Current Solutions for Privately Owned Dwellings to Transform Toward the National Ambition: A Feasibility Study.

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Chapter 1. Introduction

Problem statement

When evaluating the national ambitions to reach an energy neutral built environment and the current capacities for households to meet these, there is clear mismatch.

Global leaders from around the world joined forces to fight climate change during the United Nations Climate Change Conference in Paris in 2015 and formulated the Paris Agreement. One of their main goal is to establish an energy neutral built environment by 2050, as buildings consume more than 40% of the world energy (UNEP, 2016). The current Dutch government administration, Rutte III, signed the agreement. The national goal is to have an energy neutral, gas-free built environment by 2050 (Leefomgeving, 2017).

The housing stock represents 87% of this targeted environment (CBS, 2016). Currently less than 2% of the housing stock complies with the national ambtion (EIB, 2018). With the low replacement rate in the Netherlands of 0,4% (CBS, 2016), more than 87% of the future housing stock (2050) has already been built. Many concluded that the existing housing stock is one of the key sectors where action is needed to meet the energy goals (Ritzen, Haagen, Rovers, Vroon, & Geurts, 2016) (Visscher, 2017). The current number of annual full energy transitions need to increase from the current 2.000 (Buren, 2018) to 200.000 until 2050 if the Paris Agreement want to be achieved (Leefomgeving, 2017). That is an increase of 10.000%. These numbers quantify the gap between the national ambition and the current housing stock.

But what are the current possibilities for households to overcome this gap? The Economic Institute of Construction (EIB) recently researched to what extent current available measures had the opportunity to achieve the set ambitions of 2050. They conclude that the average household would need to invest €35.000 euros to achieve an energy neutral dwelling. Payback period of the first €12.500 would be financial feasible, further measures are currently not (EIB, 2018). To put these numbers in perspective, the average income of a household averaging 2,2 residents is €39.200 (CBS, 2016). The average housing prices is €264.000 (CBS, 2017). With 38% of our income spend on housing (CBS, 2016), allocation addition capital to invest almost an entire yearly household income, or 13% of the market value of your house with unfeasible paybacks periods is extremely difficult for the average household. Current capacities do not have the ability to overcome the gap.

The identified mismatch between the energy ambitions and the capacities of the housing stock form the problem statement for this research.

Main findings

The EIB report presents a clear mismatch between the national energy ambitions and the capacities of possible solutions on housing stock level, but it has limitations in its applicability. The first is concerning the housing stock level approach based on a general prototype of a dwelling. Before formulating strategies to overcome the stated mismatch, a full understanding of an individual dwelling's energy system is required. This abstraction for a single dwelling can be replicated for a given housing stock. When dwellings share properties, they can be allocated to groups, clusters, or typologies that make a dataset more manageable and can be used to study a stock of dwelling through extrapolation (G. Sousa, Jones, Mirzaei, & Robinson, 2017).

The second limitation is the usage of Energy Labelling to indicate energy usage. While commonly used in energy assessments (EIB, 2018) (Ritzen et al., 2016) (Buren, 2018), this Energy performance certificate used in the Netherlands, does not represent the reality accurately (Majcen, 2016; Visscher, 2017). Majcen (2016) conclude that using Energy labels may cause confusion instead of assisting the occupant, because it is not representative of actual values. An Building Energy Model is used to quantify the energy performance, as this show an acceptable accuracy of total energy consumption (Ren, Chen, & James, 2018).

A conclusion made by Vermeij (2018) concerning the knowledge and willingness to invest in sustainable measures among Dutch residents, is that the importance and use of sustainable measures is clear, but the residents miss information to come to a well-considered decision. This is confirmed by Kaal (2017). From an engineers and managers perspective, the mismatch should be explained in more detail to become more transparent, for both strategy makers and households. Further research is needed to test the feasibility of possible solutions of specific types of housing in Dutch housing stock.

This research aims to study the feasibility of possible solutions based on actual energy performance and see how these apply to specific types of housing.

Specific types of houses are selected which would have the biggest impact toward achieving the national goal. A first scope is made to focus on privately owned housing. Due to Regulations, long-term perspective and available resource housing associations are miles ahead of the privately-owned housing sector (Arnoldussen, 2017). Within the remaining 4,3 million houses (CBS, 2016), target groups are selected with the largest quantity in both amount and energy performance, with the requirement that they share properties to so that insight can be replicated for a given housing stock. This maximizes the potential impact of this research in overcoming the stated mismatch.

Goal

The main goal of this research is to evaluate the feasibility of possible solutions to overcome the stated mismatch at specific target groups which have a potential big impact. By targeting specific groups and researching their actual energy usage, a solid quantified base is provided.

Relevance

The research has societal relevance by adding quantified knowledge to one of the key sectors where action is needed to meet the energy goal and providing a complete package to residents to come a well-considered decision and to policy makers to formulate strategies. It further more has scientific relevance by updating and extending the body of knowledge on possible solutions to achieve an energy neutral built environment. Scoping interview with practice confirmed the need for quantified energy performance of specific target groups solutions and its feasibility ((Buren, 2018 #4)(Hendrix., 2018).

Research questions

The following research question and sub questions are asked. They follow a top-down approach. The belonging conceptual model is illustrated in figure 1.

'To what extent are the current solutions feasible for privately-owned dwellings to transform toward the nation ambition? '

SQ1: What are the current solutions for privately owned houses to become energy neutral?
SQ2: How can these solutions be applied in specific target groups?
SQ3: How do these solutions influence the actual energetic performance?

Method

For this first sub question, a market review is made and validated by semi-structured interviews. It is assessed what currently is proposed to improve the energetic performance toward the level of being energy neutral. An analysis is produced of issues based on given solutions and applied to typical housing. Both financial and energy indicators are established. Interviews with practice will increase specific knowledge and decrease biased data.

The second sub question is researched by case studies. First, a target group selection is made which has the most possible impact in achieving the national ambition. This is done by a literature review. Subsequently the possibilities of SQ1 are evaluated on the applicability into the target groups. This is done through a case study at each of the three groups to give insight in the made considerations and involved processes. The costs of applying the solutions to these specific target groups are analysed and form the base of the business case.

Finally, case energy simulations of each target group are used to measure the energetic performance. This will form the benefit side of the business case. Together with the investments of SQ2 a business case for all three target groups is produced, stating the feasibility to transform towards the nation ambition. This answers the main question and thereby achieving the aim of this research.

