Current solutions for the energy transition

A feasibility study for homeowners.

TU Delft

Tim Luijt

PERSONALIA

Student:	T. (Tim) Luijt
Student number:	4206053
Master:	Architecture, Urbanism & Building Science Management in the Built Environment
Address:	Saenredamstraat 4A-hs 1072CE Amsterdam
Telephone	+31 (0)6 102 308 53
Email:	tluijt@gmail.com

Delft University of Technology

1st Graduation mentor:	Alexander Koutamanis
2nd Graduation mentor:	Ilir Nase
External examiner:	Huib Plomp
Proposal date	5 April 2018

THE FCTR E

Company supervisor:	Frits Verhoef
Address:	Generaal Vetterstraat 82 1059 BW Amsterdam

EXECUTIVE SUMMARY

Households constitute 31% of the total energy consumption in the Netherlands (CBS, 2017). In the fight against climate change, reducing and eventually terminating the use of natural gas in dwellings has become a key issue in national Politics.

Following the Paris Agreement, the government aims to have two million gas-free homes, representing 28% of the housing stock, by 2030 (Nijpels, 2018) and an energy neutral housing stock by 2050 (RutteIII, 2017). Earthquakes caused by natural gas drilling in the Dutch North region have accelerated the national ambition to become gas-free. At the same time, Dutch households have the highest dependency on natural gas within Europe, using twice the amount of the average European household (Eurostat, 2016). These two extremes make the situation in the Netherlands a unique field of study. As stated in the recent national climate agreement proposal, "we are on the verge of a great reconstruction, a transformation of our seven million houses." (Nijpels, 2018). Many researchers have concluded that the existing housing stock is one of the key sectors where action is needed to meet the Paris Agreement goals (Evertzen, 2017; Ritzen, Haagen, Rovers, Vroon, & Geurts, 2016; Visscher, 2017).

The privately owned dwelling stock, representing 51% of the building stock (CBS, 2016), lacks regulations concerning energy usage, a long-term perpspective, and available resources, making it a key sector within the energy transition discussion (Arnoldussen, 2017). Due to the low annual residential replacement rate in the Netherlands, 87% of the future housing stock (2050) has already been built (CBS, 2016). A demolish-rebuild strategy would entail a relentless operation and massive construction (Dobbelsteen, 2015), and seems impossible in terms of capacity as well as waste production (T. Dijkmans, 2011).

Political tools developed by the sector table of the Built Environment in the national Climate Agreement opened the door for market parties in the Architecture, Engineering, Construction and Operating (AECO) sector to explore new transition processes. The servitization model, in which the object of sale is the performance and not the product itself (Stahel, 2008), has proven advantageous in other sectors and offers opportunities for energy transition in the built environment (Franco, De Langhe, & Venken, 2016). This yet unresearched process is discussed in this study.

The gas-free transition is considered a means to an end in the larger energy neutral framework. Gas-free residential energy infrastructure offers a base on which future technical innovations could be built to reach an energy neutral housing stock (Valk, 2018). This research is scoped toward the 2030 goal of becoming gas-free, following the current focus on the national ambition.

Problem field

There is a clear mismatch between the national ambition to reach a natural gas-free housing stock and the current ability of owner-occupiers to meet this ambition. The target is set to achieve a gas-free transition rate of 30.000 to 50.000 dwellings per year by 2021, and a rate of 200.000 by 2030 (RutteIII, 2017). This is required to meet the 2050 goals. Currently, the number of houses transitioning is around 2.000 to 5.000 per year (Buren, 2018; F. Verhoef, 2018).

The most significant barriers for homeowners, the decision-makers in the gas-free transiton in the privately onwed housing stock, are that measures are too expensive (39%), there is not adequate benefit (24%) and their knowledge of the transition process is too limited (22%) (Vermeij, 2018). That study found that the importance of sustainable measures is clear, but residents lacked the information to make well-informed decisions.

With the introduction of servitization in this field of work, a different feasibility perspective is presented and, while it has potential, the effects are unknown.

This research aims to help resolve this mismatch between the national ambition and the opportunities for households to act in the gas-free transition. To do so, missing information is provided and made understandable to homeowners. By including the servitization model, the effect of this new model is furthermore researched.

Research proposal

The main goal of this research is to explore the stated mismatch in more detail, and gain insights for homeowners, market parties and strategy makers to act in the energy transition.

The objectives are as follows: (1) conceptualize the natural gas-free transition process; (2) develop optimum homeowner focused transition packages showcasing if and how they can enter the transition process; and (3) generate a housing stock feasibility overview and assess the added value of the servitization model.

To obtain these objectives, the main research question is stated as follows:

> *"What does the energy transition process mean for the private housing stock to become gas-free?'*

The sub questions related to the main research question are:

1. *What types of dwellings are included in the private housing stock?*
2. *What types of services are currently available to transition to a gas-free dwelling?*
3. *Which processes are currently available for homeowners to transition to gas-free?*
4. *How can these processes be designed for homeowners to enter the gas-free transition?*

Research relevance

From a societal perspecitive, the empirical findings provide useful and novel insights into one on the most significant societal and political dicussions of the modern period: fighting climate change. This thesis adds knowledge about the aspect of the Dutch built environment that consumes the most energy (Ritzen et al., 2016), yet most challanging part of the Dutch built environment due to the lack of long term perspective (Arnoldussen, 2017).

From a scientific perspective, the current body of knowledge consists mostly of research on the Dutch non-profit housing sector (Hoppe, 2012; Nieboer, 2017; T. Dijkmans, 2011; Visscher, 2017). Research on private housing stock has been done by TU Delft graduate Evertzen (2017), however the focus of that work was on gallery apartment buildings. Additional knowledge is required about the remaining, more diverse, private dwellings responsible for the larger share of primary energy demand.

Research in which the effect of building level variables is translated towards the housing stock level outcomes regarding the feasibility transition rate lack in current research. Furthermore, previous studies are based on energy labeling (EIB, 2018; Valk, 2018), and therefore did not build on the findings of Majcen (2016) about the difference between theoretical and actual energy consumption. The emperical findings of this research provide evidence based on actual energy consumption and thereby includes the human factor.

Finally, scientific relevance is added by exploring the yet unresearched effect of servitization on energy transition. The research provides useful and novel insights considering this recently introduced model.

Literature review

The research focuses on the gas-free alternatives for space heating and domestic hot water (DHW). Combined they currently consume 98% of the gas consumption, and 80% of the total primary energy consumption of the housing stock. Research is performed on the three interrelated domains: building, services and users. The following research strategy guides decisions throughout the thesis: (1) reduce the energy need for space heating and DHW; (2) use renewable sources to meet energy demand; (3) supply the remaining needs as efficiently as possible with other sources than gas and (4) while remaining feasible.

The research presents the key variables of each domain influencing the transition process. The level of complexity is reduced to illustrate the important relationships and is coherent to the feasibility of this research. The research specific variables are presented in Figure A.

To account for the current housing stock situation, the researcher selected 19 target groups to represent the housing stock, representing the terraced, semi-detached and detached dwellings of the private housing stock. The 3.7 million targeted dwellings represent 83% of the private housing stock and 58% of the total housing stock. Therefore, this research adds knowledge about reducing 86% of the energy consumption of owner-occupied dwellings. Four user groups, differing in number of occupants and indoor temperature, account for the human factor.

Based on the research strategy, the air source heat pump is selected as the alternative to the gas-powered boiler providing space heating and DWH. Low, medium and high output temperature results in service alternatives A, B and C respectively. By adding solar panels, changing the heating distribution system and improving the insulation and ventilation method, the future expected, gas-free situation is formulated. The research produces quantified data about the transition process from the current to future heating methods.

The transition process is designed by starting with the input values of the features belonging to the three domains, followed by their relations. Energetic functions follow the relations, differing in the energy demand and supply circuit. The output included the feasibility step, incorporating both the initial and operational costs. The conceptual transition process is illustrated in Figure B.

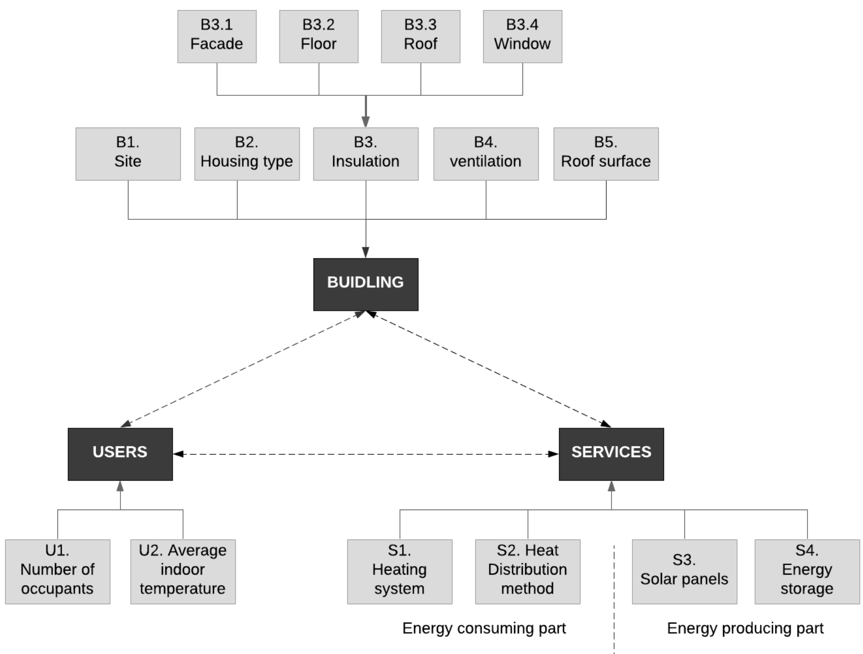


Figure A. Conceptual model of research specific variables

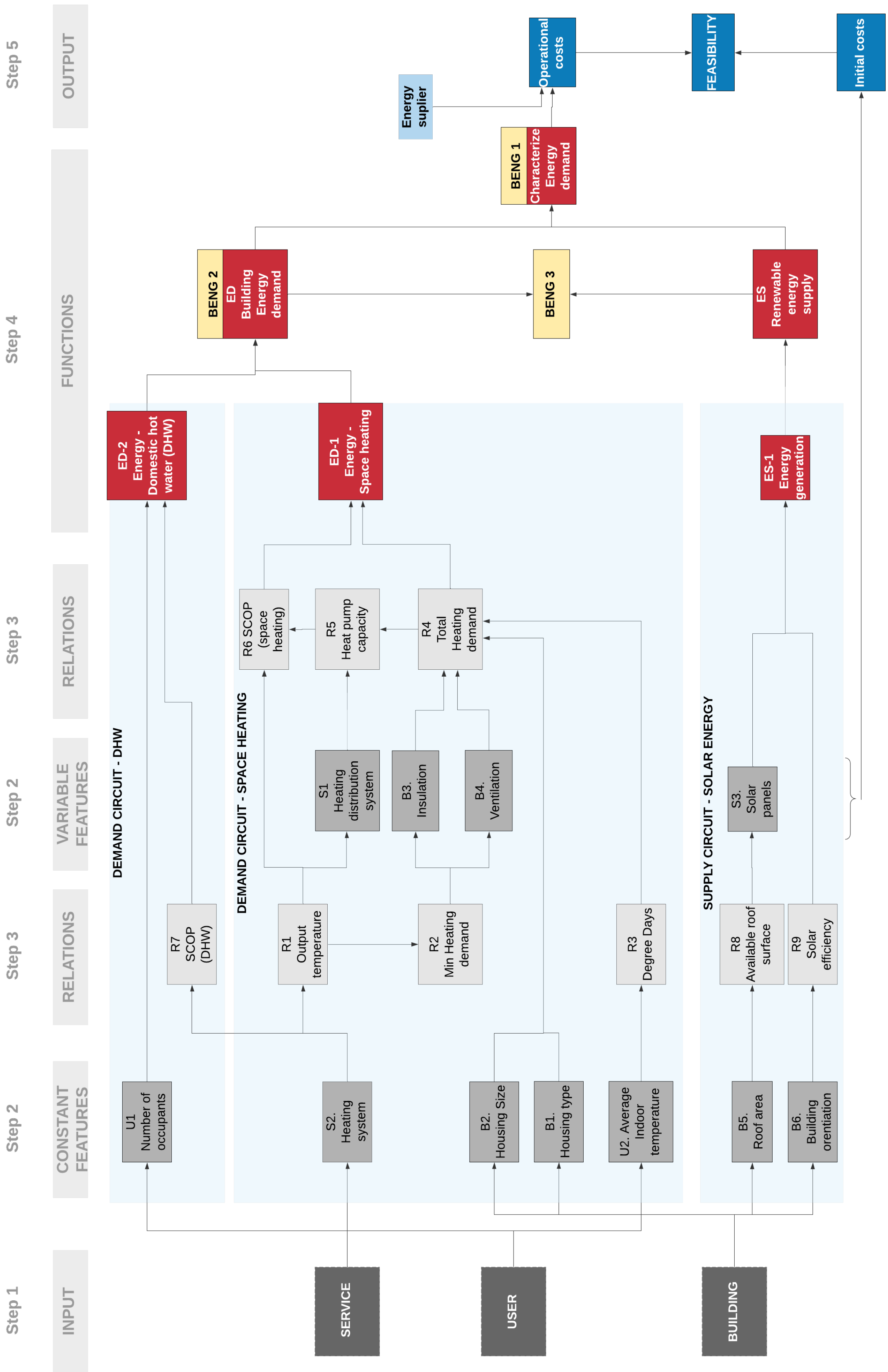


Figure B. Conceptual model of transition process, with input values, constant and variable features, relations, functions and output value.

Technical feasibility is only applicable for solar panels as they require a minimal useable roof surface. Other variables do not offer technical constraints. Besides the initial and operational cost, the research presents benefits in the form of an increase in dwelling value. Based on three different studies, this research assumes a price premium of 5% when dwellings are upgraded toward energy label A of B. Based on the graduation company's information, annual leasing costs follow a 5% interest rate with a depreciation period of 15 years.

The economic feasibility is assessed by the difference between the payback period and expected moving cycle. If homeowners are able to payback their investment within one year of the moving cycle, the transition process is perceived as economically feasible. The financial feasibility, which still requires research in the field of the gas-free transition process, is added to represent the servitization model. A financially feasible package is established if the leasing costs are lower than the difference in operational costs.

Methodology

The aim of this research is to analyse the feasibility of privately-owned dwellings transitioning to be gas-free. Table A shows how the research objectives are related to the six research steps. It also indicates which research question relates to the various steps and illustrates the different methods used at each stage.

The main method of this research is the development of a transition tool. The tool combines a Building Performance Simulation (BPS) with economic analysis. The tool produces empirical results based on different building, user and service variables. It produces outcomes based on both economic and financial feasibility. The case study validates the outcomes of the transition tool.

Case study

Empirical knowledge is acquired by studying three dwellings that underwent a gas-free transition process corresponding with service alternative A. The case study provides quantified insight that results in transition tool adjustment and more in-depth insights are gained resulting in a different tool setup. The features that lie within the case study boundaries are evaluated in a cross-case analysis, emphasizing the significant influence of human factors and the relationship between construction period and housing size with heat pump capacity.

Conclusion

The main empirical findings indicate that feasible gas-free transition packages can be developed for 33%, or 1.2 million privately owned dwellings with the processes currently available. The remaining 2.4 million dwellings do not showcase feasible business cases to enter the gas-free transition process. The results show that the dwellings that illustrate feasible transition package have the potential to decrease their 49% share of primary energy demand to 8% when gas-free, decreasing the total energy consumption of the Netherlands by 7.7%. Further details of the feasible and not feasible transition packages are presented in Table B.

The economically feasible transition packages illustrate an average initial investment of €24,800 euros to become gas-free, of which €7,300 euros represent a house value increase. The remaining €17,500 is paid back within the average moving cycles of the different user groups. Combined, the feasible transition packages demand a total investment of €31 billion euros paid back within 11 years.

The financially feasible transition packages illustrate an average 16% decrease in operational costs. In contrast with the buying option, homeowners can enter the energy transition and access annual savings without an upfront investment while also remaining flexible in their future moving plans. With an assumed depreciation period of 15 years, the buying option outperforms the leasing option after 11.3 years in terms of TCO. Hence, the servitization model offers an additional option for homeowners considering entering the transition process.

The results indicate that, hypothetically, the feasible business cases are able to achieve the national ambition to reach 1.2 million gas-free dwelling by 2030 based on current conditions. However, two main challenges are foreseen.

Table A. Connection between research chapter, objective, steps, questions and methods.

Chapter	Objective	Research step	Related research question	Method
Chapter 1. Introduction		Step 1. Define the problem field.		Literature review
Chapter 2. Literature review	1. Conceptualize the transition process	Step 2. Analyse the transition process of existing privately owned dwellings.	1. What type of dwellings are included in the private housing stock? 2. What type of services are able to provide a gas-free home? 3. What process are currently available for homeowners to become gas-free?	Literature review
Chapter 3. Methodology		Step 3. Develop the transition tool.		Transition tool
Chapter 4. Case study + Chapter 5. Findings	2. Formulate transition packages 3. Assess housing stock transition feasibility rate	Step 4. Validate the transition tool Step 5. Produce outcomes	4. How can these processes be considered feasible for homeowners?	Transition tool Case study
Chapter 6. Discussion + Chapter 7. Conclusion		Step 6. Evaluate outcomes of the tool.	Main research question: What does the energy transition mean for the private housing stock to become gas-free?	Quantitative outcomes

Table B. Feasibility conclusions for the targeted privately-owned housing stock

	Feasible transition package		*Not feasible transition packages*	
Amount of dwelling	1.2 million	33%	2.4 million	67%
Construction period	Detached	<1975	Detached	>1976
	Semi-detached	<1975	Semi-detached	>1976
	Terraced	<1945	Terraced	>1946
Primary heating demand	89.500 TJ	49%	93.200 TJ	51%
Total investment	€31 billion	43%	€41 billion	57%
Average payback period (economic feasibility)	11 years		26 years	
Difference in operational costs (financial feasibility)	- 16%		+43%	
Average initial investment	€24.800		€17.000	
Price premium	€7.300		-	

Firstly, a total initial cost of €31 billion euros is required in the upcoming 10 years, invested by either homeowners or by the service suppliers. Secondly, the current transition rate requires a 1.000% increase while the AECO sector currently is experiencing a shortage of labour.

The outcomes of this research are bound to change in the future, as the input values change over time. A sensitivity analysis is performed on two main concepts. Firstly, the influence of the interest rate on the financial feasibility rate indicates that in a scenario in which there is a scope for decrease of interest rate to 3%, this financially feasible transition percentage increased to 46%. In another scenario in which attracting capital is no longer costs effective an increased interest rate of 7% resulted in a decreased feasible transition percentage of 30%. Secondly, the influence of annual price level increase of natural gas on the economic feasibility rate indicates that when the cumulative gas price increase reaches 6%, the feasibility rate increases to 46%. When the cumulative gas price increase reaches 15%, the feasibility rate is increased to 51%.

To improve the feasibility rate, scalability, standardization, and robotics have the ability to decrease the 30% share of labour costs mainly for insulation upgrades and heat pump installations. The presented shared heat pump concept has the ability to decrease the 70% share of initial costs. The heat pump represents the largest share (60% to 70% of the minimal initial investment) with an average payback period of 24 years. While it is currently the most favourable solution, in current conditions the heat pump does not offer an empowering solution.

Stakeholder implications

Homeowners of 3.7 million dwellings are informed about how they can enter the gas-free transition with the currently available solutions. The empirical results provide insights and transparency in the decision-making process for 58% of the homeowners of the Dutch housing stock, perceived as one of the main barriers to entering the gas-free transition (Vermeij, 2018).

Policy-makers can implement the outcomes within their current strategies to achieve the ambitions for energy transition in the built environment, which currently is one of the largest political and societal national discussions. Policy-makers have the ability to influence interest rates and energy price levels, both of which influence the feasible transition rate and are quantified through a sensitivity analysis. Implementing these results could provide a different perspective for the AECO industry to approach the transition, shifting the required investment from the short-term perspective homeowners to the long-term perspective financial sector.

Market parties in the AECO sector operating in the gas-free transition can implement the results to locate their theoretical market potential, and enhance efficiency on the feasible transitions. This increases the annual transition rate and spreads out the workload, which is essential to obtain an energy neutral building stock by 2050.

Finally, the financial sector gains insights from the empirical results for their participation in the energy transition through the servitization model. The total potential market share with different interest rates provides a first risk analysis, on which the interest rate is determined.

Recommendations for further research

Further research is required to study the business principles of a service supplier operating in the gas-free transition. Business concepts concerning the critical mass, minimal revenue and operational cost barriers were not researched due to time and scope limitations. When the results of this thesis are combined with additional business knowledge, outcomes of this study should determine if the servitization process is viable for the financial sector to participate in the gas-free transition.

Further research is needed regarding the shared heat pump concept. Without accounting for the additional costs, the results indicate an improved feasibility rate of 33% to 65% based on two-neighboured dwellings.

Further research is needed to explore the legal, technical and user challenges. Aggregation also opens new technical and organisational possibilities.

The empirical results of this thesis contribute to the existing body of knowledge concerning privately owned existing housing stock entering the gas-free transition within the field of energy-efficient construction. The research differentiates itself by including and relating both detailed dwelling level insight and housing stock level feasibility results. It furthermore provides novel insights into the effect of the servitization model within the energy transition.

PREFACE

This master thesis discusses the outcomes of the graduation research towards the gas-free transition of privately-owned dwellings. The graduation process was part of the Master track Management in the Built Environment at the faculty of Architecture, Urbanism and Building Science at the Technical University of Delft. This report covers the final assessment session (P5) of the total of five assessments sessions with the graduation process, which started in February 2018.

Targeting existing dwellings during my graduation project has been the plan since my first year of the Architecture Bachelor. Combining my passion for old architecture and new innovations resulting in the energy transition focus. By including the servitization model into the energy transition focus, my interest in new business models was added. Admittingly, the environmental aspect first was a secondary reason. However, during the graduation process I have gained knowledge on the effects of our built environment of the environment in such an extent, that my order of interest is restructured.

I would like to thank the following people for their help and contribution to this thesis research. Foremost, my main mentor Alexander Koutamanis, for his patience and constructive sessions. You have been a true inspirator, able to shed light on important points throughout the process. Always guiding me and my thoughts towards the essence. Your co-operative spirit has made the whole endeavour truly a pleasure. I would like to thank my second mentor Ilir Nase, for his structured and productive feedback. You understood my challenges and were able to provide the exact answers to enhance my progress.
Discussions with the three of us were both inspirational and a pleasure.

My company mentor at THE FCTR E, Frits Verhoef, who made sure to always question the findings on their true meaning. You have changed my perspective towards the environmental challenges our society is facing and left a permanent mark on my future actions. The rest of THE FCTR E team, especially Jan-Willem van Wensem and Sander Verhoeff, thanks for your support and enthusiasm along the way. The vibe at THE FCTR E was truly inspiring, competent to face any challenge. I would furthermore like to thank my friends and family, for their help and support during the sometimes-late hours.

Tim Luijt

Amsterdam, April 2019

READERS GUIDE

This section explains the structure of this thesis, which is visualized in Figure 1.

The first chapter introduced the research proposal. Scoping decisions are stated and the research topic is formulated. The research problem is identified and different objectives are determined. Hereby, four sub questions are connected to the found objectives and the main research question is introduced. The final part elaborates on the study's relevance's.

The theoretical basis of this research is presented in the second chapter. The literature review generates an overview of the existing knowledge related to this topic. Outcomes are seen as the theoretical foundations of this research.

The methodology of this research is presented in the third chapter. The findings of the theoretical foundations are translated to a research specific methodology. The theoretical foundation of chapter two is translated into the development of the transition tool. The presented methods are able to answer the main research question.

The empirical analysis of this research is presented in the chapters four and five. The fifth chapter presents three cases studies, of which the outcomes are compared to one another in the cross-case synthesis. This chapter is seen as the empirical validation step the third chapter. The last empirical step is performance in the fifth chapter, wherein the empirical analysis is presented based on the transition tool outcomes.

The final part of this research evaluates the results. The outcomes of this research are discussed in chapter six, after which chapter seven concluded this research.

Research phase	Chapter	What does this chapter tell me?	Related research question
Defining the problem	Chapter 1. Introduction	The research topic is introduced and the main problem is defined based on the context of the background information. The main research question and relevance will be elaborated upon.	
Theoretical framework	Chapter 2. Literature review	The literature review is based upon three lines of research. The first is concerning the current situation. The second elaborates on the future situation and the third is based upon the transition process between the current and future situation	• What type of dwellings are included in the private housing stock? • What type of services are able to provide a gas-free home? • What process are currently available for homeowners to become gas-free?
Methodology	Chapter 3. Methodology	This section will elaborate on the research methodology. The transition tool, function as the main method deployed in this study, is introduced based on the theoretical foundation of chapter two.	
Empirical Analysis	Chapter 4. Case study	This section will present three case studies, functions as the validation step of the transition tool. The outcomes are compared to one another is the cross-case synthesis.	
	Chapter 5. Findings	This section will explain the empirical analyses of the study. First the outcomes will be explained from the homeowners perspective. The second phase will describe the housing stock translation.	• How can these processes be considered feasible for homeowners?
Evaluation	Chapter 6. Discussion	The findings are discussed in this section, elaborating on the main outcomes and the robustness of the findings.	
	Chapter 7. Conclusion	The final section will combine the outcomes of the previous sections and will conclude this research. Recommendations for further research are provided	Main research question: What does the energy transition mean for the private housing stock to become gas-free?

Figure 1. Research structure

TABLE OF CONTENT

CHAPTER 1. INTRODUCTION

Households constitute 31% of the total energy consumption in the Netherlands (CBS, 2017). In the fight against climate change, reducing and eventually terminating the natural gas used by the dwellings has become a key issue in national Politics.

Following the Paris Agreement, the government aims to have two million gas-free homes, representing 28% of the housing stock, by 2030 (Nijpels, 2018) and an energy neutral housing stock by 2050 (RutteIII, 2017). Besides contributing to maintain the global temperature rise below two degrees, earthquakes caused by natural gas drilling in the Dutch North region resulted in an accelerated national ambition to become gas-free. While currently representing a vital economic and energetic national resource, gas subtractions in Groningen will be decreased in the upcoming years, coming to a complete stop in 2030.

At the same time, natural gas plays a dominant role in the Dutch residential energy system, representing 75% of the total household energy consumption (CLO, 2018). Dutch households have the highest dependency on natural gas within Europe, using twice the amount of the average European household (Eurostat, 2016). The residential energy system in designed and constructed using natural gas.

The two extremes, on one hand depending largely on gas and on the other hand pioneering in reaching a gas-free housing stock, make the situation in the Netherlands a unique field of study. As stated in the recent national climate agreement proposal, 'we are on the verge of a great reconstruction, a transformation of our seven million houses.' (Nijpels, 2018). New solutions, both technical and financial, have been presented by the Architecture, Engineering, Construction and Operating (AECO) sector to support this great reconstruction. This research studies the feasibility for private homeowners to enter the gas-free transition.

1.1 RESEARCH TOPIC

Existing owner-occupied dwellings were selected as the target group in the built environment. Regulations concerning energy usage have been introduced regarding energy labels for utility building (RVO, 2018), representing 13% of Dutch buildings (CBS, 2016) and the non-profit housing sector (CLO, 2017), representing 41% of the housing stock. However, the remaining 4,3 million privately owned existing dwellings could not be targeted with regulations due to constitutional limitations. Owner occupied houses also lack a long-term perspective and available resources, making it a key sector within the energy transition discussion (Arnoldussen, 2017).

Currently, less than 2% of the housing stock complies with the national ambtion to be energy neutral (EIB, 2018). With the low annual residential replacement rate in the Netherlands of 0,4% (CBS, 2016), more than 87% of the future housing stock (2050) has already been built. Many researchers concluded that the existing housing stock is one of the key sectors where action is needed to meet the Paris agreement goals (Evertzen, 2017; Ritzen et al., 2016; Visscher, 2017). Demolition and sustainable new construction is a logical option for the energetic obsolete housing stock, but with over 2,7 million privately houses constructed before 1992 in the Netherlands alone, this would entail a relentless operation and massive construction (Dobbelsteen, 2015). Furthermore, replacement of the currently energetic obsolete stock seems impossible in terms of building and demolition capacity as well as waste production (T. Dijkmans, 2011). As it aims to have a large impact on the national ambitions, this study focusses on the existing privately-owned housing stock, which represents a key sector with a high potential impact on the energy transition.

With new political tools being explored by the sector table of the Built Environment in the national Climate Agreement, such as home-bound loans and investment payed back through the decreased energy bill (Nijpels, 2018), the door is opened for market parties to explore new transition processes. As a result, the servitization concept, in which the object of sale is the performance and not the product itself (Stahel, 2008), is recently introduced in the energy transition process for private homeowners. This concept has proven to show advantages in other sectors and offer opportunities for the energy transition. Franco, de Langhe and Venken (2016) argues that 'when the principles are applied in the context of energy use in buildings it is clear that Product Service System (PSS) and his variants offer opportunities'. This yet unresearched solution is included in this research, by exploring both the 'traditional' economic feasibility and the 'servitized' financial feasibility.

This study examines solutions for dwellings to become gas-free of which the availability is at hand and homeowners can adopts these solutions immediately. It offers a feasibility study at this point in time. Owner-occupiers must be able to become gas-free without depending on uncertain and yet undetermined possibilities, such as decentralised heat networks or hydrogen heating. Research is being performed on those possibilities and different geographic areas have been marked as potentially qualified, but with yet undefined plans and timelines. While these solutions could be of great added value, they require their own studies and approach.

Following the Paris Agreement, the Dutch national ambition is to have an energy neutral built environment by 2050 (RutteIII, 2017). Preparing the existing housing stock by eliminating gas dependency is considered the first step toward becoming energy neutral. It is currently the main objective of the national climate agreement with targets set on transition rates, while the energy neutral ambition has fewer specific targets due to its long-term vision (Leefomgeving, 2017). Natural gas-free residential energy infrastructures offers a base on which future technical innovations could be built to reach an energy neutral housing stock (Valk, 2018). It also offers opportunities to get rid of outdated services. While acknowledging the goal of becoming energy neutral by 2050, this research is scoped to the present natural gas-free ambition level of the private housing stock. It sets out to function as a means to an end in the larger energy neutral framework.

In short, this study examined the transition process of existing privately-owned dwellings to become gas-free with currently available solutions that could empower homeowners to act in the energy transition. Outcomes are evaluated on both economic and financial feasibility representing the servitization model.

1.2 RESEARCH PROBLEM

There is a clear mismatch between the national ambition to reach a natural gas-free housing stock and the current ability of owner-occupiers to meet this ambition. The national ambition is quantified in the most recent signed Dutch coalition agreement of Rutte-III, where measures regarding the built environment formed one of the four main pillars on how to fight climate change (Leefomgeving, 2017). The targets set regarding the housing stock transition are: '*Before the end of the coalition period (2021) we want to make 30.000 to 50.000 existing dwellings per year gas-free or in a such a state of energy-efficiency that they can be made gas-free on a short term. Thereby the first step is set towards a transformation of 200.000 houses per year, the tempo needed to sustain the entire housing stock by 2050.*' (RutteIII, 2017). While the exact current transition rate of existing houses is unknown, during scoping interviews and conversations with experts in this field, a number of around 2.000 to 5.000 transitions per year was estimated (Buren, 2018; F. Verhoef, 2018).

Individual homeowners are the decision-makers in the gas-free transition in privately owned dwellings and must be engaged to obtain the desired gas-free transition rate. A recent study found that the main barriers for homeowners to sustain their homes is that measures are too expensive (39%), it does not benefit them enough (24%) and knowledge is to low (22%) (Vermeij, 2018). That study found that the importance of sustainable measures is clear, but residents lacked the information to come to a well-considered decision. Information has to be provided and made understandable to homeowners. Technical insight is needed to overcome the knowledge barrier, whereas economic and financial insights are needed to overcome the costs and benefits barriers.

Until now, market parties in the AECO sector do not offer products or services that can resolve the mismatch in the (whole) housing stock. However, with the introduction of servitization in this field of work, a different feasibility perspective has presented itself and while it has great potential (Franco et al., 2016; Stahel, 2008), the effects are unknown.

Thus, there is a lack of knowledge in science and practice about:
1. Technical and economic information for homeowners to become gas-free.
2. Effects of servitization on feasibility.

1.3 RESEARCH OBJECTIVES

From an engineering and management perspective, this research aims to is to explore the stated mismatch in more detail, and gain insights for homeowners, market parties and strategy makers to act in the energy transition. To overcome the aforementioned research problems, the first objective is to conceptualise the gas-free transition process. By researching the current housing stock and the gas-free alternatives, insights into the transition process are gained. This will provide homeowners, market parties and strategy makers with an in-depth understanding of both technical and economic aspects of the transition.

The second objective is to develop optimum homeowner-focussed transition packages. This provides the owner-occupiers with the desired information and enables them to come to a well-considered decision in the gas-free transition process. Through this, knowledge is added in resolving the first part of the research problem.

The third objective is to translate the feasibility results on the building level towards a feasibility overview of the privately-owned housing stock. This provides insights in the mismatch between the national ambition and the housing stock capacity to meet this ambition, on which improvement strategies can be formulated. By including both economic and financial feasibility in the transition packages, the effect of servitization on the stated mismatch is quantified. Hereby insights are gained in the second part of the research problem.

1.4 RESEARCH QUESTIONS

The main research question, based on the problem statement and objectives of this research, is stated as follows:

'What does the energy transition process mean for the private housing stock to become gas-free?'

The sub research questions relate to the main research question and are formulated as follows:

1. *What types of dwellings are included in the private housing stock?*
2. *What types of services are currently available to transition to a gas-free dwelling?*
3. *Which processes are currently available for homeowners to transition to gas-free?*
4. *How can these processes be designed for homeowners to enter the gas-free transition?*

The first sub question focusses on the building aspects of the private housing stock. It assesses the current situation and functions as the starting point of the gas-free transition process. The second sub question focusses on the service aspects which are able to provide a gas-free dwelling. It explores the different possibilities to become gas-free and functions as the future expected situation of the transition process. With both the current and future situation examined, the third sub question conceptualises the gas-free transition process. The ability of the current housing stock to transform towards future gas-free services is studied. The last sub question explores the costs and benefits of the transition process and evaluates the feasibility for homeowners to enter the gas-free transition. The traditional business case model result in economic feasibly, while the servitization model results in financial feasibility. After answering the sub questions, homeowner transition packages can be formulated. Both the economic and financial feasibility results are projected on the Dutch housing stock, gaining insight in the effect of servitization.

1.5 DELIVERABLES

Based on the objectives and research questions, this research has two main deliverables. The first is homeowner-focussed transition packages showcasing if and how they could become gas-free. An owner-occupier should be able to select the appropriate dwelling type and receive the desired information to come to a well-considered decision, which requires insight into technical, economic and financial feasibilities. A transition tool is developed, functioning as the product of this deliverable.

The second deliverable is a housing stock feasibility overview, where the individual transition packages are translated into insights used to quantify the mismatch between the national ambition and the capacity for homeowners to become gas-free. Both the economic and financial feasibility outcomes are included, which illustrates the effect of servitization on the mismatch.

1.6 RESEARCH RELEVANCE

The research topic offers societal, scientific and sectoral relevance.

Societal relevance
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's energy (UNEP, 2016). This research aims to add knowledge on the largest energy consuming (Ritzen et al., 2016), yet most challenging (Arnoldussen, 2017), part of the Dutch built environment: the privately owned housing stock.

With almost daily media coverage of the gas-free transition in recent months, the societal relevance goes beyond the political targets. Public discussions and front-page newspaper articles debate climate effects (van Dijk, 2018) and who is going to bear the burdens of the energy transition (Bijlo, 2018). This thesis therefore adds knowledge to one of the most significant societal discussions of the modern period.

Scientific relevance
Both national and international studies have examined the energy efficiency in the existing housing stock. With different geographical and governmental regions presenting their own challenges, scholars are explored which focussed on reducing residential energy consumption in the Dutch housing stock.

Due to the relatively large and homogenous characteristics, research on the Dutch non-profit housing sector is extensive (e.g., T. Dijkmans (2011); Hoppe (2012); Nieboer (2017); Visscher (2017)). While some conclusions could be translated to private housing, feasibility studies are difficult to compare due to the missing homeowner's perspective, so more research on the private housing stock is required.

Research on the private housing stock has been done by TU Delft graduate Evertzen (2017), who researched the revitalisation of private gallery apartment buildings. While this homogenous group represents 32% of the housing stock (CBS, 2018c), it accounts for only 19% of the total primary energy demand (Ritzen et al., 2016). Additional knowledge is required on the remaining, more diverse, private dwellings responsible for the larger share of primary energy demand.

Second, when evaluating earlier studies, a gap in literature was which the effect of building level variables is translated towards the housing stock level outcomes regarding the feasibility transition rate. Studies focussed on the building and housing stock level have recently been commissioned by the by the ministry of Economic Affairs and Climate, where one explored the housing stock level barriers (EIB, 2018) and the other assessed homeowners' consequences of the energy transition (Valk, 2018). However, a lack of knowledge was identified to understand and quantify the interrelated findings of both studies, combining the building level with the housing stock level into one research. The effect of specific changes made in building, services and user domains on the overall housing stock and national ambition are not yet researched.

Third, the aforementioned studies are based on energy labelling, and therefore did not include the findings of Majcen (2016), who concluded that energy labels do not accurately represent the reality. The conclusion, that actual energy consumption of dwellings should be considering when formulating targets in future studies, has not yet been used in feasibility studies.

Finally, scientific relevance is added by exploring the yet unresearched effect of servitization on the energy transition in the existing housing stock. As previously mentioned, product-service-systems applied in the context of energy use in buildings offers opportunities. With the recent introduction of market parties' function as service suppliers that are able to (partly) transition houses to gas-free, researching these solutions offers scientific relevance.

Sectoral relevance
Scoping interview with practice confirmed the need to fill the aforementioned gaps in literature. The demand for a study linking both building and housing stock level is acknowledged, especially one providing insight into the transition rate improvement possibilities on building level (Buren, 2018). Furthermore, the added value and unexplored effects of the servitization perspective are stressed (Hendrix., 2018; F. Verhoef, 2018).

CHAPTER 2. LITERATURE REVIEW

The literature review is divided into four main parts. The first part, consisting of section one and two, aims to answers sub question one. The second part consist out of section three aiming to provide input for sub question two. The third part included the fourth section and provided theoretical underpinnings for sub question three. Hereby the last part included section five and six and obtains knowledge needed to answer the final sub question

Before the different literature review sections, background information is presented to guide the literature review. Scoping decisions throughout the chapter are based on this first section, giving insight in the main target points of the research.

Residential energy system
As stated in the introduction, Dutch households have the highest dependency on natural gas within Europe. Dutch households are most dependent on natural gas to provide energy of the European region. This part aims to get a better understanding of the Dutch residential energy system and elaborates on the scope of this research concerning the different energy supply and demand domains.

Dutch households use 31% of the total Dutch energy consumption (ECN, 2017). The largest household energy demand domains are space heating (60%) and the heating of domestic hot water, or DHW (20%) (Vastenlastenbond, 2019). This advocates the strong correlation of heating with total household energy consumption and relates to the findings that improvements in energy efficiency of heating are mainly responsible for improvements in energy efficiency of household (Parab, 2016).

When reviewing the energy sources used to generate these demands, the amount of natural gas represents a substantial part. 98% of the total natural gas consumption of household is due to space heating and DHW (CBS, 2016), the remaining part is represented by domestic cooking. Electricity is only used by 6% of the households to provide space heating and only 3% to provide DHW (CBS, 2016). This stresses the importance of targeting space heating and DHW in order to obtain a gas-free housing stock.

Besides the 80% demand of space heating and DHW, light and appliances demand 17% of the total residential energy consumption (CBS, 2016). While this is a substantial part, it is not obtained in the research scope. Light and appliances do not relate to other building, user of service variables and energy savings would only occur by less consumption or more efficient measures. Furthermore, as they do not use gas, they fail to have impact on gas-free ambition goal of this study.

The energy supply domains of the residential sector are only incorporated in this research when they follow the private homeowners focus of this study. Collective energy supply methods are excluded. Based on the renewable energy report of the CBS (2017), it is found that building related energy supply knows two domains; heat and electricity. The heat domain includes geothermal, aerothermal and solar energy. Solid biomass is excluded from this research as, it mostly offers regional heat and needs assistance from other sources and is not adequate to function as main heating installation. It is therefore not considered to be a solution in the gas-free transition and is not incorporated in this study. Secondly, solar panels are almost completely responsible for building related electricity supply and are included in the research scope. Both the private electric and heat supplies are evaluated, having the potential to influence the feasibility of gas-free solutions (Valk, 2018).

To summarize, this research will follow the gas-free national ambition level by focussing on gas-free alternatives for space heating and DWH energy demand. It furthermore includes private energy supply through electricity and heat generation.

Main domains
After the scope on energy demand and supply is made, it is determined which domains influence these factors and thereby influence the gas-free transition process. The guide produced by the Chartered Institution of Building Service (2012) is followed, which aims to design strategies to enhance energy efficiency in buildings. In the design and analysis of building energy performance, many factors are considered. They can be clustered into:

1. *Climate*: the external conditions from which buildings offer protection
2. *Building:* the parts of the building (building elements) that separate from the external conditions
3. *Services:* that consume energy to produce the required conditions inside the envelope.
4. *Users:* these refer both to the goals of the building (to provide accommodation for housing) and to interaction with its occupants.

While there are climatic differences within the Netherlands, they are limited due to our small geographical coverage. This research considers the country as one area with a consistent climate. The NEN-5060 is used to represent the average Dutch climate during one year. As a result, three interrelated domains are selected, which will function as a guidance through this report.

Research strategy
Following the three domains, a research specific strategy for obtaining the desired gas-free housing stock is determined. This line of reasoning will support decision making in the upcoming chapters. In sustainable building transformations, the Trias Energetica approach is the often taken as a leading strategy. This is a three-step approach for developing environmentally 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."*

The main difference between the Trias Energetica approach and this research is the goal. Whereas the Trias Energetica approach aims to develop environmentally sustainable concepts aiming to reduce energy, this study aims to develop concepts to become gas-free. However, the research ambition is a meaning to an end: an energy neutral building stock in 2050. Therefore, the Trias Energetica approach is incorporated in the research strategy.

Additionally, a fourth step is introduced. This step incorporates the feasibility perspective for the homeowners and adds the cost-benefit analysis in the researched strategy. The goal is to research feasible transition packages for the homeowners. Thereby the second step, using renewable sources, is only incorporated if it enhances the transition feasibility.

Translating the Trias Energetica Approach to the different aims of this study results in the following research specific strategy, in which the steps are linked to the found domains.

1. Reduce the energy need for space heating and DHW, demanded by building.
2. Use renewable sources to meet the remaining energy demand, used by services
3. Supply the remaining needs as efficient as possible with other sources than gas, used by services
4. While remaining feasible, for the users.

Literature review structure
With the background information presented, the literature review is performed in the upcoming part. The first section explores which variables influence the three main domain in the gas-free transition process. It produces a list of research specific variables of the building, services and users domains. Hereby, the second section analyses the current situation based on the different variables. The current status quo is presented and functions as the starting point of the transition. Thirdly, different gas-free alternatives formulate a future expected situation and functions as the desired situation after the transition. With the current and future situation established, the fourth section sets out to explore the different relations and functions of the transition process. Literature is found on how these factors influence both the technical and economic feasibility is the fifth section. The final part discusses different business models able to test both economic and financial feasibility. Figure 2 presents an overview of the literature review.

Section	Related sub questions
2.1 Research variables	
2.2 Current situation	SQ1. What type of dwellings are included in the private housing stock?
2.3 Future expectations	SQ2. What type of services are able to provide a gas-free home?
2.4 Transition process	SQ3. What process are currently available for homeowners to become gas-free?
2.5 Techno-economic input	SQ4. How can these processes be considered feasible for homeowners?
2.6 Business case	
2.7 Summary	

Figure 2. Literature review structure with related research sub questions.

2.1 RESEACH SPECIFIC VARIABLES

The following section explores which variables influence building energy performance on each of the three domains. Research specific variables are determined based on their influence in achieving the research strategy. The found variables form the basis of the following chapters.

A note has to be made concerning the level of complexity. The aim of this research is to test the feasibility of the gas-free transition on a housing stock level. Different housing types will be assessed, but it is not the research aim to specify a detailed dwelling energy performance analysis. Due to this purpose, the level of complexity is reduced to illustrate the main relations of variables influencing energetic performance. Individual dwelling factors, not representing the housing stock, are not be included. Averages of those factors are taken to account for the influence on the energy performance, but set as a constant during research calculations. Hence, the variables are generalized to be applicable for the Dutch housing stock.

2.1.1 Building

The research strategy related to the building domain is to reduce the demanded energy, focused on space heating and DHW. Building can vary in size, form, shape, materials, openings and location (Butcher, 2012). Translated toward the disciplines in the residential design and construction sector, they can be clustered into different groups:

1. *Site*: local weather and microclimate, site layout and shape and building orientation.
2. *Housing form*: shape and proportions of the building.
3. *Thermal Response*: the ability to exchange heat with the environment when subjected to cyclical variations
4. *Insulation:* reduction of thermal transmittance of the envelope, including the location of insulation and a number of significant construction details and size and type of glazing.
5. *Ventilation*: amount and type of openings, shape, location, functionality and control of openings, ventilation strategies, control of unwanted ventilation, shading.

The building site factors can only be addressed to individual dwellings, differing in local climates, site layout and building orientation. Site factors are therefore seen as a constant, duo to its individual nature. As before mentioned, the average Dutch yearly climate following the NEN-5060 is taken as a reference point. The building orientation follows a study of Yang et al. (2015), where residential optimum orientation in hot summer and cold winter climates in China is studied on the influence on demanding heating. Due to the climate similarities, the study results can be used in this thesis. As the optimum orientation would not result in a realistic housing stock representation, the orientation between the best and worst case is selected, wherein the front façade is facing South-West (135^{O}), back façade is facing North-East (315^{O}). With this constant, the site variable group is represented.

Housing Form
The housing form represents an important factor. Relatively simple adjustments to build form at the design stage can have a substantial effect upon energy performance (Butcher, 2012). However, at existing building, more complex and costly solutions may be necessary to make energy savings. The building form determines the exposed surface area, thus effecting the influence of the external environment. In the residential sector, two main variables influence the building form and thereby energetic performance:

- *(B1) Housing type*: determines the number of facades exposed to the external environment. In generalized form, housing type also determines the housing proportions, influencing the exposed surface area.
- *(B2) Housing size:* with the average height of Dutch dwellings being 2,8 meters (AgentschapNL, 2011), the housing size determines the volume on which services are based on to require heating, cooling and ventilation. Together with the housing type and thereby proportions, the housing size determines the heat loss surface.

Thermal response
Thermal response is the ability of a building to exchange heat with the environment when subjected to cyclic variations in temperature. It depends on the admittance of the contents and components of the structure and their surface areas (Butcher, 2012). While this variable can be used to reduce energy consumption (Butcher, 2012), residential building in the North-West European Region experience little to no energy reducing due to the primarily heating requirements. Thermal storage capacity in the structural mass does play a role in reducing peak loads forming a flexible energy system, it however does not result in lower energy heating demand (Foteinaki, Li, Heller, & Rode, 2018). As a result, thermal response is not considered a building variable in the gas-free transition process.

(B3) Insulation
Reducing the thermal transmittance of the building envelope by adding insulation can help reduce building heating demand (Butcher, 2012). As 80% of the natural gas usage is used for space heating, insulation measures have a high influence on the gas-free transition feasibility. Insulation is categorized into seven sub variables, following the NEN-1068 categories. (1) External

wall, (2) roof and (3) floor insulation is measured by the thermal resistance, or R-value, whereas (4) windows, (5) doors and (6) window frames are expressed by the thermal transmittance, or U-value. Finally, the (7) infiltration ratio determines the amount of air passing through the building, expressed in the qv;10 value.

Following the level of detail necessary to research the housing stock, thermal transmittance of the windows, doors and window frames are combined to one variable. The windows variable is selected to represent the three variables, having the largest surface and therefore largest impact on heating demand. The infiltration ratio is discussed in the succeeding part.

B4. Ventilation
The ventilation variables represents openings the building structure, that have effect on ventilation method, daylight, solar gains and control strategies. (Butcher, 2012). In terms of housing energy performance regarding the gas-free transition, advantages of openings concerning the heating demand is limited to beneficial solar gain. Solar gain is seen as individual housing variable as different orientations and shading situations result in different gains and is therefore seen as a constant. The disadvantage is heat loss through sources of uncontrolled air infiltration that increase heating demands (Butcher, 2012). This source of heat loss relates to the earlier found infiltration ratio, categorized by the NEN-1068 to building insulation.

Ventilation strategies are key to reach an integrated energy efficient design. Different ventilation methods obtain different advantages concerning the quantality of fresh air, moisture control and heat recovery (Butcher, 2012). Ventilations methods in Dutch houses are categorized intro different systems. System A represents natural ventilation, system B and C represent mechanical ventilation with respectively supply and suction by ventilators and system D represent a balanced ventilation method, possible with a heat recovery system. To decrease the complexity level, the infiltration ratio and ventilation method are combined into one variable: the ventilation method. According to graduation company interviews, in practice the two variables are often combined by selecting the highest heating loss to be leading in the calculations (Verhoeff, 2019).

B5. Roof Area
The building facilitates the usage of solar panels by presenting useful roof surface. Beside the set building orientation at 135°, the roof has to provide a minimal surface that is not affected by shadow. The most dominant factor influencing this surface is the presence and size of a dormer. Unfavourable placement potentially decreased the surface below its minimum.

To summarize, four research specific building variables are established: housing type, housing size, insulation and ventilation method. The insulation variable is sub divided by facade, floor, roof and window insulation. They provide the building input for the conceptual model presented in Figure 4.

2.1.2 Services

With the building factors influencing energetic performance explored, the next step is to analyse the services required to obtain the internal conditions to support residential user activities. Services demand or supply energy based on the user preferences, thereby indirectly influencing energetic performance. The challenge is to minimize the requirements for services in order to minimize capital and running costs as well as carbon emissions (Butcher, 2012). Following the research strategy, after the building energy demand is minimized, services should use renewable sources to meet the remaining energy demand and supply the remaining needs as efficient as possible with other sources than gas.

Different service categories are explored by following the yet to be introduced *Energy Performance of Building* (EPG) method, explained in NTA 8800 (2018), which will be officially introduced on the 1st of January 2021. The NTA 8800 has the goal to serve as a transparent and policy neutral determination method of building energy performance, based on the Energy Performance of Building Directive (EPBD) of the European Union. This method will be used to legislate energy performances in the Dutch building sector. While not yet active until 2021, the working document is with 90% finished 'sufficient ready for the market and employment' (NEN.nl, 2018). The EPG method will replace the currently used Energy Performance Coefficient (EPC) and Energy Index (EI). In anticipation on the official introduction, this research uses the new EPG method. Results will therefore be based on the latest legislation and will remain valid after 2021. The most important difference of the EPG method compared to its predecessors, it that the outcome is not an abstract but an absolute value: kWh per square meter per year. Besides the measurement methods, the EPG method includes new innovations, such as heat pumps, matching the focus of the current available solutions.

