Rapport standaard en streefwaardes bestaande

woningbouw

Daikin. (2022). Daikin Altherma 3

Productcatalogus. In Daikin (Ed.), (pp. 1-32).

De Arnhemse wijk Presikhaaf. Retrieved from https://www.duravermeer.nl/projecten/de-arnhemse-wijk-presikhaaf/

de Jonge Baas, M. (2022). Woningcorporaties investeren 500 miljoen euro extra in zonnepanelen en hybride warmtepompen. *solarmagazine*. Retrieved from https://solarmagazine.nl/nieuws-zonne-energie/i26182/woningcorporaties-investeren-500-miljoen-euro-extra-in-zonnepanelen-en-hybride-warmtepompen

De potentie van zonnepanelen in Nederland. (2018). *State of the State*. Retrieved from https://www2.deloitte.com/nl/nl/pages/data-analytics/articles/zonnepanelen.html

Decuypere, R., Robaeyst, B., Hudders, L., Baccarne, B., & Van de Sompel, D. (2022). Transitioning to energy efficient housing: Drivers and barriers of intermediaries in heat pump technology. *Energy policy, 161*, 112709.

Delft, C. Terugverdientijd verduurzamings-maatregelen.

DGMR Bouw B.V. (2019). *Vereenvoudigd Energielabel*

NTA 8800 Retrieved from https://www.omgevingsweb.nl/wp-content/uploads/po-assets/282955.pdf

Diersen, P. (2018). Eerste particuliere nul-op-de-meter-renovatie. Retrieved from https://www.aannemervak.nl/bouwsector/eerste-particuliere-nul-op-de-meter-renovatie/

DNEResearch. (2021). Nationaal Warmtepomp Trendrapport 2021.

Dongellini, M., Naldi, C., & Morini, G. L. (2015). Seasonal performance evaluation of electric air-to-water heat pump systems. *Applied thermal engineering, 90*, 1072-1081.

Doodeman, M. (2017, october 11, 2017). Rutte III neemt afscheid van woningen op gas. *Cobouw.nl*. Retrieved from https://www.cobouw.nl/marktontwikkeling/nieuws/2017/10/rutte-iii-nieuwe-en-bestaande-woningen-van-gas-los-101253396

Driel, W. v. (2022). Een warmtepomp in bestaande bouw. *warmte 365*. Retrieved from https://www.warmte365.nl/nieuws/een-warmtepomp-in-bestaande-bouw-64A6AFAE.html

Dutch New Energy Research. (2018). Nationaal warmtepomp trendrapport 2018. Retrieved from https://www.warmtepompvoorjehuis.nl/_downloads/51296919

duurzaammbo. (n.d.). Na-isolatie spouwmuren - Duurzaam MBO. Retrieved from https://www.duurzaammbo.nl/dzb-materialen/gevel/na-isolatie-spouwmuren

duurzaamvecht. (2019). *VERDUURZAMING VAN WONINGEN DEEL 2.*

BOUWJAAR 2006- 2012 - 2015. Retrieved from https://duurzamevecht.nl/documenten/informatiebladen/infoblad%2015.%20Bouwjaar%202006%20-%202015.pdf

duurzaamvecht. (n.d.). VERDUURZAMING VAN WONINGEN DEEL 2.

BOUWJAAR 1992 - 2005. In.

E3TNW. CO2 Heat Pump Water Heaters. Retrieved from http://e3tnw.org/ItemDetail.aspx?id=389

Ebbers, R. (2019). Wilt u 43.000 windmolens? Of 1.040 km2 zonnepaneel? De échte keuzes komen nu. Retrieved from https://www.vno-ncw.nl/forum/wilt-u-43000-windmolens-1040-km2-zonnepaneel-de-echte-keuzes-komen-nu

Ecobouwers. (n.d.). Wat is het rendement van een warmtepomp? Retrieved from https://www.ecobouwers.be/duurzaam-bouwen/artikels/wat-het-rendement-van-een-warmtepomp

Economische- en praktijk levensduur (2021). Retrieved from https://warmtepomp-weetjes.nl/gerelateerd/economische-en-praktijk-levensduur/

EN 442. (n.d.). *THE NEW EUROPEAN STANDARD, EN-442, FOR HOT WATER RADIATORS* Retrieved from https://radiatori.bgtherm.com/data/Decrizione%20norma%20EN%20442.pdf