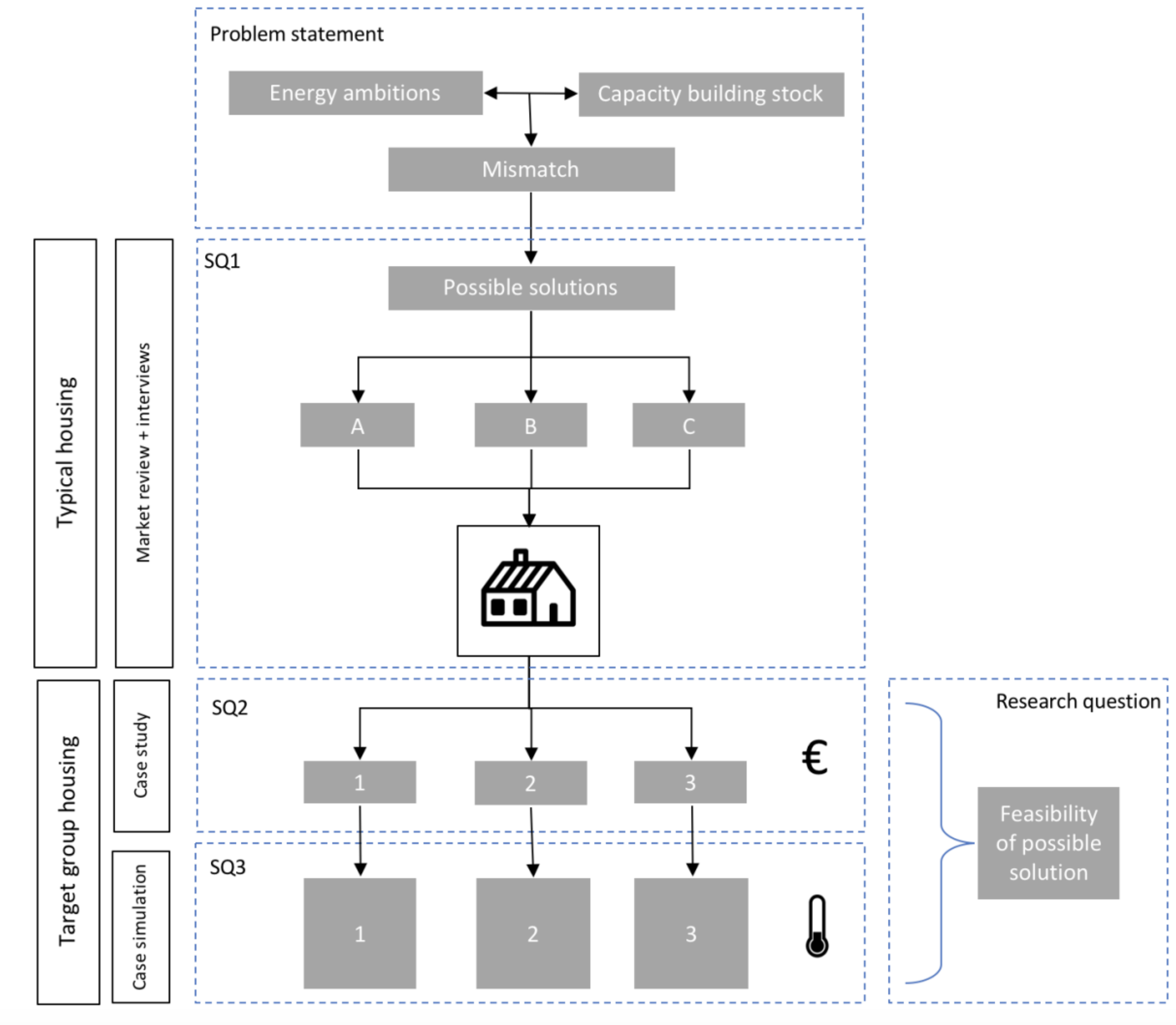

Figure 1. Conceptual model.

Chapter 2. Literature review

This section focusses on the literature review of two parts. The first part focussed on the existing mismatch between the national goal and the current energy usage in the privately-owned housing stock. It shows the relevance of making the mismatch transparent based on actual energy use, assesses the current energy level in the housing stock, identified the needed barriers to overcome and sketched possible consequences of the mismatch.

The second part will focus on the solutions. The different possible approaches and strategies are firstly discussed, where after the possible current solutions for general housing are explored. Subsequently, target groups are selected based on the biggest possible impact in reaching the national goal and are further explored. These finding form the basis of the methodology part.

2.1 The mismatch

Policies and measures

The Paris agreement aims to respond to the global climate change threat by keeping a global temperature rise this century well below 2 degrees Celsius. Following the singed agreement, Dutch policy makers made a statement: an energy neutral built environment in 2050 (RutteIII, 2017). They express their ambition is CO2 reduction. In the coalition agreement of Rutte III an emission reduction of 49% is ambitioned by 2030. From this 41 Mton CO2 reduction, the built environment has to reduce 7 Mton CO2. 2 Mton CO2 is reduced by improving insulation of housing, heat systems and heat pumps (Leefomgeving, 2017). From 2020 a sustainable transition tempo of 200.000 dwelling annually is needed to reach an energy neutral housing stock of 6 million dwelling by 2050. As earlier stated (page 3), this requires an increase of 10.000%.

The ambitions made by both European and national governmental bodies are clear. Large parts of the built environment sector are currently working to achieve the challenges in the upcoming years. Measures and regulations are introduced to guide this transition in built environment. The Dutch government sets out regulations for offices to have an obligated energy label C by 2023. Tasks forces are initiated by the Dutch Green Building Council to support the transition on educational buildings, health care, retail, logistics and offices (DGBC, 2018) representing 13% of the Dutch buildings. The housing stock represent the other 87% (CBS, 2016). Housing associations, representing 31% of the housing stock, are also regulated and have signed a joined ambition to establish an average label B across the sector by 2021.

But when evaluating the measures and regulations for the 4,3 million privately owned dwellings, they are no mandatory energy improvements or energy levels like the office and social housing sector (Arnoldussen, 2017). The difference between Dutch energy labelling and actual has already been noticed on page 3 and will be explained in more depth on page 8, yet this is the only political instrument used today. Since 2015 every dwelling that is sold is mandatory to feature an energy label, resulting is 39% coverage (EIB, 2018). This certificate however has no mandatory implications in the sense that owners could be forced to improve their buildings (Visscher, 2017).

To stimulate the energy transition, the Dutch government and local municipality have enabled financial incentives to motivate homeowners. For private home owner the total budget until 1th of January 2018 was €35,7 million (RVO, 2016). While subsides have the possibility to speed up the transition to Paris-Proof housing, current incentives are not sufficient in overcoming the financial barriers (Buren, 2018). Furthermore, knowledge and willingness to use these incentives are low. 58% of Dutch homeowners knows subsidies are available for heat-pumps, solar boilers, pellet boiler and biomass boiler. But from these, only 6% intents to use it within 12 months (Kaal, 2017).

A shift in energy tax is suggested by Rutte III to increase tax of natural usage until 170.000 m3 by 3 cent per m2 and a tax decrease on electricity until 10.000 kWh by 0,72 cent per kWh (RutteIII, 2017). Through this shift electrical heat pumps, building insulation and heat systems become slightly more profitable, but for most cases this will be insufficient to make a transition feasible. (Leefomgeving, 2017).

Replacement of the current stock seems impossible in terms of building and demolition capacity as well as waste production (T. Dijkmans, 2011). Renovation of existing buildings in The Netherlands is crucial when aiming for an energy neutral building stock in 2050. But when evaluating governmental measures and incentives to meet the national ambition at different building types, the private housing stock has very few and thereby remains a big challenge.

Energy Focus

The impact of buildings on climate is enormous. Buildings consume more than 40% of the world energy, released 1/3 of CO_2, use about 25% of harvested woods, release about 50% of fluorocarbons, produce 40% landfill materials, use 45% of energy in operations, emit 40% of carbon emissions, and accounts for about 50% of all extracted materials and use 15% of the world's useable water (UNEP, 2016). The Paris-agreement focusses on multiple of the above-mentioned aspects. In order to reach a fully sustainable built environment, all aspects need to be reduces. While some aspects are clearly related, this research will focus on how to reduce the energy part consumed by buildings.

The main reason for this focus point is that most institutions, both governmental and commercially driven, focus on this part as well. Energy consumption is therefore more tangible than for example carbon emissions. Energy usage is something homeowners can relate to as they pay their energy bill every month. Furthermore, the Economic Institution of Construction (EIB) state that further regulations concerning sustainability in the built environment would favourable be expressed in terms of energy performance (EIB, 2018). Therefor this research makes use of the knowledge people already received and what is desired form the EIB.

The Dutch green building council, an indented non-profit organisation that is committed to increase sustainably in the built environment, made a clear division to where to focus regarding energy should be pointed on. To reach an energy neutral building stock, 75% of energy used needs to be reduced by improving the building stock, the other 25% of energy used needs to be produced in a sustainable way (DGBC, 2018). This research will follow this distribution of focus. The Dutch energy system is conceptualized in figure 2. This research will focus on the energy part which can be influenced by private homeowners, market in green.

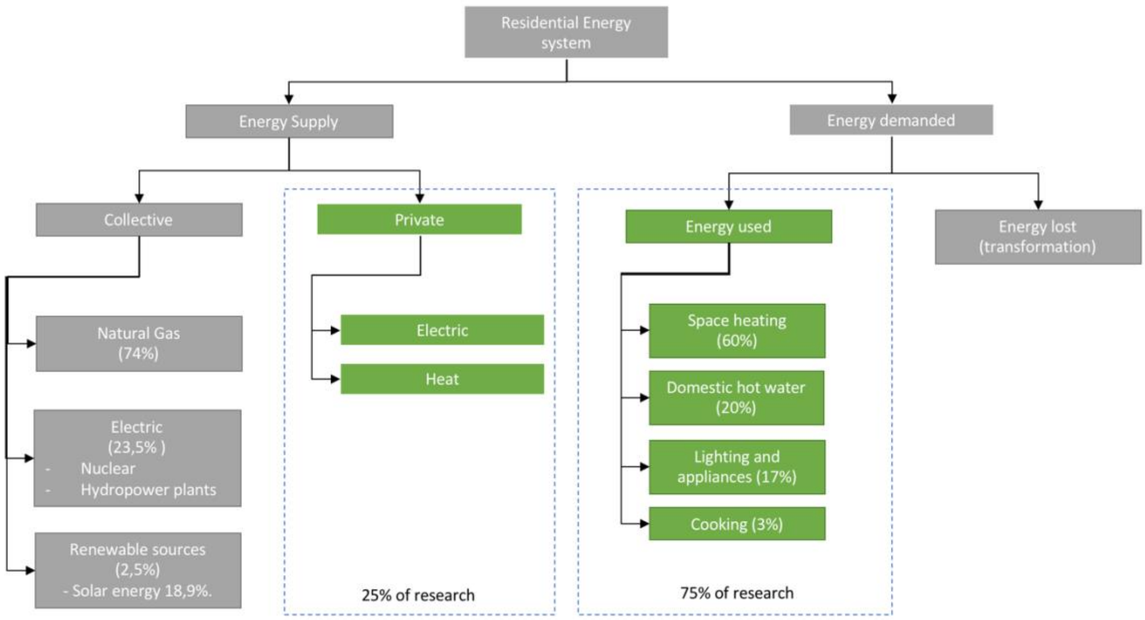

Figure 2. Based on G. Sousa, Jones, B., Mirzaei, P.A., Robinson, B. (2017), Vermeij (2018) and ((CBS)), 2012 #49).