An important aspect of the new method is the calculation of the Characteristic Energy Consumption (BENG-1) of a building. This is calculated by the combined primary energy consumption (BENG-2) of heating, humidification, ventilation, lighting, cooling, de-humidification and hot tap water reduced by the total primary building-related energy generation. A second key factor is the determination of the Renewable Energy Consumption (BENG-3). According to the NTA, the following renewable energy sources are included: solar energy, geothermal energy, ground energy, seasonal storage, wind energy, aerothermal energy and solid biomass.

Energy demanding variables

Following the stated focus on heating demand, two key EPG aspects are selected: space heating and hot tap water heating, responsible for 80% of the current household energy demand. The ventilation factor in the EPG method relates to the actual energy used by the system. Ventilation has large influence on the loss of heat, as discussed in the building domain, but direct energy usage is less than 1% of total residential energy consumption (Sousa, Jones, Mirzaei, & Robinson, 2017). Herby this factor is excluded from the service domain. The other factors, (de)humidification, lighting and cooling, lie outside this research scope. As a result, the following research specific energy demand service variables are selected.

(S1) Heating system

Heat is generated by the heating system, which functions for both the space heating and the DWH. The HR-107 boiler is current the most common heating system in the privately owned residential sector (AgentschapNL, 2011).

(S2) Heating distribution method

This variable admits the generated heat to the dwelling to achieve the desired occupant's indoor climate. It is the end of the space heating circuit. There are two main methods. Firstly, fadiative heating system are defined as a system that radiant heat transfer covers more than 50% of the total heat exchange within a conditioned space, heating the indoor temperature majorly by providing hot surfaces. Secondly, convective heating systems heat indoor thermal environment by supplying hot air and requires a lower output temperature (Z. Wang, Luo, Geng, Lin, & Zhu, 2018). Commonly used residential services are radiators to provide radiative heating and underfloor heating and Low Temperature (LT) radiators to provide convective heating.

Energy suppling services

To translating the NTA 8800 renewable sources towards the existing private housing stock, it is assessed which sources are currently used in the residential sector. In the beforementioned study of the CBS (2017), which evaluates residential energy sources, seasonal storage and wind energy are not named. As a result, they are not considered applicable for individual residential usage and excluded as research specific variable. Solid biomass has previously been excluded from this research scope. The remaining three energy generation service variables, solar, geothermal and aerothermal energy, are included in this research.

The variables are categorized based on their energy supply output. First of all, all three variables are able to supply heat. Following the same study by CBS (2017), residential applications of each variable are the following. Solar heat gain is generated by solar boilers. Geothermal heat gain is divided by ground heat, the top layer of soil influenced by the outer air, and geothermal heat originating from the inner earth section, wherein the first method is seasonal influenced, the second is not. Aerothermal heat is gained to subtract heat from the outer air. Heat pumps have the ability to transfer geothermal and aerothermal heat to space heating and DWH. These heat-supplying variables are incorporated in the heating system variable.

(S3) Solar panels

The second category of energy supplying service is able to produce electricity. From the three research variables, only solar energy is able to be converted to electricity. Residential application for this process is the usage of solar panels (CBS, 2017). As this variable involves a different circuit, it is considered as an additional research variable.

(S4) BESS

While not included in the CBS (2017) study concerning renewable energy sources, an additional energy supply system is identified: energy storage. While solar panels produce electricity during the day, households use the most electricity in the early morning and evening. The simultaneity of solar energy generation and load consumption in private households is limited. 'Selling' electricity through netting during the day and buying electricity in the morning and evening, presents disadvantages in operating costs. However, with the rapid technologic advancement of Battery Energy Storage Systems (BESS), new possibilities are presented influencing the residential energy system. This study included BESS as a form of energy storage, perceives as a promising decentralized solution (Shaw-Williams, Susilawati, & Walker, 2018). The conjunction of solar energy systems with storage batteries allows a further increase of self-consumed PV electricity (Weniger, Tjaden, & Quaschning, 2014). This is beneficial in terms of economic feasibility due to the fact that feed-in tariffs for electricity lies below the retail electricity prices. Section 2.4.2 will elaborate this effect in more detail. This introduction however stresses the added benefit for this study, hence the inclusion in the research variables.

To summarize, four research specific service variables have been formulated. Two energy demanding variables, heating distribution method and heating system, and two energy supplying variables, solar panels and BESS, are determined. They provide the service input for the conceptual model presented in Figure 4.

2.1.3 Users

Human factors often have a bigger influence on energy consumption than the services and building design. However, the way people use buildings is difficult to predict. In sustainable buildings, occupants become a major source of uncertainty in energy consumption (Butcher, 2012). Predefined fixed consumptions profiles often account for occupant's behaviour in energy simulation tools (Zhao & Magoulès, 2012). It is important that uncertainty about the actual energy consumption is minimized, therefore it is vital to understand the relation between the users and energy usage. Again, following the heating focus of this study, occupants influence is limited to the usage of space heating and domestic-hot water.

Actual energy consumption
Serval studies have focused on the effect of occupants on residential heating demand. Building simulations are often used to predict the demand. However, large differences between actual and predicted energy consumption are documented in recent research (Guerra-Santin & Silvester, 2017; Majcen, 2016). Majcen (2016) aimed to identify the gap between theoretical and actual consumption. The findings are concluded in Figure 3 and discussed below.

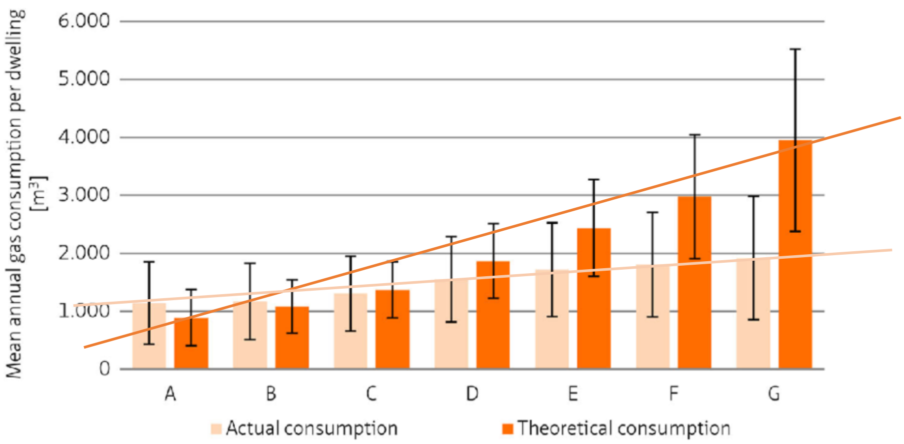


Figure 3. Actual vs theoretical consumption at a terraced dwelling based on energy label, source: Majcen (2016)

While the findings are based on energy labels, a measurement this research tends to ignore, the result show a pattern which can be abstracted. Illustrated by the added lines, a less steep line is seen with the actual consumption compared to the theoretical consumption, resulting in a reduced correlation between energy labelling and energy consumption. Furthermore, well insulated homes, represented by energy label A and B, show an energy consumption above the theoretical calculations, while bad insulated homes, represented by energy label D or lower, show the opposite result. These findings of Majcen (2016), result in a correction factor regarding the theoretical consumption, which is presented in table 1.

energy label	theoretical consumption (m3/year)	Actual consumption (m3/year)	Correction factor
A	900	1200	133%
B	1100	1200	109%
C	1400	1300	93%
D	1900	1500	79%
E	2500	1700	68%
F	3000	1800	60%
G	3950	1900	48%

Table 1. Correction factor to account for actual consumption, based on Majcen (2016).

Besides the difference in actual and theoretical consumption, Figure 3 also visualized the bandwidth of energy consumption fluctuations per energy label, whereby +30 or -30% deviations per household are presented at each energy label. This account for human factors of the occupants. Based on the findings of Majcen (2016), two user variables are presented which function as the research user variables.

(U1) Indoor temperature
The indoor temperature versus outdoor temperature directly influenced heating demand and thereby energetic performance. To compare yearly energy consumption related to indoor temperature, external weather influences need to be neutralized.

Using the number of *Degree Days* is a method to express the annual difference between indoor and outdoor temperatures in a certain year. This reduces the external weather influences to a yearly basis. In this method, the hourly difference between the outside and inside temperature is added, resulting in the number of hours the heating service need to increase the temperature by 1 degree.

With the average indoor temperature of 18 degrees C, used in studies of Majcen (2016), EIB (2018) and Valk (2018), the year 2018 counted 2868 degree days based on the KNMI measurements in the Bilt. However, as seen in the energy consumption fluctuation at similar insulated homes, different average indoor temperatures are represented. Based on the online degree day tool of www.mindergas.nl, a deviation of 1 degrees C, result is an 10% deviation in Degree Days. With the assumption that the number of degree days is directly linked to energy consumption, the found spread of -30% and +30% by (Majcen, 2016) indicates that the indoor temperature bandwidth lies between 15ºC and 21ºC. Considering the impact of the indoor temperature on the transition process, this will be looked at in more detail in section 2.2, in which different user groups will be established.

(U2) Number of occupants
While the energy demand for space heating is independent of the number of occupants, the energy demand for DHW is influenced by this variable. The demand for hot water is not related to thermal properties of the building (Majcen, 2016), but dependent on number of occupants, and their shower and bathing preferences and systems (Millieucentraal, 2018a).

To summarize, two research specific user variables are identified: the average indoor temperature and the number of occupants. These functions are the user domain input variables in the conceptual model presented in Figure 8. This figure concluded this research specific variables section and is used in the forthcoming chapters.

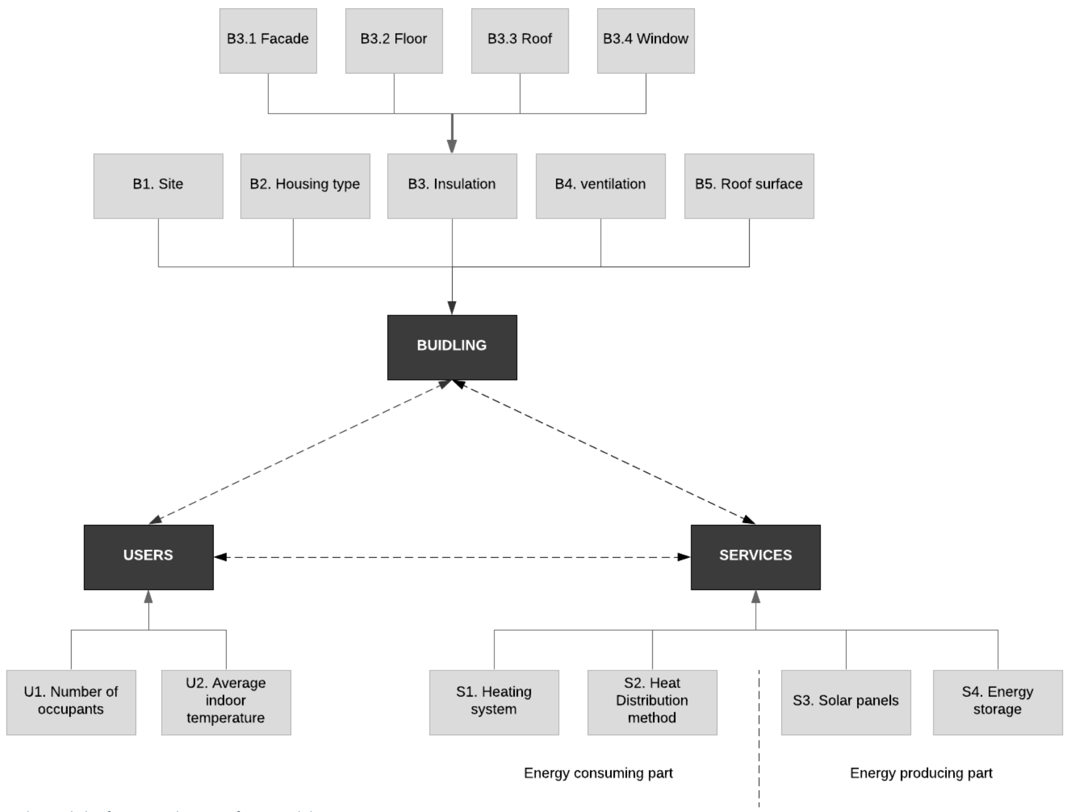


Figure 4. Conceptual model of research specific variables.

2.2 CURRENT SITUATION

In order to test the feasibility of gas-free transition solutions, it is necessary to assess the current situation. This functions as the starting point, on which the feasibility of solutions to become gas-free is tested. First of all, a target group selection is made aiming to maximize the potential impact of this research findings regarding the housing stock.

The governmental Dutch Enterprise Agency (AgentschapNL, 2011) of the ministry of Economy, Innovation and Agricultures documented the Dutch housing stock and published example dwellings representing the residential sector. The data set formulates 30 different example dwellings, divided by seven housing type and five construction periods. Based on this data set, Ritzen et al. (2016) analysed the different housing representatives on their annual primary demand contribution and housing stock share. The findings indicate that the terraced housing is the largest group, in both the number of dwellings (42%) and annual primary energy demand (41%). The second largest annual primary energy demand type (24%) is the detached dwelling, representing 14% of the number of dwellings. Thirdly, semidetached houses contribute 15% of the annual primary energy demand, while representing 15% of the housing stock. The remaining housing types consists out of different types of apartments, representing 32% of the total housing stock with a 19% annual primary energy demand share.

Based on this results, research specific target groups are selected to cope with time limitations of this study. Selection is done by aiming to have the highest potential impact on the set national ambitions. As a result, the detached, semi-detached and terraced houses are selected representing 68% of the housing stock using 81% of the annual primary energy demand. Following the homeowners focus, the private houses are selected to form the research specific target group. 94% of the detached dwellings, 89% of the semi-detached dwelling and 60% of the terraced dwellings is privately owned.

These findings are based on dwelling constructed until 2005, dwellings build from 2006 are not included. To account for this missing part, new example dwellings are added based on CBS data. Due to new building regulations introduced in 2012, construction periods are categorized from 2006 until 2011 and 2012 until 2017. While the numbers of dwellings belonging to each housing type are known until the 2017, annual primary energy demand is unfortunately not.

To assess the total impact of the found target groups, the percentages from the housing stock represent the housing stock built until 2017, while percentages on primary energy demand represents the housing stock until 2005. Based on these assumptions, the research the target groups relate to 86% of the private housing stock and 58% of the total housing stock. This study furthermore assesses the feasibility to reduce 373.700 TJ of total annual primary energy demand, representing 74% of the private housing stock and 60% of the total housing stock energy.

Each dwellings type is sub divided into different target groups based on the construction period, following the AgentschapNL (2011) data set. Concludingly, 19 different research target groups are established. Table 2 illustrates the target group in more detail based on the number of privately-owned dwellings and their annual primary energy demand. After formulating the 19 different target groups, the research specific building variables of the previous chapter have to be assessed at each target group. These dwellings representatives will function as the base cases.

Building

Following the AgentschapNL (2011) data, the building specific housing variables are matched to each target group for the dwelling constructed before 2006. This included the (B2) housing surface, (B3) different insulation measures, (B4) ventilation method and (B5) roof surface. The variables of dwelling build in the periods between 2006 and 2017 require a different source. This research supposed that the housing surface of dwellings build in the periods between 2006-2011 and 2012-2017 follow the same size as the predating period of 1992 until 2005.

The insulation variables follow the minimal requirements of each construction period. Insulation variables of dwelling built between 2006 and 2011 are based on NEN 1068 regulations introduced in 2005, the most recent construction period is based on the 2012 introduced NEN 7120. Target group specific ventilation systems of the recent construction years follow the 1992 to 2005 target groups, using a mechanical ventilation. Table 2 illustrates the building specific variables of the base cases.

Services

Secondly, the service variables of the targeted dwellings are explored on (S1) heating system and on (S2) heating distribution method. Gas powered boiler are used as the heating system (S2) for space heating and DHW in the targeted housing stock. The HR-107 boiler is currently applied to all houses (AgentschapNL, 2011). This is a high efficiency boiler with a theoretical efficiency of 107% as heat produced in the process in reused. In practice however, the boiler reaches on efficiency of 90% (Gawalo, 2018). This will be used in the base case for all dwelling types. Dwellings constructed before 2006 use radiators as heat distribution system (AgentschapNL, 2011). Data on the two later construction periods concerning the heating distribution system is not present. It assumed that that these dwellings also use radiative heating.

Table 2. Target group specifications and variables, after AgentschapNL (2011)

			Total Housing stock			Private housing stock						Building							
			quantity	energy		quantity			energy			B2. Size	B5. Layers	B3. Insulation				B4. Ventilaiton	B5. Roof area
Target group number	Dwelling type	Construction year	Number of dwellings	Dwelling Annual primary energy demand (MJ)	Total annual primary energy demand (TJ)	% private	Number of private dwellings	% of private housing stock	Total annual primary enegy demand (TJ)	% of private housing stock	% of total housing stock			facade	roof	Floor	glazing		
														R-value	R-value	R-value	U-value	system	
												m2	layers	m2 K/w	m2 K/w	m2 K/w	W/m2K	A/B/C/D	m2
1	Detached	<1964	441.000	201.179	88.720	91%	401.310	11%	80.735	16%	13%	130	2	0,36	0,39	0,15	5,20	A	128,1
2	Detached	1965-1974	119.000	177.897	21.170	95%	113.050	3%	20.111	4%	3%	144	2	0,43	0,86	0,17	5,20	A	120,7
3	Detached	1975-1991	221.000	118.880	26.272	96%	212.160	6%	25.222	5%	4%	154	2	1,30	1,30	0,52	2,90	A	125,6
4	Detached	1992-2005	178.000	96.624	17.199	98%	174.440	5%	16.855	3%	3%	172	2	2,53	2,53	2,53	1,80	B	120,8
5	Detached	2006-2011	80.000			98%	78.400	2%				172	2	2,53	2,53	2,50	1,20	B	120,8
6	Detached	2012-2017	64.000			98%	62.720	2%				172	2	4,50	6,00	3,50	1,20	B	120,8
7	Semi-Detached	<1964	285.000	148.217	42.242	84%	239.400	6%	35.483	7%	6%	110	2	0,36	0,39	0,15	5,20	A	63,7
8	Semi-Detached	1965-1974	142.000	133.274	18.925	84%	119.280	3%	15.897	3%	3%	123	2	0,43	0,86	0,17	5,20	A	65,2
9	Semi-Detached	1975-1991	224.000	87.804	19.668	90%	201.600	5%	17.701	3%	3%	123	2	1,30	1,30	1,30	2,90	A	73,4
10	Semi-Detached	1992-2005	173.000	76.169	13.177	95%	164.350	4%	12.518	2%	2%	132	2	2,53	2,53	2,53	1,80	B	74,2
11	Semi-Detached	2006-2011	78.000			95%	74.100	2%				132	2	2,53	2,53	2,50	1,20	B	74,0
12	Semi-Detached	2012-2017	62.000			95%	58.900	2%				132	2	4,50	6,00	3,50	1,20	B	74,2
13	Terraced	<1945	523.000	142.772	74.670	71%	371.330	10%	53.016	10%	8%	102	2	0,19	0,22	0,15	5,20	A	55,9
14	Terraced	1946-1964	478.000	98.017	46.852	40%	191.200	5%	18.741	4%	3%	87	2	0,36	0,39	0,15	5,20	A	57,3
15	Terraced	1965-1974	606.000	91.097	55.205	47%	284.820	8%	25.946	5%	4%	106	2	0,43	0,86	0,17	5,20	A	65,5
16	Terraced	1975-1991	879.000	71.259	62.637	61%	536.190	14%	38.208	8%	6%	106	2	1,30	1,30	0,52	2,90	A	68,6
17	Terraced	1992-2005	353.000	58.991	20.824	78%	275.340	7%	16.243	3%	3%	114	2	2,53	2,53	2,53	1,80	B	56,1
18	Terraced	2006-2011	155.000			78%	120.900	3%				114	2	2,53	2,53	2,50	1,20	B	56,1
19	Terraced	2012-2017	125.000			78%	97.500	3%				114	2	4,50	6,00	3,50	1,20	B	56,1
			5.186.000	**1.502.180**	**507.560**	**83%**	**3.777.001**	**100%**	**376.676**	**74%**	**60%**								

Users

The actual consumption correction factors of Table 1 are matched to the research target groups in Table 2. This is done based on the energy labels derived from the AgentschapNL (2011) data set. These correction factors are used during the research calculations.

Table 3. Research specific correction factors at each target group.

	Detached			Semi-detached			Terraced		
construction period	target group	Energy label (AgentschapNL,2011)	Correction factor, based on Macjen (2016)	Target group	Energy label (AgentschapNL,2011)	Correction factor, based on Macjen (2016)	Target group	Energy label (AgentschapNL,2011)	Correction factor, based on Macjen (2016)
<1945							13	G	48%
<1964	1	G	48%	7	F	60%	14	F	60%
1965-1974	2	F	60%	8	E	68%	15	E	68%
1975-1991	3	D	79%	9	C	93%	16	D	79%
1992-2005	4	B	109%	10	B	109%	17	C	93%
2006-2011	5	A	133%	11	A	133%	18	A	133%
2012-2017	6	A	133%	12	A	133%	19	A	133%

This section furthermore aims to formulate different user groups functions as input for the Transition tool. Groups are categorised based on their number of occupants and average indoor temperature settings. Relating to the different building types, on average the number of occupants is between 3 and 3,2 (AgentschapNL, 2011). However, based on the CBS (2018b), 52% of the privately-owned dwellings are occupant by two-persons households), followed by 20% four persons and 19% thee persons. It is assumed that the two-person households can be divided between working couple and elderly.

The ministry of VROM (2010) researched different temperature settings in Dutch households. 48% can be considered to have a standard pattern, setting the temperature at 19ºC during the day, 20 ºC during the evening and 16 ºC during the night. The second pattern is used by 19% of the households and consist of a low morning peak, setting the temperature at 15 ºC at day and night, and 19 ºC at the evening. The high temperature pattern, set at 21 ºC during the day and evening, and 19 ºC during the night, represents 8% of the housing stock.

Both the number of occupants and temperature settings are linked to user groups. Besides the average, three different user groups are established; working couple, family and elderly. It is assumed that standard pattern is applicable for the average and the family target group, while low pattern is relevant for the working couple and the high pattern is suited to the elderly. As a result, four user groups are established in Table 4. The number of occupants (U1) and average temperatures (U2) are used as input for the Transition model.

Table 4. User groups characteristics.

User groups	U1.number of occupants	Indoor temperature setting			U2. average indoor temperature	R10. Degree days
		day 07.00-17.00	evening 17.00-23.00	night 23.00-07.00		
1. average	3	19 °C	20 °C	16 °C	18,3 °C	2753
2. Elderly	2	21 °C	21 °C	19 °C	20,3 °C	3313
3. Working couple	2	15 °C	19 °C	15 °C	16,0 °C	2149
4. Familiy	4	19 °C	20 °C	16 °C	18,3 °C	2753

The bandwidth of 16,0ºC to 20,3ºC lies within the found user groups average indoor temperatures bandwidth of occupant's behavioural influence based on Majcen (2016), as stated in section 2.1.3. It adds a -2,0 ºC and +2,3 ºC scenario over the used 18 ºC in the feasibility studies from EIB (2018) and Valk (2018). Research outcomes therefore represents a more detailed outcome concerning user groups, acknowledging the essential impact of human factors on energetic performance. A sensitivity check of the influence of indoor temperature on the transition process will further analyse this part and is included in the empirical part.

To summarize, 19 target groups have been selected to represent the privately-owned dwellings stock. The 3.7 million targeted dwellings represent 83% of the private housing stock and 58% of the total housing stock. Thereby this research adds knowledge in reducing 86% of the energy consumption of owner-occupied dwellings. To account for the impact of the human factor, four different user groups are identified. Besides the average user, working couple, family and elderly represent the different homeowners occupying the targeted dwellings. It is assumed that all dwelling currently consume gas for space heating and DHW. This combination of building, users and service domain forms the starting point of the transition process.

2.3 FUTURE EXPECTATIONS

After stating the starting point of the transition, this section studies the future expectations and formulated a gas-free situation. The goal is to determine the future expected situation, functioning as input for the following section in which the process between current and future situation is researched. While the previous section initiated with the building domain, this part will start with the service domain followed by the building and users. The future situation, where gas is eliminated as an energy source, directly influences the service possibilities. Hence, this is the starting point of the future situation.

2.3.1 SERVICE

The four service variables are discussed below, starting with (S1) the heating system, followed by the (S2) heating distribution method, (S3) solar energy generation and (S4) Battery Energy Service System

(S1) Heating system
The heating system is responsible for both space heating and DWH. Dutch dwellings have different gas-free alternative heating system. A study commissioned by the Dutch ministry of Economic Affairs and Climate (2018), published an evaluation tool for existing dwelling to become gas-free. According this study, there are three main possibilities to become gas-free: all-electric, heat networks and green gas. Both the second and third options largely depend from municipal decision on infrastructural project in the upcoming period (Valk, 2018). They can be seen as a collective approach. Without neglecting their potential, it is currently uncertain for household to response to these alternatives. Following the scope decision to focus on current solutions enabling private homeowner to enter the transition, the focus of this study is placed on the all- electric alternatives.

The evaluation tool by Valk (2018) proposes two all-electric systems able to provide space heating and domestic hot water. The first system is an Infrared (IR) panel system providing space heating in combination with an electric power boiler for domestic hot water. In the same study, however the comfort level of a primary IR heating system is questioned as the panels deliver only local heating, confirmed by Millieucentraal (2018b). The other system is a heat pump (HP), able to conduct heat from either the ground or the outside air, used for both space heating and domestic hot water.

Before selecting the system that contribute most to achieving the research strategy, the Coefficient of Performance (COP) is introduced to compare the efficiency and renewable source usage. The COP value expresses the efficiency, representing the ratio between the input, energy consumption, and the output, useful heating energy. A higher COP means a more efficient installation. The first system, IR and electric boiler, has an COP of 1 (1 kWh of electric input equals one kWh of heating output), and does not use renewable sources (Valk, 2018). The second system, a heat pump, has an COP of 4 to 5 depending on the type (Kieft, 2015; Valk, 2018) (1 kWh of electric input equals 4 to 5 kWh of heating output). Heat pumps can subtract heat from the ground or outside air, using renewable sources to boost efficiency. The efficiency of gas-boiler, stated on page 19, can be translated towards a COP of 0,9.

When adding the current price level of gas and electricity (see Table 10) to the found COPs, the heating costs is determined in Figure 5. When comparing the current gas-boiler, and two heating system alternatives, it becomes evident that the heat pump is most coherent to the research strategy. First of all, it uses renewable sources, secondly it is the most efficient alternative and thirdly it offers a feasible option based on the running costs compared to the current heating system. The IR plus boiler option fails to meet these points. Hence, the heat pump is selected as heating system alternative.

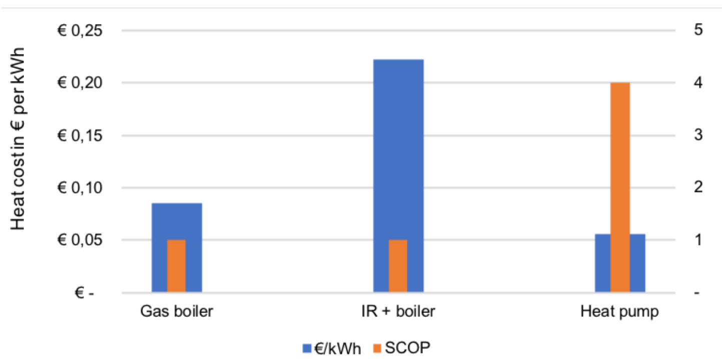


Figure 5. Running costs and SCOP's for various heating systems.

The COP of a heat pumps is mainly influenced by the temperature difference of the heat source and the heat demand (Kieft, 2015). A smaller difference results in a higher COP. As outside temperatures vary over the period of a year, the Seasonal Coefficient of Performance (SCOP) is used to indicate the yearly efficiency. The SCOP will be used in this research due to its ability to compare different heat pumps within the climate of one region.

After selecting the heat pump as main gas-free alternative, it is assessed which type of heat pump is included in this research. The first selection is made on electric heat pumps. Hybrid heat pumps use natural gas and therefore excluded. A heat pump can use multiple external energy sources: ventilation air, ground, water and outside air, (Kieft, 2015). Not all sources are applicable and scalable in the existing housing stock. First of all, ventilation air is only used by hybrid heat pumps due to the high additional heating demand. Moreover, usual application of ventilation air heat pump is constrained to air heating method, not applicable to existing residential heating systems (Latorre-Biel et al., 2018). Secondly, heat pumps using the ground as external energy source, require a costly and technical installation compared to air sourced heat pumps, decreasing the strategies feasibility point. At existing building, a minimal ground surface of 40m2 is required and gardening has to be renewed afterwards (F. Verhoef, 2018). Furthermore, not every location is suitable for ground drilling and a minimal required distance between drilling makes dense populated areas not suitable (Kieft, 2015). These factors are considered individual dwellings variables, unable to match the housing stock focus of this study. The third energy source, water, is not scalable at existing dwellings as surface water is often not available. According to Kieft (2015), the fourth heat pump using the outside air as energy source, can be applied in all existing dwellings, as all dwellings feature outside air accessibility. As a result, the air source heat pump (ASHP) is selected as the gas-free alternative for space and water heating in this research.

The last categorization which is added to the heating system variable is the output temperature. Based on the heating distribution system and building variables, which will be discussed in the following paragraph, ASHP's can produce different output temperature to match the space heating demand. The advantages of a lower output temperature are twofold. A smaller difference between input and output temperature results in a higher efficiency thus lower operational costs, and a lower required heat pump capacity thus lower initial costs. (Kieft, 2015). Low temperature space heating methods are among the highest category to increase energy efficiency (Q. Wang, Ploskić, & Holmberg, 2015). Output temperatures are divided between Low Temperature Heating (LTH) of 45 degrees C, Medium Temperature Heating (MTH) of 55 degrees C and High Temperature Heating (HTH) of 65 degrees C. A low temperature ASHP can produce both the LTH and MTH output temperature, the settings would only change. To produce the HTH output, a different technic is required, resulting is a high temperature ASHP (F. Verhoef, 2018).

While the low temperature ASHP offers the most coherency with the research strategy, by including the three different output temperatures in this research, insights on the energy transition are gained for dwellings which are not capable of upgrading to the desired insulation level or heating distribution system (e.g. monuments). By interviews with practice, the cost-benefit effect of the 45- and 55-degrees C output temperatures on the insulation level was furthermore questioned (verhoeff, 2019). Concludingly, three heating system alternatives are selected, illustrated below in Table 5.

Table 5. Service alternative specifics.

	Service alternative A	Service alternative B	Service alternative C
Heat pump type	Low temperature	Low temperature	High temperature
Output temperature	45^{o}C	55^{o}C	65^{o}C

(S2) Heating distribution system

The different output temperatures of three service alternatives have influence on the heating distribution system. As discussed in section 2.1, residential systems consist of radiative or convective heating methods. The current heating distribution might not admit enough heat, based on the output temperatures. As a result, the assumed current radiators might (partially) be replaced by either floor heating or the relatively new heating LT radiators using convection. Operating at roughly half the temperature, LT radiators normally need twice the heating surface to provide the same heat as HTH radiators (Latorre-Biel et al., 2018). However, with the introduction of small ventilators mounted between the heating surfaces of low temperature radiators, a more effective heat transportation is generated (F. Verhoef, 2018). Furthermore, according to Q. Wang et al. (2015), theoretical analysis showed that LT radiators can efficiently block cold draught and reduce the supply temperature curve to 40-45^{o}C without lowering thermal output. LT radiators are mostly used at places where floor heating systems are difficult to install, for example on the upper floors of dwellings. Hence, both the floor heating and LT radiators are selected to function as the future heating distribution system.

(S3) Solar panels

Energy generated by photovoltaic (PV) systems have the ability to (partly) compensate the increase demand of electricity through the heat pump alternatives. Most solar panels generate between 270- and 300-Watt peak (Wp) (Consumentenbond, 2019). This study selects the 300 Wp solar panel to be used during the research calculations. This theoretical maximum output energy is translated into the effective output based on the angle and orientation of the solar panels (CBS, 2017). In the calculation of the CBS, an average of correction factor of 0,875 (875kWh/kWp) is applied. Section 2.4.2 on page X will evaluate the influence of different circumstances of this correction factor.

(S4) BESS

As introduced in section 2.1, BESS can be used to meet demand through stored energy and manage PV generation intermittence. By adding BESS, the degree of self-sufficiency can improve resulting benefit in operational costs bridging the different in feed-in tariff and retail electricity prices. Translating the benefits of BESS to the four strategy steps of this research, it is only capable to increase the feasibility due to the advantage in operating costs. Thereby, the BESS should store electricity at a lower cost than the difference between selling and buying electricity from the nett.

The Dutch Minster of Economic Affairs and Climate announced that the netting arrangement (translated form the Dutch '*Salderingsregeling')* will be substituted by the return energy supply subsidy in 2020. While the details of the new subsidy are not yet known at the time of writing, the pack back period for solar panels will remain to be 7 years, indicating a similar feed-in tariff as the current netting arrangement (LenteAkkoord, 2018). Hypothetically, if the netting arrangement would be abolished, payback periods of current BESS would be around 15 years (Zelfstroom, 2018). With the current, an expected future difference between retail prices and feed-in tariffs, the payback period calculation will increase to 28 years. As a result, the BESS fails to meet the research strategy to benefit the transition feasibility and is excluded from the study.

2.3.2 BUILDING

When assessing the current building variables as shown in Figure 4, the insulation and ventilation variables have the ability to decrease the heating demand. While having influencing, it is not realistic to chance the building type of roof surface and these variables are therefore considered to be constant. Additionally, adjusting the building size to gain thermal quality is also considered an option, and will be discussed below. Meeting the research strategy, future building variables should decrease the need of energy. This can be done in twofold. First by decreasing the heating demand, secondly by facilitating energy generation. Each changeable building variable and the effect on meeting the research strategy is discussed below.

B3. Insulation

Increasing the thermal resistance through insulation upgrades decreased the heating demand. The upgrades of the four sub variables are explored.

B3.1 Façade insulation: While having a cavity in the façade structure, dwelling between 1920 and 1975 did not receive cavity wall insulation when constructed. Cavity wall insulation presents a relatively low but effective insulation measure. Houses built before 1920 usually don't have a cavity wall. Dwelling after 1975 got a degree of cavity wall insulation, but can sometimes be improved. Dwellings after 1992 got sufficient cavity wall insulation (Milleucentraal, 2018). Outer or inner wall insulation formulates the next facade insulation method, if cavity wall insulation is insufficient. Larger spatial and technical are introduced with this method.

B3.2 Floor insulation: Dependent on the height of the crawl space, floor insulation can either be placed below or on top of existing floor. Increased thickness of the package result in higher new R-value.

B3.3 Roof insulation: When evaluating the AgentschapNL (2011) data on the existing housing stock, the majority of the targeted dwellings have a sloped roof. It is therefore assumed that all the target groups have sloped roofs, whereby insulation is positioned on the inside. Increased thickness of the package result in higher new R-value.

B3.4 Window: Replacing single or double glazing by HR++ glazing improves the U-value of the glazing. If necessary, an upgrade can be made toward Triple glazing.

The proposed insulation measures are further explored in section 2.4 on page 34.

B4. Ventilation

Ventilation upgrades can be made by implementing a balanced ventilation system (D). Upgrading from a natural ventilation (system A) to a mechanical ventilation (system B and C) does not offer heating demand decrease (verhoeff, 2019) and is therefore not considered as a future building change. In a rapport of the RVO (2017), detached and terraced houses have been analysed with both natural and balanced ventilation. The results show for detached homes, balanced ventilation decreased the heating demand by 7,6 kWh/m2/year. For terraced houses the increase is 9,0 kWh/m2/year. It is assumed that the sem-detached dwellings are positioned in between these two, resulting a heating demand decreases of 8,3 kWh/m2/year. These decreases are used in the research calculation.

B2. Building size

Besides these more traditional insulation measures, a recently introduced concept is explored; the solutions of the Prêt-à-Loger. At the Solar Decathlon Europe 2014 competition, the team from the TU Delft received the Sustainability award for their view on the sustainable challenge in the existing housing stock. As visualized in Figure 6, their solution to upgrade thermal performance is a greenhouse structure surrounding the back façade and roof. Besides the thermal performance upgrade, another great importance lies in the added value to the occupants: *"In spring and autumn the added space can be used as living space, in winter it's a winter garden buffer, and in summer it can be fully opened, becoming the terrace to the garden."* (Dobbelsteen, 2015). Thus, the incentive for homeowners to act regarding the energy transition increased. Besides a well-insulated home, their useable floor surface increased by approximately 10m2 for terraced houses (Prêt-à-Loger, 2019). With the average Dutch dwelling price of €2.666 per square meter (CBS, 2018c), the financial incentive furthermore becomes evident.

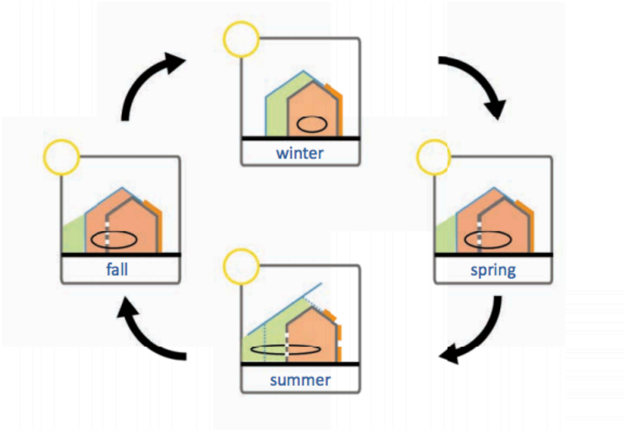


Figure 6. Prêt-à-Loger at the TU Delft Green Village, source: www.thegreenvillage.org

As the greenhouse skin consist out of a lightweight construction, it offers opportunity for façade leasing, contribution to the added servitization focus of this research. While the particular façade of the Prêt-à-Loger has not yet been evaluated on the façade leasing ability, research in this field has become extensive in recent years. Having the goal to identify the main drivers and barriers to delivery of integrated Facades-as-a-Services, Azcarate Aguerre (2018) found that the main implementation drivers applicable for the residential sector are saving energy expenses, not requiring or having liquidity for alternative investments and increasing the residual value of their property. They furthermore conclude that a comprehensive methodology to compare linear and circular contracting processes in terms of their Total Costs of Ownership (TCO) is still necessary. By including the greenhouse concepts in both the economic and financial feasibility, the recommendations are followed.

Heating demand measurement

The stated building variables are capable to decrease the heating demand, thus lowering operational costs and positively effecting the transition feasibility. To measure the effects, a heating demand measurement method is searched for. Energy labelling and Energy Index are common energy measurement method for existing building, however they are replaced by the EPG method, as explained in section 2.1.2. As this research is focused on space heating and DWH, the EPG method and the three BENG indicators are translated to this research in figure 7.

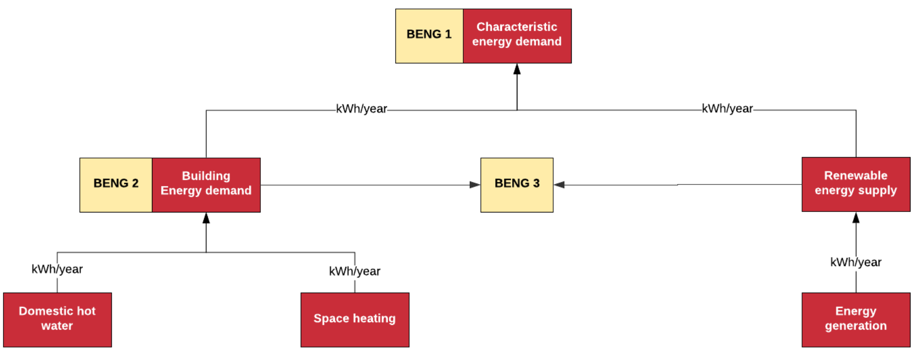


Figure 7. Research specific variables influencing the BENG indicators

Both the current situation and the effect of future insulation, ventilation and greenhouse measures will be expressed in heating demand per square meter per year (kWh/m2/year). However, when reviewing the Dutch literature on heating demand expressed in kWh/m2/year related to construction period, a gap in literature is found. Furthermore, no documenting is found on the relation between energy label of energy index on heating demand. Guerra-Santin and Silvester (2017) mentions one relation between energy label D/E and a primary energy demand of 350-400 kWh/m2/year. Substantiation is however absent, as is the share of space heating.

The study of Fuerst, Oikarinen, and Harjunen (2016), performed in the Helsinki climate with sub-zero long-term averages in the cold winter, did formulate a relation between energy labelling and energy demand. The bandwidths were as followed: Energy label A: 0 -100 kWh/m2/year, energy label B: 101-120 kWh/m2/year, energy label C: 121-140 kWh/m2/year, energy label D: 141-180 kWh/m2/year. energy label E: 180-230 kWh/m2/year, energy label F; 231-280 kWh/m2/year, energy label G; 281 and higher kWh/m2/year. However, due to the relatively warmer climate of the Netherlands, it is expected that the bandwidths show lower energy demands. Furthermore, there is a difference in the studies energy demand and the heating demand, where this research refers to. The Light and appliances are added, which also results in a decrease of the found bandwidths.

As no references where found, the different heating demand contribution of different building variables are calculated based on the R-value, expressing the heat loss per square meter through thermal transmittance and the heat loss surfaces of the façade, floor, roof and windows based on the AgentschapNL (2011) data set.

2.3.3 Users

After analysing the future services and building variables, the future user variables are explored. The number of occupants (U1) is a constant in this research, and will not change between current and future. The adjustability of the second variable, average indoor temperature (U2) requires careful formulating. First of all, it is acknowledged that the average indoor temperature is not an easy to adjust variable. Every occupier has its own preferences concerning the indoor climate and this should be respected; there is no right or wrong. However, it is hypothesised that very few occupants know the effect of their temperature setting on their operational costs. By including the different user groups, with different average indoor temperatures, the effects are quantified from the perspective of the homeowner, in both the current and future situation. Research outcomes will identify the economic result of a high or low average indoor temperature. As most households are economically driven (Vermeij, 2018; Kaal, 2017), this could impact the indoor temperature awareness.

Summarized, this section explored the ability of current situation variables to change according to the future expectations within the gas-free transition. Within the service domain, the air source heat pump is selected as the gas-powered boiler alternative providing space heating and DHW. Based on three different output temperatures, service alternatives A, B and C are established. Both underfloor heating and LT radiators are selected as future heating distribution systems. Solar panels with a peak power of 300 Wp are selected providing energy generation. Due to the currently unfeasible business case, the BESS does not benefit this research strategy and is excluded from the research. Secondly, regarding the building domain variables, different insulation measures are selected and ventilation method upgrades have been identified. A greenhouse solution is added offering both thermal quality improvement as additional floor surface. Finally, the goal to identify the economic result of changes in indoor temperature is added in the user domain, potentially impacting the occupant's awareness concerning the indoor climate. With both the current situation and future expectations formulated, the transition process is explores in the upcoming chapter.

2.4 TRANSITION PROCESS

After establishing the current situation and the future expectations, this section aims to give insights in the transition process, going from the current situation to the desired gas-free situation. It combines the acquired knowledge and presents an overview that is able to analyse the key relations between the building, services and users' domains. To study the different relations between the variables, a conceptual model is developed, which is illustrated in Figure 9. The figure is structured according to the steps stated in Figure 8, which will be explained in more detail below.

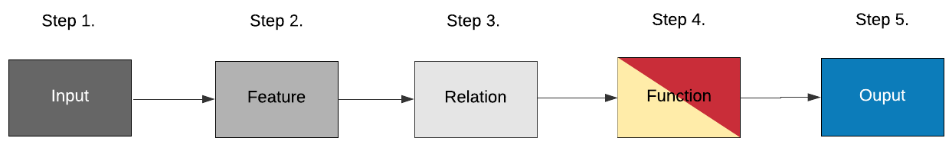


Figure 8. Transition process steps

Step 1. Input
The transition process starts with the building, user and service selection. The combination of these three groups represent the private housing stock and forms the input for the transition process.

Step 2. Feature
The different building, user and service groups each have their own features. The constant features in the transition process, as discussed in section 2.2 do not change in the transition process, while the variable features, discussed in section 2.3, might change during the process.

Step 3. Relations
Thirdly, the individual features are linked to one another by different relations. Changing the features will result in different relations values. Nine relations have been established, which will be further explained in the succeeding section.

Step 4. Functions
The combination of different features and relations result in functions, which come in twofold. First, the energetic performance function (marked in red) translate the relations and features toward the energy demand circuit, including space heating and DWH, and energy supply circuit, including solar panels. Secondly, the performance measurement function translates the different energetic performances to the EPG method, including the BENG 1, 2 and 3 norms.

Step 5. output
Finally, the output consists of the transition feasibility. When including the energy retail prices, which will be assessed in section 2.7, the operational costs derives from the energetic performance function. Secondly, a change or upgrade regarding the variable features results in an initial costs function, as illustrated at the bottom right of Figure 9.

With the input features formulated for the different target groups, user groups and service systems in section 2.2 and 2.3, the different variable features and relations influencing the energy demand and supply circuit are now explored. The circuits both have their own features, relations and functions and can operate individually. Calculations and input values belonging to each relation are presented. Where applicable, initial costs are introduced. The sequence of the introduced relations and features follow the dependencies between the relations; at each step is it stated on which its value is based on following the arrows in Figure 9.

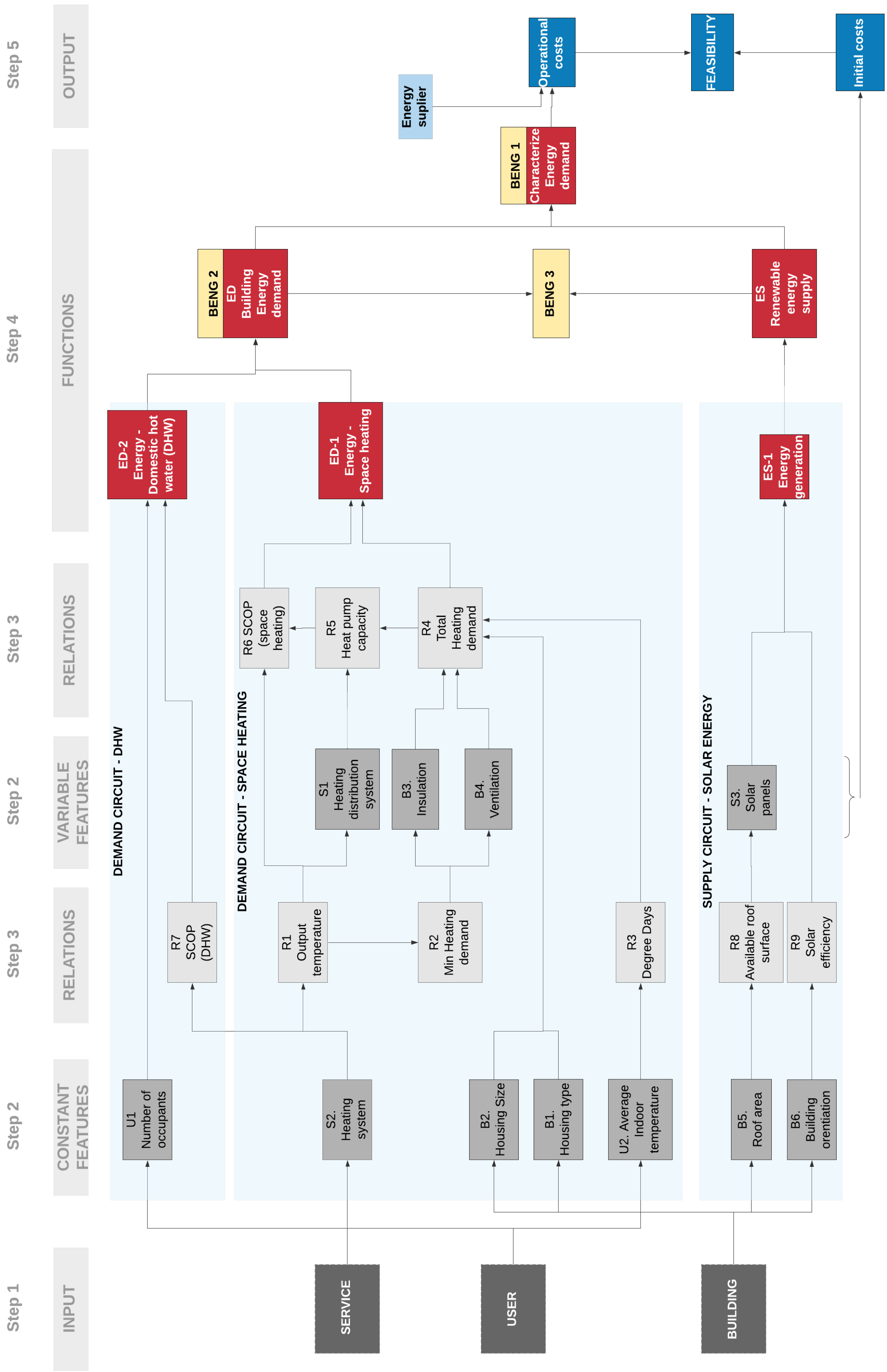


Figure 9. Conceptual model of transition process with research features, relations and functions.

2.4.1 ENERGY DEMAND CIRCUIT

The scheme presented in Figure 10 summaries the energy demand circuit part of Figure 9 and functions as a guidance for this section.

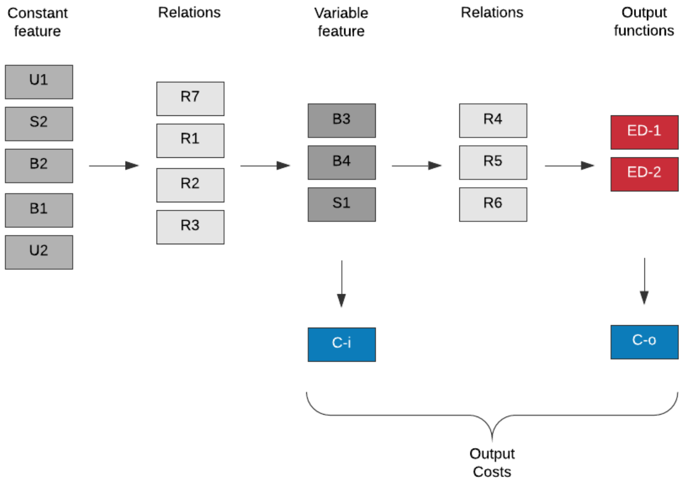


Figure 10. Conceptual model of energy demand circuit

R1. Output temperature
Based on the selected service system, the output temperature is determined. Dwellings constructed before 1975 were designed to function at an outdoor temperature of -20 °C operating at 90 °C output temperature. After 1975 however, the standard was decreased to operate at outdoor temperature of -10 °C. This results in a decrease of necessary output temperature to 67,5 °C to obtain enough heat with the current radiators (verhoeff, 2019). With a margin of 2,5 °C, it is assumed that the current heating distribution method operates at an output temperature of 65 °C and is able to obtain the required comfort level. Alternative A, B and C respectively produce 45 °C, 55 °C and 65 °C output temperature, stated in Table 5.