Eneco. (2022). Wat is normaal verbruik? Retrieved from https://www.eneco.nl/klantenservice/meters-meterstanden/normaal-verbruik/

Energie, D. B. (2021). *Standaard en Streefwaarden: uitkomst traject begeleidingscommissie*. Retrieved from https://open.overheid.nl/repository/ronl-d66296a8-3478-4e6e-b232-aa13395a6e13/1/pdf/uitkomst-begeleidingscommissie-standaard-en-streefwaarden.pdf

Energie in Nederland in 2019. (2020). Retrieved from https://www.energieinnederland.nl/feiten-en-cijfers/uitgebreid/2019

Energielabelcertificerende instelling b.v. (2021). *Energielabel woningen* Retrieved from https://www.rvo.nl/sites/default/files/2021/08/energielabel-voorbeeld-woningen.pdf

Energieplein. (2020). Warmtepomp ontwikkeling zet stijgende lijn voort. Retrieved from https://www.energieplein.nl/ontwikkeling-warmtepomp-zet-stijgende-lijn-voort/

Energymatters. (2014). *RENDEMENT HR-KETEL*

NADER ONDERZOEK TBV WARMTEREGELING. Retrieved from https://www.internetconsultatie.nl/wijzigingwarmteregeling/document/1316
ERVARINGEN IN PRESIKHAAF EN MALBURGEN, ARNHEM. Retrieved from https://www.smartenergycities.nl/wp-content/uploads/2017/04/02SMECPresikhaafMalburgen.pdf
EXED. (n.d.). Besparing spouwmuurisolatie. Retrieved from http://www.info-en-advies.nl/spouwmuurisolatie/besparing
Expertise Centrum Warmte. (2021). Factsheet voor het maken van de transitievisie warmte en uitvoeringsplannen door gemeenten. Retrieved from https://www.expertisecentrumwarmte.nl/themas/technische+oplossingen/techniekfactsheets+energiebronnen/warmtenetten/default.aspx
Gandiglio, M. A. R. T. A., Ferrero, D., Lanzini, A., & Santarelli, M. (2020). Fuel cell cogeneration for building. *REHVA J, 57*, 21-25. Retrieved from https://www.comsos.eu/com18/com18-cont/uploads/2020/03/Fuel-cell-cogeneration-for-building-sector_-European-status-1.pdf
Geertsma, P. (2016). Wanneer is het energielabel ingevoerd? Retrieved from https://www.technischwerken.nl/kennisbank/duurzaamheid/wanneer-is-het-energielabel-ingevoerd/
golantec. (n.d.). Geluidsdemping warmtepompen: Warmtepompomkasting. Retrieved from https://www.golantec.be/geluidswering%20warmtepompen.html
Goudappel, E. (2019). *Integratie van duurzaamheidsadvies in het aankoopproces van bestaande grondgebonden woningen.* Saxion,
Graabak, I., Jaehnert, S., Korpås, M., & Mo, B. (2017). Norway as a battery for the future european power system—impacts on the hydropower system. *Energies, 10*(12), 2054.
Groupe Atlantic Nederland BV. (2020). Aurea 5 R32 Hybrid add-on