Energy label vs Actual energy use

Following the Paris Agreement, the term 'Paris-Proof' was introduced. This could be defined as buildings which meet the goal of the Paris agreement and thereby being energy neutral by 2050. As introduced on page 3, there is a difference between Energy Performance Certificated (or EPCs) and actual energy performance. EPCs give a hypothecated indication of the required energy to provide a certain average temperature in the building and depend on physical characteristics of the building. Form a political perspective, it is a crucial instrument for benchmarking and formulating policy goals (Visscher, 2017).

Remaining at this political perspective, energy labels are the Dutch EPC that express the energy performance of existing houses as required by the European EPBD (Visscher, 2017). Energy labels run from G to A, wherein A is the most energy economical. The average energy bill is €120/month (D. Brounen, 2018). The energy label does show in an understandable way if the energy bill is higher of lower. From 2021, new buildings should meet the requirement of BENG, Bijna-EnergieNeutraal Gebouw (Almost-Energy Natural Building). BENG requires some form of energy generating and is added to the labelling system.

As only 39% of the houses has an energy label, the EIB (2018) made an assumption on the total housing stock illustrated in table 1. The reasonable size of label A and B has to do with the regulations for new construction projects which have been activated for some years now. The majority of the private housing stock received a label C, which complies whit the tipping point of the efficiency gap, which will be explained on page 9. The remaining 1,9 million houses, with a label D or lower show the greatest opportunities for energy improvement measures.

	Private housing stock					
Label	rental		owned		total	
BENG	47.200	5%	52.600	1%	99.800	2%
A	129.400	14%	632.600	14%	762.000	14%
B	92.400	10%	451.900	10%	544.300	10%
C	184.900	20%	1.310.400	30%	1.495.300	28%
D	147.900	16%	677.800	15%	825.700	15%
E	101.700	11%	451.900	10%	553.600	10%
F	83.200	9%	406.700	9%	489.900	9%
G	157.100	17%	406.700	9%	563.800	11%
Total	**943.800**		**4.390.600**		**5.334.400**	

Table 1. Energy Labels of private housing stock, based on EIB (EIB).

The result illustrated in table 1 are used to showcase the big challenge that remains. As will be further explained on page 9, the BENG label house is not yet a Paris-Proof house, meaning that less than 1% of the current privately-owned housing stock complies with the national goal of being energy neutral.

But as stated before, this form of labeling does not align with actual energy consumption. The actual domestic energy use is besides the physical characteristics of a dwelling, largely influenced by the use and behavior of the tenants consumption (Visscher, 2017). It a combination of building bound energy and user depended energy. In a research by Majcen (2016) the actual energy consumption was compared with the theoretical use according to the EPC's. One of the conclusion was that the dwellings with the worst label (G) in practice use far less energy as expected, while the most advanced dwellings (A) use much more. The large difference between the theory and practice is called the performance gap is recognized in more and more international studies (Visscher, 2017). Energy labels may cause confusion instead of assisting the occupant, because it is not representative of actual values (see page 3).

This research aims to give transparent insight in the feasibility of transforming privately owned housing to become energy neutral. The acknowledged performance gap has to minimalized in order to increase the accuracy of the findings of this report. The conclusion of Majcen (2016) that in the future the actual energy consumption of houses should be takin into account when formulating targets, is followed. Insight in actual energy use is demanded so that measures developed to meet the targets will have a better chance of success.

Energy measurement

To comply with the demand to minimize the performance gap, this section is used to select the right energy measurement system that will be used in this research. The government has two other Energy Performance Certificates, the Energy-Index (EI) and Energy Performance Coefficient (EPC, from this point on used at this term). The EI consist of 150 indicators, compared to the 10 indicators of Energy labels, and is often used at social rental sector dwellings (RVO, 2016). Duo to the focus on privately owned housing, this system is not used in this research.

The EPC is a calculation method is mostly used at newly built and renovated dwellings (RVO, 2016). The calculation method, laid down in Dutch standard NEN5128 for dwellings, uses more detail than energy labelling. The building is simulated bases on construction years, building layers, floor surface and building methods. Secondly, insulation details are stated concerning the construction, glass and doors. Ventilation and heating details are specified. Boiler types and alternative energy systems complete the calculation. Connecting this method to BENG, a EPC of 0,2 is required. The Paris-Proof definition state that building related energy usage should be the same as the energy generated. An EPC of 0,0 complies with the stated definition of a Paris-Proof house.

As the previously stated, in aiming for the actual energy usage, the behavioural connected energy usage is one of the reasons for the performance gap. The recently introduced NOM (Nul-Op-De-Meter, translated: Zero-On-The-Meter) housing also include the energy used by the users, like washing machine, fridge and computer. The nett energy usage should be zero and thereby follows this statement.

When evaluating the options to decrease the performance gap based on the behavioural reason with practice, it was concluded that this part was difficult to overcome by the AEC sector and requires a societal movement (Buren, 2018; Hendrix., 2018). While this reason is not neglected, this research follows the need from practice and will therefore not focus on this aspect. The evaluation of governmental Energy Performance Certificates demonstrate that the EPC has the most potential to be used. An EPC of 0,0 complies with the Paris-Proof ambition and will therefore be the ambition for this research. The performance gap duo to behavioural use is noticed but will not be the focus point.

Current feasibility

Aa previously stated, energy labels do not show actual energy performance. Still it is widely used, and report using this labelling can still be of value. The EIB (2018) recently did a research on the expediency of currently available measures to reach an energy neutral housing stock by 2050. While not being specific enough for this research, it gives an up-to-date overview on the situation. The EIB report therefor is analysed, and afterword’s questioned on its accuracy.

One of the findings of the EIB was the recognition of the ‘efficiency gap’. This definition is explained due to the fact that financial-economical expediency of sustainable measures in the built environment is negatively correlated with the intensity of the ambition level. Steps from an energy inefficient building towards a reasonable energy efficient building are characterized by a reasonable favourable business case. On the other hand, steps from a reasonable energy efficient building towards a high energy efficient building are characterized by a more problematic business case. Finally, steps from a high energy efficient building towards an energy neutral building are unprofitable from a financial perspective. This patron is called the efficiency gap.

The average cost to enhance the energy label from G to C in private housing costs €12.500. To improve to label A requires an additional €10.000. Reaching an energy neutral house requires an additional €22.500, reaching a total of €35.000 (EIB, 2018). The EIB (2018) quantified the gap between costs and benefits of reaching a certain energy label. They conclude that for an average homeowner investing beyond label C is currently financially not feasible (a 6% discount ratio and lifespan of 25 years is used). Reaching an Energy label BENG, which (as described on page 9) has a higher energy usage than the Paris-Proof goal, would result in a 50+ years payback period. This clearly illustrates the mismatch with the national ambitions and the possibilities homeowners have to meet this ambition.

But, as stated in the beginning of this sector, these results need to be further researched before they can be applied due to the difference of the energy labels used in the EIB report and actual energy usage used in this report. Secondly, the EIB report evaluated an average house In the Netherlands while one of the key characteristics of the housing stock is that it is very heterogeneous (Jaffe & Stavins, 1994). This research sets out to further specify this current feasibility study on actual energy consumption and specific target groups to have the most impact in reaching the national ambition. Specific building type efficiency gaps based on actual energy consumption could be generated.

Main barriers

As quantified above, investing in energy measures toward an energy neutral house are substantial. When finding possible solutions to test the feasibility of the energy transition, it is needed to acknowledge the existing barriers. They form the main challenge; this feasibility study will see to what extant the barriers can be overcome. This section sets out to research the main barriers for private homeowner to invest in energy efficient measures.