S1. Heating distribution method*, result of R1.*
The heating distribution method transfers the heat from the closed heat pump water system to the building in order to obtain the desired comfort level of the occupants. The heat pump output temperature (R1) influences the method, as a lower output temperature results in a less effective distribution method. It is assessed to what extant the required heating distribution method needs to be changed at the three different service systems. As stated in section 2.2, it is assumed that the current situation distribution method consists out of radiators at all target groups. As service alternative C operated at the same output temperature as the current situation, no heating distribution method improvements are required.

In assessing the required change at service alternative A and B, it is assumed that spatial adjustment with an increased radiator size will receive occupant's resistance, as additional spatial adjustments have to be made. Thus, in evaluating radiators alternatives, the condition is set that the size of the original radiators cannot increase; future dimension should be equal to current dimensions. Radiators have been commonly oversized to cover the window width and overcome cold draught from poor insulation. With LTH radiators designed at the same dimensions as the conventional radiators, from a thermal performance perspective by both small-scale renovations (such as improving the air-tightness) or relativity large-scale renovation (such as replacing the windows), they can provide an acceptable operative temperature after retrofitting when they are combined with a 45ºC output temperature (Q. Wang et al., 2015).

A replacement rate calculation, which is further explained in Appendix 1, confirms this conclusion. It is found that if 78% of the radiators are replaced with equal sized LT radiators operating at 45ºC, the same amount of heat is admitted. The found replacement ratio of LT radiators operating at 55ºC is 22%. These rates are further exponentially reduced when insulation and ventilation upgrades are applied, which are, explained in the following section, essential at both alternative A and B. Taken this decrease into account while incorporate a safety margin, due to time and scope limitations it is assumed that service alternative A operating at 45ºC requires a 70% replacement ratio of LT radiators, and alternative B operating at 55ºC requires a 20% replacement ratio.

The following step is to use the replacement ratio to determine the initial costs of a new heating distribution system. To calculate these costs, an assumption is made based on the graduation companies pricing level. The heat pumps capacity (R5) is used to formulated the price level, as this determines the amount of heat the low temperatures have to admit to the dwelling. The price level of the €700/kW of heat pump capacity, including installation and VAT, is used in this research. This represents the Strada DBE low temperature radiator is manufacture JAGA, equal to the calculations illustrated in Appendix 1.

R2. Heating demand*, result of R1*
Depending of different output temperature, a minimal heating demand requirement is set. If the heating demand exceeds this requirement, the service system is no longer capable of maintaining the desired occupant's temperature settings (verhoeff, 2019). As stated in section 2.3.1, no literature has been found to identify the minimal heating demand.

When translating the minimal energy label C, the graduation company requires to install service alternative A to heating demand, a value of approximately 80 kWh/m2/year is found using the transition tool. This is done by assessing the current heating demand of target group 9 and 17, representing an energy label C dwelling. It is assumed that this value is the minimal required heating demand at service alternative A. For survive alternative B, operating at 55ºC, similar steps are taken but then with energy label D. This result in a minimal required heating demand of 120 kWh/m2/year.

However, other research suggests that the optimal selection of insulation measures and thereby heating demand is mainly dependent on their ability to save operational energy and less on the output temperature (R1) (Q. Wang et al., 2015). These findings advocate that the relations between heating demand and output temperature plays a secondary role, and that the heating demand should be optimized by assessing the costs and benefits of additional insulation and ventilation measures. This

Case study validation, presented in chapter four, is needed to test the first assumption and see how this relates to the literature review findings. Insight on answering the question, if the output temperature plays a primary or secondary role in determining the heating demand, has to be obtained.

R3. Degree Days*, result of U2.*
As described on page 15, an increase of average indoor temperature by 1ºC results in a 10% increase of degree days. With the degree days at 18,0 ºC set at 2686 based on the 2018 Dutch climate year, the different average indoor temperatures of each user group result in different degree days using this starting point.

B3 + B4. Insulation and ventilation *result of R2.*
To meet the minimal requirements concerning the heating demand (R2) of the different alternatives, some dwellings require an upgrade in insulation and ventilation to research the stated minimums. The goal of this section is to select the most effective upgrades, while minimizing the costs. Financial optimums have to be found, as this enhance the feasibility outcomes. The framework of Pikas, Thalfeldt, Kurnitski, and Liias (2015) is used as guidance. The outcomes of this study where not considered relevant as they were based on the new construction project, neglecting energy performance and installation costs of existing building.

Two sources of input, one following the graduation company and one following the AgentschapNL (2011) data, are presented in Appendix 2. Prices include installation costs and VAT. Based on the inflation of the seven-year gap in price level between the two sources, the prices of THE FCTR E can be perceived valid based on the AgentschapNL (2011) data. Only the HR++ window upgrade shows a relatively large deviation. It is assumed that the prices of THE FCTR E represent average retail prices and are used in this research.

To determine the costs input for the greenhouse construction, the project manual of Prêt-à-Loger (2014) is used. In the calculations two levels, differing in the ambition to become energy neutral, are presented. The second ambition level is used in this research and has an initial cost €31.322, or €211 per square meter of gross area based on an average terraced house. Combined with other insulation measures applied on the other façade, the heating demand decreased from 130 to 34 kWh/m2/year. Due to the fact that the greenhouse includes half of the thermal envelope, it is assumed the glass façade accounts for half of the heating demand decrease, resulting in a delta heating demand of -48 kWh/m2/year.

Standardization and scalability advantages have been integrated in the cost of the greenhouse solution, which is based on the homogeneous characteristics of terraced houses (Prêt-à-Loger, 2014). Detached and semi-detached dwellings do not share one type dwelling type and have more heterogeneous features (Ritzen et al., 2016). It is expected that prices at these housing types will therefore increase exponentially. Furthermore, these dwelling types have more than 2 facades, resulting in increased initial cost or, if only applied to one façade result in decreased heating demand performance. Due to this missing information the greenhouse solution is only considered at terraced houses built.

To reduce the number of insulation and ventilation measures, stated in Appendix 2, the following simplification step is taken to decrease the number of insulation measures. This is due to time and scope limitations. While the two façade insulation measures theoretically can both be applied in one dwelling, this does not seem likely in practice. This would result in an R-value almost two times higher than the current construction requirements of the NEN 7120. The beneficial effects of this upgrade in twofold on the energetic performance would be relatively low compared to one measure. For this reason, this research assumes that the façade upgrades are mutual exclusive. Additionally, the window measures are mutual exclusive as well; only one measure can be selected. The following seven insulation upgrades and one ventilation upgrade are selected:

Figure 11. Insulation and ventilation upgrade measures

Code		type	condition	R-value	€/m2
FL-1	Floor	Bottom insulation	Crawl space >0,5 m	2,5	28
FA-1	Facade	Cavity wall	Build 1920-1975	2,5	28
FA-2		Inner wall	build after 1980	3,5	200
RO-1	Roof	sloped roof		3,5	110

Code		type	condition	U-value	€/m2
WI-1	Window	HR++		1,1	100
WI-2		Triple		0,8	240

Code		type	heating demand	decrease kWh/m2/year	€/ floor surface
VE-1		Balanced	Detached	9	35
			Semi-detached	8,3	
			Terrassed	7,6	

Code			condition	decrease kWh/m2/year	€ total
GH-1	greenhouse facade		Terraced built befor 1992	48	211

The following step is to link these costs to the different target groups. The data set of AgentschapNL (2011) provided the surfaces of the façade, floor, roof and windows. Combined with the current R-value stated in Table 2, the specific current heating demand of the façade, floor, roof and windows can be calculated. This forms the base case at which insulation upgrades are applied. After the base cases are established, the specific insulation and ventilation upgrades can be applied to the different target groups. For each upgrade, the decrease in kWh/m2/year is assessed using the delta U-value as a function the heat loss area and of the degree days. As a result, the impact of different upgrades on the total heating demand is explored. Combination of different upgrades can achieve the minimal heating demand (R2) of the three alternative heat pumps.

To select to costs optimum upgrade combination, the price per decrease heating demand step (€/Δ1 kWh/m2/year) is determined. Table 6 illustrates the different steps taken for the façade insulation. The orange market area indicates the current situation. The blue marked area indicated the decrease in heating demand, whereas the red market area indicated the costs per kWh/m2/year. The principle of table four is performed for the six different insulation upgrades and the ventilation upgrades, which are illustrated in Appendix 3. Appendix 3. Insulation steps:

Table 6. Facade insulation upgrades.

Target group	Insulation measures FACADE				FA-1 - RC value 2,5						FA-2 - RC value 3,5					
					Costs	Total costs	new R-value	New heating demand	decrease in heating	Extra costs	Costs	Total costs	new R-value	New heating	decrease in heating	Extra costs
	current R-value	Facade Area m2	specific heat loss W/K	kWh/m2/year	€/m2	€	R-value	kWh/m2/ year	kWh/m2/ year	€/kWh/m2/ year	€/m2	€	R-value	kWh/m2/ year	kWh/m2/ year	€/kWh/m2/year
1	0,36	136,7	379,7	48	€ 28	€ 3.828	2,50	6,9	41	€ 93	€ 200	€ 27.340	3,50	5,0	43,3	€ 632
2	0,43	164,7	383,0	44	€ 28	€ 4.612	2,50	7,6	36	€ 127	€ 200	€ 32.940	3,50	5,4	38,5	€ 855
3	1,30	144,0	110,8	16	€ 28	€ 4.032	2,50	8,1	8	€ 537	€ 200	€ 28.800	3,50	5,8	9,8	€ 2.931
4	2,53	150,9	59,6	10			2,50				€ 200	€ 30.180	3,50	7,5	2,9	€ 10.456
5	2,53	151,0	59,7	13			2,50				€ 200	€ 30.200	3,50	9,2	3,5	€ 8.555
6	4,50	151,0	33,6	7			2,50						3,50			
7	0,36	97,8	271,7	41	€ 28	€ 2.738	2,50	5,9	35	€ 78	€ 200	€ 19.560	3,50	4,2	36,6	€ 534
8	0,43	104,7	243,5	37	€ 28	€ 2.932	2,50	6,4	31	€ 96	€ 200	€ 20.940	3,50	4,6	32,5	€ 644
9	1,30	96,6	74,3	15	€ 28	€ 2.705	2,50	8,0	7	€ 365	€ 200	€ 19.320	3,50	5,7	9,7	€ 1.990
10	2,53	108,5	42,9	10			2,50				€ 200	€ 21.700	3,50	7,1	2,7	€ 8.024
11	2,53	109,0	43,1	12			2,50				€ 200	€ 21.800	3,50	8,7	3,3	€ 6.565
12	4,50	109,0	24,2	7			2,50						3,50			
13	0,19	49,0	257,9	42	€ 28	€ 1.372	2,50	3,2	39	€ 36	€ 200	€ 9.800	3,50	2,3	39,5	€ 248
14	0,36	53,0	147,2	28	€ 28	€ 1.484	2,50	4,0	24	€ 62	€ 200	€ 10.600	3,50	2,9	25,1	€ 423
15	0,43	58,3	135,6	24	€ 28	€ 1.632	2,50	4,1	20	€ 82	€ 200	€ 11.660	3,50	2,9	21,0	€ 555
16	1,30	58,4	44,9	9	€ 28	€ 1.635	2,50	4,8	4	€ 370	€ 200	€ 11.680	3,50	3,4	5,8	€ 2.017
17	2,53	58,4	23,1	5			2,50				€ 200	€ 11.680	3,50	3,7	1,4	€ 8.142
18	2,53	58,4	23,1	7			2,50				€ 200	€ 11.680	3,50	5,4	2,1	€ 5.670
19	4,50	58,4	13,0	4			2,50						3,50			

As a result, every insulation and ventilation upgrade is now quantified based on their capability to decrease the heating demand with the associated costs. Cost optimum packages can be generated, decreasing the heating demand of each target group toward the minimal requirements of the different heat pump types.

Following the method used by Pikas, Kurnitski, Liias, and Thalfeldt (2015), the costs per decreased heating demand can be compared with the max decreased heating demand of each upgrade, illustrated in Figure 12. The blue lines represent the cost per heating demand decrease, while the green lines represent the maximum decreased heating demand. In target group 1 illustrated in figure 17a, floor insulation is for example a cost-effective insulation upgrade, whereas the ventilation upgrade is the least cost-effective upgrade. If a different target group, for example 17 (terraced dwelling building between 1992 and 2005) a different scheme is produced as illustrated in Figure 12. Minimal façade and floor insulation legislation of that period result in an unnecessary upgrade concerning façade measure type 1 and floor measure type 1. Furthermore, the effectiveness of for example a roof insulation upgrade decreases due to the relatively small upgrade step; from the current R-value 2,5 to the future 3,5. Figure 12 can be generated for the 19 different target groups and user groups.

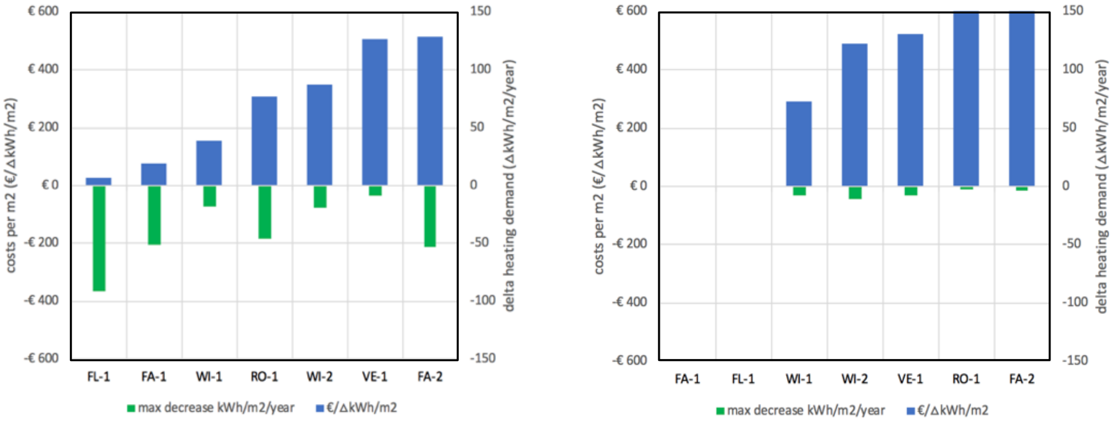


Figure 12. Cost and maximum decreased heating demand of different insulation and ventilation upgrades at target group 1 (left) and target group 17 (right)

Keeping target group 1 dwelling as an example, the following section elaborates on selecting the most cost-effective insulation and ventilation measures to achieve certain minimal heating demand level. Service alternative B requires a heating demand equal of below 120 kWh/m2/year. The most cost-effective strategy to achieve this level is to apply Floor insulation type 1 and Façade insulation type 1, as illustrated as step one and two in figure 18. A heating demand level of 91 kWh/m2/year is achieved through an initial investment of €6.432. Service alternative A requires a heating demand equal of lower than 80 kWh/m2/year. The most cost-effective strategy to achieve this level is to add step 3, Window insulation type 1, resulting in a new heating demand of 77 kWh/m2/year achieved through an initial investment of €9.262. These steps can be replicated for each target group.

Figure 13. Costs effective packages for target group 1 to reach the minimal requirement of the service alternative A and B.

	measure	€/△kWh/m2	max decrease kWh/m2/year	€/m2	area size	Costs per upgrade	new heating demand	total costs
current	none					€ 0	207	0
step 1	FL-1	€ 35	-74	€ 28	93 m2	€ 2.604	133	€ 2.604
step 2	FA-1	€ 93	-41	€ 28	137 m2	€ 3.828	91	€ 6.432
step 3	WI-1	€ 192	-15	€ 100	28 m2	€ 2.830	77	€ 9.262
step 4	RO-1	€ 380	-37	€ 110	128 m2	€ 14.091	40	€ 23.353
step 5	VE-1	€ 506	-9	€ 35	130 m2	€ 4.550	31	€ 27.903

Cost effective heating demand upgrade packages can now be formulated for each target group to obtain certain minimal requirement. The outcomes give quantified insights regarding the building variables in the efficiency gap, concluded by the EIB (2018) as the main the main barrier for the energy transition.

R4. Total heating demand, *result of R3, B1, B2, B3 and B4*

To calculate the total heating demand, four steps are followed. First of all, the different heat loss coefficients (U-values) of the facade (FA), floor (FL), roof (RO) and window (WI) are multiplied by the respectively heat loss surfaces resulting in specific heat loss per building component. Input origins form the AgentschapNL (2011) data set. Secondly, the ventilation (VE) heat loss coefficient, set at 1,16 W/m2 (verhoeff, 2019) is multiplied by the housing surface. Thirdly, the combined total heat loss is multiplied by the degree days (R3) to account for the behavioural component of the users. Finally, the found target group specific correction factor of Table 1 based on Majcen (2016) is multiplied with the found heating demand. This results in the total heating demand.

R5. Heat pump capacity*, result of R4 and S1*

To require the desired comfort level, the heat pump capacity has to be balanced with the total space heating demand and the heating distribution system. A higher heating demand requires a larger capacity, while a convective heating distribution system requires less capacity to transfer heat to the surrounding compared to a radiative system. To account for these different influences determining the heat pump capacity, the values of the graduation company are taken as input. THE FCTR E developed these capacity characteristics in consultation with the heat pump manufacturer NIBE. With more than 30 NIBE heat pumps installations through THE FCTR E and several hundred in the Netherlands through other service companies, it is assumed that these values are accurate.

The heat pump capacity determination of THE FCTR E is translated to be adaptable in this research in three steps. First of all, a translation step is made from the gas demand per year to the total heating demand per year. The gas demand is divided by the calorific value of gas of 35.17 MJ/m3, multiplied by the 3,6 kWh that 1 MJ consist and multiplied by the SCOP of a gas-powered boiler. This results in the space heating demand per year (R4). Secondly, based on the graduation companies input, for each heating demand value and service alternative the required heat pump capacity is selected. In the final step the heat pump capacity is linked to a specific heat pump type. This is done to provide insights in manufactures information regarding SCOP and pricing. To assure consistency in the research, the air source heat pumps of manufacturer NIBE are selected and used throughout the subsequently parts of the report. Furthermore, result of the case studies performed in chapter five will be based on these particular heat pumps. Table 7 illustrates the different steps and provides on overview on which the heat pump capacity can be selected based on total heating demand and heating distribution method.

Table 7. Heat pump capacity, based on heating demand and service alternative, based on THE FCTRE (2019)

	R4	R5		R5		R5	
gas demand for space heating /year	space heating demand/year	Serivce alternative A: 30% radiative 70% convective	NIBE type:	Serivce alternative B: 80% radiative 20% convective	NIBE type:	Serivce alternative C: 100% radiative 0% convective	NIBE type:
0 m3	0 kWh	6 kW	F2040 (6kW)	6 kW	F2040 (6kW)	8 kW	F2300 (8kW)
1200 m3	10560 kWh	6 kW	F2040 (6kW)	6 kW	F2040 (6kW)	8 kW	F2300 (8kW)
1440 m3	12672 kWh	6 kW	F2040 (6kW)	8 kW	F2040 (8kW)	8 kW	F2300 (8kW)
1680 m3	14784 kWh	8 kW	F2040 (8kW)	8 kW	F2040 (8kW)	8 kW	F2300 (8kW)
1920 m3	16896 kWh	8 kW	F2040 (8kW)	12 kW	F2120 (12kW)	14 kW	F2300((14kW)
2160 m3	19008 kWh	12 kW	F2120 (12kW)	12 kW	F2120 (12kW)	14 kW	F2300((14kW)
2400 m3	21120 kWh	12 kW	F2120 (12kW)	12 kW	F2120 (12kW)	20 kW	F2300((20kW)
2640 m3	23232 kWh	16 kW	F2120 (16kW)	16 kW	F2120 (16kW)	20 kW	F2300((20kW)
2880 m3	25344 kWh	16 kW	F2120 (16kW)	16 kW	F2120 (16kW)	20 kW	F2300((20kW)
3120 m3	27456 kWh	16 kW	F2120 (16kW)	16 kW	F2120 (16kW)	20 kW	F2300((20kW)
3360 m3	29568 kWh	16 kW	F2120 (16kW)	16 kW	F2120 (16kW)	20 kW	F2300((20kW)
3600 m3	31680 kWh	20 kW	F2120 (20kW)	20 kW	F2120 (20kW)	20 kW	F2300((20kW)
3840 m3	33792 kWh	20 kW	F2120 (20kW)	20 kW	F2120 (20kW)	20 kW	F2300((20kW)
4080 m3	35904 kWh	20 kW	F2120 (20kW)	20 kW	F2120 (20kW)	20 kW	F2300((20kW)

The retail prices of graduation company are used to account for the gross initial cost of the different heat pumps, which are stated in Appendix 6. The net initial costs, used in the transition tool calculations, decrease the retail prices with the current available subsidy on heat pump following the ISDE 2019 of the RVO.

R6. SCOP (space heating)*, result of R5 and R1.*

After the heat pump capacity has been examined, the SCOP can be determined based on the product characteristics and output temperatures. This is done by following the product information of the manufacture NIBE. In the product manuals, the different SCOP are stated, based on the average Dutch climate and different output temperatures. Table 8 combines the space heating SCOP's of the different heat pumps based on the output temperature. The SCOP of the DHW are also added, and discussed in the following section. To compare the SCOP of the different heat pump with the current situation, the gas-powered boiler is added to Table 8. The SCOP of the current situation is not correlated with the output temperature, it remains constant at 0,90 as discussed on page 24. The values of Table 9 serve as input for the Transition tool.

Table 8. SCOP of different heat pumps and a gas-powered boiler

Manufacturer	R5 Heat pump capacity	Type	R6 SCOP space heating at: 45 °C	55 °C	65 °C	R7 SCOP DHW Tapwater 55°C
LT heat pump (alternative A and B)						
NIBE	6 Kw	F2040-6	3,30	2,80		2,55
NIBE	8 Kw	F2040-8	3,40	2,80		2,55
NIBE	12 Kw	F2120-12	3,77	3,04		2,79
NIBE	16 Kw	F2120-16	3,76	3,06		2,81
NIBE	20 Kw	F2120-20	3,79	3,10		2,85
HT heat pump (alternative C)						
NIBE	8 kW	F2300-8			2,59	2,89
NIBE	14 Kw	F2300-14			2,59	2,89
NIBE	20 Kw	F2300-20			2,55	2,93
Gas-powered boiler						
		HR-107	0,90	0,90	0,90	0,90

When adding the costs of electricity and gas to the different SCOP values, an economic analysis can be made to assesses the influence of the SCOP on operational costs. To do so, an example dwelling with a current annual operational cost of €1.000 for space heating using the HR-107 boiler is compared with different electric heat pump alternatives in Figure 14. As the graph indicates, a decrease in operational costs only occurs when the SCOP of the electric alternative is below 2,7. The SCOP bandwidths of alternative A, B and C are added.

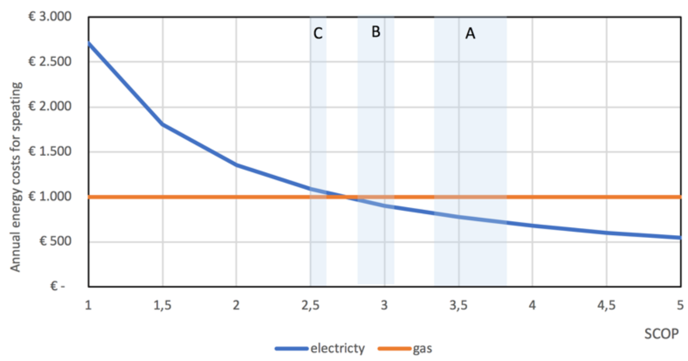


Figure 14. Annual cost with different space heating SCOP's and energy sources.

Operational costs decrease is perceived as the largest benefit of gas-free transition (Valk, 2018). With this tipping point known, the bandwidth of the difference in operational costs can be assessed, giving insight is these future benefits. Alternative A result in an annual operation costs decrease between 18% and 28%, while alternative B results in decrease between 3% and 13%. Alternative C does not result in operational costs decrease, but increased the annual cost between 5% and 6%. Concludingly, operational costs decrease regarding space heating, perceived as one of the main benefits of the energy transition, can now be quantified. While alternative A and B positively influence the economic feasibility, alternative C does not in the current situation.

It is noted that the SCOP is positively correlated with the heat pump capacity. According to Verhoeff (2019), this is due to the fact the relatively large pumps gain an benefit over small capacity pumps by a more efficient internal process. Figure 15 combines the heat pump capacity resulting in initial costs and space heating SCOP resulting in operational costs. The figure illustrated initial costs per kW capacity, and the operational costs per kWh of heat.

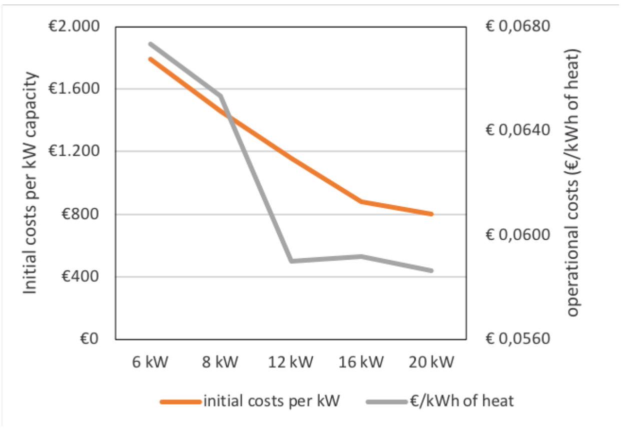


Figure 15. The effect of heat pump capacity on initial cost and operational costs

It becomes evident that a high capacity heat pump, relatively, decreases both initial and operational costs resulting is an improved pack back period. In return, high capacity heat pumps are a result of dwellings with a high heating demand resulting in higher operational costs. Future research is demanded to assess the economic effect of over-dimensioned heat pump capacity, thus increasing the initial costs, but decreasing the operational costs by improved SCOP. This study does not incorporate this finding in further calculations.

***R7. SCOP (DHW)**, result of R5*

Following the same steps of the space heating SCOP, the SCOP of domestic hot water is determined based on the heat pump capacity. However, due to the separate demand structure of DHW, the SCOP it not influenced by the heating distribution system. Based on the different values presented in Table 8, the bandwidth or operational costs influence compared to the current situation can again be assessed. The low temperature heat pump, representing alternative A and B, results in an annual cost deviation between 6% increase and 5% decrease, while the high temperature heat pump from alternative C decrease annual costs by 6% to 8%. The bandwidth of DHW SCOPs related to service alternative shows adversative results compared to the space heating SCOP. The DWH efficiencies are positively correlated with output temperature, while the space heating efficiencies are negatively correlated. This due to the fact that the high temperature heat pumps are designed to produce output temperature above 55 degrees C. Due to the lower share of total household energy demand by DWH (20%) compared with space heating (60%) and the relatively lower annual savings bandwidth of domestic hot water, improving the SCOP of space heating demand should be leading in the quest to explore economic feasibility.

With the energy demand circuit features and relations known, the energy demand functions can now be calculated.

ED1. Space heating energy demand, *result of R4 and R6.*
The energy demand for space heating is derived from the deviation of the total heating demand (R4) by the space heating SCOP (R6). In the current situation the output value is expressed in m3 gas per year by using the calorific value, while at the three electric service alternative the energy demand is expressed in kWh/year.

ED2. DHW energy demand, *result of U1 and R7*
The final step required to calculate the DWH energy demand is to examine the average heating demand per person. Based on an average shower time of five minutes per day per person at 40 degrees C consuming 10 litres of hot water, a yearly gas consumption of 73 m3 of gas per person in needed (Vastenlastenbond, 2019). To account for other domestic hot water usage, such as kitchen usage and an occasionally bath, it is assumed that average person requires 100 m3 of gas per year on domestic hot water usage. With the efficiency of HR-107 boiler and the calorific value of gas, this result in 879 kWh of heat per occupant per year on domestic hot water. With this final value known, the energy demand for DHW is determined by multiplying the heating demand per occupant by the number of occupants (U1) and divided by the DHW SCOP (R7). Again, the current situation the output value is expressed in m3 gas per year by using the calorific value, while at the three electric service alternative the energy demand is expressed in kWh/year.

ED. Building energy demand, *result of ED1 and ED2.*
The combined energy demand of DWH and space heating results the building energy demand.

2.4.2 ENERGY SUPPLY CIRCUIT

Following the same structure as the energy demand circuit, this section aims to give insight in supply circuit based on the conceptual scheme presented in Figure 16.

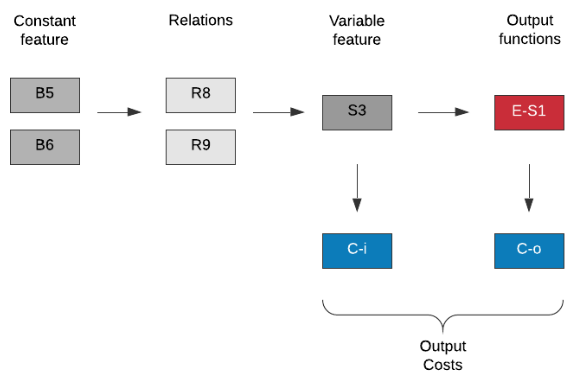


Figure 16. Conceptual model of energy supply circuit

R8. Available roof surface, *result of B5*
Based on the roof area (B5), presented in Table 2, it is necessary to evaluate the available roof surface of each dwelling type. In this study, it is assumed that the roof surface is sloped at a 45 degrees angel and that only one side of the roof is admitted to enough sunshine to install solar panels. Hence, the total roof surface, derived from the AgentschapNL (2011) data set, is divided by two to formulate the gross available roof surface.

The second step is to determine the net available roof surface by including the roof edge, dormer and shadow factor. A margin of 0,3m at the four edge's accounts for the first factor. Data concerning the amount of dormer present in the private dwelling stock is not found. Therefore, the photographs in the AgentschapNL (2011) data set are used to estimate the roof surface of an average dormer. As a result, it is assumed that a dormer decreases the remaining available roof surface by 30%. Shadow is perceived as in individual dwellings characteristics and while being variable, the third factor is set at 0% in this research.

To calculate the net available roof surface derived from the abovementioned values, the third step includes the width to length ratio of the different housing types. Based on the case study of Ritzen et al. (2016), it is assumed that terraced houses have a width to length ratio of 1:2 and detached houses have a ratio of 1:1. Semi-detached dwellings were not included in the study, thus it is assumed that the ratio lies between these two resulting in a 1:1,5 ratio. With these ratio's known, the edge margins can now be subtracted from the width and length and the dormer factor can be subtracted from the remaining surface. Thereby, the net available roof surface is calculated.

S3. Number of solar panels, *result of R8.*
With the available roof surface and the width to length ratio's known, the number of solar panels can be determined. This is done by evaluating the number solar panels, having a dimension of 1x1.65 m, that fit on the found width and length. The number of panels and rows in both portrait and landscape are examined and the highest value is selected. The calculation of the available roof surface and the number of solar panels is illustrated in Appendix 8. By adding solar panels, an initial costs amount is introduced. The retail prices of the graduation company THE FCTR E serve as input, and are stated in Appendix 7. The VAT on solar panels, accounting for 17% of the initial costs, is subsidized and is subtracted. The prices represent 300Wp solar panels.

R9. Solar efficiency, *result of B6*
In perfect conditions, a 300Wp solar panel annually generates 300 kWh. However, as experienced during the graduation internship, a standard correction factor of 0.9 is generally added by the industry to account for the not perfect conditions (verhoeff, 2019), resulting in an energy supply of 270 kWh/panel/year. The efficiency of solar energy generation is furthermore determined by the orientation and angle at which the panels are installed. Based on the table of Hespul, presented in Appendix 4, the combinations of these two influences result in a performance factor. As mentioned in section 2.1, the building orientation is set at 135 degrees. Based on the study of Ritzen et al. (2016), it is assumed that the average roof is sloped at 45 degrees. The combination result in a solar efficiency performance factor of 0.92, meaning the maximum energy output is reduced by 8%. Concludingly, this study assumes that one solar panel generated 248 kWh per year. Page 24 mentioned the efficiency factor used by the CBS in their calculations, resulting in a net energy generation of 262 kWh per year. This demonstrates the assumed sub-ideal orientation used in this research, aiming to produce realistic outcomes instead of best-case results.

ES1. Energy generation, *result of S3 and R9*
With both the number of solar panels (S3) and solar efficiency (R9) known, the total solar energy supply can be calculated. These technical performances are compared with the economic costs and benefits in the upcoming section.

Techno-economic analysis solar panels
To quantify the effect of the set orientation on the transition process and feasibility, this section aims to examine the economic effect of building orientation concerning solar panel energy generation. A techno-economic analysis is made, aiming to provide a better understanding of the influence of the different research variables of the supply circuit.

First of all, the initial costs of one solar panel is examined. When installing 8 solar panels, the average price of a 300Wp solar panel including installation and subsidy is €300 per panel (Appendix 7). In perfect conditions, a 300Wp solar panel annually generates 300 kWh. With the standard correction factor of 0,9 the initial costs are €1,11 to produce 1 kWh/year. With the set orientation at 135 degrees and a sloped roof of 45 degrees, the performance correction factor of 0,92 increase the initial cost to €1,20 to produce 1 kWh/year. Installed at the same angle, solar panels orientated at the South, which have the higher performance factor, result in an initial cost of €1,12/kWh/year and an east or west orientation, having an energy performance factor of 0,77, results in an initial cost of €1,44/kWh/year. Assuming that one of the two sides of the roof has a surface orientated in this spectrum, the bandwidth of the initial costs is determined.

Secondly, the economic gain of solar panels is determined. Due to the difference in electricity retail price and PV feed-in tariff, to calculate the operational costs of the energy supply by solar panels, the Self-Sufficiency Rate (SSR) concept is introduced. This rate represents the percentage of solar energy that is directly used, and thereby not purchased from the net supplier. If this is the case, the economic benefit of 1kWh equals the retail price of 1 kWh of electricity. Considering the fact that solar energy is only generated during the day time, the peak price level of €0,231/kWh is taken. However, if the solar energy cannot by directly used in the residential energy system, it is sold through netting and delivered back to the grid. Again, considering the day time energy generation period, the peak PV feed-in tariff of €0,073/kWh is selected. With the further expected increase spread between PV feed-in tariffs and prices of grid electracy (Weniger et al., 2014), the economic benefit of using the solar generated electricity on-site on the household level than feeding it into the grid will only enlarge in the future.

To asses this research specific self-sufficiency rates, the framework of (Weniger et al., 2014) is adapted to be used in this study and based on Dutch climate input form (Energieopwek.nl, 2019). Through this website, the hourly data on solar generation in the Netherlands is translated into an average daily cycle of energy supply. Furthermore, national energy retail prices are taken as a reference point. Three different orientations, corresponding with the earlier found initial costs are added, resulting in three different graphs examining the average hourly energy generation. Besides the orientation factor, the number of panels furthermore influences the energy supply. Based on the set conditions and housing features, detached houses are able to install 20 solar panels, semi-detached dwellings between 10 and 12 solar panels and terraced housing provide enough roof surface to install 8 solar panels. The two extremes, terraced and detached dwellings are used in the calculation. The average total daily solar energy generation for different situation can be now calculated.

Subsequently, the energy demand is added necessary to examine the self-sufficiency rate. The average space heating energy demand of both the detached and terraced dwelling groups is added to the DWH energy demand assuming an average household, following the outcomes of the transition tool. The heating demand is furthermore specified to the different service alternatives A, B and C, and translated into an hourly energy demand to be comparable with the solar energy gains. In this calculation, it is assumed heat pump energy demand is constant throughout the day. In reality, there is a small deviation (Energieopwek.nl, 2019) but for scoping reasons this is not considered. Furthermore, electricity demanded by other sources, such as lighting and applications, is not incorporated.

When combining the energy supply of solar panels and the energy demand of heat pumps, Figure 17 is presented where figure 15a represents a detached dwelling build between 1975 and 1991 and figure 15b represent a terraced dwelling build in the same period. These research specific graphs give quantified insight in the self-sufficiency rates, necessary to determine the economic feasibility of solar panels.

With both the initial costs per kWh/year and the operational benefits per kWh known, the payback period of solar panels based on building orientation, target group and service alternative can be calculate giving insight in the economic feasibility. By deviating the initial costs by the energy tariff of purchasing or netting, dependent of the self-sufficient ratio, the pack back periods are acquired. The outcomes of the different situations are presented in
Table 9.

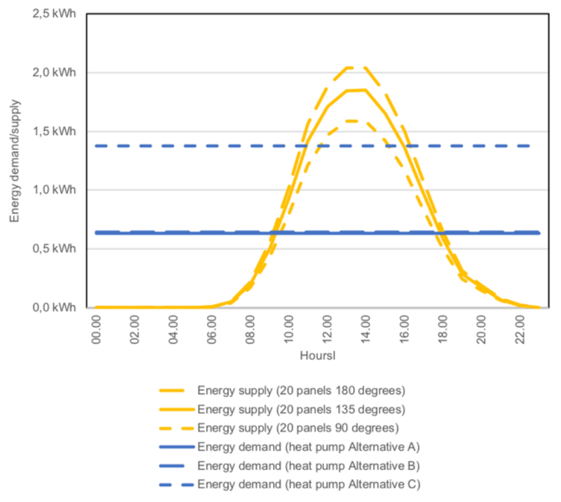


Figure 17a. Average daily energy demand vs supply, det. dwelling group 3

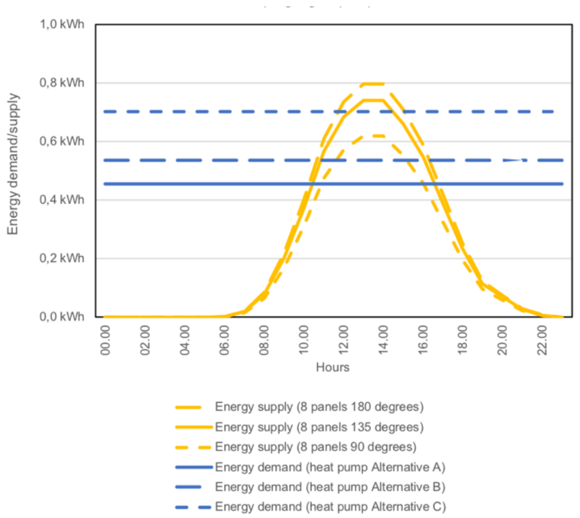


Figure 17b. Average daily energy demand vs supply, ter. dwelling group 16

Terraced dwelling type 16, 8 solar panels, average user group						
	180º		135º		90º	
	PBP	SSR	PBP	SSR	PBP	SSR
alternative A	5 year	84%	6 year	72%	8 year	67%
B	5 year	93%	6 year	83%	7 year	76%
C	5 year	100%	5 year	98%	7 year	92%

Detached dwelling type 3, 20 solar panels, average user group						
	180º		135º		90º	
	PBP	SSR	PBP	SSR	PBP	SSR
alternative A	7 year	56%	8 year	51%	10 year	47%
B	7 year	58%	8 year	54%	10 year	49%
C	5 year	96%	6 year	90%	7 year	84%

Table 9. Payback Period (PBP) and Self-Sufficiency Rate (SSR) of solar panels, based on building orientation, target group and service alternative

The above-mentioned table, validates that the assumed building orientation of 135 degrees, as found in section X, lies between the best (180 degrees) and worst (90 degrees) case. The results presented from table 10 demonstration an average different in self-sufficiency between the best and worst case of 12%, or 2 to 3 year in additional payback period. A conclusion of Weniger et al. (2014), in which the impact of the orientation of solar panels on the degree of self-sufficiency is considered to have no major impact, is thereby questioned.

Based on these findings, the following conclusions concerning the economic feasibility of solar panels can be made. First of all, the self-sufficiency rate and thereby economic feasibility decreases when the solar energy supply surpluses the demand as it cannot be consumed simultaneously. This means that the service alternatives efficiency (SCOP) is negatively correlated with solar benefits; a higher efficiency reduces the heating demand, increasing the surpluses which decreased the self-sufficient ratio. Furthermore, size of the PV system is negatively correlated with economic feasibility when the sufficient rate becomes lower than 100%. Based on these conclusions, from a purely economic perspective focussed only on solar panels it can be argued the number of solar panels should be dimensioned to below a 100% self-sufficiency rate.

On the contrary, solar panels produce renewable energy contribution to the energy transition. One could argue, from an environmental perspective, that every added solar panel reduces the need for fossil-based energy generation. As this study focusses on the feasibility from the homeowner's perspective, a balance has to be found. Hence, the number of solar panels has to maximized within the margin of technical feasibility, as explained in section 2.5.1, and economic feasibility, which will be explained in section 2.6

Additionally, as the heat pumps shifts the energy source from gas to electricity, the total residential electricity demand increases. Illustrated by the blue lines in figure 20, a higher electricity increased the self-sufficiency ratio, which in return increasing economic feasibility. This advocated that the combination of a heat pump and solar panels has an enlarged effect on the energy transition feasibly, compared to separate usage.

2.4.3 BENG

With both the energy demand and supply circuits determined, the BENG energy measurement method norms can be calculated. The BENG 2 norm represent the found building energy demand (ED). In the BENG 1 norm the heating demand is decreased by the energy generation, resulting in the characteristic energy demand. The relation between the fossil building energy demand and renewable energy supply expresses the BENG 3 norm. Hereby, the EPG method outcomes are specified, predating future national legislation.

2.5 TECHNO-ECONOMIC INPUT

The following section examines the technical feasibility and costs and benefits of the transition process, functioning as the literature review input for sub question four.

2.5.1 Technical feasibility

The goal of this section is to assess the technical feasibility of the proposed future alternatives. The technical feasibility of the established transition process is explored by assessing the ability to change or upgrade the different variable features necessary of the transition process. The building domain is first examined, followed by the service domain.

(B3) Insulation. Upgrading the insulation is technical feasible, as every dwelling is able to acquire a certain level of thermal resistance. For each target group, the different insulation steps presented in Figure 13, are capable to obtain the minimal required heating demand level of service alternative A. Thus, insulation measures are considered technical feasible.

(B4) Ventilation. Upgrading the ventilation is also perceived to be technical feasible. Changing the ventilation method is not restricted by building variables.

(S1) *Heating distribution system.* By replacing the existing radiators by either floor heating or low temperature radiators, this feature can be changed. While some dwellings are not designed to cope with floor heating, low temperature radiators are technical applicable in every dwelling, resulting in a technical feasible feature.

(S2) Heat pump. The air source heat pump (ASHP) is selected based on its capability to be installed at the whole existing housing stock, as described on page 23. While the inside unit is bigger than a traditional boiler, this research supposes it can be installed in the same technical space of the replaced boiler. Meeting the technical and spatial requirements, the heat pump is considered technical feasible.

(S3) Solar panels. Roof surface has to be available to install solar panels. While generally solar panels are placed with a minimum of six panels due to the relatively costly shared distributor, technically one could install only one solar panel for this feature to be considered technical feasible. Illustrated in the calculation of Appendix 8, if the available roof surface fails to provide an area larger than 1.00 x 1.65 m2, it is technically not feasible to install solar panels. This could be causes by for example a relatively

large dormer. Furthermore, as the calculation stated, the shadow factor can affect the technical feasibility of solar panels. Again, if the situation fails to provide an area larger than the area of 1 solar panel, solar panels cannot be installed.

To summarize, technical feasibility is formulated: only useable roof surface is a critical factor influencing the technical feasibility of solar panels. Other variables do not offer any technical constrains.

2.5.2 Costs

Initial costs have been introduced in section 2.4 by the various variable features and will therefore not be included. Firstly, indirect costs will be examined, followed by the operational costs that function as the benefits side of the transition. Other indirect benefits will be discussed in the last part of this paragraph.

Indirect costs
Besides the direct initial cost of upgraded insulation and ventilation measures, heat pump, heating distribution system and solar panels, another indirect cost component present itself. In the future, gas-free situation, the added features will demand additional spatial requirements. As a result, the useable floor area is decreased. If this is related to the average Dutch square meter price of €2.666 (CBS, 2018c), indirect costs occur.

While insulation and ventilation upgrades, heating distribution system and solar panels influences on the useable floor area are minimal, the heat pump installation does require additional space over the current gas-powered boiler it will replace. An average heat pump including boiler requires 1 square meters of floor area at a height of 2 meter, while the gas-powered boiler requires 0,5 square meter of floor area at a height of 1 meter. To make the effect tangible; it is like adding a large sized fridge to your house. For larger dwellings with enough technical space, the indirect costs increase will be minimal. However, in for example apartments in urban areas, which offer relatively little technical space and high square meter prices, the indirect costs increase can be substantial. Indirect costs are therefore related to dwelling size and average square meter price. While acknowledging this fact, the indirect costs are excluded from the research due to the individual dwelling nature.

Operational cost
The operational costs are a function of the found energy demand and supply and the Dutch retail prices of energy. The average electricity retail prices of the three largest energy suppliers of the Netherlands (Essent, Nuon & Eneco) are used in this research, based on the pricing level of the 1st of January 2019. Off peak energy prices differ from peak prices. In the largest part of the Netherlands, the off peak period is from 23.00 to 7.00 (Pricewise.nl, 2019). While 8 of the 24 hours (33%) per day lie in the off-peak period, due to the difference in price, household tends to use the electricity more during off-peak hours. As a result, A 50/50% division between peak and off-peak retail prices is assumed. This is in line with graduation company's calculation methods. For the feed-in tariff of solar panel energy, the peak price level is selected as the panels only generate energy during the day. Table 10 summarized these findings.

Table 10. Research specific energy prices.

Energy source		Retail price, price level 2019			division	research price level	
Gas						€	0,750
Electricity	demand	peak	€	0,231	50%	€	0,222
		off-peak	€	0,214	50%		
	supply	peak	€	-0,073	100%	€	-0,073
		off-peak	€	-0,059	0%		

When becoming gas free, the contract with the gas supplier can be stopped. Besides the operational cost of the natural gas, the network costs and fixed charges can be eliminated, representation respectively a cost of €175 and €35 per year based on the same three Dutch energy suppliers. As household already have an electricity supplier, fixed costs of the electricity are not increased.

2.5.3 Benefits

Besides the operational costs difference resulting in economic benefits, the transition process also adds value to the dwelling in form of a price premium. However, the cost of improving the energy performance of a dwelling does not (proportionally) increase the value of the dwelling (Visscher, 2017). In this field of research, the first paper to use empirically data on the capitalization of thermal efficiency in residential dwelling, Brounen and Kok (2011) found that Dutch homebuyers are willing to pay a premium for homes that have been labelled as more energy efficient. The results show that this price premium varies with the energy label category of the energy performance certificate. Quantified findings illustrate that A-labelled homes transact at a price premium of 10,2% as compared to similar homes with the intermediate D-label, and dwellings with a G-label transact at a discount of some 5%. The study of Fuerst et al. (2016), which invested whether energy efficiency ratings are able to create additional incentives to invest in energy efficient housing in Finland, found that there is a price premium of 3,3% for the most energy efficient class of building. However, the market does not seem to differentiate between low and medium rated units. Similar research performed in the U.S. conclude that homes with a green certification programme demonstrate a sale price primum of 11,7% (Zhang, Li, Stephenson, & Ashuri, 2018).

It becomes evident that the indirect benefits of the improved energy performance increase the dwelling value, in the form of a price premium percentage related to the property value. To stay within a safety margin, and not develop optimistic scenarios, the average of the found studies (8,4%) is reduced to 5%, which is used as a premium for dwellings that upgrade to energy label A and B. With the beforementioned average Dutch square meter price of €2.666 and the average dwelling sized from the target groups based on AgentschapNL (2011), dwelling type related price premiums are determined and illustrated in Table 11. Based on the findings of Brounen and Kok (2011), this research furthermore assumes that dwelling belonging to energy label C and D have a 50% price premium, compared to the lower energy labels.

Table 11. Price premiums of different target groups

	Detached			Semi-detached			Terraced		
construction period	target group	Energy label (AgentschapNL, 2011)	premium price increase (absolut)	Target group	Energy label (AgentschapNL, 2011)	premium price increase (absolut)	Target group	Energy label (AgentschapNL, 2011)	premium price increase (absolut)
<1945							13	G	€ 14.130
<1964	1	G	€ 20.928	7	F	€ 16.663	14	F	€ 14.130
1965-1974	2	F	€ 20.928	8	E	€ 16.663	15	E	€ 14.130
1975-1991	3	D	€ 10.464	9	C	€ 8.331	16	D	€ 7.065
1992-2005	4	B	€ 0	10	B	€ 0	17	C	€ 7.065
2006-2011	5	A	€ 0	11	A	€ 0	18	A	€ 0
2012-2017	6	A	€ 0	12	A	€ 0	19	A	€ 0

It is assumed that the premium price increase is only provided on the insulation and ventilation upgrades, as they have a longer lifespan than the 15 years of the heat pumps. With these measures an energy label A or B is furthermore achieved. There is a lack of research on the price premium beyond this level. As a result, other initial costs, e.g. heat pumps and solar panels, are not compensated by this price premium, however they will result in benefits through lower operational costs. Subsequently, the absolute price premium cannot be larger than the initial costs of insulation and ventilation. If this for example accounts for €10.000, the premium price increase is equal to this increase. If the total initial cost of insulation and ventilation surpluses the premium price increase, for example €30.000, then the maximum price increase is determined by the presented value in table 13.

Summarized, after the direct initial costs of different building and service features have been established in the previous section, this section examined the indirect initial cost due to spatial requirements of the transition process. It furthermore explored the operational costs, where the difference between the current and future situation results in the first benefits aspect. Finally, the second economic benefit concept is added, by evaluating the price premium of energy efficient buildings. The found quantified data presented in Table 10 and 11, combined with the initial costs presented in section 2.5, functions as input for the transition tool that will be introduced in section 3.4.

2.6 BUSINESS CASE

With the presented insight in the cost and benefits of the transition process, the different business cases are introduced. This section functions as the literature review input for sub question four. As stated in the introduction, this study will focus on two business case principles: economic and financial. Both are separately discussed below.