MONOBLOC WARMTEPOMP DC INVERTER INSTALLATIE-, BEDIENINGS- EN

SERVICE HANDLEIDING. Retrieved from https://groupe-atlantic.nl/wp-content/uploads/2021/07/3933-Aurea-5_handl_Interactief.pdf
Gustafsson, S.-I. (2000). Optimisation of insulation measures on existing buildings. *Energy and buildings, 33*(1), 49-55.
Hans van Eck (Producer). (2015). Energielabels in Nederland. Retrieved from https://040energie.nl/wp040/wp-content/uploads/2015/06/presentatie-Energie040-HvE.pdf
Harmsen, R., Van Breevoort, P., Planje, W., Bakker, E., & Wagener, P. (2009). Energiebesparingen CO_2-reductiepotentieel hybride lucht/water warmtepomp in de bestaande woningbouw. In: Ecofys, TNO, ECN en BDH.
Heat Geek (Writer). (2017). Why NOT to use LOW LOSS HEADERS! The Low Loss header explained. [Youtube]. In.
Hepbasli, A., & Kalinci, Y. (2009). A review of heat pump water heating systems. *Renewable and Sustainable Energy Reviews, 13*(6-7), 1211-1229.
Hesaraki, A., Ploskic, A., & Holmberg, S. (2015). Integrating low-temperature heating systems into energy efficient buildings. *Energy Procedia, 78*, 3043-3048.
Heurman, B. (2021). Van het gas af met slecht geïsoleerde woning door warmtepomp van Vattenfall: dit moet je weten over terugverdientijd bij prijskaartje van €10.000 tot €15.000. Retrieved from https://www.businessinsider.nl/kosten-terugverdientijd-warmtepomp-vattenfall-feenstra-isolatie-energie/
hieropgewekt. (n.d.). Stroomschema hybride warmtepomp. Retrieved from https://www.hieropgewekt.nl/hybride-warmtepomp-wanneer-is-dat-een-goed-idee
Hogeweg, C. (2021). Standaard en streefwaarden. Retrieved from https://aedes.nl/verduurzaming/standaard-en-streefwaarden
Horowitz, C. A. (2016). Paris agreement. *International Legal Materials, 55*(4), 740-755.
intergas-verwarming. (n.d.). xource all electric. Retrieved from https://www.intergas-verwarming.nl/app/uploads/2020/08/Xource-Folder.pdf
Janssen, M. A., & Jager, W. (2002). Stimulating diffusion of green products. *Journal of Evolutionary Economics, 12*(3), 283-306.
kemkens. (nd). Hybride warmtepomp. Retrieved from https://www.kemkens.nl/warmtepompen/hybride-warmtepomp/#:~:text=%E2%80%8BDe%20aanschafkosten%20van%20een,dan%20bij%20een%20cv%2Dketel.&text=De%20hybride%20warmtepomp%20is%20vooral%20geschikt%20voor%20volledig%20ge%C3%AFsoleerde%20woningen

kennes, v. (2022). ENERGIELABELS: VOORKOM EEN LAGER LABEL NA RENOVATIE. Retrieved from https://www.knaufinsulation.nl/nieuws/energielabels-voorkom-een-lager-label-na-renovatie

Klimaatakkoord. (2019). Retrieved from

klimaatexpert. (nd). COP, SCOP en rendement van een warmtepomp. Retrieved from https://www.scribbr.nl/bronnengenerator/apa/new/webpage/

Kosten warmtepomp [2022]: prijzen + info. (2021). Retrieved from https://www.warmtepomp-info.nl/kosten-warmtepomp/#:~:text=Lucht%2Dwater%20warmtepomp.&text=Een%20dergelijke%20warmtepomp%20kopen%20gaat,onttrekt%20warmte%20aan%20de%20buitenlucht.

Kranzl, L., Kalt, G., Müller, A., Hummel, M., Egger, C., Öhlinger, C., & Dell, G. (2013). Renewable energy in the heating sector in Austria with particular reference to the region of Upper Austria. *Energy policy, 59*, 17-31.

Lefevere, O. (n.d.). Dit kan je doen aan prijsstijging gas | Tips gasverbruik. Retrieved from https://blog.energiebespaarders.nl/dit-kan-je-doen-aan-de-stijgende-prijs-van-energie/#:~:text=Koken%3A%205%20procent%20gasverbruik,jaarlijks%20zo'n%2037m3%20gas.

Linssen, B. (1993). *De mogelijkheden voor de elektrische warmtepomp als CO2-reductietechniek in Nederland*: Energieonderzoek Centrum Nederland.

Maeyaert, L. Energetische renovatie van een sociale woontoren: analyse van de bestaande toestand en het bewonersgedrag.

Majcen, D., Itard, L., & Visscher, H. (2013). *Energy labels in Dutch dwellings-their actual energy consumption and implications for reduction targets.* Paper presented at the CLIMA 2013 11th REHVA World Congress & 8th International Conference on IAQVEC (Prague, Czech Republic).