A recent research of Vermeij (2018) set out to evaluate the opinion of the Dutch inhabitant toward the energy transition. It was found that the main barriers for privately owned housing is that measures are too expensive (39%), it does not benefit much for themselves (24%) and knowledge is to low (22%) (Vermeij, 2018). A 2011 study by Britnell & Dixon, for the retrofit2050 program in the UK, surveyed the factors that shape current and future retrofitting activities and found that the key trigger to advance the retrofit agenda would be achieving financial gain from undertaking retrofit measures (Ayyad, 2017). This support the main financial barrier. To verify these result, scoping interviews were held with practice. Both verify the financial barrier as being the most important to overcome. Furthermore, the AEC sector needs solve the knowledge barrier (Buren, 2018; Hendrix., 2018). This is again verified by Vermeij (2018), stating is that the importance and use of sustainable measures is clear, but the residents miss information to come to a well-considered decision.

The Dutch government did a research about the knowledge about energy saving measures in general and heat-pumps in particular. A surprising result is that when asked about the way people save energy in their homes, more people tent to lower the heating then take insulation measures (Kaal, 2017). Choosing to put on an extra sweater instead of investing in insulation shows an outdated way of thinking. Furthermore, 45% of the questioned homeowners could not tell what a heat pump was. At the same time, 90% knew about the gas free ambition and on average it was expected that in the year 2042 this would be accomplished (Kaal, 2017). People know about the ambition, but do not know the measures on how to get there.

These main barriers support the relevance of this research. This report sets out to quantify investments of current energy saving and generating solutions on specific target groups. With actual energy performance indicators, it tests the feasibility of the building specific investment period and payback period giving insight in the main barrier. Furthermore, it gives transparent information to come to a well-considered decision overcoming the knowledge barrier.

Possible consequences

The key trigger to advance the retrofit agenda besides achieving a financial gain from undertaking retrofit measures would be legislation and tax incentives (Ayyad, 2017). As stated on page 3, the Dutch government already intents to increase tax on gas and decrease tax on electricity. An observation is made when these incentives are combined with high investment costs and long payback periods, as stated on page 10.

As described on page 7 other sectors already encounter regulations, demanding mandatory upgrades of building that do not meet the standard. Most of the researches conducted to overcome the energy barriers were concerned with commercial buildings and office spaces. That is mainly because the most active and resourceful forces of the market are corporations and investors who own commercial and administrative buildings, rather than individuals who mostly own properties on mortgage. (Ayyad, 2017).

It could be hypothesized that when tax will continue to increase in favor for electricity over gas to lower the payback time and stimulate the transition and initial investment would remain considerable, the struggle for lower income to participate in the energy transition would only increase in time. This effect is only enhanced by the fact that households with lover income, usually occupy relatively older dwellings with higher energy costs in the first place (Hamilton et al., 2014). And further by the expected price increase of natural due to the reduction in Dutch gas availability (Honore, 2017). Especially in lower income and social housing the energy costs are a relatively large part of the housing costs. If the energy demand is not reduced it is estimated that in 2025 85% of the housing costs for tenants in social housing will be energy costs, compared to 32% in 2009 (T. Dijkmans, 2011). While this research focusses on private housing, these number shows the importance. The already existing social gap between mid and high income also plays a role in the energy transition.

There are a number or factors influencing the market value of a house. Location is often the first mentioned, but other are for example zoning and development permission and demographic factors (Kamal, 2016).
On individual housing level, the quality of housing also plays a role in the market value. According to Harding, et al., (Harding, Rosenthal, & Sirmans), lack of maintenance depreciates the value of building by 2.5% annually. With the new ambition of energy neutral housing, there is a factor which can no longer be ignored: energy consumption (D. Brounen, 2018; D. Brounen, Kok, N. , 2011)

The point of improvement on the EIB report are stated. But in a hypothesis that the costs to transform to an energy neutral house will be €35.000, the average value of a Dutch home of €264.00 could be decreased to €229.000 if it no energy measures has been applied. This off course remains speculating and has no validation. But it does sketch a scenario of possible consequences when the mismatch is not solved.

These possible consequences of the mismatch between possible solutions and national ambitions are an additional reasons why transparent insight is demanded. They furthermore react to the existing barrier of being not beneficial for the household themselves, stated at page 11. If energy performance is influencing the market value of their houses, the beneficial gains of the energy transition are made understandable.

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2.2 The solutions

Duo Energetica

The mismatch between the Paris-Proof ambition and current housing stock and the importance has been addressed. In order to decrease this mismatch an approach is now formulated based on a general household. The *Trias Energetica* approach is often used. This is a three-step approach for developing environmental sustainable concepts (van Timmeren, 2012). The principle is described as followed: "The first step is to reduce the need for or use of anything. The next step is to use renewable sources to meet the need. And if the first to steps are not sufficient, the third step can be applied: supply the remaining needs as efficiently as possible." Considering the goals of an energy neutral housing stock in 2050, the last step of the Trias Energetica can be eliminated. This results in a *Duo Energetica* approach, whereby a Paris-Proof housing stock is reached by preventing unnecessary use of energy and use sustainable resources for the remaining energy usage.

Possible Solutions

Following the Duo Energetica, solutions to improve the energy system of the housing stock can be divided into those two categories. The fist are measures to reduce the energy needed. As figure x illustrated, 60 % of the energy is used by space heating. Proper insulation in the floor, walls and roof will increase this demand. New heating systems, such as heat-pumps will further reduce the energy that is needed to keep the dwelling on the desired temperature. This new system can also reduce the energy needed for domestic hot water, representing 20% of the total energy use. The last two main residential energy consumers, lightning (17%) and cooking (3%), can be reduced by installing new efficient devices, such as LED-lighting and Electrical cooking. When aiming for an energy neutral housing stock, all four categories need to be addressed and this report will do so. It is however expected that the first two main energy categories are more challenging to solve. They are depended on more complex measures compared to new light bulbs and are less influenced by the behavioural aspect as explained on page 9. The lights are easier to switch off when not used than the whole heating system. While addressing this issue would benefit the energy consumption, it is not the goal of this research.

The second category of the Duo Energetica is using sustainable resources for the remaining energy usage. Following figure 2, this is divided into electric and heat generation. The electric possibilities mostly make use of solar energy. Investing is solar panels among Dutch residents, is currently the most considered option (Vermeij, 2018). Possibilities for heat generation are heat-pumps, solar boilers, pellet boiler and biomass boilers (Kaal, 2017). These measures, belonging to the formulated Duo Energetica approach, form the solutions that are explored during the research.

The proposed measures have to be researched in detail. All specifications need to be known: initial investment, covering both purchasing and installation cost, possible subsidies, component applicability, proposed energy savings, maintenance costs, life span and dependencies of other measures. A provisional business case applicable to typical housing will combine these measures and state the different payback times.

First insights

In preparation for the more detailed research, a first overview of improvements measures is stated. An attempt is made from the Dutch government to generalize all the different measures (Rijksoverheid, 2018). Seven measures were investigated, ranging from simple to complex improvements. Table 2 combines the investment costs, subsidies and yearly savings which result in the payback period. It demonstrated that insulation measures and solar panels have a relatively shorter payback period. New heating systems have a slightly higher payback time. When all measures are combined the payback-period is 11 years.

Improvement measure	1-time costs (incl. Instalment)		subsidy		Yearly savings		payback time (year)
Insulation cavity wall	€	2.100			€	550	4
Solar panels	€	4.400	€	750	€	470	8
Insulation roof	€	5.200			€	650	8
Insulation below house	€	1.800			€	200	9
Heat-pump (5kW hybrid) with HR-boiler	€	4.000	€	1.500	€	240	10
Solar boiler	€	3.300	€	1.100	€	120	18
Triple glass (instead of double)	€	9.600			€	180	53
Total (average)	**€**	**30.400**	**€**	**3.350**	**€**	**2.410**	**11**

Table 2. Payback time per improvement measures, bases on Rijksoverheid (2018).

One-time vs Step-by-step

Private homeowners have two main options by which they can reach the environmental ambitions. They can either invest step by step by doing small improvements or do a one-time large investment in the form of an (energy) retrofit. While exhausting the literature concerning the right approach to reach the 2050 goals, both views, which are diametrically opposed from each other, are supported.

From a purely energy consumption perspective, the one-time energy retrofit will be the favourable strategy. All energy measures will be done simultaneously and therefore energy usage will be minimalized and sustainable energy generation will be maximized from the moment the retrofit has taken place. With the step-by-step approach this will take longer. But form an economical perfective, energy retrofitting shows benefits as well. According to Lockwood (2009), in many cases, the most economical way to improve building energy efficiency is to combine a series of building improvements to be implemented simultaneously, rather than one by one over a long period of time. The main argument is the reduced installations costs if steps are taken simultaneously.

On the other hand, the step-by-step approach is explained as the more favourable option by many others. The conception is that by doing renovations that strive for the highest possible level, at very high costs, will limit the applicability to several state-of-the-art projects and will not be applicable to the majority. This is due to several reasons.