2.6.1 Economic feasibility

Previous feasibility studies have based their conclusions on the economic feasibility of the energy transition in the residential sector (EIB, 2018; Ritzen et al., 2016; T. Dijkmans, 2011; Valk, 2018). Economic feasibility is defined by the Cambridge Business Dictionary as the "*the degree to which the economic advantages of something to be made, done, or achieved are greater than the economic costs*". In analysing this definition, three concepts are translated towards the research scope. First of all, economic advantages present itself it twofold: the decrease in operational costs and increase in property value. Secondly, the economic costs are represented by the initial costs of the transition process. The third step is to analyse the "*… are greater than… "*definition. Relating this to the research focus of owner-occupied dwellings, the payback period of the transition process should be less than the period the homeowner will remain the owner-occupier. If this is the case, then the economic advantage will be greater than the economic costs, resulting in an economic feasibly transition process.

Since the second half of the nineties the Dutch moving mobility rate, which represents the moved persons per year, decreased from 12% is 1995 to 8% in 2014 (PBL, 2014). This represents an average moving cycle of 12,5 year. However younger people tend to move more frequently than older people (CBS, 2014). When the research user groups are evaluated, working couples' tent to move once every 10 years, families once every 16 years and elderly once every 20 years (PBL, 2014). While cycle movement from real estate prices influence the average moving cycle (CBS, 2014), they are excluded from this research as it hard to predict this factor. Therefore, the study is isolated from the contextual effects. The found moving cycles of each target group functions as the input value for the economic feasibility.

If the payback period is less than the found moving cycles, it makes sense to invest in the transition process from an purely economic perspective. From the homeowners perspective the economic gain between moving cycle and payback period should be substantial, to outperform factors like the time-consuming process and laborious activities that come along with the transition process. If the difference between the payback period and moving cycle is two months, one could argue that it is not worth doing, as the gains do not outperform the efforts and economic motivation is lacking. As a result, this research argues that the different between payback period and moving cycle should be equal or higher than one year, for economic feasibility to occur. The following economic feasibility definition is maintained:

$$Economic\ feasilbility = \frac{intial\ cost - price\ premium}{\Delta\ operational\ costs} < \ (moving\ cycle - 1\ year)$$

The delta operational cost is annual indexed by 1,3%, representing the average Dutch Consumer Price Index (CPI) of the last 10 years.

2.6.2 Financial feasibility

While many studies have based their conclusions are economic feasibility (EIB, 2018; Kieft, 2015; Valk, 2018), no studies have been found that base their conclusions on the financial feasibility regarding the energy transition in privately owned dwellings. The term financial feasibility in this research refers to the servitization model. As introduced on in section 1.1, this aims to see products as service following, where the object of sale in the performance and not the product itself (Stahel, 2008).

While the concept of servitization was introduced in businesses three decades ago (Vandermerwe & Rada, 1988), it was only recognized as a trend in different Dutch sectors in 2016 by the ABN AMRO (Kemps, 2016). It seems that both market parties and consumers where not considering the servitization model to be applicable in different sectors. Service-oriented business model gained traction in both the industry and society. Building of the idea of circular economies, the Façade Research Group of the TU Delft Faculty of Architecture and the Built Environment is recently established (2016) that studies the possibilities to apply the servitization model to building facades. Moreover, a societal trend is emerging in which consumers do not own products, but only pay for the performance. Consumers are introduced to new successful lease concepts for furniture (IKEA), bicycles (Swapfiets) and even art (State of Art). Price-premiums are payed to unburden and guaranty performance.

As a result of these current conditions, practice only recently applied the servitization concepts to the gas-free transition. While not substantiated, the relatively low interest rate of current conditions could furthermore be a supporting factor. When reviewing this model, it sets out to unburden the homeowners in the transition process and provides information to come to a well-considered decision. As earlier mentioned, this is one of the main barriers of the energy transition. Translating the servitization model to this research scope, homeowners do not own the energy transition related product, but acquire the performances they offer. The investment in a heat pump, heating distribution system and solar panels is translated into one performance agreement: a comfortable indoor climate (in an energy efficient way without using gas). The graduation company THE FCTR E, is the first service supplier which offers this performance agreement.

The service supplier acquires capital to invest in these transition process measures and becomes the owner. Homeowners sign a lease contract, in which the performance agreement is integrated. While the specifications of the lease contract can very, this research follows the graduation companies' contract. A leasing contract is signed for 15 years, but can be stopped each year, resulting in de-installation costs of approximately €1.500 (F. Verhoef, 2018). Ownership will remain at the service supplier after the 15 years, when the situation will be revaluated based on the performance and if necessary upgrades will be obtained. A (Dutch) copy of the terms and conditions can be found online at https://www.thefctre.com/nl/.

A condition of objects integrated in the servitization is that they must be retainable. Insulation measures stays with the home, while services do not stay with the home. As a result, the insulation measures are excluded from the leasing costs. These measures are integrated in the financial feasibility calculations through the increased property value.

Homeowners advantages

With the servitization model, homeowners are able to act in the energy transition without having to invest a relatively high sum of initial capital. This investment is one of the main barriers for homeowners to sustain their homes is expensive (Vermeij, 2018). With initial costs varying between 15.000 and 30.000 euros, this represents a substantial amount. A recent report of the Rabobank concerning the capital savings of Dutch citizens, found that the median savings per person is €10.600 (Prins, 2018). With two adults for each user group, this translates to a combined savings of €21.200. It is furthermore questioned if it desired to invest such a quantity of personal savings with a timeframe of for example 10 years. Though the leasing contract, households can obtain the operational decrease benefits, without having to invest. A second advantage of the leasing model is that while the economic feasibility is depended on the expected occupants moving cycle, financial feasibility is not. An occupier could decide to move within one year, of stay the dwelling for another 40 years; the leasing costs remain constant. This could be a large incentive for homeowners with uncertainty concerning their future moving plans. Additionally, the service provider unburdens the homeowners process towards the actual transition in assessing the correct measures based on the homeowner's situation and is accountable for the service, monitoring and maintenance of the products.

Leasing costs

These advantages, naturally, come at a price. The service supplier is a commercial company which need to obtain a healthy business case to offer the service. From the homeowner's perspective, the advantages are translated in the annual leasing costs, replacing the initial costs. Therefore, the leasing costs are accessed, expressed in the annual percentage of the initial costs. To do so, the following section reasons from the perspective of the service supplier.

First of all, capital has to be attracted to purchase the products, over which interest has to be paid. As seen in other leasing sectors, the interest rate is seen as a large influence on the leasing costs. It is for this reason, that e.g. car leasing companies are often owned by banks; they can provide capital at low interest rates. The interest rate is primary related to the perceived risk of the investment. Due to the high political and social pressure, the large potential market of 4,3 million privately owned dwellings (CBS, 2016) in the Netherlands alone and usage of high quality services (Verhoef, 2018), the graduation company has achieved to convince investors to provide capital at an interest rate of 5%. At the moment of writing, conversations with large institutional investors, such as pension funds, are taken place. The goal is to reduce the perceived risk even further and attract capital at an interest rate of 3%, commonly charged by institutional investors. While supported by governmental parties, it is uncertain if this level of interest rate is achieved. For this reason, a 5% interest rate is assumed during the calculations.

Second only, the depreciation period has to be determined. Again, following the graduation company's information, a depreciation period of 15 years is selected. If other products are selected, this period might vary and the price-quality ratio comes into play. As the price level of the graduation companies' products are selected as input values, the belonging depreciation period is used to remain consistent. It is noted that other studies use different life spans. The study of Latorre-Biel et al. (2018) for examples uses a 'conservative estimation' of the life span of an Air Source Heat Pump of 10 years.

Based on the annuity method, different depreciation periods and interest rates result in different annual leasing costs as a percentage of the initial costs, which are presented in Table 12. This illustrates different scenarios and provides a bandwidth of annual leasing's costs. The selected combination of a deprecation period of 15 years and an interest rate of 5% results in an annual leasing costs of 9,5% of the initial costs.

From the perspective of the service supplier, an annual leasing income of 9,5% of initial costs, results in a payback period of 10,5 years (100%/9,5%=10,5 year). With the depreciation period of 15 years, the service supplier gains benefit in the remaining 4,5 years that have to account for the company's expenditures and profits. This is considered to be a healthy business case.

Table 12. Annual leasing costs as a percentage of initial costs, based on interest & profit rate and depreciation period

		Depreciation period			
		10 years	15 years	20 years	25 years
Interest rate	3%	11,6%	8,3%	6,7%	5,7%
	4%	12,2%	8,9%	7,3%	6,3%
	5%	12,7%	9,5%	7,9%	7,0%
	6%	13,3%	10,1%	8,6%	7,7%
	7%	13,9%	10,8%	9,3%	8,4%

When the decreased operational costs decrease outperforms the leasing costs, a financially feasible business case is presented for homeowners. In this case, costs neutrality is achieved, a key focus point in political discussions regarding the gas-free transition (RutteIII, 2017). This result in the following equation, where as a negative percentage indicates the decrease in total annual costs, and a positive percentage indicates an increase in total annual operational costs.

$$Financial\ feasilbility\ = \frac{Leasing\ costs}{\Delta\ operational\ costs}\ <\ 100\%$$

Both the leasing costs and the operational cost are annual indexed by 1,3%, representing the average Dutch Consumer Price Index (CPI) of the last 10 years. In this equation, insulations costs are considered to affect the price premium and therefore cancel each other out. In most cases, the price premium will be higher than the initial costs of insulation. It is however expected that is some cases, this assumption causes difficulties. For example, badly insulated dwellings might require a larger investment than the price premium, which currently will be excluded from the financial feasibility business case. The effect of this observation has to be quantified during the calculations and evaluated on its influence on financial feasibility.

2.7 SUMMARY

Chapter 2 elaborates on the theoretical underpinnings of this research. This research is scoped to the existing privately-owned housing stock to become gas-free by targeting the energy used for space heating and domestic hot water. A four-step research strategy is formulated, covering the building, service and user domains, to achieve the research objective.

Section 2.1 elaborates on the variables of the different domains influencing the transition process. Figure 4 presents an overview of the main significant variables, divided within the building, service and user domain.

Section 2.2 elaborates on the current situation. Aiming to have a large impact on the national energy transition within the time limitations of this research, 19 target groups are selected to represent the private housing stock. Combined they represent 58% of the total Dutch housing stock, using 60% of the housing's stocks primary energy. Three different user groups are formulated to represent the human factors: working couple, family and elderly. It is assumed that the current heating services of the targeted housing are powered by natural-gas. Thereby, the starting point of the transition process is illustrated.

Section 2.3 elaborates on the future expected, gas-free situation. The literature review illustrates that the air source heat pump is the service that is most coherent to the research strategy to improve the energy efficiency and become gas-free. A lack of knowledge is identified in the cost-benefits effect of three different types of air-source heat pumps: low, medium or high temperature. The resulting effects on the building, service and user domains are assessed. To predate new legislation, the EPG method is included with the BENG indicators to calculate the heating demand.

Section 2.4 elaborates on the transition process for dwellings to become gas-free. Figure 9 presents a conceptual model which functions as the basis for the transition tool. Different input values, features, relations, functions and output values have been quantified for the research variables of both the energy demand and energy supply circuit. Among other things, the analysis shows a techno-economic analysis of optimum insulation packages to acquire certain heating demand levels thereby quantifying the efficiency gap concerning insulation measures. It is furthermore stated which heat pump are applied at which dwelling specifications. By assessing their SCOP, the bandwidth of annual costs difference between gas and electricity is identified. In addition, the effect of solar panels on the gas-free transition process using all electric heat pumps has been researched, stressing the added value of a combined system on the transition feasibility.

Section 2.5 elaborates on the techno-economic input value for the transition processes. Technical feasibility is only applicable at the implementation of solar panels related to the minimal usable roof surface. Other features do not offer any technical constrains. The costs and benefits of the transition process are identified. Costs consist out of initial costs, operational costs, while benefits are experienced in the form of a price premium. Based on empirical research, it is assumed that a 5% house value increase is experienced with an increase in energy performance which is presented in Table 11.

Section 2.6 elaborates on two business case principles. The economic feasibility is assessed by the difference between the payback period and expected moving cycle. If homeowners are able to payback their investment within 1 year of the moving cycle, the transition process is perceived as economically feasible as they are engages to enter go through the process by substantial benefits. The financial feasibility, yet unresearched in the field on the gas-free transition process, is added to represent the servitization model. A financially feasible package is established if the leasing costs are less than the difference in operational costs.

CHAPTER 3. METHODOLOGY

This chapter elaborates on the methodology of this research. Section 3.1 elaborates on the research design, where after the second section elaborates on the deployed methods to obtain the research objectives. Section 3.3 elaborates on the data collected data within this research. Section 3.4 elaborates on the workings of the transition tool and provides the basis for the quantitative analysis in chapter four and five. Section 3.5 provides a summary of this chapter.

3.1 RESEARCH DESIGN

This research deploys a quantitative research strategy throughout the process. This research uses both the deductive and inductive approach. A deductive approach is applied in the development of the transition tool. This approach is coherent with the feasibility nature of this thesis. The indicative approach is applied by the introduction of the servitization model, exploring this concept from a yet unresearched perspective.

The main aim of this research is to analyse the feasibility of privately-owned dwellings to become gas-free. Research objectives are formulated to provide a strategy to reach the aim of the research. After the first objective was achieved by the literature review, the second objective of this research is to develop optimum individual homeowners focused transition packages. Subsequently, the third objective translate these packages toward the housing stock level and assess the housing stock feasibility rate of both economic and financial feasibility.

To guide this research, the following six research steps are formulated:

1. Define the problem field by evaluating the current context of this field of study and to identify the gap in literature.
2. Analyse the transition process of existing privately-owned dwellings to become gas-free.
3. Develop a transition tool based on the found theoretical underpinnings which is able to produce individual homeowners transition packages.
4. Validate the transition tool through case studies.
5. Produce outcomes which are able to obtain the main objectives.
6. Evaluate the outcomes of the transition tool.

Table 13 presents how the research steps are connected to the different chapters, objectives and questions. Furthermore, the different methods used at each research step is showed. The following section elaborates on each method in more detail.

Table 13. Connection between research chapter, objective, steps, questions and methods.

Chapter	Objective	Research step	Related research question	Method
Chapter 1. Introduction		Step 1. Define the problem field.		Literature review
Chapter 2. Literature review	1. Conceptualize the transition process	Step 2. Analyse the transition process of existing privately owned dwellings.	1. What type of dwellings are included in the private housing stock? 2. What type of services are able to provide a gas-free home? 3. What process are currently available for homeowners to become gas-free?	Literature review
Chapter 3. Methodology		Step 3. Develop the transition tool.		Transition tool
Chapter 4. Case study + Chapter 5. Findings	2. Formulate transition packages 3. Assess housing stock transition feasibility rate	Step 4. Validate the transition tool Step 5. Produce outcomes	4. How can these processes be considered feasible for homeowners?	Transition tool Case study
Chapter 6. Discussion + Chapter 7. Conclusion		Step 6. Evaluate outcomes of the tool.	Main research question: What does the energy transition mean for the private housing stock to become gas-free?	Quantitative outcomes

3.2 METHOD

This section elaborates on the methods deployed within this research, as illustrated in the right column of Table 13. The literature review is performed in the second chapter and does not require more specification. Hence, the transition tool is explored followed by the case study method.

Transition tool
The main method of this research is the deployment of a transition tool that is capable to combine the findings of the literature review and produce outcomes regarding the feasibility of the transition process for different building, user and service variables. The transition tool consists out of two components. Firstly, a Building Performance Simulation (BPS) model is developed. This model produced energetic performance predications regarding energy demand and supply for different building, user and service domain variables. As before mentioned, this thesis focusses on the space heating and DHW energy consumption. The BPS component is able to quantify the effect of different variable features on the energy demand regarding these focus points. Secondly, a feasibility analysis is added. This second component translates the energetic performance and variable features changes into costs and benefits. The relation between the costs and benefits expressed in both economic and financial feasibility, giving insights in the effect of servitization. Hence, the transition tool is able to produce homeowners focused transition packages that can be translated towards a housing stock feasibility overview. The operational details of the transition tool are elaborated on in section 3.4.

Case study
The final method deployed in this research is a case study to gain empirical knowledge and validate the transition tool outcomes. The framework of Yin (2009) is selected to function as a guideline. The case study is performed through a quantitative approach, corresponding to the quantitative nature of the transition tool. After insights from transition processes in practice are incorporated, the transition tool is validated and able to develop the desired output values. The case study is presented in the fourth chapter.

3.3 DATA COLLECTION

This section elaborates on the collected data within this research. It elaborates on the different data sources used in the transition tool and the sample collection of the case study.

Transition tool
Data collected in section 2.2, 2.3 and 2.4 functions as the input values for the BPS component of the transition tool. While this component consists out of a number of sources, the data set of AgentschapNL (2011) accounts for a relatively large share. Mainly the current situation concerning the building and service domain are based on this data set. AgentschapNL is part of the Dutch Ministry of Economic Affairs, Agriculture and Innovation. The data set adheres to a recurring national assessment of the Dutch housing stock and is considered a reliable source of input.

Data collected in section 2.5 and 2.6 functions as the input value for the feasibility component of the transition tool. Again, while data origins from multiple sources, one large data source is identified. The graduation company's pricing levels have been used to determine the initial costs of the heating system, solar panels and heating distribution method. Efficiency rates of corresponding products have been used to maintain consistency in the price-quality ratio. Section 3.4.2 elaborates on the data collection of the transition tool from both the BPS and feasibility component in more detail.

Case study
Access to cases in which similar transition processes took place are provided by the graduation company THE FCTR E. Quantitative data is collected from both the homeowners and the monitoring system of THE FCTR E. Chapter four analyses the data used in the case studies in more detail.

3.4 TRANSITION TOOL

This section elaborates on how the tool operates by formulating a roadmap, followed by an overview of the input variables and their sources. Finally, it illustrates how output values are produced and how they are used to develop the transition packages.

3.4.1 ROAD MAP

The goal of the transition tool is to obtain quantified insights in both energetic and economic outputs of the transition process. The different steps taken in the transition tool are analytically discussed in the form of a road map. It follows the feature-relation-function structure of the conceptual model as presented in Figure 9.

INPUT

1. **Select target group**
   By selecting one of the 19 target groups, the constant building input features are presented: (B1) housing type, (B2) housing size and (B5) roof area.
2. **Select user group**
   One of the four user groups is selected: either average, working couple, family or elderly. As a result, the (U1) number of occupants and (U2) average indoor temperature is provided
   - *The combination of 19 target groups and 4 user groups result in 76 scenarios. The found combination of variables B1, B2, B5, U1 and U2 are unique for every scenario. Once set, they will not change in the transition process. The next step is to assign a service system to the 76 scenarios.*
3. **Select service alternative**
   The current gas-powered situation or the gas-free service alternative A, B or C can be selected. As a result, input value regarding the building insulation (B3), ventilation method (B4), heating distribution method heating system (S1) and solar panels (S3) will be provided.
   - *By adding the four service alternatives, the different between the alternatives of each of 76 target-user group scenarios can be examined. As a result, 304 scenarios are formulated.*
   - *Once the three domain variables have been selected, the different relations between the features are presented. The energy demand circuit, explained in section 2.4.1, and energy supply circuit, explained in section 2.4.2, is followed to determine the value of the different relations.*
   - *The optimal costs-benefit insulation step of Figure 13 is found using goal seek within the heating demand bandwidth of each alternative explained on page 23.*

FUNCTION

4. **Energetic functions**
   Based on the relations, the energetic performance of each scenarios is calculated. The energy demand circuit is divided into space heating and DWH demand, while the energy supply circuit includes the solar energy supply. Combined they result in the total primary energy demand. Dependent on the service system, this is expressed in gas or electricity consumption per year.

5. **EPG measurement**
   The three BENG measurements can be calculated based on the different energetic functions following Figure 7. Thereby, results are translated to generate insight for future legislation.

OUTPUT

6. **Initial costs**
   Based on the found values of step 3, initial costs present itself at the variable features that are changed in the transition process.
   - *The combination of the different initial costs is selected based on the optimal costs-benefit result. As a result, the homeowners focussed transition packages can be formulated based on the initial costs measures.*
   - *The initial costs function as the first input value for both the economic and financial feasibility assessment.*
7. **Operational costs**
   The retail prices of energy multiplied with the energetic performance results of step 4. The self-sufficiency rates of solar energy are included in the energy supply calculations regarding the operational costs.
   - *The operation costs function as the second input value for both the economic and financial feasibility assessment.*
8. **Feasibility**
   The price premium effect is added to the initial costs and operational cost to result in the economic feasibility. The annual leasing percentages replaces the initial cost component to result in the financial feasibility.

As outcomes are based on calculations, the tool is developed in Excel. The transition tools dashboard visualized the different steps and follows the conceptual model in Figure 11, of which two example calculations are presented in Figure 18 and 20. The first example represent target group 1 with an average user group and service alternative A. The second example represent target group 17 with the family user group and service alternative B.

Figure 18. Example 1. Dashboard overview of target group 1, average user group with service alternative A

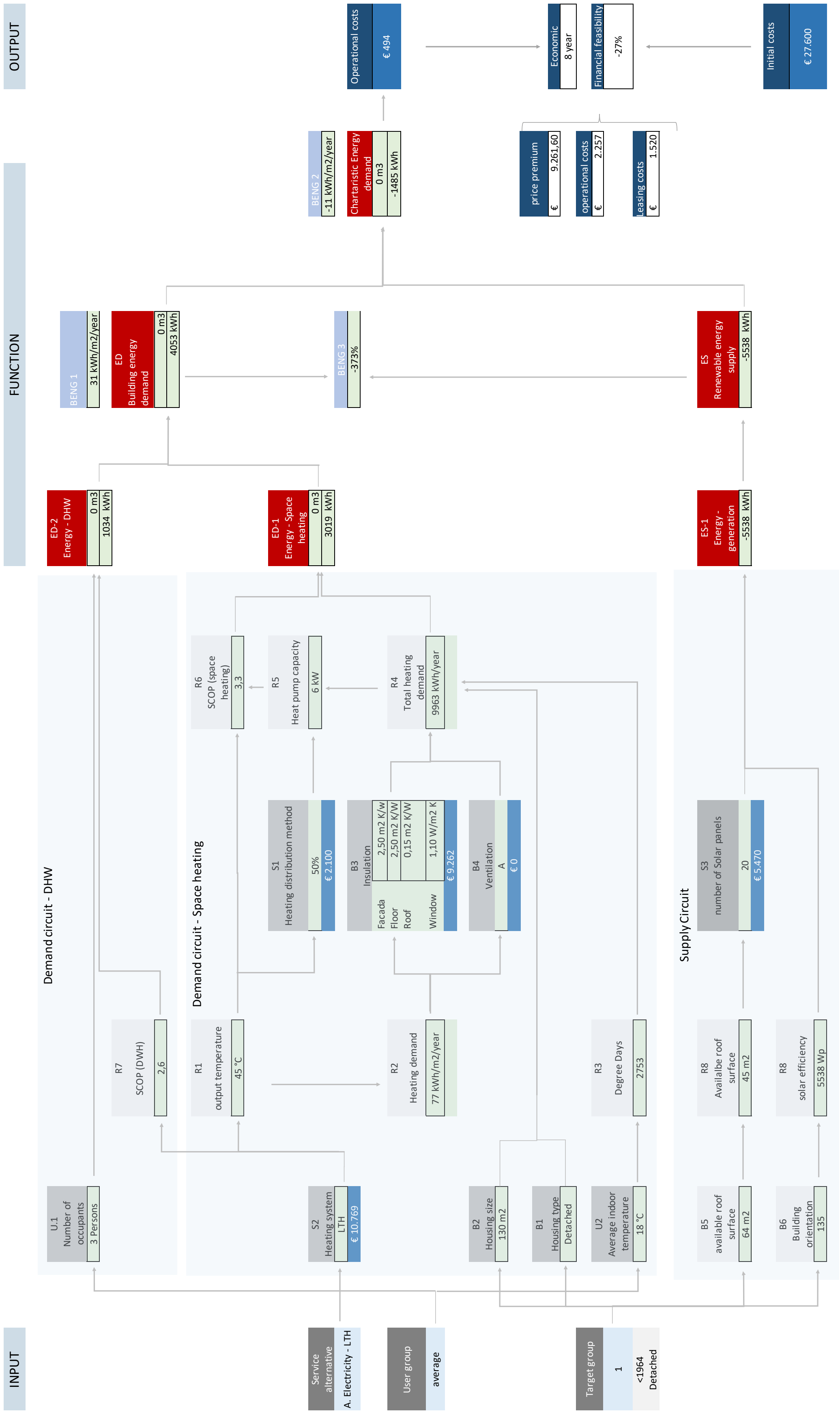
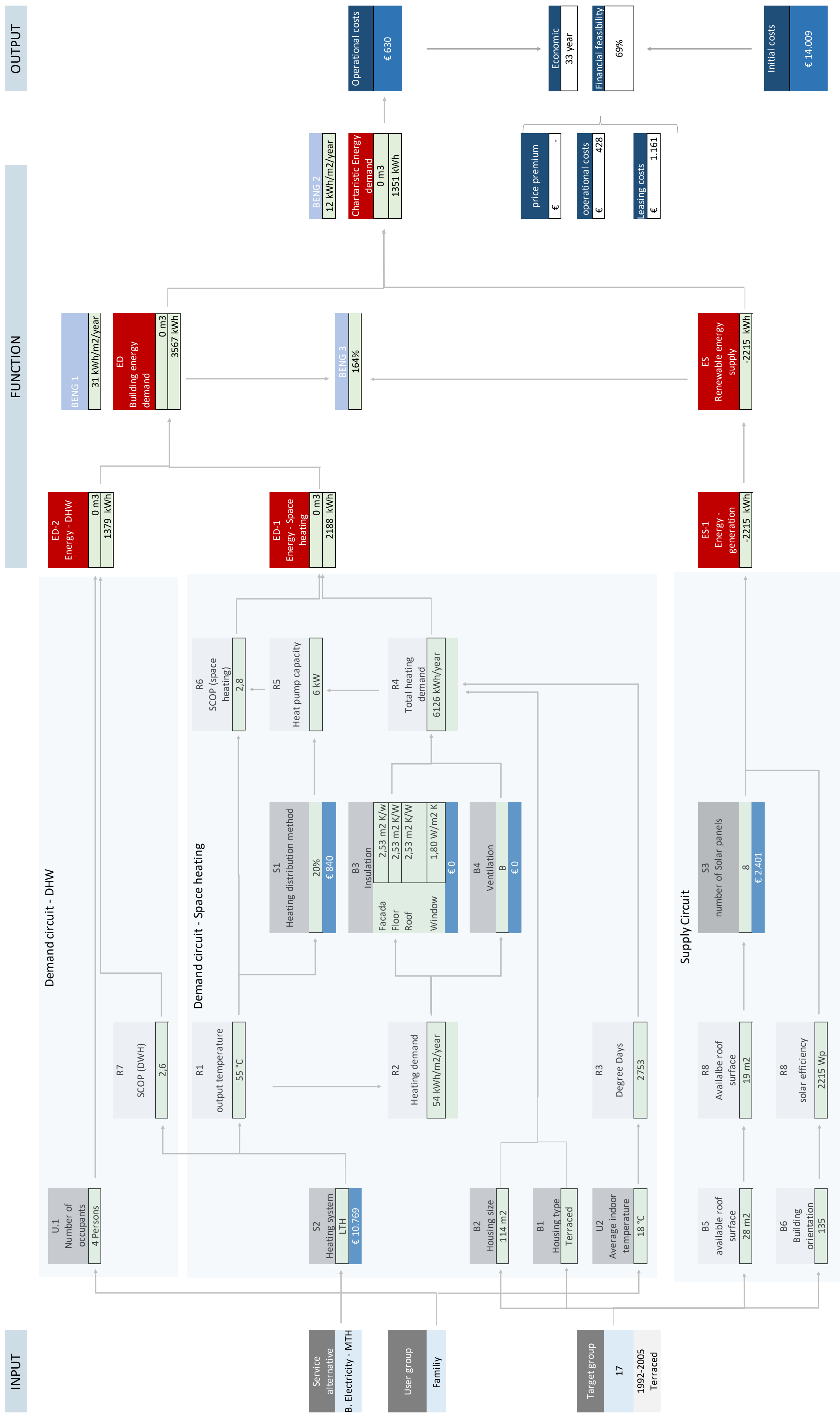


Figure 19. Example 2. Dashboard overview of target group 17, family user group with service alternative B



3.4.2 INPUT VALUES

To give insight where the input values or the transition tool is based on, an overview is created stating the sources of the value following the seven steps of the road map. At each feature, relations of function, either a table, figure, appendix or page is stated on which the input data is explained. References are found in the belonging sources.

Step 1+2. Constant features input value	Source:
B1. Building type	Table 2
B2. Building size	Table 2
B5. Roof area	Table 2
U1. Number of occupants	Table 4
U2. Average indoor temperature	Table 4

Step 3. Relations and variable features input value, in followed sequence	
R1. Output temperature.	Explained on page 22
S1. Heating distribution method	Explained on page 22
R2. Heating demand	Explained on page 23
R2. Degree days	Table 4, explained on page 23
R4. Total heating demand	Explained on page 25
B3 + B4. Insulation and ventilation	Techno-economic analysis on page 23 to 35
R5. Heat pump capacity	Table 7
R6. SCOP space heating	Table 8
R7. SCOP DHW	Table 8
R8. Available roof surface	Page 28/29
S3. Number of solar panels	Page 29
R9. Solar efficiency	Page 29, Appendix 4

Step 4. Initial costs	
S1. Heating distribution method	Page 22
B3. Insulation	Figure 11
B4. Ventilation.	Figure 11
R5. Heat pump	Appendix 6
S3. Number of solar panels	Appendix 7

Step 5. Energy functions	
ED1. Energy demand - space heating	Result of R6 and R4
ED2. Energy demand - DHW	Result of U1 and R7
ES1. Energy supply – solar panels	Result of S3 and R8
ES2. Energy supply – BESS	Result of S4
Total primary energy demand	ED1 + ED2 + ES1 + ES2

Step 6. Measurement functions	
EPG	Figure 7

Step 7. Operational costs	
Retail prices	Table 10

Step 8. Feasibility	
Economic feasibility	Section 2.7.1
Financial feasibility	Section 2.7.2

3.2.3 OUTPUT VALUES

The goal of the transition tool is to obtain the following two objectives: (1) to produce optimum packages for homeowners to enter the gas-free transition and (2) to assess housing stock feasibility. Table 14 illustrates the most relevant output values of target group 1 with an average user group. This scheme can be formulated for each of the 76 scenarios representing the different housing and user groups. A more detailed overview is presented in Appendix 9.

Table 14. Transition tool outputs - Target group 1 and average user group.

Scenariosamenvatting		Detached	<1964	130 m2	
		1GAS	1A	1B	1C
	construction_period	<1964	<1964	<1964	<1964
	Housing_type	Detached	Detached	Detached	Detached
	Surface	130 m2	130 m2	130 m2	130 m2
User	**User_group**	average	average	average	average
service	**Convective_heating_method**	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
insulation result	**minimal_heating_demand**	166	61	106	166
Energetic performance	**Tot_gas_consumption**	2749 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-2084 kWh	434 kWh	3811 kWh
	BENG_1	186	27	46	72
	BENG_2	186	-16	3	29
	BENG_3	0%	-266%	1275%	145%
Costs	**Tot_operational_costs**	€ 2.298	€ 361	€ 921	€ 1.671
	Initial_costs_insulation	€ -	€ 9.261,60	€ 2.604,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,52)	€ 1.936,16	€ 1.376,71	€ 626,57
	Initial_costs	€ -	€ 27.599,75	€ 20.867,49	€ 22.896,52
	housing_value_increase	€ -	€ 9.261,60	€ -	€ -
Average user group	**pay_back_period**	0 year	9 year	15 year	37 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43
	Annual_cost_in_decrease	0%	-18%	6%	55%

The transition tool produces outcomes for homeowners of one of the 76 current scenarios, presenting quantified insights in the energetic performance and belonging initial and operational costs of three alternatives to become gas-free. The most favourable service alternative showcases if and how the owner-occupiers can enter the gas free transition process. Homeowners focussed packages can be derived from the scenario's, which state until what level insulation measures have to applied, which type of heat pump should be installed and how many solar panels can be fitted on the roof, to achieve this optimal gas-free result.

As service alternative A provides the most favourable business case in the example in table 14, the optimum homeowners transition package is based on this alternative. An example of a homeowner's transition package is presented in Appendix 16.

The payback period is used in the economic feasibility determination, where the green market value represents a viable business case and red market value a not viable business case. The same structure is used with the financial feasibility. Thereby the transition tool has the ability to achieve the two research objectives. First, the tool creates transition packages for homeowners that show if, and if so, how homeowners could enter the energy transition in an economic or financially feasible option. Second, the feasibility outcomes are translated toward the housing stock, quantifying which part is feasible with the proposed solutions.

3.4 SUMMARY

The aim of this research is to analyse the feasibility of privately-owned dwellings to become gas-free. Research objectives are formulated to provide a strategy to reach the aim of the research. Six research steps are presented in Table 14 guiding the research to obtain the objectives. It furthermore indicates which research question related to the different steps and illustrates the different methods used at each step.

The main method of this research is the development of a transition tool, which is empirically validates by case studies. The tool combines a Building Performance Simulation (BPS) with an economic analysis. The tool produces empirical results based on different building, user and service variables. It produces outcomes to achieve the two research objectives, first by creating transition packages for homeowners and secondly to relate both economic and financial feasibility to the housing stock level.

EMPIRICAL PART

CHAPTER 4. CASE STUDY

Case studies is used in this research to gain empirical knowledge. The goal is to validate the transition tool outcomes. The framework of Yin (2009) is selected to function as a guideline. Four steps are identified, starting with the boundaries which include the input data limitations, followed by the unit of analysis that include the data conversion. Subsequently, the data is linked to the proposition for each of the cases in section 1, 2 and 3. Finally, section 4 follows the final step of Yin (2009) by interpreting the findings is a cross case synthesis.

While terraced, semi-detached and terraced dwellings differentiate on for example heat loss facades, they generally don't illustrate large differences in their building, service and user's domain. The targeted housing stock is less or more uniform. Due to these similarities, individual case study findings can be translated toward the targeted private housing stock.

Boundaries
The first step is to define the boundaries (Yin, 2009). The case study involves Dutch privately-owned dwellings and is performed within a measurement period of the 4 to 5 months. The type of evidence that is collected origins from heat pump sensors. Therefore, case study results acquire insight in the heating demand circuit. Due to the lack of data on the supply demand circuit, this part is excluded from this validation step. However, solar panel data, as presented in the literature review, is extensive as they have been present in the Dutch residential sector for over a decade. Hence, the exclusion for solar panels is not considered to be a problem regarding the transition tool validation.

Due to the graduation internship at THE FCTR E, the cases are selected from their portfolio. This is done in twofold. First of all, the projects are selected based on the available data. To access this data, it is required that sensors have to be installed and linked to the monitoring system. As the company instalment history is relatively short, not every project meets this requirement. As a result, from the approximately 50 projects, 13 meet this requirement. Secondly, the data which is collected is examined on its accuracy and applicability for this research. Appendix 9 presents an overview of this step. To be considered useful for this research, the cases must (1) have a minimal measurement period of three months, (2) must include an air-source heat pump following this research scope, (3) present enough data to perform the case study allocated to certain field of the transition tool and (4) show realistic data

The main characteristics of the three cases regarding the target group, user group and service alternative are illustrated in Table 15. A complete overview of known data for each case is presented in the following sections. The cases represent three of the 19 different target groups, two of the four user groups and one of the three service alternatives. Result from these combinations are reflected towards conclusions regarding the absent target group, user groups and service alternative.

	CASE 1	CASE 2	CASE 3
Data period	4 months	5 months	4 months
Target group	Type 3	Type 17	Type 1
Construction period	1975-1991	1992-2005	<1965
Housing type	Detached	Terraced	Detached
Housing size	156 m2	198 m2	248 m2
User group	Elderly	Family	Family
# Occupants	2	5	4
Average indoor temp	20	21,5	20,5
Service alternative	A	A	A
Output temperature	35 °C	35 °C	41 °C
Heat pump capacity	12 kW	12 kW	20 kW

Table 15. Selected case study characteristics.

Input data limitations
As the proposed tool evaluates a transition, it is necessary to compare the old, gas-powered, situation with the new, all-electric, situation in the three cases. Data from the old utility bills is used as input for the old situation, whereas the heat pumps sensor generate input for the new situation. Unfortunately, information regarding any building upgrades (e.g. insulation and ventilation) between the old and new situation is not present. Furthermore, in case 2 and 3 it is not known which insulation and ventilation upgrades have been applied since the construction period. It is therefore assumed that these dwellings have not received upgraded on these domains since construction.

Moreover, the type of gas-powered boiler in the old/current situation is unknown. Following literature review findings, it is assumed that in each case the commonly used HR-107 boiler was used to generate heat, resulting in 0,9 SCOP for both space heating and DWH.

Another limitation to the input data is the combined SCOP of space heating and DWH, while the transition tool separated these two values. To solve this issue, it is assumed that the found input values for SCOP of DWH is accurate and set as a constant. With this assumption, the SCOP of space heating can be subtracted from the combined value. Due to the fact that the SCOP of DWH is only depended on one variable, the heat pump type, while the SCOP of space heating is a result of multiple other variables and service alternatives, it is not expected that this assumption result in inaccurate outcomes.

Unit of Analysis

Based on the case specific data overview, stated in appendix 11, this section assesses which unit of analysis the case study is able to validate. In the old/current situation, only the total energy demand (ED) is directly retrieved from the data. Therefore, this will function as the unit of analysis. Based on this value, it can be assessed if the combination of target group, user group and set service values presents a realistic gas consumption, used as a reference to calculate the difference in operational costs. For the new/future situation, more data points are available, which are visualized in Figure 20. Data that origins directly from the sensors is marked in green, while data that is indirectly derived is marked in blue. The indirect values of these relations and functions can however be included in the case study, as they rely on generally expected calculation methods. The grey marked boxes represent data parameters that are not known. As some features (U1, U2, S2, B1 and B2) function as input values, they are not considered as units of analysis. Indirect values that are a direct result of these features (R3 and R1) are not included either. As a result, the following eight units are validated: (S1) heating distribution system, (R2) heating demand, (R4), total heating demand, (R5), heat pump capacity, (R6) SCOP space heating and (R7) SCOP DWH. For each unit, both the current gas-powered situation and the future all-electric situation is assessed.

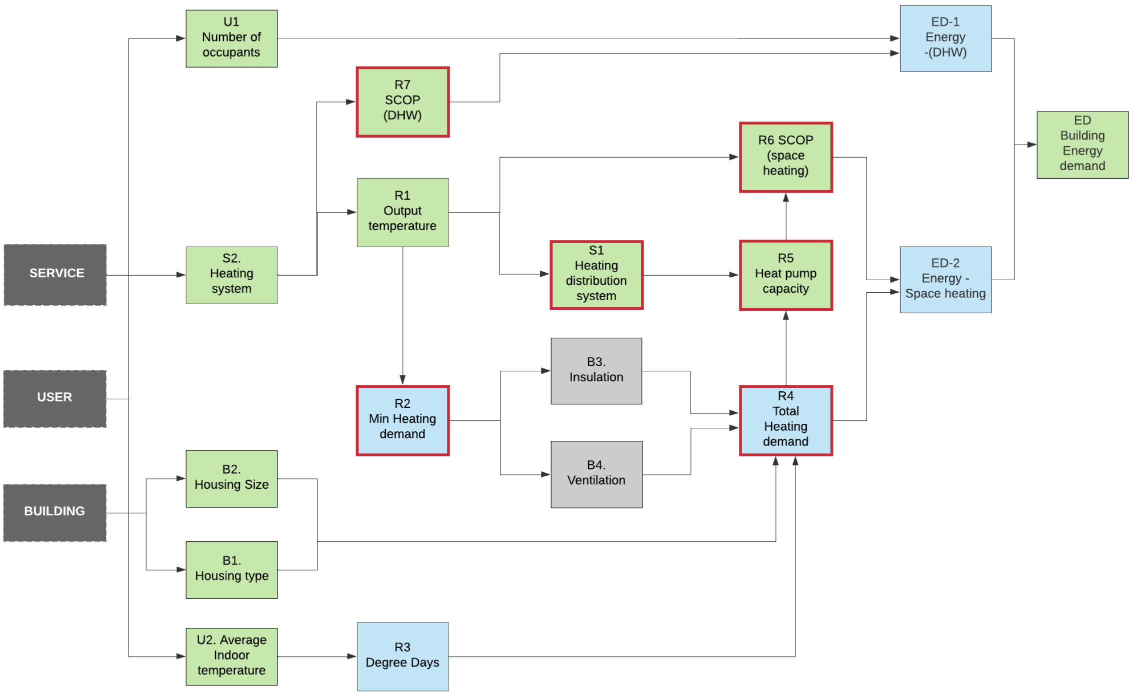


Figure 20. Case study input overview of new/future situation, where green represent direct values, blue represents indirect values, grey represents unknown values and red outlines boxes represent the units of analysis.

Data conversion

The first step is to adjust the input data of the transition tool concerning the target and user group to match the case study specifics presented in Table 15. By aligning these values, the results are based on the same input data and results can be compared. Secondly, the transition tool outcomes form both the current situation and service alternative A, as this alternative is used in the cases, are presented for each of the three cases. The outcomes are organized according to the found analysis units. Subsequently, the found input value of the three cases are placed in the same framework as the transition tool outcomes. Thirdly, the found data points are translated from the measurement periods to an annual period. This is done by using the average monthly gas consumptions of Dutch households stated by energiesite (2019). Appendix 12 illustrates these steps and concludes with the case specific annual energy demand and SCOP for both space heating and DWH. As a result, the deviation between the transition tool and the three cases can be examined, functioning as the quantified case study foundation on which conclusions are based.

Readers guide
At each case, first the input value adjustments of the transition tool are stated to match the case specifics. Secondly, the results of the case study are introduced for both the current and future situation. At each section, main deviations are examined and reasoning is provided.

4.1 Case 1

Case 1 is located in Amsterdam at the Johan Braakensiehof, and represents a detached dwelling build in 1960. However, due to an insulation upgrade executed 10 years ago, the dwelling is considered to have similar insulation characteristics as a dwelling constructed in the 1975 – 1991 period and is therefore perceived as a dwelling belonging to target group 3. The building deviation compared to the target groups specifics where minimal, the dwelling size had to be increased from 154 to 156 m2. The occupants are an elderly couple with an average indoor temperature of 20°C. The user group elderly allied exactly with the users of case 1 and did not require any change. Table 16Appendix 11 presents a more detailed overview of case 1 and presents analysis unit values of the transition tool and case study in both the old/current and new/future situation.

Figure 21. Case 1 - street view (source: maps.google.com) and top view (source: solarmonkey.nl)

Old situation
The results indicate a deviation of -11% regarding the total energy demand (ED) between the case and the transition tool. This account for a deviation of -6% in (total) heating demand (R2, R4). As both values are based on the same inputs, it is questioned why the deviation is not equal. Reasoning for this deviation could be found in the presents of underfloor heating, functioning as a more efficient heat admitter (see page 17) thus reducing the heating demand. Furthermore, a deviation in the level of thermal resistance in the building envelope could influence the heating demand.

Results current situation
It is assumed that between the old and the current situation, building upgrades are made concerning the insulation (B3) or ventilation (B4) due to the decrease in heating demand (R2) by 60 kWh/m2/year. The transition tool decreased the heating demand by 90 kWh/m2/year to meet the minimal requirement. A finding can be identified regarding this minimal required heating demand (R2): the heating demand of 103 kWh/m2/year provides enough thermal resistance for the heat pump to obtain the occupants set indoor temperature, even at lower output temperature than the proposed 45°C. This indicates a transition tool adjustment. Additionally, it can be stated that with a 50% convective and 50% radiative heating method (S1) operating at an output temperature (R1) of 35°C, enough heat is admitted to obtain the required indoor temperature. This indicates a second transition tool adjustment

The heat pump capacity (R5) is increased from a 6kW to a 12kW, which follows the increased heating demand. Based on this new input value, the transition tool would have selected the 12kW variant, validating this section. When assessing the space heating SCOP, a deviation of 39% is found. This is attributed to the effect of a lowered output temperature of 35°C, argued on page 27.

Finally, when evaluating the energy demand, the space heating energy demand (ED-1) is found to be 8% lower. Despite the increased heating demand, reasoning is found in the higher SCOP. The DWH energy demand (ED-2) is 69% higher in the dwelling case, while the SCOP only has a deviation of 10%. This implies that the occupant's energy demand is 1634 kWh/year per person, 85% higher than initially anticipated based on the literature review on page 29.

Table 16. Case study analysis of case 1

parameter	Specific parameter	code		Unit	MODEL		CASE 1		case 1	
							De Boer		Old/current deviation	New/future deviation:
Features - constant				target group	3		3			
construction					1975-1991		1975-1991			
Housing		B1		#	Detached		Detached			
Surface		B2		m2	156		156			
# layers		B5		#	2		2			
Roof orientation		B6		degrees	165		165			
				user group	Elderly		Elderly			
Number of		U1		#	2		2			
Average		U2		degrees C	20,0 °C		20,0 °C			
Features - variable				Service alternative	Gas- Current	A. Electricity - LTH	Gas-current	A. Electricity - LTH		
Insulation	facade	B3 .1	R-value	m2 K/w	1,3	2,5	1,3	?		
	Roof	B3 .2	R-value	m2 K/w	0,52	3,5	0,52	?		
	Ground Floor	B3 .3	R-value	m2 K/w	1,3	2,5	1,3	?		
	Glazing insulation	B3 .4	U-value	W/m2 K	2,9	1,1	2,9	?		
Ventilation		B4	method	A,B,C,D	A	A	A	?		
Analysis units										
Heating		S1 .1		% radiative	100%	30%	50%	50%	-50%	67%
		S1 .2		% convectice	0%	70%	50%	50%	50%	-29%
Relations										
output temperature		R1		degree C	65 °C	45 °C	65 °C	35 °C	0%	-22%
Heating demand		R2		kWh/m2/year	171	81	160	103	-6%	27%
Total heating demand		R4		kWh/year	26742	12663	25036	16069	-6%	27%
heat pumps capacity		R5	power	kW		6 kW		12 kW		100%
Efficiency - space heating		R6		SCOP	0,9	3,3	0,9	4,6	0%	39%
Efficiency - tap water heating		R7		SCOP	0,9	2,6	0,9	2,8	0%	10%
Functions - Energetic performance					1	2				
Gas	space heating	ED1-G		m3 gas/year	3040 m³		2845 m³		-11%	
	domestic hot water	ED2-G		m3 gas/year	162 m³					
Electricty	space heating	ED1-E		kWh/year		3811 kWh		3514 kWh		-8%
	domestic hot water	ED2-E		kWh/year		689 kWh		1167 kWh		69%

4.2 Case 2

Case 2 represents a terraced dwelling build in 2003 and is situated in Hilversum at the Kolhornse Weg. The second case requires more input values adjustment compared to the first case. First of all, the dwelling size is increased from 114 to 198 m2. Secondly, the user group variables are adjusted to 1 additional person resulting in 5 occupants and an increase in average indoor temperature from 18,3 to 21,5 °C. Table 17 presents a more detailed overview of case 2 and presents illustrates unit values of the transition tool and case study in both the old/current and new/future situation.

Figure 22. Case 2 - street view (source: maps.google.com) and top view (source: solarmonkey.nl)

Old situation
The results indicate a deviation of -14% in the total energy demand (ED) between the case and the transition tool. This account for a deviation of +3% in (total) heating demand (R2, R4). As both values are based on the same inputs, it is again questioned why the deviation is not equal. Based on the small heating demand deviations, it is assumed no insulation measures are taken after construction. Reasoning for this deviation could be found in the presents of underfloor heating, functioning as a more efficient heat admitter (see page 17) thus reducing the heating demand.

New situation
When evaluating the case study heating demand (R2) between the old and new situation, a decrease of 33% is found. Based on these findings, it is assumed building upgrades are made concerning the insulation (B3) or ventilation (B4). The 57 kWh/m2/year is below the set minimal requirement of 90 kWh/m2/year. Heat is admitted by convective heating (S2) in the whole dwelling, operating at 35°C output temperature (R1). This combination lies within the research margins to obtain enough heat to acquire the desired occupant's indoor climate. Hence, the results do not indicate transition tool adjustments.

While the heating demand is found to be positively correlated with the heat pump capacity, there is a negatively relations when comparing the transition tool and the case. This is attributed to the disparity between the research heating demand bandwidth on which the heat pump capacity is selected (8kW) and the case study heat pump (12kW). The fact that the dwelling is fully heating using convection amplifies this divergently. An explanation could be found that during the graduation internship, the researcher experienced clients who requested an oversized heat pump to encounter possible future building or user changes.

When assessing the space heating SCOP, a deviation of 11% is found which origins form the increased heat pump capacity. The case study SCOP equals the research input values for a 12kW heat pump operating at 45°C, while the dwelling has an output temperature of 35°C. The SCOP of case 2 is almost 20% lower than the SCOP of case 1, which operate with the same capacity and output temperature. This indicates that the average indoor temperature, which is 1.5°C higher in case 2 compared to the tool, is affecting this decrease. Section 2.3.1 acknowledges the influence of the indoor temperature on the SCOP, but due to the complexity scope of the transition tool is assumed to be constant based on an average indoor temperature of 18 °C.

Finally, when evaluating the energy demand, the space heating energy demand (ED-1) of case 2 is 40% lower compared to the transition tool outcomes. This is attributed to the 33% decrease of heating demand and 35% increase in SCOP. The DWH energy demand (ED-2) is equal between the tool and case study within a margin of 2%. However due to the 10% SCOP increase, the results indicate that the occupants demand is 944 kWh/year per person, 5% higher than initially anticipated based on the literature review on page 29.