Menkveld, M., Rovers, V., en Arjan, C. T., & van Binnenlandse Zaken, O. M. (2020). Kosten en baten isolatiestandaard en streefwaarden voor woningen. Retrieved from https://open.overheid.nl/repository/ronl-61f48748-bc52-4152-9f99-5c25e470bdc6/1/pdf/kosten-en-baten-isolatiestandaard-en-streefwaarden-woningen.pdf

merford. (n.d.). Omkasting warmtepomp. Retrieved from https://www.stillewarmtepomp.nl/omkasting-warmtepomp

Met BENG op weg naar energiezuinig wonen. (2021). Retrieved from https://wesselinkisolatie.nl/story/met-beng-op-weg-naar-energiezuinig-wonen/

Milieu Centraal. (n.d.). Stap voor stap mijn huis energiezuinig maken. Retrieved from https://www.milieucentraal.nl/energie-besparen/isoleren-en-besparen/alles-over-isoleren/

Ministerie van Algemene Zaken. (2021). Vanaf 1 januari 2022 meer subsidie voor isolatie en warmtepomp. Retrieved from https://www.rijksoverheid.nl/actueel/nieuws/2021/12/30/vanaf-1-januari-2022-meer-subsidie-voor-isolatie-en-warmtepomp#:%7E:text=Vanaf%201%20januari%202022%20meer%20subsidie%20voor%20isolatie%20en%20warmtepomp,-Nieuwsbericht%20%7C%2030%2D12&text=Per%201%20januari%20gelden%20nieuwe,kosten%20vergoed%2C%20maar%2030%25

Ministerie van Algemene Zaken. (2022). Vragen en antwoorden: hybride warmtepomp de standaard in 2026. Retrieved from https://www.rijksoverheid.nl/documenten/publicaties/2022/05/23/qena-hybride-warmtepomp-standaard-in-2026#:~:text=Huiseigenaren%20zijn%20verplicht%20om%20vanaf,zoals%20aansluiting%20op%20het%20warmtenet.

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (2021). Geluidseisen warmtepompen en airco's worden aangescherpt. Retrieved from https://www.rijksoverheid.nl/actueel/nieuws/2021/03/23/geluidseisen-warmtepompen-en-airco%E2%80%99s-worden-aangescherpt#:%7E:text=Per%201%20april%202021%20worden,geluid%20veroorzaken%20bij%20de%20buren.

Mouzeviris, G., & Papakostas, K. (2020). *Air-to-water heat pumps: the impact of climate, compressor technology, water output temperature and sizing on the seasonal coefficient of performance for heating.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Naar betere betaalbaarheid in aardgasvrije wijken: hoe gemeenten beter kunnen profiteren van recente innovaties. (2019). *topsectorenergie*. Retrieved from https://www.topsectorenergie.nl/nieuws/naar-betere-betaalbaarheid-aardgasvrije-wijken-hoe-gemeenten-beter-kunnen-profiteren-van

Nationaal Programma. Retrieved from https://www.regionale-energiestrategie.nl/default.aspx