The first reasons have to do with the long payback periods on investments. While there is a great discussion about this length, during scoping interviews with practice resulted in a payback period of about 20 years (Buren, 2018). A disadvantage of this period is that is limited investments in better and cheaper solutions in the future. (T. Dijkmans, 2011). The EIB agrees on this argument and state that an important advance of the step-by-step approach is that this could profit the technological advancements of installations of heat-pumps of solar panels. The cost of the investment decrease in time, making it extra attractive to start with energy savings now and later in time make the step toward, then reduced in price measures toward an energy neutral situation. (EIB, 2018). Furthermore, the renovation concept is closed. Future expansion of improvements is technically difficult and therefore expensive (T. Dijkmans, 2011).

Another reason is the exponentially increased investment when a higher ambition is aspired. It could be argued that it is smarter to renovate until energy label A while adding extra space to your dwelling, costing €56.000, than renovating until energy label A++ without adding space for €78.000 (Liebregts, 2009). A side note to this argument is that in the last 9 years technical innovations become more accessible which might influence the quantified costs of this comparison. Further research is needed to verify this argument.
Furthermore, renovation in steps increases acceptance and raises awareness. A change of behaviour is desired of the occupants when drastic energy saving measures are taken. If change is gradual, occupants receive positive feedback from the changes e.g. a lower energy bill and increased comfort, which increases the willingness for further improvements (T. Dijkmans, 2011). It could be argued that for private homeowners, the main target group of this research, this is more a personal choice. If homeowners decided themselves to energy retrofit, the desired change of behaviour is already present and don’t have to be seen as a negative argument.

The EIB (EIB, 2018) did a calculation on both strategies to assess the total costs it would take to make the complete housing stock energy neutral by 2050. The needed investment was compared with the annual energy saving. For the one-time energy retrofit option this resulted in an energy saving of 0,85 PJ per €1 billion investment. For the step-by-step approach this resulted in an energy saving of 1,19 PJ per €1 billion investment. This quantifies the preference of the step-by-step approach.

For private homeowners count that freedom of choice is very important. Purely effective, it seems that step-by-step improvements show more potential. But as many private homeowners show differences in their situation, freedom of choice is favourable (EIB, 2018).

To summarize this section, both the one-time and step-by-step options must be considered in this research due the freedom of choice which is important to consumers. The step-by-step approaches however seems to be more feasible, based on the ability to implement future technologies, but also have a larger energy reduction for the same financial investment.

Target groups selection

The specific measures and strategies described in the previous section are applied to a selection of target groups with the aim to have the most possible impact in achieving the national ambition. This part will select the target group based on a high quantify and high energy performance. Giving insight in these specific target groups gives the opportunity to have a big impact on the energy transition.

The AgentschapNL (2011), part of the Ministry of Economy, Innovation and Agricultures published a document of example dwelling in the Netherlands. This is the most detailed and recent assessment of the housing stock and is used for this target group selection. It is noticed that the source is seven years old, but details about the building stock before this time is expected to be still accurate. Energy consumption might be improved in the meantime, but this accounts for the whole housing stock. The influence of the selection process is thereby relatively low.

Seven types of dwellings are distinguished based on their typology and accordingly the number of dwellings and annual primary energy demand of each type is stated. The terraced housing scored in both the number of dwellings (42%) and annual primary energy demand (41%) the highest percentage of being present in the Dutch housing stock (Ritzen et al., 2016). Within this number of dwellings, mostly row houses, large scale repetition is common and resulted in communities with a large number of exactly the same dwellings (Ritzen et al., 2016).

The second largest annual primary energy demand type (24%) is the detached houses represent, representing 14% of the number of dwellings. Duo to this reason, it could be argued that potential energy savings at these type is high and should thereby be researched. But while the terraced housing show potential for standardization, the detached housing does not. Analysing targets group which can give insights to translate a broader target group does not apply.

The terraced housing is therefore being selected by its ability to have the most impact. To further specify this type, a subcategory is made based on construction period. Based on construction period terraced housing can be divided into five different periods: 1) until 1945, 2) from 1946 until 1964, 3) from 1965 until 1974, 4) from 1975 until 1991 and 5) after 1992 (AgentschapNL, 2011). Figure 3 illustrates how the annual total primary energy demand per dwelling subcategory based on construction period. Complying with the aim to have the biggest impact, three terraced housing are selected based on their high total energy demand. The terraced houses built between in the 1946-1964 period form target group 1, built in the 1965-1974 period form target group 2 and built in the 1975-1991 form target group number 3.

Within this three targets, large scale repetition is common and resulted in communities with a large number of exactly the same dwellings (Ritzen et al., 2016). This shows great potential for this research, as insights of a study on an average target group house can be translated to the whole target group.

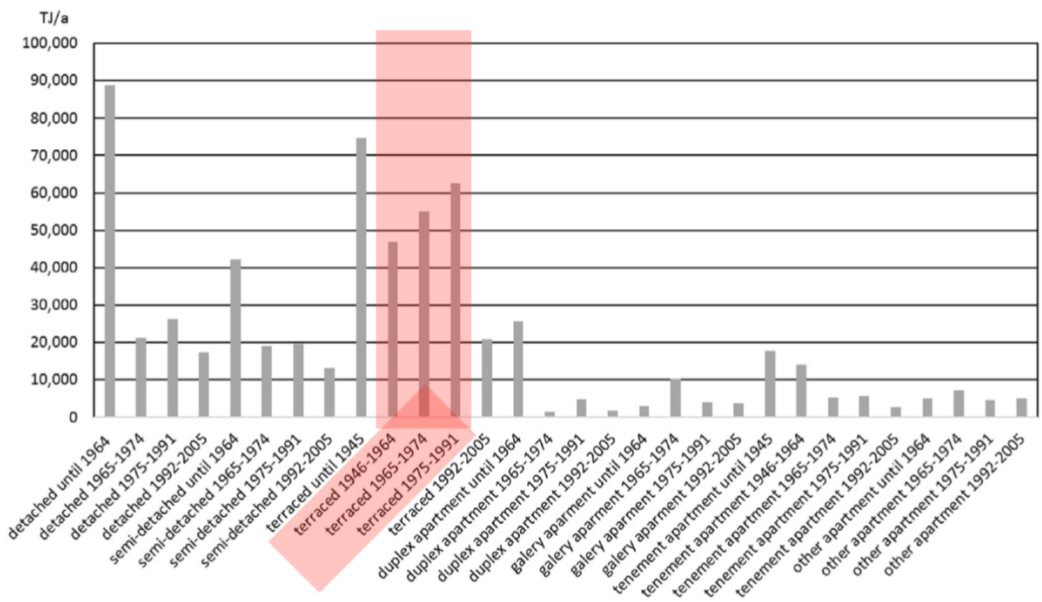


Figure 3. Annual total primary energy demand per dwelling subcategory based on construction period. After Ritzen et al. (2016).

The main specifications of each target groups, concerning quantity, energy usage, spatial layout, resident's information and original and 2011 condition, are combined in figure 4. The spatial planning concerning floorplans, sections and facades are combined with the images of typical houses of each target group can be found in appendix 1. To get an understanding behind these specifications, each group is now further explored.

Group 1: 1946-1964

Terraced dwellings from the building period 1946 to 1964 were rapidly built to meet the screaming demand of housing after World War II. As the focus on energy efficiency has mainly emerged after the first oil crisis in 1973, dwellings before this time are characterized by poor energy efficiency. In the period until 1965 there were no regulations concerning energy efficiency in residential buildings. Therefor the dwelling did not receive insulation when built (De Pauw, 1994). Furthermore, these houses are generally inhabited by the lower social classes with no financial means to combat these problems themselves. Besides this, these houses are small and have comfort problems (T. Dijkmans, 2011). A very early version of the systematic construction system was introduced in this target group (AgentschapNL, 2011).

Group 2: 1965-1974

While the size of these houses increased, figure x and appendix 1 illustrate, the specification concerning insulation and heating methods were similar to terraced housing built between 1946-1964 duo the still lacking governmental regulations. This target groups shares the findings of T. Dijkmans (2011) on the first target group about income level, shize and comfort problems. The systematic construction methods was further developed, but still remains fairly simple (AgentschapNL, 2011).

Group 3: 1975-1991

In the period between the first (1973) and second energy crisis (1979) the National Insulation Program was introduced which offered subsides to improve housing insulation, both new and existing houses. (De Pauw, 1994). Regulations concerning energetic performance of new houses increased during this period. In 1975 the minimal Rc of the roof and faced has to be 1,3 m^2K/W, this increased to mandatory double glazing in the Livingroom in 1979. The next step was a required Rc of 1,3 m^2K/W for the ground floor four years later. Finally, in 1988 the regulations prescribed a minimal Rc of 2,0 m^2K/W for the roof and facade.