Table 17. Case study analysis of case 2

parameter	Specific parameter	code		Unit	MODEL		CASE 2		case 2	
							Stasser			
Features - constant				target group	17		17			
construction					1992-2005		1992-2005			
Housing		B1		#	Terraced		Terraced			
Surface		B2		m2	198		198			
# layers		B5		#	2		3			
Roof orientation		B6		degrees	105		105			
				user group	Family		Family			
Number of		U1		#	5		5			
Average		U2		degrees C	21,5 °C		21,5 °C			
Features - variable				Service alternative	Gas- Current	A. Electricity - LTH	Gas- Current	A. Electricity - LTH		
Insulation	facade	B3 .1	R-value	m2 K/w	2,53	2,53	2,53	?		
	Roof	B3 .2	R-value	m2 K/w	2,53	2,53	2,53	?		
	Ground Floor	B3 .3	R-value	m2 K/w	2,53	2,53	2,53	?		
	Glazing insulation	B3 .4	U-value	W/m2 K	1,8	1,1	1,8	?		
Ventilation		B4	method	A,B,C,D	B	B	B	?		
Analysis units									Old/current deviation	New/future deviation:
Heating		S1 .1		% radiative	100%	30%	50%	0%	-50%	-100%
		S1 .2		% convectice	0%	70%	50%	100%	50%	43%
Relations										
output temperature		R1		degree C	65 °C	45 °C	65 °C	35 °C	0%	-22%
Heating demand		R2		kWh/m2/year	91	86	94	57	3%	-33%
Total heating demand		R4		kWh/year	18110	16957	18682	11288	3%	-33%
heat pumps capacity		R5	power	kW		8 kW		12 kW	0%	50%
Efficiency - space heating		R6		SCOP	0,9	3,4	0,9	3,8	0%	11%
Efficiency - tap water heating		R7		SCOP	0,9	2,6	0,9	2,8	0%	10%
Functions - Energetic performance					1	2				
Gas	space heating	ED1-G		m3 gas/year	2059 m³		2123 m³		-14%	
	domestic hot water	ED2-G		m3 gas/year	405 m³					
Electricty	space heating	ED1-E		kWh/year		4987 kWh		2996 kWh		-40%
	domestic hot water	ED2-E		kWh/year		1724 kWh		1687 kWh		-2%

4.3 Case 3

The third case represent a detached dwelling build in 1948 located in Laren on the Vinkebaan, comparable with target group 3. The transition tool dwelling size required an increase from 130 to 248 m2. As the roof is thatched, which has an R-value of approximately 1,5 m2 K/W (ISSO, 2015), the original roof insulation value of 0,36 m2 K/W is adjusted. The dwelling is occupied by a four persons family, matching the family input value. The average indoor temperature is increased from 18,3ºC to 20,5ºC. Table 18 illustrated a more detailed overview of case 3 and presents analysis unit values of the transition tool and case study in both the old/current and new/future situation.

Figure 23. Case 3 - street view (source: maps.google.com) and top view (source: solarmonkey.nl)

Old situation
The results indicate a deviation of -55% regarding the total energy demand (ED) between the case and the transition tool. This account for a deviation of -53% in (total) heating demand (R2, R4). Due to the high difference, it is assumed that the dwelling received thermal resistance upgrades in parts of the envelope since it was constructed in 1948.

New situation
Due to the small deviation in the new and old heating demand (R2), it is assumed no building measures are applied regarding the envelope thermal resistance in the gas-free transition process. Similar to case 1, the heating demand of 118 kWh/m2/year exceeds the found minimal requirement of 90 kWh/m2/year. The heating demand of 118 kWh/m2/year provides enough thermal resistance for the heat pump to obtain the occupants set indoor temperature, even at a 9% lower temperature output than the proposed 45ºC. This indicates a transition tool adjustment. The heating distribution method (S1) follows the transition tool division of radiative and convective admittance method. With an output temperature of 41ºC, enough heat is admitted to obtain the required indoor temperature.

The heat pump capacity (R5) is increased from an 8kW to a 20kW, which follows the increased heating demand. Based on this new input value, the transition tool would have selected the 20W variant, validating this selection. When assessing the space heating SCOP of the case study with the research specific input value of a 20kW heat pump variant operating at 45ºC, a value of 3,8 is found. It is assumed that the deviation in SCOP of 23% is attributed to the lower output temperature.

Finally, when evaluating the energy demand, the space heating energy demand (ED-1) is 37% higher. Despite the increased SCOP, the dominant factor is the more than 50% reduced heating demand between the transition tool and the case study. The transition tool variant incorporated more insulation measures and obtains a heating demand of 60 kWh/m2/year. The DWH energy demand (ED-2) is within a margin of 1% equal in the case study as the transition tool. However, based on the decreased DHW SCOP from 2,8 to 2,6, the original DWH energy demand of 879 kWh/year per person is increased by 8%.

Table 18. Case study analysis of case 3.

parameter	Specific parameter	code		Unit	MODEL		CASE 3		case 3	
							Huizing		Old/current deviation	New/future deviation:
Features - constant				target group						
construction					<1945					
Housing		B1		#	Detached		Detached			
Surface		B2		m2	248		248			
# layers		B5		#	2		2			
Roof orientation		B6		degrees	90		90			
				user group						
Number of		U1		#	4		4			
Average		U2		degrees C	20,5 °C		20,5 °C			
Features - variable				Service alternative	Gas- Current	A. Electricity - LTH	Gas- Current	A. Electricity - LTH		
Insulation	facade	B3 .1	R-value	m2 K/w	0,36	2,5	0,36	?		
	Roof	B3 .2	R-value	m2 K/w	1,5	3,5	1,5	?		
	Ground Floor	B3 .3	R-value	m2 K/w	0,39	2,5	0,39	?		
	Glazing insulation	B3 .4	U-value	W/m2 K	5,2	1,1	5,2	?		
Ventilation		B4	method	A,B,C,D	A	A	A	?		
Analysis units										
Heating		S1 .1		% radiative	100%	30%	50%	25%	-50%	-17%
		S1 .2		% convectice	0%	70%	50%	75%	50%	7%
Relations										
output temperature		R1		degree C	65 °C	45 °C	65 °C	41 °C	0%	-9%
Heating demand		R2		kWh/m2/year	268	60	126	118	-53%	96%
Total heating demand		R4		kWh/year	66482	14953	31222	29278	-53%	96%
heat pumps capacity		R5	power	kW		8 kW		20 kW	0%	150%
Efficiency - space heating		R6		SCOP	0,9	3,4	0,9	4,2	0%	23%
Efficiency - tap water heating		R7		SCOP	0,9	2,6	0,9	2,8	0%	10%
Functions - Energetic performance					1	2				
Gas	space heating	ED1-G		m3 gas/year	7557 m³		3548 m³		-55%	
	domestic hot water	ED2-G		m3 gas/year	324 m³					
Electricty	space heating	ED1-E		kWh/year		5.087		6.974		37%
	domestic hot water	ED2-E		kWh/year		1.379		1.363		-1%

4.3 Cross-case analysis.

Based on the quantified case study result concerning the eight analysis units, this section presents a cross-case analysis and the resulting transition tool improvement based on the case study results. Improvements are made in twofold; quantified result regarding the transition tool input value and qualitative result regarding the transition tool setup. Furthermore, insights are gained on the influence of the building, service and user domain.

Transition tool validation
Table 19 summarized the cross-case analysis outcomes of the analysis units, where green cells indicate results that lies within the transition tool bandwidths and red cells indicate results outside of the stated bandwidths thus requiring revaluation.

Table 19. Analysis units cross case validation

	analysis units	model assumption	case 1	case 2	case 3
S1	heating distribution method	>70%	50%	100%	75%
R2	Heating demand	< 90 kWh/m2/year	103 kWh/m2/year	57 kWh/m2/year	118 kWh/m2/year
R5	heat pumps capacity	see table 9	12kW	12kW	20kW
R6	SCOP - space heating	see table 10	4,6	3,8	4,2
R7	SCOP - DWH	See table 10	2,8	2,8	2,8

The results indicate that two analysis units require an adjustment in the transition tool. First of all, the heating distribution method (S1) requires an adjustment. Based on the findings of case 1, the minimal required percentage of convective heating distribution system of 70% is reduced to 50% at service alternative A. At this convective heating ratio, operating at an output temperature of 45°C, the distribution method is able to admit enough heat to obtain the occupiers indoor climate.

Secondly, the minimal heating demand (R2) requires an adjustment. Based on the findings of case 3, the minimal required heating demand of service alternative A is increased from the original 90 kWh/m2/year to 118 kWh/m2/year. The demand for case study validation on minimal heating demand requirement, as explained on page 23, is hereby followed. Due to the exclusion of service alternative B, no empirical insights are gained for that alternative. However, the current value of 120 kWh/m2/year has to follow a similar adjustment. It is assumed that this minimal heating demand is 140 kWh/m2. The other analysis units have not illustrated issues of concern during the case study analysis. Hence, the presented values are preserved.

Additionally, two insights were gained based on a qualitative reasoning. The first insight stresses the importance of decreased heating energy demand, as a result of improved insulation and ventilation. Currently, the transition tool primarily determines the heating energy based on the minimal requirement of the three service alternatives. But as explained in the previous paragraph, this minimal requirement is now increased to 118 kWh/m2/year, which is relatively high. The gained insights however, propose that this relation should be secondary, only indicating a bandwidth. The primary relations to determine the insulation and ventilation upgrades should be based on optimal costs-benefit selection. In other words, finding the optimum in the efficiency gap presented in Figure 12. As a result, the transition tool setup is adjusted and determines the insulation and ventilation upgrades based on an cost-benefit optimum.

Secondly, the positive correlation of the heat pump capacity and SCOP is emphasized by the oversized heat pump capacity of the second case, coherent with the findings of Figure 15. This specific case indicates that the SCOP improved, reducing the space heating demand and consequently increased energy savings. This finding strengthens the notion of the benefits of 2 neighbouring houses sharing a heat pump. It is expected that one shared 16kW heat pump for two neighboured homeowners, offers a substantial economic benefit over two separate 8kW heat pumps.

Features
Table 20 presents the cross-case analysis of the features in the transition process. At each analysis, differences in features are stated. When features are corresponding between cases, they are not displayed. Where applicable results are identified that lie within the case study boundaries. Findings which cannot be research due to missing data, are marked as N.A. (not applicable).

Table 20. Cross-case analysis feature overview

		Case 1 Features	case 2 Features	findings	case 2 features	case 3 features	findings	Case 1 Features	case 3 features	findings
Target group		type 3	typ 17		Type 17	type 1		type 3	type 1	
	Construction period	1975-1991	1992-2005	n.a.	1992-2005	<1945	large heat pump (20kW)	1975-1991	<1945	large heat pump (20kW)
B1	housing type	Detached	Terraced	n.a.	Terraced	Detached	n.a.			
B2	housing size	156 m2	198 m2	n.a.	198 m2	248 m2	large heat pump (20kW)	156	248 m2	large heat pump (20kW)
User group		Elderly	Familiy	energy demand + 33%	Familiy	Familiy	Energy demand -12%	Elderly	Familiy	Enery demand + 24%
U1	occupants	2	5	DHW energy demand + 20%	5	4	DWH energy demand - 19%	2	4	DHW energy demand + 102%
U2	average indoor temp.	20,0 °C	21,5 °C	Heating demand +15%, SCOP - 18%	21,5 °C	20,5 °C	Heating demand - 10%	20	20,5 °C	heating demand - 5%
Service alternative										
R1	output temperature				35 °C	41 °C	Higher SCOP	35 °C	41 °C	Higher SCOP
R6	Heat pump capacity				12 kW	20kW	higher initial costs	12kW	20kW	higher inital costs

The main finding that is derived from Table 20, emphasizes the importance of the human factor affecting the energy demand outcomes. The cross-case analysis of case 1 and 2 result in significant higher energy demand of 33% which is partly caused by more occupants and a higher average indoor temperature. Indoor temperature setting differentiates form the research user groups and show contradictive result between case 1 and 2, as it is most common for elderly to have a higher average indoor temperature compared to families. One reason that could explain these contradictory results is that the family may have a young child (new born) and therefore they could favour a higher temperature. However, this assumption cannot be verified.

4.4 SUMMARY

Empirical knowledge is acquired by studying three dwellings that underwent a gas-free transition process corresponding with service alternative A. The case study provides quantified insight that result in transition tool adjustment and more in-depth insight are gained resulting in a different tool setup. The features that lies within the case study boundaries are evaluated in a cross-case analysis, emphasising the significant influence of human factors and the relation between construction period and housing size with heat pump capacity. To conclude, the transition tool has been empirically validated and can be used in the following chapter to produce outcomes in order to obtain the research objectives.

CHAPTER 5. RESULTS

The goal of this chapter is to analyse the results of the validated transition tool. The first section elaborates on the homeowner-focussed optimum transition packages. The second section analyses the different economic and financial feasibility outcomes, which will be subjected to a sensitivity analysis. The third section assesses the building, user and service domains influences, where after the fourth section analyses the most important features of the transition process. The fifth section aims to give insights in improvement opportunities. The final section summarizes the results.

5.1 TRANSITION PACKAGES

Transition packages are formulated for 76 current situation scenarios, representing 19 target groups with four different user groups. Consequently, three different gas-free service alternatives are evaluated for each of the 76 current scenarios, resulting in 228 future gas-free alternative scenarios. Based on the economic and financial feasibility definitions of section 2.6, two business cases are presented for each of the 228 gas-free scenarios.

The empirical results of the transition packages of for individual homeowners are presented in Figure 24, in which the most favourable service alternative is selected. Based on this overview, homeowners of 58% of the Dutch housing stock can select the situation that is most appropriate for the respective occupant regarding housing type, construction period and user group. The detailed transition tool outcomes of each scenario are presented in Appendix 13, which formulated the homeowner-focussed transition packages. The overview is reduced to visualise the best economic and financial feasibility outcomes in Appendix 14. The results state a detailed overview of which building and service features should be applied in order to obtain a gas-free dwelling in the most feasible way, of which an example is presented in Appendix 16.

Homeowners now have insight in both economic and financial feasibility showcasing if and how they can enter the gas-free transition process. Thereby one of the main barriers for homeowners to enter the transition process is resolved: information is presented to come to a well-considered decision.

5.2 ECONOMIC AND FINANCIAL FEASIBILITY

The results of the individual homeowners' packages are translated towards the housing stock level to generate a feasibility overview. This is done by adding the number of dwellings and their energy consumption (presented in Table 2) to the outcomes of Figure 24.

The empirical results indicate that feasible gas-free transition packages can be developed for 1.2 million private homeowners. The remaining 2.4 million dwellings present an unfeasible business cases to enter the gas-free transition process. The results furthermore show that the 33% that present a feasible business case consume 49% of the total primary energy of the targeted privately-owned dwellings. Additional findings are presented in Table 21.

Table 21. Feasibility conclusions for the targeted privately-owned housing stock.

	Feasible transition package		*Not feasible transition packages*	
Amount of dwelling	1.2 million	33%	2.4 million	67%
Construction period	Detached	<1975	Detached	>1976
	Semi-detached	<1975	Semi-detached	>1976
	Terraced	<1945	Terraced	>1946
Primary heating demand	89.500 TJ	49%	93.200 TJ	51%
Total investment	€31 billion	43%	€41 billion	57%
Average payback period (economic feasibility)	11 years		26 years	
Difference in operational costs (financial feasibility)	- 16%		+43%	
Average initial investment	€24.800		€17.000	
Price premium	€7.300		-	

The mismatch between the national ambitions to reach a natural gas-free housing stock and the current ability of owner-occupiers to meet this ambition is quantified. The results of this study indicate that feasible transition packages are formulated for 1.2 million dwellings, while the national ambition is to obtain 2 million gas-free dwellings by 2030 (RutteIII, 2017). This ambition does not differentiate between non-profit sector dwellings (41%) and privately-owned dwellings (59%). With this dwelling distribution applied to the ambition level, the outcomes suggest that in an optimum scenario the current solutions are able to achieve the national ambitions. This does require an investment of €31 billion euro paid back in 11 years.

		<1945	<1965 / 1946-1964	1965-1974	1975-1991	1992-2005	2006-2011	2012-2017
Detached	traget group		1	2	3	4	5	6
	Optimal service alternative		A	A	A	A	A	B
	Average		9 year	9 year	15 year	25 year	25 year	24 year
			-18%	-21%	19%	36%	37%	47%
	Optimal service alternative		A	A	A	A	A	A
	Working couple		12 year	11 year	18 year	22 year	22 year	23 year
			-3%	-11%	38%	57%	50%	59%
	Optimal service alternative		A	A	A	A	A	B
	Familiy		9 year	9 year	15 year	25 year	25 year	24 year
			-17%	-20%	18%	34%	35%	45%
	Optimal service alternative		A	A	A	A	B	A
	Elderly		8 year	7 year	13 year	25 year	24 year	21 year
			-38%	-35%	6%	36%	47%	44%
Semi-detached	traget group		7	8	9	10	11	12
	Optimal service alternative		A	A	A	A	B	A
	Average		10 year	11 year	21 year	26 year	29 year	26 year
			-15%	-6%	42%	59%	54%	60%
	Optimal service alternative		A	A	A	A	A	A
	Working couple		12 year	13 year	27 year	27 year	27 year	28 year
			2%	5%	70%	77%	69%	79%
	Optimal service alternative		A	A	A	A	B	A
	Familiy		10 year	11 year	21 year	26 year	29 year	26 year
			-14%	-6%	40%	56%	51%	57%
	Optimal service alternative		A	A	A	A	A	A
	Elderly		8 year	9 year	20 year	30 year	27 year	28 year
			-24%	-23%	26%	44%	40%	56%
Terraced	traget group	13	14	15	16	17	18	19
	Optimal service alternative	A	A	A	A	A	A	A
	Average	9 year	13 year	13 year	23 year	30 year	32 year	29 year
		-23%	4%	7%	53%	77%	75%	69%
	Optimal service alternative	A	A	A	A	A	A	A
	Working couple	13 year	16 year	17 year	30 year	32 year	30 year	31 year
		7%	24%	29%	81%	99%	80%	88%
	Optimal service alternative	A	A	A	A	A	A	A
	Familiy	9 year	13 year	13 year	23 year	30 year	32 year	29 year
		-22%	4%	6%	50%	72%	53%	64%
	Optimal service alternative	A	A	A	A	A	A	A
	Elderly	8 year	10 year	10 year	20 year	29 year	27 year	32 year
		-33%	-16%	-11%	41%	73%	56%	58%

Figure 24. Transition tool output based on optimal service alternatives.

Economic versus financial feasibility

The empirical results illustrate that with the current assumptions the economic feasibility offers a similar feasible transition rate of 33% compared to the financial feasibility. The outcomes specify that the feasible transition processes require a total investment of €31 billion. With the buying option homeowners experience an average initial investment of €24,800 to become gas-free with a payback period of 11 years. The leasing option results in an average decrease of 16% in annual operational costs.

However, the servitization model showcases additional advantages from the homeowner's perspective. First of all, while the economic feasibility is dependent on the expected occupants' moving cycle, the financial feasibility is not. The financial feasibility percentage is the same when an occupier decides to move within one year or stay at the dwelling for another 40 years. This could be an incentive for homeowners with uncertainty concerning their future moving plans. Secondly, entering the gas-free transition through the servitization model does not require an initial investment, which varies between €15,000 and €30,000 euros. With the found median savings of the research user groups of €21,200, the leasing option offers an additional perspective for homeowners not able or willing to invest such a large part of their personal savings to enter the energy transition with a payback period of at least 8 years.

Besides the feasibility rates, a Total Cost of Ownership (TCO) calculation for both options provides a more quantitative analysis of the difference between the buy and lease options. Based on the annual average Dutch Consumer Price Index (CPI) of the last 10 years, the CPI is set at 1.3% to calculate the Net Present Value (NPV) of both the economic and financial model. A time period of 20 years is examined, covering the bandwidths of average moving cycles of the user groups. Target group 1, with average user groups and service alternative A, is selected as example dwelling during the calculations, however the results are applicable for every target group. It is assumed that the energy price level follows the CPI. In this example, the initial insulation costs equal the price premium and are therefore not incorporated into the TCO calculation. Based on the input table presented in Appendix 14, Figure 25 presents the TCO outcomes of both the buy and lease option.

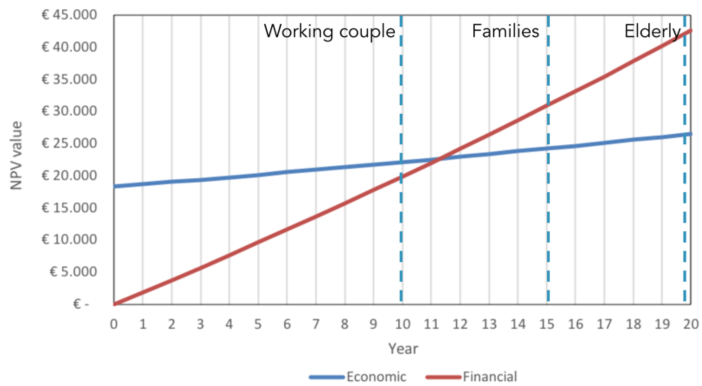


Figure 25. Total Cost of Ownership for both the buy and lease option, based on CPI of 1,3%.

Figure 25 indicates that in terms of TCO, buying outperforms leasing after 11.3 years. With the average moving cycle of a working couple, families and elderly, respectively 10, 16 and 20 years, only the working couple user groups should experience advantages from a theoretical perspective. There is however a large deviation in the moving cycles between different homeowners. More generalized, the results show that for homeowners who will keep living in their homes for less than 11.3 years, leasing the services to obtain gas-free dwelling is, based on the cost-benefit perspective, more attractive than buying.

5.3 BUILDING, USER AND SERVICE

Building

Results of the analysis indicate that the payback periods tend to decrease with the age of the building. This advocates that while old dwellings require relatively large investments (insulation, heat pump and solar panels), they obtain a substantial decrease in operational costs. Newer dwellings require 'medium' investments (heat pump and solar panels), but obtain a relatively small gain in operational costs.

Figure 26 combines the optimum payback periods with the initial costs and the total primary heating demand. The total primary heating demand is stated on the left Y-axis and follows the framework of Ritzen et al. (2016), yet based on actual energetic consumption as recommended by Majcen (2016). Secondly, the payback periods are presented on the right Y-axis. The green columns indicate economically feasible business cases and the red ones economically unfeasible business cases. Thirdly, the initial costs of service alternative A are added, which represent the initial costs x €1,000.

The analysed figure shows evidence that dwellings which demand the most energy in the current situation are the dwellings which offer the most feasible business cases. Two conceptual findings graphs are developed for the building domain, both based on the outcomes of Figure 26.

Figure 27 indicates that relatively older dwellings, which consume the most primary heating demand of the Dutch housing stock, are economically feasible to enter the gas-free transition process, despite their high initial costs. Targeting these dwellings will have the most effect on reducing the energy demand of the private housing stock. When the construction periods of dwelling become relatively younger, both the initial costs and the heating demand (and thereby impact on energy transition) decrease. The payback period however increases, resulting in less feasible business. At a certain point, the initial costs reach a constant level. Newer constructed houses do not affect these minimum initial costs, as they represent the minimal required investment for the transition process, consisting of the heat pump (60%) and solar panels (40%).

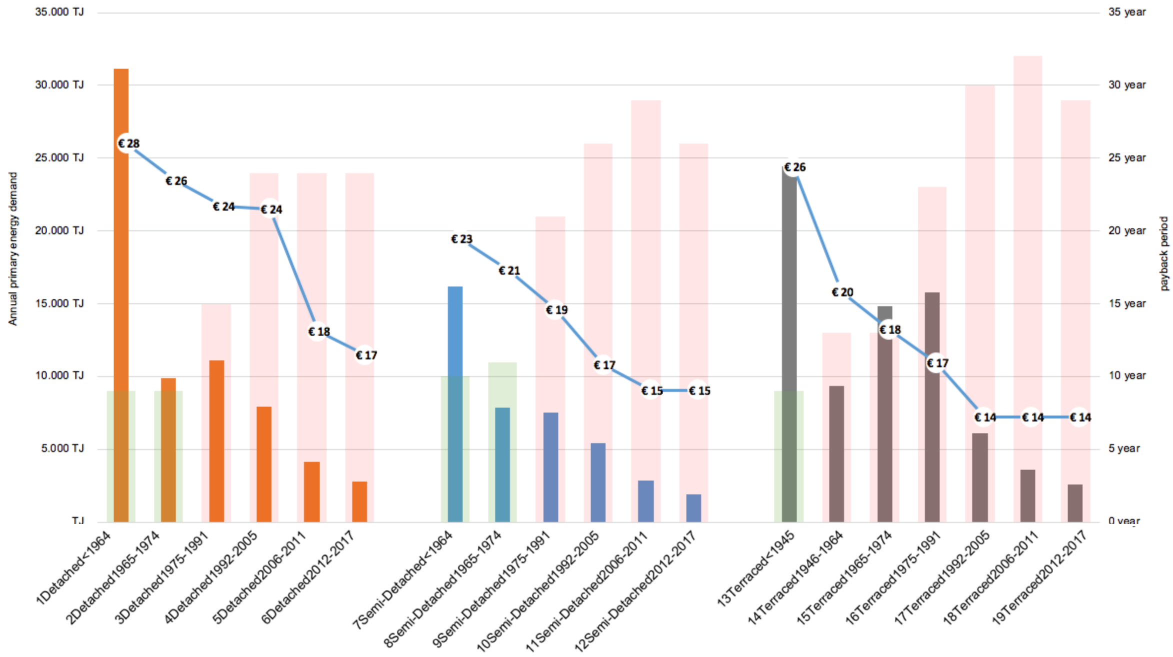


Figure 26. Annual primary heating demand of current situation versus payback period (year) at each target group, representing the average user group and optimal service alternative.

Figure 28 differentiates the three dwellings types, based on initial costs and payback periods. The figure shows evidence that while detached houses have the highest initial costs, the payback period is the lowest. Terraced houses require a lower investment, but yield a higher payback period. Dwellings that are 10 years old, which are perceived to be relatively new, still demand an investment between €14,000 and €18,000 euros to become gas-free.

The 19 dwellings types are placed in the impact/effort matrix in Figure 29, which is a subtraction from the Urgent-Impact matrix of Eisenhower (Luxafor, 2019). The impact axis is related to the primary energy demand. The effort axis is related to the payback period. The impact/effort matrix supports the decision-making process of both market and governmental parties. Dwelling types with a low effort present feasible business cases, which could be targeted by market parties. Dwelling types with a high impact and high effort present appropriate situations for governmental parties to develop incentives for homeowners to enter the transition.

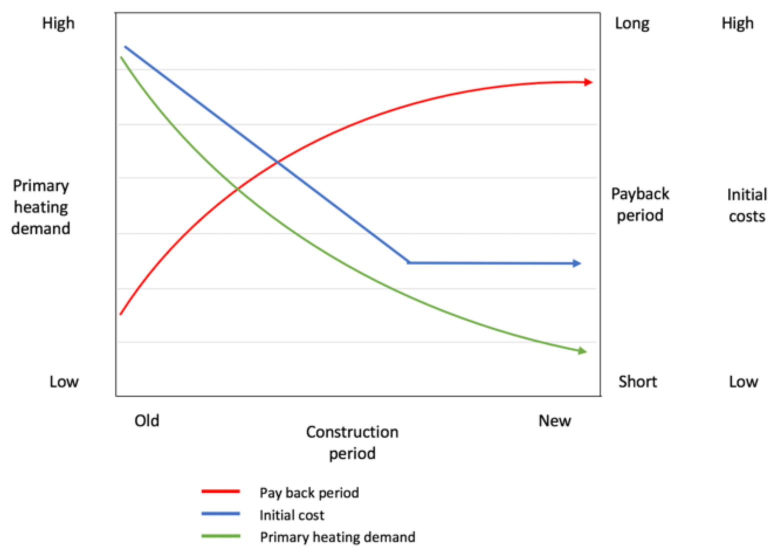


Figure 27. Conceptual effect of construction period on primary heating demand and payback period.

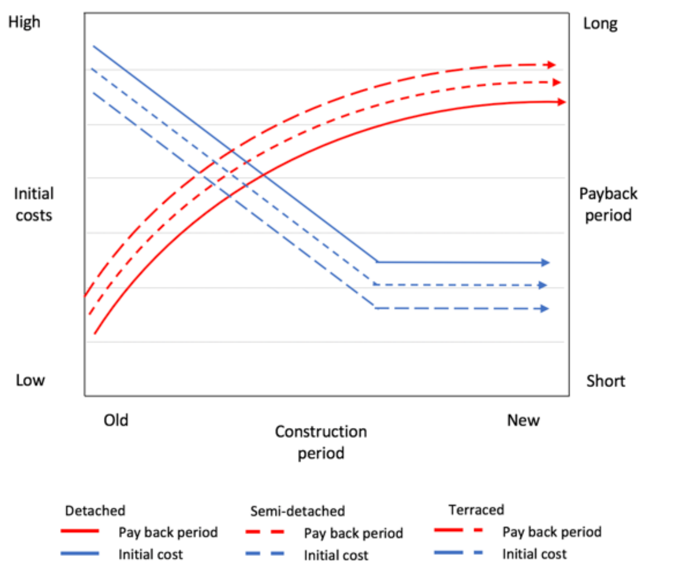


Figure 28. Conceptual effect of initial costs and payback period of detached, semi-detached and terraced dwellings.

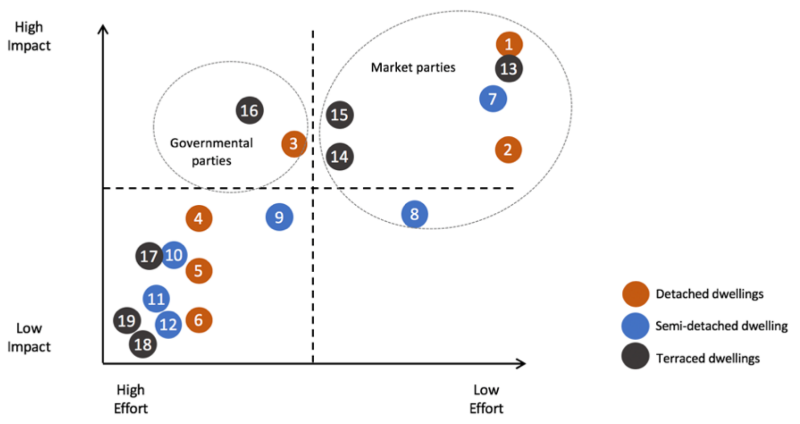


Figure 29. Impact/effort matrix, after Eisenhouwer

Users

The Payback periods of the different user groups are analysed in Figure 30. These empirical results indicate that indoor temperature is positively correlated with the transition feasibility. User groups with a higher average indoor temperature show higher feasibility rates compared to user groups with low average temperatures. Increased benefits obtained through the difference in operational cost between current and future cause this effect. The average indoor temperature difference of 2 degrees between the user groups, results in a 20% difference in payback periods. However, the results show that the effect of user groups on payback period decreases for dwellings built after 1992. Due to the better-insulated dwellings, the space-heating share of the operation costs decreased, thus decreasing the gained benefits of higher average indoor temperatures.

The results furthermore show that while space heating remains the primary energy demand factor, the share of DWH increases after the transition process. Figure 31 indicates that the average share of DWH increases from 9% in the current situation to 28% in the future situation. The figure shows evidence that the effect of indoor temperature changes is decreased in the future gas-free situation while changes in DWH usage have a relatively larger effect. This implicates that household awareness regarding energy usages shifts during the gas-free transition.

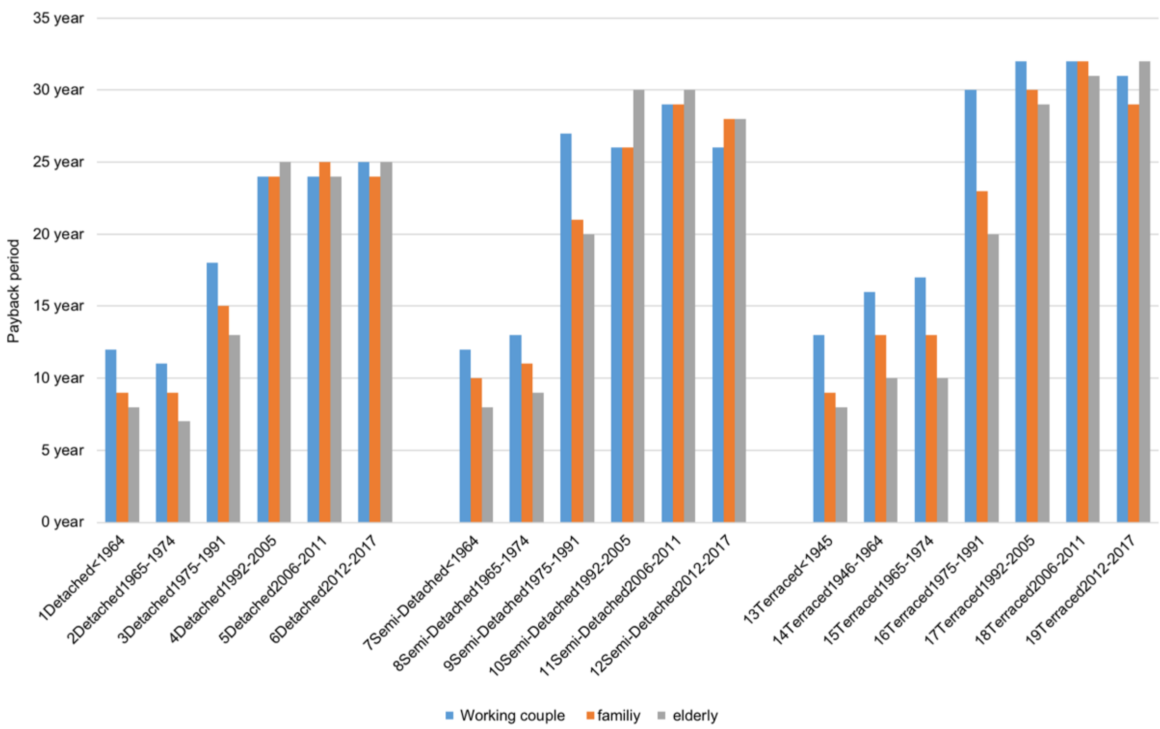


Figure 30. Influence of user groups on payback period.

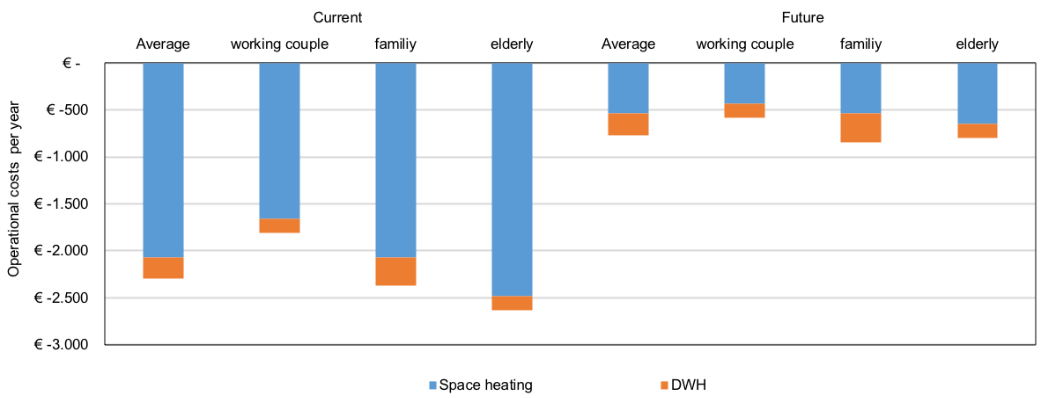


Figure 31. Operational costs of space heating and DWH for different user groups in current and future situation, based on target group 1.

Service

The results indicate that service alternative A, representing a low temperature heat pump operating at 45°C output temperature, is the most feasible heating system in the gas-free transition. From the 228 gas-free scenario's, 224 scenarios show the most economic and financially feasible business case for service alternative A. Four scenarios favoured service alternative B (medium temperature heat pump) as most feasible heating system. The results furthermore show that alternative C (high temperature heat pump) yielded the least favourable payback period in every scenario. It becomes evident that while additional investments are required to provide low temperature heating, the reduced operational costs by both the reduced energy consumption and increased SCOP yielded the lowest payback period.

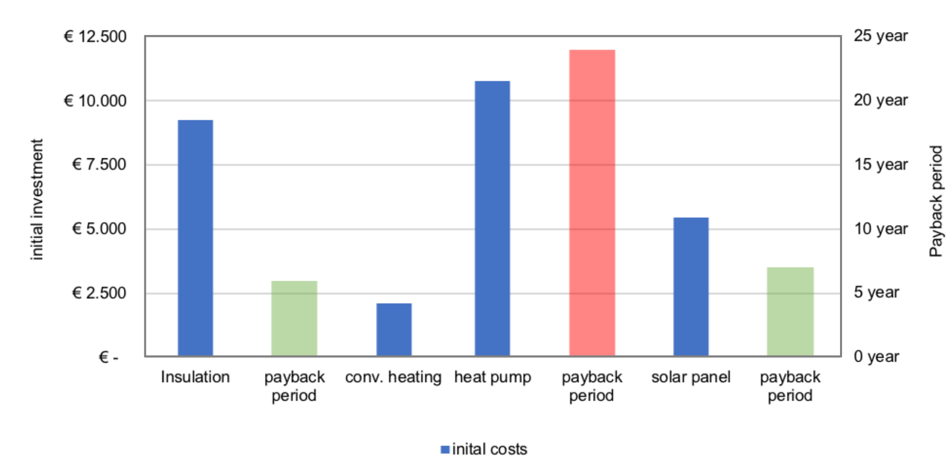


Figure 32. Initial investment and payback period of individual services.

The empirical results indicate that the air-source heat pump does not present a favourable business case for 67% of the targeted private housing stock. Figure 32 presents the initial investment and payback period of the individual services based on the dwelling of target group 1 with an average user group. The results indicate that while currently being the most favourable solutions to become gas-free, an individual heat pump does not offer an empowering solution to become gas-free. Only when combining the payback period with insulation and solar panels, a feasible transition package is presented. It shows that by adding solar panels, the overall payback period of the gas-free transition decreases

The results furthermore indicate that for dwellings with upgrade restrictions, for example monuments, the gas-free transition illustrates an average payback period of 40 years. With the assumption that most monumental dwellings belong to the earlier construction period of the three housing types, this payback period belongs to service alternative C, which requires no changes to the current insulation level or heating distribution method. With 36,000 monumental dwellings in the Netherlands (RCE, 2019), this group represents 1% of the total housing stock. However, it is expected that due to insulation restrictions, monumental dwellings consume a lot of energy. It becomes evident that there lies a large challenge for this type of dwellings.

5.4 MOST IMPORTANT FEATURES

As described in section 1.6, the combination of both in-depth quantification of features on building level and the belonging housing stock feasibility level outcomes, lacks in current research. The empirical results indicate what the most important features are that influence the housing stock transition feasibility and adds knowledge to fill this gap. Input features that can be categorized based on their linear, exponential or non-existing correlations with the transition feasibility. Features which are linear correlated with the transition feasibility, show the same ratio between initial costs and operational costs thus an equal payback period. Other features show exponential functions, where the ratio between the initial costs and operational costs in not linear, and payback periods differentiate. Table 22 appoints the features to the different categories, after which the correlations are discussed in more detail.

Table 22. Correlation of individual features with transition feasibility

	Linear correlated	*Exponential correlated*	*Not correlated*
Feature	U1. Average indoor temperature B6. Building orientation	B1. Housing type (number of facades) B2. Housing size B3. Insulation level B5. Roof area S1. Heating system	U2. Number of occupants B4. Ventilation method

Linear correlated features

U1. Average indoor temperature. Results demonstrate that an average indoor temperature increases of 1 degree's result is a 10% increase in space heating energy demand. As Figure 24 illustrates, in relatively older dwellings the indoor temperature is positively related with the transition feasibility.

B6. Building orientation. The findings indicate that the orientation influences the payback period of solar panels in a bandwidth of 2 to 3 years, based on a 90 to 180 degrees orientation bandwidth. The table of Hespul (Appendix 4) illustrates a linear correlation. The effect of solar gains for different building orientation is not researched.

Exponential correlated features

B2. Housing size. Results show that the housing size is a key factor in the transition feasibility. It effects both the operational and initial costs. With a share of 91% in the current and 72% in the future situation (see Figure 31), space heating energy demand is the largest operational costs influencer. Larger homes furthermore require larger capacity heat pumps (S1) to obtain the desired indoor temperature, and offer a larger roof area (B5).

S1. Heating system. Findings indicate that this feature is a second key factor in the transition feasibility. The heating system accounts for 60% of the minimal initial transition cost and determines the efficiency influencing the operational costs. The exponential positive correlation between heating system and transition feasibility is illustrated by the relatively decreased initial costs and relatively decreased operational costs for higher capacity size heat pump. Based on this finding, it can be concluded that dwelling with a higher heating demand gain benefits by reduced relatively initial and operational costs. The payback period is thereby decreased; hence feasibility is improved.

B3. Insulation level. The insulation variable represents a third key factor influencing the transition feasibility. As the investment per decreased heating demand step increases with higher ambitions level regarding the heating demand per square meter, this factor illustrates an exponential negative correlation. Each decreased heating demand steps result in a less economical attractive insulation measures, decreasing the payback period. It is the only variable feature that determines the total heating demand, thus influencing 60% of the initial costs through the heat pump capacity and 91% of the operational costs through the space heating demand. While the results quantify the efficiency gap in section 2.4, further research is needed to translate the individual insulation and ventilation upgrades into a cost-benefit optimum package within the gas-free transition process framework, taking the characteristics of Figure 12 into consideration.

B1. Housing type. The empirical results indicate that detached homes yield in the most favourable feasibility outcomes, followed by semi-detached homes. This is contradictory with the increased heating loss surface resulting in an increased heating demand and higher insulation upgrades per square meter. It is therefore assumed that the effect of increased housing size, corresponding with housing type, is superior to the housing type variable.

B5. Roof area. The results indicate that a larger roof area enhances the transition feasibility. Solar panels are payed back between 5 to 8 years, decreasing the overall payback period. This effect however decreases exponentially, as more solar panels reduce the SSR and thereby economic gains. Future research is required to find the optimum number of solar panels for different orientations and household electricity usage, taking the outcomes of Figure 17 into consideration.

Not correlated features

U2. Number of occupants. Within the research, this features solely influenced the DHW demand. Due to the DHW SCOP on the 'break-even point' in the gas versus electricity graph of Figure 14, the operational costs in both the current and future situation is equal. Hence, the number of occupants is not correlated with the transition feasibility.

B4. Ventilation upgrades. The results indicate that the ventilation upgrade costs of improving the heating demand by 1 kWh/m2/year were among the least attractive upgrades to require a certain minimal heating demand level. A ventilation upgrades is not applied at any of the dwelling transformation packages and thereby ventilation is not considered as a feature increasing the transition feasibility.

5.5 IMPROVEMENT STRATAGIES

After analysing the current feasibility outcomes, this section aims to give in-depth insights in the different components influencing feasibility and evaluates the feasibility improvement possibilities. The possibilities to decrease the payback period are assessed, first by evaluating the initial costs and second by analysing the operation costs.

5.4.1 Decrease initial costs

The initial costs of the transition process can be divided into three categories: (1) the retail price of the product, (2) the labour costs and (3) the subsidy. Based on the transition process of target group 1 with an average user group and service alternative A, Figure 33 presents the total initial cost per feature and per category, while Figure 34 presents the initial costs per feature.

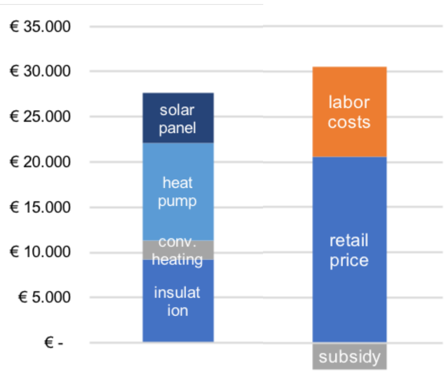


Figure 33. Total initial costs per feature and per category.

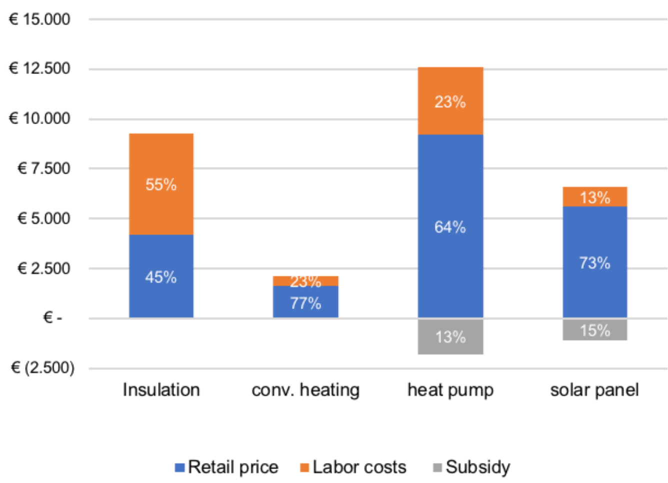


Figure 34. Initial costs per feature.

It becomes evident that the heat pump is the largest initial expense, followed by the insulation upgrades. Convective heating illustrates a relatively small part.

Retail price
The results indicate that the retail price represents the largest share of initial costs in the gas-free transition (62%). Especially the convective heating distribution, solar panels and heat pump have a relatively high retail price contribution.

The primary reason for the decrease of retail price are technological enhancements. Solar panels show a steady initial cost decrease in the last years. According to the National Renewable Energy Laboratory of the U.S., solar panels' initial costs decreased with 7% between 2017 and 2018, which can be seen as a global trend (Feldman, 2018). Heat pumps do not illustrate the same retail price decrease possibilities due to the already fully developed process. While heat pumps are relatively new to the Netherlands, they have been providing residential heating in the northern parts of Europe for over two decades. Since 1995, the heat pump market in Sweden has increased rapidly, with reported sales for 2012 reaching almost 40,000 units (Karlsson, Axell, & Fahlén, 2019). Based on a personal conversation at the graduation company with a 20+ years experienced heat pump specialist, heat pump retail prices have decreased minimally over the last 10 years as the chemical process has reached its most efficient stadium (F. Verhoef, 2018). It is furthermore expected that the retail prices of insulation and convective follow the same line of reasoning.

Subsidy
The results furthermore show that 8% of the total investment is subsidised by the government. Governmental price support in the form of subsidies has the goal to reduce the natural gas usage and increase the use of renewable sources (RVO, 2016). The amount of subsidy is related to the retail prices. To facilitate the gas-free transition, subsidy is provided on heat pumps and solar panels to achieve a certain price level that is considered reasonable. However, if the retail price decreases, due to for example technological enhancements, the subsidy will decrease respectively. Hence, the net initial costs will only decrease once the retail price decrease surpluses the current subsidy. Accounting for between 13% and 15% of the initial costs for heat pumps and solar panels, a significant price reduction is not expected in the near future.

Labour costs

Labour cots represent 30% of the total investment. Analysing the labour cost in Figure 33 and 34, the largest absolute gains can be made by decreasing the labour costs of the insulation upgrade and heat pump installation. Different concepts offer opportunities to decrease the labour costs share and thereby increase the gas-free transition feasibility.

First of all, scalability presents beneficial prospects. The analysed labour costs are based on single home installation. However, if neighboured dwellings, a street or an entire neighbourhood is targeted, the advantages of scale economy are introduced. Big contracts for dwelling types with shared characteristics show potential decrease in labour costs.

Secondly, the standardization concept illustrated a labour cost decrease opportunity. A recent article of The Dutch Financial Newspaper (FD) headlined: "Heat pump prices could drop 30% in 10 years" (Maarsen, 2018). While the outcomes of this article cannot be verified, it does illustrate that a price decrease is expected. According to the article, heat pumps can primarily decrease in price if mechanics gain more experience and improve efficiency and installation period. An example from practice regarding the heat pump installation illustrated the benefits of standardization. A typical heat pump installation of the graduation company THE FCTR E requires two days of work for two mechanics. Recently, an installation process was finished in just 1 day. However, the following installation took an entire week, due to unforeseen circumstances. This advocates the importance of standardization.

Thirdly, robotization in parts of the transition process offers opportunities. Currently, there is a shortage of labour forces to facilitate the energy transition (F. Verhoef, 2018). When considering the increase of the current gas-free transition rate of 5,000 to 10,000 dwellings per year towards the national ambition of 200,000 transitions per year, labour forces shortages will become a bottleneck in the process. Shortages will increase the labour costs share of the initial costs, decreasing the feasibility. This advocates the focus for robotization in parts of the transition process. Not only can it resolve the shortage, it could also decrease the current labour costs.

Due to the relatively small differences in dwelling characteristics, the existing Dutch housing stock presents large opportunities for scalability, standardization and robotization. This research provides 19 target groups with similar characteristics and transition processes. Based on the empirical results of this study, future research is needed to assess the opportunities for labour costs decreasing concepts.

5.5.2 Decrease operational costs

Decreasing the future operational costs can be done in twofold: first by increasing the efficiency of the energetic services, secondly by decreasing the energy demand.

Efficiency

The efficiency of solar panels is incorporated in the before-mentioned annual initial cost decrease of 7% and is thereby not incorporated in this section. It is furthermore not foreseen that a large efficiency enhancement in heat pump SCOP will be presented in the near future, due to the before-mentioned optimised chemical process. Therefore, efficiency increase is not perceived as a viable option to decrease operational costs. In contrast, efficiency could also decrease due to the depreciation of energetic performance. Further research is needed to verify this depreciation of performance and its effect on the transition feasibility.

Decreasing energy demand

Secondly, the human factor is addressed. Energy demand derives from obtaining the desired indoor climate through space heating and by mostly shower and bath time through enough provided DHW. By increasing the occupant's awareness of these effects, transition feasibility outcomes could be enhanced. To quantify this effect, the influence of 1°C decrease in average temperature and a 50% DHW decrease is assessed.

Based on the transition tool outcomes of the example dwelling of target group 1, a 1°C decrease in indoor temperature results in a decrease of €54 euros per year (-10%). In the current situation, an annual decrease of €200 euros (-10%) in operational costs is calculated. In both the current and future situation, a 50% shower time reduction would result in €75 euros (-50%) annual costs benefit based on a two-person household.

The results indicate to some extent that by increasing the occupant's awareness of these effects, transition feasibility outcomes could be enhanced. However, due to the relatively low contribution to the difference between the current and future operational costs, the effects are relatively small in future gas-free dwellings, especially regarding average indoor temperature.

5.6 SUMMARY

This chapter analyses the research results. Section 5.1 presents the results of the transition packages formulated for 19 different target groups and 4 different user groups. The most optimum transition packages are stated for 76 scenarios to become gas-free, showcasing a detailed overview for homeowners on how they can enter the gas-free transition in the most feasible way. Thereby one of the main barriers for homeowners to act in the gas-free transition is resolved.

The empirical results of section 5.2 indicate that feasible gas-free transition packages can be developed for 1.2 million private dwellings. The remaining 2.4 million dwellings present unfeasible business cases to enter the gas-free transition process. The feasible 33% of the targeted housing stock consumed 49% of the primary energy.

Economic feasible transition packages illustrate an average initial investment of €24.800 euro of which €7.300 is perceived as a house value increase. A total investment of €33 billion euro is required, paid back within 11 years. Financially feasible transition packages illustrate an average 16% decrease in operational costs. With the servitization model, homeowners can enter the energy transition and access annual savings without up-front investment and while remaining flexible in their moving plans. In terms of TCO, the buying option outperforms the leasing option after 11.3 years.

Section 5.3 elaborates on the influence of the building, user and service domain on the feasibility results. The results indicate that the payback period tend to increase when dwelling become newer as they obtain a relatively smaller gain in operational costs to payback the initial investment. The results show that indoor temperature is positively correlated with the transition feasibility. This effect however decreases when dwellings obtain insulation upgrades. Service alternative A, representing a low temperature heat pump, is the most feasible heating system.

Section 5.4 elaborates on the most important features influencing the feasibility results and indicates that housing size, heating system and insulation level form the key factors. They are exponentially correlated, meaning that costs-benefits optimum values can be determined. Combined they represent 78% of the total initial investment, influencing 91% of the operational costs in the current situation and 72% of the operational costs in the future situation.