nefit-bosch. (n.d.-a). All-electric bodemwarmtepompen. Retrieved from https://www.nefit-bosch.nl/producten/warmtepompen/all-electric-warmtepompen
nefit-bosch. (n.d.-b). Compress Hybrid 3000i binnenunit. Retrieved from https://www.nefit-bosch.nl/producten/warmtepompen/lucht-water-warmtepomp/compress-hybrid-3000i-aws
nefit-bosch. (n.d.-c). TrendLine II. Retrieved from https://www.nefit-bosch.nl/producten/cv-ketels/trendline-ii
nefit-bosch. (n.d.-d). Warmtepomp buffervaten. Retrieved from https://www.nefit-bosch.nl/producten/boilers-en-buffervaten/warmtepomp-buffervaten
Nefit. (2016). Technische Bulletin. *Technische informatie voor de installatiemarkt, Nummer 44*, 1-12. Retrieved from https://www.warmteservice.nl/medias/root/prod_link_dataB-Technisch%20bulletin.pdf?context=bWFzdGVyfHJvb3R8MzcxMjc1M3xhcHBsaWNhdGlvbi9wZGZ8aDVhL2g3NS84ODc4Njc2NTQxNDcwLnBkZnw0MjU3YjA5MjIwMzUwMzRjMjI4NGQ5YzllYmI3ZDY0ZjY5YmE1MDM0OWZkOWFhZTc3MDY4YzRmMDFhYTNhNTk3
Nesbakken, R., & Strøm, S. (1993). *The choice of space heating system and energy consumption in Norwegian household*. Retrieved from
NIBE. (n.d.). Is het installeren van een warmtepomp bij renovatie mogelijk? Retrieved from https://aardgasvrij.nibenl.eu/woning-geschikt/is-het-installeren-van-een-warmtepomp-bij-renovatie-ook-mogelijk#:~:text=Een%20warmtepomp%20kan%20je%20huis,liever%20nog)%2035%C2%B0C.
Ollongren, K. H. (2021). BRIEF VAN DE MINISTER VAN BINNENLANDSE ZAKEN EN KONINKRIJKSRELATIES, [Kamerbrief]. Retrieved from https://www.tweedekamer.nl/downloads/document?id=1fb068ac-0f5a-48ab-8b87-cb276680f99c
Omrekening MMBTU naar kubieke meter aardgas. (2019). Retrieved from https://www.energieconsultant.nl/energiemarkt/energie-berekeningen-uit-de-praktijk/omrekening-mmbtu-naar-kubieke-meter-aardgas/
Østergaard, D. S. (2018). Heating of existing buildings by low-temperature district heating.
Overstappen.nl. (2022a). Gasprijzen per energieleverancier in 2022 l Vergelijk de gasprijs! Retrieved from https://www.overstappen.nl/energie/gasprijzen/#:%7E:text=Momenteel%20betreft%20de%20gasprijs%20gemiddeld,inclusief%20energiebelasting%2C%20ODE%20en%20BTW.
Overstappen.nl. (2022b). Stroomprijzen Bekijk de stroomprijs per kWh van 19 leveranciers. Retrieved from https://www.overstappen.nl/energie/stroomprijs/#:%7E:text=Momenteel%20betreft%20de%20stroomprijs%20gemiddeld,%E2%82%AC0%2C2407%20per%20kWh
Paris Proof. Retrieved from https://www.dgbc.nl/themas/paris-proof
pentecbv. (n.d.). Open verdeler. Retrieved from https://www.pentecbv.nl/onze-producten/open-verdeler
Plaatsing warmtepomp. (n.d.). Retrieved from https://www.warmtepompverwarming.net/warmtepompen/plaatsing-warmtepomp/
Planbureau voor de Leefomgeving. (2019). *STARTANALYSE AARDGASVRIJE*

BUURTEN. Retrieved from https://www.pbl.nl/sites/default/files/downloads/pbl-2019-startanalyse-aardgasvrije-buurten-achtergrondrapport_4049.pdf
PlanLoCaL. (2021). *Estimating the heat demand of a hypothetical community building.* . Retrieved from https://www.cse.org.uk/local-energy/download/estimating-the-heat-demand-of-a-hypothetical-community-building-79
Project stroomversnelling Heerhugowaard Interduct. (2020). Retrieved from https://www.interduct.nl/referentie/stroomversnelling-heerhugowaard/
Qsilence B.V. (n.d.). Next generation PVT. In.
Qsilence BV. (2022). Zonder gas verwarmen én koelen. Retrieved from https://www.qsilence.com/en_GB/#
recticelinsulation. (n.d.). Rc-waarde calculator | Recticel Insulation. Retrieved from https://www.recticelinsulation.com/nl/rc-waarde-calculator
Redactie. (2016, January 1, 2016). Nul op de meter in Tilburg grote tegenvaller. *FluxEnergie*. Retrieved from https://www.fluxenergie.nl/nul-op-de-meter-in-tilburg-grote-tegenvaller/?gdpr=accept
regionaalenergieloket. (n.d.). Hoe weet ik of mijn huis geïsoleerd is? Retrieved from https://regionaalenergieloket.nl/handleiding-isolatie-bepalen
Reichler, M. B. (2019). *The Purchase Decision-making Process for Renewable Heating Technologies: A Consumer Perspective.* University of Gloucestershire,
Remeha. (2021). REMEHA ELGA-ACE HYBRIDE ONTWERPHANDLEIDING. Retrieved from https://tools.remeha.nl/wp-content/uploads/sites/11/2020/12/Remeha-Elga-Ace-ontwerphandleiding-2020-Remeha-27-10-2020-def.pdf