The result of this shift in regulations is that epically the dwelling from in the earlier period did not receive quality insulations. A remarkable point, is the decrease form HR glass from the second target group to this one. Double glazing installed by the delivery will barely be replaced by HR glass (AgentschapNL, 2011).

	1946-1964	1965-1974	1975-1991
Quantity			
total	478.000	606.000	879.000
private	191.000	285.000	536.000
Key figure			
average usable floor area (m2)	87	106	106
Average residents	2,8	3,0	3
Energy usage			
Total Energy Primary Use (MJ)	98.000	91.097	71.259
Gas usage (m3/year)	2.246	2.030	1.542
Electricity (kWh/year)	783	924	924
Energy costs, exl. VAT / year	€ 1.485	€ 1.416	€ 1.201
Building layout			
rooms	4-5	4-5	4-5
building layers	3	3	3
Residents age			
<35	14%	10%	
35-64	57%	59%	73%
>65	29%	31%	
Residents situation			
single	32%	21%	20%
familiy	30%	31%	43%
two persons	30%	40%	28%
Originally energy level			
Energy regulations	None	Present bud minimal	Rc 1,3 - Rc 2,0
insulation measures	None	not sufficient	not sufficient
Glass	Singel	mostly single	mostly dubble
Boiler	Local gas & electric	Local gas	VR boiler
Heating method	few Central heating	Central was upcoming	Central heating
ventilation	Natual		
Current (2011) energy level			
Insulation measures:			
Glazing	double (60%), HR (12%)	double (60%), HR (18%)	double (69%), HR (10%), single (21%)
Facade	27%	35%	present, not high
Floor	7%	8%	present, not high
Roof - flat	16%	17%	present, not high
Roof - sloping	14%	26%	present, not high
Heating method	90% central heating	almost all central heating	Central heating
Boiler	HR-combiketel (53%), CR/VR boiler (33%), local (10%)	HR-combiketel (61%), CR/VR boiler (33%), local (1%)	HR-combiketel (63%), CR/VR boiler (29%), city heating (5%)
ventilation	Natural (91%), mechanic (9%)	Natural (82%), mechanic (18%)	mechanic (53%), natural (44%)
"'Kierdichting'"	27%	35%	All

Figure 4. Specifications of target housing. After AgentschapNL (2011) & Ritzen et al. (2016)

The development of systematic construction methods in this period increased. The use of prefab concrete walls and facades was used, and new to this period were the concrete floor with attached insulation. Later dwellings received the than newly introduced prefab concrete fronts and system roofing.

Two side notes have to be made. In the last seven years, the conciseness about the environmental issues has grown among the public. It is expected that the percentages of figure x belonging by 'Current (2011) energy level' are increased in recent years. Further research is needed to assess the current energy level. Secondly, while analysing the total primary energy demand per dwellings category, a difference in results is founds. Figure x, produced after Ritzen et al. (2016) is originally based on the research of AgentschapNL (2011). Figures X, directly based on the same AgentschapNL (2011) research, however shows a difference in Annual total primary energy demand per dwelling subcategory that figure x. Further research is needed to find the reason behind this.

Impact

Giving insight in the selected target groups energy transition possibilities show potential to have a big impact in reaching the national goal of an energy neutral built environment. The three target groups combined represent 2 million houses of which 1 million are privately owned, representing respectively 25% and 24% of the total housing stock. The combined total primary energy use is 260.000 MJ and the total annual energy costs, excl. VAT, is € 1,3 billion. This research makes an attempt to decrease these values.

This group of housing needs urgent improvements, was built before built before (sufficient) energy regulations and consist out of a repeated type of dwelling. This offers a great challenge based on environmental aspects due to the high energy use and offers technical and economical chances for standardization possibilities. Further research is needed on specific dwellings of each target group to fully understand the current characteristic and possibilities test the feasibility on becoming energy neutral.

Besides giving insight in the energy usage and belonging technical specification on specific target group building level, the details presented in figure x will support the search in for suitable case studies. The repetitive cases have to comply with this analyse. This way the insight can be translated to a wider target group, resulting in a large impact on reaching the national ambition.

Duo Energetica possibilities

Following the first step to prevent unnecessary use of energy, figure x illustrated the achievement than can be made in improving the building insulation. In many cases of the thirst and second target group, this is not present. And while mostly present in the third target group, these do not achieve the current quality demanded.

The percentage of implementation of the second step of the Duo Ecologica, using sustainable resources, is expected to be very low. As earlier described, inhabitants of the targeted houses generally represent the lower social classes with no financial means (T. Dijkmans, 2011). As Cayla, Maizi, and Marchand (2011) conclude, the least well-off household face a strong capital constraint for equipment purchases. With these measures costing initial capital with a current low return on investment, implementation of for example solar panels would be a challenge. Therefore, this an opportunity for this target group and therefor this research.

Maintenance in the target group

Costs of adding extra floor area are not included. These expenses are not spread. They consist out of unpredictable, costly, one-time investments.

When talking to homeowners about the costs of the maintenance of their homes, very few can quantify these expensive. The average costs of maintenance for a household is €300 per month (Vereniging-Eigen-Huis, 2018) Vereniging-Eigen-Huis (2018) did a research on how much it will cost to update different housing typologies within two years. Extensions of the home are not accounted. They conclude that it would cost €471 per month to upgrade the first target group, €393 per month for the second and €226 for the third target group.

These costs have to be considered when evaluating the feasibility of current solution form a financial perspective. The 38% of annual income spend on housing, stated on page 3, does not account for these maintenance costs. This reduces the spendable income for energy improvement measures and decreases financial feasibility form the homeowner's perspective.

Building Energy Models

The energy measurement section on page 9 and 10 state the need to research the actual energy usage. Paris-Proof is linked to an EPC of 0,0. To calculate the actual energy usage building energy models can be used. Behavioural factors, such as the rebound effect (Visscher, 2017), have the possibilities to influence these models. But as Ren et al. (2018) concludes, building energy models and their validation methods show an acceptable accuracy of total energy consumption. This research will therefor make use of a building simulation tool. The outcomes are used to evaluate the energy savings and thereby feasibility of current solution on the specific target groups.

Housing Stock Energy Models

Due to the homogenous building characteristics in each target group, the analyse of on individual house has the possibility be translated to the whole target group. This can be done though Housing Stock Energy Models (HSEMs). They have the ability to estimate the baseline energy demand of the existing housing stock, as well as to predict the effectives of applying different retrofit measures and renewable technologies on reducing the energy demand (He, 2014). Due to the large focus of energy measures on existing dwellings, a large number of HSEM have been developed in the recent years. To select the right model, the framework of G. Sousa, Jones, B., Mirzaei, P.A., Robinson, B. (2017) is used. They evaluated 29 commonly used models and made categories at which HSEMs would be best used at different researched. A selection based on the information of the case studies and building energy models could be made. By selecting the right Housing Stock Energy Models, a prediction can be quantified on how the specific target groups could affect the housing stock.

Chapter 3. Methods

The main goal is to quantify the feasibility of current solutions in target groups which would have the biggest impact on achieving the national ambition. This section stated the methods used in this research to answer the three sub questions and the goal belonging to each question.

SQ1: ***What are the current solutions for privately owned houses to become energy neutral?***

A market review is performed. The literature study provided the strategy that is followed and a number of possible measures how this strategy can be achieved. Furthermore, it stated the specifications that need to be researched of each measure. A market research is performed to translate the finding from literature to answer the sub question. Semi structured Interviews with practice will validate the findings.

Independent parties with experience in applying or advising energy saving measures in existing buildings are selected to give insight in the less transparent current commercial market. A scoping interview with practice confirmed this approach of dealing with the current obstacles in the energy improvement sector (Buren, 2018). It is desired to have a second independent source to verify the information to decrease possible biased data.

The goal of the approach is to formulate a business case that combines all specifications and is applicable on a typical privately-owned house. This way, the current solutions for private homeowners are properly evaluated and can be applied in the next step.

SQ2: How can these solutions be applied in specific target groups?

This is done through case studies. The literature study provided three target groups which combined can have a possible big impact in achieving the national goal. Three different case studies, one for each target group, will test the appliance of the current solutions, established in SQ1, on the specific types of housing.

The case studies are used to give insight on the applicability, considerations and processes of the current energy improvements solutions specified to target groups houses. The received data is translated into three building specific business cases. These will form the costs side of the feasibility study. Case selection is done based on the average specification of figure x. A case is searched for that show similar characteristics. This way, insight can be applied on a larger scale duo the large-scale repetition of the chosen target group, explained on page 17.