The final section analysed the feasibility improvement possibilities. Firstly, the 30% labour costs illustrate opportunities for scalability, standardization and robotics to enhance efficiency and lower costs, mainly at insulation upgrades and heat pump installation respectively characterized by 55% and 23% labour costs share. Secondly, the 70% share of products costs perceives little decreasing opportunities by technologic enhancement due to the compensation of reduced subsidies.

CHAPTER 6. DISCUSSION

The results of this research are discussed in the following chapter. The first section elaborates on answering the main research question, followed by further research recommendations. The second section discusses the sensitivity of the results and present two sensitivity analysis. The final section discusses the limitations and reliability of the research.

6.1 RESEARCH RESULTS

The main research question is stated as follows: *What does the energy transition process mean for the private housing stock to become gas-free?*

The mismatch between the national ambitions to reach a natural gas-free housing stock and the current ability of owner-occupiers to meet this ambition is quantified. To answer the main research question, the results of this research are discusses based on the outcomes of the impact/effort matrix, presented in Figure 29.

High impact/low effort dwellings
The results indicate that only 33% or 1.2 million dwelling of the targeted private housing stock showcase a feasible business case to enter the gas-free transition. And while this number of dwellings is in line with the national ambition if the deviations of non-profit sector and private dwelling is applied to the target to obtain 2 million gas-free dwelling by 2030, two main challenges are foreseen.

First of all, a total initial cost of €31 billion euros is required, which is payed back within 11 years. Within the traditional model, in which homeowners buy the services to obtain a gas-free dwelling, this capital is invested by homeowners. With the average initial costs of a feasible transition package exceeding the median savings of a household, a large challenge is foreseen to attract such a substantial quantity of personal savings from Dutch homeowners. However, the servitization model shifts the required investment form the relatively short-term perspective homeowners to the long-term perspective service supplier that attracts capital from the financial sector. The empirical results show that the servitization model offers a similar feasible transition rate compared to traditional model, while homeowners can enter the energy transition without an upfront investment and while remaining flexible in their moving plans. It becomes evident that the servitization model offers a high potential additional option to obtain a gas-free private housing stock.

Secondly, a challenge is foreseen to obtain the required transition rate of 200,000 dwellings per year as the AECO sector is currently experiencing a shortage of labour at a transition rate that is less than 5% of the require rate. Besides the means-to-an-end perspective from an energetic perspective, the gas-free transition is also a means to an end from a sectorial perspective. The AECO sector needs to prepare itself for the great reconstruction of the housing stock (Nijpels, 2018). The sector should gain experience, enhance process efficiency by scalability, standardization and robotization and educate workforces with the currently feasible dwellings to get the transition rate up to speed. The current annual transition rate of 2,000 to 5,000 dwellings needs to be increased towards an annual transition rate of 200,000 dwellings, the rate that is required to obtain an energy-neutral housing stock by 2050. If this required transition rate is not achieved soon, the number of annual transitions towards 2050 will exceed 200,000 transitions. This results in a more concentrated workload, while currently the shortage of labour is perceived as one of the main bottlenecks in the energy transition (SER, 2018). Thereby it is important to obtain the desired transition rate as quickly as possible and spread the workload over the remaining 30 years. The empirical results of this thesis illustrate which dwellings present feasible business cases and should be targeted first to gain experience.

Within the larger energy-neutral framework, the empirical results are based on the first step: to become gas-free. The second step, becoming energy neutral before 2050, is not researched. However, to provide information for homeowners to come to a well-considered decision regarding the total energy transition, a 30-year lookout is discussed. The investment to go from an energy label A to NZEB equals the total investment needed to improve from energy label G to A, however yields a significantly lower energy saving resulting in payback period over 30 years (EIB, 2018). Thereby, even for dwellings that currently showcase feasible transition packages to become gas-free, an additional unfeasible investment of €25,000 euros is required within 30 years. This results in an investment of €50,000 euros purely to meet the energy goals in the obsolete part of the Dutch housing stock. It is however these dwellings that also demand the most capital for yearly maintenance on non-energetic issues. Questions could be raised on promoting the first feasible step to homeowners, with the knowledge that within the next 30 years, an additional investment is demanded that could not be paid back within the average moving cycle.

Alternatively, these 'high impact' dwellings offer potential for the demolish-rebuild strategy. The average construction value of the researched dwellings is €110,000 euros (Verbouwkosten, 2019). Thus, for an additional €60,000 euros a new dwelling could be constructed, meeting the energy demands and reducing the additional maintenance costs of non-energetic issues.

Furthermore, these dwellings can be designed according to the homeowner's current spatial demands, differing from the spatial requirement of the dwelling types built during the post-war housing shortage (Ritzen et al., 2016).

However, the demolish-rebuild strategy faces challenges. First of all, the current annual demolishing rate of 0,4% of privately-owned dwellings should be increased by a factor 3 to demolish the 1.2 million obsolete dwellings in the upcoming 30 years. This seems impossible in terms of building and demolition capacity as well as waste production (T. Dijkmans, 2011). Furthermore, preserving the existing housing stock offers cultural and historic value, the key pillar of the Prêt-à-Loger (2014) project. Therefore, the demolish-rebuild strategy should target dwellings that are not only obsolete from an energetic perspective, but also fail to meet the current spatial demands of homeowners and cultural and historical value of the building stock. Further research is needed to identify which part of the housing stock complies with these demolish-rebuild criteria. The empirical results presented in the impact/effort matrix in Figure 29 can be used to facilitate decision making, targeting the high impact/high effort dwellings.

Low impact/high effort dwellings

The other 2.4 million do not present a feasible business case. The empirical results indicate that the air-source heat pump does not present a favourable business case for 67% of the targeted private housing stock. Depending on the number of solar panels, the heat pump represents 60% to 70% of the minimal initial investment to become gas-free with an average payback period of 24 years. As stated in section 5.4, it is not expected that either the product price or efficiency of heat pumps will show enhancements. While currently being the most favourable solution for homeowners to become gas-free, the heat pump does not offer an empowering solution for 2.4 million dwellings to become gas-free. The focus on the heat pump within the current technical and organisational infrastructures as the main solution for the gas-free transition is thereby questioned.

Criticism is expressed on the construction method of dwellings built in the last decade. While the pressured political gas-free ambition follows a series of events from the past years, the knowledge and importance of constructing energy-efficient dwellings dates back to well before the second century. The empirical results indicate that it is these dwellings that offer the least attractive transition packages for homeowners. Even dwellings built after the increased legislation concerning the minimal insulation in 2012, require an investment of €14,000 to €17,000 euros to become gas-free with an unfeasible payback period. While these dwellings are not the first priority due to their low impact, they face the largest challenge in the energy transition.

Further research recommendations

Sub question one and two have been answered in full. The results show the research variables of the types of dwellings that are included in the private housing stock and to what extant currently available services are able to transition these dwellings to become gas-free. In answering sub question three, the empirical results exhaust the service and building aspects of individual dwellings to enter the transition process in full. From the perspective of the homeowners and society, the servitization model offer an additional possibility to enter the gas-free transition.

However, this study did not include the business principles of the servitization model due to time, scope and educational background limitations. Hereby sub question three, which questioned which processes are currently available for homeowners to become gas-free, demand further research to assess if the servitization model offers a viable and workable business model form the perspective of the investors and service suppliers. This requires a study in the field of business principles.

Questions regarding the long-term viability of this business model remain unanswered. The minimal number of clients, the efficiency enhancement by standardization opportunities and the operational costs requires further research. Furthermore, it is possible that new technical solutions offer a better proposition for homeowner within the 15-year contract. In this case, the homeowners would cancel the leasing contract due to the cancel possibility and demand the more efficient solutions. If the services lose their added value in the energy transition while they have not yet been paid back in full, a loss occurs for the service-supplier. The conditions for a viable business model need to be substantiated for companies or investors to enter the transition process as a service supplier. Only then it will become evident if the servitization model has a future in the gas-free transition process.

Anticipatory on further research, business principle that have been studied during the graduation internship at THE FCTRE are presented to position further research. The 15-year lease contract is based on the expected depreciation period of the offered services. After the contract has ended, technical performances are analysed resulting in two options: either decreased leasing costs following the decreased performance, or a new offer following performance of new services. Within this period, the service supplier guarantees a comfortable dwelling indoor temperature and sufficient DHW. Bankruptcy is covered by a separate holding, in which the services and contracts are positioned. By including a separate monthly fee within the leasing costs, monitoring and maintenance agreements will be maintained.

Secondly, further research is recommended on the shared heat pump concept. The empirical results of two sections (the cross-case analysis of section 4.4 and the exponential correlation results of section 5.4) indicate the shared heat pump potential. This concept advocates supplying heat for two or more neighboured dwellings by one heat pump, decreasing both initial investment and operational costs. To illustrate this concept, Figure 35 presents the initial costs per kW capacity and operational cost derived from the SCOP for two example dwellings. The second example dwelling requires twice the amount of total heating demand over the first dwelling. This could be causes by either an increased dwelling size (B2) or decrease insulation level (B3). The figure furthermore includes the shared heat pump concept.

	Individual heat pump		Shared heat pump concept		Added value
	Dwelling 1	Dwelling 2	Dwelling 1a	Dwelling 1b	
Annual total heating demand (kWh/year)	5000	10000	5000	5000	
Heat pump	8kW	16kW	16 kW		
Initial costs	€ 11.674	€ 14.093	€ 7.046	€ 7.046	
Relative Initial costs (€/kW)	€ 1.459	€ 881	€ 881	€ 881	-40%
SCOP	3,3	3,8	3,8		
Annual operational costs	€ 336	€ 584	€ 292	€ 292	
Relative operational costs (€/kWh of heat)	€ 0,067	€ 0,058	€ 0,058	€ 0,058	-14%

Figure 35. Shared heat pump concept, correlation of heating system on initial and operational costs.

The results indicate that a shared heat pump with two neighboured house has the potential to decreases the initial costs by 40% and decreasing the operational cost by 14%. A sensitivity analysis, calculating the effect of the shared heat pump concept with two neighboured dwellings on the housing stock feasibility rate, indicates an increase economic and financial feasibility rate to 65% (based on an assumption that 60% of the transition costs are represented by the heat pump, the case at the minimal investment level). Additional costs have not been accounted for in this calculation.

Based on this quantification of the added value of the shared heat pump concept, further research is required to explore the belonging legal, technical and user challenges. Answers are required to questions such as where to place the heat pump and what the cost-benefit optimum number of clustered dwellings would be. Aggregation furthermore opens new technical and organisational possibilities.

6.2 SENSITIVITY ANALYSIS

This thesis examines solutions for dwellings to become gas-free of which the availability is at hand and assesses the feasibility at this point in time. The outcomes of the transition tool are bound to change due to different input values in the future. While the outcomes are based on a number of input values, the influence of two key input variables are discussed through a sensitivity analysis on their influence on the economic or financial feasibility rate.

Interest rate
Current conditions favour relatively low interest rates, this is however bound to change in upcoming years. The interest rate and depreciation period are the two determining factors to calculate the leasing costs and thereby influencing the financial feasibility. To assess the influence, a sensitivity analysis is performed on the influence of interest rate and depreciation period on the financial feasibility rate. The outcomes are presented in Table 23, of which the details are stated in appendix 18.

Table 23. Outcomes of sensitivity analysis of the influence of interest rate and depreciation period on the financial feasibility transition rate

		Depreciation period		
		10 years	15 years	20 years
Interest rate	2%	30%	51%	81%
	3%	13%	46%	58%
	4%	0%	38%	51%
	5%	0%	33%	51%
	6%	0%	33%	46%
	7%	0%	30%	33%
	8%	0%	23%	33%

Analysing Table 23, the bandwidth of the financial feasibility rate on the selected 15-year depreciation period showcases a fluctuation between 23% and 51%. The results indicate that with an interest rate of 4% or lower, the financial feasibility rate outperforms the economic feasibility rate. When the interest rate increased to 7% or higher, the economic feasibility rate outperforms the financial feasibility rate. These findings support decision making for the financial sector. As previously mentioned, the interest rate is related to the risk of the investment. The result however also indicates the total theoretical market at different interest rates, an important factor influencing the risk perceived by investors.

The outcomes furthermore emphasise the large influence of the depreciation period on the financial feasibility rate. Within the research, a 15-year depreciation period was assumed based on the graduation company's information. The analysed table shows evidence that an increased depreciation period drastically improves the financial feasibility rate and thereby market opportunities. Further research is needed to explore the depreciation periods of the individual transition features. When identifying the additional cost, a cost-benefit analysis can be performed taking the benefit outcomes of Table 23, as a starting point.

Energy price level

The results of Figure 14 suggest that the difference between the electricity and gas retail price has a large influence on the transition feasibility rates. The break-even point is obtained at a lower SCOP when the difference in retail price increases. To quantify this effect, a sensitivity analysis is presented to measure the influence of the annual gas retail price increase on the transition feasibility rate. The effect is measured in a 5-, 10- and 15-year outlook.

In the last 10 years the retail price of natural gas increased by 77%, while the electricity price decreased by 7% during the same period (CBS, 2018a). Future expectations implicate that the tax on natural gas will increase, while the tax on electricity will decrease (Greenhome, 2018). Based on the minimal increase of the electricity price in the past 10 years and the future expectation, it is assumed that this price level remains constant in the sensitivity analysis. The outcomes are presented Table 24 and the analysis is presented in Appendix 19.

Table 24. Outcomes of the sensitivity analysis of the influence of annual gas retail price increase on the economic and financial feasibility rate

		Time frame			
		current	5 year	10 year	15 year
Annaul gas retail price level increase	2%	33%	46%	46%	46%
	4%	33%	46%	46%	46%
	6%	33%	46%	46%	51%
	8%	33%	46%	51%	51%

The results indicate that with a relatively small gas retail price increase, an additional group of 475,000 dwellings would become feasible to become gas-free. When the cumulative gas price increase reached 6%, this additional group illustrates a feasible business case resulting in a transition rate of 46%. When the cumulative gas price increase reaches 15%, an additional 210,000 dwellings illustrate an economically feasible business case resulting in transition rate of 51%.

As described in section 2.5.2, policy makers influence the retail price of gas through tax. Policy makers thereby have the ability to influence the gas-free transition feasibility rate by increasing the gap between electricity and gas prices. The analysed figure shows quantified insights in the impact of tax changes on the housing stock feasibility to become gas-free, assisting policy makers in their decision-making process.

6.3 LIMITATIONS & RELIABILITY

Limitations

First, empirical findings are derived from three case studies in which all transition processes have been by implemented by one service company. It could be argued that the empirical findings are therefore based on limited empirical evidence. The validation process of the transition tool could therefore lack an evident empirical basis, resulting in research outcomes of which the credibility could be harmed.

Secondly, the unit of analyses of the conducted case studies fail to include the insulation level, ventilation method and solar panel energy generation. Empirical knowledge on these research variables is not obtained. Studies on solar panels provided detailed information during the literature study, which is used in the transition tool. An efficiency gap analysis has been presented for insulation and ventilation measures, however the optimum insulation step has not been researched. As a result, the effect of the insulation level and ventilation method on achieving the optimum transition package is still behind compared to other parts of this research.

Thirdly, while included in the research, the price premium effect of the gas-free transition process should be explored in greater depth. The degree of increased dwelling value by sustainable measure has a large effect on the housing stock feasibility. This effect has not received enough attention from literature and, as Zhang et al. (2018) conclude, remains a large challenge for cost-benefits analyses.

Fourthly, the graduation company's pricing levels have been used to determine the initial costs of the heating system, solar panels and heating distribution method. Efficiency rates of corresponding products have been used to maintain consistency in the price-quality ratio. Services from other manufacturers, offered by other service companies, might result in different price-quality ratios. A broader scope of service manufactures could resolve this limitation.

Finally, within this research, three output temperatures were tested; 45, 55 and 65ºC. The empirical results indicate that the heating system operating on 45 ºC offers the most feasible transition package. However, service alternative can operate on an output temperature as low a 30ºC (verhoeff, 2019). Existing dwelling do require large insulation and ventilation upgrades which become relatively more expensive at each insulation step, as quantified in Figure 13. Based on the transition tool framework, further research is needed to determine the most feasible output temperature in a bandwidth of 30 to 50 ºC.

Quality of data
The dataset of AgentschapNL (2011) provided the main input data to assess the current situation. Since the research outcomes are based on this starting point, the reliability of this source is discussed. The dataset evaluated the housing stock characteristics at that moment of writing, meaning seven years prior to this research. Within this timeframe, the awareness toward environmental aspects increased, with the Paris Agreement signed roughly in the middle of this seven-year period.

Input data is categorized by housing size, heat loss areas and insulation level. It is not expected that first two categories experience large differences during this period. However, it is uncertain which insulation upgrades are applied to the 19 target groups in the last seven years. These upgrades are not encountered for in the research calculations. Following the research conclusion, a higher insulation level results in a less feasible transition process. The conclusion, in which 1.2 million privately owned dwellings showcased a feasible transition process, might require a decreased adjustment. As no other datasets were available for the researcher, this reliability issue could not have been prevented.

Nevertheless, the transition tool remains to be of added value with this reliability issue taken into consideration. Homeowners who applied insulation measures can select the construction period that illustrates the largest similarities concerning the insulation level.

CHAPTER 7. CONCLUSIONS

The overall aim of this thesis is to explore the mismatch between the national ambition and the opportunities for household to enter the gas-free transition in more detail, and gain insights for homeowners, market parties and strategy makers to act in the energy transition. For this purpose, a transition tool is developed that generates quantified insights in the ability for different dwelling and user groups to become gas-free with different gas-free services.

This research presents homeowners focussed optimum transition packages for different terraced, semi-detached and detached dwelling types representing 83% of the Dutch private housing stock. Based on the empirical result presented in Figure 24 and Appendix 13, a homeowner is able to select the situation that is most appropriate for the respective occupant regarding housing type, construction period and user group, and obtain both technical and economic/financial information on how to enter the gas-free transition in the most feasible way.

The main empirical findings indicate that feasible gas-free transition packages can be developed for 33%, or 1.2 million privately owned dwellings with the currently available processes. The remaining 2.4 million dwellings do not showcase feasible business cases to enter the gas-free transition process.

When the transition packages are compared to the energy consumption, the results indicate that the dwellings that illustrate feasible transition packages have a combined primary energy consumption of 49% of the targeted private housing stock. These dwellings combined have the potential to decrease their share of primary energy demand to 8% when becoming gas-free. This would decrease the total energy consumption of the Netherlands by 7.7%. The large energy decrease is attributed to the fact that high energy-consuming dwellings express favourable business cases, while low energy consuming dwellings demonstrate unfavourable business cases. This is consistent with previous findings concerning the efficiency gap, in which building energy efficiency is negatively correlated with transition feasibility (EIB, 2018). The results show that detached and semi-detached dwellings constructed before 1975 and terraced dwellings constructed before 1945 experience feasible transition packages.

The economically feasible transition packages (the buy option) illustrate an average initial investment of €24,800 euros to become gas-free, of which €7,300 euros is perceived as a house value increase. The remaining €17,500 is paid back within the average moving cycles of the different user groups. Combined, the feasible transition packages demand a total investment of €31 billion euros paid back within 11 years.

The financially feasible transition packages (the lease options, derived from the servitization model) illustrate an average 16% decrease in operational costs. In contrast with the buying option, homeowners can enter the energy transition and access annual savings without an upfront investment and while remaining flexible in their future moving plans. With an assumed deprecation period of 15 years, the buying options outperforms the leasing option after 11.3 years in terms of TCO. Hence, the servitization model offers an additional perspective for homeowners to enter the transition process.

The empirical results indicate that in the current conditions the servitization model offers a similar feasibility rate of 33% compared with the traditional model. However, these outcomes are bound to change as current conditions favour relatively low interest rates. Within this research an interest rate of 5% is used. In a scenario in which this condition persists and there is a scope for decrease of interest rate to 3%, this financially feasible transition percentage increases to 46%. In another scenario in which attracting capital is not cheap anymore, an increased interest rate to 7% resulted in a decreased feasible transition percentage to 30%. This is attributed to the effect of interest rate on annual leasing costs.

The mismatch between the national ambitions to reach a natural gas-free housing stock and the current ability of owner-occupiers to meet this ambition is quantified. The results of this study indicate that feasible transition packages are formulated for 1.2 million dwellings, while the national ambition is to obtain 2 million gas-free dwellings by 2030 (RutteIII, 2017). This ambition does not differentiate between non-profit sector dwellings (41%) and privately-owned dwellings (59%). With this dwelling distribution applied to the ambition level, the outcomes suggest that in an optimum scenario the current solutions are able to achieve the national ambitions. However, two main challenges are foreseen. First of all, a total initial cost of €31 billion euros is required in the upcoming 10 years, invested by either homeowners or by the service suppliers. Secondly, a challenge is foreseen to obtain the required transition rate of 200,000 dwellings per year as the AECO sector is currently experiencing a shortage of labour at a transition rate that is less than 5% of the required rate.

Further results regarding improvement opportunities to increase the feasibility rate come in two-fold. Firstly, the 30% share of labour costs illustrates improvement opportunities in scalability, standardization and robotics. Mainly insulation upgrades and heat pump installations illustrate potential due to their large labour costs share, respectively 55% and 23%. Secondly, the 70% share of product costs illustrates minimal improvement opportunities at current concepts, as technological innovation enhancements in the upcoming years is expected to be compensated by reduced subsidies. The heat pump represents the largest share (60% to 70% of the minimal initial investment) with an average payback period of 24 years. While currently being the most favourable solution, in current conditions an individual heat pump does not offer an empowering solution for homeowners to become gas-free.

In addition to the main conclusions, findings indicate that feasibility occurs in scenarios where the current operational costs are high. The results suggest that target groups with relativity old dwellings and user groups with high average indoor temperature settings (e.g., elderly) favour more feasible transition packages. This is attributed to the decreasing contribution of operational costs after the gas-free transition, increasing the operational gain of high energy consuming household and thereby enhancing the transition feasibility.

The empirical results furthermore point out that the low temperature (45ºC) heat pump is, despite the larger initial investment, the most favourable heating system. This is attributed to both the decreased energy demand from higher insulation requirements and the increased SCOP at low temperature heating. This result is in line with previous research, indicating the added value of low temperature heating (Q. Wang et al., 2015). This thesis evaluated output temperature of 45, 55 and 65 ºC. In further research a larger bandwidth of 30 to 50 ºC could specify the optimum output temperature for each target group in more detail.

Further practical implications of the outcomes are beneficial to a large variety of stakeholders. Homeowners of 3.7 million dwellings are informed on if and how they can enter the gas-free transition with the current solutions at hand. The empirical results provide insights and transparency in the decision-making process for 83% of the homeowners of the Dutch housing tock, perceived as one of the main barriers to enter the gas-free transition (Vermeij, 2018).

Policy makers can implement the outcomes within their current strategies to obtain the desired ambition level regarding the energy transition in the built environment, which currently is one of the largest political and societal national discussions. The empirical results indicate that with the current condition the servitization model offers a similar feasible transition rate. However, with the effect of two political instruments (energy price levels and interest rates) quantified, the servitization model offers opportunities to outperform the traditional model. Implementing these results could provide a different perspective for the AECO industry to approach the transition, shifting the required substantial investment of €31 billion euro from the short-term perspective homeowners to the long-term perspective financial sector.

Market parties in the AECO sector operating in the gas-free transition can implement the results to locate their theoretical market potential and gain experience to` enhance efficiency on the feasible transitions. This increases the annual transition rate and spreads out the work load, which is essential to obtain an energy neutral building stock by 2050. By clustering the dwellings into different target groups, this research identifies the improvement potential of scalability and standardization.

The financial sector gains insights from the empirical results for their participation in the energy transition through the servitization model. The total potential market share with different interest rates provides a first risk analysis, on which the interest rate is determined.

Recommendations for further research

This research exhausted the services and building aspects of individual dwellings to enter the transition process in full. Based on the empirical results, it becomes evident that from a service and building perspective servitization has a future in the gas-free transition process. Further research is required to study the business principles of a service supplier operating in the gas-free transition. Business concepts concerning the critical mass, minimal revenue and operational costs barriers were not researched due to time and scope limitations. When the presented building knowledge of this thesis is combined with additional business knowledge, outcomes of this study should determine if the servitization process is viable for the financial sector to participate in the gas-free transition.

Additionally, further research is needed regarding the shared heat pump concept. With this de-centralized solution, both initial costs of the heat pump and operational costs are reduced, by respectively 40% and 14%. Without accounting for the additional costs, results of a first sensitivity analysis indicate an improve feasibility rate from 33% to 65%, based on two neighboured dwellings. Based on the evident feasibility rate improvements, further research is needed to explore the legal, technical and user challenges. Aggregation furthermore opens new technical and organisational possibilities.

The empirical results of this thesis contribute to the existing body of knowledge concerning privately owned existing housing stock to enter the gas-free transition within the field of energy-efficient buildings. The research differentiates itself by including and relating both detailed dwelling level insight and housing stock level feasibility results. It furthermore provides novel insights in the effect and the potential of the servitization model within the energy transition.

CHAPTER 8. REFLECTION

This chapter reflects on the chosen research approach, outcomes relationship with the broader context and the scientific value.

Research approach
The main research method of this research consisted out of the transition tool. Due to the prominent role of the gas-free transition in current societal discussions, statements concerning the ability of the existing housing stock to become gas-free were made by many AECO sector professionals, of which reasoning is not always provided. Furthermore, research is often performed from a certain perspective and showcases preferred outcomes. Transparency concerning the outcomes lacked.

As a result, the choice was made to develop a transition tool myself based on literature review. This way, an in-depth understanding was gained concerning the transition process and the influence of the separate features on the overall feasibility outcomes. Without this knowledge of the building, users and services details, outcomes would not have been well-grounded. The goal was to develop a tool that matched the desired level of complexity to answer the research questions, while remaining clear and understandable for the reader.

When evaluating this approach, the transition tool generated the desired answers to obtain the research objectives. The tool combined both detailed building aspects and housing stock feasibility overview. The level of complexity demanded careful consideration, as time and scope limitations were present while having almost endless possibilities to further specify the details of the transition tool. Variables related to individual dwelling characteristics, such as orientation, site layout and shape, are not integrated into the tool and therefore their influence on the feasibility results are not researched. Therefore, while aiming to provide the desired information for homeowners to come to a well-considered decision, the research approach did not incorporate the effects of the individual dwelling details.

By developing the transition tool myself, this did result in a large 'calculation' part of my thesis. While consuming a fair amount of time due to the relatively uneducated background, it is perceived as an essential step to come to well considered results. When evaluating the time-management process of the research, time limitations did occur to study for example the shared heat pump concept in more depth.

Broader context
The graduation topic illustrates a strong relationship with current scientific, professional and social discussions. While already being relevant during my field of study selection 15 months ago, research concerning the gas-free transition process has become more extensive since then. It seems that every AECO sector professional has an opinion, one more backup by empirical facts than others. This research is able to support the discussions by the development of a transparent transition tool with a level of detail which is able to calculate the most important values, while remaining clear and understandable for the reader.

Projects results are transferable and adaptable to future changes by the flexible transition tool. While currently not publicly shared, the transition tool has the ability to function as tool for policymakers and market parties in both the AECO and financial sector.

The empirical results are positioned in a verity of other feasibility studies concerning the energy transition of the existing housing stock. As mentioned before, it was perceived as necessary to develop a transition tool from scratch. Other research in this field of study with more time, capacity and data available are likely to formulate more substantiated results. However, the approach of this research is seen as sufficiently accurate to draw conclusions.

Scientific Value
In view of the Master track Management in the Built Environment, the research linked to a number of aspects which have been discussed in the two-year curriculum. Firstly, it aims to solve energy efficiency problems, which have been central in many parts of the track. Secondly, knowledge on the multi-actor decision-making process to resolve large scale problems is applied to identify which outcomes are specified to the different aims and goals of the stakeholders

However, the graduation topic was not specifically discussed during the Master track. The curriculum focusses on managerial aspect of the Built Environment, academically discussing topics mainly on a relatively higher level such as Corporate Real Estate Management (CREM) and housing corporations, which are due to their long-term vision more applicable to managerial challenges. Privately owned dwellings, while presenting more than half of the Dutch building stock, are less discussed.

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Appendix 1. Replacement calculation heating distribution method

Radiator alternatives coping with lower output temperatures consist out of floor heating or low temperature radiators. First the amount of the current radiators that need to be replaced by LT radiators to produce the same amount of heat with the same dimensions is calculated. The heating capacity of a standard radiator (Brugman, type 11, 600x1200x12mm) function at 65 °C is set at 812W (Warmteservice, 2019). The heating capacity decrease of 55 °C and 45°C is calculated through the installer's selection tool of manufacture JAGA, as illustrated in appendix 1a. JAGA produces high efficiency radiators, assumed not to be installed at the target groups. However, the percental decrease in power operational at different output temperature is used to calculate the standard panels heating capacity. As a result, the output capacity of standard radiant panels can be calculated for different output temperatures. Secondly, the heating capacity of a Low temperature (LT) radiator with the same dimensions is assessed. Finally, through goal seeking the combination of standard radiators and LT radiators is calculated. As visualized in the figure below, the output capacity of the combination equals the set 812W with the same dimensions.

			Alternative:	Current / C	B	A
			output temperature	65 °C	55 °C	45 °C
Radiative heating distribution system						
Radiator	brugman standaard paneel radiators	Type + dimensions: T11 600*1200*12	heating capacity (per radiator)	812 W	537 W	291 W
	strada wand	Type + dimensions: T11 600*1200*12	normal	1345 W	889 W	482 W
			heating capacity percentage	100%	66%	36%
			ouput capacity	812 W	537 W	291 W
			missing capacity	0 W	275 W	521 W
Convective heating distribution system						
LTV radiator	type: JAGA, strada + DBE.	Type + dimensions: T11 600*1200*12	heating capacity (per LT radiator)	1962 W	1471 W	961 W
			Percentage base case	242%	181%	118%
			Radiative heating distibution method	100%	71%	22%
			Convectice heating distibution method	0%	29%	78%
			output capacity	812 W	812 W	812 W

Appendix 1a: Jaga selection tool

Selectiemodel Installateurs 2019-01

Voor noodzakelijke toebehoren, opties en aansluitsets zie Catalogus

	A	B	C
Aanvoer ºC	65	55	45
Retour ºC	55	45	35
Omgeving º(	20	20	20

(EN442, EN1397 en EN16430)

LA/2018-12-10 **Aantal resultaten** 2

								Verwarming			
								75/65/20º	65/55/20º	55/45/20º	45/35/20º
Uitvoering	Model	Kleur	Productcode	H in cm	L in cm	Type	D in cm	Watt	Watt	Watt	Watt
Horizontaal Wand	Strada Wand	Jaga kleur	STRW.06512011.klr	65	120	11	12	1852	1345	889	482
Horizontaal Wand	Strada Wand	Jaga kleur	STRW.06512011.klrDBE	65	120	11DBE	12	2452	1962	1471	961

Appendix 2. Insulation upgrades retail price:

	type	condition	THE FCTR E (2018) heating demand	THE FCTR E (2018) Price including VAT	AGENTSCHAP NL (2011) heating demand	AGENTSCHAP NL (2011) Price including VAT
			New R-value	€/m2	New R-value	€/m2
Floor	Bottom insulation	Crawl space >0,5 m	2,5	€ 28	2,5	€ 22
	Floor insulation	Crawl space <0,5 m	2,5	€ 36		
	Bottom insulation	Crawl space >0,5 m	3,5	€ 34		
	Floor insulation	Crawl space <0,5 m	2,5	€ 43		
Facade	Cavity wall	Build 1920-1975	2,5	€ 28	2,5	€ 23
	Outer wall	build before 1920	3,5	€ 320		
	Inner wall	build after 1980	3,5	€ 200		
Roof		sloped roof	3,5	€ 110	2,5	€ 57
			U-value	€/m2		
Window	HR++		1,1	€ 100	1,1	€ 178
	Triple		0,8	€ 240		

Appendix 3. Insulation steps:

Target group	Insulation measures FACADE				FA-1 - RC value 2,5 Costs	Total costs	new R-value	New heating demand	decrease in heating	Extra costs	FA-2 - RC value 3,5 Costs	Total costs	new R-value	New heating	decrease in heating	Extra costs
	current R-value	Facade Area m2	specific heat loss W/K	kWh/m2/year	€/m2	€	R-value	kWh/m2/ year	kWh/m2/ year	€/kWh/m2/ year	€/m2	€	R-value	kWh/m2/ year	kWh/m2/ year	€/kWh/m2 /year
1	0,36	136,7	379,7	48	€ 28	€ 3.828	2,50	6,9	41	€ 93	€ 200	€ 27.340	3,50	5,0	43,3	€ 632
2	0,43	164,7	383,0	44	€ 28	€ 4.612	2,50	7,6	36	€ 127	€ 200	€ 32.940	3,50	5,4	38,5	€ 855
3	1,30	144,0	110,8	16	€ 28	€ 4.032	2,50	8,1	8	€ 537	€ 200	€ 28.800	3,50	5,8	9,8	€ 2.931
4	2,53	150,9	59,6	10			2,50				€ 200	€ 30.180	3,50	7,5	2,9	€ 10.456
5	2,53	151,0	59,7	13			2,50				€ 200	€ 30.200	3,50	9,2	3,5	€ 8.555
6	4,50	151,0	33,6	7			2,50						3,50			
7	0,36	97,8	271,7	41	€ 28	€ 2.738	2,50	5,9	35	€ 78	€ 200	€ 19.560	3,50	4,2	36,6	€ 534
8	0,43	104,7	243,5	37	€ 28	€ 2.932	2,50	6,4	31	€ 96	€ 200	€ 20.940	3,50	4,6	32,5	€ 644
9	1,30	96,6	74,3	15	€ 28	€ 2.705	2,50	8,0	7	€ 365	€ 200	€ 19.320	3,50	5,7	9,7	€ 1.990
10	2,53	108,5	42,9	10			2,50				€ 200	€ 21.700	3,50	7,1	2,7	€ 8.024
11	2,53	109,0	43,1	12			2,50				€ 200	€ 21.800	3,50	8,7	3,3	€ 6.565
12	4,50	109,0	24,2	7			2,50						3,50			
13	0,19	49,0	257,9	42	€ 28	€ 1.372	2,50	3,2	39	€ 36	€ 200	€ 9.800	3,50	2,3	39,5	€ 248
14	0,36	53,0	147,2	28	€ 28	€ 1.484	2,50	4,0	24	€ 62	€ 200	€ 10.600	3,50	2,9	25,1	€ 423
15	0,43	58,3	135,6	24	€ 28	€ 1.632	2,50	4,1	20	€ 82	€ 200	€ 11.660	3,50	2,9	21,0	€ 555
16	1,30	58,4	44,9	9	€ 28	€ 1.635	2,50	4,8	4	€ 370	€ 200	€ 11.680	3,50	3,4	5,8	€ 2.017
17	2,53	58,4	23,1	5			2,50				€ 200	€ 11.680	3,50	3,7	1,4	€ 8.142
18	2,53	58,4	23,1	7			2,50				€ 200	€ 11.680	3,50	5,4	2,1	€ 5.670
19	4,50	58,4	13,0	4			2,50						3,50			

Appendix 3.1 Specific heating demand based of Facade (B3.1)

Target group	Insulation measures FLOOR				FL-1 - RC value 2,5 Costs	Total costs	new R-value	New heating	decrease in heating	Extra costs
	current R-value	Ground floor area m2	specific heat loss	kWh/m2/year	€/m2	€	R-value	kWh/m2/ year	kWh/m2/ year	€/kWh/m2 /year
1	0,15	93,0	620,0	79	€ 28	€ 2.604	2,50	4,7	74	€ 35
2	0,17	101,0	594,1	68	€ 28	€ 2.828	2,50	4,6	64	€ 45
3	0,52	95,0	182,7	26	€ 28	€ 2.660	2,50	5,4	20	€ 130
4	2,53	104,0	41,1	7			2,50			€ 0
5	2,50	104,0	41,6	9			2,50			€ 0
6	3,50	104,0	29,7	6			2,50			€ 0
7	0,15	66,0	440,0	66	€ 28	€ 1.848	2,50	4,0	62	€ 30
8	0,17	60,0	352,9	54	€ 28	€ 1.680	2,50	3,7	50	€ 34
9	1,30	66,0	50,8	11	€ 28	€ 1.848	2,50	5,5	5	€ 365
10	2,53	67,0	26,5	6			2,50			€ 0
11	2,50	67,0	26,8	7			2,50			€ 0
12	3,50	67,0	19,1	5			2,50			€ 0
13	0,15	55,0	366,7	59	€ 28	€ 1.540	2,50	3,6	56	€ 28
14	0,15	47,0	313,3	59	€ 28	€ 1.316	2,50	3,6	56	€ 24
15	0,17	52,0	305,9	54	€ 28	€ 1.456	2,50	3,7	50	€ 29
16	0,52	51,0	98,1	20	€ 28	€ 1.428	2,50	4,2	16	€ 90
17	2,53	56,0	22,1	5			2,50			€ 0
18	2,50	56,0	22,4	7			2,50			€ 0
19	3,50	56,0	16,0	5			2,50			€ 0

Appendix 3.2 Specific heating demand based of floor (B3.2)

Target group	Insulation measures ROOF				RO-1 - RC value 3,5					
					Costs	Total costs	new R-value	New heating demand	decrease in heating deman	Extra costs
	current R-value	Roof area	specific heat loss	kWh/m2/year	€/m2	€	R-value	kWh/m2/ year	kWh/m2/ year	€/kWh/m2/year
1	0,39	128,1	328,5	42	€ 110	€ 14.091	3,50	4,7	37,1	€ 380
2	0,86	120,7	140,3	16	€ 110	€ 13.277	3,50	4,0	12,1	€ 1.093
3	1,30	125,6	96,6	14	€ 110	€ 13.816	3,50	5,1	8,6	€ 1.612
4	2,53	120,8	47,7	8	€ 110	€ 13.288	3,50	6,0	2,3	€ 5.751
5	2,53	120,8	47,7	10	€ 110	€ 13.288	3,50	7,4	2,8	€ 4.705
6	6,00	120,8	20,1	4			3,50			€ 0
7	0,39	63,7	163,3	25	€ 110	€ 7.007	3,50	2,7	21,8	€ 321
8	0,86	65,2	75,8	12	€ 110	€ 7.172	3,50	2,8	8,7	€ 824
9	1,30	73,4	56,5	12	€ 110	€ 8.074	3,50	4,4	7,4	€ 1.095
10	2,53	74,2	29,3	7	€ 110	€ 8.162	3,50	4,8	1,8	€ 4.413
11	2,53	74,0	29,2	8	€ 110	€ 8.140	3,50	5,9	2,3	€ 3.611
12	6,00	74,2	12,4	3			3,50			€ 0
13	0,22	55,9	254,1	41	€ 110	€ 6.149	3,50	2,6	38,6	€ 159
14	0,39	57,3	146,9	28	€ 110	€ 6.303	3,50	3,1	24,8	€ 254
15	0,86	65,5	76,2	13	€ 110	€ 7.205	3,50	3,3	10,1	€ 710
16	1,30	68,6	52,8	11	€ 110	€ 7.546	3,50	4,0	6,8	€ 1.109
17	2,53	56,1	22,2	5	€ 110	€ 6.171	3,50	4	1,4	€ 4.478
18	2,53	56,1	22,2	7	€ 110	€ 6.171	3,50	5	2,0	€ 3.119
19	6,00	56,1	9,4	3						€ 0

Appendix 3.3 Specific heating demand based of Roof (B3.2)

Target group	Insulation measures Window				WI-1 - U-value of 1,1						WI-2 - U-value of 0,8					
					Costs	Total costs	new U-value	New heating demand	decrease in heating	Extra costs	Costs	Total costs	new U-value	New heating demand	decrease in heating	Extra costs
	current U-value	Window area m2	specific heat loss	kWh/m2/year	€/m2	€	U-value	kWh/m2/ year	kWh/m2/ year	€/kWh/m2/year	€/m2	€	U-value	kWh/m2/ year	kWh/m2/ year	€/kWh/m2/year
1	5,20	28,3	147,2	19	€ 100	€ 2.830	1,10	4,0	14,7	€ 192	€ 240	€ 6.792	0,80	2,9	15,8	€ 429
2	5,20	36,3	188,8	22	€ 100	€ 3.630	1,10	4,6	17,1	€ 213	€ 240	€ 8.712	0,80	3,3	18,3	€ 475
3	2,90	34,7	100,6	14	€ 100	€ 3.470	1,10	5,4	8,8	€ 394	€ 240	€ 8.328	0,80	3,9	10,3	€ 810
4	1,80	39,6	71,3	12	€ 100	€ 3.960	1,10	7,6	4,8	€ 818	€ 240	€ 9.504	0,80	5,5	6,9	€ 1.374
5	1,20	39,6	47,5	10			1,10	9,3		€ 0	€ 240	€ 9.504	0,80	6,8	3,4	€ 2.811
6	1,20	39,6	47,5	10			1,10	9,3		€ 0	€ 240	€ 9.504	0,80	6,8	3,4	€ 2.811
7	5,20	26,0	135,2	20	€ 100	€ 2.600	1,10	4,3	16,0	€ 162	€ 240	€ 6.240	0,80	3,1	17,2	€ 363
8	5,20	31,3	162,8	25	€ 100	€ 3.130	1,10	5,2	19,5	€ 160	€ 240	€ 7.512	0,80	3,8	21,0	€ 358
9	2,90	27,4	79,5	17	€ 100	€ 2.740	1,10	6,3	10,3	€ 267	€ 240	€ 6.576	0,80	4,6	12,0	€ 550
10	1,80	29,0	52,2	12	€ 100	€ 2.900	1,10	7,3	4,6	€ 628	€ 240	€ 6.960	0,80	5,3	6,6	€ 1.055
11	1,20	29,0	34,8	10			1,10	8,9	0,8	€ 0	€ 240	€ 6.960	0,80	6,5	3,2	€ 2.158
12	1,20	29,0	34,8	10			1,10	8,9	0,8	€ 0	€ 240	€ 6.960	0,80	6,5	3,2	€ 2.158
13	5,20	21,1	109,7	18	€ 100	€ 2.110	1,10	3,8	14,0	€ 151	€ 240	€ 5.064	0,80	2,7	15,0	€ 337
14	5,20	21,4	111,3	21	€ 100	€ 2.140	1,10	4,5	16,7	€ 128	€ 240	€ 5.136	0,80	3,3	17,9	€ 287
15	5,20	25,4	132,1	23	€ 100	€ 2.540	1,10	4,9	18,4	€ 138	€ 240	€ 6.096	0,80	3,6	19,7	€ 309
16	2,90	19,3	56,0	11	€ 100	€ 1.930	1,10	4,4	7,1	€ 271	€ 240	€ 4.632	0,80	3,2	8,3	€ 557
17	1,80	21,8	39,2	9	€ 100	€ 2.180	1,10	5	3,4	€ 637	€ 240	€ 5.232	0,80	4	4,9	€ 1.070
18	1,20	21,8	26,2	8			1,10	8		€ 0	€ 240	€ 5.232	0,80	6	2,8	€ 1.863
19	1,20	21,8	26,2	8			1,10	6		€ 0	€ 240	5.232,00	0,80	6	3	€ 1.863

Appendix 3.4 Specific heating demand based of Windows (B3.3)

Target group	VENTILATION measures ventilation			VE-1 - balanced heating			
	total surface			Costs	Total costs	decrease in heating deman	Extra costs
	Floor surface m2	specific heat loss W/K	kWh/m2/year	€/m2	€	kWh/m2/ year	€/kWh/m2/year
1	130	151,7	19	€ 35	€ 4.550	9,0	€ 506
2	144	168,0	19	€ 35	€ 5.040	9,0	€ 560
3	154	179,7	25	€ 35	€ 5.390	9,0	€ 599
4	172	200,7	35	€ 35	€ 6.020	9,0	€ 669
5	172	200,7	43	€ 35	€ 6.020	9,0	€ 669
6	172	200,7	43	€ 35	€ 6.020	9,0	€ 669
7	110	128,3	19	€ 35	€ 3.850	8,3	€ 464
8	123	143,5	22	€ 35	€ 4.305	8,3	€ 519
9	123	143,5	30	€ 35	€ 4.305	8,3	€ 519
10	132	154,0	35	€ 35	€ 4.620	8,3	€ 557
11	132	154,0	43	€ 35	€ 4.620	8,3	€ 557
12	132	154,0	43	€ 35	€ 4.620	8,3	€ 557
13	102	119,0	19	€ 35	€ 3.570	7,6	€ 470
14	87	101,5	19	€ 35	€ 3.045	7,6	€ 401
15	106	123,7	22	€ 35	€ 3.710	7,6	€ 488
16	106	123,7	25	€ 35	€ 3.710	7,6	€ 488
17	114	133,0	30	€ 35	€ 3.990	7,6	€ 525
18	114	133,0	43	€ 35	€ 3.990	7,6	€ 525
19	114	133,0	43	€ 35	€ 3.990	7,6	€ 525

Appendix 3.5 Specific heating demand based of Ventilation (B4)

Appendix 4. Table of Hespul.

Zonne Instralling																									
hoek	Orientatie (in graden) N= 0, Z= 180 graden)																								
	360	345	330	315	300	285	270	255	240	225	210	195	180	165	150	135	120	105	90	75	60	45	30	15	0
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
0	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%	88%
5	84%	84%	85%	85%	86%	86%	87%	88%	89%	91%	91%	91%	91%	91%	90%	90%	89%	88%	87%	86%	86%	85%	84%	84%	84%
10	80%	81%	82%	82%	84%	85%	87%	89%	91%	93%	94%	94%	94%	93%	92%	92%	90%	89%	87%	85%	83%	82%	81%	80%	80%
15	77%	77%	78%	79%	81%	84%	87%	89%	92%	95%	95%	95%	96%	95%	94%	93%	91%	88%	86%	84%	81%	79%	77%	77%	77%
20	73%	74%	75%	76%	79%	82%	86%	89%	92%	96%	96%	97%	98%	97%	95%	94%	91%	88%	85%	82%	79%	76%	73%	73%	73%
25	70%	71%	72%	72%	76%	81%	86%	89%	93%	96%	97%	98%	99%	98%	96%	95%	91%	87%	84%	80%	76%	73%	70%	70%	70%
30	65%	67%	68%	70%	74%	79%	84%	88%	92%	96%	97%	98%	100%	98%	96%	95%	91%	87%	83%	78%	73%	69%	66%	65%	65%
35	60%	62%	65%	67%	72%	77%	82%	86%	91%	95%	97%	98%	100%	98%	96%	94%	90%	85%	81%	76%	70%	66%	62%	61%	60%
40	55%	59%	64%	68%	70%	75%	80%	85%	90%	95%	96%	98%	100%	98%	96%	94%	89%	84%	79%	73%	68%	63%	58%	57%	55%
45	51%	57%	62%	68%	67%	73%	78%	83%	88%	93%	95%	97%	99%	97%	94%	92%	87%	82%	77%	71%	65%	63%	60%	55%	51%
50	46%	54%	61%	69%	67%	72%	76%	81%	87%	92%	94%	96%	97%	95%	93%	91%	86%	80%	75%	69%	63%	62%	62%	54%	46%
55	43%	50%	57%	64%	64%	69%	74%	79%	84%	89%	91%	93%	96%	93%	91%	89%	83%	78%	73%	66%	60%	57%	54%	49%	43%
60	40%	46%	52%	59%	62%	66%	71%	77%	82%	87%	89%	91%	93%	91%	89%	86%	81%	76%	70%	64%	58%	52%	46%	43%	40%
65	37%	43%	48%	54%	59%	64%	69%	74%	79%	84%	86%	88%	90%	88%	86%	83%	78%	73%	68%	61%	55%	50%	44%	41%	37%
70	34%	39%	44%	49%	54%	60%	66%	71%	76%	81%	82%	83%	87%	85%	83%	81%	75%	70%	65%	59%	53%	47%	42%	38%	34%
75	32%	37%	42%	46%	51%	57%	62%	67%	72%	77%	78%	80%	83%	81%	79%	77%	72%	67%	62%	56%	50%	45%	40%	36%	32%
80	31%	35%	39%	44%	49%	54%	59%	64%	69%	74%	74%	75%	79%	77%	75%	73%	68%	64%	59%	53%	48%	43%	38%	34%	31%
85	29%	33%	37%	41%	46%	51%	56%	61%	65%	70%	70%	71%	74%	72%	71%	69%	65%	60%	56%	50%	45%	41%	36%	32%	29%
90	27%	31%	35%	38%	43%	48%	53%	57%	61%	65%	67%	68%	69%	68%	67%	65%	61%	57%	53%	48%	43%	38%	34%	31%	27%

Appendix 5. User group specifications

User groups	U1.number of occupants	Indoor temperature setting			U2. average indoor temperature	R10. Degree days
		day 07.00-17.00	evening 17.00-23.00	night 23.00-07.00		
1. average	3	19 °C	20 °C	16 °C	18,3 °C	2753
2. Elderly	2	21 °C	21 °C	19 °C	20,3 °C	3313
3. Working couple	2	15 °C	19 °C	15 °C	16,0 °C	2149
4. Familiy	4	19 °C	20 °C	16 °C	18,3 °C	2753

Appendix 6. Heat pump initial costs.