Remeha. (n.d.). Hoe bepaal je het benodigde vermogen van een warmtepomp? Retrieved from https://www.remeha.nl/veelgestelde-vragen/warmtepompen/hoe-bepaal-je-het-benodigde-vermogen-van-een-warmt
Rettig ICC. *Handboek voor lage temperatuur-radiatoren*: Radson.
Rijksdienst voor Ondernemend Nederland. (2019). *Handleiding voor de erkend deskundige energielabel woningbouw*. Retrieved from https://www.rvo.nl/sites/default/files/2019/12/handleiding-erkend-deskundige-energielabel-rvonl-versie-1-4-november-2017.pdf
Rovers, R., Morck, O., Lupisek, A., Pihelo, P., Kuusk, K., Kalamees, T., . . . Borodinecs, A. (2017). WP3: Deliverable 3.8: Guide with concepts of renovation packages for different types of building. Retrieved from https://www.more-connect.eu/wp-content/uploads/2019/07/MORE-CONNECT_WP3_D3.8-Guide-with-renovation-concepts.pdf
Rutte, M., Pechtold, A., Buma, S., & Segers, G. (2017). Vertrouwen in de toekomst. Regeerakkoord 2017-2021. *Retrieved on March, 18*, 2020.
RVO. (2020). Infographic-NTA8800-nieuw-energielabel-gebouwen-en-woningen-2021. In RVO (Ed.).
Segers, R., Niessink, R., Van Den Oever, R., & Menkveld, M. (2019). *Warmtemonitor 2017*: Petten: CBS TNO.
Slimster. (2022a). Bodem-water warmtepomp / water-water warmtepomp kosten? Retrieved from https://slimster.nl/warmtepomp/warmtepomp-kosten/bodem-water-warmtepomp-prijs/
Slimster. (2022b). PVT-panelen kopen? Ontdek PVT-paneel prijs & soorten. Retrieved from https://slimster.nl/zonneboiler/pvt-panelen/#:~:text=Wil%20je%20een%20volledig%20PVT,25.000%20voor%20een%20volledig%20systeem
Smorenburg, P. (2021). Sloveens warmtepompwonder. Retrieved from https://www.ew-installatietechniek.nl/artikelen/sloveens-warmtepompwonder
SpeedComfort. (2022). SpeedComfort, de slimme radiator-ventilator: home. Retrieved from https://www.speedcomfort.nl/
Stokman, E. (Writer). (2021). Hybride warmtepompinstallatie: Installeren. In.
termical. (n.d.). Termical: Voorzetwand hout. Retrieved from https://www.termical.nl/Berekeningen/Vzw_hout
Tigchelaar, C., Rovers, V., Zwamborn, A., & Cox, E. (2022). Duiding van de eindgebruikerskosten voor het aardgasvrij maken van Nederlandse woningen.
Triple Solar BV. (2022). Hoe werkt een Triple Solar warmtepomppaneel en veel gestelde vragen. Retrieved from https://triplesolar.eu/introductie-pvt-warmtepomp-paneel/veelgestelde-vragen-pvt/
Uitgebreid PV Systeem Ontwerp. Retrieved from https://www.tudelft.nl/?id=59084
van Beuzekom, T. I., van Dam, M., & Slootweg, J. (2016). Verduurzaming van verwarming vereist integrale aanpak. *Energie+*.
van den Wijngaart, R., & van Polen, S. (2020). *BEPALING ENERGIEBESPARING DOOR ISOLATIE VAN WONINGEN IN DE STARTANALYSE 2020*. Retrieved from https://www.pbl.nl/sites/default/files/downloads/pbl-2020-bepaling-energiebesparing-woningen-startanalyse-2020_4284.pdf
van der Schoor, T. (2020). Op naar beter: bewonerservaringen met NOM. Retrieved from https://research.hanze.nl/ws/portalfiles/portal/34901729/Vanderschoor_2020_Installateurszaken_Opnaarbeter.pdf
van der Wilt, P. (2020). Test: omkasting warmtepomp. Retrieved from https://www.consumentenbond.nl/warmtepomp/omkasting-warmtepomp
van der Wilt, P. (2022). Beste warmtepomp. Retrieved from https://www.consumentenbond.nl/warmtepomp/beste-warmtepomp
van Leeuwen, R. P., De Wit, J., & Smit, G. J. M. (2017). Review of urban energy transition in the Netherlands and the role of smart energy management. *Energy conversion and management, 150*, 941-948.
van Moorsel, P. (2013). *De waardering van consumenten voor een energiezuinige woning.*
VASCO. (2018). Which radiators are suitable for low temperature heating>. Retrieved from https://vasco.eu/en-gb/blog/radiators/which-radiators-are-suitable-low-temperature-heating
Vattenfall. (2022). Warmtepomp voor duurzame warmte | Vattenfall. Retrieved from https://www.vattenfall.nl/producten/warmtepomp/
Verbouwkosten B.V. (2022). Vloerverwarming Prijs | De kosten per m², Infrezen en Offerte 2022. Retrieved from https://www.scribbr.nl/bronnengenerator/apa/new/webpage/
verwarminginfo. (2019). Lucht-water warmtepomp. Retrieved from https://www.verwarminginfo.nl/warmtepomp/warmtepomp-lucht-water#:~:text=De%20prijs%20van%20een%20lucht,vermogen%20en%20de%20bestaande%20situatie