The structure from a previous business cases on the different target groups of AgentschapNL (2011) found in appendix 2, is used as a starting point. The quantified findings of this research will outperform the previous evaluation by assessing modern-day solutions, and actual energy performance instead of the unrepresentative energy labelling as described on page 8.

SQ3: How do these solutions influence the actual energetic performance?

An energy simulation will be used to quantify the influence of the used measures on the energetic performance of the specific target group houses. The outcome of this simulation will be used to formulate the actual benefits needed.

The objective is to formulate a business case for each target group, by combining these result with the costs analyse of SQ2.

Research output

The provided methods for approaching the different sub question result in the research output. The research output are three business cases belong to three target groups selected on their biggest possible impact. Both financial investment and actual energy savings are stated. The feasibility of current solutions to transform privately owned dwelling toward the national ambition is quantified and the research question can be answered. As a result, the main aim of this research is accomplished.

After completion, the following point could be discussed. Concepts relevant in the challenge to transform existing buildings in becoming energy neutral effects can be applied to specific buildings instead of the whole building stock. The efficiency gap, as discussed on page 9, was the main conclusion of the EIB. This gap can now be quantified for each target group, giving insight to the existing barriers. Furthermore, the three cases can be compared with other housing types and their applicability can be discussed. Additionally, when combining these this data set to specific homeowner data, for example concerning their potential investment capital, a more detailed approach will be created to investigate what is currently possible and what is not yet economically feasible for individual private homeowners.

Chapter 4. Research Plan

There are three main tasks that need to be achieved to start the research. The tasks have to be accomplished before starting with each sub question. It is therefore not necessary that all tasks have been achieved at this stage. The tasks are the following:

SQ1: Finding Market review parties
Progress: 75%

Two independent parties with experience in applying energy saving measures in existing buildings have been found and with both a meeting has taken place.

The first is Greenhome (www.greenhome.nl). This is an independent platform that has the ambition to make the energy transition as transparent and easy as possible. It furtherer is the partner of 65 municipalities in the Netherlands, representing the regional energy office (Dutch: Regional Energyloket) responsible for answering all questions of the inhabitants concerning the energy measures for your home (Greenhome, 2018). Greenhome has agreed to provide information which they think can answer the sub question.

The second party is the Energiebespaarders (www.energiebespaarder.nl). They are a connecting platform between homeowners and energy improvement market parties. While they expressed their willingness to participate, an agreement still has to be made.

SQ2: Case study selection
Progress: 66%

Case target group 1: found. Super Power (http://www.superpower.nu/) . Start-up at YesDelft! Which aims to developed the world first home subscription.
Case study: performed a case study on the first target group. This case study is explored and deepened where possible.

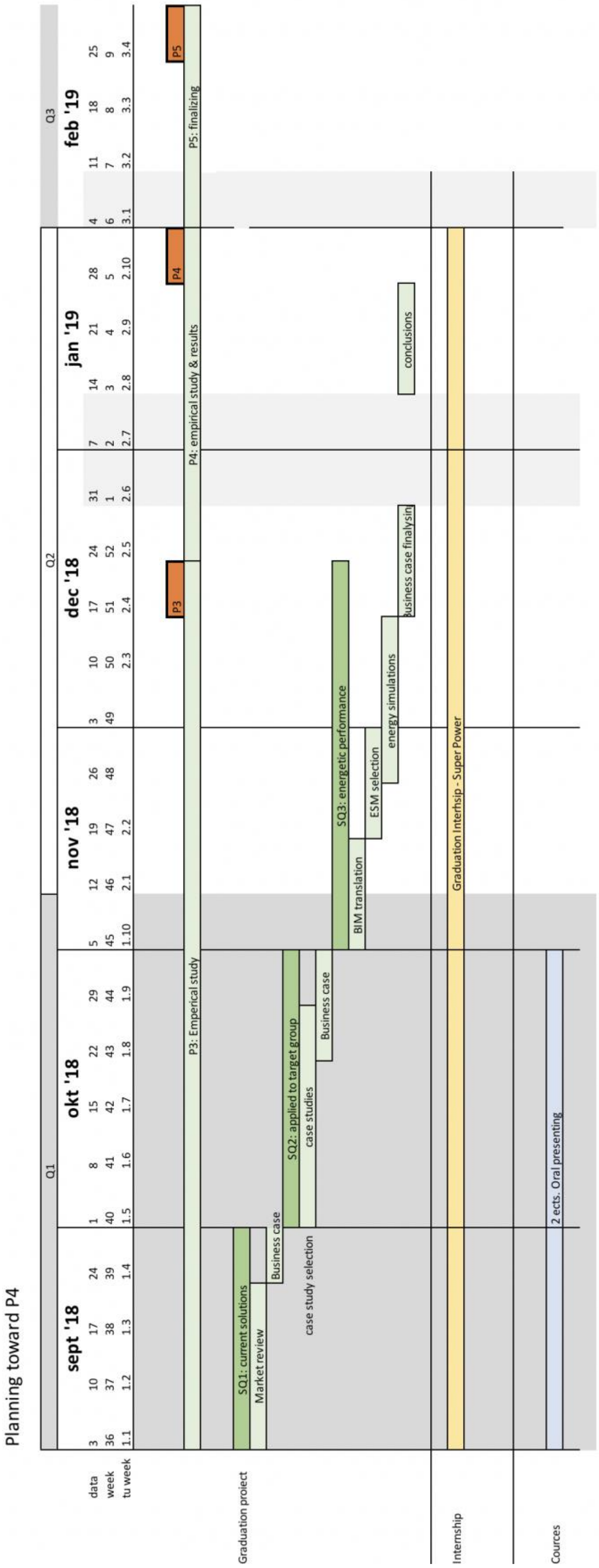
Case target group 2: found. Company: Dura Vermeer (www.duravermeer.nl) - one of the largest construction companies in the Dutch AEC sector.
Case study: Pilot house transformation which complies with the characteristics of this target group. More details about the house are not yet received. Furthermore, it is also a home-bound financing pilot. Expected construction start this summer, design plan is used for this case study.

Case target group 3: not found yet.

SQ3: Energy simulation selection
Progress: 10% (literature review)

Selecting the right energy simulation is depended on the provided cases. It is expected that the case studies have some form of energy simulation done. It has to evaluated if these existing simulations can be used as a starting point. If energy simulations are not present, a new BIM model has to be constructed based on the case findings.

Planning toward P4:



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Appendixes.

1. Spatial specific's and images of the three target groups:

Group 1: Terraced housing 1946-1964

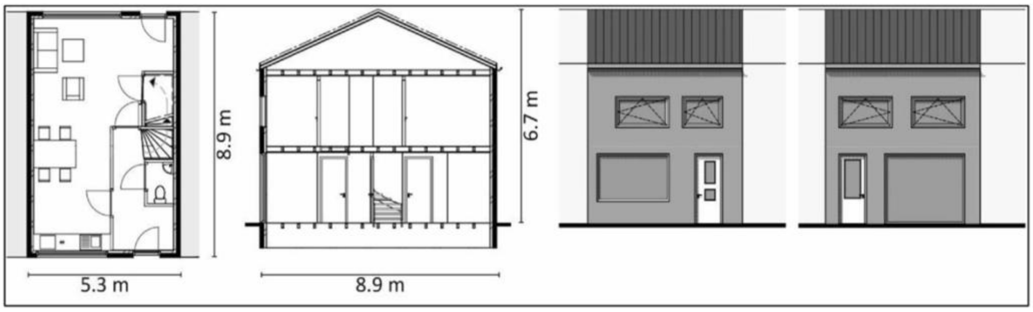


Figure x. Typical floorplan, cross section and facades (front and back, from (Ritzen, 2016 #51@@author-year).

Figure x Images of typical Dutch terraced house from the 1946-1964 period, from ((CBS)), 2012 #49@@author-year).

Group 2: Terraced housing 1965-1974

Figure x Images of typical Dutch terraced house from the 19656-1974 period, from ((CBS)), 2012 #49@@author-year).

Group 3: Terraced housing 1975-1991

Figure x Images of typical Dutch terraced house from the 1946-1964 period, from ((CBS)), 2012 #49@@author-year).

2. Energy specifications and proposed energy improvement packages in 2011.

Source: AgentschapNL (2011).