Initial costs of NIBE heat pumps, based on THE FCTR E pricing levels.

low temperature heat pumps (alternative A + B)

Type	capacity (kW)	Retail price	subsidie	net price
F2040-6	6	€12.569	€1.800	€10.769
F2040-8	8	€13.674	€2.000	€11.674
F2120-12	12	€15.879	€2.000	€13.879
F2120-16	16	€16.493	€2.400	€14.093
F2120-20	20	€18.391	€2.400	€15.991

high temperature heat pump (alternative C)

Type	capacity (kW)	Retail price	subsidie	netto price
F2300-8	8	€15.697	€2.000	€13.697
F2300-14	14	€17.525	€2.400	€15.125
F2300-20	20	€19.827	€2.400	€17.427

Appendix 7. Initial costs - Solar panels

Solar panels	
source:	THE FCTR E
Condition:	sloped roorf, including installation and VAT.
type:	300 WP

number of panels	Costs	Subside 17%	Research price level
4	€ 1.889	€ 321	€ 1.568
5	€ 2.141	€ 364	€ 1.777
6	€ 2.392	€ 407	€ 1.986
7	€ 2.644	€ 450	€ 2.195
8	€ 2.892	€ 492	€ 2.401
9	€ 3.156	€ 537	€ 2.620
10	€ 3.396	€ 577	€ 2.819
11	€ 3.663	€ 623	€ 3.040
12	€ 4.489	€ 763	€ 3.726
13	€ 4.729	€ 804	€ 3.925
14	€ 4.969	€ 845	€ 4.125
15	€ 5.277	€ 897	€ 4.380
16	€ 5.517	€ 938	€ 4.579
17	€ 5.757	€ 979	€ 4.778
18	€ 6.110	€ 1.039	€ 5.071
19	€ 6.350	€ 1.079	€ 5.270
20	€ 6.590	€ 1.120	€ 5.470
21	€ 6.930	€ 1.178	€ 5.752
22	€ 7.268	€ 1.236	€ 6.032

number of panels	Costs	Subside 17%	Research price level
23	€ 7.508	€ 1.276	€ 6.232
24	€ 7.748	€ 1.317	€ 6.431
25	€ 8.062	€ 1.371	€ 6.692
26	€ 8.302	€ 1.411	€ 6.891
27	€ 8.542	€ 1.452	€ 7.090
28	€ 8.782	€ 1.493	€ 7.289
29	€ 9.022	€ 1.534	€ 7.488
30	€ 9.262	€ 1.574	€ 7.687
31	€ 9.502	€ 1.615	€ 7.886
32	€ 9.756	€ 1.659	€ 8.098
33	€ 9.996	€ 1.699	€ 8.297
34	€ 10.236	€ 1.740	€ 8.496
35	€ 10.476	€ 1.781	€ 8.695
36	€ 11.195	€ 1.903	€ 9.292
37	€ 11.435	€ 1.944	€ 9.491
38	€ 11.675	€ 1.985	€ 9.690
39	€ 11.915	€ 2.026	€ 9.889
40	€ 12.155	€ 2.066	€ 10.088

Appendix 8. Number of solar panels calculation.

number of solar panels

Scenario result:

Dwelling surface	106 m2
Number of layers	2 layers
current or alternative?	B. Electricity - MTH
Housing type	Terraced
Target group	16

output

Gross available roof surface	34,3 m2
Net available roof surface	23,9 m2
number of panels	8 St

calculation

Gross roof dimensions

Width-length ratio		1 :	1
Width			5,9 m
length			5,9 m

factors influencing available roof area

Edge margin	left/right		0,3 m
	top/down		0,3 m
Dormer factor		12%	30%
shadow factor			0%

Net roof dimensions

net roof surface	23,9 m2
width	4,9 m
lenght	4,9 m

dimensions solar panels

	Width (m)	Lenght (m)
Portrait	1,00 m	1,65 m
Landscape	1,65 m	1,00 m

lay-out plan

Portrait	Number of panels	4
	Number of rows	2
	Total	8
Landscape	Number of panels	2
	Number of rows	4
	Total	8

Number of panels

Portrait	8 St
Landscape	8 St
largest	8 St

Appendix 9. Complete overview of output values (target group 1 & 2 for average users)

Scenariosamenvatting	1 current	1A	1B	1C	2 current	2A	2B	2C
Veranderende cellen:								
target_group	1	1	1	1	2	2	2	2
service alternative	0	A	B	C	0	A	B	C
Resultaatcellen:								
target_group	1	1	1	1	2	2	2	2
construction_period	<1964	<1964	<1964	<1964	1965-1974	1965-1974	1965-1974	1965-1974
B1 Housing_type	Detached	Detached	Detached	Detached	Detached	Detached	Detached	Detached
B2 Surface	130 m2	130 m2	130 m2	130 m2	144 m2	144 m2	144 m2	144 m2
B5 floors	2 layers	2 layers	2 layers	2 layers	2 layers	2 layers	2 layers	2 layers
B6 building_orientaiton	135,0 °	135,0 °	135,0 °	135,0 °	135,0 °	135,0 °	135,0 °	135,0 °
user_group	average	average	average	average	average	average	average	average
U1 Number_of_occupents	3 persons	3 persons	3 persons	3 persons	3 persons	3 persons	3 persons	3 persons
U2 average_indoor_temperature	18 °C	18 °C	18 °C	18 °C	18 °C	18 °C	18 °C	18 °C
B3 facade	0,36	2,5	0,36	0,36	0,43	2,5	0,43	0,43
B3 insulation_roof	0,15	0,15	0,15	0,15	0,17	0,17	0,17	0,17
B3 Ground_Floor	0,39	2,5	2,5	0,39	0,86	2,5	2,5	0,86
B3 Glazing_insulation	5,2	1,1	5,2	5,2	5,2	5,2	5,2	5,2
B4 Ventilation_metod	A	A	A	A	A	A	A	A
S1 radiant_heating_method	100%	50%	80%	100%	100%	50%	80%	100%
S1 Convective_heating_method	0%	50%	20%	0%	0%	50%	20%	0%
S2 Heat_pumP_TYPee	-	LTH	LTH	HTH	-	LTH	LTH	HTH
S3 Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels	0 panels	20 panels	20 panels	20 panels
R1 minimal_heating_demand	166	61	106	166	169	69	106	169
R2 total_heating_demand	21546	7987	13828	21546	24353	9967	15206	24353
R3 available_roof_surface	64 m2	64 m2	64 m2	64 m2	60 m2	60 m2	60 m2	60 m2
R4 output_temperature	65 °C	45 °C	55 °C	65 °C	65 °C	45 °C	55 °C	65 °C
R5 Efficiency_space_heating	0,9	3,3	2,8	2,6	0,9	3,3	2,8	2,6
R6 Efficiency_DHW	0,9	2,6	2,6	2,9	0,9	2,6	2,6	2,9
R7 heat_pumps_capacity	0	6	8	20	0	6	8	20
R8 solar_efficiency	277 kWh	277 kWh	277 kWh	277 kWh	277 kWh	277 kWh	277 kWh	277 kWh
R9 Degree_days	2753	2753	2753	2753	2753	2753	2753	2753
ED1-G Gas_space_heating	2449 m³	0 m³	0 m³	0 m³	2768 m³	0 m³	0 m³	0 m³
ED2-G Gas_Domestic_hot_water	300 m³	0 m³	0 m³	0 m³	300 m³	0 m³	0 m³	0 m³
ED1-E Elec_space_heating	-	2.420	4.939	8.450	-	3.020	5.431	9.550
ED2-E Elec_Domestic_hot_water	0 kWh	1034 kWh	1034 kWh	900 kWh	0 kWh	1034 kWh	1034 kWh	900 kWh
ES1 Elec_solar_panels	0 kWh	-5538 kWh	-5538 kWh	-5538 kWh	0 kWh	-5538 kWh	-5538 kWh	-5538 kWh
ES2 Elec_BESS								
Etot-G Tot_gas_consumption	2749 m³	0 m³	0 m³	0 m³	3068 m³	0 m³	0 m³	0 m³
Etot-E Tot_electricity_consumption	0 kWh	-2084 kWh	434 kWh	3811 kWh	0 kWh	-1484 kWh	926 kWh	4912 kWh
BENG_1	186	27	46	72	187	28	45	73
BENG_2	186	-16	3	29	187	-10	6	34
BENG_3	0%	-266%	1275%	145%	0%	-373%	598%	113%
oper_Costs_gas_space_heating	€ 2.073	€ -	€ -	€ -	€ 2.313	€ -	€ -	€ -
oper_Costs_gas_DHW	€ 225	€ -	€ -	€ -	€ 225	€ -	€ -	€ -
oper_costs_elec_space_heating	€ -	€ 538	€ 1.097	€ 1.877	€ -	€ 671	€ 1.206	€ 2.122
oper_costs_elec_DHW	€ -	€ 230	€ 230	€ 200	€ -	€ 230	€ 230	€ 200
op_costs_elec_solar_panels	€ -	€ (406)	€ (406)	€ (406)	€ -	€ (406)	€ (406)	€ (406)
Tot_operational_costs	€ 2.298	€ 361	€ 921	€ 1.671	€ 2.537	€ 495	€ 1.030	€ 1.916
Initial_costs_insulation	€ -	€ 9.261,60	€ 2.604,00	€ -	€ -	€ 7.439,60	€ 2.828,00	€ -
inital_costs_ventilation								
initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -	€ -	€ 2.100,00	€ 1.120,00	€ -
initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00
inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
Tot_initial_costs	€ -	€ 27.599,75	€ 20.867,49	€ 22.896,52	€ -	€ 25.777,75	€ 21.091,49	€ 22.896,52
Heating_method	€ -	€ 174,03	€ 92,81	€ -	€ -	€ 174,03	€ 92,81	€ -
Heat_pump	€ -	€ 892,40	€ 967,42	€ 1.444,18	€ -	€ 892,40	€ 967,42	€ 1.444,18
Solar_panels	€ -	€ 453,26	€ 453,26	€ 453,26	€ -	€ 453,26	€ 453,26	€ 453,26
Tot_leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43
Tot_leasing_costs_initial	€ -	€ 9.261,60	€ 2.604,00	€ -	€ -	€ 7.439,60	€ 2.828,00	€ -
Delta_operational_costs	€ (0,52)	€ 1.936,16	€ 1.376,71	€ 626,57	€ (0,59)	€ 2.042,06	€ 1.506,60	€ 621,26
Initial_costs	€ -	€ 27.599,75	€ 20.867,49	€ 22.896,52	€ -	€ 25.777,75	€ 21.091,49	€ 22.896,52
housing_value_increase	€ -	€ 9.261,60	€ -	€ -	€ -	€ 7.439,60	€ -	€ -
pay_back_period	0 year	9 year	15 year	37 year	0 year	9 year	14 year	37 year
Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43
Annual_cost_in_decrease	0%	-18%	6%	55%	0%	-21%	0%	50%

Appendix 10. Case study selection overview.

Case number:	1	2	3	4	5	6	7	8	9	10	11	12	13
Client	Messelink	Stassar	Bauer	Veldman	Morshuis	de Boer	Rinck	Huizing	Jonker	van Dam	van Dijk	vd Berg	Westdorp
(1) Measuring period	X	V	V	V	V	V	X	V	V	V	X	X	X
starting point	01-12-18	01-09-18	01-10-18	01-09-18	01-09-18	01-08-18	01-12-18	01-09-18	01-10-18	01-08-18	01-12-18	01-11-19	01-11-19
most recent data point	01-01-19	01-01-19	01-01-19	01-01-19	20-12-18	01-01-19	01-01-19	01-01-19	01-01-19	01-01-19	20-12-18	20-12-18	20-12-19
months	1	4	3	4	4	5	1	4	3	5	1	2	2
(2) Heat pump	V	V	V	X	V	V	V	V	X	X	V	V	V
source	Air-source	Air-source	Air-source	Water-source	Air-source	Air-source	Air-source	Air-source	Water-source	Water-source	Air-source	Air-source	Air-source
output temp (degree C)	42	35	45	35	45	35	39	41	36	33	39	55	
(3) Data points	V	V	X	V	V	V	X	V	V	X	X	X	X
average indoor temperatre (degree C)	20,5	21,5	21	16	22,5	20	22,5	20,5	20	17,5		20	
COP (space heating + DHW) (kWh)	2,93	3,57		3,85	7,56	3,76		3,98	3,69	4,1	9,27		
space heating - heating demand (kWh)	62,9	1893	11127	120	18555	4543		7403	6610	5522	23155		931
domestic hot water - heating demand (kWh)	833	3378	2138	3876	3359	1405		919	1802		4957		4745
Building energy demand (kWh)	306	1587		1039	2897	1580	971	2090	2279	1342	3031	1426	
(4) Realistic data	V	V	X	V	X	V	X	V	V	X	X	X	X
if no, reason					COP to high					no DHW	COP to high		

Appendix 11a. Case study input from heat pump data point - Case 1

		data measuring point	Heating demand, space heating [kWh]	monthly total	Heating demand, DHW. [kWh]	monthly total	Total energy consumption heat pump[kWh]	monthly total
June								
		30-06-18 11:57	27,5		406,5		0	
July		01-07-18 04:04	27,5		406,6		0	
		31-07-18 14:23	27,5		641		133	
Aug		01-08-18 08:04	27,5		641		133	
		31-08-18 18:40	33		856,7		215	
Sept	start	01-09-18 08:26	33		857,2		215	
	end	30-09-18 15:06	189,1	156 kWh	1073,5	216 kWh	321	106 kWh
Oct	start	01-10-18 02:58	189,1		1073,5		321	
	end	31-10-18 23:07	795,4	606 kWh	1392,5	319 kWh	555	234 kWh
Nov	start	01-11-18 04:42	795,4		1392,5		555	
	end	30-11-18 22:57	2599,6	1804 kWh	1653,3	261 kWh	1035	480 kWh
Dec	start	01-11-18 04:42	795,4		1392,5		555	
	end	31-12-18 23:08	4543,1	3748 kWh	2002,5	610 kWh	1566	1011 kWh
Jan	start	01-01-19 00:10	4543,1		2002,5		1566	
	end	31-01-19 10:37	7013,3	2470 kWh	2383,1	381 kWh	2294	728 kWh
Feb		01-02-19 06:19	7013,3		2383,1		2294	
		01-02-19 15:45	7051,6		2391,6		2582	
total				8785 kWh		1787 kWh		2559 kWh

Appendix 11b. Case study input from heat pump data point - Case 2.

		data measuring point	Heating demand, space heating [kWh]	monthly total	Heating demand, DHW. [kWh]	monthly total	Total energy consumption heat pump[kWh]	monthly total
June								
		30-06-18 22:15	0		60,5		0	
July		01-07-18 09:46	0		60,7		0	
		31-07-18 13:41	0		408,7		12	
Aug		01-08-18 06:20	0		409,5		12	
		31-08-18 21:11	2,5		590,4		19	
Sept		01-09-18 07:50	2,5		590,4		19	
		30-09-18 22:30	178,3		898		64	
Oct	start	01-10-18 01:22	178,3		898		64	
	end	31-10-18 22:45	775,9	598 kWh	1313,4	415 kWh	374	310 kWh
Nov	start	01-11-18 00:29	775,9		1313,4		374	
	end	30-11-18 23:06	2111,1	1335 kWh	1987	674 kWh	923	549 kWh
Dec	start	01-12-18 01:09	2111,1		1987		923	
	end	31-12-18 22:41	3779,3	1668 kWh	2696,1	709 kWh	1586	663 kWh
Jan	start	01-01-19 00:30	3779,3		2696,1		1586	
	end	31-01-19 23:50	6048	2269 kWh	3354,3	658 kWh	2499	913 kWh
Feb		01-02-19 00:06	6048		3354,3		2499	
		01-02-19 15:48	6117,6		3372,1		2525	
total				5870 kWh		2456 kWh		2435 kWh

Appendix 11c. Case study input from heat pump data point - Case 3.

		data measuring point	Heating demand, space heating [kWh]	monthly total	Heating demand, DHW. [kWh]	monthly total	Total energy consumption heat pump[kWh]	monthly total
April		20-04-18 09:28	526,2		419,7		0	
		30-04-18 23:43	927,9		703		0	
May		01-05-18 01:01	927,9		703		0	
		31-05-18 20:24	1349,8		1383		0	
June		01-06-18 07:32	1349,8		1383		0	
		30-06-18 14:07	1429,1		2059,8		174	
July		01-07-18 09:48	1429,1		2059,8		174	
		31-07-18 10:19	1429,1		2588,3		174	
Aug		01-08-18 06:39	1429,1		2588,3		174	
		31-08-18 12:48	1487		2969,3		174	
Sept		01-09-18 08:25	1487		2969,3		174	
		30-09-18 23:12	2092,3		3566,5		174	
Oct		01-10-18 00:52	2092,3		3566,5		174	
		31-10-18 22:08	4219,2		4179,2		174	
Nov	start	01-11-18 00:35	4219,2		4179,2		174	
	end	30-11-18 22:19	8132,2	3913 kWh	4705,5	526 kWh	1077	903 kWh
Dec	start	01-12-18 00:46	8132,2		4705,5		1077	
	end	31-12-18 22:01	12369	4237 kWh	5234,1	529 kWh	2285	1208 kWh
Jan	start	01-01-19 05:03	12369		5234,1		2285	
	end	31-01-19 21:58	17296,9	4928 kWh	5884	650 kWh	3898	1613 kWh
Feb		01-02-19 01:36	17296,9		5884		3898	
		01-02-19 15:46	17433,4		5898		3946	
total				13078 kWh		1705 kWh		3724 kWh

Appendix 12. Data conversion and SCOP calculations for case studies

CASE 1			Direct data				Indirect data			
month	% energy /month (energiesite.nl)		Heating demand, space heating (R1)	heating demand, DHW	Energy demand heat pump, both space heating and DHW	COP, both space heating and DHW	COP, DHW (R5)	COP, Space heating (R6)	Energy demand, space heating (ED-1)	Energy demand, DHW (ED-2)
2	15%									
3	13%									
4	7%									
5	4%	45%	7285 kWh	1482 kWh	2122 kWh	4,13				
6	3%									
7	2%									
8	2%									
9	3%		156 kWh	216 kWh	106 kWh	3,51				
10	7%		606 kWh	319 kWh	234 kWh	3,95				
11	13%	55%	1804 kWh	261 kWh	480 kWh	4,30				
12	15%		3748 kWh	610 kWh	1011 kWh	4,31				
1	17%		2470 kWh	381 kWh	728 kWh	3,92				
Yearly total	100%	100%	16069 kWh	3268 kWh	4681 kWh	4,02	2,80	4,57	3514 kWh	1167 kWh

CASE 2			Direct data				Indirect data			
month	% energy /month (energiesite.nl)		Heating demand, space heating (R1)	heating demand, DHW	Energy consumption heat pump, both space heating and DHW	COP, both space heating and DHW	COP, DHW (R5)	COP, Space heating (R6)	Energy demand, space heating (ED-1)	Energy demand, DHW (ED-2)
2	15%									
3	13%									
4	7%									
5	4%	48%	5418 kWh	2267 kWh	2248 kWh	3,42				
6	3%									
7	2%									
8	2%									
9	3%									
10	7%		598 kWh	415 kWh	310 kWh	3,27				
11	13%	52%	1335 kWh	674 kWh	549 kWh	3,66				
12	15%		1668 kWh	709 kWh	663 kWh	3,59				
1	17%		2269 kWh	658 kWh	913 kWh	3,21				
Yearly total	100%	100%	11288 kWh	4724 kWh	4683 kWh	3,43	2,80	3,77	2996 kWh	1687 kWh

CASE 3			Direct data				Indirect data			
month	% energy /month (energiesite.nl)		Heating demand, space heating (R1)	heating demand, DHW	Energy consumption heat pump, both space heating and DHW	COP, both space heating and DHW	COP, DHW (R5)	COP, Space heating (R6)	Energy demand, space heating (ED-1)	Energy demand, DHW (ED-2)
2	15%									
3	13%									
4	7%									
5	4%									
6	3%	55%	16201 kWh	2112 kWh	4613 kWh	3,97				
7	2%									
8	2%									
9	3%									
10	7%									
11	13%		3913 kWh	526 kWh	903 kWh	4,92				
12	15%	45%	4237 kWh	529 kWh	1208 kWh	3,94				
1	17%		4928 kWh	650 kWh	1613 kWh	3,46				
Yearly total	100%	100%	29278 kWh	3817 kWh	8337 kWh	4,07	2,80	4,20	6974 kWh	1363 kWh

Appendix 13. Transition tool outcomes for each scenario

Scenariosamenvatting		Detached 1GAS	<1964 1A	130 m2 1B	1C
	construction_period	<1964	<1964	<1964	<1964
	Housing_type	Detached	Detached	Detached	Detached
	Surface	130 m2	130 m2	130 m2	130 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
insulation result	minimal_heating_demand	166	61	106	166
Energetic performance	Tot_gas_consumption	2749 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-2084 kWh	434 kWh	3811 kWh
	BENG_1	186	27	46	72
	BENG_2	186	-16	3	29
	BENG_3	0%	-266%	1275%	145%
Costs	Tot_operational_costs	€ 2.298	€ 361	€ 921	€ 1.671
	Initial_costs_insulation	€ -	€ 9.261,60	€ 2.604,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,52)	€ 1.936,16	€ 1.376,71	€ 626,57
	Initial_costs	€ -	€ 27.599,75	€ 20.867,49	€ 22.896,52
	housing_value_increase	€ -	€ 9.261,60	€ -	€ -
Average user group	pay_back_period	0 year	9 year	15 year	37 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43
	Annual_cost_in_decrease	0%	-18%	6%	55%
	User_group	Working co	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	129	57	129	129
	Tot_gas_consumption	2111 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-2597 kWh	1157 kWh	1563 kWh
	BENG_1	143	23	52	55
	BENG_2	143	-20	9	12
	BENG_3	0%	-213%	479%	354%
	Tot_operational_costs	€ 1.820	€ 248	€ 1.081	€ 1.172
	Initial_costs_insulation	€ -	€ 6.431,60	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,41)	€ 1.572,02	€ 738,18	€ 648,02
	Initial_costs	€ -	€ 24.769,75	€ 18.263,49	€ 19.166,52
	housing_value_increase	€ -	€ 6.431,60	€ -	€ -
Working couple	pay_back_period	0 year	12 year	25 year	30 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.588,33
	Annual_cost_in_decrease	0%	-3%	43%	52%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	166	61	106	166
	Tot_gas_consumption	2849 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1739 kWh	779 kWh	4111 kWh
	BENG_1	193	29	49	74
	BENG_2	193	-13	6	32
	BENG_3	0%	-318%	711%	135%
	Tot_operational_costs	€ 2.373	€ 438	€ 997	€ 1.738
	Initial_costs_insulation	€ -	€ 9.261,60	€ 2.604,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,52)	€ 1.934,50	€ 1.375,05	€ 634,84
	Initial_costs	€ -	€ 27.599,75	€ 20.867,49	€ 22.896,52
	housing_value_increase	€ -	€ 9.261,60	€ -	€ -
Family	pay_back_period	0 year	9 year	15 year	36 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43
	Annual_cost_in_decrease	0%	-17%	6%	53%
	construction_period	<1964	<1964	<1964	<1964
	Housing_type	Detached	Detached	Detached	Detached
	Surface	130 m2	130 m2	130 m2	130 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	199	38	128	199
	Tot_gas_consumption	3147 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-3346 kWh	1094 kWh	5229 kWh
	BENG_1	213	17	51	83
	BENG_2	213	-26	8	40
	BENG_3	0%	-166%	506%	106%
	Tot_operational_costs	€ 2.597	€ 81	€ 1.067	€ 1.986
	Initial_costs_insulation	€ -	€ 23.352,60	€ 2.604,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,63)	€ 2.514,85	€ 1.528,62	€ 610,02
	Initial_costs	€ -	€ 41.690,75	€ 20.867,49	€ 22.896,52
	housing_value_increase	€ -	€ 20.928,10	€ -	€ -
Eldery	pay_back_period	0 year	8 year	14 year	38 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43
	Annual_cost_in_decrease	0%	-38%	-1%	50%

Scenariosamenvatting		Detached 2GAS	1965-1974 2A	144 m2 2B	2C
	construction_period	1965-1974	1965-1974	1965-1974	1965-1974
	Housing_type	Detached	Detached	Detached	Detached
	Surface	144 m2	144 m2	144 m2	144 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
insulation result	minimal_heating_demand	169	69	106	169
Energetic performance	Tot_gas_consumption	3068 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1484 kWh	926 kWh	4912 kWh
	BENG_1	187	28	45	73
	BENG_2	187	-10	6	34
	BENG_3	0%	-373%	598%	113%
Costs	Tot_operational_costs	€ 2.537	€ 495	€ 1.030	€ 1.916
	Initial_costs_insulation	€ -	€ 7.439,60	€ 2.828,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,59)	€ 2.042,06	€ 1.506,60	€ 621,26
	Initial_costs	€ -	€ 25.777,75	€ 21.091,49	€ 22.896,52
	housing_value_increase	€ -	€ 7.439,60	€ -	€ -
Average user group	pay_back_period	0 year	9 year	14 year	37 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43
	Annual_cost_in_decrease	0%	-21%	0%	50%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	132	54	132	132
	Tot_gas_consumption	2360 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-2492 kWh	1344 kWh	#N/B
	BENG_1	144	21	48	#N/B
	BENG_2	144	-17	9	#N/B
	BENG_3	0%	-222%	412%	#N/B
	Tot_operational_costs	€ 2.007	€ 271	€ 1.123	#N/B
	Initial_costs_insulation	€ -	€ 7.439,60	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.680,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 13.878,71	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,46)	€ 1.735,41	€ 883,31	#N/B
	Initial_costs	€ -	€ 25.777,75	€ 21.028,23	€ 20.594,52
	housing_value_increase	€ -	€ 7.439,60	€ -	€ -
Working couple	pay_back_period	0 year	11 year	24 year	#N/B
	Leasing_costs	€ -	€ 1.519,68	€ 1.742,61	€ 1.706,67
	Annual_cost_in_decrease	0%	-11%	43%	#N/B
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	169	69	106	169
	Tot_gas_consumption	3168 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1139 kWh	1271 kWh	5212 kWh
	BENG_1	193	31	47	75
	BENG_2	193	-8	9	36
	BENG_3	0%	-486%	436%	106%
	Tot_operational_costs	€ 2.612	€ 571	€ 1.107	€ 1.982
	Initial_costs_insulation	€ -	€ 7.439,60	€ 2.828,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,59)	€ 2.040,40	€ 1.504,93	€ 629,53
	Initial_costs	€ -	€ 25.777,75	€ 21.091,49	€ 22.896,52
	housing_value_increase	€ -	€ 7.439,60	€ -	€ -
Family	pay_back_period	0 year	9 year	14 year	36 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.897,43
	Annual_cost_in_decrease	0%	-20%	0%	49%
	construction_period	1965-1974	1965-1974	1965-1974	1965-1974
	Housing_type	Detached	Detached	Detached	Detached
	Surface	144 m2	144 m2	144 m2	144 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	203	63	127	203
	Tot_gas_consumption	3531 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-2111 kWh	1110 kWh	6553 kWh
	BENG_1	216	24	46	84
	BENG_2	216	-15	8	46
	BENG_3	0%	-262%	499%	85%
	Tot_operational_costs	€ 2.884	€ 355	€ 1.071	€ 2.280
	Initial_costs_insulation	€ -	€ 11.069,60	€ 2.828,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.680,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 13.878,71	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,71)	€ 2.528,34	€ 1.812,68	€ 603,64
	Initial_costs	€ -	€ 29.407,75	€ 23.856,23	€ 22.896,52
	housing_value_increase	€ -	€ 11.069,60	€ -	€ -
Eldery	pay_back_period	0 year	7 year	13 year	38 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.742,61	€ 1.897,43
	Annual_cost_in_decrease	0%	-35%	-2%	45%

Scenariosamenvatting		Detached 3GAS	1975-1991 3A	154 m2 3B	3C
	construction_period	1975-1991	1975-1991	1975-1991	1975-1991
	Housing_type	Detached	Detached	Detached	Detached
	Surface	154 m2	154 m2	154 m2	154 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
insulation result	minimal_heating_demand	95	65	95	95
Energetic performance	Tot_gas_consumption	1956 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1453 kWh	700 kWh	1000 kWh
	BENG_1	112	27	41	42
	BENG_2	112	-9	5	6
	BENG_3	0%	-381%	792%	554%
Costs	Tot_operational_costs	€ 1.703	€ 502	€ 980	€ 1.047
	Initial_costs_insulation	€ -	€ 6.130,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,35)	€ 1.201,56	€ 723,30	€ 656,59
	Initial_costs	€ -	€ 24.468,15	€ 18.263,49	€ 19.166,52
	housing_value_increase	€ -	€ 6.130,00	€ -	€ -
Average user group	pay_back_period	0 year	15 year	25 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.588,33
	Annual_cost_in_decrease	0%	19%	46%	55%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	74	58	74	74
	Tot_gas_consumption	1492 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-2147 kWh	-787 kWh	-539 kWh
	BENG_1	85	22	31	32
	BENG_2	85	-14	-5	-4
	BENG_3	0%	-258%	-703%	-1027%
	Tot_operational_costs	€ 1.356	€ 348	€ 649	€ 705
	Initial_costs_insulation	€ -	€ 2.660,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,27)	€ 1.008,07	€ 706,13	€ 650,99
	Initial_costs	€ -	€ 20.998,15	€ 17.078,15	€ 19.166,52
	housing_value_increase	€ -	€ 2.660,00	€ -	€ -
Working couple	pay_back_period	0 year	18 year	24 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.415,27	€ 1.588,33
	Annual_cost_in_decrease	0%	38%	52%	69%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	95	65	95	95
	Tot_gas_consumption	2056 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1109 kWh	1044 kWh	1304 kWh
	BENG_1	117	29	43	44
	BENG_2	117	-7	7	8
	BENG_3	0%	-500%	530%	425%
	Tot_operational_costs	€ 1.778	€ 578	€ 1.056	€ 1.114
	Initial_costs_insulation	€ -	€ 6.130,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,35)	€ 1.199,90	€ 721,64	€ 663,94
	Initial_costs	€ -	€ 24.468,15	€ 18.263,49	€ 19.166,52
	housing_value_increase	€ -	€ 6.130,00	€ -	€ -
Family	pay_back_period	0 year	15 year	25 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.513,50	€ 1.588,33
	Annual_cost_in_decrease	0%	18%	45%	52%
	construction_period	1975-1991	1975-1991	1975-1991	1975-1991
	Housing_type	Detached	Detached	Detached	Detached
	Surface	154 m2	154 m2	154 m2	154 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	114	70	114	114
	Tot_gas_consumption	2193 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1599 kWh	859 kWh	#N/B
	BENG_1	125	26	42	#N/B
	BENG_2	125	-10	6	#N/B
	BENG_3	0%	-346%	645%	#N/B
	Tot_operational_costs	€ 1.881	€ 469	€ 1.015	#N/B
	Initial_costs_insulation	€ -	€ 10.162,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.680,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 13.878,71	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,42)	€ 1.411,47	€ 865,39	#N/B
	Initial_costs	€ -	€ 28.500,15	€ 21.028,23	€ 20.594,52
	housing_value_increase	€ -	€ 10.162,00	€ -	€ -
Eldery	pay_back_period	0 year	13 year	24 year	#N/B
	Leasing_costs	€ -	€ 1.519,68	€ 1.742,61	€ 1.706,67
	Annual_cost_in_decrease	0%	6%	47%	#N/B

Scenariosamenvatting		Detached 4GAS	1992-2005 4A	172 m2 4B	4C
	construction_period	1992-2005	1992-2005	1992-2005	1992-2005
	Housing_type	Detached	Detached	Detached	Detached
	Surface	172 m2	172 m2	172 m2	172 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
insulation result	minimal_heating_demand	73	64	73	73
Energetic performance	Tot_gas_consumption	1735 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1147 kWh	6 kWh	250 kWh
	BENG_1	89	26	32	34
	BENG_2	89	-7	0	1
	BENG_3	0%	-483%	99244%	2219%
Costs	Tot_operational_costs	€ 1.538	€ 570	€ 826	€ 880
	Initial_costs_insulation	€ -	€ 6.020,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,30)	€ 967,87	€ 711,86	€ 657,65
	Initial_costs	€ -	€ 24.358,15	€ 17.078,15	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Average user group	pay_back_period	0 year	25 year	24 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.415,27	€ 1.588,33
	Annual_cost_in_decrease	0%	36%	46%	61%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	57	57	57	57
	Tot_gas_consumption	1320 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1862 kWh	-1329 kWh	-1125 kWh
	BENG_1	67	21	24	26
	BENG_2	67	-11	-8	-7
	BENG_3	0%	-297%	-417%	-492%
	Tot_operational_costs	€ 1.227	€ 411	€ 529	€ 575
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,24)	€ 815,67	€ 697,20	€ 651,81
	Initial_costs	€ -	€ 18.338,15	€ 17.078,15	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	22 year	24 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.415,27	€ 1.588,33
	Annual_cost_in_decrease	0%	57%	59%	76%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	73	64	73	73
	Tot_gas_consumption	1835 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-802 kWh	350 kWh	554 kWh
	BENG_1	94	28	34	35
	BENG_2	94	-5	2	3
	BENG_3	0%	-690%	1581%	1000%
	Tot_operational_costs	€ 1.613	€ 646	€ 902	€ 947
	Initial_costs_insulation	€ -	€ 6.020,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,30)	€ 966,20	€ 710,19	€ 665,00
	Initial_costs	€ -	€ 24.358,15	€ 17.078,15	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Family	pay_back_period	0 year	25 year	24 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.415,27	€ 1.588,33
	Annual_cost_in_decrease	0%	34%	44%	57%
	construction_period	1992-2005	1992-2005	1992-2005	1992-2005
	Housing_type	Detached	Detached	Detached	Detached
	Surface	172 m2	172 m2	172 m2	172 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	88	79	88	88
	Tot_gas_consumption	1927 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-835 kWh	578 kWh	936 kWh
	BENG_1	99	27	36	38
	BENG_2	99	-5	3	5
	BENG_3	0%	-663%	959%	591%
	Tot_operational_costs	€ 1.682	€ 639	€ 953	€ 1.032
	Initial_costs_insulation	€ -	€ 6.020,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.800,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 11.673,97	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,37)	€ 1.042,51	€ 728,63	€ 648,90
	Initial_costs	€ -	€ 25.963,49	€ 18.263,49	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Eldery	pay_back_period	0 year	25 year	25 year	30 year
	Leasing_costs	€ -	€ 1.652,72	€ 1.513,50	€ 1.588,33
	Annual_cost_in_decrease	0%	36%	47%	56%

Scenariosamenvatting		Detached 5GAS	2006-2011 5A	172 m2 5B	5C
	construction_period	2006-2011	2006-2011	2006-2011	2006-2011
	Housing_type	Detached	Detached	Detached	Detached
	Surface	172 m2	172 m2	172 m2	172 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
insulation result	minimal_heating_demand	85	76	85	85
Energetic performance	Tot_gas_consumption	1957 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-671 kWh	703 kWh	1004 kWh
	BENG_1	100	28	36	38
	BENG_2	100	-4	4	6
	BENG_3	0%	-825%	788%	552%
Costs	Tot_operational_costs	€ 1.704	€ 675	€ 981	€ 1.047
	Initial_costs_insulation	€ -	€ 6.020,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.800,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 11.673,97	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,35)	€ 1.028,66	€ 723,36	€ 656,59
	Initial_costs	€ -	€ 25.963,49	€ 18.263,49	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Average user group	pay_back_period	0 year	25 year	25 year	29 year
	Leasing_costs	€ -	€ 1.652,72	€ 1.513,50	€ 1.588,33
	Annual_cost_in_decrease	0%	37%	46%	55%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	66	66	66	66
	Tot_gas_consumption	1493 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1400 kWh	-785 kWh	-536 kWh
	BENG_1	76	24	28	29
	BENG_2	76	-8	-5	-3
	BENG_3	0%	-395%	-706%	-1033%
	Tot_operational_costs	€ 1.357	€ 513	€ 650	€ 705
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,27)	€ 842,98	€ 706,17	€ 650,98
	Initial_costs	€ -	€ 18.338,15	€ 17.078,15	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	22 year	24 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.415,27	€ 1.588,33
	Annual_cost_in_decrease	0%	50%	52%	69%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	85	#GETAL!	85	85
	Tot_gas_consumption	2057 m³	76 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-326 kWh	1048 kWh	1308 kWh
	BENG_1	105	30	38	40
	BENG_2	105	-2	6	8
	BENG_3	0%	-1697%	528%	423%
	Tot_operational_costs	€ 1.779	€ 752	€ 1.057	€ 1.115
	Initial_costs_insulation	€ -	€ 6.020,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.800,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 11.673,97	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,35)	€ 1.026,99	€ 721,70	€ 663,93
	Initial_costs	€ -	€ 25.963,49	€ 18.263,49	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Family	pay_back_period	0 year	25 year	25 year	29 year
	Leasing_costs	€ -	€ 1.652,72	€ 1.513,50	€ 1.588,33
	Annual_cost_in_decrease	0%	35%	45%	52%
	construction_period	2006-2011	2006-2011	2006-2011	2006-2011
	Housing_type	Detached	Detached	Detached	Detached
	Surface	172 m2	172 m2	172 m2	172 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	102	90	102	102
	Tot_gas_consumption	2194 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-316 kWh	863 kWh	1844 kWh
	BENG_1	112	30	37	43
	BENG_2	112	-2	5	11
	BENG_3	0%	-1753%	642%	300%
	Tot_operational_costs	€ 1.882	€ 754	€ 1.016	€ 1.234
	Initial_costs_insulation	€ -	€ 19.308,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.800,00	€ 1.680,00	€ -
	initial_costs_heat_pump	€ -	€ 11.673,97	€ 13.878,71	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,42)	€ 1.127,45	€ 865,54	€ 647,62
	Initial_costs	€ -	€ 39.251,49	€ 21.028,23	€ 20.594,52
	housing_value_increase	€ -	€ -	€ -	€ -
Eldery	pay_back_period	0 year	35 year	24 year	32 year
	Leasing_costs	€ -	€ 1.652,72	€ 1.742,61	€ 1.706,67
	Annual_cost_in_decrease	0%	28%	47%	56%

Scenariosamenvatting		Detached 6GAS	2012-2017 6A	172 m2 6B	6C
	construction_period	2012-2017	2012-2017	2012-2017	2012-2017
	Housing_type	Detached	Detached	Detached	Detached
	Surface	172 m2	172 m2	172 m2	172 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
insulation result	minimal_heating_demand	71	62	71	71
Energetic performance	Tot_gas_consumption	1683 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1285 kWh	-157 kWh	74 kWh
	BENG_1	86	25	31	33
	BENG_2	86	-7	-1	0
	BENG_3	0%	-431%	-3525%	7515%
Costs	Tot_operational_costs	€ 1.499	€ 539	€ 789	€ 841
	Initial_costs_insulation	€ -	€ 6.020,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,29)	€ 959,71	€ 709,17	€ 657,90
	Initial_costs	€ -	€ 24.358,15	€ 17.078,15	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Average user group	pay_back_period	0 year	25 year	24 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.415,27	€ 1.588,33
	Annual_cost_in_decrease	0%	37%	47%	62%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	55	55	55	55
	Tot_gas_consumption	1280 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-1970 kWh	-1456 kWh	-1262 kWh
	BENG_1	65	21	24	25
	BENG_2	65	-11	-8	-7
	BENG_3	0%	-281%	-380%	-439%
	Tot_operational_costs	€ 1.196	€ 387	€ 501	€ 544
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,23)	€ 809,31	€ 695,10	€ 652,01
	Initial_costs	€ -	€ 18.338,15	€ 17.078,15	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	23 year	25 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.415,27	€ 1.588,33
	Annual_cost_in_decrease	0%	59%	60%	78%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	71	62	71	71
	Tot_gas_consumption	1783 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-940 kWh	188 kWh	378 kWh
	BENG_1	91	27	33	34
	BENG_2	91	-5	1	2
	BENG_3	0%	-589%	2953%	1466%
	Tot_operational_costs	€ 1.574	€ 616	€ 866	€ 908
	Initial_costs_insulation	€ -	€ 6.020,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,29)	€ 958,04	€ 707,51	€ 665,25
	Initial_costs	€ -	€ 24.358,15	€ 17.078,15	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Family	pay_back_period	0 year	25 year	24 year	29 year
	Leasing_costs	€ -	€ 1.519,68	€ 1.415,27	€ 1.588,33
	Annual_cost_in_decrease	0%	36%	45%	59%
	construction_period	2012-2017	2012-2017	2012-2017	2012-2017
	Housing_type	Detached	Detached	Detached	Detached
	Surface	172 m2	172 m2	172 m2	172 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	20 panels	20 panels	20 panels
	minimal_heating_demand	85	85	85	85
	Tot_gas_consumption	1865 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-541 kWh	382 kWh	725 kWh
	BENG_1	95	29	34	36
	BENG_2	95	-3	2	4
	BENG_3	0%	-1023%	1451%	764%
	Tot_operational_costs	€ 1.635	€ 704	€ 909	€ 985
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.800,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 11.673,97	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 5.469,52	€ 5.469,52	€ 5.469,52
	Delta_operational_costs	€ (0,35)	€ 930,47	€ 725,40	€ 649,20
	Initial_costs	€ -	€ 19.943,49	€ 18.263,49	€ 19.166,52
	housing_value_increase	€ -	€ -	€ -	€ -
Eldery	pay_back_period	0 year	21 year	25 year	30 year
	Leasing_costs	€ -	€ 1.652,72	€ 1.513,50	€ 1.588,33
	Annual_cost_in_decrease	0%	44%	48%	57%

Scenariosamenvatting		Semi-Detached	<1964	110 m2	
		7GAS	7A	7B	7C
	construction_period	<1964	<1964	<1964	<1964
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	110 m2	110 m2	110 m2	110 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	10 panels	10 panels	10 panels
insulation result	minimal_heating_demand	171	58	109	171
Energetic performance	Tot_gas_consumption	2437 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	196 kWh	2542 kWh	5405 kWh
	BENG_1	195	27	48	74
	BENG_2	195	2	23	49
	BENG_3	0%	1413%	109%	51%
Costs	Tot_operational_costs	€ 2.065	€ 456	€ 977	€ 1.613
	Initial_costs_insulation	€ -	€ 7.186,40	€ 1.848,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 2.818,72	€ 2.818,72	€ 2.818,72
	Delta_operational_costs	€ (0,45)	€ 1.608,41	€ 1.087,32	€ 451,30
	Initial_costs	€ -	€ 22.873,75	€ 16.275,35	€ 17.943,72
	housing_value_increase	€ -	€ 7.186,40	€ -	€ -
Average user group	pay_back_period	0 year	10 year	15 year	40 year
	Leasing_costs	€ -	€ 1.300,01	€ 1.195,59	€ 1.487,00
	Annual_cost_in_decrease	0%	-15%	5%	50%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	10 panels	10 panels	10 panels
	minimal_heating_demand	133	58	133	133
	Tot_gas_consumption	1868 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-156 kWh	3163 kWh	3507 kWh
	BENG_1	149	24	54	57
	BENG_2	149	-1	29	32
	BENG_3	0%	-1774%	88%	79%
	Tot_operational_costs	€ 1.638	€ 378	€ 1.115	€ 1.191
	Initial_costs_insulation	€ -	€ 4.586,40	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.818,72	€ 2.818,72	€ 2.818,72
	Delta_operational_costs	€ (0,35)	€ 1.259,87	€ 522,61	€ 446,20
	Initial_costs	€ -	€ 20.273,75	€ 15.612,69	€ 16.515,72
	housing_value_increase	€ -	€ 4.586,40	€ -	€ -
Working couple	pay_back_period	0 year	12 year	30 year	37 year
	Leasing_costs	€ -	€ 1.300,01	€ 1.293,82	€ 1.368,66
	Annual_cost_in_decrease	0%	2%	47%	56%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	10 panels	10 panels	10 panels
	minimal_heating_demand	171	58	109	171
	Tot_gas_consumption	2537 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	541 kWh	2886 kWh	5709 kWh
	BENG_1	203	30	51	77
	BENG_2	203	5	26	52
	BENG_3	0%	512%	96%	49%
	Tot_operational_costs	€ 2.140	€ 532	€ 1.053	€ 1.680
	Initial_costs_insulation	€ -	€ 7.186,40	€ 1.848,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 2.818,72	€ 2.818,72	€ 2.818,72
	Delta_operational_costs	€ (0,45)	€ 1.606,75	€ 1.085,66	€ 458,65
	Initial_costs	€ -	€ 22.873,75	€ 16.275,35	€ 17.943,72
	housing_value_increase	€ -	€ 7.186,40	€ -	€ -
Family	pay_back_period	0 year	10 year	15 year	39 year
	Leasing_costs	€ -	€ 1.300,01	€ 1.195,59	€ 1.487,00
	Annual_cost_in_decrease	0%	-14%	5%	48%
	construction_period	<1964	<1964	<1964	<1964
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	110 m2	110 m2	110 m2	110 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	10 panels	10 panels	10 panels
	minimal_heating_demand	206	70	131	206
	Tot_gas_consumption	2772 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	244 kWh	3066 kWh	6705 kWh
	BENG_1	222	27	53	86
	BENG_2	222	2	28	61
	BENG_3	0%	1136%	90%	41%
	Tot_operational_costs	€ 2.316	€ 466	€ 1.093	€ 1.902
	Initial_costs_insulation	€ -	€ 7.186,40	€ 1.848,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 2.818,72	€ 2.818,72	€ 2.818,72
	Delta_operational_costs	€ (0,55)	€ 1.848,67	€ 1.221,66	€ 413,27
	Initial_costs	€ -	€ 22.873,75	€ 17.460,69	€ 20.245,72
	housing_value_increase	€ -	€ 7.186,40	€ -	€ -
Eldery	pay_back_period	0 year	8 year	14 year	49 year
	Leasing_costs	€ -	€ 1.300,01	€ 1.293,82	€ 1.677,76
	Annual_cost_in_decrease	0%	-24%	3%	55%

Scenariosamenvatting		Semi-Detached	1965-1974	123 m2	
		8GAS	8A	8B	8C
	construction_period	1965-1974	1965-1974	1965-1974	1965-1974
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	123 m2	123 m2	123 m2	123 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	10 panels	10 panels	10 panels
insulation result	minimal_heating_demand	149	68	99	149
Energetic performance	Tot_gas_consumption	2382 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	806 kWh	2608 kWh	5216 kWh
	BENG_1	170	29	44	65
	BENG_2	170	7	21	42
	BENG_3	0%	343%	106%	53%
Costs	Tot_operational_costs	€ 2.023	€ 591	€ 992	€ 1.571
	Initial_costs_insulation	€ -	€ 4.611,60	€ 1.680,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 2.818,72	€ 2.818,72	€ 2.818,72
	Delta_operational_costs	€ (0,44)	€ 1.431,24	€ 1.030,97	€ 451,56
	Initial_costs	€ -	€ 20.298,95	€ 16.107,35	€ 17.943,72
	housing_value_increase	€ -	€ 4.611,60	€ -	€ -
Average user group	pay_back_period	0 year	11 year	16 year	40 year
	Leasing_costs	€ -	€ 1.300,01	€ 1.195,59	€ 1.487,00
	Annual_cost_in_decrease	0%	-6%	8%	51%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	10 panels	10 panels	10 panels
	minimal_heating_demand	116	53	116	116
	Tot_gas_consumption	1825 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-96 kWh	3027 kWh	3359 kWh
	BENG_1	130	22	47	50
	BENG_2	130	-1	25	27
	BENG_3	0%	-2874%	91%	82%
	Tot_operational_costs	€ 1.605	€ 391	€ 1.085	€ 1.158
	Initial_costs_insulation	€ -	€ 4.611,60	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.818,72	€ 2.818,72	€ 2.818,72
	Delta_operational_costs	€ (0,35)	€ 1.214,11	€ 520,37	€ 446,41
	Initial_costs	€ -	€ 20.298,95	€ 15.612,69	€ 16.515,72
	housing_value_increase	€ -	€ 4.611,60	€ -	€ -
Working couple	pay_back_period	0 year	13 year	30 year	37 year
	Leasing_costs	€ -	€ 1.300,01	€ 1.293,82	€ 1.368,66
	Annual_cost_in_decrease	0%	5%	48%	57%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	10 panels	10 panels	10 panels
	minimal_heating_demand	149	68	99	149
	Tot_gas_consumption	2482 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	1151 kWh	2953 kWh	5520 kWh
	BENG_1	177	32	47	67
	BENG_2	177	9	24	45
	BENG_3	0%	241%	94%	50%
	Tot_operational_costs	€ 2.098	€ 668	€ 1.068	€ 1.639
	Initial_costs_insulation	€ -	€ 4.611,60	€ 1.680,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 2.818,72	€ 2.818,72	€ 2.818,72
	Delta_operational_costs	€ (0,44)	€ 1.429,58	€ 1.029,31	€ 458,91
	Initial_costs	€ -	€ 20.298,95	€ 16.107,35	€ 17.943,72
	housing_value_increase	€ -	€ 4.611,60	€ -	€ -
Family	pay_back_period	0 year	11 year	16 year	39 year
	Leasing_costs	€ -	€ 1.300,01	€ 1.195,59	€ 1.487,00
	Annual_cost_in_decrease	0%	-6%	8%	49%
	construction_period	1965-1974	1965-1974	1965-1974	1965-1974
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	123 m2	123 m2	123 m2	123 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	10 panels	10 panels	10 panels
	minimal_heating_demand	179	59	119	179
	Tot_gas_consumption	2705 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	102 kWh	3146 kWh	6475 kWh
	BENG_1	193	23	48	75
	BENG_2	193	1	26	53
	BENG_3	0%	2715%	88%	43%
	Tot_operational_costs	€ 2.265	€ 435	€ 1.111	€ 1.851
	Initial_costs_insulation	€ -	€ 7.741,60	€ 1.680,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 2.818,72	€ 2.818,72	€ 2.818,72
	Delta_operational_costs	€ (0,53)	€ 1.830,10	€ 1.153,86	€ 414,38
	Initial_costs	€ -	€ 23.428,95	€ 17.292,69	€ 20.245,72
	housing_value_increase	€ -	€ 7.741,60	€ -	€ -
Eldery	pay_back_period	0 year	9 year	15 year	49 year
	Leasing_costs	€ -	€ 1.300,01	€ 1.293,82	€ 1.677,76
	Annual_cost_in_decrease	0%	-23%	6%	56%

Scenariosamenvatting		Semi-Detached	1975-1991	123 m2	
		9GAS	9A	9B	9C
	construction_period	1975-1991	1975-1991	1975-1991	1975-1991
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	123 m2	123 m2	123 m2	123 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
insulation result	minimal_heating_demand	84	66	84	84
Energetic performance	Tot_gas_consumption	1475 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	186 kWh	1404 kWh	1582 kWh
	BENG_1	105	29	38	40
	BENG_2	105	2	11	13
	BENG_3	0%	1784%	237%	210%
Costs	Tot_operational_costs	€ 1.343	€ 536	€ 807	€ 846
	Initial_costs_insulation	€ -	€ 5.444,80	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,25)	€ 806,58	€ 536,00	€ 496,51
	Initial_costs	€ -	€ 22.039,69	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ 5.444,80	€ -	€ -
Average user group	pay_back_period	0 year	21 year	29 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	42%	55%	71%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	66	66	66	66
	Tot_gas_consumption	1117 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-188 kWh	249 kWh	401 kWh
	BENG_1	80	25	29	30
	BENG_2	80	-2	2	3
	BENG_3	0%	-1769%	1335%	828%
	Tot_operational_costs	€ 1.074	€ 453	€ 550	€ 584
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,19)	€ 621,32	€ 524,30	€ 490,40
	Initial_costs	€ -	€ 16.594,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	27 year	29 year	36 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	70%	69%	89%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	84	66	84	84
	Tot_gas_consumption	1575 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	531 kWh	1749 kWh	1886 kWh
	BENG_1	113	31	41	42
	BENG_2	113	4	14	15
	BENG_3	0%	626%	190%	176%
	Tot_operational_costs	€ 1.418	€ 613	€ 883	€ 914
	Initial_costs_insulation	€ -	€ 5.444,80	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,25)	€ 804,92	€ 534,34	€ 503,86
	Initial_costs	€ -	€ 22.039,69	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ 5.444,80	€ -	€ -
Family	pay_back_period	0 year	21 year	29 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	40%	52%	66%
	construction_period	1975-1991	1975-1991	1975-1991	1975-1991
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	123 m2	123 m2	123 m2	123 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	101	66	101	101
	Tot_gas_consumption	1614 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-192 kWh	1810 kWh	2089 kWh
	BENG_1	115	25	42	44
	BENG_2	115	-2	15	17
	BENG_3	0%	-1732%	184%	159%
	Tot_operational_costs	€ 1.447	€ 452	€ 897	€ 959
	Initial_costs_insulation	€ -	€ 11.597,80	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,30)	€ 994,80	€ 550,04	€ 488,02
	Initial_costs	€ -	€ 28.192,69	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ 8.331,25	€ -	€ -
Eldery	pay_back_period	0 year	20 year	28 year	36 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	26%	50%	66%