Verwarmingsketel kopen? Beste ketels + prijzen 2022. (2022). Retrieved from https://www.scribbr.com/apa-citation-generator/new/webpage/
Verwoolde, L. (2017). *styedenbouw.nl*.
Visser, M. (2016). De prijselasticiteit van onze energievraag. Retrieved from https://www.clingendaelenergy.com/inc/upload/files/energiepodium_12-1-2016_visser.pdf
voor de Leefomgeving, P. P. (2020). Beschikbaarheid en toepassingsmogelijkheden van duurzame biomassa. Verslag van een zoektocht naar gedeelde feiten en opvattingen.
voor Veiligheid, O. (2015). Aardbevingsrisico's in Groningen. *Onderzoek naar de rol van veiligheid van burgers in de besluitvorming over de gaswinning (1959-2014)*.
VRAAG NAAR WARMTEPOMP NEEMT FORS TOE DOOR OORLOG IN OEKRAÏNE. (2022). *bnr*. Retrieved from https://www.bnr.nl/nieuws/binnenland/10468916/vraag-naar-warmtepomp-neemt-fors-toe-door-oorlog-in-oekraine
warmtepomp-paneel. (nd). Radiatoren en extra warmteafgifte met boostventilatoren. Retrieved from https://warmtepomp-panel.nl/dbe2.html
warmtepomp-weetjes.nl. (n.d.). Air source heat pump in hybrid mode LT/HT (<55°C/70°C) In.
Warmtepomp indicatietabel (2021). Retrieved from https://warmtepomp-weetjes.nl/uitleg/warmtepomp-indicatietabel/
Warmtepompvergelijker. (2022). Hoe bespaar je met een warmtepomp? En wanneer is mijn huis geschikt? – Warmtepompvergelijker. Retrieved from https://warmtepompvergelijker.nl/hoe-bespaar-je-met-een-warmtepomp-en-wanneer-is-mijn-huis-geschikt/
Warmteservice. (2022). Nefit-Bosch Enviline lucht/water warmtepomp. Retrieved from https://www.warmteservice.nl/Duurzaam/Warmtepomp/All-electric-lucht-water-warmtepomp/Nefit-Bosch-Enviline-hybride-lucht-water-warmtepomp/p/03550340
Wijnant, E. (1987). Stookkostenberekening Hastelweg Eindhoven. *TU Eindhoven. Fac. Bouwkunde: publicaties Bouwkundewinkel*.
Wit, J. d. (2022). Verkoop warmtepompen neemt wereldwijd toe, Nederlander heeft meer voorlichting nodig. *warmte 365*. Retrieved from https://www.warmte365.nl/nieuws/verkoop-warmtepompen-neemt-wereldwijd-toe-nederlander-heeft-meer-voorlichting-nodig-64A6AFB5.html
Woonbewust. (2022). Afbeelding Het nieuwe energielabel in 2021. Retrieved from https://woonbewust.nl/energielabel-woningen
woonwijzerwinkel. (n.d.). Retrieved from www.woonwijzerwinkel.nl
Zhang, J., Wang, R., & Wu, J. (2007). System optimization and experimental research on air source heat pump water heater. *Applied thermal engineering, 27*(5-6), 1029-1035.
Zuilhof, J. (2020). Is jouw huis geschikt voor een warmtepomp? Zo kom je erachter! Retrieved from https://www.hier.nu/themas/investeren-in-je-huis/is-jouw-huis-geschikt-voor-een-warmtepomp-zo-kom-je-erachter