Group 1: Terraced housing 1946-1964

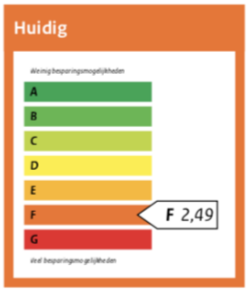
Kenmerken woning	
Gebruiksoppervlakte (m^2)	87,0
Aantal bewoners	2,8

Bouwdelen	Huidig			Besparingspakket			Investeringskosten	
	Opp. (m^2)	Rc-Waarde (m^2 K/W)	U-Waarde (W/m^2K)	Opp. (m^2)	Rc-Waarde (m^2 K/W)	U-Waarde (W/m^2K)	Per m^2	Totaal
Begane grondvloer [3]	47,0	0,32	1,72	47,0	2,53	0,36	€ 20	€ 940
Plat dak [3]	-	-	-	-	-	-	-	€ 0
Hellend dak [3]	57,3	0,39	1,54	57,3	2,53	0,36	€ 53	€ 3.040
Achter- en voorgevel								
– Gesloten [3]	42,3	0,36	1,61	42,3	2,53	0,36	€ 21	€ 890
– Enkelglas [3]	6,5		5,20	-		-	€ 139	€ 900
– Dubbelglas [3]	14,9		2,90	-		-	€ 142	€ 2.110
– HR^{++} glas	-		-	21,4		1,80		
Zijgevel								
– Gesloten	53,0	0,36	1,61	53,0	2,53	0,36	€ 21	€ 1.110
– Enkelglas	-		-	-		-	-	€ 0
– Dubbelglas	1,8		2,90	-		-	€ 142	€ 260
– HR^{++} glas	-		-	1,8		1,80		

Installatie	Huidig	Besparingspakket	Investeringskosten
Ruimteverwarming [3]	HR107 ketel	HR107 ketel	-
Warmtapwater	Combitap HR	Combitap HR	
Ventilatie	Natuurlijke ventilatie	Natuurlijke ventilatie	

Rijwoning, tussen: Investeringskosten [2] meest voorkomende subtype van energieniveau 'huidig' naar energieniveau 'besparingspakket'	€ 7.880

Energieprestaties subtype tussen	Huidig	Besparingspakket	Besparing
EI (-)	2,49	1,17	1,32
Energielabel	F	B	4 energielabel(s)
Totaal primair energiegebruik (MJ)	98.017	45.890	52.127
Gasgebruik (m^3/jaar) [1]	2.246	953	1.293
Hulpenergie, verlichting, PV (kWh/jaar) [1]	783	783	0
CO_2 emissie (kg/jaar)	4.441	2.140	2.302
Energiekosten, exclusief BTW per jaar	€ 1.485	€ 915	€ 570



1 Op basis van de EI-berekening, maar met een binnentempertuur van 16,5°C i.p.v. 18°C, zonder comfortcorrectie bij lokale verwarming en keukengeiser en directe aftrek van de opbrengst van PV.
2 De investeringen van 'Huidig' naar 'Besparingspakket' zijn exclusief BTW en gelden bij projectmatige aanpak. Prijspeil 1 maart 2010.
3 Telt mee bij investering meestvoorkomende subtype.

Group 2: Terraced housing 1965-1974

Kenmerken woning	
Gebruiksoppervlakte (m²)	106,0
Aantal bewoners	3,0

Bouwdelen	Huidig			Besparingspakket			Investeringskosten	
	Opp. (m²)	Rc-Waarde (m² K/W)	U-Waarde (W/m² K)	Opp. (m²)	Rc-Waarde (m² K/W)	U-Waarde (W/m² K)	Per m²	Totaal
Begane grondvloer [3]	52,0	0,17	2,33	52,0	2,53	0,36	€ 20	€ 1.040
Plat dak [3]	-	-	-	-	-	-	-	€ 0
Hellend dak [3]	65,5	0,86	0,89	65,5	2,53	0,36	€ 53	€ 3.470
Achter- en voorgevel								
– Gesloten [3]	40,5	0,43	1,45	40,5	2,53	0,36	€ 21	€ 850
– Enkelglas [3]	4,3		5,20	-		-	€ 139	€ 600
– Dubbelglas [3]	21,3		2,90	-		-	€ 142	€ 3.020
– HR++ glas	-		-	25,6		1,80		
Zijgevel								
– Gesloten	58,3	0,43	1,45	58,3	2,53	0,36	€ 21	€ 1.220
– Enkelglas	-		-	-		-	-	€ 0
– Dubbelglas	1,8		2,90	-		-	€ 142	€ 260
– HR++ glas	-		-	1,8		1,80		

Installatie	Huidig	Besparingspakket	Investeringskosten
Ruimteverwarming [3]	HR107 ketel	HR107 ketel	–
Warmtapwater	Combitap HR	Combitap HR	
Ventilatie	Natuurlijke ventilatie	Natuurlijke ventilatie	

Rijwoning, tussen: Investeringskosten [2] meest voorkomende subtype van energieniveau 'huidig' naar energieniveau 'besparingspakket'	€ 8.980

Energieprestaties subtype tussen	Huidig	Besparingspakket	Besparing
EI (-)	2,08	1,18	0,90
Energielabel	E	B	3 energielabel(s)
Totaal primair energiegebruik (MJ)	91.097	51.491	39.606
Gasgebruik (m³/jaar) [1]	2.030	1.050	980
Hulpenergie, verlichting, PV (kWh/jaar) [1]	924	924	0
CO_2 emissie (kg/jaar)	4.136	2.392	1.744
Energiekosten, exclusief BTW per jaar	€ 1.416	€ 984	€ 432

1 Op basis van de EI-berekening, maar met een binnentempertuur van 16,5°C i.p.v. 18°C, zonder comfortcorrectie bij lokale verwarming en keukengeiser en directe aftrek van de opbrengst van PV.
2 De investeringen van 'Huidig' naar 'Besparingspakket' zijn exclusief BTW en gelden bij projectmatige aanpak. Prijspeil 1 maart 2010.
3 Telt mee bij investering meestvoorkomende subtype.

Group 3: Terraced housing 1975-1991

Kenmerken woning	
Gebruiksoppervlakte (m²)	106,0
Aantal bewoners	3,0

Bouwdelen	Huidig			Besparingspakket			Investeringskosten	
	Opp. (m²)	Rc-Waarde (m² K/W)	U-Waarde (W/m² K)	Opp. (m²)	Rc-Waarde (m² K/W)	U-Waarde (W/m² K)	Per m²	Totaal
Begane grondvloer [3]	51,0	0,52	1,28	51,0	2,53	0,36	€ 20	€ 1.020
Plat dak [3]	-	-	-	-	-	-	-	€ 0
Hellend dak [3]	68,6	1,30	0,64	68,6	2,53	0,36	€ 53	€ 3.640
Achter- en voorgevel								
– Gesloten [3]	40,6	1,30	0,64	40,6	2,53	0,36	€ 21	€ 850
– Enkelglas [3]	3,1		5,20	-		-	€ 139	€ 430
– Dubbelglas [3]	16,2		2,90	-		-	€ 142	€ 2.300
– HR++ glas	-		-	19,3		1,80		
Zijgevel								
– Gesloten	58,4	1,30	0,64	58,4	2,53	0,36	€ 21	€ 1.230
– Enkelglas	-		-	-		-	-	€ 0
– Dubbelglas	1,8		2,90	-		-	€ 142	€ 260
– HR++ glas	-		-	1,8		1,80		

Installatie	Huidig	Besparingspakket	Investeringskosten
Ruimteverwarming [3]	HR107 ketel	HR107 ketel	–
Warmtapwater	Combitap HR	Combitap HR	
Ventilatie	Natuurlijke ventilatie	Natuurlijke ventilatie	

Rijwoning, tussen: Investeringskosten [2] meest voorkomende subtype van energieniveau 'huidig' naar energieniveau 'besparingspakket'	€ 8.240

Energieprestaties subtype tussen	Huidig	Besparingspakket	Besparing
EI (-)	1,64	1,17	0,47
Energielabel	D	B	2 energielabel(s)
Totaal primair energiegebruik (MJ)	71.259	50.749	20.510
Gasgebruik (m³/jaar) [1]	1.542	1.037	505
Hulpenergie, verlichting, PV (kWh/jaar) [1]	924	924	0
CO_2 emissie (kg/jaar)	3.268	2.369	899
Energiekosten, exclusief BTW per jaar	€ 1.201	€ 978	€ 223

1 Op basis van de EI-berekening, maar met een binnentempertuur van 16,5°C i.p.v. 18°C, zonder comfortcorrectie bij lokale verwarming en keukengeiser en directe aftrek van de opbrengst van PV.
2 De investeringen van 'Huidig' naar 'Besparingspakket' zijn exclusief BTW en gelden bij projectmatige aanpak. Prijspeil 1 maart 2010.
3 Telt mee bij investering meestvoorkomende subtype.