Scenariosamenvatting		Semi-Detached	1992-2005	132 m2	
		10GAS	10A	10B	10C
	construction_period	1992-2005	1992-2005	1992-2005	1992-2005
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	132 m2	132 m2	132 m2	132 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
insulation result	minimal_heating_demand	69	69	69	69
Energetic performance	Tot_gas_consumption	1341 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	486 kWh	982 kWh	1125 kWh
	BENG_1	89	29	33	34
	BENG_2	89	4	7	9
	BENG_3	0%	684%	339%	295%
Costs	Tot_operational_costs	€ 1.242	€ 603	€ 713	€ 745
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,22)	€ 639,12	€ 529,03	€ 497,15
	Initial_costs	€ -	€ 16.594,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Average user group	pay_back_period	0 year	26 year	29 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	59%	60%	76%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	54	54	54	54
	Tot_gas_consumption	1012 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-468 kWh	-81 kWh	45 kWh
	BENG_1	67	22	25	26
	BENG_2	67	-4	-1	0
	BENG_3	0%	-710%	-4098%	7424%
	Tot_operational_costs	€ 996	€ 391	€ 477	€ 505
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,17)	€ 604,78	€ 518,86	€ 490,90
	Initial_costs	€ -	€ 16.594,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	27 year	30 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	77%	76%	96%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	69	69	69	69
	Tot_gas_consumption	1440 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	831 kWh	1326 kWh	1429 kWh
	BENG_1	96	31	35	36
	BENG_2	96	6	10	11
	BENG_3	0%	400%	251%	233%
	Tot_operational_costs	€ 1.317	€ 679	€ 789	€ 812
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,22)	€ 637,45	€ 527,37	€ 504,50
	Initial_costs	€ -	€ 16.594,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Family	pay_back_period	0 year	26 year	29 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	56%	56%	71%
	construction_period	1992-2005	1992-2005	1992-2005	1992-2005
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	132 m2	132 m2	132 m2	132 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	83	70	83	83
	Tot_gas_consumption	1452 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	151 kWh	1302 kWh	1540 kWh
	BENG_1	97	26	35	37
	BENG_2	97	1	10	12
	BENG_3	0%	2201%	255%	216%
	Tot_operational_costs	€ 1.326	€ 528	€ 784	€ 837
	Initial_costs_insulation	€ -	€ 7.520,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,27)	€ 797,25	€ 541,66	€ 488,79
	Initial_costs	€ -	€ 24.114,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Eldery	pay_back_period	0 year	30 year	28 year	36 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	44%	55%	72%

Scenariosamenvatting		Semi-Detached	2006-2011	132 m2	
		11GAS	11A	11B	11C
	construction_period	2006-2011	2006-2011	2006-2011	2006-2011
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	132 m2	132 m2	132 m2	132 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
insulation result	minimal_heating_demand	80	69	80	80
Energetic performance	Tot_gas_consumption	1501 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	460 kWh	1486 kWh	1670 kWh
	BENG_1	100	29	36	38
	BENG_2	100	3	11	13
	BENG_3	0%	723%	224%	199%
Costs	Tot_operational_costs	€ 1.362	€ 597	€ 825	€ 866
	Initial_costs_insulation	€ -	€ 12.760,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,26)	€ 765,36	€ 537,35	€ 496,38
	Initial_costs	€ -	€ 29.354,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Average user group	pay_back_period	0 year	38 year	29 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	45%	54%	70%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	62	62	62	62
	Tot_gas_consumption	1137 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-134 kWh	313 kWh	470 kWh
	BENG_1	76	24	28	29
	BENG_2	76	-1	2	4
	BENG_3	0%	-2483%	1063%	707%
	Tot_operational_costs	€ 1.090	€ 465	€ 564	€ 599
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,20)	€ 624,52	€ 525,35	€ 490,30
	Initial_costs	€ -	€ 16.594,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	27 year	29 year	36 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	69%	68%	88%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	80	69	80	80
	Tot_gas_consumption	1601 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	804 kWh	1831 kWh	1974 kWh
	BENG_1	107	31	39	40
	BENG_2	107	6	14	15
	BENG_3	0%	413%	182%	168%
	Tot_operational_costs	€ 1.437	€ 673	€ 901	€ 933
	Initial_costs_insulation	€ -	€ 12.760,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,26)	€ 763,70	€ 535,69	€ 503,73
	Initial_costs	€ -	€ 29.354,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Family	pay_back_period	0 year	38 year	29 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	43%	51%	65%
	construction_period	2006-2011	2006-2011	2006-2011	2006-2011
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	132 m2	132 m2	132 m2	132 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	96	87	96	96
	Tot_gas_consumption	1645 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	849 kWh	1908 kWh	2196 kWh
	BENG_1	110	32	40	42
	BENG_2	110	6	14	17
	BENG_3	0%	391%	174%	151%
	Tot_operational_costs	€ 1.471	€ 683	€ 919	€ 982
	Initial_costs_insulation	€ -	€ 4.620,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,31)	€ 786,92	€ 551,66	€ 487,87
	Initial_costs	€ -	€ 21.214,89	€ 16.520,22	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Eldery	pay_back_period	0 year	27 year	30 year	36 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.369,03	€ 1.443,87
	Annual_cost_in_decrease	0%	40%	56%	65%

Scenariosamenvatting		Semi-Detached	2012-2017	132 m2	
		12GAS	12A	12B	12C
	construction_period	2012-2017	2012-2017	2012-2017	2012-2017
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	132 m2	132 m2	132 m2	132 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
insulation result	minimal_heating_demand	68	68	68	68
Energetic performance	Tot_gas_consumption	1320 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	431 kWh	917 kWh	1055 kWh
	BENG_1	88	28	32	33
	BENG_2	88	3	7	8
	BENG_3	0%	771%	362%	315%
Costs	Tot_operational_costs	€ 1.227	€ 590	€ 698	€ 729
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,22)	€ 635,88	€ 527,97	€ 497,25
	Initial_costs	€ -	€ 16.594,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Average user group	pay_back_period	0 year	26 year	29 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	60%	61%	77%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	53	53	53	53
	Tot_gas_consumption	996 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-511 kWh	-132 kWh	-10 kWh
	BENG_1	66	21	24	25
	BENG_2	66	-4	-1	0
	BENG_3	0%	-651%	-2527%	-34069%
	Tot_operational_costs	€ 984	€ 381	€ 465	€ 492
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,17)	€ 602,25	€ 518,03	€ 490,98
	Initial_costs	€ -	€ 16.594,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	28 year	30 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	79%	77%	97%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	68	68	68	68
	Tot_gas_consumption	1420 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	776 kWh	1262 kWh	1359 kWh
	BENG_1	95	31	35	35
	BENG_2	95	6	10	10
	BENG_3	0%	428%	263%	244%
	Tot_operational_costs	€ 1.301	€ 667	€ 775	€ 797
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,22)	€ 634,21	€ 526,31	€ 504,60
	Initial_costs	€ -	€ 16.594,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Family	pay_back_period	0 year	26 year	29 year	35 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	57%	57%	72%
	construction_period	2012-2017	2012-2017	2012-2017	2012-2017
	Housing_type	Semi-Detached	Semi-Detached	Semi-Detached	Semi-Detached
	Surface	132 m2	132 m2	132 m2	132 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	12 panels	12 panels	12 panels
	minimal_heating_demand	82	82	82	82
	Tot_gas_consumption	1427 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	639 kWh	1224 kWh	1455 kWh
	BENG_1	95	30	34	36
	BENG_2	95	5	9	11
	BENG_3	0%	520%	272%	228%
	Tot_operational_costs	€ 1.307	€ 637	€ 767	€ 818
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 3.726,25	€ 3.726,25	€ 3.726,25
	Delta_operational_costs	€ (0,26)	€ 670,21	€ 540,37	€ 488,91
	Initial_costs	€ -	€ 16.594,89	€ 15.334,89	€ 17.423,25
	housing_value_increase	€ -	€ -	€ -	€ -
Eldery	pay_back_period	0 year	25 year	28 year	36 year
	Leasing_costs	€ -	€ 1.375,22	€ 1.270,80	€ 1.443,87
	Annual_cost_in_decrease	0%	54%	56%	73%

Scenariosamenvatting		Terraced 13GAS	<1945 13A	102 m2 13B	13C
	construction_period	<1945	<1945	<1945	<1945
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	102 m2	102 m2	102 m2	102 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
insulation result	minimal_heating_demand	179	32	124	179
Energetic performance	Tot_gas_consumption	2379 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-181 kWh	3318 kWh	5760 kWh
	BENG_1	205	20	54	78
	BENG_2	205	-2	33	56
	BENG_3	0%	-1223%	67%	38%
Costs	Tot_operational_costs	€ 2.021	€ 290	€ 1.067	€ 1.609
	Initial_costs_insulation	€ -	€ 11.171,00	€ 1.540,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,44)	€ 1.730,79	€ 953,35	€ 410,98
	Initial_costs	€ -	€ 26.440,21	€ 15.549,21	€ 17.525,58
	housing_value_increase	€ -	€ 11.171,00	€ -	€ -
Average user group	pay_back_period	0 year	9 year	16 year	43 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.452,34
	Annual_cost_in_decrease	0%	-23%	10%	52%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	140	66	140	140
	Tot_gas_consumption	1823 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	523 kWh	3573 kWh	3905 kWh
	BENG_1	157	27	57	60
	BENG_2	157	5	35	38
	BENG_3	0%	424%	62%	57%
	Tot_operational_costs	€ 1.603	€ 446	€ 1.124	€ 1.197
	Initial_costs_insulation	€ -	€ 2.912,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,34)	€ 1.157,24	€ 479,65	€ 405,82
	Initial_costs	€ -	€ 18.181,21	€ 15.194,55	€ 16.097,58
	housing_value_increase	€ -	€ 2.912,00	€ -	€ -
Working couple	pay_back_period	0 year	13 year	32 year	40 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.259,17	€ 1.334,01
	Annual_cost_in_decrease	0%	7%	49%	58%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	179	32	124	179
	Tot_gas_consumption	2479 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	163 kWh	3663 kWh	6064 kWh
	BENG_1	214	23	58	81
	BENG_2	214	2	36	59
	BENG_3	0%	1355%	60%	37%
	Tot_operational_costs	€ 2.096	€ 366	€ 1.144	€ 1.677
	Initial_costs_insulation	€ -	€ 11.171,00	€ 1.540,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,44)	€ 1.729,13	€ 951,69	€ 418,33
	Initial_costs	€ -	€ 26.440,21	€ 15.549,21	€ 17.525,58
	housing_value_increase	€ -	€ 11.171,00	€ -	€ -
Family	pay_back_period	0 year	9 year	16 year	42 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.452,34
	Annual_cost_in_decrease	0%	-22%	10%	49%
	construction_period	<1945	<1945	<1945	<1945
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	102 m2	102 m2	102 m2	102 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	216	39	102	216
	Tot_gas_consumption	2702 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-323 kWh	2197 kWh	7016 kWh
	BENG_1	233	19	43	91
	BENG_2	233	-3	22	69
	BENG_3	0%	-687%	101%	32%
	Tot_operational_costs	€ 2.263	€ 258	€ 818	€ 1.888
	Initial_costs_insulation	€ -	€ 11.171,00	€ 2.912,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 17.427,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,53)	€ 2.004,17	€ 1.444,50	€ 373,84
	Initial_costs	€ -	€ 26.440,21	€ 16.921,21	€ 19.827,58
	housing_value_increase	€ -	€ 11.171,00	€ -	€ -
Eldery	pay_back_period	0 year	8 year	12 year	53 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.643,11
	Annual_cost_in_decrease	0%	-33%	-13%	56%

Scenariosamenvatting		Terraced 14GAS	1946-1964 14A	87 m2 14B	14C
	construction_period	1946-1964	1946-1964	1946-1964	1946-1964
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	87 m2	87 m2	87 m2	87 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
insulation result	minimal_heating_demand	156	59	100	156
Energetic performance	Tot_gas_consumption	1840 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	380 kWh	1920 kWh	3929 kWh
	BENG_1	186	30	48	71
	BENG_2	186	4	22	45
	BENG_3	0%	582%	115%	56%
Costs	Tot_operational_costs	€ 1.616	€ 414	€ 756	€ 1.203
	Initial_costs_insulation	€ -	€ 4.940,00	€ 1.316,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,33)	€ 1.201,82	€ 859,72	€ 413,57
	Initial_costs	€ -	€ 20.209,21	€ 15.325,21	€ 16.097,58
	housing_value_increase	€ -	€ 4.940,00	€ -	€ -
Average user group	pay_back_period	0 year	13 year	18 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	4%	19%	57%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	122	59	122	122
	Tot_gas_consumption	1402 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	36 kWh	2251 kWh	2476 kWh
	BENG_1	142	26	51	54
	BENG_2	142	0	26	28
	BENG_3	0%	6218%	98%	89%
	Tot_operational_costs	€ 1.288	€ 338	€ 830	€ 880
	Initial_costs_insulation	€ -	€ 2.800,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,26)	€ 949,99	€ 457,85	€ 407,84
	Initial_costs	€ -	€ 18.069,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ 2.800,00	€ -	€ -
Working couple	pay_back_period	0 year	16 year	31 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	24%	55%	72%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	156	59	100	156
	Tot_gas_consumption	1940 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	725 kWh	2265 kWh	4233 kWh
	BENG_1	196	34	51	74
	BENG_2	196	8	26	49
	BENG_3	0%	306%	98%	52%
	Tot_operational_costs	€ 1.691	€ 491	€ 833	€ 1.270
	Initial_costs_insulation	€ -	€ 4.940,00	€ 1.316,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,33)	€ 1.200,16	€ 858,06	€ 420,91
	Initial_costs	€ -	€ 20.209,21	€ 15.325,21	€ 16.097,58
	housing_value_increase	€ -	€ 4.940,00	€ -	€ -
Family	pay_back_period	0 year	13 year	18 year	38 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	4%	18%	54%
	construction_period	1946-1964	1946-1964	1946-1964	1946-1964
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	87 m2	87 m2	87 m2	87 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	187	41	120	187
	Tot_gas_consumption	2053 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-433 kWh	2206 kWh	4688 kWh
	BENG_1	207	20	51	79
	BENG_2	207	-5	25	54
	BENG_3	0%	-511%	100%	47%
	Tot_operational_costs	€ 1.776	€ 234	€ 820	€ 1.371
	Initial_costs_insulation	€ -	€ 11.243,00	€ 1.316,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,39)	€ 1.542,38	€ 956,05	€ 404,72
	Initial_costs	€ -	€ 26.512,21	€ 15.325,21	€ 16.097,58
	housing_value_increase	€ -	€ 11.243,00	€ -	€ -
Eldery	pay_back_period	0 year	10 year	16 year	40 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	-16%	12%	52%

Scenariosamenvatting		Terraced 15GAS	1965-1974 15A	106 m2 15B	15C
	construction_period	1965-1974	1965-1974	1965-1974	1965-1974
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	106 m2	106 m2	106 m2	106 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
insulation result	minimal_heating_demand	137	66	137	137
Energetic performance	Tot_gas_consumption	1945 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	952 kWh	3990 kWh	4287 kWh
	BENG_1	161	30	59	61
	BENG_2	161	9	38	40
	BENG_3	0%	233%	56%	52%
Costs	Tot_operational_costs	€ 1.696	€ 541	€ 1.216	€ 1.282
	Initial_costs_insulation	€ -	€ 3.088,40	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,35)	€ 1.153,99	€ 479,17	€ 413,06
	Initial_costs	€ -	€ 18.357,61	€ 15.194,55	€ 16.097,58
	housing_value_increase	€ -	€ 3.088,40	€ -	€ -
Average user group	pay_back_period	0 year	13 year	32 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.259,17	€ 1.334,01
	Annual_cost_in_decrease	0%	7%	46%	54%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	107	67	107	107
	Tot_gas_consumption	1484 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	636 kWh	2510 kWh	2756 kWh
	BENG_1	123	27	45	47
	BENG_2	123	6	24	26
	BENG_3	0%	348%	88%	80%
	Tot_operational_costs	€ 1.350	€ 471	€ 887	€ 942
	Initial_costs_insulation	€ -	€ 1.456,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,27)	€ 878,38	€ 462,12	€ 407,44
	Initial_costs	€ -	€ 16.725,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ 1.456,00	€ -	€ -
Working couple	pay_back_period	0 year	17 year	30 year	40 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	29%	52%	69%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	137	66	137	137
	Tot_gas_consumption	2045 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	1297 kWh	4334 kWh	4591 kWh
	BENG_1	170	33	62	64
	BENG_2	170	12	41	43
	BENG_3	0%	171%	51%	48%
	Tot_operational_costs	€ 1.771	€ 618	€ 1.293	€ 1.350
	Initial_costs_insulation	€ -	€ 3.088,40	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 1.120,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 11.673,97	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,35)	€ 1.152,33	€ 477,51	€ 420,41
	Initial_costs	€ -	€ 18.357,61	€ 15.194,55	€ 16.097,58
	housing_value_increase	€ -	€ 3.088,40	€ -	€ -
Family	pay_back_period	0 year	13 year	32 year	38 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.259,17	€ 1.334,01
	Annual_cost_in_decrease	0%	6%	44%	52%
	construction_period	1965-1974	1965-1974	1965-1974	1965-1974
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	106 m2	106 m2	106 m2	106 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	164	58	104	164
	Tot_gas_consumption	2180 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	330 kWh	2402 kWh	5119 kWh
	BENG_1	181	24	44	69
	BENG_2	181	3	23	48
	BENG_3	0%	671%	92%	43%
	Tot_operational_costs	€ 1.872	€ 403	€ 863	€ 1.467
	Initial_costs_insulation	€ -	€ 5.628,40	€ 1.456,00	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 15.125,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,42)	€ 1.468,06	€ 1.007,67	€ 404,11
	Initial_costs	€ -	€ 20.897,61	€ 15.465,21	€ 17.525,58
	housing_value_increase	€ -	€ 5.628,40	€ -	€ -
Eldery	pay_back_period	0 year	10 year	15 year	43 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.452,34
	Annual_cost_in_decrease	0%	-11%	8%	56%

Scenariosamenvatting		Terraced 16GAS	1975-1991 16A	106 m2 16B	16C
	construction_period	1975-1991	1975-1991	1975-1991	1975-1991
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	106 m2	106 m2	106 m2	106 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
insulation result	minimal_heating_demand	77	61	77	77
Energetic performance	Tot_gas_consumption	1227 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	780 kWh	1733 kWh	1847 kWh
	BENG_1	102	28	37	38
	BENG_2	102	7	16	17
	BENG_3	0%	284%	128%	120%
Costs	Tot_operational_costs	€ 1.157	€ 503	€ 715	€ 740
	Initial_costs_insulation	€ -	€ 1.428,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,20)	€ 653,71	€ 441,97	€ 416,50
	Initial_costs	€ -	€ 16.697,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ 1.428,00	€ -	€ -
Average user group	pay_back_period	0 year	23 year	32 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	53%	62%	79%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	60	60	60	60
	Tot_gas_consumption	924 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	404 kWh	748 kWh	852 kWh
	BENG_1	77	25	28	29
	BENG_2	77	4	7	8
	BENG_3	0%	549%	296%	260%
	Tot_operational_costs	€ 929	€ 419	€ 496	€ 519
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,15)	€ 509,64	€ 433,08	€ 410,13
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	30 year	32 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	81%	78%	99%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	77	61	77	77
	Tot_gas_consumption	1327 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	1124 kWh	2078 kWh	2152 kWh
	BENG_1	110	32	40	41
	BENG_2	110	11	20	20
	BENG_3	0%	197%	107%	103%
	Tot_operational_costs	€ 1.232	€ 580	€ 791	€ 808
	Initial_costs_insulation	€ -	€ 1.428,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,20)	€ 652,05	€ 440,30	€ 423,85
	Initial_costs	€ -	€ 16.697,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ 1.428,00	€ -	€ -
Family	pay_back_period	0 year	23 year	32 year	38 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	50%	59%	74%
	construction_period	1975-1991	1975-1991	1975-1991	1975-1991
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	106 m2	106 m2	106 m2	106 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	93	65	93	93
	Tot_gas_consumption	1316 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	558 kWh	1980 kWh	2184 kWh
	BENG_1	109	26	40	42
	BENG_2	109	5	19	21
	BENG_3	0%	397%	112%	101%
	Tot_operational_costs	€ 1.223	€ 454	€ 770	€ 815
	Initial_costs_insulation	€ -	€ 3.358,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,24)	€ 769,34	€ 453,39	€ 408,25
	Initial_costs	€ -	€ 18.627,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ 3.358,00	€ -	€ -
Eldery	pay_back_period	0 year	20 year	31 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	41%	58%	76%

Scenariosamenvatting		Terraced 17GAS	1992-2005 17A	114 m2 17B	17C
	construction_period	1992-2005	1992-2005	1992-2005	1992-2005
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	114 m2	114 m2	114 m2	114 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
insulation result	minimal_heating_demand	54	54	54	54
Energetic performance	Tot_gas_consumption	996 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	675 kWh	1007 kWh	1062 kWh
	BENG_1	77	25	28	29
	BENG_2	77	6	9	9
	BENG_3	0%	328%	220%	209%
Costs	Tot_operational_costs	€ 984	€ 480	€ 553	€ 566
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,15)	€ 503,64	€ 429,99	€ 417,61
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Average user group	pay_back_period	0 year	30 year	33 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	77%	74%	93%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	42	42	42	42
	Tot_gas_consumption	743 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	-77 kWh	182 kWh	239 kWh
	BENG_1	57	19	21	22
	BENG_2	57	-1	2	2
	BENG_3	0%	-2875%	1219%	927%
	Tot_operational_costs	€ 794	€ 313	€ 370	€ 383
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,12)	€ 481,21	€ 423,74	€ 411,00
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	32 year	33 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	99%	93%	116%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	54	54	54	54
	Tot_gas_consumption	1096 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	1020 kWh	1351 kWh	1367 kWh
	BENG_1	85	28	31	31
	BENG_2	85	9	12	12
	BENG_3	0%	217%	164%	162%
	Tot_operational_costs	€ 1.058	€ 556	€ 630	€ 633
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,15)	€ 501,98	€ 428,33	€ 424,96
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Family	pay_back_period	0 year	30 year	33 year	38 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	72%	69%	86%
	construction_period	1992-2005	1992-2005	1992-2005	1992-2005
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	114 m2	114 m2	114 m2	114 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	65	65	65	65
	Tot_gas_consumption	1038 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	708 kWh	1107 kWh	1239 kWh
	BENG_1	80	26	29	30
	BENG_2	80	6	10	11
	BENG_3	0%	313%	200%	179%
	Tot_operational_costs	€ 1.015	€ 487	€ 576	€ 605
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,18)	€ 527,60	€ 438,99	€ 409,59
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Eldery	pay_back_period	0 year	29 year	32 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	73%	71%	91%

Scenariosamenvatting		Terraced 18GAS	2006-2011 18A	114 m2 18B	18C
	construction_period	2006-2011	2006-2011	2006-2011	2006-2011
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	114 m2	114 m2	114 m2	114 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
insulation result	minimal_heating_demand	73	65	73	73
Energetic performance	Tot_gas_consumption	1246 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	1079 kWh	1792 kWh	1912 kWh
	BENG_1	96	29	35	36
	BENG_2	96	9	16	17
	BENG_3	0%	205%	124%	116%
Costs	Tot_operational_costs	€ 1.171	€ 570	€ 728	€ 754
	Initial_costs_insulation	€ -	€ 3.990,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,20)	€ 601,36	€ 442,95	€ 416,41
	Initial_costs	€ -	€ 19.259,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Average user group	pay_back_period	0 year	32 year	32 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	57%	61%	78%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	57	57	57	57
	Tot_gas_consumption	938 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	443 kWh	795 kWh	902 kWh
	BENG_1	72	23	26	27
	BENG_2	72	4	7	8
	BENG_3	0%	500%	279%	246%
	Tot_operational_costs	€ 940	€ 428	€ 506	€ 530
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,16)	€ 511,97	€ 433,85	€ 410,06
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	30 year	32 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	80%	77%	98%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	73	65	73	73
	Tot_gas_consumption	1346 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	1424 kWh	2137 kWh	2216 kWh
	BENG_1	104	32	38	39
	BENG_2	104	12	19	19
	BENG_3	0%	156%	104%	100%
	Tot_operational_costs	€ 1.246	€ 646	€ 805	€ 822
	Initial_costs_insulation	€ -	€ 3.990,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,20)	€ 599,70	€ 441,29	€ 423,76
	Initial_costs	€ -	€ 19.259,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Family	pay_back_period	0 year	32 year	32 year	38 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	53%	58%	73%
	construction_period	2006-2011	2006-2011	2006-2011	2006-2011
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	114 m2	114 m2	114 m2	114 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	88	88	88	88
	Tot_gas_consumption	1339 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	1510 kWh	2052 kWh	2261 kWh
	BENG_1	103	33	37	39
	BENG_2	103	13	18	20
	BENG_3	0%	147%	108%	98%
	Tot_operational_costs	€ 1.240	€ 665	€ 786	€ 832
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,24)	€ 575,01	€ 454,57	€ 408,14
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Eldery	pay_back_period	0 year	27 year	31 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	56%	57%	75%

Scenariosamenvatting		Terraced 19GAS	2012-2017 19A	114 m2 19B	19C
	construction_period	2012-2017	2012-2017	2012-2017	2012-2017
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	114 m2	114 m2	114 m2	114 m2
User	User_group	average	average	average	average
service	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
insulation result	minimal_heating_demand	64	64	64	64
Energetic performance	Tot_gas_consumption	1124 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	1016 kWh	1408 kWh	1496 kWh
	BENG_1	87	28	32	33
	BENG_2	87	9	12	13
	BENG_3	0%	218%	157%	148%
Costs	Tot_operational_costs	€ 1.079	€ 555	€ 643	€ 662
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,18)	€ 523,75	€ 436,61	€ 417,00
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Average user group	pay_back_period	0 year	29 year	32 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	69%	67%	85%
	User_group	Working couple	Working couple	Working couple	Working couple
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	50	50	50	50
	Tot_gas_consumption	843 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	189 kWh	495 kWh	578 kWh
	BENG_1	65	21	24	24
	BENG_2	65	2	4	5
	BENG_3	0%	1175%	448%	384%
	Tot_operational_costs	€ 869	€ 372	€ 440	€ 458
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,14)	€ 496,92	€ 428,90	€ 410,52
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Working couple	pay_back_period	0 year	31 year	33 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	88%	84%	106%
	User_group	Familiy	Familiy	Familiy	Familiy
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	64	64	64	64
	Tot_gas_consumption	1224 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	1360 kWh	1753 kWh	1800 kWh
	BENG_1	94	31	35	35
	BENG_2	94	12	15	16
	BENG_3	0%	163%	126%	123%
	Tot_operational_costs	€ 1.154	€ 632	€ 719	€ 730
	Initial_costs_insulation	€ -	€ -	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,18)	€ 522,09	€ 434,95	€ 424,35
	Initial_costs	€ -	€ 15.269,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Family	pay_back_period	0 year	29 year	32 year	38 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	64%	63%	79%
	construction_period	2012-2017	2012-2017	2012-2017	2012-2017
	Housing_type	Terraced	Terraced	Terraced	Terraced
	Surface	114 m2	114 m2	114 m2	114 m2
	User_group	Elderly	Elderly	Elderly	Elderly
	Convective_heating_method	0%	50%	20%	0%
	Heat_pumP_TYPee	-	LTH	LTH	HTH
	Number_of_solar_panels	0 panels	8 panels	8 panels	8 panels
	minimal_heating_demand	77	69	77	77
	Tot_gas_consumption	1191 m³	0 m³	0 m³	0 m³
	Tot_electricity_consumption	0 kWh	855 kWh	1589 kWh	1761 kWh
	BENG_1	92	27	33	35
	BENG_2	92	7	14	15
	BENG_3	0%	259%	139%	126%
	Tot_operational_costs	€ 1.130	€ 520	€ 683	€ 721
	Initial_costs_insulation	€ -	€ 3.990,00	€ -	€ -
	inital_costs_ventilation				
	initial_costs_heating_method	€ -	€ 2.100,00	€ 840,00	€ -
	initial_costs_heat_pump	€ -	€ 10.768,63	€ 10.768,63	€ 13.697,00
	inital_costs_solar_panels	€ -	€ 2.400,58	€ 2.400,58	€ 2.400,58
	Delta_operational_costs	€ (0,21)	€ 610,13	€ 446,95	€ 408,85
	Initial_costs	€ -	€ 19.259,21	€ 14.009,21	€ 16.097,58
	housing_value_increase	€ -	€ -	€ -	€ -
Eldery	pay_back_period	0 year	32 year	31 year	39 year
	Leasing_costs	€ -	€ 1.265,36	€ 1.160,94	€ 1.334,01
	Annual_cost_in_decrease	0%	58%	63%	82%

Appendix 14. Economic and financial feasibility of research scenarios (summary of appendix 12)

Scenariosamenvatting		Detached	<1964	130 m2		Detached	1965-1974	144 m2		Detached	1975-1991	154 m2	
		1GAS	1A	1B	1C	2GAS	2A	2B	2C	3GAS	3A	3B	3C
Average user group	pay_back_period	0 year	9 year	15 year	37 year	0 year	9 year	14 year	37 year	0 year	15 year	25 year	29 year
	Annual_cost_in_decrease	0%	-18%	6%	55%	0%	-21%	0%	50%	0%	19%	46%	55%
Working couple	pay_back_period	0 year	12 year	25 year	30 year	0 year	11 year	24 year	32 year	0 year	18 year	24 year	29 year
	Annual_cost_in_decrease	0%	-3%	43%	52%	0%	-11%	43%	53%	0%	38%	52%	69%
Family	pay_back_period	0 year	9 year	15 year	36 year	0 year	9 year	14 year	36 year	0 year	15 year	25 year	29 year
	Annual_cost_in_decrease	0%	-17%	6%	53%	0%	-20%	0%	49%	0%	18%	45%	52%
Eldery	pay_back_period	0 year	8 year	14 year	38 year	0 year	7 year	13 year	38 year	0 year	13 year	24 year	32 year
	Annual_cost_in_decrease	0%	-38%	-1%	50%	0%	-35%	-2%	45%	0%	6%	47%	56%

Scenariosamenvatting		Detached	1992-2005	172 m2		Detached	2006-2011	172 m2		Detached	2012-2017	172 m2	
		4GAS	4A	4B	4C	5GAS	5A	5B	5C	6GAS	6A	6B	6C
Average user group	pay_back_period	0 year	25 year	24 year	29 year	0 year	25 year	25 year	29 year	0 year	25 year	24 year	29 year
	Annual_cost_in_decrease	0%	36%	46%	61%	0%	37%	46%	55%	0%	37%	47%	62%
Working couple	pay_back_period	0 year	22 year	24 year	29 year	0 year	22 year	24 year	29 year	0 year	23 year	25 year	29 year
	Annual_cost_in_decrease	0%	57%	59%	76%	0%	50%	52%	69%	0%	59%	60%	78%
Family	pay_back_period	0 year	25 year	24 year	29 year	0 year	25 year	25 year	29 year	0 year	25 year	24 year	29 year
	Annual_cost_in_decrease	0%	34%	44%	57%	0%	35%	45%	52%	0%	36%	45%	59%
Eldery	pay_back_period	0 year	25 year	25 year	30 year	0 year	35 year	24 year	32 year	0 year	21 year	25 year	30 year
	Annual_cost_in_decrease	0%	36%	47%	56%	0%	28%	47%	56%	0%	44%	48%	57%

Scenariosamenvatting		Semi-Detach	<1964	110 m2		Semi-Detach	1965-1974	123 m2		Semi-Detach	1975-1991	123 m2	
		7GAS	7A	7B	7C	8GAS	8A	8B	8C	9GAS	9A	9B	9C
Average user group	pay_back_period	0 year	10 year	15 year	40 year	0 year	11 year	16 year	40 year	0 year	21 year	29 year	35 year
	Annual_cost_in_decrease	0%	-15%	5%	50%	0%	-6%	8%	51%	0%	42%	55%	71%
Working couple	pay_back_period	0 year	12 year	30 year	37 year	0 year	13 year	30 year	37 year	0 year	27 year	29 year	36 year
	Annual_cost_in_decrease	0%	2%	47%	56%	0%	5%	48%	57%	0%	70%	69%	89%
Family	pay_back_period	0 year	10 year	15 year	39 year	0 year	11 year	16 year	39 year	0 year	21 year	29 year	35 year
	Annual_cost_in_decrease	0%	-14%	5%	48%	0%	-6%	8%	49%	0%	40%	52%	66%
Eldery	pay_back_period	0 year	8 year	14 year	49 year	0 year	9 year	15 year	49 year	0 year	20 year	28 year	36 year
	Annual_cost_in_decrease	0%	-24%	3%	55%	0%	-23%	6%	56%	0%	26%	50%	66%

Scenariosamenvatting		Semi-Detach	1992-2005	132 m2		Semi-Detach	2006-2011	132 m2		Semi-Detach	2012-2017	132 m2	
		10GAS	10A	10B	10C	11GAS	11A	11B	11C	12GAS	12A	12B	12C
Average user group	pay_back_period	0 year	26 year	29 year	35 year	0 year	38 year	29 year	35 year	0 year	26 year	29 year	35 year
	Annual_cost_in_decrease	0%	59%	60%	76%	0%	45%	54%	70%	0%	60%	61%	77%
Working couple	pay_back_period	0 year	27 year	30 year	35 year	0 year	27 year	29 year	36 year	0 year	28 year	30 year	35 year
	Annual_cost_in_decrease	0%	77%	76%	96%	0%	69%	68%	88%	0%	79%	77%	97%
Family	pay_back_period	0 year	26 year	29 year	35 year	0 year	38 year	29 year	35 year	0 year	26 year	29 year	35 year
	Annual_cost_in_decrease	0%	56%	56%	71%	0%	43%	51%	65%	0%	57%	57%	72%
Eldery	pay_back_period	0 year	30 year	28 year	36 year	0 year	27 year	30 year	36 year	0 year	25 year	28 year	36 year
	Annual_cost_in_decrease	0%	44%	55%	72%	0%	40%	56%	65%	0%	54%	56%	73%

Scenariosamenvatting		Terraced	<1945	102 m2		Terraced	1946-1964	87 m2		Terraced	1965-1974	106 m2		Terraced	1975-1991	106 m2	
		13GAS	13A	13B	13C	14GAS	14A	14B	14C	15GAS	15A	15B	15C	16GAS	16A	16B	16C
Average user group	pay_back_period	0 year	9 year	16 year	43 year	0 year	13 year	18 year	39 year	0 year	13 year	32 year	39 year	0 year	23 year	32 year	39 year
	Annual_cost_in_decrease	0%	-23%	10%	52%	0%	4%	19%	57%	0%	7%	46%	54%	0%	53%	62%	79%
Working couple	pay_back_period	0 year	13 year	32 year	40 year	0 year	16 year	31 year	39 year	0 year	17 year	30 year	40 year	0 year	30 year	32 year	39 year
	Annual_cost_in_decrease	0%	7%	49%	58%	0%	24%	55%	72%	0%	29%	52%	69%	0%	81%	78%	99%
Family	pay_back_period	0 year	9 year	16 year	42 year	0 year	13 year	18 year	38 year	0 year	13 year	32 year	38 year	0 year	23 year	32 year	38 year
	Annual_cost_in_decrease	0%	-22%	10%	49%	0%	4%	18%	54%	0%	6%	44%	52%	0%	50%	59%	74%
Eldery	pay_back_period	0 year	8 year	12 year	53 year	0 year	10 year	16 year	40 year	0 year	10 year	15 year	43 year	0 year	20 year	31 year	39 year
	Annual_cost_in_decrease	0%	-33%	-13%	56%	0%	-16%	12%	52%	0%	-11%	8%	56%	0%	41%	58%	76%

Scenariosamenvatting		Terraced	1992-2005	114 m2		Terraced	2006-2011	114 m2		Terraced	2012-2017	114 m2	
		17GAS	17A	17B	17C	18GAS	18A	18B	18C	19GAS	19A	19B	19C
Average user group	pay_back_period	0 year	30 year	33 year	39 year	0 year	32 year	32 year	39 year	0 year	29 year	32 year	39 year
	Annual_cost_in_decrease	0%	77%	74%	93%	0%	57%	61%	78%	0%	69%	67%	85%
Working couple	pay_back_period	0 year	32 year	33 year	39 year	0 year	30 year	32 year	39 year	0 year	31 year	33 year	39 year
	Annual_cost_in_decrease	0%	99%	93%	116%	0%	80%	77%	98%	0%	88%	84%	106%
Family	pay_back_period	0 year	30 year	33 year	38 year	0 year	32 year	32 year	38 year	0 year	29 year	32 year	38 year
	Annual_cost_in_decrease	0%	72%	69%	86%	0%	53%	58%	73%	0%	64%	63%	79%
Eldery	pay_back_period	0 year	29 year	32 year	39 year	0 year	27 year	31 year	39 year	0 year	32 year	31 year	39 year
	Annual_cost_in_decrease	0%	73%	71%	91%	0%	56%	57%	75%	0%	58%	63%	82%

Appendix 15. Total Cost of Ownership calculation input

Conditions	
CPI	1,3%
energy price	0%

Example dwelling: target group 1, average user, service alternative A

			t= 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
economic	initial costs	€ 27.599,00																					
	price premium	€ 9.261,00																					
	net initial costs	€ 18.338,00	€ 18.338																				
	operational cost	€ 361,00		€ 361	€ 366	€ 370	€ 375	€ 380	€ 385	€ 390	€ 395	€ 400	€ 406	€ 411	€ 416	€ 422	€ 427	€ 433	€ 438	€ 444	€ 450	€ 455	€ 461
TCO			€ 18.338	€ 18.699	€ 19.065	€ 19.435	€ 19.810	€ 20.191	€ 20.576	€ 20.966	€ 21.361	€ 21.761	€ 22.167	€ 22.577	€ 22.994	€ 23.415	€ 23.842	€ 24.275	€ 24.713	€ 25.157	€ 25.606	€ 26.062	€ 26.523
financial	inital costs	€ 9.261,00																					
	price premium	€ 9.261,00																					
	net initial cost	€ -																					
	operational cost	€ 361,00		€ 361	€ 366	€ 370	€ 375	€ 380	€ 385	€ 390	€ 395	€ 400	€ 406	€ 411	€ 416	€ 422	€ 427	€ 433	€ 438	€ 444	€ 450	€ 455	€ 461
	leasing costs	€ 1.519,00		€ 1.519	€ 1.539	€ 1.559	€ 1.579	€ 1.600	€ 1.620	€ 1.641	€ 1.663	€ 1.684	€ 1.706	€ 1.728	€ 1.751	€ 1.774	€ 1.797	€ 1.820	€ 1.844	€ 1.868	€ 1.892	€ 1.917	€ 1.941
TCO			€ -	€ 1.880	€ 3.784	€ 5.714	€ 7.668	€ 9.648	€ 11.653	€ 13.685	€ 15.742	€ 17.827	€ 19.939	€ 22.078	€ 24.245	€ 26.440	€ 28.664	€ 30.917	€ 33.198	€ 35.510	€ 37.852	€ 40.224	€ 42.627

Appendix 16. Example of a transition package for homeowners (target group 1, average user group)

	Insulation measures - Façade: FA-1 (cavity wall) - Floor: FL-1 (bottom insulation) - Roof: no measures - Window: WI-1 (HR++)	€9.261
	Heating distribution system	€2.100
	Heat pump - LTH air source 8kW	€10.768
	Solar panels - 20x 300Wp solar panels	€5.469
Costs	Total initial costs	€27.599
Benefits	Yearly operational costs savings Housing value increase	€1.936 €9.261
Feasibility: Economic Financial	Payback period Annual operational costs	9 years - 18 %

Appendix 17. Initial costs break down in retail price, labour costs & subsidy of target group 1, average user group and service alternative A. After homedeal.nl (2019), THE FCTRE (2019)

	B3 insulation (homedeal.nl, 2019)		S1 heating distrubution method (THE FCTR E)		S2 Heat pump (THE FCTR E)		S4 Solar panels (THE FCTR E)	
Product retail price	€ 4.167	45%	€ 1.617	77%	€ 9.218	64%	€ 5.601	73%
labor costs	€ 5.094	55%	€ 483	23%	€ 3.350	23%	€ 988	13%
Subsidy	€ 0	0%	€ 0	0%	-€ 1.800	13%	-€ 1.120	15%
total	€ 9.261	100%	€ 2.100	100%	€ 10.768	100%	€ 5.469	100%

Appendix 18. Sensitivity analysis of the influence on interest rate and depreciation period on the financial feasibility rate

depreciation period		10 year							15 year							20 year						
interest rate		2%	3%	4%	5%	6%	7%	8%	2%	3%	4%	5%	6%	7%	8%	2%	3%	4%	5%	6%	7%	8%
leasing costs difference		16,21%	22,1%	27,9%	33,7%	40,2%	46,3%	53,3%	-18,74%	-12,6%	-6,3%	0,0%	6,3%	13,7%	20,6%	-36,09%	-29,5%	-23,2%	-16,8%	-9,5%	-2,1%	5,7%
1	401.310	-4,7%	0,1%	4,9%	9,6%	15,0%	20,0%	25,7%	-33,4%	-28,4%	-23,2%	-18,0%	-12,8%	-6,8%	-1,1%	-47,6%	-42,2%	-37,0%	-31,8%	-25,8%	-19,7%	-13,4%
2	113.050	-8,2%	-3,5%	1,0%	5,6%	10,8%	15,6%	21,1%	-35,8%	-31,0%	-26,0%	-21,0%	-16,0%	-10,2%	-4,7%	-49,5%	-44,3%	-39,3%	-34,3%	-28,5%	-22,7%	-16,5%
3	212.160	38,3%	45,3%	52,2%	59,1%	66,9%	74,1%	82,4%	-3,3%	4,0%	11,5%	19,0%	26,5%	35,3%	43,6%	-24,0%	-16,1%	-8,6%	-1,0%	7,7%	16,5%	25,7%
4	174.440	58,0%	66,1%	73,9%	81,8%	90,7%	99,0%	108,4%	10,5%	18,8%	27,4%	36,0%	44,6%	54,6%	64,1%	-13,1%	-4,1%	4,5%	13,1%	23,1%	33,1%	43,7%
5	78.400	59,2%	67,3%	75,2%	83,1%	92,1%	100,5%	110,0%	11,3%	19,7%	28,3%	37,0%	45,7%	55,7%	65,3%	-12,4%	-3,4%	5,3%	13,9%	24,0%	34,1%	44,7%
6	62.720	70,8%	79,5%	88,0%	96,5%	106,1%	115,1%	125,3%	19,5%	28,4%	37,7%	47,0%	56,3%	67,1%	77,3%	-6,1%	3,7%	13,0%	22,2%	33,1%	43,9%	55,3%
7	239.400	-1,2%	3,8%	8,7%	13,6%	19,2%	24,4%	30,3%	-30,9%	-25,7%	-20,4%	-15,0%	-9,6%	-3,4%	2,5%	-45,7%	-40,1%	-34,7%	-29,3%	-23,1%	-16,8%	-10,2%
8	119.280	9,2%	14,8%	20,2%	25,7%	31,8%	37,5%	44,1%	-23,6%	-17,9%	-11,9%	-6,0%	-0,1%	6,9%	13,4%	-39,9%	-33,7%	-27,8%	-21,8%	-14,9%	-8,0%	-0,7%
9	201.600	65,0%	73,4%	81,6%	89,8%	99,1%	107,8%	117,6%	15,4%	24,1%	33,0%	42,0%	51,0%	61,4%	71,3%	-9,3%	0,1%	9,1%	18,1%	28,5%	39,0%	50,0%
10	164.350	84,8%	94,1%	103,4%	112,6%	122,9%	132,6%	143,7%	29,2%	38,9%	49,0%	59,0%	69,0%	80,8%	91,8%	1,6%	12,1%	22,2%	32,2%	43,9%	55,7%	68,0%
11	74.100	79,0%	88,0%	97,0%	105,9%	115,9%	125,3%	136,0%	25,1%	34,5%	44,3%	54,0%	63,7%	75,1%	85,8%	-1,6%	8,6%	18,3%	28,1%	39,4%	50,8%	62,7%
12	58.900	85,9%	95,4%	104,6%	113,9%	124,3%	134,1%	145,2%	30,0%	39,8%	49,9%	60,0%	70,1%	81,9%	93,0%	2,2%	12,8%	22,9%	33,1%	44,8%	56,6%	69,0%
13	371.330	-10,5%	-6,0%	-1,5%	2,9%	8,0%	12,7%	18,0%	-37,4%	-32,7%	-27,9%	-23,0%	-18,1%	-12,5%	-7,1%	-50,8%	-45,7%	-40,8%	-36,0%	-30,3%	-24,6%	-18,6%
14	191.200	20,9%	27,0%	33,0%	39,0%	45,8%	52,2%	59,4%	-15,5%	-9,1%	-2,6%	4,0%	10,6%	18,2%	25,5%	-33,5%	-26,7%	-20,1%	-13,5%	-5,9%	1,8%	9,9%
15	284.820	24,3%	30,7%	36,9%	43,0%	50,0%	56,6%	64,0%	-13,0%	-6,5%	0,2%	7,0%	13,8%	21,6%	29,1%	-31,6%	-24,5%	-17,8%	-11,0%	-3,1%	4,7%	13,0%
16	536.190	77,8%	86,8%	95,7%	104,5%	114,5%	123,9%	134,5%	24,3%	33,7%	43,3%	53,0%	62,7%	73,9%	84,6%	-2,2%	7,9%	17,6%	27,2%	38,5%	49,8%	61,6%
17	275.340	105,7%	116,1%	126,4%	136,6%	148,2%	159,0%	171,3%	43,8%	54,6%	65,8%	77,0%	88,2%	101,2%	113,5%	13,1%	24,8%	36,0%	47,2%	60,2%	73,3%	87,0%
18	120.900	103,4%	113,7%	123,8%	133,9%	145,4%	156,1%	168,2%	42,2%	52,9%	63,9%	75,0%	86,1%	98,9%	111,1%	11,8%	23,4%	34,5%	45,5%	58,4%	71,3%	84,9%
19	97.500	96,4%	106,4%	116,2%	125,9%	137,0%	147,3%	159,0%	37,3%	47,7%	58,3%	69,0%	79,7%	92,1%	103,9%	8,0%	19,2%	29,9%	40,5%	53,0%	65,4%	78,6%
total dwellings		3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990
feasible dwellings		1.125.090	484.380	371.330					1.932.550	1.720.390	1.435.570	1.244.370	1.244.370	1.125.090	885.690	3.060.000	2.185.390	1.932.550	1.932.550	1.720.390	1.244.370	1.244.370
feasiblity rate		30%	13%	10%	0%	0%	0%	0%	51%	46%	38%	33%	33%	30%	23%	81%	58%	51%	51%	46%	33%	33%

Appendix 19. Sensitivity analysis of the influence of annual gas price increase on economic feasibility rate

			2%			4%			6%			8%		
			5 year	10 year	15 year	5 year	10 year	15 year	5 year	10 year	15 year	5 year	10 year	15 year
target group	number of dwellings	payback period	-9%	-10%	-12%	-10%	-13%	-15%	-11%	-15%	-18%	-13%	-17%	-20%
1	401.310	9 year	8 year	8 year	8 year	8 year	8 year	8 year	8 year	8 year	7 year	8 year	7 year	7 year
2	113.050	9 year	8 year	8 year	8 year	8 year	8 year	8 year	8 year	8 year	7 year	8 year	7 year	7 year
3	212.160	15 year	14 year	13 year	13 year	13 year	13 year	13 year	13 year	13 year	12 year	13 year	12 year	12 year
4	174.440	24 year	22 year	22 year	21 year	22 year	21 year	20 year	21 year	20 year	20 year	21 year	20 year	19 year
5	78.400	24 year	22 year	22 year	21 year	22 year	21 year	20 year	21 year	20 year	20 year	21 year	20 year	19 year
6	62.720	24 year	22 year	22 year	21 year	22 year	21 year	20 year	21 year	20 year	20 year	21 year	20 year	19 year
7	239.400	10 year	9 year	9 year	9 year	9 year	9 year	8 year	9 year	8 year	8 year	9 year	8 year	8 year
8	119.280	11 year	10 year	10 year	10 year	10 year	10 year	9 year	10 year	9 year	9 year	10 year	9 year	9 year
9	201.600	21 year	19 year	19 year	19 year	19 year	18 year	18 year	19 year	18 year	17 year	18 year	17 year	17 year
10	164.350	26 year	24 year	23 year	23 year	23 year	23 year	22 year	23 year	22 year	21 year	23 year	22 year	21 year
11	74.100	29 year	27 year	26 year	26 year	26 year	25 year	25 year	26 year	25 year	24 year	25 year	24 year	23 year
12	58.900	26 year	24 year	23 year	23 year	23 year	23 year	22 year	23 year	22 year	21 year	23 year	22 year	21 year
13	371.330	9 year	8 year	8 year	8 year	8 year	8 year	8 year	8 year	8 year	7 year	8 year	7 year	7 year
14	191.200	13 year	12 year	12 year	11 year	12 year	11 year	11 year	12 year	11 year	11 year	11 year	11 year	10 year
15	284.820	13 year	12 year	12 year	11 year	12 year	11 year	11 year	12 year	11 year	11 year	11 year	11 year	10 year
16	536.190	23 year	21 year	21 year	20 year	21 year	20 year	19 year	20 year	20 year	19 year	20 year	19 year	18 year
17	275.340	30 year	27 year	27 year	26 year	27 year	26 year	25 year	27 year	25 year	25 year	26 year	25 year	24 year
18	120.900	32 year	29 year	29 year	28 year	29 year	28 year	27 year	28 year	27 year	26 year	28 year	27 year	26 year
19	97.500	29 year	27 year	26 year	26 year	26 year	25 year	25 year	26 year	25 year	24 year	25 year	24 year	23 year
	total dwellings	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990	3.776.990
	feasible dwelling:	1.244.370	1.720.390	1.720.390	1.720.390	1.720.390	1.720.390	1.720.390	1.720.390	1.720.390	1.932.550	1.720.390	1.932.550	1.932.550
	feasiblity rate	33%	46%	46%	46%	46%	46%	46%	46%	46%	51%	46%	51%	51%